FW: Initial Reference List, Draft Class 3 PMR

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January WIPP file

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Attached is a list of reference documents in the DRAFT Class 3 PMR that NMED would like a copy of or a link to. Please let me know when you think these will be available. Thanks.

Requested References Draft Class 3 PMR Initial Listing

Case, J., Kelsall, P. and Withiam, J., 1987, "Laboratory Investigation of Crushed Salt Consolidation," *Rock Mechanics: Proceedings of the 28th US Symposium*, Edited by: I.W. Farmer, J. J. K. Daemen, C. S. Desai, C.E. Glass and S.P. Neuman, Tucson, Arizona, pp. 189-196.

Case, J. and Kelsall, P., 1987, "Coupled Processes in Repository Sealing," *Proceedings of the Conference on Coupled Processes Associated with Nuclear Waste Repositories*, Academic Press, Orlando Florida, pp. 591-604.

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Golder Associates, November 30, 2006. Letter to Rick Chavez: Early Time Generation of Methane and Hydrogen in Filled Panels at the WIPP.

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Kehrman, R., 2012, *Revised Calculations to Support Panel Closure*, URS Interoffice Correspondence to R.R. Chavez dated September 4, 2012, File# URS:12:179, Washington TRU Solutions, Carlsbad New Mexico.

Mellegard, K., Pfeifle, T. and Hansen, F., 1999, *Laboratory Characterization of Mechanical and Permeability Properties of Dynamically Compacted Crushed Salt*, SAND98-2046, Sandia National Laboratories, Albuquerque, New Mexico.

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Nelson, R., 2011, "Radiolytic Hydrogen Generation and Methanogenesis in WIPP, An Empirical Point of View," *Proceedings of the Waste Management 2011 Conference*, Phoenix, Arizona.

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Rothfuchs, T, and K. Wieczorek, 2010, "Backfill Compaction and EDZ Recovery," *Proceedings of the U.S.-German Workshop on Salt Repository Research,* May 25-28, 2010, Jackson, Mississippi.

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U.S. Department of Energy (DOE), 1996, *Detailed Design Report for an Operational Phase Panel-Closure System,* DOE/WIPP 96-2150, U.S. Department of Energy, WIPP Project Office, Carlsbad, New Mexico.

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Zimmerly, B., and Zavicar, J., 2012, *Construction Methods Assessment for Run-of-Mine Salt Panel Closures*, Interim Report For Scenario 1 Testing, Washington TRU Solutions, Carlsbad New Mexico.

An Excel spreadsheet of the hydrogen and methane monitoring data used in the evaluation presented in Appendix D

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No	Author	Title	Date	Copyrighted	Comments
1	Bear, J.	Dynamics of Fluids in Porous Media, Dover Publications, New York.	Jan-72	Yes	Panel Closure http://books.google.com/books/about/Dynamics_of_Fluids_in_Porous_Media.html?id=lurrmlFGhTEC
2	Callahan, G.	Crushed Salt Constitutive Model, Sandia National Laboratories Report SAND98-2680, Sandia National Laboratories, Albuquerque, New Mexico.	Mar-99	No	Panel Closure
3	Callahan, G. and DeVries, K.	Analysis of Backfilled Transuranic Waste Storage Rooms, RE/SPEC, Inc., report to Sandia National Laboratories SAND91-7052, RE/SPEC, Inc., Rapid City, South Dakota	Apr-91	No	Panel Closure
4	Case, J. and Kelsall, P.	Coupled Processes in Repository Sealing, Proceedings of the Conference on Coupled Processes Associated with Nuclear Waste Repositories, Academic Press, Orlando Florida, pp. 591-604.	Jan-87	Yes	Panel Closure http://www.sciencedirect.com/science/book/9780127016207
5	Case, J., Kelsall, P. and Withiam, J.	Laboratory Investigation of Crushed Salt Consolidation, Rock Mechanics: Proceedings of the 28th US Symposium, Edited by: I.W. Farmer, J. J. K. Daemen, C. S. Desai, C.E. Glass and S.P. Neuman, Tucson, Arizona, pp. 189-196	Jul-87	Yes	Panel Closure http://www.onepetro.org/mslib/servlet/onepetropreview?id=ARMA-87-0189
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8	Fernandez, J. and Richardson, A.	A Review of the Available Technologies for Sealing a Potential Underground Nuclear Waste Repository at Yucca Mountain, Nevada, SAND93-3997, Sandia National Laboratories, Albuquerque, New Mexico.	Nov-94	Yes	Panel Closure http://www.worldcat.org/title/review-of-the-available-technologies-for-sealing-a-potential-underground-nuclear-waste-repository-at-yucca-mountain-nevada/oclc/36563530
9	Freeze, A. and Cherry, J.	Groundwater, Prentice Hall, Englewood Cliffs, New Jersey.	Jan-79	Yes	Panel Closure http://books.google.com/books/about/Groundwater.html?id=feVQAAAAMAAJ

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10	Golder Associates.	Letter to Rick Chavez: Early Time Generation of Methane and Hydrogen in Filled Panels at the WIPP.	Nov-06	No	Not cited in the PMR's. This document was requested by NMED in an email dated 1/22/13.
11	Hansen, F., Callahan, G., Loken, M. and Mellegard, K.	Crushed-Salt Constitutive Model Update, SAND97-2601, Sandia National Laboratories, Albuquerque, New Mexico.	Jan-98	No	Panel Closure
12	Hilf, J.	Compacted Fill, Chapter 7, Foundation Engineering Handbook, Winterkorn, H., and Fang, HY. Editors, McGraw Hill, New York.	Jan-75	Yes	Panel Closure http://books.google.com/books?id=X8hEt3l1SPQC&printsec=frontcover&dq=Foundation+Engineering+Handbook&hl=en&sa=X&ei=vtnuUIyYHKKg2gWhzYDYDw&ved=0CDUQ6AEwAA
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14	Kehrman, R.	Revised Calculations to Support Panel Closure, URS Interoffice Correspondence to R.R. Chavez dated September 4, 2012, File# URS:12:179, Washington TRU Solutions, Carlsbad New Mexico.	Sep-12	No	Panel Closure
15	Kelsall, P., Case, J., Meyer, D., Franzone, F. and Coons, W.	Schematic Designs for Penetration Seals for a Repository in Richton Dome, Topical Report, D'Appolonia Consulting Engineers, Albuquerque, New Mexico.	Jan-83	Yes	Panel Closure http://www.ntis.gov/search/product.aspx?ABBR=DE86007014
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21	Nelson, R.	Radiolytic Hydrogen Generation and Methanogenesis in WIPP, An Empirical Point of View, Proceedings of the Waste Management 2011 Conference, Phoenix, Arizona.	Mar-11	No	Panel Closure
22	New Mexico Environmental Department (NMED)	WIPP Hazardous Waste Facility Permit, November 30, 2010, Section 2, Explain Why the Modification is Needed, U.S. Department of Energy, Carlsbad, New Mexico.	Nov-10	Unknown Reference	Panel Closure
23	New Mexico Environmental Department (NMED)	WIPP Hazardous Waste Facility Permit, June 29, 2012, Part 4 - Geologic Repository Disposal, U.S. Department of Energy, Carlsbad, New Mexico.	Jun-12	See current WIPP HWFP	Panel Closure
24	Nuclear Waste Partnership LLC (NWP)	Design Report for a Panel Closure System at the Waste Isolation Pilot Plant, October 2012	Oct-12	No	Panel Closure
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28	Shor, A., Baes, C. and Canonico, C.	Consolidation and Permeability of Salt in Brine, ORNL-5774, Oak Ridge National Laboratory, Oak Ridge, Tennessee.	Jul-81	No	Panel Closure

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30	Slezak, S., and Lappin, A.	Potential for and Possible Impacts of Generation of Flammable and/or Detonable Gas Mixtures During the WIPP Transportation, Test, and Operational Phases, Memo to Darrel Mercer, and Craig Fredrickson, January 5, 1990, Sandia National Laboratories, Albuquerque, New Mexico.	Jan-90	No	Panel Closure
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32	U.S. Congress	Section 310 of Public Law 108-447 of the Consolidated Appropriations Act of 2005	Jan-05	No	VOC
33	U.S. Department of Energy (DOE)	Annual Transuranic Waste Inventory Report - 2012 (Data Cutoff Date 12/31/2011), DOE/TRU-12-3425, Revision 0	Oct-12	No	Panel Closure
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35	U.S. Department of Energy (DOE)	Detailed Design Report for an Operational Phase Panel-Closure System, DOE/WIPP 96-2150, U.S. Department of Energy, WIPP Project Office, Carlsbad, New Mexico.	Jan-96	No	Panel Closure
36	U.S. Department of Energy (DOE)	TRU Waste Baseline Inventory Report	Jun-96	No	VOC
37	U.S. Department of Energy (DOE)	DOE/WIPP-11-3443-2, Semi-Annual VOC, Hydrogen, and Methane Data Summary Report for Reporting Period July 1, 2011 through December 31, 2011.	Apr-12	No	VOC
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39	U.S. Department of Energy (DOE)	DOE/WIPP-12-3492-1, Semi-Annual VOC, Hydrogen, and Methane Data Summary Report for Reporting Period January 1, 2012 through June 30, 2012.	Oct-12	No	VOC
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41	U.S. Evironmental Protection Agency (EPA)	Human Health Toxicity Values in Superfund Risk Assessments, OSWER Directive 9285.7-53.	Dec-03	No	VOC
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45	Washington Group International.	Letter to D. Mercer, CBFO: Estimation of Hydrogen Rates from Radiolysis in WIPP Panels	Jul-06	No	Not cited in the PMR's. This document was requested by NMED in an email dated 1/22/13.
46	Washington TRU Solutions (WTS)	Fabrication and Installation of Bulkhead at P6RM7 Intake S2750/W1070, W. O. Number 1107579M74B610, Washington TRU Solutions, Carlsbad, New Mexico	Nov-11	Yes	Panel Closure
47	Westinghouse Electric Corporation	Underground Facilities Typical Disposal Panel, Drawing No. 51-W-214-W, Westinghouse Waste Isolation Division, Waste Isolation Pilot Plant, Carlsbad, New Mexico	Jan-95	No	Panel Closure This drawing is contained in the Renewal Application, Part A and also as Renewal Application Appendix M3.
48	Zerwekh, A.	Gas Generation from Radiolytic Attack of TRU-Contaminated Hydrogenous Waste, LA-7674-MS, Los Alamos Scientific Laboratory, Los Alamos, NM	Jun-79	No	Panel Closure

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49	Zimmerly, B., and Zavicar, J.	Construction Methods Assessment for Run-of-Mine Salt Panel Closures, Interim Report For Scenario 1 Testing, Washington TRU Solutions, Carlsbad New Mexico	Dec-12	No	Panel Closure
50	An Excel spreadsheet of the hydrogen and methane monitoring data used in the evaluation presented in Appendix D		Jan-13	No	Not cited in the PMR's. This document was requested by NMED in an email dated 1/22/13.

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Analyses of Backfilled Transuranic Wastes Disposal Rooms

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ANALYSES OF BACKFILLED TRANSURANIC WASTES DISPOSAL ROOMS

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ABSTRACT

The Waste Isolation Pilot Plant (WIPP) is a U.S. Department of Energy (DOE) research and development facility established to demonstrate the safe geologic disposal of transuranic (TRU) wastes generated from defense-related activities. Crushed salt and crushed-salt treatments are the candidate materials to be used as backfill around waste and waste packages in the underground disposal rooms. In response to room closure, the backfill is anticipated to compact sufficiently such that an effective seal is formed reducing brine inflow and radionuclide transport. In this report, different backfill and backfill/TRU waste combinations are investigated based on finite element simulations for a 200-year period conducted to examine and compare the sealing efficacy of different backfill scenarios. Specifically, disposal room content scenarios investigated include crushed salt, a crushed salt/bentonite mixture, crushed salt covering TRU waste, crushed salt/bentonite covering TRU waste, crushed salt covering a mixture of crushed salt and shredded metallic waste, and crushed salt covering vitrified waste. The simulations were conducted with the thermomechanical finite element program SPECTROM-32. The report includes a description of constitutive relations used to simulate the backfill and host rock formation including viscoplastic (creep), nonlinear elastic, creep consolidation, and nonlinear elastic and consolidation mixture models. The simulation results show that the backfill attains average void fractions less than 5 percent in all cases except for the case with crushed salt/bentonite covering TRU waste, which is only slightly greater than 5 percent. The time required to attain these void fractions varies considerably between cases.

The content of this report was effective as of April 1991. This report was prepared by RE/SPEC Inc. under Contract 40-2512 with Sandia National Laboratories.

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1.0 INTRODUCTION

1.1 BACKGROUND

The U.S. Department of Energy is planning to dispose of transuranic wastes (TRU) at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. The current mission of the WIPP is to provide a research and development facility to demonstrate the safe management, storage, and disposal of TRU wastes generated by U.S. Government defense programs. Sandia National Laboratories is conducting procedural and technical activities to assess compliance of the WIPP with regulatory requirements. Performance of seal, barrier, and backfill materials is being studied as part of these activities.

A key candidate component of the room backfill system is crushed salt. Crushed salt is an attractive candidate because it is readily available from the mining operations, it is compatible with the host rock, and it is expected to consolidate into a low-permeability mass comparable to the intact salt as a result of the creep closure of the surrounding rock mass. Crushed salt has been shown to consolidate relatively quickly when subjected to a hydrostatic stress [Holcomb and Hannum, 1982; Pfeifle and Senseny, 1985; Stroup and Senseny, 1987, and Holcomb and Zeuch, 1988]. Therefore, the backfill is expected to lower the effective permeability in the rooms and reduce the total time required for complete encapsulation of the waste. In addition, the backfill may be engineered so that it actually adsorbs radionuclides and thus, provides an additional barrier around the waste. Crushed salt and varying amounts of bentonite, a montmorillonite-rich clay, have been proposed as candidate backfill materials that improve the properties of pure crushed salt. The addition of bentonite reduces permeability and increases the absorbing ability of the mixture. However, the addition of bentonite may have its drawbacks. Preliminary results from consolidation tests suggest that the rate of consolidation for crushed salt/bentonite backfills is less than that for pure crushed salt [Pfeifle, 1990; Stroup and Senseny, 1987]. This result implies that the time required for complete encapsulation of the waste is longer for the crushed salt/bentonite backfills. Another disadvantage of bentonite is that it swells in the presence of water or brine [Pusch, 1980]. In a storage room where the backfill is confined, a swelling pressure may develop. This swelling pressure may be large and could add significantly to the time required for complete encapsulation of the waste since the natural tendency of the intact rock to deform into the room is decreased.

Because of the importance of backfills at WIPP, knowledge of their constitutive behavior and the ability to perform long-term structural analyses of backfill schemes are required. Clearly, an understanding of the mechanical behavior of crushed salt is important at WIPP. Optimization of the backfill emplacement is necessary to promote room stability, to enable sufficient backfill consolidation to reduce brine

flow which retards the transport of soluble radionuclides, and to maintain sufficient gas permeability to avoid gas pressurization [Butcher, 1990].

1.2 SCOPE

The study presented in this report was conducted to investigate the consolidation of backfill and waste in disposal room configurations at the WIPP. Six cases were investigated that included the following assumed room contents:

1. Completely filled with crushed salt.
2. Completely filled with a 70 percent crushed salt — 30 percent bentonite (by weight) mixture.
3. TRU waste covered with crushed salt.
4. TRU waste covered with a 70 percent crushed salt — 30 percent bentonite (by weight) mixture.
5. An 80 percent crushed salt — 20 percent shredded metallic waste (by volume) mixture covered with crushed salt.
6. Vitrified waste covered by crushed salt.

To solve these six problems, representative constitutive relations were developed and implemented for the crushed salt and TRU waste. Numerical simulations of the backfill, waste, and creeping host bedded salt formation were conducted for 200 years. The finite element program, SPECTROM-32 [Callahan et al., 1990], was used to perform the analyses.

1.3 REPORT ORGANIZATION

This report includes six chapters and three appendixes. Chapter 2 describes the constitutive relations and material parameters used to describe the backfill materials, waste materials, and the host rock formation. Chapter 3 describes the finite element idealization of the disposal room configuration and procedures used to conduct the analyses. The results of the analyses are given in Chapter 4, and Chapter 5 provides the conclusions of the study. References cited in the report are given in Chapter 6. Appendix A includes stress-porosity data from simulated TRU waste compaction experiments. Appendix B contains a comparison of results obtained with the finite element program SANCHO [Weatherby and Brown, 1990 and Weatherby, 1989] to the comparable analyses described here. Appendix C contains average void fraction and mean stress results from the analyses.

2.0 CONSTITUTIVE RELATIONS AND MATERIAL PROPERTIES

This chapter presents the constitutive relationships or models used to represent the various materials associated with the analysis of TRU waste disposal rooms. The models presented are for the natural or intact rock salt, crushed salt, crushed salt mixed with other materials, and TRU waste. Each of these material models are discussed separately in the following subsections. Because temperature variations within the repository are assumed to be small, the thermal strains are neglected in each of the discussions; however, the thermal strain rates may be included as a component of the total strain rate in each of the models as reported previously [Callahan et al., 1990].

2.1 INTACT SALT

The total strain rate for the natural rock salt or intact salt constitutive model is assumed to include two components. The components consist of elastic and creep contributions, and the total strain rate is written as

$$\dot{\epsilon}_{ij} = \dot{\epsilon}^e_{ij} + \dot{\epsilon}^c_{ij} \tag{2-1}$$

The elastic strains (ϵ^e_{ij}) are assumed to be linear elastic and given by Hooke's Law (e.g., Timoshenko and Goodier [1970]). The creep strains (ϵ^c_{ij}) are described by Munson et al. [1989]. Summaries of the linear elastic and creep portions of the model are given here for completeness.

2.1.1 Linear Elastic Model

The elastic strains, ϵ^e_{ij}, are the contribution from the stress field given by Hooke's law

$$\epsilon^e_{ij} = C_{ijkl}\sigma_{kl} \tag{2-2}$$

where C_{ijkl} is the matrix of elastic constants and σ_{kl} is the stress tensor.

For an isotropic body, there are two independent elastic constants and Equation 2-2 can be written as

$$\epsilon^e_{ij} = \frac{1}{E}\left[(1+\nu)\,\sigma_{ij} - \nu\sigma_{kk}\delta_{ij}\right] \tag{2-3}$$

where the elastic material constants E and ν represent Young's modulus and Poisson's ratio. We may also write Equation 2-3 in terms of the bulk modulus (K) and shear modulus (G) for the material as

$$\epsilon^e_{ij} = \frac{\sigma_m}{3K}\,\delta_{ij} + \frac{S_{ij}}{2G} \tag{2-4}$$

where

$$\begin{aligned} \sigma_m &= \frac{\sigma_{kk}}{3}, \text{ mean stress} \\ S_{ij} &= \sigma_{ij} - \sigma_m \delta_{ij}, \text{ deviatoric stress} \\ \delta_{ij} &= \text{Kronecker delta.} \end{aligned} \tag{2-5}$$

Equation 2-3 may be rearranged to give the elastic constitutive equations for stress in terms of strain

$$\sigma_{ij} = \frac{E}{(1+\nu)(1-2\nu)} \left[(1-2\nu)\, \epsilon^e_{ij} + \nu \epsilon^e_{kk} \delta_{ij} \right] \tag{2-6}$$

2.1.2 Creep Model

For the inelastic creep strains, the modified Munson-Dawson material model [Munson et al., 1989] is used. The model is written as

$$\dot{\epsilon}^c_e = F \dot{\epsilon}_s \tag{2-7}$$

where $\dot{\epsilon}^c_e$ is the invariant inelastic strain-rate measure, and $\dot{\epsilon}_s$ is the steady-state strain rate. The transient function F consists of three branches — a workhardening branch, an equilibrium branch, and a recovery branch and is written in that order as

$$F = \begin{cases} \exp\left[\Delta \left(1 - \frac{\varsigma}{\epsilon^f_t}\right)^2\right] & \varsigma < \epsilon^f_t \\ 1 & \varsigma = \epsilon^f_t \\ \exp\left[-\delta \left(1 - \frac{\varsigma}{\epsilon^f_t}\right)^2\right] & \varsigma > \epsilon^f_t \end{cases} \tag{2-8}$$

Δ and δ are the workhardening and recovery parameters, respectively, and ϵ^f_t is the transient strain-rate limit. The internal variable ς is governed by the evolutionary equation

$$\dot{\varsigma} = (F-1)\, \dot{\epsilon}_s \tag{2-9}$$

and the transient strain-rate limit is given by

$$\epsilon^f_t = K_o e^{cT} \left(\frac{\sigma_e}{\mu}\right)^m \tag{2-10}$$

where K_o, c, m, and μ are material parameters, T is temperature, and σ_e is an invariant stress measure described later.

The workhardening parameter is defined as a function of stress

$$\Delta = \alpha + \beta \log\left(\frac{\sigma_e}{\mu}\right) \tag{2-11}$$

where α and β are material parameters. Because of insufficient laboratory data to allow evaluation, the recovery parameter δ is taken to be a constant.

The steady-state strain rate is the sum of the three individual strain-rate mechanisms acting in parallel

$$\dot{\epsilon}_s = \sum_{i=1}^{3} \dot{\epsilon}_{s_i} \tag{2-12}$$

The three contributing mechanisms — dislocation climb, an undefined mechanism, and glide are written respectively as

$$\dot{\epsilon}_{s_1} = A_1 \left(\frac{\sigma_e}{\mu}\right)^{n_1} \exp\left(-\frac{Q_1}{RT}\right) \tag{2-13}$$

$$\dot{\epsilon}_{s_2} = A_2 \left(\frac{\sigma_e}{\mu}\right)^{n_2} \exp\left(-\frac{Q_2}{RT}\right) \tag{2-14}$$

$$\dot{\epsilon}_{s_3} = \left(\hat{B}_1 e^{-Q_1/RT} + B_2 e^{-Q_2/RT}\right) \sinh\left[q\left(\frac{\sigma_e - \sigma_0}{\mu}\right)\right] H\left(\sigma_e - \sigma_0\right) \tag{2-15}$$

where

μ = normalizing parameter (MPa)

q = activation volume

$A_1,\ A_2,\ \hat{B}_1,\ B_2,\ n_1,\ n_2,$
$Q_1,\ Q_2,\ \sigma_0,\ K,\ m,\ \alpha,\ \beta,\ \delta$ = experimental constants (see Table 2-1)

R = 1.987, universal gas constant $(\frac{\text{cal}}{\text{mol-K}})$

$H(.)$ = Heaviside step function.

To generalize the Munson-Dawson model to three-dimensional states of stress, Fossum et al. [1988] is followed to determine flow potential functions generalized according to Mises and Tresca types of flow potential functions. The inelastic tensorial strain-rate components may be written as

$$\dot{\epsilon}^c_{ij} = \dot{\epsilon}^c_e \frac{\partial \sigma^f_e}{\partial \sigma_{ij}} \tag{2-16}$$

where the invariant inelastic strain-rate measure is

$$\dot{\epsilon}^c_e = \dot{\epsilon}^c_e\left(T,\ \sigma_e,\ \epsilon^c_e\right) \tag{2-17}$$

The two invariant stress measures in Equations 2-16 and 2-17 are given by

$$\begin{aligned} \sigma_e^f &= \sigma_e^f(\sigma_m,\ J_2,\ J_3) \\ \sigma_e &= \sigma_e(\sigma_m,\ J_2,\ J_3) \end{aligned} \tag{2-18}$$

where the mean stress (σ_m), the second invariant of the deviator stress (J_2), and the third invariant of the deviator stress (J_3) are given by

$$\begin{aligned} \sigma_m &= \frac{\sigma_{kk}}{3} \\ J_2 &= \tfrac{1}{2} S_{ij} S_{ji} \\ J_3 &= \tfrac{1}{3} S_{ij} S_{jk} S_{ki} \end{aligned} \tag{2-19}$$

The Lode angle (ψ), which is a convenient alternative to J_3, is given by

$$\psi = \tfrac{1}{3} \sin^{-1}\left[\frac{-3\sqrt{3} J_3}{2 J_2^{3/2}}\right], \quad \left(-\frac{\pi}{6} \le \psi \le \frac{\pi}{6}\right) \tag{2-20}$$

The partial derivative given in Equation 2-16 may be determined using the chain rule as

$$\frac{\partial \sigma_e^f}{\partial \sigma_{ij}} = \frac{\partial \sigma_e^f}{\partial \sigma_m}\frac{\partial \sigma_m}{\partial \sigma_{ij}} + \frac{\partial \sigma_e^f}{\partial J_2}\frac{\partial J_2}{\partial \sigma_{ij}} + \frac{\partial \sigma_e^f}{\partial \psi}\frac{\partial \psi}{\partial J_3}\frac{\partial J_3}{\partial \sigma_{ij}} \tag{2-21}$$

The derivatives of the invariants in Equation 2-21 are the same regardless of the invariant stress and strain measures selected. These derivatives [Callahan, 1982] are

$$\begin{aligned} \frac{\partial \sigma_m}{\partial \sigma_{ij}} &= \frac{\delta_{ij}}{3} \\ \frac{\partial J_2}{\partial \sigma_{ij}} &= S_{ij} \\ \frac{\partial \psi}{\partial J_3}\frac{\partial J_3}{\partial \sigma_{ij}} &= -\frac{\sqrt{3}}{2 J_2^{3/2} \cos 3\psi}\, t_{ij} \end{aligned} \tag{2-22}$$

where

$$t_{ij} = S_{ip} S_{pj} - \tfrac{2}{3} J_2 \delta_{ij}$$

Therefore, to define completely the inelastic strain-rate measure required by Equation 2-17, the invariant stress and strain-rate measures need to be prescribed. The equivalent inelastic strain-rate measure is given by the Munson-Dawson material model in Equation 2-7. Two types of invariant stress measures are considered.

These are termed the pressure-dependent and frictional forms of the invariant stress measure. The pressure-dependent form is similar to the Mises-Schleicher plastic potential, and the frictional form is similar to the Mohr-Coulomb plastic potential. Mathematically, these stress measures are

$$\sigma_e^f = 3\tau\sigma_m + \sqrt{3J_2} \quad \text{(pressure-dependent)} \tag{2-23}$$

$$\sigma_e^f = 2\sin\tau\sigma_m + \left(\cos\psi - \frac{\sin\psi\sin\tau}{\sqrt{3}}\right) 2\sqrt{J_2} \quad \text{(frictional)} \tag{2-24}$$

The variable τ is a material constant termed the flow dilatancy parameter. The other invariant stress measure (σ_e) that needs to be described is taken to be identical to those given in Equations 2-23 and 2-24, except that the parameter τ is replaced by a different variable (θ), viz

$$\sigma_e = 3\theta\sigma_m + \sqrt{3J_2} \tag{2-25}$$

$$\sigma_e = 2\sin\theta\sigma_m + \left(\cos\psi - \frac{\sin\psi\sin\theta}{\sqrt{3}}\right) 2\sqrt{J_2} \tag{2-26}$$

The variable θ is a material constant termed the frictional parameter. If $\theta = \tau$, then $\sigma_e = \sigma_e^f$; however, this is not required theoretically.

Equation 2-21 requires the partial derivatives of the invariant stress measures with respect to stress. Differentiation of Equations 2-23 and 2-24 provides these quantities for the pressure-dependent and frictional forms for the invariant stress measures. These quantities are as follows:

Pressure-Dependent

$$\begin{aligned} \frac{\partial\sigma_e^f}{\partial\sigma_m} &= 3\tau \\ \frac{\partial\sigma_e^f}{\partial J_2} &= \frac{\sqrt{3}}{2\sqrt{J_2}} \\ \frac{\partial\sigma_e^f}{\partial\psi} &= 0 \end{aligned} \tag{2-27}$$

Frictional

$$\begin{aligned}
\frac{\partial \sigma_e^f}{\partial \sigma_m} &= 2\sin\tau \\
\frac{\partial \sigma_e^f}{\partial J_2} &= \left[\frac{\cos 2\psi}{\cos 3\psi} + \frac{\sin\tau}{\sqrt{3}}(\tan 3\psi \cos\psi - \sin\psi)\right]\frac{1}{\sqrt{J_2}} \\
\frac{\partial \sigma_e^f}{\partial \psi} &= -\left[\sin\psi + \frac{\cos\psi \sin\tau}{\sqrt{3}}\right] 2\sqrt{J_2}
\end{aligned} \tag{2-28}$$

By letting τ go to zero in Equations 2-23 and 2-24, we eliminate the mean-stress dependence and obtain Mises- and Tresca-types of invariant stress measures, respectively. θ is also set to zero such that $\sigma_e = \sigma_e^f$. Thus, Equations 2-23 and 2-24 become

$$\sigma_e = \sqrt{3J_2} \quad \text{(Mises)} \tag{2-29}$$

$$\sigma_e = 2\cos\psi\sqrt{J_2} \quad \text{(Tresca)} \tag{2-30}$$

and the derivatives in Equations 2-27 and 2-28 become

Mises

$$\begin{aligned}
\frac{\partial \sigma_e}{\partial \sigma_m} &= 0 \\
\frac{\partial \sigma_e}{\partial J_2} &= \frac{\sqrt{3}}{2\sqrt{J_2}} \\
\frac{\partial \sigma_e}{\partial \psi} &= 0
\end{aligned} \tag{2-31}$$

Tresca

$$\begin{aligned}
\frac{\partial \sigma_e}{\partial \sigma_m} &= 0 \\
\frac{\partial \sigma_e}{\partial J_2} &= \left[\frac{\cos 2\psi}{\cos 3\psi}\right]\frac{1}{\sqrt{J_2}} \\
\frac{\partial \sigma_e}{\partial \psi} &= -2\sin\psi\sqrt{J_2}
\end{aligned} \tag{2-32}$$

Substituting Equations 2-31, 2-22, and 2-21 into Equation 2-16 gives the familiar generalization for the Mises flow potential

$$\dot{\epsilon}^c_{ij} = \frac{3\dot{\epsilon}^c_e}{2\sqrt{3J_2}} S_{ij} \tag{2-33}$$

and substituting Equations 2-32, 2-22, and 2-21 into Equation 2-16 gives the generalization for the Tresca flow potential

$$\dot{\epsilon}^c_{ij} = \dot{\epsilon}^c_e \left\{ \left[\frac{\cos 2\psi}{\cos 3\psi} \right] \frac{S_{ij}}{\sqrt{J_2}} + \left[\frac{\sqrt{3} \sin \psi}{J_2 \cos 3\psi} \right] t_{ij} \right\} \tag{2-34}$$

Finally, substitution of Equation 2-7 into Equations 2-33 and 2-34 gives the generalization of the Munson-Dawson model for Mises (octahedral shear) and Tresca (maximum shear) types of flow potentials, respectively. The Tresca flow generalization was used in the analyses reported here.

Equation 2-34 is seen to be indeterminant as the Lode angle approaches ± 30. In other words, the flow potential forms corners at $\psi = \pm 30$ and the direction of straining is not unique. To eliminate this problem computationally, Equation 2-34 is evaluated in the limit as $\psi \rightarrow \pm 30$. Performing this limiting operation, Equation 2-34 becomes

$$\lim_{\psi \rightarrow \pm 30} \left(\dot{\epsilon}^c_{ij} \right) = \dot{\epsilon}^c_e \left\{ \frac{S_{ij}}{\sqrt{3J_2}} \mp \frac{t_{ij}}{2J_2} \right\} \tag{2-35}$$

In SPECTROM-32, Equation 2-35 is used when the Lode angle is within 0.25 degrees of $\pm 30°$.

2.1.3 Material Properties for Intact Salt

The linear elastic parameter values for the constitutive relation given in Equation 2-3 and the parameter values for the Munson-Dawson constitutive equation given in Equation 2-7 are presented in Table 2-1. Density of the intact salt is 2,140 kg/m^3. The intact salt material parameters were taken from Munson [1989] for pure halite.

2.2 CRUSHED SALT

The total strain rate for the crushed salt constitutive model is assumed to consist of two components. The components are nonlinear elastic and creep consolidation contributions and the total strain rate is written as

$$\dot{\epsilon}_{ij} = \dot{\epsilon}^e_{ij} + \dot{\epsilon}^c_{ij} \tag{2-36}$$

Table 2-1. Material Parameter Values for Intact Salt[a]

Parameter	Units	Value
Elastic Parameter Values		
E	MPa	31,000
ν	—	0.25
Munson-Dawson Creep Parameter Values		
A_1	yr^{-1} s^{-1}	2.645E+30 8.386E+22
A_2	yr^{-1} s^{-1}	3.050E+20 9.672E+12
Q_1/R Q_1	K cal/mol	12,581 25,000
Q_2/R Q_2	K cal/mol	5,032 10,000
n_1	—	5.5
n_2	—	5.0
$\hat{B}_1$	yr^{-1} s^{-1}	1.919E+14 6.086E+06
B_2	yr^{-1} s^{-1}	9.568E+05 3.034E–02
q	—	5.335E+03
σ_o	MPa	20.57
μ	MPa	12,400
m	—	3
K_o	—	6.275E+5
c	K^{-1}	9.198E–3
α	—	–17.37
β	—	–7.738
δ	—	0.58

(a) Munson [1989] for pure halite.

The nonlinear elastic, ϵ_{ij}^e, and creep consolidation strains, ϵ_{ij}^c, are described by Callahan [1990] but are included here for completeness. Both the nonlinear elastic and creep consolidation portions of the model describe the material behavior in bulk (volumetric) and in shear (deviatoric). Although other models exist and are under consideration to describe the behavior of crushed salt (e.g., Zeuch [1989]), the nonlinear elastic and creep consolidation models for crushed salt were adapted from those given by Sjaardema and Krieg [1987].

2.2.1 Nonlinear Elastic Model for Crushed Salt

The elastic model described in Section 2.1.1 is applicable to the crushed salt with the following described procedure used to incorporate the nonlinearity in a piecewise manner.

For the nonlinear elastic model, the functional forms for the elastic constants given by Sjaardema and Krieg [1987] are adopted. They propose bulk and shear moduli as exponential functions of the current density, ρ_s. Tensile stresses and extensile strains are assumed to be positive. Functional forms of the elastic constants are written in terms of the total volumetric strain, ϵ_v ($\epsilon_v = \epsilon_{kk} = \epsilon_{11} + \epsilon_{22} + \epsilon_{33}$), using the relation

$$\rho_s = \frac{\rho_0^s}{1 + \epsilon_v} \tag{2-37}$$

where ρ_0^s is the initial or original density of the material. The bulk modulus and shear modulus (K_s and G_s) are given by

$$\begin{aligned} K_s &= K_0 e^{\frac{K_1 \rho_0}{1+\epsilon_v}} \\ G_s &= G_0 e^{\frac{G_1 \rho_0}{1+\epsilon_v}} \end{aligned} \tag{2-38}$$

where K_0, K_1, G_0, and G_1 are material constants.

At any time, the current values of Young's modulus and Poisson's ratio are computed from the current values of bulk and shear modulus using the relations

$$\begin{aligned} E &= \frac{9 K_s G_s}{3 K_s + G_s} \\ \nu &= \frac{3 K_s - 2 G_s}{6 K_s + 2 G_s} \end{aligned} \tag{2-39}$$

Equations 2-39 are used in Equation 2-3 to compute the elastic strains.

To solve the nonlinear elastic problem, the method of load incrementation is used to approximate the tangent modulus. The following set of simultaneous equations has to be solved in the direct stiffness finite element approach

$$[K_t]\{u\} + \{f\} = 0 \tag{2-40}$$

where f is the total load (or unload) vector, u is the displacement, and the tangent stiffness matrix K_t is a function of displacement (strain).

$$K_t = K_t(u) \tag{2-41}$$

The load vector is divided into a number of small increments Δf such that the series of tangent moduli will approximate a given stress-strain curve. K_t is first approximated assuming $\epsilon_v = 0$, or we are assuming that $\Delta u^0 = 0$ and

$$\left[K_t^0\right]\{\Delta u^1\} + \{\Delta f^1\} = 0 \tag{2-42}$$

Repetition of this process for each of the load increments may be written as

$$\{\Delta u^n\} = -\left[K_t^{n-1}\right]^{-1}\{\Delta f^n\} \tag{2-43}$$

The process is continued for each of the load increments, and the displacement is accumulated, i.e.,

$$\{u\} = \{u\} + \{\Delta \delta^n\} \tag{2-44}$$

Clearly, the functional forms adopted for bulk and shear moduli (Equations 2-38) allow increase without bound. Therefore, maximum values for bulk modulus K_f and shear modulus G_f are introduced based on the fully consolidated or intact values for the material. If either the intact bulk or shear modulus values are reached, the tangent modulus is no longer allowed to change, and the material is assumed to be intact with a constant stiffness.

2.2.2 Creep Consolidation Model for Crushed Salt

To develop the creep consolidation constitutive equation, general considerations are first observed and then specific functional forms are guided by available laboratory data. From the application of thermodynamic concepts, the three-dimensional generalization for creep strain rates is given by Fossum et al. [1988]. Following this approach, two continuum internal variables are assumed, the average inelastic volumetric strain, $\epsilon^c_{eq_1}$, and the average equivalent inelastic shear strain, $\epsilon^c_{eq_2}$.

$$\dot{\epsilon}^c_{ij} = \dot{\epsilon}^c_{eq_1}\frac{\partial \sigma^f_{eq_1}}{\partial \sigma_{ij}} + \dot{\epsilon}^c_{eq_2}\frac{\partial \sigma^f_{eq_2}}{\partial \sigma_{ij}} \tag{2-45}$$

For the first portion (volumetric) of Equation 2-45, the invariant strain-rate measure is

$$\dot{\epsilon}^c_{eq_1} = \dot{\epsilon}_v(\sigma_m) \tag{2-46}$$

The volumetric strain rate $\dot{\epsilon}^c_v$ is described empirically by Sjaardema and Krieg [1987] based on hydrostatic laboratory test data on crushed salt as

$$\dot{\epsilon}^c_v = \frac{(1+\epsilon_v)^2}{\rho_0} B_0\left[1 - e^{-B_1\sigma_m}\right] e^{\frac{A\rho_0}{1+\epsilon_v}} \tag{2-47}$$

where

$$\begin{aligned} \epsilon_v &= \epsilon_{kk}, \text{ total volumetric strain} \\ \epsilon_v^c &= \epsilon_{kk}^c, \text{ volumetric creep strain} \\ \sigma_m &= \frac{\sigma_{kk}}{3}, \text{ mean stress} \\ \rho_0^s &= \text{initial density} \\ B_0,\, B_1,\, A &= \text{material constants (see Table 2-3).} \end{aligned}$$

The invariant stress measure is given by

$$\sigma_{eq_1}^f = \sigma_m \tag{2-48}$$

For the second portion (deviatoric) of Equation 2-45, the invariant strain-rate measure is taken to be

$$\dot{\epsilon}_{eq_2}^c = \eta \dot{\epsilon}_{eq_1}^c = \eta \dot{\epsilon}_v \left(\sigma_m\right) \tag{2-49}$$

and the invariant stress is assumed to be a scalar multiple of the octahedral shear stress

$$\sigma_{eq_2}^f = \sigma_e = \sqrt{3J_2} \tag{2-50}$$

where J_2 is the second invariant of the stress deviator ($J_2 = \frac{1}{2} S_{ij} S_{ij}$). Substituting into Equation 2-45 and performing the required differentiation gives

$$\dot{\epsilon}_{ij}^c = \dot{\epsilon}_v^c \frac{\delta_{ij}}{3} + \eta \dot{\epsilon}_v^c \frac{3 S_{ij}}{2\sigma_e} \tag{2-51}$$

η is selected such that in a uniaxial test, the lateral components of $\dot{\epsilon}_{ij}^c$ equal zero. This requires that $\eta = -\frac{2}{3}$. Simple example problems that illustrate the creep consolidation behavior with and without the deviatoric component are given by Callahan [1990]. After substituting for $\dot{\epsilon}_v^c$ in Equation 2-51, the strain rate components are given by

$$\dot{\epsilon}_{ij}^c = \frac{\left(1+\epsilon_v\right)^2}{\rho_0} B_0 \left[1 - e^{-B_1 \sigma_m}\right] e^{\frac{A\rho_0}{1+\epsilon_v}} \left\{ \frac{\delta_{ij}}{3} - \frac{S_{ij}}{\sigma_e} \right\} \tag{2-52}$$

Obviously, the creep consolidation equation will allow unlimited consolidation. Therefore, a cap is introduced that eliminates further consolidation when the intact material density ρ_f is reached. Thus, when the condition

$$|\epsilon_v| \geq \left| \frac{\rho_0}{\rho_f} - 1 \right| \tag{2-53}$$

is satisfied, no further creep consolidation occurs. In addition, the creep consolidation is not permitted to generate tensile stresses. The procedure used to eliminate any tensile stresses is the same as described by Callahan et al. [1990]. An option is included that allows a consolidating material's constitutive model to be redefined following complete consolidation. For example, a crushed salt material can be prescribed to behave according to the intact salt constitutive relation given in Equation 2-34 following complete consolidation.

2.2.3 Combined Crushed Salt Model

The final equation for the total strain in the constitutive model for crushed salt (neglecting thermal strains) is obtained by substituting Equations 2-4 and 2-52 into Equation 2-36

$$\dot{\epsilon}_{ij} = \frac{\dot{\sigma}_m}{3K}\delta_{ij} + \frac{\dot{S}_{ij}}{2G} + \frac{(1+\epsilon_v)^2}{\rho_0} B_0 \left[1 - e^{-B_1\sigma_m}\right] e^{\frac{A\rho_0}{1+\epsilon_v}} \left\{\frac{\delta_{ij}}{3} - \frac{S_{ij}}{\sigma_e}\right\} \tag{2-54}$$

The above equation may be collapsed to yield the total volumetric strain-rate ($\dot{\epsilon}_v$) expression for the model. Performing this operation yields

$$\dot{\epsilon}_v = \frac{\dot{\sigma}_m}{K} + \frac{(1+\epsilon_v)^2}{\rho_0} B_0 \left[1 - e^{-B_1\sigma_m}\right] e^{\frac{A\rho_0}{1+\epsilon_v}} \tag{2-55}$$

When the combined nonlinear elastic and creep consolidation model is used, the relative change in the Euclidean or L_2 norm of the volumetric strain is monitored over time and the stiffness is updated when the change is greater than a user prescribed tolerance. Further details may be found in Callahan [1990].

2.2.4 Material Properties for Crushed Salt

The nonlinear elastic parameter values describing the nonlinear moduli for crushed salt defined in Equation 2-38 are given in Table 2-2. Table 2-2 also gives the assumed initial and final (intact) densities for the crushed salt used in this study. Engineering of the backfill could change the initial density substantially. Table 2-3 presents the parameter values for the creep consolidation constitutive equation given in Equation 2-52. The crushed salt material parameters are taken from Sjaardema and Krieg [1987].

Table 2-2. Nonlinear Elastic Material Parameters for Crushed Salt

Parameter	Units	Value
K_0	MPa	0.01760[a]
K_1	m^3/kg	0.00653[a]
G_0	MPa	0.01060[a]
G_1	m^3/kg	0.00653[a]
K_f	MPa	20,626[b]
G_f	MPa	12,423[b]
ρ_0^s	kg/m^3	1,400[c]
ρ_f	kg/m^3	2,140[a]

(*a*) Sjaardema and Krieg [1987].

(*b*) Computed using Equation 2-38 at ρ_f.

(*c*) Weatherby [1989].

Table 2-3. Creep Consolidation Material Parameters for Crushed Salt

Parameter	Units	Value[a]
B_0	$kg/m^3 \cdot s^{-1}$ $kg/m^3 \cdot yr^{-1}$	$1.3 \times 10^{+8}$ $4.10 \times 10^{+15}$
B_1	MPa^{-1}	0.82
A	m^3/kg	-1.73×10^{-2}

(a) Sjaardema and Krieg [1987].

2.3 CRUSHED SALT MIXTURES

For the TRU waste disposal rooms, two crushed salt mixtures are of current interest: (1) crushed salt mixed with bentonite and (2) crushed salt mixed with TRU waste.

2.3.1 Crushed Salt/Bentonite Mixture Model

The functional form of the constitutive model selected to represent crushed salt/bentonite mixtures is identical to the crushed salt model since testing completed to date is inadequate to formulate a new constitutive model for crushed salt/bentonite mixtures. Therefore, Equation 2-52 applies to crushed salt/bentonite using material parameter values specific to the crushed salt/bentonite mixture given in Section 2.3.3.1.

2.3.2 Crushed Salt/TRU Waste Mixture Model

A possible waste treatment consists of simply mixing TRU waste with crushed salt and allowing the crushed salt to encapsulate the waste as the disposal room closes and the crushed salt consolidates. To develop constitutive relations for these types of mixtures, it is assumed that the TRU waste component consists of shredded metal wastes, is linear elastic, and is effectively an inert noninteracting material. Therefore, Equations 2-3 and 2-4 apply to the inert mixture material. Mixture theory is used to combine the crushed salt constitutive relations (nonlinear elasticity and creep consolidation) with the TRU waste.

2.3.2.1 Creep Consolidation Response of TRU Waste and Crushed Salt Mixtures

The creep consolidation model for a consolidating material mixed with another inert material is developed in this section. The creep consolidation relation for crushed salt is developed in Section 2.2.2 with the volumetric creep strain rate for crushed salt consolidation given in Equation 2-47. To distinguish the volumetric strain of the crushed salt from that of the mixture, the following definitions are used in the development:

$$\begin{aligned} \epsilon_{vs} &= \text{total volumetric strain of crushed salt} \\ \epsilon_v &= \text{total volumetric strain of the mixture.} \end{aligned}$$

The total volume of the mixture (V) is

$$V = V_s + V_m \tag{2-56}$$

where

$$\begin{aligned} V_s &= \text{volume of crushed salt} \\ V_m &= \text{volume of inert material.} \end{aligned}$$

Equation 2-56 may also be written as

$$V = \frac{m_s M}{\rho_s} + \frac{m_m M}{\rho_m} \tag{2-57}$$

where

$$\begin{aligned} m_s &= \text{mass fraction of salt} \\ m_m &= \text{mass fraction of inert material} \\ \rho_s &= \text{current density of the crushed salt} \\ M &= \text{total mass of the mixture.} \end{aligned}$$

Dividing Equation 2-57 by the total mass gives

$$\frac{1}{\rho} = \frac{m_s}{\rho_s} + \frac{m_m}{\rho_m} \tag{2-58}$$

where ρ is the current density of the mixture. If the density of the mixture is known, the density of the crushed salt can be found from Equation 2-58 as

$$\rho_s = \frac{\rho \rho_m m_s}{\rho_m - \rho m_m} \tag{2-59}$$

The initial density of the mixture ρ_0 can be found by substituting the initial crushed salt density into Equation 2-58

$$\rho_0 = \frac{\rho_0^s \rho_m}{m_s \rho_m + m_m \rho_0^s} \tag{2-60}$$

The rate of change of the density of the mixture is given by differentiating Equation 2-58 with respect to time. The volumetric strain of the inert material is assumed to be small such that the density of the inert material is constant. Performing the differentiation yields

$$\dot{\rho} = \frac{m_s \rho^2}{\rho_s^2} \dot{\rho}_s \tag{2-61}$$

If the relationships between the density and volumetric strain, i.e.,

$$\rho = \frac{\rho_0}{1 + \epsilon_v} \tag{2-62}$$

$$\rho_s = \frac{\rho_0^s}{1 + \epsilon_{vs}} \tag{2-63}$$

are substituted into Equation 2-61, the volumetric strain rate for the mixture is determined as

$$\dot{\epsilon}_v = \frac{m_s \rho_0}{\rho_0^s} \dot{\epsilon}_{vs} \tag{2-64}$$

The current density of the crushed salt may be expressed as

$$\rho_s = \frac{M_s}{V_s} = \frac{m_s M}{v_s V} = \frac{m_s \rho}{v_s} \tag{2-65}$$

where M_s is the mass of the salt. Thus, the volume fraction of the crushed salt v_s is

$$v_s = \frac{m_s \rho}{\rho_s} \tag{2-66}$$

The initial volume fraction of crushed salt is obtained by substituting the initial densities into Equation 2-66

$$v_0^s = \frac{m_s \rho_0}{\rho_0^s} \tag{2-67}$$

Substituting Equation 2-67 into Equation 2-64 yields

$$\dot{\epsilon}_v = v_0^s \dot{\epsilon}_{vs} \tag{2-68}$$

Thus, Equation 2-68 describes the volumetric strain rate of crushed salt mixed with an inert material in terms of the volumetric strain rate of the crushed salt. Assuming that the volumetric strain rate is the sum of the elastic and creep portions, Equation 2-68 may be written as

$$\dot{\epsilon}_v^c + \dot{\epsilon}_v^e = v_0^s \left(\dot{\epsilon}_{vs}^c + \dot{\epsilon}_{vs}^e \right) \tag{2-69}$$

The elastic strain rates are assumed to be negligible compared to the creep consolidation strain rates. To evaluate the relative magnitudes of the strain rates, conditions applicable to analyses relevant to our situation will be considered. Based on an initial density of 1,400 kg/m^3, the initial bulk modulus of crushed salt is about 150 MPa and the final value at full consolidation is that of intact salt, or 20,626 MPa. If the mean stress in the crushed salt is assumed to change from zero to the lithostatic value of nearly 15 MPa compression over a 50-year period, the elastic strain rate can be computed to be about 6.3E-11 s^{-1} based on the initial bulk modulus and 4.6E-13 s^{-1} based on the final bulk modulus value. If a pressure of 0.1 MPa compression in the crushed salt is assumed and the initial density is used, a creep consolidation strain rate of about 2.3E-7 s^{-1} is computed. Thus, the elastic strain rate is about three to six orders of magnitude less than the creep consolidation strain rate. As the crushed salt consolidates, both the elastic and creep consolidation strain rates decrease. However, the effective pressure in the crushed salt also increases with time, which increases the creep consolidation strain rate. In addition, when the inert material is mixed with the crushed salt, the stiffness of the mixture is increased, which reduces the elastic strain rate. Therefore, neglecting the elastic strain rates appears to be a reasonable assumption and the relation for the volumetric creep strain of the mixture becomes

$$\dot{\epsilon}_v^c = v_0^s \dot{\epsilon}_{v_s}^c \tag{2-70}$$

where $\dot{\epsilon}_{v_s}^c$ is given by Equation 2-52.

2.3.2.2 Nonlinear Elastic Response of TRU Waste and Crushed Salt Mixtures

For the nonlinear elastic model, the derivation of the elastic constants for a mixture of two dissimilar materials is required. One material behaves nonlinearly and the other material is linear. Many different methods exist for representing the continuum properties of multiphase materials with different distributions of the phases. Maxwell's model considers randomly sized spheres of one material distributed in another (e.g., Parrott and Stuckes, [1975]). Other examples of property bounds established for multiphase materials may be found in Hashin and Shtrikman [1962], Corson [1974], and Milton [1982]. Corson [1974], referencing another researcher who used energy theorems of classical elasticity theory to establish bounds for effective bulk and shear moduli, states that his resultant bounds were precisely the volume-fraction average of the modulus of each phase (upper bound) and the inverse of the volume-fraction average of the inverse modulus (lower bound). Therefore, although many complex methods exist to establish bounds for the elastic moduli in a mixture, the simple rule of mixtures is relied upon because precise knowledge of the properties and the distribution of the phases in the two-component system is not available.

The rule of mixtures states that a given property for a mixture (Θ) is simply a function of the component properties (θ_i) weighted according to their volume

fractions (v_i). Parallel and series combinations are typical simple forms that may be stated mathematically as

$$\Theta = v_i\theta_i \tag{2-71}$$

$$\frac{1}{\Theta} = \frac{v_i}{\theta_i} \tag{2-72}$$

and $\Sigma v_i = 1$. These two mixture forms provide simple upper and lower bounds. Either Equation 2-71 or 2-72 could be used to formulate the effective moduli for the two-component mixture. Equation 2-71 is used to develop the moduli for the mixture, which gives the upper bound or higher stiffnesses. Thus, the elastic moduli for the mixture are

$$K = v_s K_s + v_m K_m \tag{2-73}$$

$$G = v_s G_s + v_m G_m \tag{2-74}$$

where

v_s = volumetric fraction of crushed salt
v_m = volumetric fraction of inert material
K_m = bulk modulus of the inert material
G_m = shear modulus of the inert material.

The functional form of the nonlinear elastic material model for crushed salt is described in Section 2.2.1 with the bulk (K_s) and shear (G_s) moduli defined by Equations 2-38 as

$$K_s = K_0 e^{K_1 \rho_s} \tag{2-75}$$

$$G_s = G_0 e^{G_1 \rho_s} \tag{2-76}$$

where K_0, K_1, G_0, and G_1 are material constants. The moduli for the inert material are assumed to be constant but the volume fraction and the moduli for the crushed salt will change with consolidation. Since the volume fractions for the compacting material mixture changes, the mass fractions of the components are the desirable input variables since they are constant. Thus, expressions for the mass fractions in terms of the component densities and volume fractions are required. The density of the crushed salt and the inert material may be expressed as

$$\rho_s = \frac{M_s}{V_s} = \frac{m_s M}{v_s V} = \frac{m_s \rho}{v_s} \tag{2-77}$$

$$\rho_m = \frac{M_m}{V_m} = \frac{m_m M}{v_m V} = \frac{m_m \rho}{v_m} \tag{2-78}$$

where

ρ_m = density of the inert material
ρ = density of the mixture
M_s = mass of salt
M_m = mass of inert material.

Solving Equations 2-77 and 2-78 for the volume fractions gives

$$v_s = \frac{m_s \rho}{\rho_s} \tag{2-79}$$

$$v_m = \frac{m_m \rho}{\rho_m} \tag{2-80}$$

The total volume of the mixture (V) at any time is

$$V = V_s + V_m \tag{2-81}$$

Equation 2-81 may also be written as

$$V = \frac{m_s M}{\rho_s} + \frac{m_m M}{\rho_m} \tag{2-82}$$

Dividing Equation 2-82 by the total mass gives

$$\frac{1}{\rho} = \frac{m_s}{\rho_s} + \frac{m_m}{\rho_m} \tag{2-83}$$

After algebraic manipulation, Equation 2-83 may be written

$$\rho = \frac{\rho_s \rho_m}{m_s \rho_m + m_m \rho_s} \tag{2-84}$$

Solving Equation 2-84 for the crushed salt density yields

$$\rho_s = \frac{m_s \rho \rho_m}{\rho_m - m_m \rho} \tag{2-85}$$

Substitution of Equation 2-85 into Equations 2-79 and 2-80 yields expressions for the volume fractions in terms of the mass fractions and densities

$$v_s = \frac{m_s \rho_m}{m_s \rho_m + m_m \rho_s} \tag{2-86}$$

$$v_m = \frac{m_m \rho_s}{m_s \rho_m + m_m \rho_s} \tag{2-87}$$

Similarly, the mass fractions can be expressed as

$$m_s = \frac{v_s \rho_s}{v_s \rho_s + v_m \rho_m} \tag{2-88}$$

$$m_m = \frac{v_m \rho_m}{v_s \rho_s + v_m \rho_m} \tag{2-89}$$

With the volume fractions given by Equations 2-86 and 2-87, the elastic moduli can be determined by substitution into Equations 2-73 and 2-74. The procedure given in Section 2.2.1 can then be followed to solve the nonlinear elastic mixture problem.

Now, expressions are needed for the final values of the bulk and shear moduli, which depend on the final volume fractions of the mixed materials when the void fraction is zero. If the void volume is considered to reside entirely in the crushed salt, the crushed salt volume (V_s) may be expressed as

$$V_s = V_v + V_{is} \tag{2-90}$$

where V_v and V_{is} are the volumes of the voids and the intact (solid) salt, respectively, and the total volume of the mixture is given in Equation 2-81. The porosity of the crushed salt (ϕ_s) is defined as

$$\phi_s = \frac{V_v}{V_s} = \frac{V_s - V_{is}}{V_s} = 1 - \frac{\rho_s}{\rho_{is}} \tag{2-91}$$

where ρ_{is} is the density of intact salt. The volume fraction of the crushed salt (v_s) is given by

$$v_s = \frac{V_v + V_{is}}{V} \tag{2-92}$$

From Equations 2-90, 2-91, and 2-92, we have

$$V_v = \phi_s V_s = \phi_s \{V_v + V_{is}\} = \phi_s v_s V \tag{2-93}$$

Using Equation 2-93, the porosity of the mixture (ϕ) is

$$\phi = \frac{V_v}{V} = \phi_s v_s \tag{2-94}$$

Since the sum of the volume fractions equals one, i.e.,

$$\phi + v_{is} + v_m = 1 \tag{2-95}$$

the volume fraction of salt is given as

$$v_{is} = 1 - \phi - v_m \tag{2-96}$$

Therefore, the final volume of the crushed salt V_s^f, which is the same as the volume of solid salt, is obtained when $V_v = 0$ which implies that $\phi_s = 0$ and $\phi = 0$

$$V_s^f = V_{is} = v_{is} V \tag{2-97}$$

Thus, the final volume of the mixture is

$$V^f = V_{is} + V_m = v_{is} V + V_m \tag{2-98}$$

The volume fraction of the mixture remaining after full consolidation (v^f) is obtained by dividing Equation 2-98 by the volume (V) giving

$$v^f = v_{is} + v_m = 1 - \phi \tag{2-99}$$

The final volume fractions for salt (v_{is}^f) and the inert material (v_m^f) are then determined as

$$v_{is}^f = \frac{v_{is}}{v^f} \tag{2-100}$$

$$v_m^f = \frac{v_m}{v^f} \tag{2-101}$$

The final density and moduli of the mixture can then be determined from mixture theory as

$$\rho^f = v_{is}^f \rho_{is} + v_m^f \rho_m \tag{2-102}$$

$$K^f = v_{is}^f K_{is} + v_m^f K_m \tag{2-103}$$

$$G^f = v_{is}^f G_{is} + v_m^f G_m \tag{2-104}$$

2.3.3 Material Properties for Crushed Salt Mixtures

2.3.3.1 Crushed Salt/Bentonite Mixture

The functional forms of the crushed salt/bentonite mixture constitutive relations were selected to be the same as those present in Section 2.2 for crushed salt. However, the material parameters were modified based on available information to be more representative of the crushed salt/bentonite mixture. The nonlinear elastic parameter values describing the nonlinear moduli for a 70/30 percent by weight crushed salt/bentonite mixture defined in Equation 2-38 are given in Table 2-4. Table 2-4 also gives the initial and final or intact densities for the crushed salt/bentonite mixture. The final or intact material density was taken to be 2,260 kg/m^3. Pfeifle [1990] gives a value of 2,266 kg/m^3 for a 70/30 percent by weight crushed salt/bentonite mixture, assuming a solid density for salt of 2,120 kg/m^3 and a solid density for bentonite of 2,700 kg/m^3. The initial material density was selected such that the initial porosity of the crushed salt/bentonite mixture was the same as that assumed for the crushed salt. Because of the lack of test data for the elastic properties of the crushed salt/bentonite mixtures, the parameter values for the nonlinear elastic moduli were assumed to be the same as crushed salt. However, the K_1 and G_1 parameters were computed based on the final density value such that the ultimate moduli values (K_f and G_f) are reached when the mixture attains the final density.

Table 2-5 presents the parameter values for the creep consolidation constitutive equation given in Equation 2-52. The crushed salt/bentonite material parameters are taken from Pfeifle [1990]. The material parameter values for the creep consolidation model for the crushed salt/bentonite experiments conducted by Pfeifle [1990] at various moisture contents are given in Table 2-5. The property values labeled *Selected* represent the parameter value set chosen to represent the crushed

salt/bentonite backfill. These parameter values were selected because they represent the three tests performed by Pfeifle [1990] reasonably well; however, they do not represent the tests well over a wide range in pressures as discussed in the next paragraphs.

Table 2-4. Nonlinear Elastic Material Parameters for Crushed Salt/Bentonite

Parameter	Units	Value
K_0	MPa	0.01760[a]
K_1	m^3/kg	0.00945[b]
G_0	MPa	0.01060[a]
G_1	m^3/kg	0.00945[b]
K_f	MPa	20,626[a]
G_f	MPa	12,423[a]
ρ_0	kg/m^3	1,478.5[c]
ρ_f	kg/m^3	2,260[d]

(*a*) Assumed identical to crushed salt (see Table 2-2).

(*b*) Computed from Equation 2-38 using ρ_f with K_f and G_f values.

(*c*) Computed so that initial porosity was identical to crushed salt.

(*d*) Engineering estimate.

Table 2-5. Creep Consolidation Model Parameter Values for Crushed Salt/Bentonite

Test I.D.	Moisture Content (%)	Hydrostatic Pressure (MPa)	Parameter Values[a]		
			A ($m^3 \cdot kg^{-1} \times 10^{-3}$)	B_0 ($kg \cdot m^{-3} \cdot s^{-1} \times 10^{21}$)	B_1 (MPa^{-1})
CS1	5.3	3.45 to 14	-33.9	0.972	.693
CS4	5.24	3.45 to 14	-34.5	1.021	.509
CS3	9.97	3.45 to 7	-30.3	0.970	.084
Selected Crushed Salt/ Bentonite Values			-34.5	1.000	.600

(*a*) CS1, CS4, and CS3 parameter values taken from Pfeifle [1990].

Figure 2-1 plots the log of the volumetric strain rate resulting from the parameter sets given in Table 2-5 for various fractional densities with an assumed applied pressure of 15 MPa. In this series of curves, the selected parameter values for crushed salt/bentonite seem to fairly well represent the parameter values given by Pfeifle [1990]. Since very little pressure build up is observed in the crushed salt until the backfill is nearly compacted, the parameter sets are also illustrated for lower pressures. Figure 2-2 illustrates the same information presented in Figure 2-1 except that the assumed applied pressure is 0.05 MPa. In this series of curves, the curve for the selected parameter values is similar to the lower curve that was generated with the parameter values labeled *CS4* in Table 2-5. Also note that the volumetric strain rates for the crushed salt/bentonite are higher than the crushed salt for low values of fractional density.

Figure 2-3 compares the change in volumetric strain rate with time for crushed salt and crushed salt/bentonite bodies under a constant pressure of 0.05 MPa. The parameter values for the crushed salt model given in Table 2-3 were derived by Sjaardema and Krieg [1987] based on hydrostatic consolidation tests conducted by Holcomb and Shields [1987] on crushed WIPP salt with added water. The test duration for these crushed salt tests was typically 23 days. The parameter values for the crushed salt/bentonite model given in Table 2-5 were derived by Pfeifle [1990] from multistage tests on crushed salt/bentonite mixtures with added water. Pfeifle's test durations ranged from 272 to 305 days, which included a final permeability measurement stage. The duration of Stage One in the tests ranged from 70 to 118 days. The curves in Figure 2-3 were generated using the analytical solution for creep consolidation given in Callahan [1990]. Figure 2-3 shows that the volumetric strain rate for the crushed salt/bentonite is higher than that of the crushed salt during early time with the strain rates for both decreasing with time. After about .01 year, the strain rate for the crushed salt/bentonite becomes less than the crushed salt strain rate.

2.3.3.2 Crushed Salt/TRU Waste Mixture

Material parameter values for crushed salt are given in Section 2.2.4. Therefore, to describe material properties for the crushed salt/TRU waste mixture, only the TRU waste properties need to be defined. Subsequently, mixture properties can be computed from the equations derived in Section 2.3.2.2. The TRU waste mixed with the crushed salt is assumed to consist of shredded metal wastes. The simulated metallic wastes tested by Butcher et al. [1991] included cut up steel, copper, lead, and aluminum scrap, and Butcher et al. [1991] assumed a solid density of 7,360 kg/m^3. Additional discussion of probable metallic waste composition is given by Butcher [1989] where the assumed solid density of metallic waste is 7,860 kg/m^3. Table 2-6 gives properties and assumed volume fractions of steel, aluminum, copper, lead, and tantalum [Butcher, 1990] used in this study. The composite material properties given in Table 2-6 are assumed to be representative of the shredded metallic waste. For crushed salt, an initial density of 1,400 kg/m^3 is assumed. The

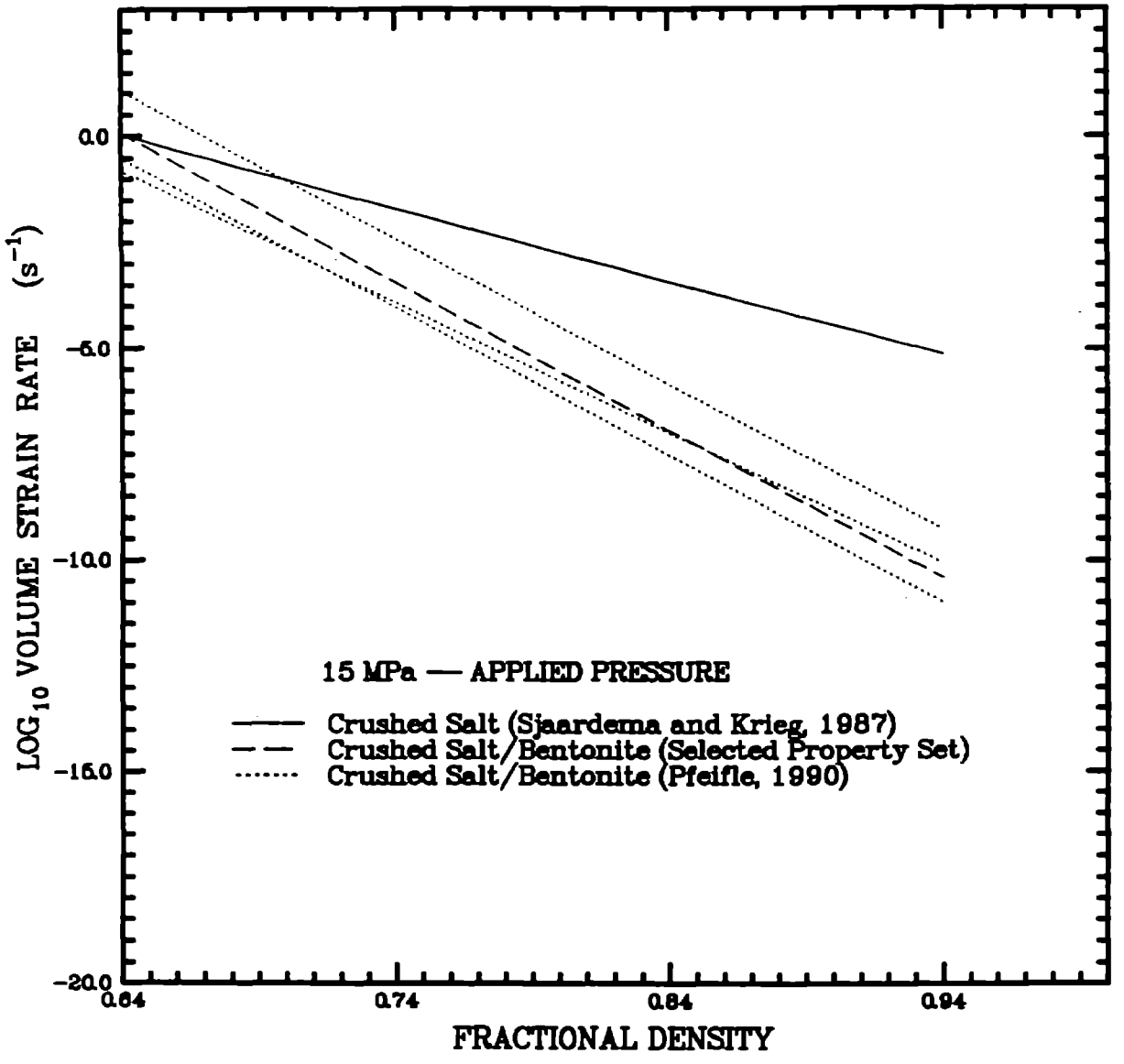


Figure 2-1. Volumetric Strain As a Function of Fractional Density for an Applied Pressure of 15 MPa.

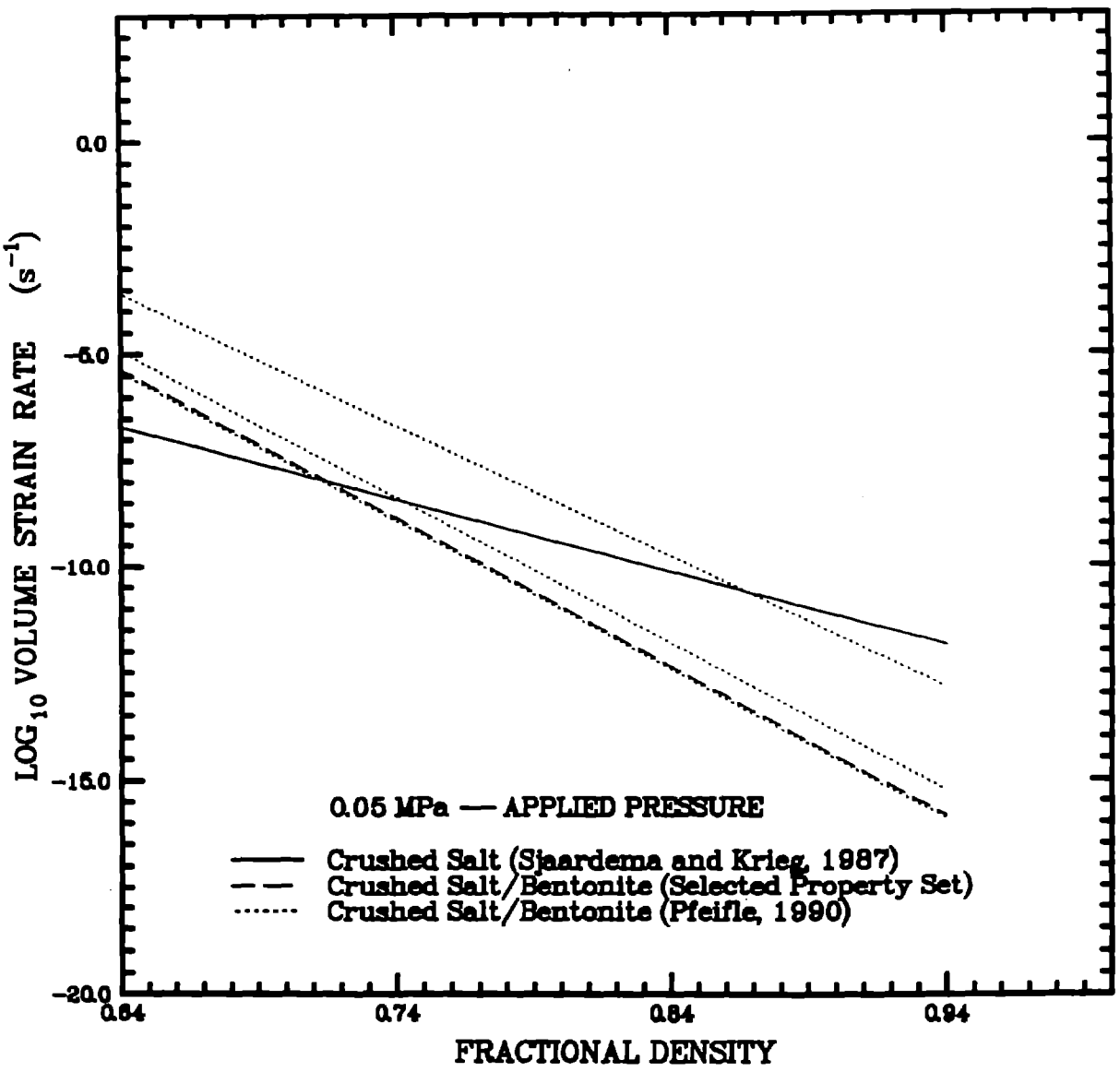


Figure 2-2. Volumetric Strain As a Function of Fractional Density for an Applied Pressure of 0.05 MPa.

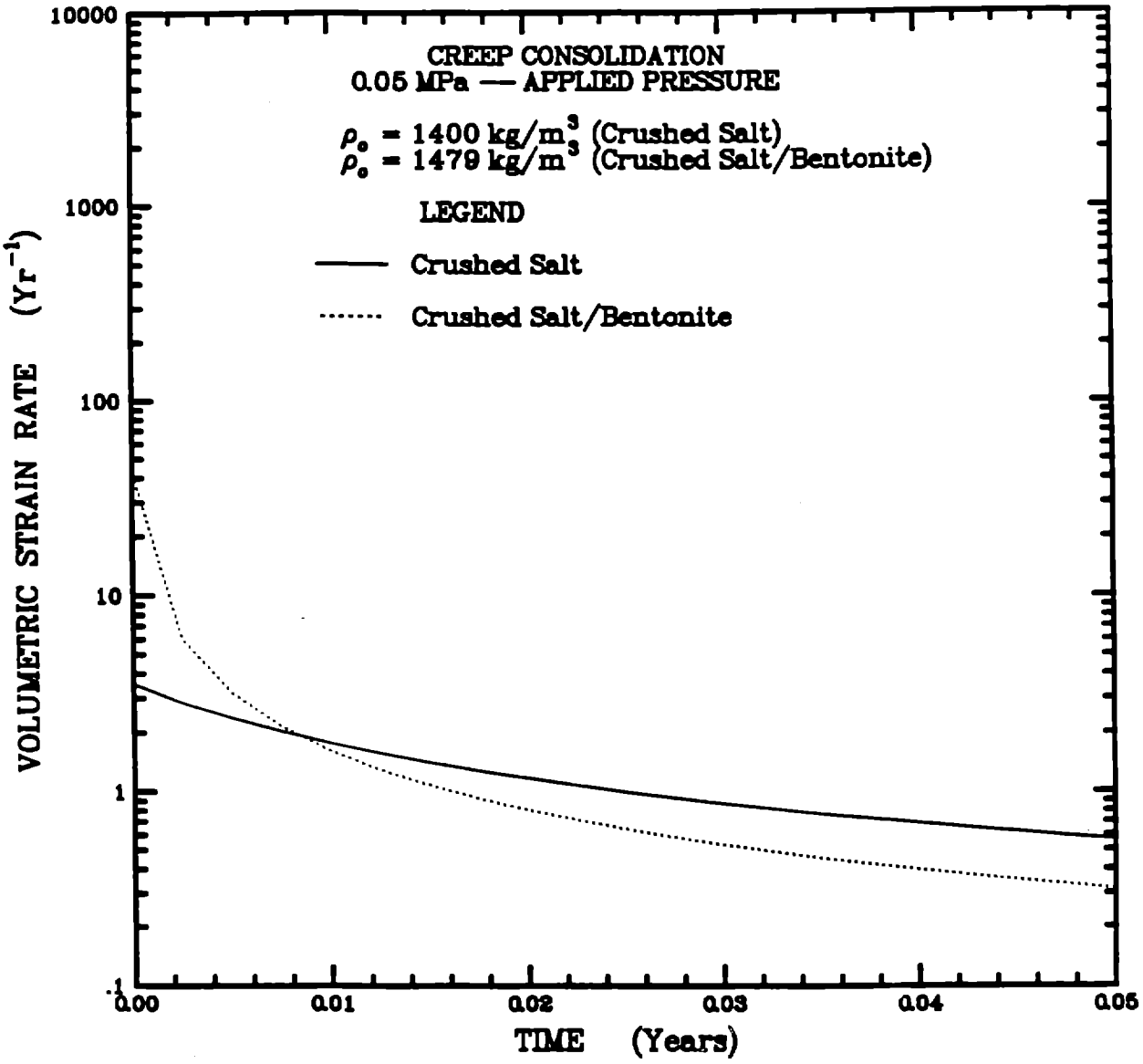


Figure 2-3. Change in Volumetric Strain Rate With Time for an Applied Pressure of 0.05 MPa.

initial crushed salt/shredded metal waste mix is assumed to be 80/20 percent by volume.

Table 2-6. Metallic Waste Components Properties

Component	Volume (%)	Density ($kg \times m^{-3}$)	Modulus of Elasticity (GPa)	Poisson's Ratio (—)	Shear Modulus[a] (GPa)	Bulk Modulus[b] (GPa)
Steel	64	7,860[c]	207[c]	0.27[c]	81	150
Aluminum	14	2,700[d]	69[d]	0.33[c]	26	68
Copper	11	8,960[d]	117[d]	0.34[c]	44	122
Lead	7	11,350[d]	14[d]	0.30[e]	5	12
Tantalum	4	16,600[d]	186[d]	0.27[e]	73	135
Composite[f]	100	7,845	163	0.29	64	125

(*a*) Computed using $\frac{E}{2(1+\nu)}$.

(*b*) Computed using $\frac{E}{3(1-2\nu)}$.

(*c*) McClintock and Argon [1966].

(*d*) Lynch [1974].

(*e*) Engineering estimate.

(*f*) Computed using Equation 2-71.

From the given properties, the initial density and mass fractions can be computed using Equations 2-84, 2-88, and 2-89. Substituting the given values yields the initial density of the mixture $\rho_0 = 2,690\ kg/m^3$, mass fraction of the salt $m_s = 0.417$, and mass fraction of the shredded metallic waste $m_m = 0.584$. From Equations 2-91 and 2-94, initial values for the porosities of the salt and the mixture are found to be $\phi_s = 0.346$ and $\phi = 0.277$. From Equation 2-96, the volume fraction of solid salt is $v_{i_s} = 0.523$. Therefore, from Equations 2-99, 2-100, and 2-101, respectively, $v^f = 0.723$, $v^f_{i_s} = 0.724$, and $v^f_m = 0.277$. From Equations 2-102, 2-103, and 2-104, respectively, the final density is $\rho^f = 3,720\ kg/m^3$, the final bulk modulus is $K^f = 49,500$ MPa, and the final shear modulus is $G^f = 26,600$ MPa.

2.4 TRU WASTE

Two TRU waste forms are considered in this section: (1) a mixture of metallic, combustible, and sludge wastes and (2) a vitrified TRU waste. Two material models are required to characterize the behavior of these two TRU waste forms: (1) a

nonlinear elastic model to represent the composite TRU waste mixture and (2) a linear elastic model to represent the vitrified waste.

TRU waste forms are nonstandard and considerably variable in nature and quantity (e.g., see Butcher [1989]). TRU waste drums will be randomly placed within storage rooms at the WIPP site without regard to waste type. Wastes types may also be mixed within individual drums. Because of this random placement and mixture of wastes, it is necessary to assume that the waste drums can be characterized by a composite (or mechanically equivalent) waste drum. Therefore, a nonlinear elastic material model is developed to represent the composite TRU waste. Although TRU waste compaction is known to be irreversible, it is modeled as a nonlinear elastic material recognizing that the model is valid only if the load on the waste is monotonically increasing.

Vitrification is a possible waste treatment. Therefore, a model is developed to represent the glass-like substance resulting from a TRU vitrification process.

2.4.1 Nonlinear Elastic

As a first attempt, the nonlinear elastic model described in Section 2.2.2 was used to describe the behavior of a composite TRU waste. However, the functional form presented for the bulk modulus (Equation 2-38) did not adequately fit the simulated TRU waste compaction data. Therefore, an alternate functional form for the nonlinear elastic model was developed that fits the simulated TRU waste compaction data better. This model is

$$\sigma_a = \frac{1}{\kappa} ln(\frac{\phi}{\phi_0}) \tag{2-105}$$

where

σ_a = axial stress, $\sigma_a = 3\sigma_m$
σ_m = mean stress
κ = material parameter
ϕ = porosity
ϕ_0 = initial porosity.

The assumption stated above (i.e., $\sigma_a = 3\sigma_m$) is significant. The need for this assumption stems from the fact that the experiments were conducted on the compaction of simulated waste in rigid steel sleeves [Butcher et al., 1991] and only the axial stress component was measured. To evaluate the parameter values for the TRU waste model, all three stress components need to be known. Two bounding assumptions to infer values for the lateral stress components are (1) the lateral stress components are zero (i.e., $\sigma_a = 3\sigma_m$) and (2) the lateral stress components are equal to the axial stress (i.e., $\sigma_a = \sigma_m/3$). Assumption 1 represents an unconfined test, and Assumption 2 represents a hydrostatic test. Neither assumption is correct

in the sense that it represents the conditions in the experiment; however, the two assumptions bound the true stress conditions. The first assumption was adopted because it provides the less stiff representation of the TRU waste. The less stiff representation is felt to be more conservative because it provides less resistance to room closure and lower back pressure on the surrounding backfill, which increases the time required to obtain lower porosities in the backfill surrounding the TRU waste.

In terms of porosity, Equation 2-105 may be stated as

$$\phi = \phi_0 \exp(\kappa \sigma_a) \tag{2-106}$$

Porosity and density are defined as

$$\phi = 1 - \frac{\rho}{\rho_f} \tag{2-107}$$

$$\rho = \frac{\rho_0}{1 + \epsilon_v} \tag{2-108}$$

where

ρ = current density
ρ_0 = initial density
ρ_f = final density or intact material density
ϵ_v = volumetric strain.

Parameters ϕ_0 and κ are found by fitting Equation 2-106 to axial stress/porosity data (Appendix A) using least squares methods. Equation 2-106 implies an initial porosity of ϕ_0 and a porosity that approaches zero as the compressive stress (compressive stress is taken to be negative) approaches infinity.

From the TRU waste compaction equation, expressions for the moduli need to be derived to complete the nonlinear elastic model. The tangent bulk modulus (K) can be stated as

$$K = \frac{d\sigma_m}{d\epsilon_v} = \frac{d\sigma_m}{d\phi} \frac{d\phi}{d\rho} \frac{d\rho}{d\epsilon_v} \tag{2-109}$$

Performing the differentiation indicated in Equation 2-109 on Equation 2-105 results in

$$K = \frac{\rho^2}{3\kappa\rho_0(\rho_f - \rho)} \tag{2-110}$$

From Equation 2-110, the initial bulk modulus (K_i) is

$$K_i = \frac{\rho_0}{3\kappa(\rho_f - \rho_0)} \tag{2-111}$$

Also note that the bulk modulus is infinite when the final density is reached. Therefore, from a practical standpoint, it is necessary to prescribe a final bulk modulus

value that corresponds to an intact material density that is less than ρ_f when performing analyses. Equation 2-110 may also be expressed in terms of the porosity as

$$K = \frac{(1-\phi)^2 \rho_f}{3\kappa\phi\rho_0} \tag{2-112}$$

To derive a corresponding functional form for the shear modulus (G), a constant value for Poisson's ratio of $\nu = 0.25$ is assumed. Poisson's ratio expressed in terms of K and G is

$$\nu = \frac{3K - 2G}{6K + 2G} \tag{2-113}$$

Substituting the value for Poisson's ratio into Equation 2-113 and solving for G yields

$$G = \frac{3}{5}K \tag{2-114}$$

Therefore, using Equation 2-110, the expression for the shear modulus is

$$G = \frac{\rho^2}{3\lambda\rho_0(\rho_f - \rho)} \tag{2-115}$$

where $\lambda = \frac{5}{3}\kappa$.

With the nonlinear elastic moduli described by Equations 2-110 and 2-115, the nonlinear elastic model is completed using the procedure described in Section 2.2.1.

2.4.2 Vitrified Waste

Vitrified waste is assumed to be a linear elastic material. Therefore, the constitutive relation given in Section 2.1.1 also applies to the vitrified waste.

2.4.3 Material Properties for TRU Waste

The laboratory data used to determine the constitutive parameters for TRU waste compaction were obtained from Sandia National Laboratories (SNL). Tests were performed on three general types of simulated waste: combustible, metallic, and sludge wastes. The data consist of axial stress (σ_a) versus porosity (ϕ) pairs for each of the waste types and are reproduced in Appendix A. The assumption discussed in Section 2.4.1 (i.e., $\sigma_a = 3\sigma_m$) is applied to interpret and use the axial stress data. The experimental data and their corresponding fits to Equation 2-106 are shown in Figure 2-4. Because of the assumption discussed above, ordinate values in Figure 2-4 need to be divided by three to obtain information relating mean stress to porosity. Equation 2-106 fits the data quite well over most of the stress range; however, as seen in Figure 2-4, the fits are rather poor in the low-stress regime.

Table 2-7 contains parameters describing the individual waste types. The average solid densities for each of the waste types were obtained from Butcher et al.

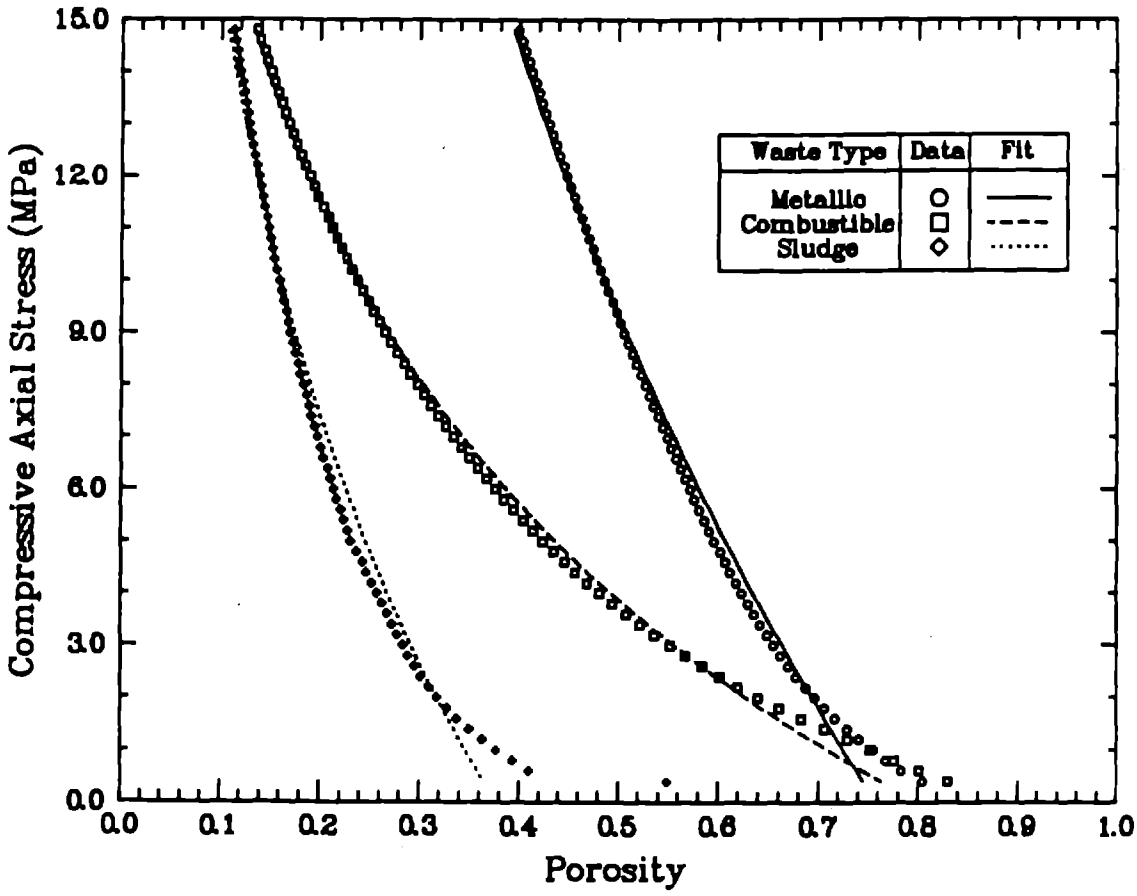


Figure 2-4. Compaction Data (Appendix A) and Fits for Individual Waste Types.

[1991]. The model parameters (ϕ_0 and κ) were determined for each of the waste types by fitting the experimental data to Equation 2-106. Initial densities were calculated from the solid density values and the fitted initial porosity values for each waste type using the following relationship:

$$\rho_0 = \rho_f (1 - \phi_0) \tag{2-116}$$

Table 2-7. Individual Waste Type Characteristics

Waste Type	Solid Density ρ_f (kg/m^3)	Initial Porosity ϕ_0	κ (MPa^{-1})	Initial Density ρ_0 (kg/m^3)
Combustible	1,920	0.801	0.121	383
Metallic	4,000	0.758	0.044	967
Sludge	2,370	0.377	0.085	1,480

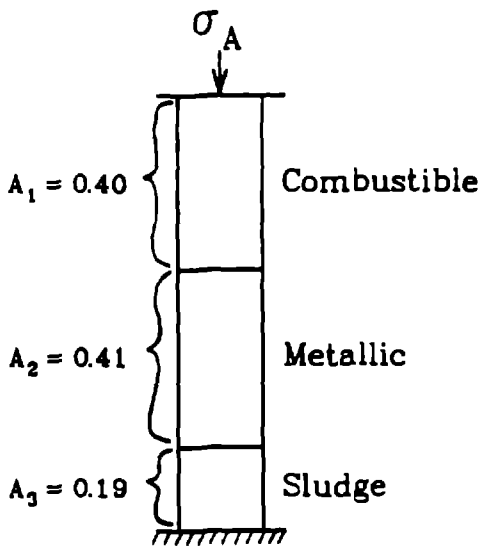
2.4.3.1 Models for Composite Waste Canisters

In this section, the waste drums are characterized by a composite (or mechanically equivalent) waste drum. A composite TRU waste drum as determined by Butcher et al. [1991] initially contains 40 percent combustible waste, 41 percent metallic waste, and 19 percent sludge waste by volume.

Two one-dimensional methods of combining the individual waste characteristics together to form a composite waste model are examined. The first model assumes that the three individual waste types are analogous to three nonlinear springs in series. The second model assumes that the three individual waste types are analogous to three nonlinear springs in parallel. Diagrams of the series and parallel models are shown in Figures 2-5 and 2-6, respectively. The following sections describe how stress/porosity data is generated and fitted to the nonlinear elastic functional form describing the waste.

Series Model

In the series model (Figure 2-5), the initial length of each spring is proportional to the initial volume fraction of the waste type it represents. Axial stress is assumed to be the same in all three materials and is equivalent to the stress in the composite model. Stress/porosity data pairs were generated at stress levels ranging from 0 to −25 MPa. The porosity for each of the individual waste types was found using Equation 2-106 and the parameter values in Table 2-7. The porosity of the

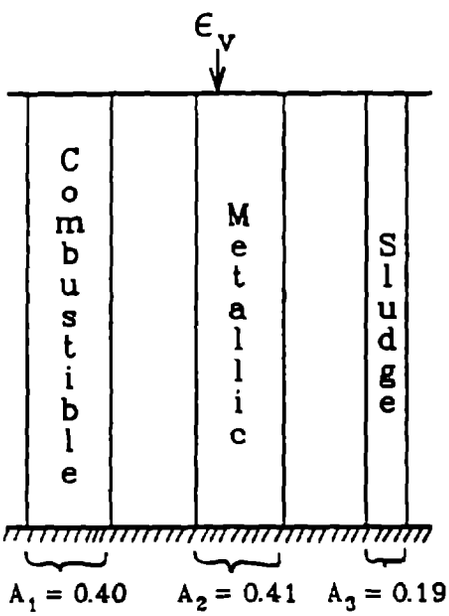


$$\sigma_A = \sigma_1 = \sigma_2 = \sigma_3$$

$$\epsilon_v = \frac{A_1\epsilon_1 + A_2\epsilon_2 + A_3\epsilon_3}{A_1 + A_2 + A_3}$$

Note: Subscripts 1, 2, and 3 refer to the three waste components.

Figure 2-5. Composite Series Model.



$$\sigma_A = \frac{A_1\sigma_1 + A_2\sigma_2 + A_3\sigma_3}{A_1 + A_2 + A_3}$$

$$\epsilon_v = \epsilon_1 = \epsilon_2 = \epsilon_3$$

Note: Subscripts 1, 2, and 3 refer to the three waste components.

Figure 2-6. Composite Parallel Model.

composite series model was determined from

$$\phi = \frac{\text{Void Volume}}{\text{Total Volume}} = \frac{V - V_s}{V} \tag{2-117}$$

where V is the total volume at the current stress and is determined by

$$V = V_0 \sum_{i=1}^{3} \frac{A_i \rho_{0_i}}{\rho_{s_i}(1 - \phi_i)} \tag{2-118}$$

and V_s is the volume of solid materials and is determined from the individual wastes by

$$V_s = V_0 \sum_{i=1}^{3} \frac{A_i \rho_{0_i}}{\rho_{s_i}} \tag{2-119}$$

where

V_0 = initial volume of composite waste
A_i = initial volume percentage of waste type i
ρ_{0_i} = initial density of waste type i
ρ_{s_i} = solid density of waste type i
ϕ_i = porosity of waste type i, determined from Equation 2-106.

Parallel Model

The parallel model (Figure 2-6) assumes that the cross-sectional area of each spring is proportional to the original volume fraction of the waste type it represents. Each waste type is assumed to strain the same amount. Stress/porosity data pairs were generated at volumetric strain increments of the composite waste. Since the volumetric strain of each of the individual wastes is equivalent to the volumetric strain of the composite waste, the porosity of each component can be found from the following relationship

$$\phi_i = 1 - \frac{\rho_{0_i}}{\rho_{s_i}(1 + \epsilon_v)} \tag{2-120}$$

where ϵ_v is the volumetric strain of the composite model. Note that since each of the individual wastes is modeled using Equation 2-106, the composite model can only be strained until one of the individual wastes approaches zero porosity. At this point, stress approaches infinity. In this case, the sludge waste is the first to approach zero porosity.

Once the individual porosities are known, Equations 2-117, 2-118, and 2-119 can be used to determine the porosity of the composite waste. The stress in each individual waste type can be found from Equation 2-106 as

$$\sigma_{a_i} = \frac{\ln(\phi_i) - \ln(\phi_{0_i})}{\kappa_i} \tag{2-121}$$

The composite stress can then be determined from the individual stresses as

$$\sigma_a = \frac{\sum_{i=1}^{3} A_i \sigma_{a_i}}{\sum_{i=1}^{3} A_i} = \sum_{i=1}^{3} A_i \sigma_{a_i} \tag{2-122}$$

2.4.3.2 Results

The generated stress/porosity data pairs for both models were fitted to the nonlinear functional form in Equation 2-106. The resulting parameters are shown in Table 2-8. Figure 2-7 shows the generated stress/porosity data pairs and the corresponding least squares fit for each model. The series model fits the nonlinear elastic functional form very well except at very low stresses. The parallel model, however, does not fit the functional form very well. Therefore, the series model was selected to represent the TRU waste. As the compressive stress approaches infinity, the functional form in Equation 2-106 approaches zero porosity; whereas, the parallel model data approaches a porosity of 0.52.

Table 2-8. Composite Waste Characteristics

Model	Solid Density ρ_f (kg/m^3)	Initial Porosity ϕ_0	κ (MPa^{-1})	Initial Density ρ_0 (kg/m^3)
Series	2,790	0.650	0.068	978
Parallel	2,790	0.637	0.169	1,010

The solid density of the composite waste is determined from the relationship

$$\rho_f = \frac{m}{V_s} = \frac{V_0 \sum_{i=1}^{3} A_i \rho_{0_i}}{V_s} \tag{2-123}$$

where m is the mass of the composite waste and the solid volume, V_s, is found using Equation 2-119. Equation 2-116 can then be used to determine the initial density of the composite waste for each model. The calculated values of initial and solid densities for the two models are shown in Table 2-8.

2.4.3.3 Composite TRU Waste Properties

Series and parallel formulations are derived in the preceding sections to represent the composite TRU waste package. Since the series representation provides the best

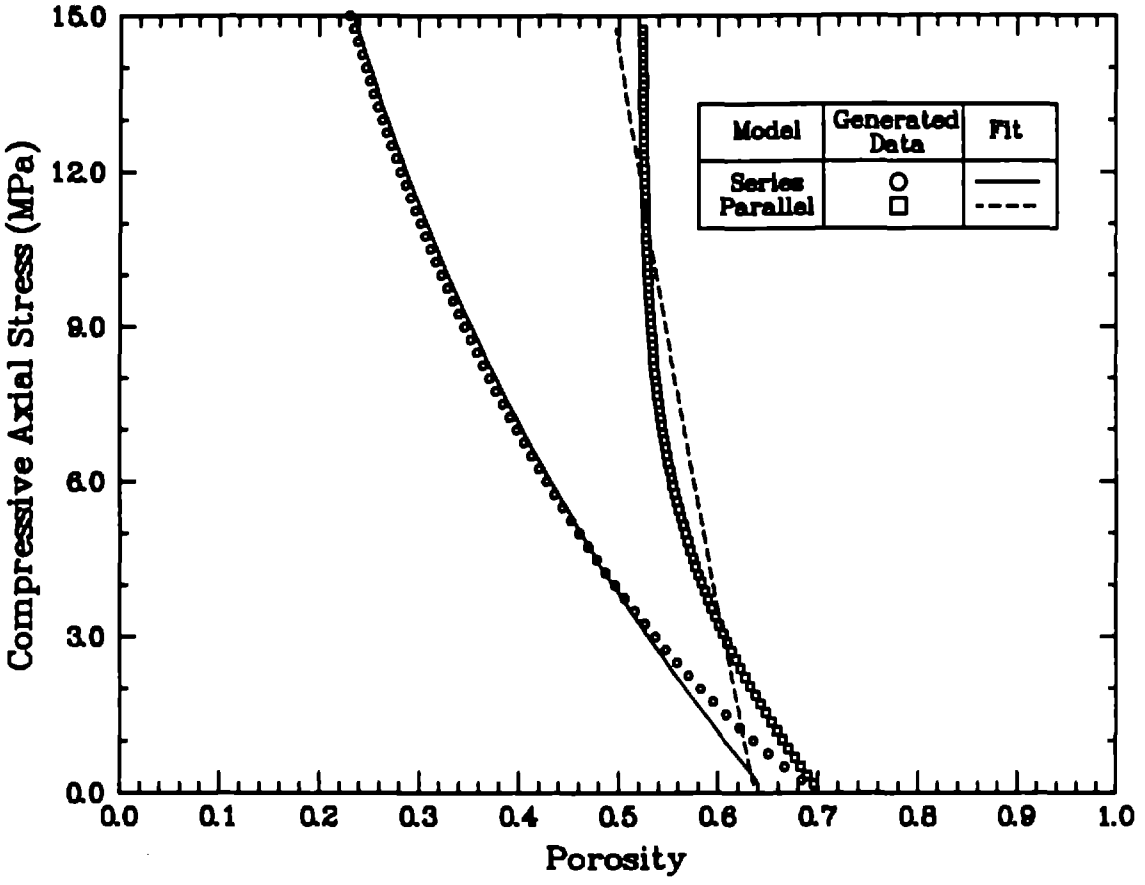


Figure 2-7. Generated Data and Fits for Composite Models.

fit to the simulated TRU waste compaction data, parameter values generated using the series model are chosen to represent the TRU waste. However, the parameter values require modification to represent the selected composite TRU waste. The composite TRU waste drum as determined by Butcher et al. [1991] initially contains 40 percent combustible waste, 41 percent metallic waste, and 19 percent sludge waste by volume. The drum weights and the average solid densities for each of the three waste types is taken from Butcher et al. [1991] and are shown in Table 2-9. The volume of the drum used for encapsulating the wastes is 0.21 m^3 (55 gal). The volume of the solids is calculated by dividing the drum weight by the solid density, ρ_f (i.e., the density of fully compacted, consolidated waste). The initial density, ρ_o, is calculated by dividing the drum weight by the drum volume.

Table 2-9. TRU Waste Drum Characteristics

Waste Type	Drum Weight (kg)	Solid Density (kg/m^3)	Solids Volume (m^3)	Initial Density (kg/m^3)
Combustible	77.0	1,920	0.0401	367
Metallic	101.5	4,000	0.0254	483
Sludge	218.0	2,370	0.0920	1,038
Composite[a]	114.0	2,593	0.0439	542

(a) Based on Volumetric Distribution of 40 percent Combustible, 41 percent Metallic, and 19 percent Sludge.

Using the percentage volumetric distribution of waste types, the volume of solids in the "typical composite TRU waste package" is 0.044 m^3. The weight and initial density of the composite TRU drum are 114 kg and 542 kg/m^3, respectively. The solid density of the typical composite TRU waste drum (fully consolidated) can then be calculated to be 2,593 kg/m^3. The initial porosity (void fraction), ϕ_o, is calculated from the Equation 2-120, which yields a value of 79 percent.

As shown in Table 2-8, the series model representation corresponds to an initial porosity of 0.65 and an initial density of 978 kg/m^3; whereas, the selected representative composite TRU waste has an initial porosity of 0.79 and initial density of 542 kg/m^3. Thus, a difference exists between the series model representation of the TRU waste and the described typical composite TRU waste package. The series model results in a poor estimate of initial density and porosity of the typical composite TRU waste package. If the appropriate initial density and porosity values of the typical composite TRU waste package are used, the least squares curve of the series model will not be followed. As a compromise resolution to this problem, the appropriate initial density value was deemed the most important parameter, and the product of κ and initial density was maintained constant. Thus, ρ_0=542 kg/m^3

and κ=0.122 MPa^{-1} was used for the selected composite TRU waste. In addition, since the moduli are infinite when the final density is reached, a final density value of 2,599 kg/m^3 was selected so that the actual final density of 2,593 kg/m^3 could be attained without causing numerical difficulties.

In summary, the composite TRU waste has an initial density of 542 kg/m^3, an initial porosity of 79 percent, and a final density of 2,599 kg/m^3. Equations 2-110 and 2-115 are used to compute the moduli as a function of density. The parameter values used in these equations are κ=0.1224 MPa^{-1} and λ=0.2040 MPa^{-1}. Substitution of these values into Equations 2-110 and 2-115 gives values for the bulk and shear moduli of 5,442 MPa and 3,265 MPa, respectively, at a density of 2,593 kg/m^3.

2.4.3.4 Vitrified Waste Properties

The linear elastic parameter values for the constitutive relation given in Equation 2-3 are given in Table 2-10. The vitrified waste material parameters are taken from McClintock and Argon [1966] for glass. Density of glasses range from about 2,200 to 3,800 kg/m^3.

Table 2-10. Elastic Constants for Vitrified Waste

Parameter	Units	Value
E	MPa	67,560
ν	—	0.25

3.0 FINITE ELEMENT IDEALIZATION OF DISPOSAL ROOM

The finite element program SPECTROM-32 was used in this study to analyze the structural behavior of a hypothetical WIPP room for storing nonheat-producing transuranic (TRU) waste. The configuration modeled consists of an infinite series of disposal rooms 10.06 m wide by 4.0 m high and separated by pillars spaced at 40.54 m on center in the horizontal direction. Because one of the objectives of this study was to obtain results for comparison with the results obtained from similar calculations performed by Weatherby [1989] using SANCHO, geometric simplifications were made for consistency. The geometric simplifications made include:

1. The rooms were assumed to be located in a homogeneous layer of bedded salt thus eliminating the need to model the numerous stratigraphic layers present at the WIPP.

2. The deformation was assumed to be symmetric about a horizontal plane that passes through the center of the rib. Hence, the modeled region consists of the material above the symmetry plane.

3. The vertical extent of the region to be modeled was limited to 27 m above the room centerline. A boundary located this close to an excavation can be expected to influence the results; however, comparisons of the different backfill scenarios should not be compromised.

The finite element mesh used for all of the calculations presented in this report is shown in Figure 3-1. The finite element mesh contains 400 nodes and 399 four-node, quadrilateral elements. The finite element mesh is composed of three distinct regions that were used to represent the materials necessary to analyze the different room scenarios. The room detail given in Figure 3-1 shows the regions used to represent the TRU waste (if present) and the backfill materials. Region One is approximately a 4.69 m wide by 1.45 m high area in the lower left corner of the mesh. This model region represents the space occupied by the TRU waste. Region Two surrounds Region One and extends to the boundary of the room surface. Region Two was used to represent the backfill material that covers the waste. Regions One and Two comprise the disposal room and the remaining region represents the intact salt in the vicinity of the disposal room. The corners of the disposal room were assumed to be round (0.23 m radius) to match those at the WIPP site. The cross-sectional area of the waste and backfill regions are 6.77 m^2 and 3.28 m^2, respectively, yielding the total cross-sectional area for one-fourth of the disposal room of approximately 10.05 m^2. Symmetry conditions require no displacements normal to the boundary along the bottom, left, and right edges of the mesh. These kinematic constraints were prescribed as the boundary conditions for the mesh. The temperature throughout the modeled region was specified as 300 K.

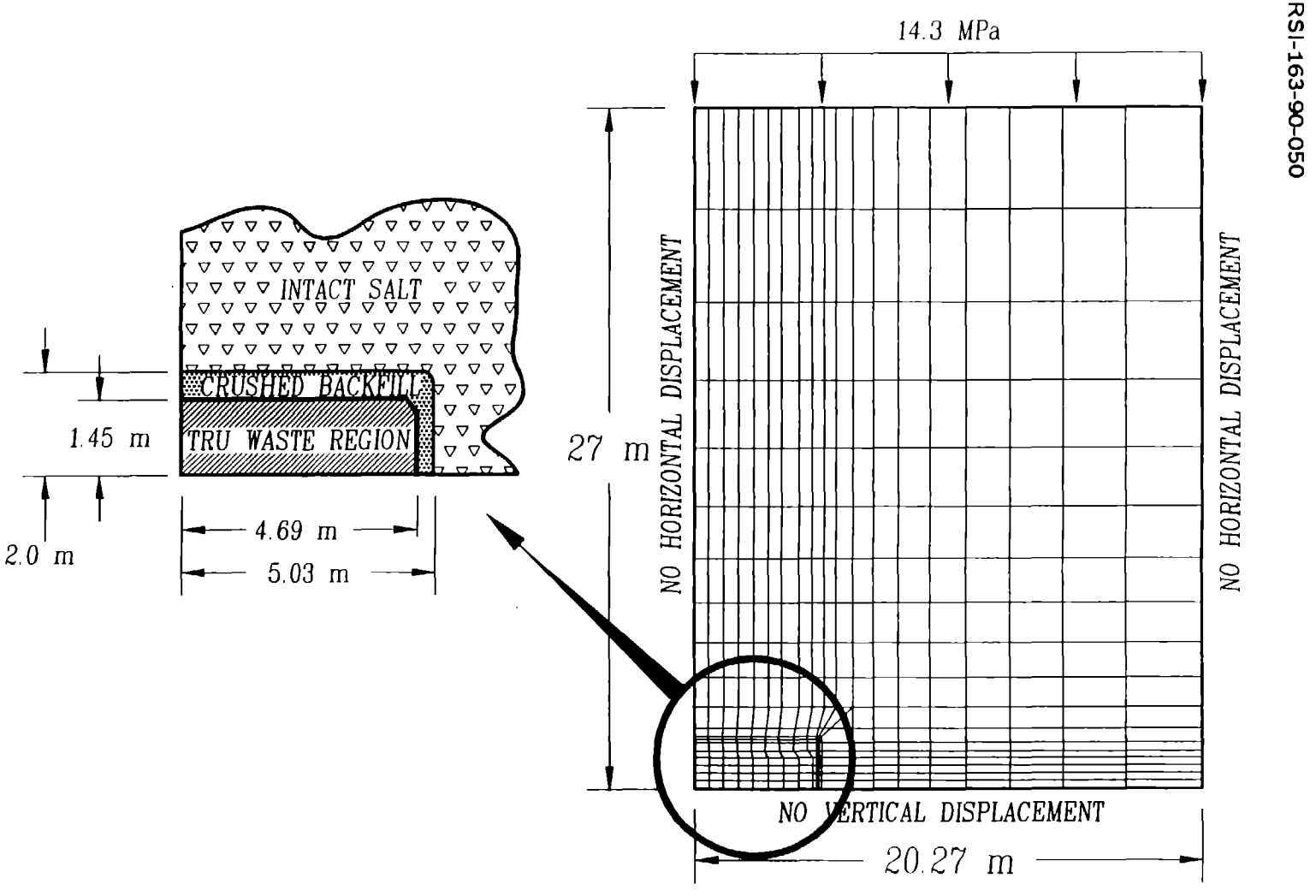


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Figure 3-1. Finite Element Mesh of Disposal Room.

The initial stress field before excavation was assumed to be a homogeneous, lithostatic state of stress. The magnitude of the initial stress field was defined by prescribing a superincumbent overburden traction of 14.3 MPa as shown in Figure 3-1. Gravitational forces were neglected with lateral earth pressure coefficients equal to one. Therefore, the initial state of stress everywhere in the defined problem region was $\sigma_x = \sigma_y = \sigma_z$ =−14.3 MPa. The initial stress condition for each of the analyses following excavation was established by excavating the disposal room into the host medium under the assumed lithostatic stress condition. Subsequently, the backfill was emplaced under stress-free conditions (i.e., body forces were neglected in the backfill). As a consequence of the assumed symmetry condition about the bottom boundary, the waste in the finite element model is located in the center of the room and is surrounded on all four sides by the backfill material. In the actual configuration, the waste will rest on the floor of the room and be surrounded by the backfill material on three sides.

4.0 RESULTS OF DISPOSAL ROOM ANALYSES

In this chapter, results are presented for six different room emplacement scenarios. Because these results are based on mechanical properties derived from a limited number of experiments and the constitutive models considered are currently in the development stage, results should be tempered with the validity of the specific properties and constitutive relations used to produce them. Numerical simulations of the different room emplacement scenarios were conducted assuming the following room contents.

1. Room completely filled with crushed salt.
2. Room completely filled with a 70 percent crushed salt — 30 percent bentonite (by weight) mixture.
3. TRU waste covered with crushed salt.
4. TRU waste covered with a 70 percent crushed salt — 30 percent bentonite (by weight) mixture.
5. An 80 percent crushed salt — 20 percent shredded metallic waste (by volume) mixture covered with crushed salt.
6. Vitrified waste covered with crushed salt.

The constitutive relations and material properties of the intact salt, backfill materials, and wastes used for these calculations are given in Chapter 2 and the finite element idealization is discussed in Chapter 3. In each of these analyses, the backfill and TRU waste were stress-free in the room at the beginning of the simulation (time = 0), and the creep deformation was simulated for 200 years. Additional details of each analysis and specific results are provided in the remainder of this chapter. Appendix B provides a comparison of selected results obtained from this study and those obtained by Weatherby [1989] and Weatherby and Brown [1990] using SANCHO for the first three aforementioned analyses. Appendix C includes history plots of void fraction and mean stress for each of the analyses.

4.1 ROOM FILLED WITH CRUSHED SALT

The closure of a room filled with crushed salt was analyzed assuming an initial density for the crushed salt to be approximately 65 percent of the intact density of salt. The initial and fully compacted densities specified for the crushed salt were 1,400 kg/m^3 and 2,140 kg/m^3, respectively. This corresponds to an initial void fraction of approximately 35 percent. During the course of the simulation, the volume of the crushed salt backfill was sufficiently reduced such that all of the

voids were removed and the density of the crushed salt reached the intact density of salt. When crushed salt elements attained the intact salt density, the crushed salt elements were changed to a creeping material obeying the Munson-Dawson constitutive model. The Munson-Dawson model parameter values used are the same as those for intact salt given in Chapter 2.

The room closure history of the disposal room backfilled with crushed salt is shown in Figure 4-1. In this figure and throughout this report, the horizontal closure is the change in the width at the midheight of the room expressed as a percentage of the original room width. Similarly, the vertical closure is the change in the height of the room at the center of the roof expressed as a percentage of the original room height. The maximum horizontal and vertical closures obtained for this analysis are 11 percent and 28 percent, respectively.

The void reduction in the disposal room expressed as a percentage of the initial void volume is shown in Figure 4-2 as a function of time. In this figure and throughout this report, the void reduction is the difference between the initial void volume and the current void volume expressed as a percentage of the initial void volume. Thus, the void reduction value will always be zero at the beginning of an analysis and will increase to 100 percent when the material becomes fully consolidated (voids are no longer present). The void reduction values were computed from the following relationship.

$$v = \frac{V_v^o - V_v}{V_v^o} \tag{4-1}$$

where

v = the void reduction in the element or region

V_v = the void volume in the element or region

V_v^o = the initial void volume inside the element or region.

As shown in Figure 4-2, 95 percent of the original void in the room is eliminated after approximately 19 years. The average void fractions presented in Appendix C were calculated using the following relationship:

$$v_f^o \equiv \frac{V_v}{V^o} = \frac{V_v^o + \Delta V}{V^o} \tag{4-2}$$

where

v_f^o = the void fraction in the element or region

V^o = the original volume of the element or region

ΔV = the difference between the current volume and the initial volume inside the element or region.

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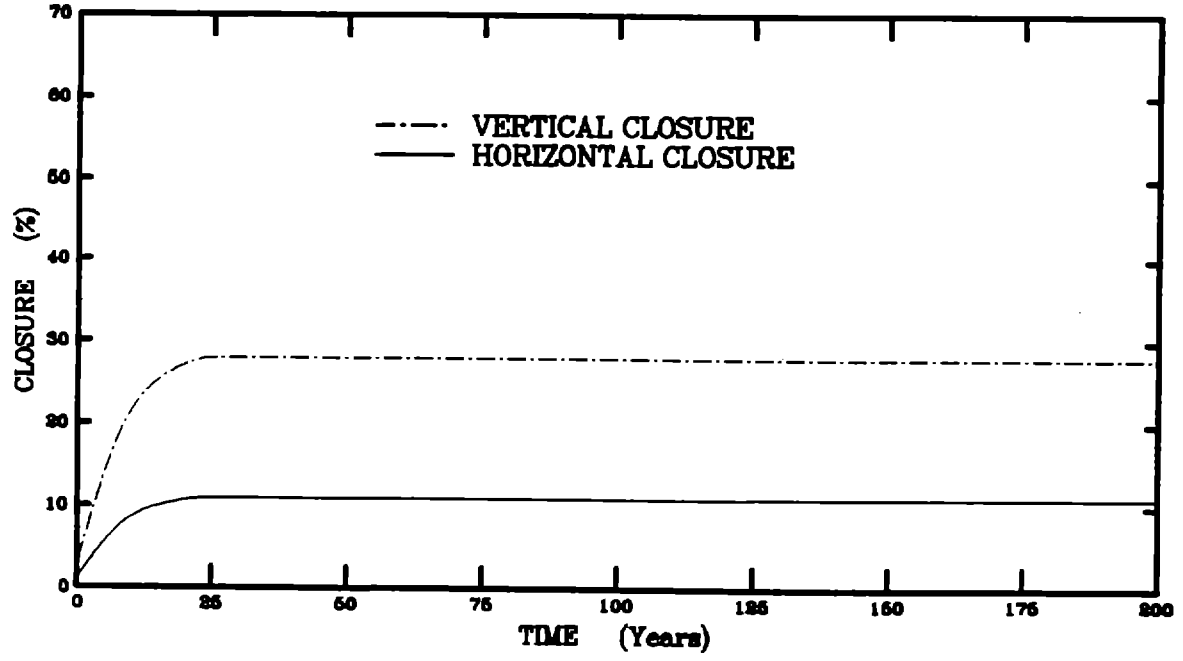

Figure 4-1. Room Closure History of a Disposal Room Filled With Crushed Salt.

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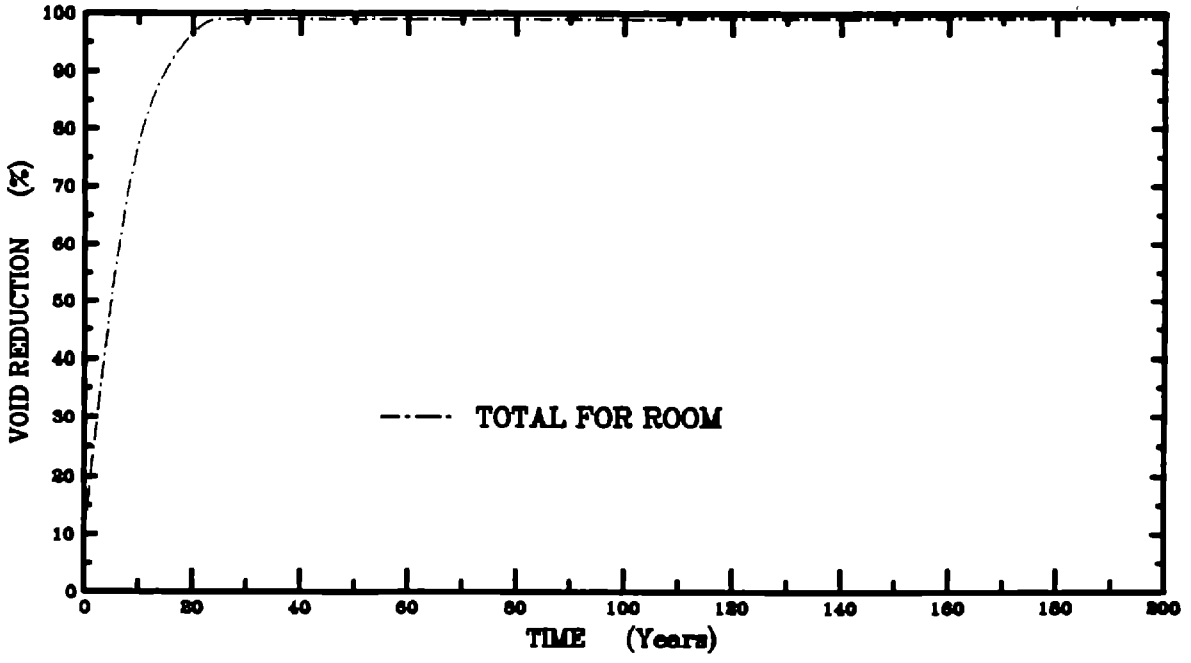

Figure 4-2. Void Reduction in the Disposal Room Filled With Crushed Salt as a Function of Time.

As illustrated in Appendix C, the average void fraction in the room decreases to 5 percent of the total room volume approximately 13 years after emplacement of the backfill. Note, however, that Weatherby [1989] used the current volume for V^o rather than the original volume. Therefore, his computed values are expected to be consistently higher than values computed using Equation 4-2 since the volume is decreasing.

The relationship between void fractions that are computed based on the initial volume and current volume can be easily developed. Equation 4-2 is written for the void fraction v_f in terms of the current volume as

$$v_f = \frac{V_v}{V^o + \Delta V} = \frac{V_v^o + \Delta V}{V^o + \Delta V} \tag{4-3}$$

From Equation 4-2, the volume change may be computed as

$$\Delta V = v_f^o V^o - V_v^o \tag{4-4}$$

The void fraction based on current volume is obtained by substituting Equation 4-4 into Equation 4-3, which gives

$$v_f = \frac{v_f^o V^o}{V^o \left(1 + v_f^o\right) - V_v^o} \tag{4-5}$$

Dividing the numerator and denominator in Equation 4-5 by the initial volume, V^o, and noting that the initial porosity is $\phi_0 = \frac{V_v^o}{V^o}$ gives

$$v_f = \frac{v_f^o}{1 + v_f^o - \phi_0} \tag{4-6}$$

When a two component backfill system such as TRU waste (superscript t) and crushed salt (superscript c) is considered, Equation 4-6 can be used to develop the void fraction equations based on the current volume. Assuming that the void fractions based on the initial volume for the TRU waste and crushed salt regions (i.e., $v_f^{t^o}$ and $v_f^{t^o}$) are known from Equation 4-2, the void fractions in the TRU waste and crushed salt based on the current volume are

$$v_f^t = \frac{v_f^{t^o}}{1 + v_f^{t^o} - \phi_0^t} \tag{4-7}$$

$$v_f^c = \frac{v_f^{c^o}}{1 + v_f^{c^o} - \phi_0^c} \tag{4-8}$$

where ϕ_0^t and ϕ_0^c are the initial porosities for the TRU waste and crushed salt regions, respectively.

The total room void fraction (superscript r) can be computed on a volume-weighted basis from the TRU waste and crushed salt void fractions based on their current volumes

$$v_f^r = \frac{v_f^t V^t + v_f^c V^c}{V^t + V^c} \tag{4-9}$$

The current volumes of the TRU waste and the crushed salt are

$$V^t = V^{t^o} + \Delta V^t \tag{4-10}$$

$$V^c = V^{c^o} + \Delta V^c \tag{4-11}$$

where

V^{c^o} = initial volume of the backfill element or region

V^{t^o} = initial volume of the waste element or region

ΔV^c = volume change of the backfill element or region

ΔV^t = volume change of the waste element or region.

From Equation 4-4, Equations 4-10 and 4-11 become

$$V^t = V^{t^o}\left(1 + v_f^{t^o}\right) - V_v^{t^o} \tag{4-12}$$

$$V^c = V^{c^o}\left(1 + v_f^{c^o}\right) - V_v^{c^o} \tag{4-13}$$

where

$V_v^{c^o}$ = initial void volume of the backfill element or region

$V_v^{t^o}$ = initial void volume of the waste element or region.

Substituting Equations 4-12 and 4-13 into Equation 4-9 gives the void fraction for the room based on the current volume of the room.

4.2 ROOM FILLED WITH CRUSHED SALT/BENTONITE

The closure of a room filled with a crushed salt/bentonite mixture (70 percent crushed salt and 30 percent bentonite by weight) was simulated for 200 years. The initial density and fully compacted or final density of the crushed salt/bentonite mixture used in this calculation was 1,478.5 kg/m^3 and 2,260 kg/m^3, respectively, which corresponds to an initial void fraction of approximately 35 percent (the same as that used for the crushed salt backfill calculations). In this simulation, the crushed salt/bentonite backfill did not consolidate sufficiently to reduce all of the voids and the fully consolidated density was not reached.

The horizontal and vertical closures of the disposal room backfilled with crushed salt are shown in Figure 4-3. The maximum horizontal and vertical closures obtained are 10 percent and 24 percent, respectively. Comparing these results with the crushed salt results in Figure 4-1 shows that the crushed salt and crushed salt/bentonite closures are nearly the same in both magnitude and rate for the first 5 years. This indicates that the room closure is primarily driven by the initial state of stress in the host rock formation and that there is little host rock — backfill interaction during the first 5 years. Thereafter, the crushed salt/bentonite backfill room closure rates become significantly less than the crushed salt backfill room closure rates until about 23 years when the crushed salt is essentially fully compacted. After 23 years, the crushed salt backfill room closure rate is close to zero and closure is virtually complete; the crushed salt/bentonite backfill room closure rate is nonzero but small and closure continues. Thus, the crushed salt/bentonite room closures accumulate slowly and approach the fully compacted, crushed salt room closures asymptotically. Since the crushed salt and crushed salt/bentonite backfilled rooms were both at the same initial void fractions, the ultimate or final state of closures of each should be the same. The comparison of closure rates between crushed salt and crushed salt/bentonite backfills may be better understood using Figures 2-1 through 2-3. These figures compare the volumetric strain rates for simple constant stress situations. The crushed salt/bentonite consolidation rates are initially greater than those of the crushed salt and eventually become significantly less which causes the crushed salt/bentonite backfill to approach full consolidation at a much slower rate than crushed salt.

The void reduction in the disposal room expressed as a percentage of the total initial void volume is shown in Figure 4-4 as a function of time. As shown in Figure 4-4, approximately 14 percent of the original void volume remains in the room after 200 years. Comparison of the crushed salt (Figure 4-2) and crushed salt/bentonite void reductions again shows the much slower rate at which the crushed salt/bentonite backfill approaches full consolidation. As illustrated in Appendix C, the average void fraction reached 5 percent after approximately 191 years.

4.3 ROOM FILLED WITH TRU WASTE AND CRUSHED SALT

The closure of a room filled with TRU waste surrounded by crushed salt was simulated for a 200-year period. The initial and fully compacted densities used in this calculation for the TRU waste were 542 kg/m^3 and 2,593 kg/m^3, respectively, corresponding to an initial void fraction of approximately 79 percent. The initial and fully compacted densities specified for the crushed salt were 1,400 kg/m^3 and 2,140 kg/m^3, respectively, corresponding to an initial void fraction of approximately 35 percent. The crushed salt was changed to a creeping material obeying the Munson-Dawson constitutive model when the volume of the crushed salt was sufficiently reduced such that all of the voids were removed and the density reached the intact density of salt. The Munson-Dawson model parameter values used are the same as

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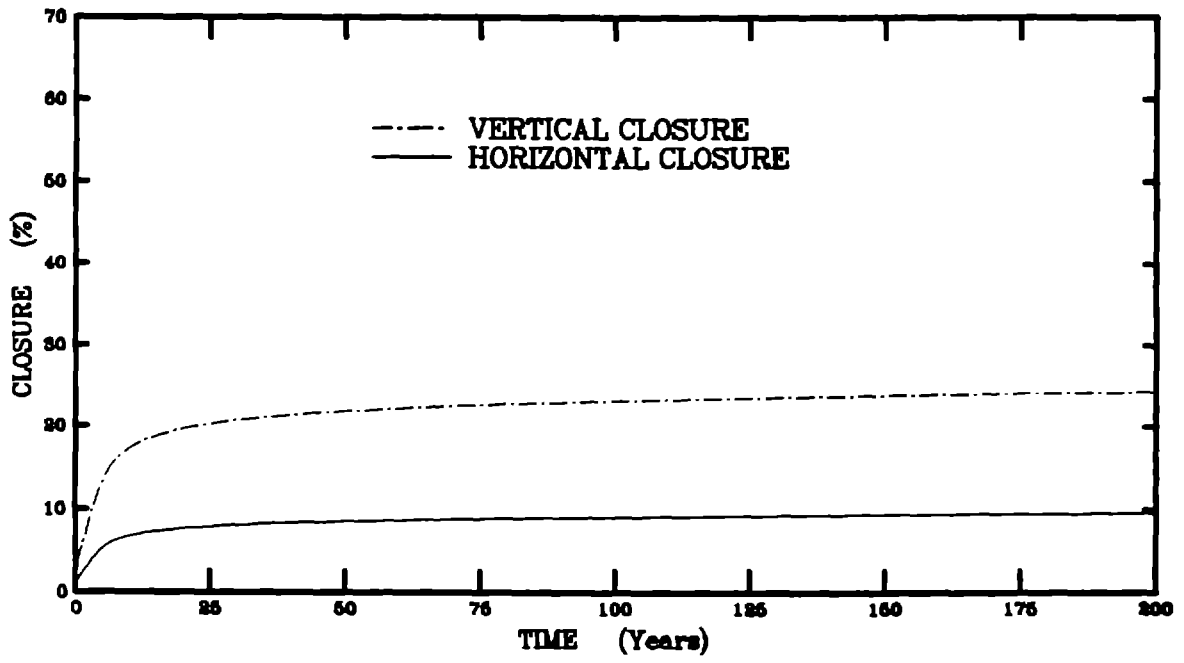

Figure 4-3. Room Closure History of a Disposal Room Filled With Crushed Salt/Bentonite.

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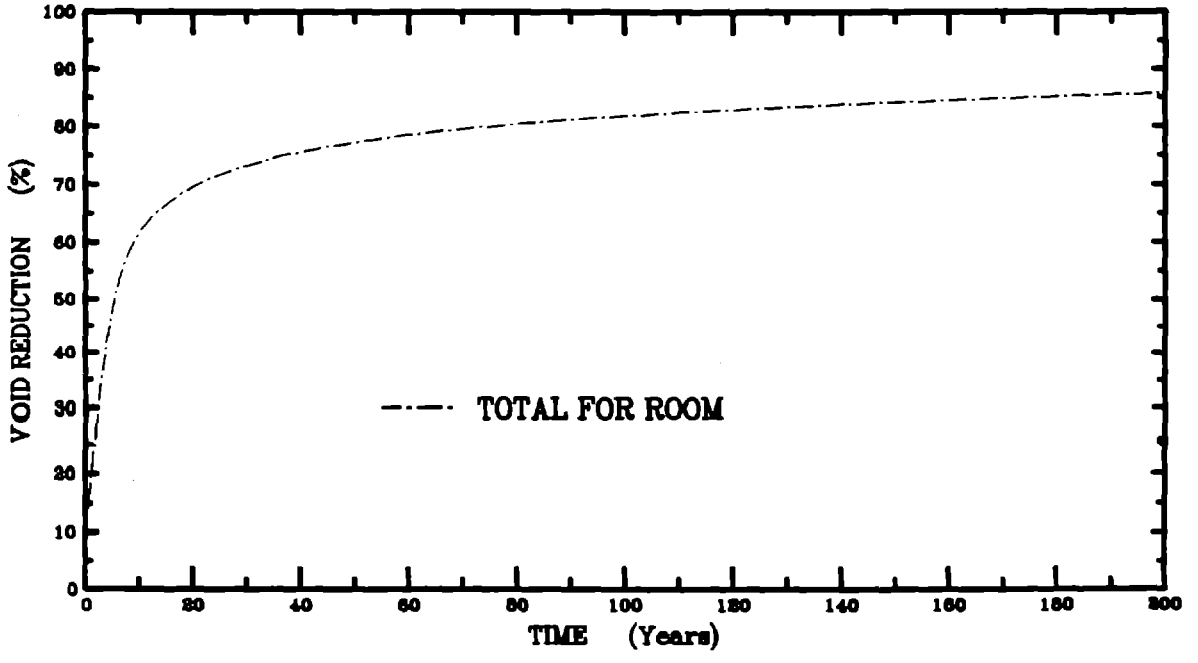

Figure 4-4. Void Reduction in the Disposal Room Filled With Crushed Salt/Bentonite as a Function of Time.

those for intact salt given in Chapter 2. Thus, following complete consolidation, the crushed salt becomes intact salt. Initially, the stiffnesses of the crushed salt and TRU waste are very low compared to the host salt formation and the initial porosity of the TRU waste is very high (79 percent) compared with the crushed salt (35 percent). Therefore, very little resistance to room closure is provided by the backfill and waste. As the crushed salt and TRU waste compact, they become stiffer and provide stabilizing forces for the underground structure and reduce the room closure rate. However, the stiffness of the TRU waste remains quite low until it is compacted to within 80 percent of its fully compacted density. Because the stiffness of the TRU waste is low, little support is provided for the crushed salt backfill, and the rate of consolidation of the crushed salt is slower than when the room is completely filled with crushed salt.

The horizontal and vertical closures of the disposal room backfilled with TRU waste and crushed salt are shown in Figure 4-5. The maximum horizontal and vertical closures obtained are 21 percent and 54 percent, respectively. Comparing these closure results with the closure results obtained for the room completely filled with crushed salt (Figure 4-1) shows that the crushed salt and crushed salt/TRU waste closures are nearly the same in both magnitude and rate for the first 5 years. This supports the earlier supposition that there is little interaction between the host rock formation and the room contents during this initial period. When the TRU waste, which has an initial void ratio of 79 percent, is present in the room, the closure rates remain large until about 50 years. At 50 years, the average void fraction in the TRU waste is about 7 percent, and the TRU waste has become stiffer and provides more resistance to room closure.

The void reduction in the waste region, backfill region, and for the entire disposal room expressed as a percentage of the total initial void volume of the respective regions are shown in Figure 4-6 as a function of time. The percent void reduction for each region was computed using Equation 4-1. Comparison of Figure 4-6 with Figure 4-2 for the crushed salt further supports the observation made above with regard to room closure rates and backfill interaction. During the simulation period, the contents of the backfilled region were changed to intact salt one element at a time upon full consolidation. During the 200 years simulated, all of the crushed salt became fully consolidated except for a small region in the corner of the room. Similarly, all the void in the waste was virtually eliminated; however, the waste required considerably more time to reach a fully compacted state. Approximately 30 years were required to reduce the void volume to 95 percent of the initial void volume for the crushed salt, while 68 years were required for the TRU waste. As shown in Figure 4-6, the combined contents of the room required approximately 60 years to reduce the void volume by 95 percent. As illustrated in Appendix C, the average void fraction reached 5 percent in the backfill region, waste region, and in the room after 15, 60, and 50 years, respectively.

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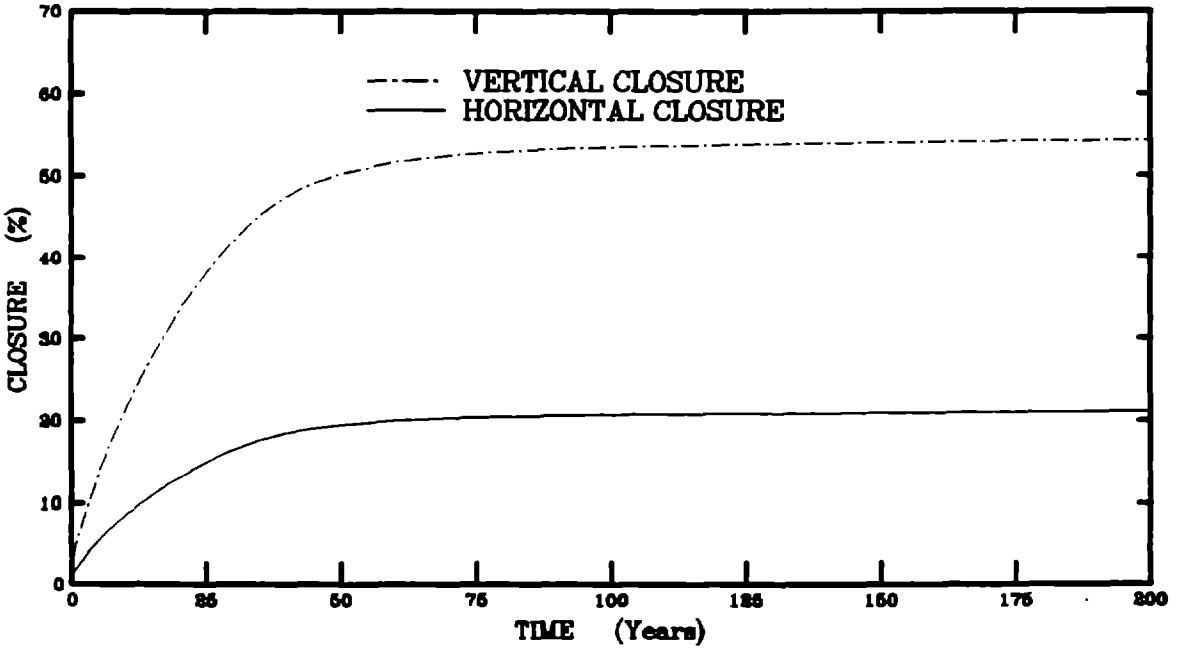

Figure 4-5. Room Closure History of a Disposal Room Filled With TRU Waste and Crushed Salt.

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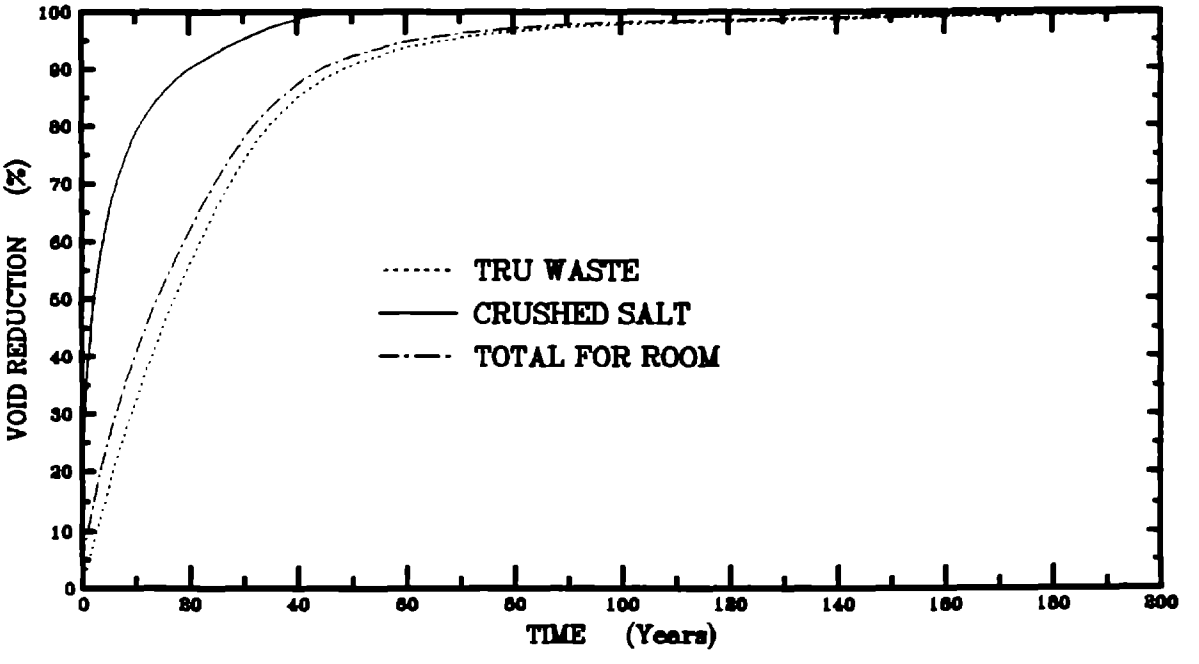

Figure 4-6. Void Reduction in the Disposal Room Filled With TRU Waste and Crushed Salt as a Function of Time.

4.4 ROOM FILLED WITH TRU WASTE AND CRUSHED SALT/BENTONITE

The closure of a room filled with TRU waste surrounded by a crushed salt/bentonite mixture was simulated for a 200-year period. The initial and fully compacted densities for the TRU waste used in this calculation were 542 kg/m^3 and 2,593 kg/m^3, respectively, corresponding to an initial void fraction of approximately 79 percent. The initial and fully compacted densities specified for the crushed salt/bentonite mixture were 1,478.5 kg/m^3 and 2,260 kg/m^3, respectively, corresponding to an initial void fraction of approximately 35 percent. During the simulation, the volume of ten crushed salt/bentonite material elements were sufficiently reduced such that all of the voids were removed and the density reached the intact density of the fully consolidated salt/bentonite mixture. For this analysis, the crushed salt/bentonite was changed to a nonlinear elastic material following complete consolidation. The elastic properties for a mixture of crushed salt and bentonite are given in Chapter 2.

The horizontal and vertical closures of the disposal room backfilled with TRU waste and crushed salt are shown in Figure 4-7. The maximum horizontal and vertical closures obtained are 18 percent and 55 percent, respectively. As discussed previously, the room closure rates and magnitudes during the initial 5-year period are essentially the same as in the other analyses. The void reduction in the waste region, backfill region, and for the entire disposal room expressed as a percentage of the total initial void volume of the respective regions are shown in Figure 4-8 as a function of time. The percent void reduction for each region was computed using Equation 4-1. During the 200 years simulated, little of the crushed salt/bentonite backfill or the TRU waste became fully consolidated. After 200 years, the initial void volume was reduced by 87 percent for the crushed salt/bentonite, 93 percent for the TRU waste. As shown in Figure 4-8, the void volume of the total combined contents of the room was ultimately reduced by 92 percent. As illustrated in Appendix C, the average void fractions in the backfill region, waste region, and in the room after 200 years are 4.4 percent, 5.4 percent, and 5.1 percent, respectively.

4.5 ROOM FILLED WITH VITRIFIED WASTE AND CRUSHED SALT

The closure of a room filled with vitrified waste surrounded by crushed salt was analyzed assuming an initial density for the crushed salt to be 65 percent of the density of intact salt. The initial and fully compacted densities specified for the crushed salt were 1,400 kg/m^3 and 2,140 kg/m^3, respectively. This corresponds to an initial void fraction of approximately 35 percent. The vitrified waste was modeled as a linearly elastic material as described in Chapter 2. In this simulation, the crushed salt backfill consolidated sufficiently to remove all of the voids, and the density of the crushed salt reached the intact density of salt. At this point in the simulation, the crushed salt was changed to a creeping material obeying the

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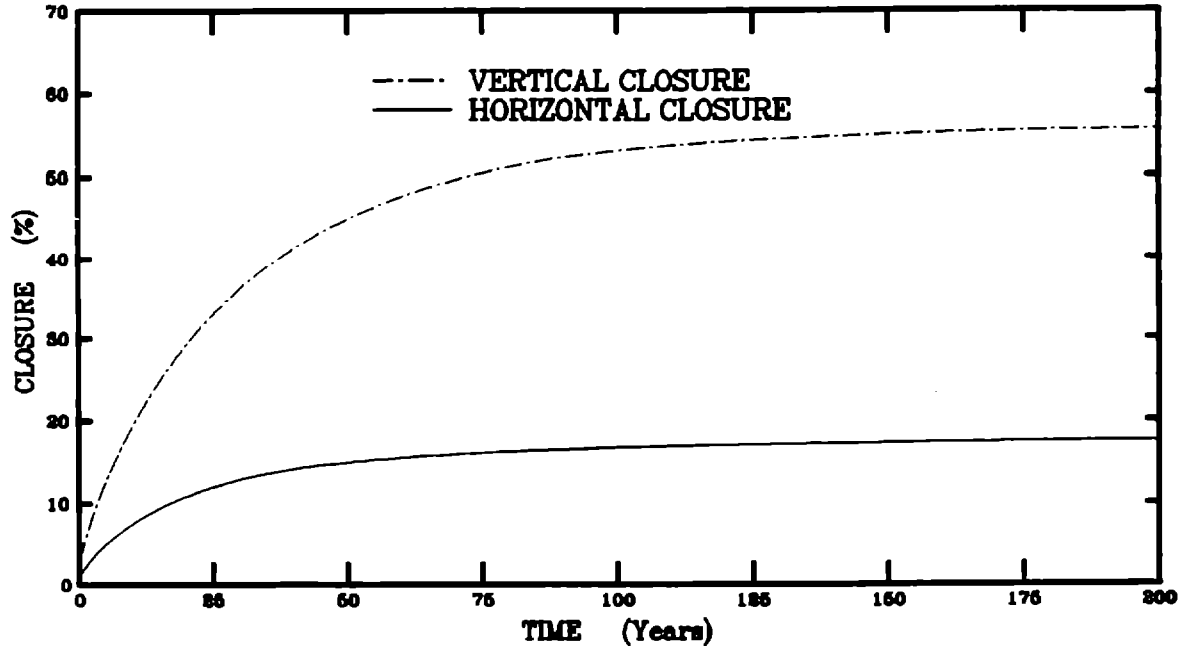

Figure 4-7. Room Closure History of a Disposal Room Filled With TRU Waste and Crushed Salt/Bentonite.

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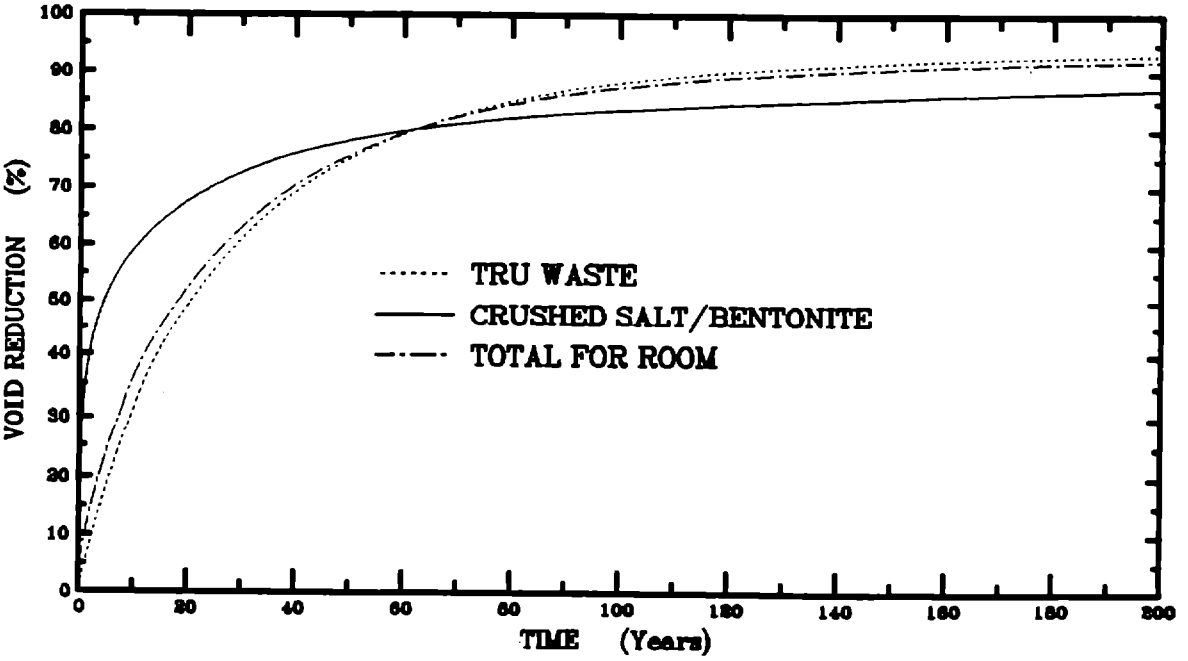

Figure 4-8. Void Reduction in the Disposal Room Filled With TRU Waste and Crushed Salt/Bentonite as a Function of Time.

Munson-Dawson constitutive model. The Munson-Dawson model parameter values used are the same as those given for intact salt in Chapter 2.

The horizontal and vertical closures of the disposal room backfilled with vitrified waste and crushed salt are shown in Figure 4-9. The maximum horizontal and vertical closures obtained are 2.4 percent and 9.4 percent, respectively. These closures are substantially less than the other cases examined which illustrates the effect of a stiff TRU waste component with zero initial porosity. In this case, with the stiff TRU waste component, the waste and backfill interact with the host rock formation earlier in time. Comparing Figure 4-9 with the closure results from the other analyses shows that the vitrified waste and backfill have little effect on the host rock deformation for approximately 1 year; whereas, the other cases show little impact for approximately 5 years. The stiffness of the vitrified waste provides the mechanism for more rapid consolidation of the surrounding crushed salt backfill and subsequent back pressure on the host formation, which slows the rate of deformation and reduces the overall magnitude of room closure. As shown in Figure 4-10, 95 percent of the void in the region filled with crushed salt is eliminated after 13 years. As illustrated in Appendix C, the average void fraction reaches 5 percent in the backfill region within 6 years.

4.6 ROOM FILLED WITH CRUSHED SALT AND SHREDDED METAL MIXED WITH CRUSHED SALT

The closure of a room filled with shredded metallic waste mixed with crushed salt was analyzed assuming the mixture contained 80 percent crushed salt and 20 percent metallic waste by volume. The shredded metal/crushed salt mixture was surrounded on all sides by crushed salt. The initial and fully compacted densities specified for the crushed salt were 1,400 kg/m^3 and 2,140 kg/m^3, respectively. This corresponds to an initial void fraction of approximately 35 percent. The initial and fully compacted densities specified for the crushed salt/shredded metal mixture were 2,689 kg/m^3 and 3,717 kg/m^3, respectively. This corresponds to an initial void fraction of approximately 28 percent. During the simulation, the shredded metal/crushed salt mixture and the crushed salt backfill consolidated sufficiently to remove all of the voids. When the crushed salt and shredded metal/crushed salt elements attained their respective intact densities, the elements were changed to a creeping material obeying the Munson-Dawson constitutive model. The Munson-Dawson model parameter values used are the same as those given for intact salt in Chapter 2.

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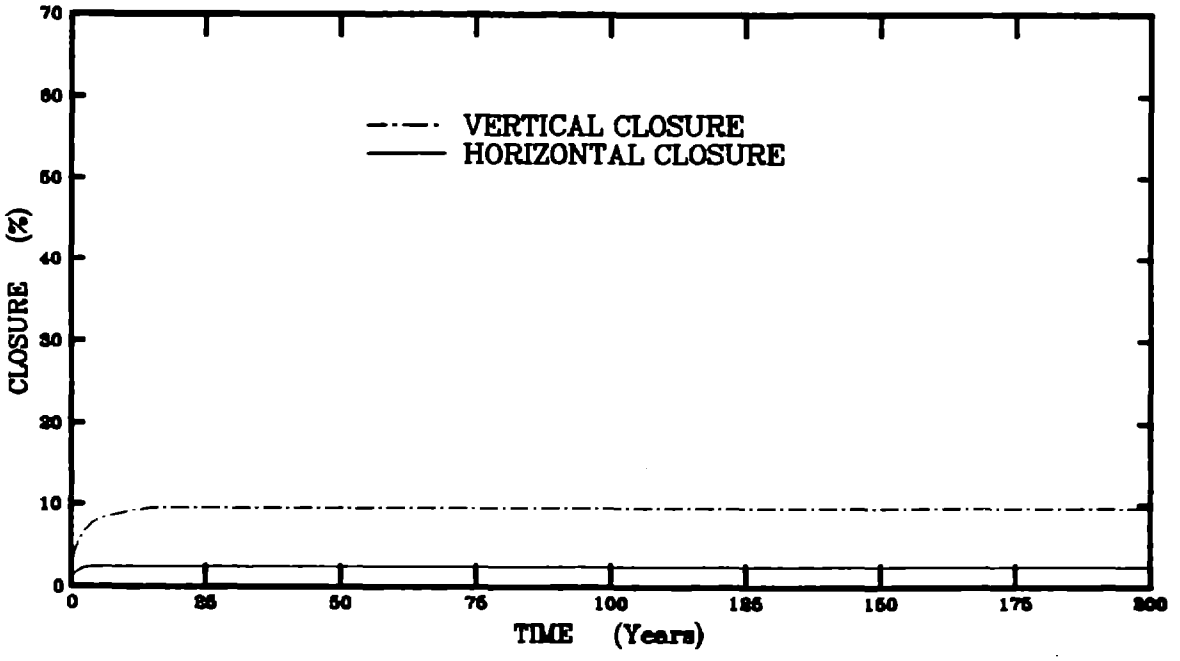

Figure 4-9. Room Closure History of a Disposal Room Filled With Vitrified Waste and Crushed Salt.

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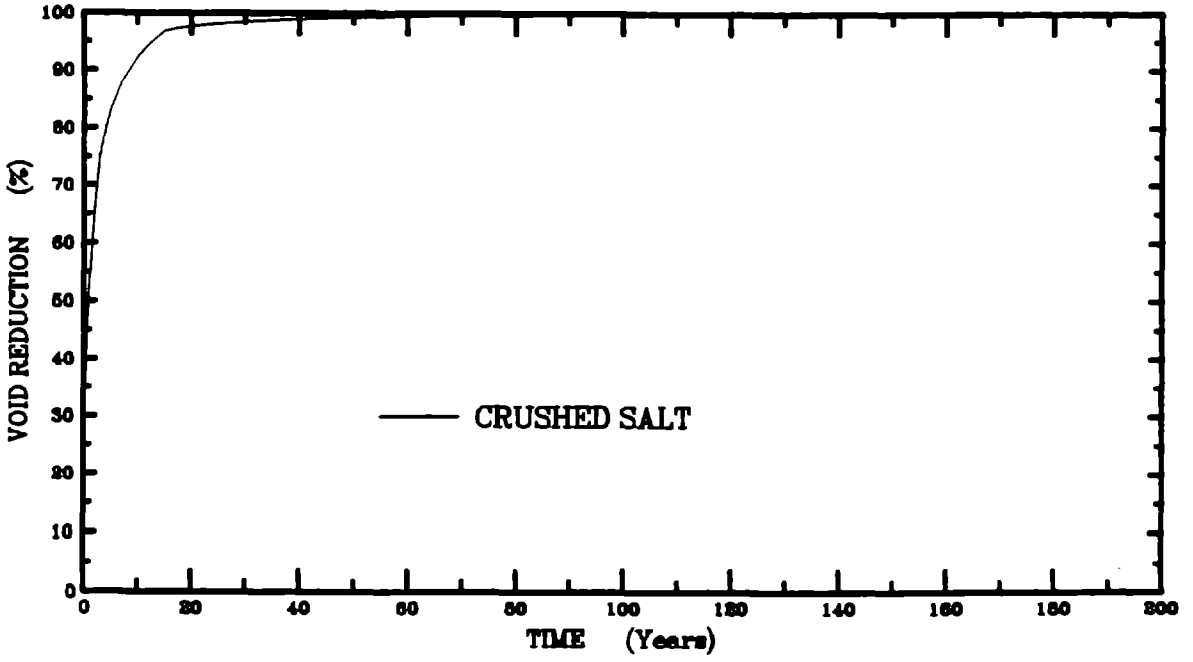

Figure 4-10. Void Reduction in the Disposal Room Filled With Vitrified Waste and Crushed Salt as a Function of Time.

The horizontal and vertical closures of the disposal room backfilled with shredded metal/crushed salt and crushed salt are shown in Figure 4-11. The maximum horizontal and vertical closures obtained are 9.6 percent and 24.2 percent, respectively. Comparison of these room closure results with those for crushed salt (Figure 4-1) shows identical behavior during the initial period with the final closures being less for the shredded metal/crushed salt mixture. Combining the shredded metal waste with the crushed salt includes two items that effect the room closure: (1) the initial porosity of the shredded metal/crushed salt mixture is less than that of the pure crushed salt and (2) the shredded metal/crushed salt mixture becomes a stiffer structural member than the pure crushed salt upon compaction. These two items result in less room closure and faster consolidation of the crushed salt backfill covering the shredded metal/crushed salt mixture.

The void reduction in the waste region, backfill region, and for the entire disposal room expressed as a percentage of the total initial void volume of the respective regions are shown in Figure 4-12 as a function of time. The percent void reduction for each region was computed using Equation 4-1. Approximately 16 years were required to reduce the void volume to 95 percent of the initial void volume for the crushed salt, while 11 years were required for the shredded metal/crushed salt mixture. As shown in Figure 4-12, the combined contents of the room required 12 years to reduce the void volume by 95 percent of the initial void volume. As illustrated in Appendix C, the average void fraction in the backfill region, waste region, and in the room reach 5 percent after approximately 11 years.

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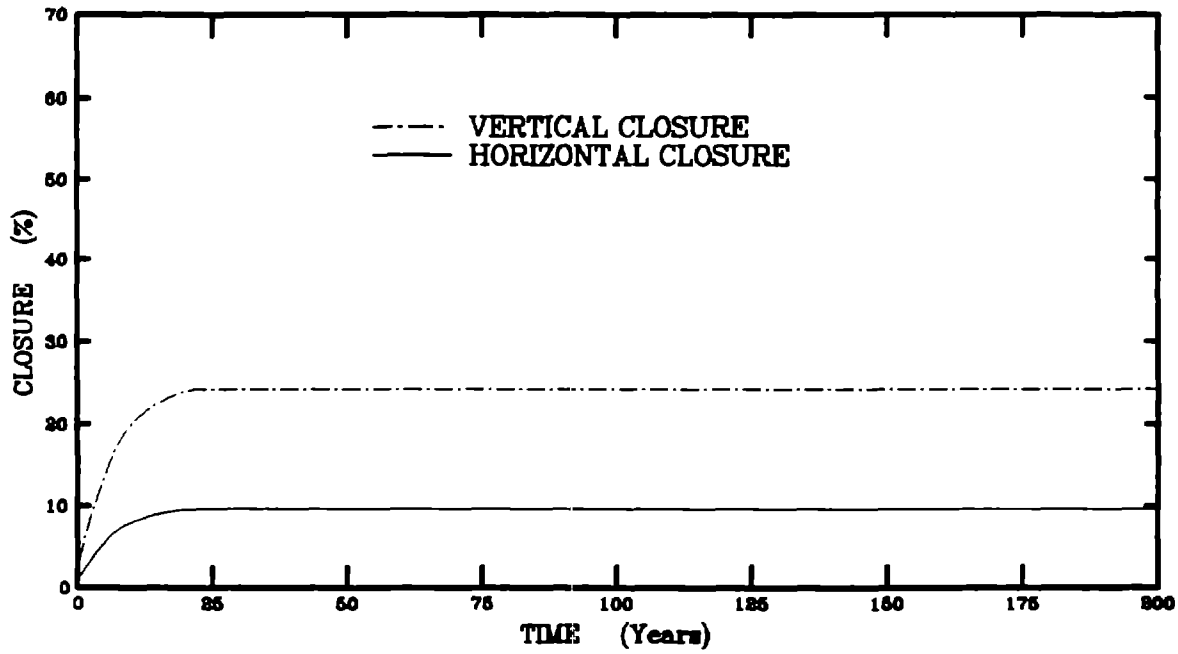

Figure 4-11. Room Closure History of a Disposal Room Filled With Crushed Salt and a Shredded Metal/Crushed Salt Mixture.

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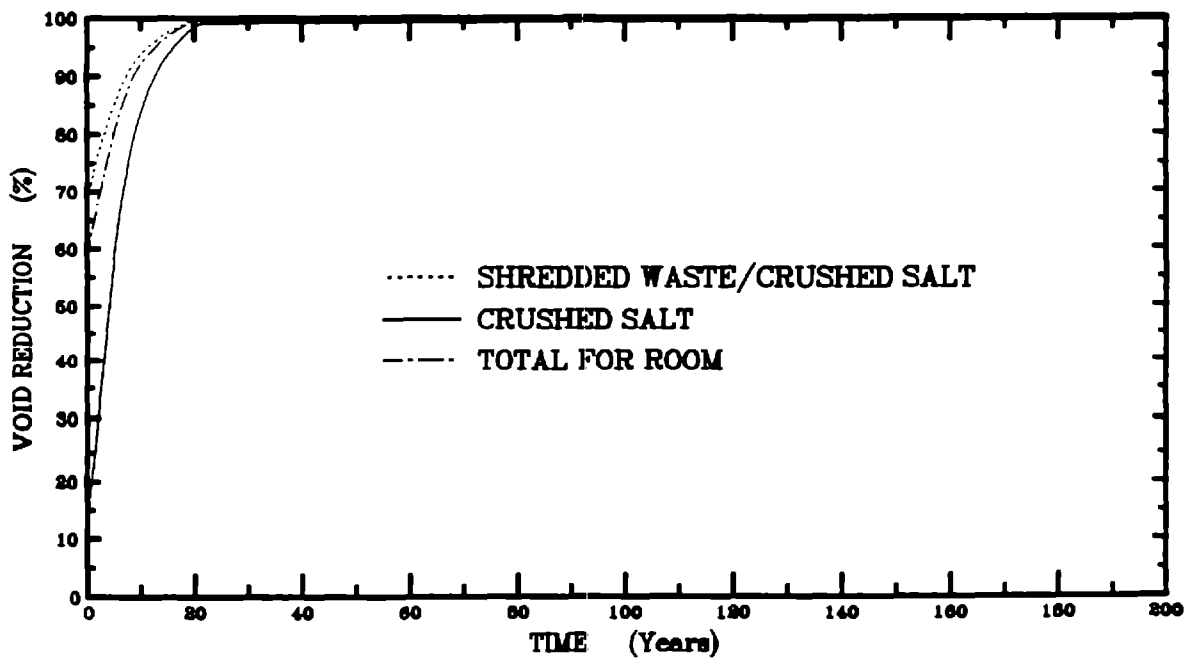

Figure 4-12. Void Reduction in the Disposal Room Filled With Crushed Salt and a Shredded Metal/Crushed Salt Mixture as a Function of Time.

5.0 SUMMARY AND CONCLUSIONS

Constitutive relations were developed and modified to simulate the backfill and host rock formation for disposal room configuration at WIPP including viscoplastic (creep), nonlinear elastic, creep consolidation, and nonlinear elastic and consolidation mixture models. These constitutive models were incorporated into the finite element computer code SPECTROM-32. The TRU waste model contains major uncertainties and assumptions that could significantly affect the results obtained. Weaknesses exist for the crushed salt constitutive model particularly with respect to its deviatoric response. The volumetric behavior of the backfill is based on hydrostatic laboratory tests, but the deviatoric response included is hypothetical. Further testing and analysis of crushed salt is required to guide the development of its constitutive model. The completed development effort provides a calculational support tool to investigate operational and performance questions relevant to the WIPP disposal room waste isolation strategies.

Different WIPP disposal room backfill configurations were examined for a simulation period of 200 years. Room contents investigated include crushed salt, a crushed salt/bentonite mixture, crushed salt covering TRU waste, crushed salt/bentonite covering TRU waste, crushed salt covering a mixture of crushed salt and shredded metallic waste, and crushed salt covering a vitrified waste. The results show that disposal room contents do not significantly affect room closure during the initial 5-year period. This is illustrated in Figures 5-1 and 5-2, which include plots of the vertical and horizontal room closure histories, respectively, for each of the cases analyzed. The one exception is the stiff, nonporous vitrified waste, which provides resistance to room deformation very early in time.

In most cases, the average void fractions became less than 5 percent within 200 years although the time required to obtain these reduced void fraction values varies significantly for the different backfill configurations. In this case, the void fraction values are computed using the initial void volume of the region as given by Equation 4-2. The one case that did not attain an average void fraction less than 5 percent is the crushed salt/bentonite mixture covering TRU waste, which reached a value of 5.09 percent after 200 years. Table 5-1 gives the time required for the average void fractions in the room, TRU waste, and surrounding backfill material to reach a value of 5 percent, and the time required for the average void fraction in the room (i.e., room refers to and includes all room contents) to reach a value of 0.5 percent. At an average void fraction of 0.5 percent, the room contents, including waste and backfill, are essentially fully compacted.

The results given in Table 5-1 are consistent with the room contents. When a stiff material is covered with crushed salt as in the case of the vitrified waste, the crushed salt compacts rapidly since the vitrified waste deforms little and the room deformation is absorbed almost entirely by the crushed salt backfill. Conversely, the TRU waste packages have initial void ratios much higher than the crushed salt and

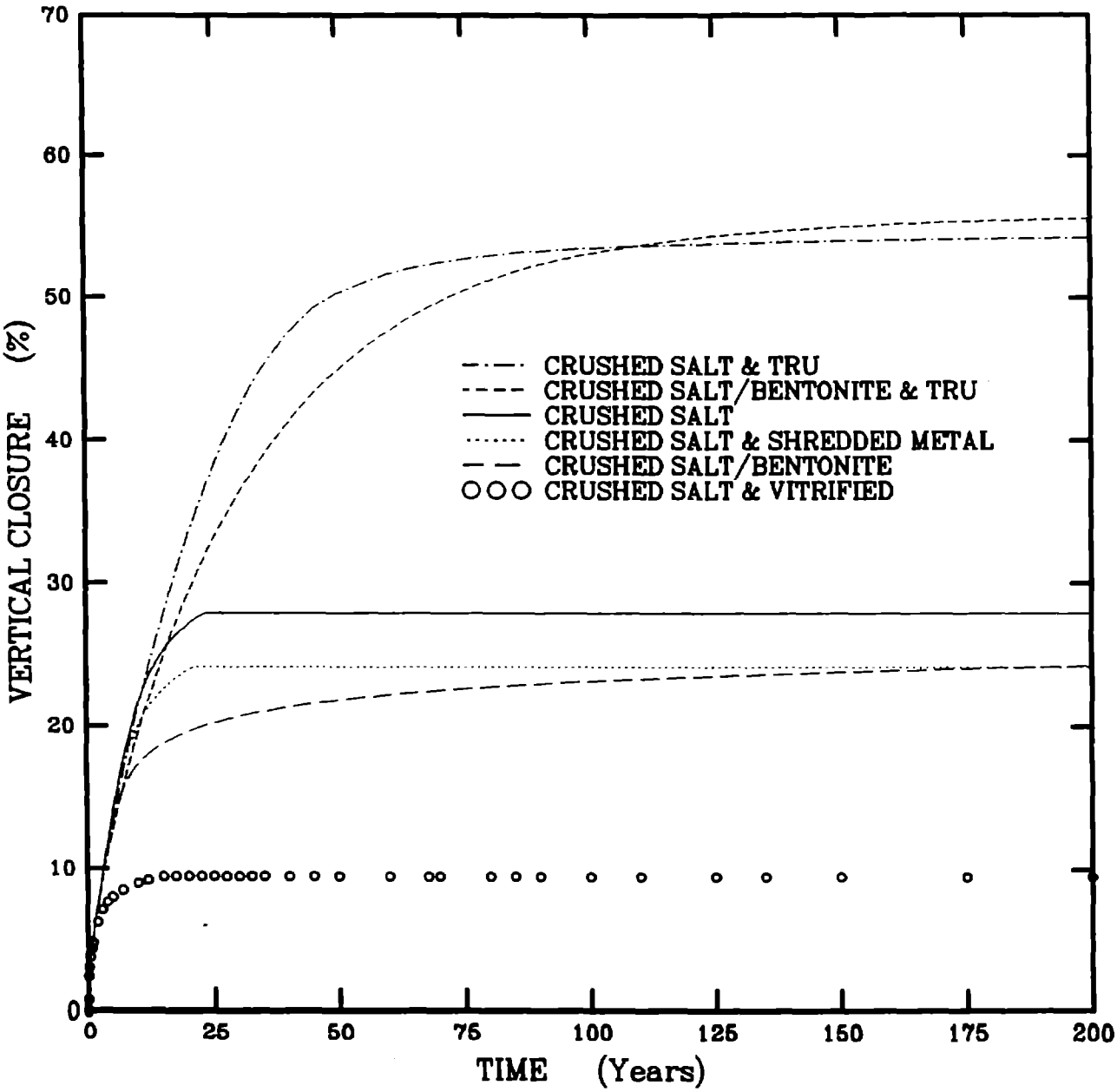

Figure 5-1. Comparisons of Vertical Closure Histories for Different Room Emplacement Scenarios.

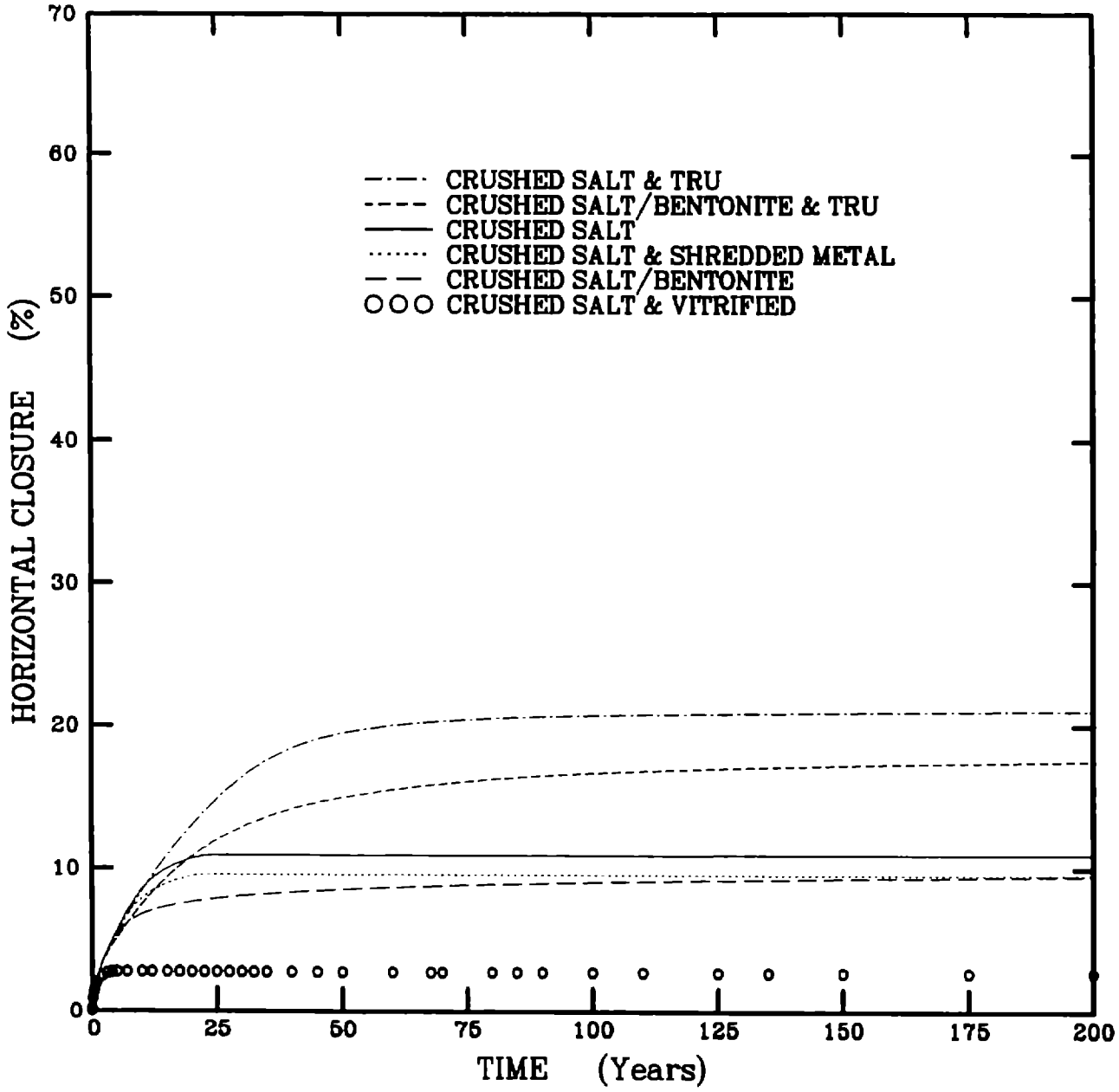

Figure 5-2. Comparisons of Horizontal Closure Histories for Different Room Emplacement Scenarios.

are significantly softer until the TRU waste is compacted significantly. Therefore, when TRU waste is included in the room, most of the room deformation is absorbed by the soft TRU waste resulting in longer times to attain reduced void fractions. When crushed salt/bentonite mixtures are assumed to be the backfill material, the consolidation rate is reduced and the times shown in Table 5-1 are significantly greater. However, as discussed in Chapter 2, the creep consolidation parameter values for crushed salt/bentonite mixtures are based on only three tests. Further testing on crushed salt/bentonite mixtures may provide information that will have a significant impact on these results.

Table 5-1. Average Void Fraction Comparisons for the Analyses

Analysis	Time to Reach Void Fraction Value (Yr)			
	5 Percent			0.5 Percent
	Room	Waste	Backfill	Room
Crushed Salt	12.7	NA[a]	12.7	22.8
Crushed Salt/Bentonite	191.2	NA	191.2	>200
Crushed Salt and TRU Waste	59.7	49.7	14.8	166.3
Crushed Salt/Bentonite and TRU Waste	200[b]	—[c]	146.8	>200
Crushed Salt and Crushed Salt/Shredded Metal Mixture	10.2	9.9	10.6	19.4
Crushed Salt/Vitrified Waste	1.3	NA	6.0	13.5

(*a*) Not applicable.
(*b*) Actual value was 5.09 percent at 200 years.
(*c*) Value was 5.4 percent at 200 years.

Results from SPECTROM-32 and SANCHO are compared for backfilled disposal room problems with crushed salt and crushed salt-bentonite (Appendix B). The calculated deformations and stresses from the two analyses agree reasonably well despite differences in methodology such as the consolidation model, intact salt creep model, finite strain, and material properties.

6.0 NOMENCLATURE

A = creep consolidation material parameter $[m^3/kg]$

A_1 = Munson-Dawson material parameter $[s^{-1}]$

A_2 = Munson-Dawson material parameter $[s^{-1}]$

B_0 = creep consolidation material parameter $[\frac{kg}{m^3 \cdot s}]$

B_1 = creep consolidation material parameter $[\text{MPa}^{-1}]$

$\hat{B}_1$ = Munson-Dawson material parameter $[s^{-1}]$

B_2 = Munson-Dawson material parameter $[s^{-1}]$

c = Munson-Dawson material parameter $[K^{-1}]$

C_{ijkl} = compliance tensor $[\text{MPa}^{-1}]$

E = Young's modulus [MPa]

$\{f\}$ = load vector [MN]

F = Munson-Dawson transient function

G = shear modulus [MPa]

G^f = fully compacted mixture shear modulus [MPa]

G_f = solid (intact) shear modulus [MPa]

G_m = inert material shear modulus [MPa]

G_s = crushed salt shear modulus [MPa]

G_0 = nonlinear elastic shear modulus material constant [MPa]

G_1 = nonlinear elastic shear modulus material constant $[m^3/kg]$

$H(.)$ = Heaviside step function

J_2 = second invariant of deviator stress $[\text{MPa}^2]$

J_3 = third invariant of deviator stress $[\text{MPa}^3]$

K = bulk modulus [MPa]

K^f = fully compacted mixture bulk modulus [MPa]

K_f = solid (intact) bulk modulus [MPa]

K_m = inert material bulk modulus [MPa]

K_o = Munson-Dawson material parameter

K_s = crushed salt bulk modulus [MPa]

$[K_t]$ = tangent stiffness matrix [MPa]

K_0 = nonlinear elastic bulk modulus material constant [MPa]

K_1 = nonlinear elastic bulk modulus material constant $[m^3/kg]$

m = Munson-Dawson material parameter

m_s = mass fraction of salt

m_m = mass fraction of inert material

M = total mass [kg]

M_m = inert material mass [kg]

M_s = crushed salt mass [kg]

n_1 = Munson-Dawson material parameter

n_2 = Munson-Dawson material parameter

q = Munson-Dawson activation volume

Q_1 = Munson-Dawson activation energy [cal/mol]

Q_2 = Munson-Dawson activation energy [cal/mol]

R = universal gas constant $[\frac{cal}{mol-K}]$

S_{ij} = deviatoric stress tensor [MPa]

t_{ij} = square of the deviator of the reduced stress [MPa^2]

u = displacement [m]

T = temperature $[K]$

v = void reduction

v^f = fully compacted volume fraction of a mixture

v_f = void fraction based on current volume

v_f^o = void fraction based on initial volume

v_f^c = void fraction for backfill region based on current volume

$v_f^{c^o}$ = void fraction for backfill region based on initial volume

v_f^t = void fraction for waste region based on current volume

$v_f^{t^o}$ = void fraction for waste region based on initial volume

v_f^r = void fraction for room region based on current volume

v_{is} = volume fraction of solid salt in crushed salt

v_{is}^f = fully compacted volume fraction of solid salt in crushed salt

v_m = volume fraction of inert material

v_m^f = fully compacted volume fraction of inert material

v_s = volume fraction of crushed salt

v_0^s = initial volume fraction of crushed salt

V = total volume $[m^3]$

V^o = initial volume $[m^3]$

V_{is} = solid salt volume within crushed salt $[m^3]$

V_m = inert material volume $[m^3]$

V_s = crushed salt volume $[m^3]$

V^c = volume of backfill region $[m^3]$

V^{c^o} = initial volume of backfill region $[m^3]$

$V_v^{c^o}$ = initial void volume of backfill region $[m^3]$

V^f = fully compacted mixture volume $[m^3]$

V_s^f = fully compacted crushed salt volume $[m^3]$

V^t = volume of waste region $[m^3]$

V^{t^o} = initial volume of waste region $[m^3]$

$V_v^{t^o}$ = initial void volume of waste region $[m^3]$

V_v = void volume $[m^3]$

V_v^o = initial void volume $[m^3]$

α = Munson-Dawson material parameter

β = Munson-Dawson material parameter

δ = Munson-Dawson recovery parameter

δ_{ij} = Kronecker delta

Δ = Munson-Dawson workhardening parameter

Δf = incremental load [MPa]

Δu = incremental displacement $[m]$

ΔV = volume change $[m^3]$

ΔV^c = volume change in backfill region $[m^3]$

ΔV^t = volume change in waste region $[m^3]$

ϵ_s = steady-state strain

ϵ_v = total volumetric strain

ϵ_{vs} = total volumetric strain of crushed salt in a mixture

ϵ_{s_1} = steady-state strain for dislocation climb

ϵ_{s_2} = steady-state strain from an undefined mechanism

ϵ_{s_3} = steady-state strain for glide

ϵ_e^c = invariant creep strain measure

ϵ_t^f = Munson-Dawson transient strain limit

ϵ_v^c = inelastic volumetric strain

ϵ_{vs}^c = inelastic volumetric strain of crushed salt in a mixture

ϵ_{ij} = total strain tensor

ϵ_{ij}^c = creep strain tensor

ϵ_{ij}^e = elastic strain tensor

$\epsilon_{eq_1}^c$ = equivalent inelastic shear strain measure

$\epsilon_{eq_2}^c$ = equivalent inelastic shear strain measure

ς = Munson-Dawson internal variable

η = empirical constant for creep consolidation model

Θ = generic property of a mixture

θ = frictional material parameter in creep flow potential (dimensionless for pressure-dependent, degrees for frictional)

θ_i = generic property of ith material in a mixture

κ = material constant in nonlinear TRU waste model [MPa^{-1}]

λ = material constant in nonlinear TRU waste model [MPa^{-1}]

μ = Munson-Dawson material parameter [MPa]

ν = Poisson's Ratio

ρ = density [kg/m^3]

ρ^f = fully compacted mixture density [kg/m^3]

ρ_f = final or intact material density [kg/m^3]

ρ_m = inert material density [kg/m^3]

ρ_{is} = solid salt density within crushed salt [kg/m^3]

ρ_s = crushed salt density $[kg/m^3]$

ρ_0 = initial material density $[kg/m^3]$

ρ_0^s = initial crushed salt density $[kg/m^3]$

σ_a = axial stress [MPa]

σ_e = invariant stress measure [MPa]

σ_m = mean stress [MPa]

σ_0 = Munson-Dawson cut-off stress [MPa]

σ_e^f = invariant stress measure [MPa]

$\sigma_{eq_1}^f$ = invariant stress measure [MPa]

$\sigma_{eq_2}^f$ = invariant stress measure [MPa]

σ_{ij} = stress tensor [MPa]

τ = flow dilatancy material parameter in creep flow potential (dimensionless for pressure-dependent, degrees for frictional)

ϕ = porosity

ϕ_s = crushed salt porosity

ϕ_0 = initial porosity

ϕ_0^c = initial porosity of backfill region

ϕ_0^t = initial porosity of waste region

ψ = Lode angle [degrees]

$\dot{\chi}$ = time rate of change of variable χ $[s^{-1}]$

σ_{kk} = repeated indices imply summation ($\sigma_{kk} = \sigma_{11} + \sigma_{22} + \sigma_{33}$)

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APPENDIX A

SIMULATED TRU WASTE STRESS POROSITY DATA

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APPENDIX A
SIMULATED TRU WASTE STRESS — POROSITY DATA

A.1 SUMMARY

Appendix A includes axial stress-porosity data pairs supplied by Sandia National Laboratories. The data are representative of experiments conducted on simulated TRU waste by Butcher et al. [1991].

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Compressive Stress MPa	Metallic Waste Porosity	Combustible Waste Porosity	Sludge Waste Porosity	Average Repository Porosity
0.4	0.805	0.830	0.549	0.765
0.6	0.783	0.801	0.410	0.722
0.8	0.768	0.776	0.394	0.696
1.0	0.755	0.752	0.377	0.672
1.2	0.741	0.729	0.363	0.649
1.4	0.729	0.706	0.350	0.628
1.6	0.717	0.683	0.338	0.607
1.8	0.706	0.661	0.328	0.588
2.0	0.696	0.640	0.318	0.570
2.2	0.687	0.620	0.310	0.553
2.4	0.678	0.602	0.302	0.538
2.6	0.670	0.584	0.296	0.525
2.8	0.662	0.567	0.289	0.512
3.0	0.655	0.552	0.284	0.499
3.2	0.649	0.536	0.278	0.488
3.4	0.642	0.522	0.273	0.477
3.6	0.636	0.508	0.268	0.467
3.8	0.630	0.494	0.263	0.457
4.0	0.624	0.482	0.258	0.447
4.2	0.618	0.469	0.253	0.438
4.4	0.612	0.457	0.247	0.429
4.6	0.607	0.446	0.243	0.421
4.8	0.602	0.435	0.237	0.412
5.0	0.596	0.424	0.231	0.404
5.2	0.591	0.414	0.228	0.397
5.4	0.586	0.404	0.224	0.390
5.6	0.581	0.394	0.221	0.383
5.8	0.576	0.385	0.217	0.376
6.0	0.572	0.376	0.214	0.370
6.2	0.567	0.367	0.211	0.363
6.4	0.562	0.358	0.208	0.357
6.6	0.558	0.350	0.204	0.351
6.8	0.553	0.342	0.201	0.345
7.0	0.549	0.334	0.198	0.339
7.2	0.544	0.326	0.195	0.334
7.4	0.540	0.319	0.192	0.328
7.6	0.535	0.312	0.190	0.323

Compressive Stress MPa	Metallic Waste Porosity	Combustible Waste Porosity	Sludge Waste Porosity	Average Repository Porosity
7.8	0.531	0.305	0.187	0.318
8.0	0.527	0.298	0.184	0.313
8.2	0.523	0.291	0.181	0.308
8.4	0.518	0.285	0.179	0.303
8.6	0.514	0.278	0.176	0.298
8.8	0.510	0.272	0.174	0.293
9.0	0.506	0.266	0.171	0.289
9.2	0.502	0.260	0.169	0.284
9.4	0.498	0.254	0.167	0.280
9.6	0.494	0.249	0.164	0.276
9.8	0.490	0.243	0.162	0.272
10.0	0.486	0.238	0.160	0.267
10.2	0.482	0.232	0.157	0.263
10.4	0.478	0.227	0.155	0.259
10.6	0.475	0.222	0.153	0.255
10.8	0.471	0.217	0.151	0.252
11.0	0.467	0.212	0.149	0.248
11.2	0.463	0.208	0.147	0.244
11.4	0.459	0.203	0.145	0.241
11.6	0.456	0.198	0.143	0.237
11.8	0.452	0.194	0.141	0.233
12.0	0.448	0.190	0.139	0.230
12.2	0.445	0.185	0.137	0.226
12.4	0.441	0.181	0.135	0.223
12.6	0.438	0.177	0.133	0.220
12.8	0.434	0.173	0.131	0.216
13.0	0.430	0.169	0.129	0.213
13.2	0.427	0.165	0.128	0.210
13.4	0.423	0.162	0.126	0.207
13.6	0.420	0.158	0.124	0.204
13.8	0.417	0.154	0.122	0.201
14.0	0.413	0.151	0.120	0.198
14.2	0.410	0.147	0.118	0.195
14.4	0.406	0.144	0.117	0.192
14.6	0.403	0.140	0.115	0.189
14.8	0.399	0.137	0.113	0.186

APPENDIX B

COMPARISON OF SPECTROM-32 AND SANCHO RESULTS

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APPENDIX B
COMPARISON OF SPECTROM-32 AND SANCHO RESULTS

B.1 INTRODUCTION

The purpose of Appendix B is to compare results obtained using SPECTROM-32 and presented in this report to those obtained using SANCHO [Weatherby, 1989 and Weatherby and Brown, 1990] for those types of problems common between the different analyses. Fundamental differences between the analyses are discussed in the next section before these results are presented.

B.2 DIFFERENCES BETWEEN ANALYSES

Several differences exist between the methods used to analyze the backfilled disposal rooms. The two most significant differences relate to the constitutive relations used for the various materials and the finite-strain formulation in SANCHO versus the small-strain formulation in SPECTROM-32. The following sections elaborate on the differences between the analyses.

B.2.1 Basic Problem Parameters

The basic problem parameters consist of the room and pillar geometry, depth of the room, mesh refinement of the modeled region, temperature, and boundary conditions. The same basic problem parameters were used for all SPECTROM-32 analyses, and except for a variation in the mesh refinement, the basic problem parameters in the SPECTROM-32 analyses are identical to the crushed-salt backfill and crushed-salt/TRU waste SANCHO analyses presented by Weatherby [1989]. However, the crushed salt/bentonite backfill analysis presented by Weatherby and Brown [1990] differs from the other analyses in two ways: (1) the total mesh height was 54 m rather than 27 m and (2) the overburden pressure was 14.8 MPa rather than 14.3 MPa as shown in Figure 3-1. The mesh refinement used for the SPECTROM-32 analyses is shown in Figure 3-1 and does not vary significantly from that used by SANCHO for the crushed-salt backfill and crushed-salt/TRU waste analyses.

B.2.2 Crushed Salt Model and Material Constants

The crushed-salt consolidation volumetric response model used in both analyses was developed by Sjaardema and Krieg [1987]. Although the nonlinear elastic component of the crushed salt consolidation model was the same in the SPECTROM-32 and SANCHO analyses, corresponding elastic material constants for crushed salt used in the SANCHO analyses were reduced by a factor of 12.5 [Weatherby, 1989]. This reduction in elastic properties stems from a recommendation by Morgan [1987]

that is based on the usage of the early version of the reference constitutive relation for salt creep (i.e., WIPP secondary creep law) that produced good agreement between calculated and measured deformations of WIPP field experiments. Table B-1 gives the nonlinear elastic model for crushed salt along with the respective parameters values used in the two analyses. Note that volumetric compaction is taken to be negative.

Table B-1. Nonlinear Elastic Model and Material Parameters for Crushed Salt

Parameter	Units	Value (SPECTROM-32 Analyses)	Value (SANCHO Analyses)
K_0	MPa	0.01760	0.00141
K_1	m^3/kg	0.00653	0.00653
G_0	MPa	0.01060	0.000864
G_1	m^3/kg	0.00653	0.00653
K_f	MPa	20,626	1,653
G_f	MPa	12,423	1,013
ρ_0	kg/m^3	1,400	1,400
ρ_f	kg/m^3	2,140	2,140

$$K = K_0 e^{\frac{K_1 \rho_0}{1+\epsilon_v}}$$

$$G = G_0 e^{\frac{G_1 \rho_0}{1+\epsilon_v}}$$

where ϵ_v = total volumetric strain

$$\rho_0 = \rho\,(1 + \epsilon_v)$$

Note: If $K > K_f$, then $K = K_f$ and $G = G_f$

If $G > G_f$, then $G = G_f$ and $K = K_f$

The volumetric creep consolidation component of the crushed salt model is essentially the same for the SANCHO and SPECTROM-32 analyses. The crushed salt consolidation model developed by Sjaardema and Krieg [1987] given in Chapter 2 was implemented into SANCHO [Weatherby, 1989] and SPECTROM-32 [Callahan, 1990]. The volumetric creep consolidation model parameters values used in the two analyses were identical and are given in Table 2-3 for crushed salt and Table 2-5 for the crushed salt/bentonite mixture.

A deviatoric component was added to the creep consolidation model used in SPECTROM-32. Volumetric-only models are deficient because they produce unrealistic results. For example, a cylinder subjected to uniaxial compression will

also compact laterally since the cylinder has a mean stress component. As discussed in Chapter 2, a deviatoric component was arbitrarily developed to offset the lateral strain components generated under uniaxial loading. A more complex deviatoric component is difficult to justify since, until recently, laboratory data for creep consolidation were limited to tests conducted under hydrostatic loading. SANCHO used a form of the WIPP secondary creep law for intact salt as modified by Sjaardema and Krieg [1987] for the deviatoric response of the crushed salt.

B.2.3 Intact Salt Model

Recently, a new WIPP reference constitutive relation for intact salt creep was proposed [Munson, 1989]. The original baseline WIPP constitutive relation (secondary creep law) along with a Mises-type flow potential was used in the SANCHO analyses. The Munson-Dawson constitutive relation (see Chapter 2) along with a Tresca flow potential was used in the SPECTROM-32 analyses to describe the intact salt behavior. This combination was recommended by Munson [1989] because of favorable results from a previous study [Munson et al., 1989].

Similar to the crushed salt, the elastic properties of intact salt recommended by Munson [1989] were reduced by a factor of 12.5 for the SANCHO analyses. The SPECTROM-32 analyses did not use reduced elastic constants. Note that in both sets of analyses, the crushed salt elastic constants approach the intact salt elastic constants as the crushed salt becomes fully consolidated; however, the properties in the SANCHO analyses were modified by the 12.5 reduction factor.

B.2.4 TRU Waste Model

The SPECTROM-32 analyses used the nonlinear elastic material model developed in Section 2.4 for the TRU waste; whereas, SANCHO used a volumetric plasticity model.

B.3 COMPARISON OF RESULTS

Three common analyses performed using SPECTROM-32 and SANCHO exist for comparison:

1. Room completely backfilled with crushed salt.
2. Room completely backfilled with crushed salt/bentonite.
3. Room containing TRU waste covered with crushed salt.

The SANCHO results for each of these analyses were obtained by digitizing the graphical information presented in Weatherby [1989] and Weatherby and Brown [1990]. Figures B-1 through B-6 compare the room closure and average void fraction results obtained for the room simulations using SANCHO and SPECTROM-32.

Figure B-1 compares the room closure results and Figure B-2 compares the average void fraction for the two analyses of the room backfilled completely with crushed salt. The SPECTROM-32 results show faster room closure than SANCHO and consequently a shorter time to fully consolidate the backfill. Figures B-3 and B-4 show the same results for the crushed salt/bentonite backfill analysis. Despite the differences between the SPECTROM-32 and SANCHO analyses, the crushed salt/bentonite backfill analyses results compare extremely well. Figures B-5 and B-6 illustrate the comparison of the room closures and average void fractions obtained for the TRU waste covered with crushed salt.

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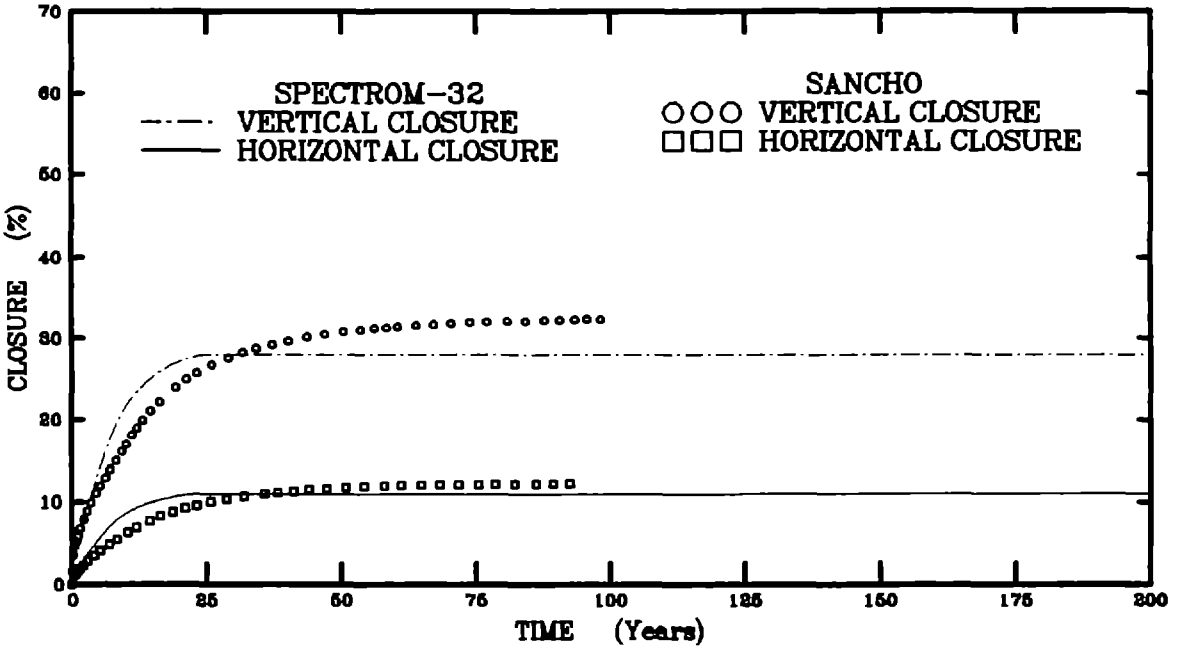

Figure B-1. Comparison of Room Closures for a Room Filled With Crushed Salt.

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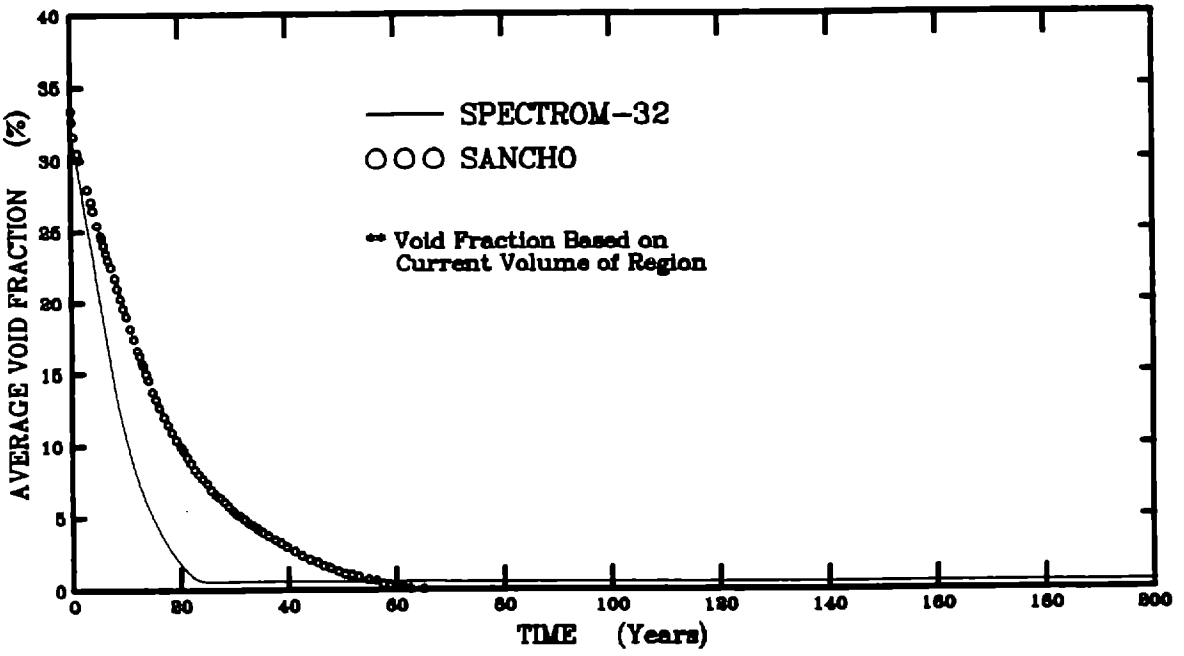

Figure B-2. Comparison of the Average Void Fractions in a Room Filled With Crushed Salt (Current Volume).

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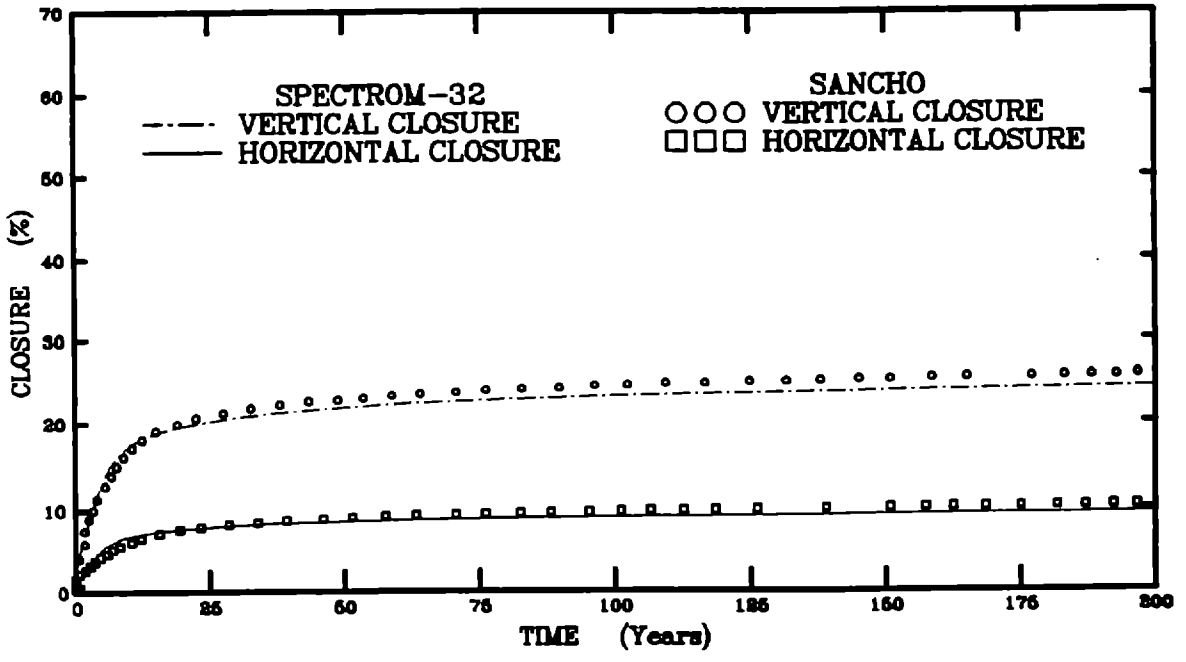

Figure B-3. Comparison of Room Closures for a Room Filled With Crushed Salt/Bentonite.

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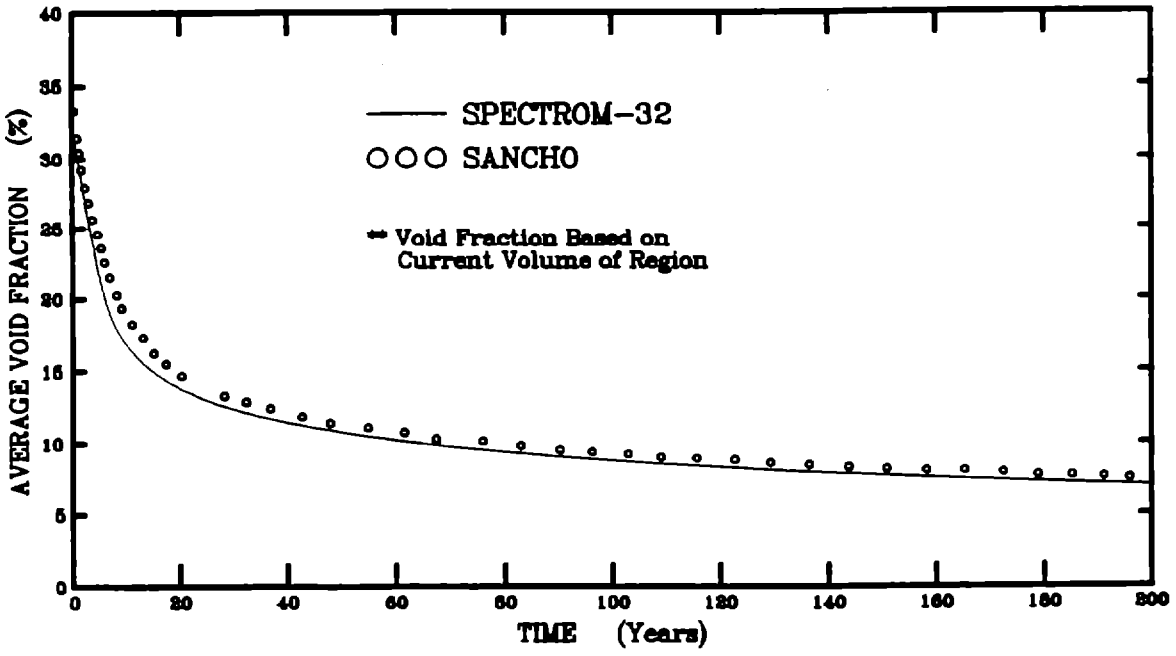

Figure B-4. Comparison of Room Closures for a Room Filled With Crushed Salt/Bentonite (Current Volume).

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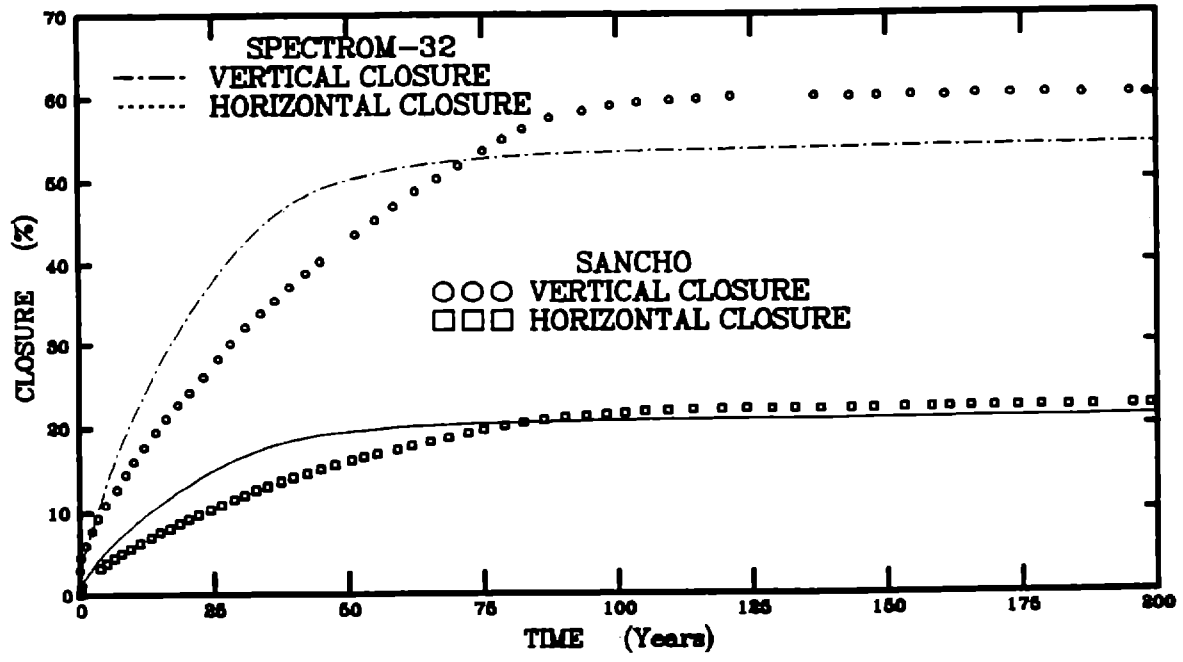

Figure B-5. Comparison of Room Closures for a Room Containing TRU Waste and Crushed Salt.

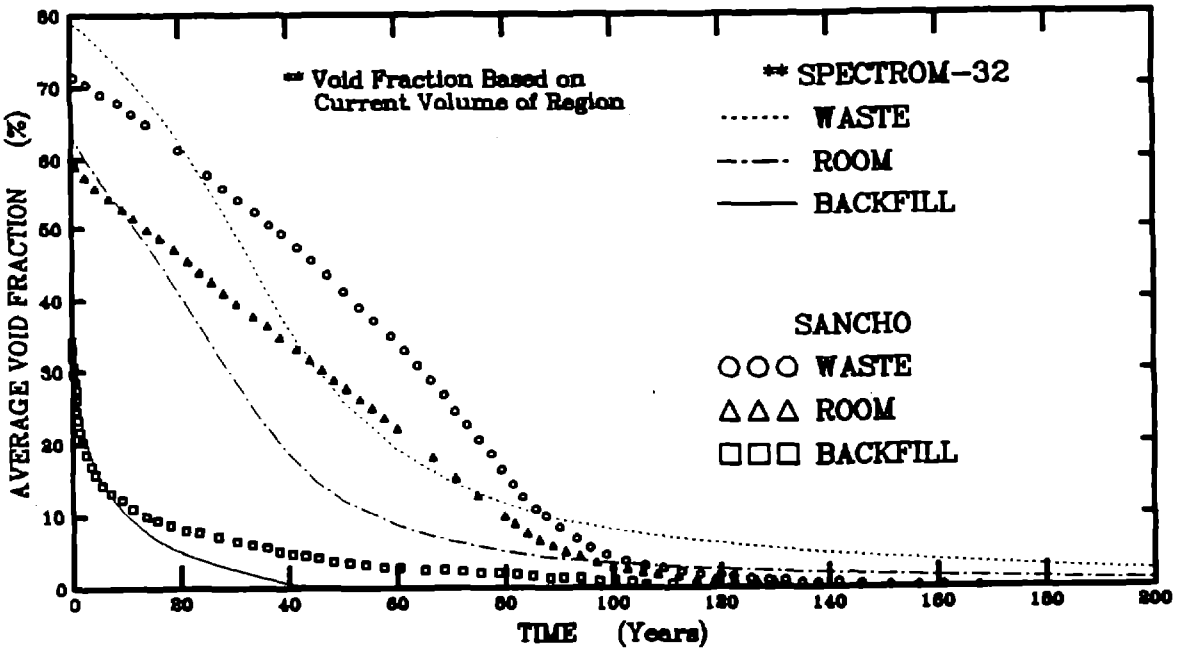

Figure B-6. Comparison of the Average Void Fractions in a Room Containing TRU Waste and Crushed Salt (Current Volume).

The results obtained from the TRU waste problem (Figures B-5 and B-6) are somewhat similar but do not compare as well as the two previously discussed analyses. An important component in this analysis is the TRU waste, and the constitutive models used in SPECTROM-32 and SANCHO for TRU waste are considerably different. Thus, the difference in the TRU waste model is thought to be the primary reason for the larger discrepancies between the two solutions.

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APPENDIX C

AVERAGE VOID FRACTION
AND
MEAN STRESS RESULTS

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APPENDIX C
AVERAGE VOID FRACTION AND MEAN STRESS RESULTS

C.1 SUMMARY

Appendix C includes average void fraction and mean stress results for the six cases investigated in Figures C-1 through C-6 and Figures C-7 through C-12, respectively. The average void fractions shown are computed using Equation 4-2, which is based on the initial volume of the region considered. When more than one component is included in a storage room, the average void fractions for each of the components are shown. For example, the case involving crushed salt and TRU waste room contents, with results shown in Figure C-3, includes three curves — one curve each for the TRU waste, crushed salt, and room. Each of these curves was computed using Equation 4-2 with the void volume and initial volume representing the specific region of interest. The curve labeled *Room* represents the average void fraction of the combined waste and backfill in the room (i.e., total room contents). The average void fraction for the room is computed by weighting the average void fractions in the waste and the backfill according to their respective volumes and dividing by the initial volume of the room.

Figures C-7 through C-12 illustrate the mean stress at three distinct locations in the room. These three locations are labeled *Center*, *Roof*, and *Rib*. *Center* refers to the center of the room with mean stress results taken from the element nearest the center of the room. *Roof* refers to the center of the room near the roof with mean stress results taken from the backfill element nearest the center of the room at the intact salt/backfill interface along the roof. *Rib* refers to the midheight of the room near the rib with mean stress results taken from the backfill element nearest the midheight of the room at the intact salt/backfill interface along the rib.

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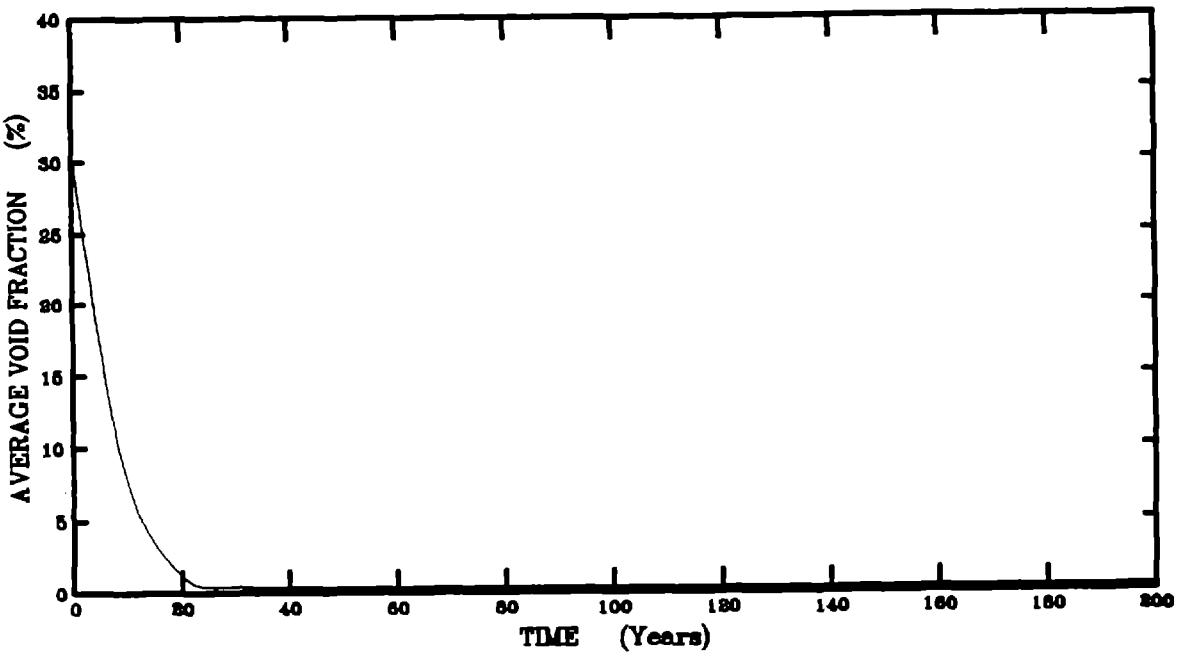

Figure C-1. Average Void Fraction in a Disposal Room Filled With Crushed Salt.

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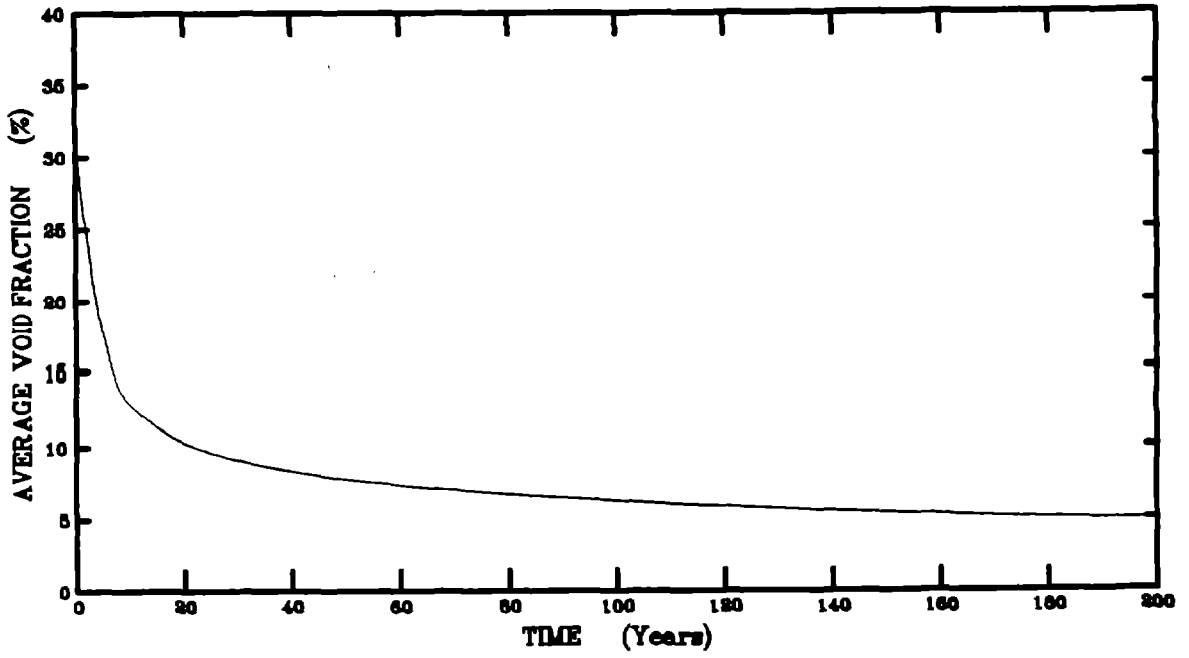

Figure C-2. Average Void Fraction in a Disposal Room Filled With Crushed Salt/Bentonite.

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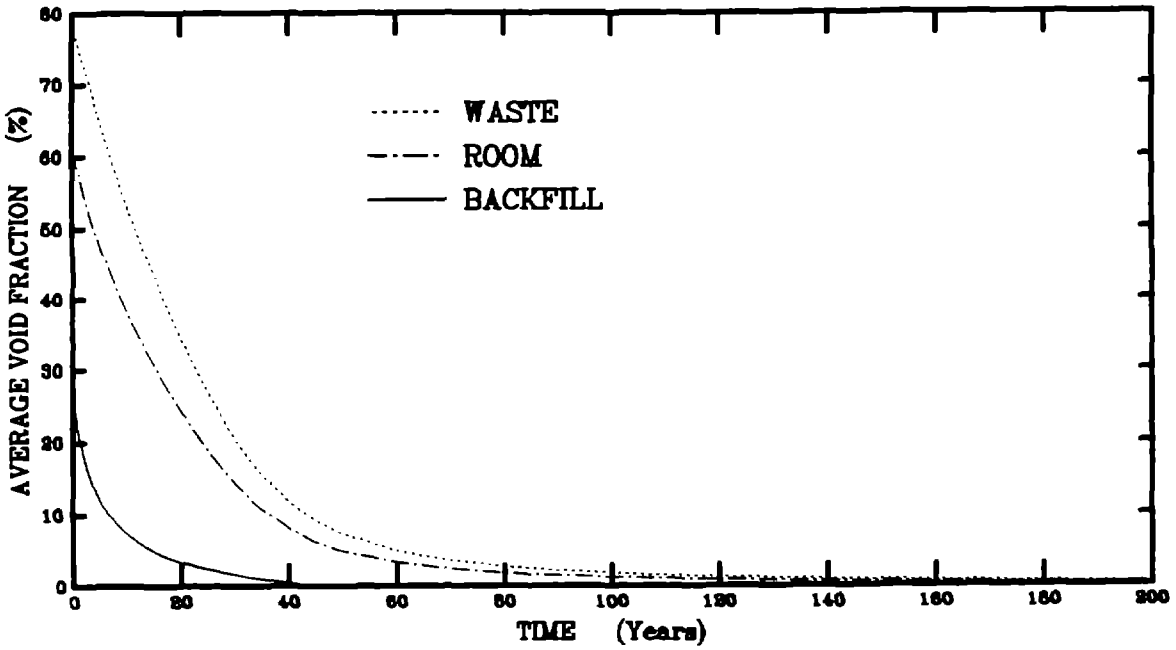

Figure C-3. Average Void Fraction in a Disposal Room Filled With TRU Waste and Surrounded by Crushed Salt.

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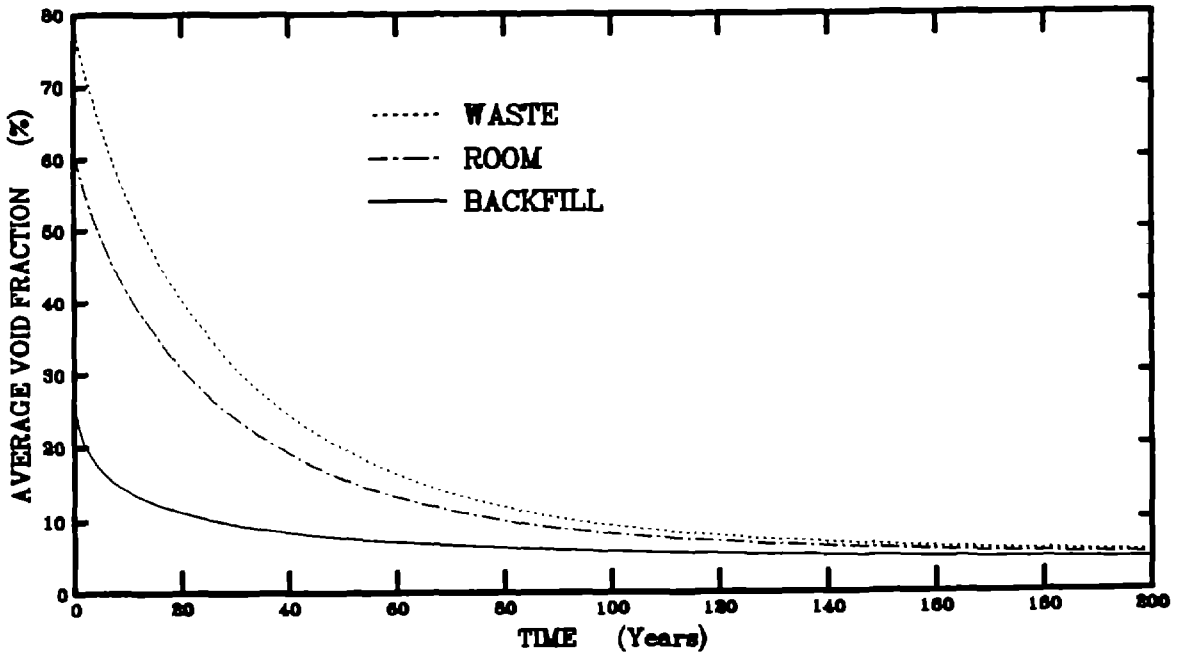

Figure C-4. Average Void Fraction in a Disposal Room Filled With TRU Waste and Surrounded by Crushed Salt/Bentonite.

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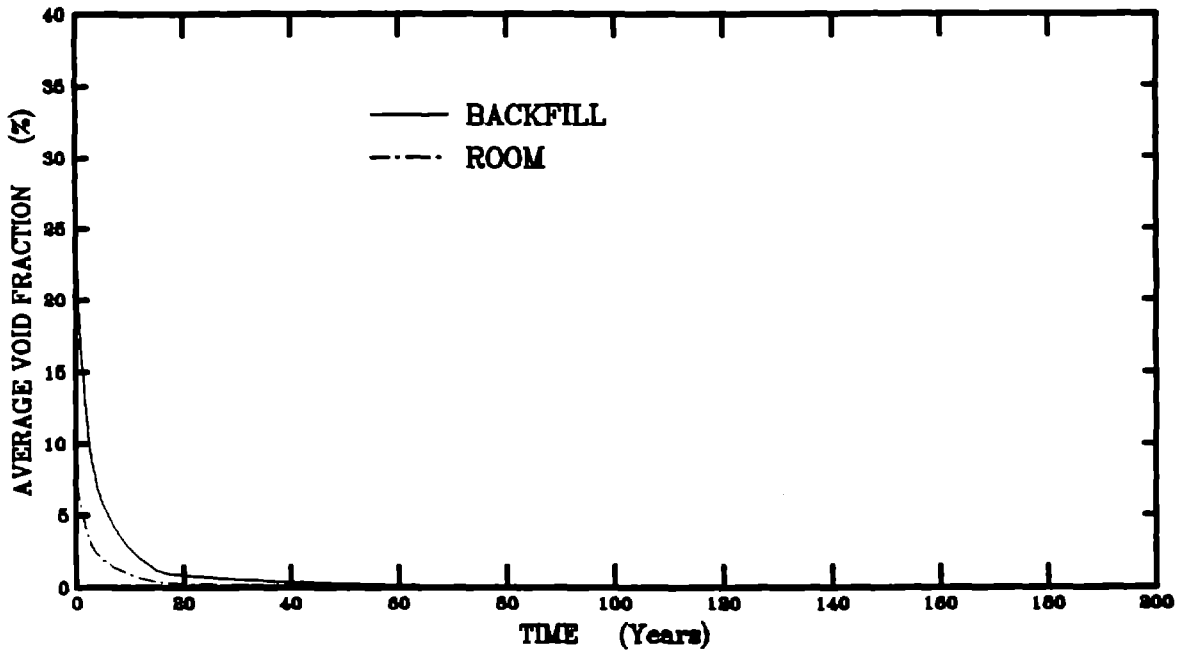

Figure C-5. Average Void Fraction in a Disposal Room Filled With Vitrified Waste and Surrounded by Crushed Salt.

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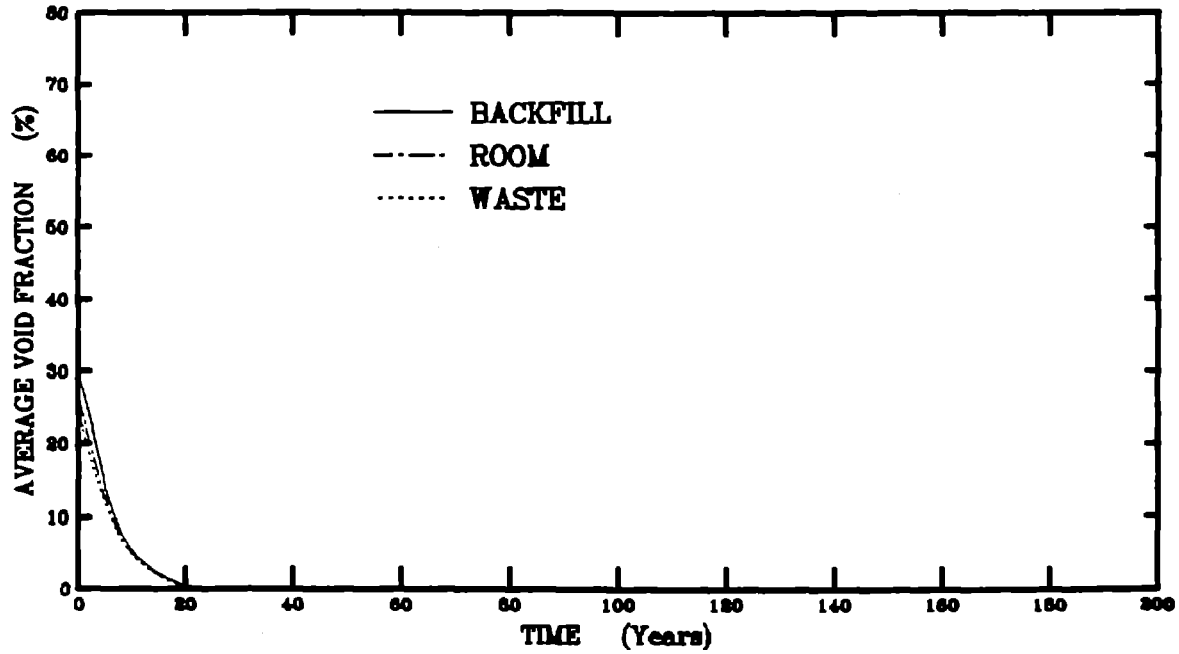

Figure C-6. Average Void Fraction in a Disposal Room Filled With a Mixture of Shredded Metallic Waste and Surrounded by Crushed Salt.

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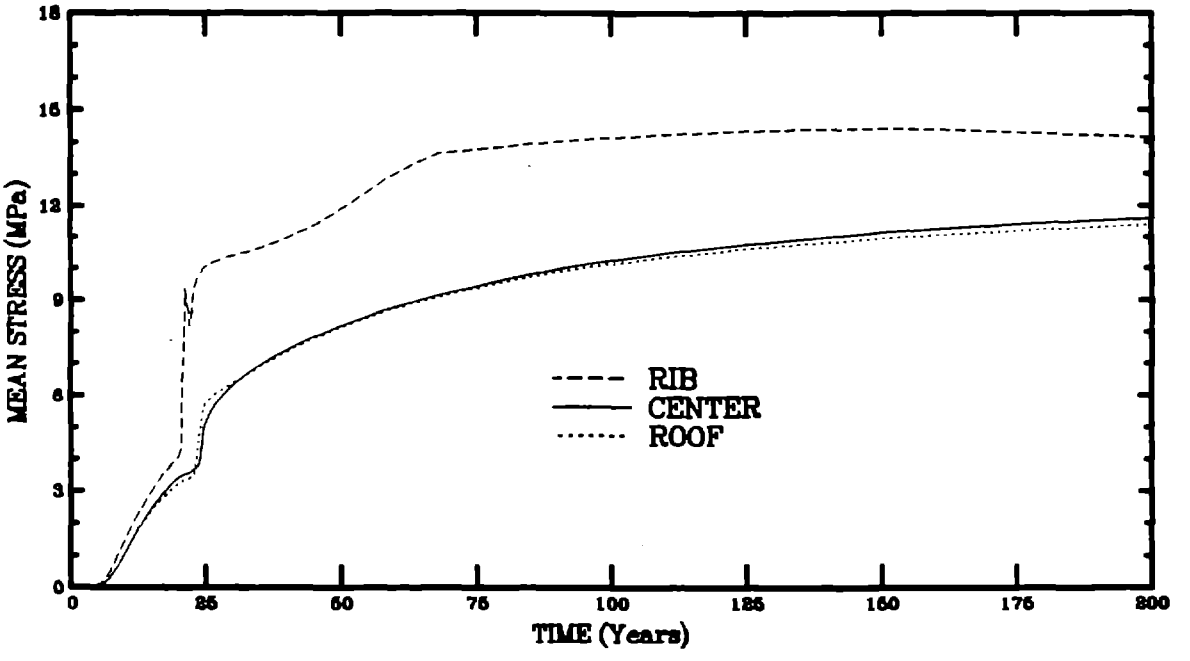

Figure C-7. Mean Stress History in a Disposal Room Filled With Crushed Salt.

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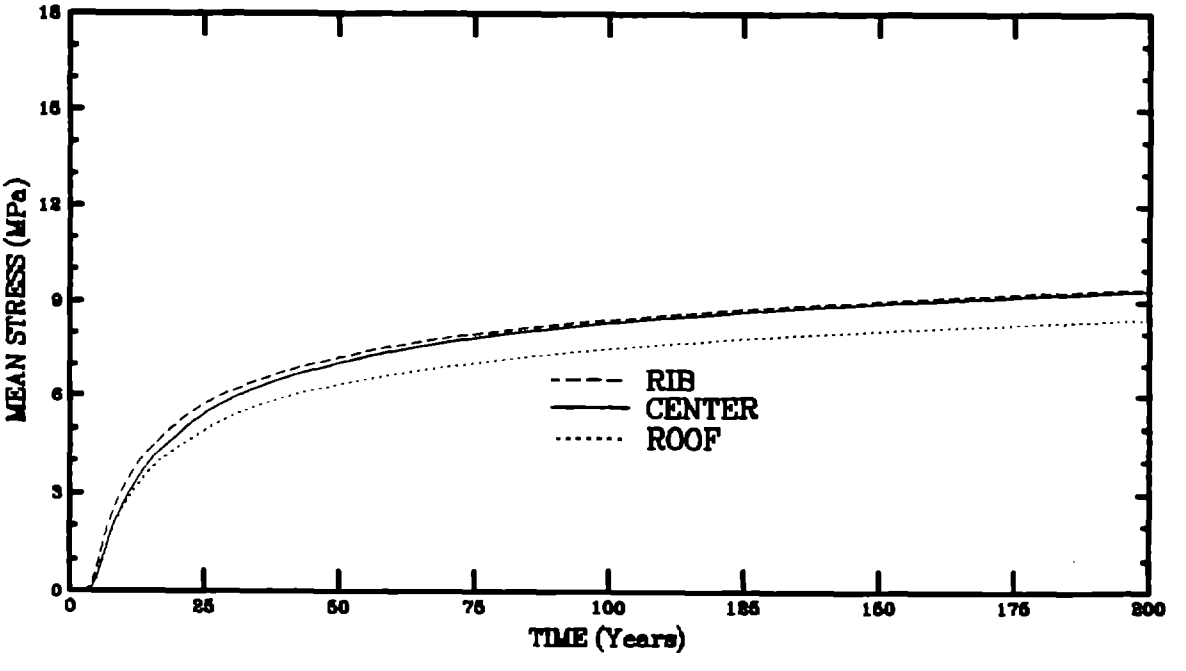

Figure C-8. Mean Stress History in a Disposal Room Filled With Crushed Salt/Bentonite.

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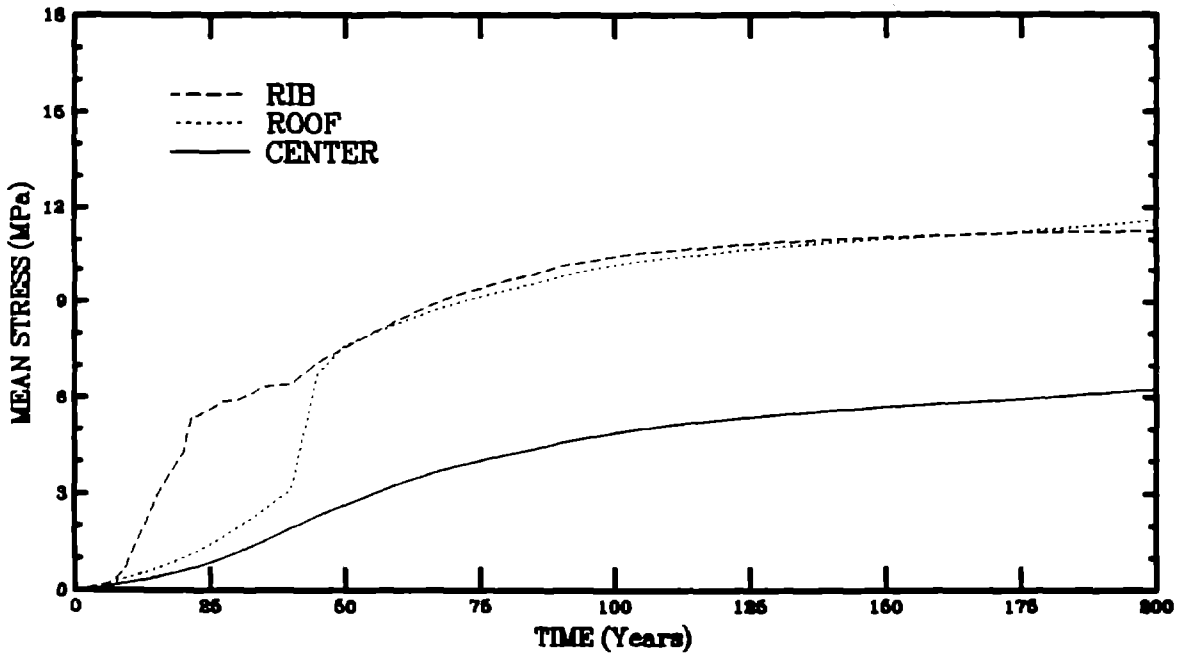

Figure C-9. Mean Stress History in a Disposal Room Filled TRU Waste and Surrounded by Crushed Salt.

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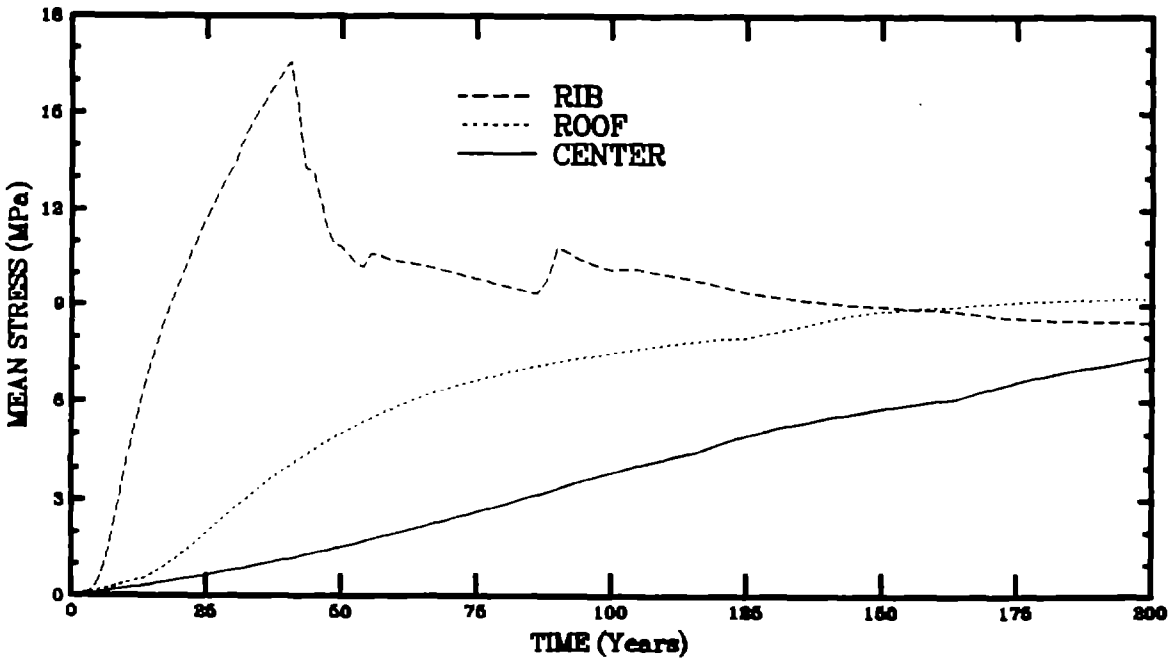

Figure C-10. Mean Stress History in a Disposal Room Filled With TRU Waste and Surrounded by Crushed Salt/Bentonite.

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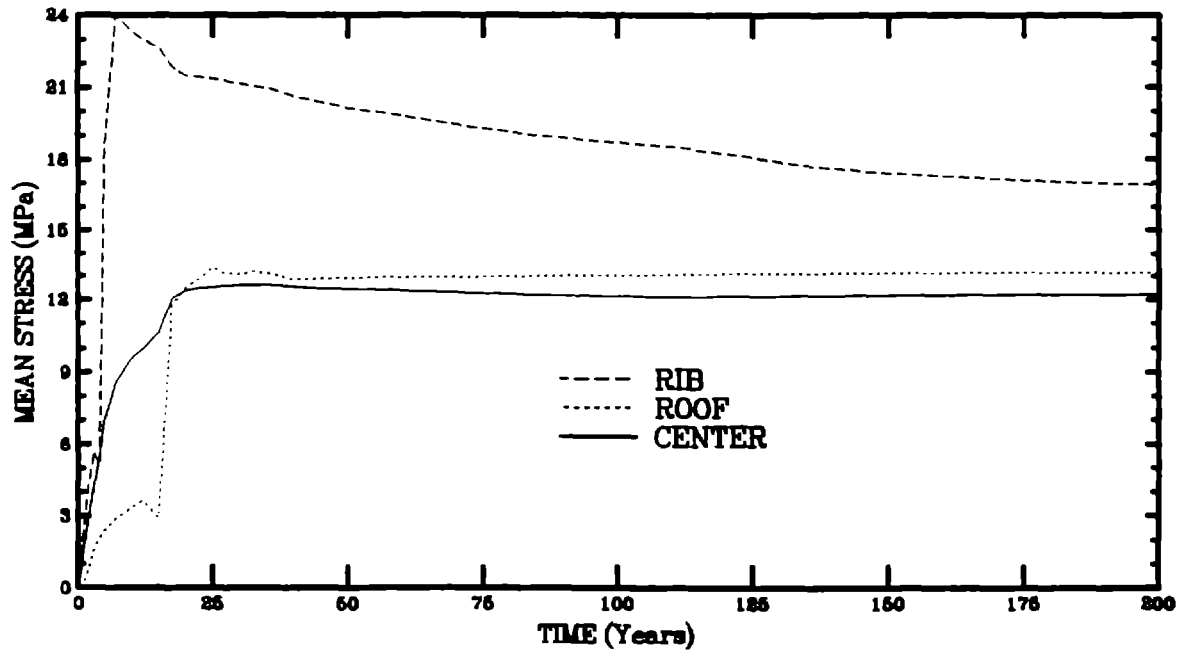

Figure C-11. Mean Stress History in a Disposal Room Filled With Vitrified Waste and Surrounded by Crushed Salt.

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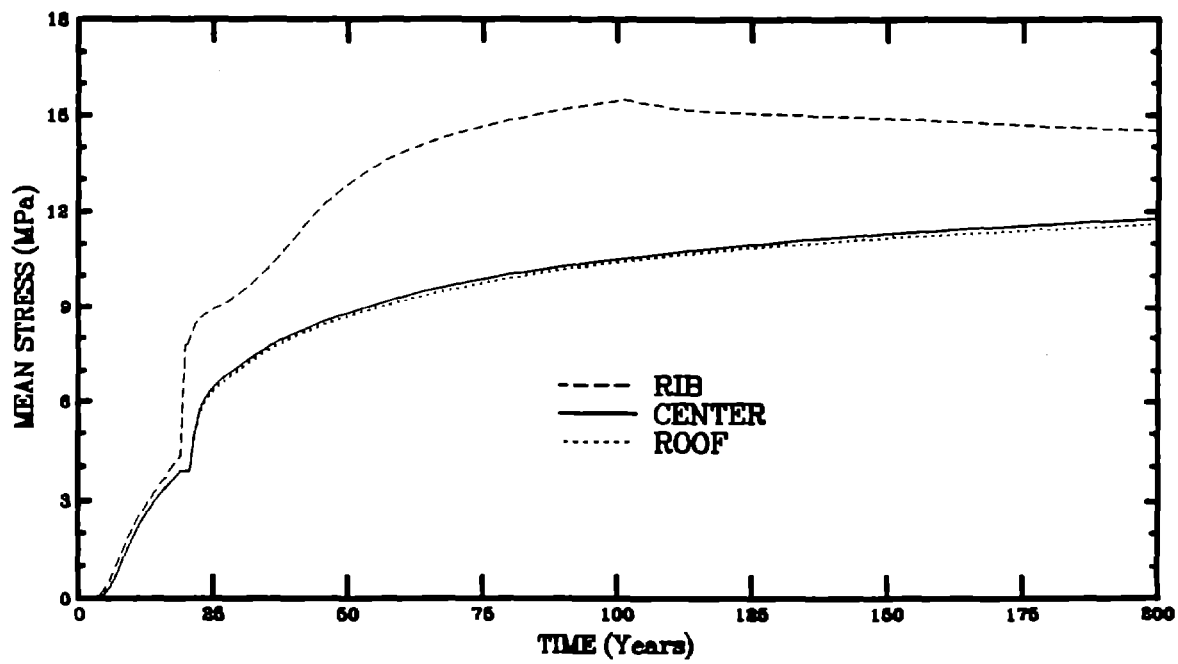

Figure C-12. Mean Stress History in a Disposal Room Filled With a Mixture of Shredded Metallic Waste and Surrounded by Crushed Salt.

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Crushed Salt Constitutive Model

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Sandia Contract No. AG4911

ABSTRACT

The constitutive model used to describe the deformation of crushed salt is presented in this report. Two mechanisms X dislocation creep and grain boundary diffusional pressure solution X are combined to form the basis for the constitutive model governing the deformation of crushed salt. The constitutive model is generalized to represent three-dimensional states of stress. Upon complete consolidation, the crushed-salt model reproduces the Multimechanism Deformation (M-D) model typically used for the Waste Isolation Pilot Plant (WIPP) host geological formation salt. New shear consolidation tests are combined with an existing database that includes hydrostatic consolidation and shear consolidation tests conducted on WIPP and southeastern New Mexico salt. Nonlinear least-squares model fitting to the database produced two sets of material parameter values for the model X one for the shear consolidation tests and one for a combination of the shear and hydrostatic consolidation tests. Using the parameter values determined from the fitted database, the constitutive model is validated against constant strain-rate tests. Shaft seal problems are analyzed to demonstrate model-predicted consolidation of the shaft seal crushed-salt component. Based on the fitting statistics, the ability of the model to predict the test data, and the ability of the model to predict load paths and test data outside of the fitted database, the model appears to capture the creep consolidation behavior of crushed salt reasonably well.

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1.0 INTRODUCTION

1.1 BACKGROUND

Construction of the Waste Isolation Pilot Plant (WIPP) was initiated by the U.S. Department of Energy (DOE) in 1981 to develop the technology for the safe management, storage, and disposal of transuranic (TRU) radioactive wastes generated by the DOE defense programs. The WIPP, located in southeastern New Mexico at a depth of approximately 655 meters in bedded halites, is designed to be a full-scale geologic repository. Access to the facility is provided through vertical shafts. Since these shafts provide direct communication from the underground facilities through the upper lithologic units to the surface, they will be sealed to limit fluid flow into the repository and to prevent hazardous materials from migrating out of the repository. The U.S. Environmental Protection Agency (EPA) has determined that the WIPP can safely contain transuranic waste and that it will comply with EPA's radioactive waste disposal standards.

Crushed salt has been selected as one of the primary seal components for permanent sealing of the WIPP underground openings. Crushed salt's desirable characteristics include chemical compatibility, eventual mechanical similarity with the host salt formation, and ready availability from site excavation. Laboratory tests have shown that crushed salt achieves desirable permeability characteristics as consolidation increases the material density. In addition, voids and fractures close and heal in salt in response to applied loads. After sufficient time, loading of the crushed salt resulting from creep closure of the shaft will form a long-term seal component from the reconsolidated crushed salt. Development of an understanding of these consolidation processes in crushed salt has been fundamental to the design and analysis of a credible seal system.

Because crushed salt is an important seal material, its constitutive model must satisfy the needs of performance assessment and regulatory compliance. To gain an understanding of the crushed-salt consolidation processes, laboratory testing and theoretical model development have been conducted over the last several years. The WIPP crushed-salt material model or constitutive model, which relates stress and strain, predicts deformations and stresses in the underground sealing system. The magnitude of the stresses and strains throughout the isolation system determines the location and extent of the disturbed rock zone and serviceability of the seal components. Laboratory testing has been used to develop the constitutive model from a phenomenological viewpoint and to evaluate the material constants associated with the model. The objective of this report is to provide the current version of the mechanical material model appropriate for describing crushed-salt deformation.

1.2 EARLIER WORK

Crushed salt has received international attention over the past 20 years primarily within a repository setting. Thus, an earlier study [Callahan et al., 1995] searched the literature for constitutive models developed for crushed salt. Ten models, based to varying degrees on phenomenology, micromechanics, or empiricism, were found. Three of these models were selected for detailed examination. The three models are those attributable to Sjaardema and Krieg [1987], Zeuch and Holcomb [Zeuch, 1990], and Spiers and coworkers [Spiers and Brzesowsky, 1993]. These constitutive models were developed to reproduce hydrostatic (isostatic) consolidation laboratory tests and include only the volumetric strain component. The Sjaardema and Krieg model is empirical and was retained for comparative purposes since it has been used in the past for calculation of crushed-salt problems at the WIPP. The Zeuch and Holcomb model was constructed for nominally dry crushed salt and is based on isostatic hot-pressing models combined with dislocation creep. The Spiers and coworkers model was formulated for wet crushed-salt aggregates and is based on grain boundary diffusional pressure solution processes. These three models were modified to include other effects thought to be important for WIPP salt. A flow potential and associated three-dimensional generalization were developed for the models so that they could operate over a wide range of stress triaxialities (ratio of mean stress to effective or deviatoric stress) and be applicable to arbitrary states of stress. A database of applicable crushed-salt laboratory tests was constructed comprising 40 hydrostatic consolidation tests and 10 shear consolidation tests. The experimental data were fit to determine values for the material parameters associated with each of the models. The hydrostatic and shear consolidation tests and their combination were fit separately so that three different parameter value sets were obtained. If a constitutive model truly represents the material and the data are unbiased, changes in parameter values among fits would be minimal. However, in this earlier study, the change in the parameter values was significant. These three models performed about equally well with the modified Spiers model exhibiting moderate superiority.

Following completion of the earlier study [Callahan et al., 1995], the constitutive model formulation was found to be inadequate at high fractional densities. In addition, because of the heavy bias in the database toward hydrostatic consolidation tests and because none of the shear consolidation tests reached high enough fractional densities to exhibit positive lateral strains, the constants associated with the flow potential made it impossible for the simulated crushed salt to move toward a volume-preserving flow (as is exhibited by intact salt) as the fractional density approached one. Most of the test data in the crushed-salt laboratory database exhibit a positive lateral-to-axial strain-rate ratio; whereas, the lateral-to-axial strain-rate ratio is negative for a triaxial test conducted on intact salt. However, as the crushed salt consolidates, the lateral deformation must change direction at some density level (i.e., cease to move inward and begin to

move outward as is observed for the intact salt tests). In addition to being a function of the density, this change in lateral strain direction is also, undoubtedly, a function of the state of stress. Having identified these shortcomings in the crushed-salt model, two additional shear consolidation tests were conducted to expand the database at higher fractional densities near 0.8 [RE/SPEC Inc., 1996]. The functional form of the flow potential for the models was modified, and the models were refit to the database. This study, discussed in RE/SPEC Inc. [1996] and Callahan et al. [1996], resulted in satisfactory model predictions over a wide range of fractional densities and stress triaxialities. However, the governing deformation mechanisms for crushed salt with varying degrees of added moisture were contained independently in two separate models.

Thus, the next study [Callahan et al., 1998; Hansen et al., 1998] incorporated the governing mechanisms — dislocation creep and pressure solution — into a single model. In addition, four new laboratory shear consolidation experiments were conducted with fractional densities near the initial fractional density (approximately 0.9) expected in the dynamically compacted crushed-salt seal [Sandia National Laboratories, 1996]. These tests expanded the database into fractional density ranges previously untested and provide information on the crushed-salt flow behavior as its density increases. These tests were added to the experimental database, which was fit to obtain material parameter values for the crushed-salt, combined-mechanism constitutive model. Up to this point, laboratory tests had included only hydrostatic and shear consolidation tests.

Laboratory testing was conducted in parallel with the constitutive model refinement work reported here. The laboratory work is reported separately [Mellegard et al., 1999] and includes test results from six shear consolidation tests and three constant strain-rate tests. Results from four of the shear consolidation tests have previously been considered in the constitutive model evaluation. The constitutive model development work reported here includes: (1) determination of the material model parameter values from the database updated with the two additional shear consolidation tests, (2) verification of the constitutive model through prediction of the constant strain-rate tests, and (3) demonstration of the constitutive model predictions for typical shaft sealing problems and comparison with earlier results.

1.3 REPORT ORGANIZATION

This report focuses on the mechanical constitutive behavior of crushed salt. In particular, Chapter 2.0 summarizes the constitutive model, provides the three-dimensional generalization of the model, and reduces the general model form to response models for specific types of laboratory tests used in the model fitting process. Chapter 3.0 summarizes the crushed-salt experimental database, along with recently completed tests used to fit the constitutive model and determine its material constants. Chapter 4.0 describes the nonlinear least-squares fitting procedure used to fit the constitutive model to the experimental database and presents the resulting parameter values. Chapter 5.0 presents verification of the constitutive model through prediction of constant strain-rate tests. Chapter 6.0 presents the results of typical shaft sealing calculations and compares the results to earlier versions of the constitutive model. The final chapter (Chapter 7.0) includes a summary and conclusions, which is followed by a list of references and three appendices.

2.0 CRUSHED-SALT CONSTITUTIVE MODEL

Details of the crushed-salt constitutive model that combine the dislocation creep and pressure solution deformation mechanisms are presented in detail by Hansen et al. [1998]. Therefore, this chapter simply summarizes the constitutive model equations for use later in the report. The chapter includes the general form of the crushed-salt constitutive model, the three-dimensional generalization for the creep consolidation model, and the reduction of the constitutive model to specific laboratory test forms used to fit the laboratory data and evaluate the material model parameters. Tensile stresses and extensile strains are assumed to be positive throughout this report.

2.1 GENERAL FORM OF THE CRUSHED-SALT CONSTITUTIVE MODEL

The total strain rate for the crushed-salt constitutive model is assumed to consist of two components. The components include nonlinear elastic $\left(\dot{\epsilon}_{ij}^{e} \right)$ and creep consolidation $\left(\dot{\epsilon}_{ij}^{c} \right)$ contributions, and the total strain rate is written as:

$$\dot{\epsilon}_{ij} = \dot{\epsilon}_{ij}^{e} + \dot{\epsilon}_{ij}^{c} \tag{2-1}$$

When the strains become finite, the expressions for strain rate should be interpreted as the rate of deformation. Both the nonlinear elastic and creep consolidation portions of the model describe the material behavior in bulk (volumetric) and in shear (deviatoric). However, as shown later, when the fractional density approaches unity, the creep consolidation portion of the model only describes deviatoric material behavior and is, in fact, the creep deformation model used for intact salt. The nonlinear elastic portion of the model presented by Callahan et al. [1995] has not changed and will not be presented again. The creep consolidation portion of the model is included in Hansen et al. [1998] and is summarized for use in the model fitting process discussed in Chapter 4.0. However, note that in this summary, parameter values η_2 and κ_2 included in Hansen et al. [1998] have been dropped since both are equal to one.

2.2 CREEP CONSOLIDATION MODEL

The creep consolidation model is of primary concern, and thus, this section is divided into subsections that summarize important portions of the crushed-salt consolidation model. Typically, equations proposed to describe the behavior of a particular material are written in one-dimensional form or as scalar relationships. To be useful in numerical analyses and applicable to a variety of laboratory experiments with different load paths, constitutive models must be generalized to include three-dimensional states of stress. The first subsection presents the generalization of the creep consolidation model. The next subsection collapses or reduces the generalized form of the creep consolidation equation to specific laboratory test conditions, which yields simplified forms that can be used in fitting the model to the experimental database. The

third subsection presents the effective strain-rate model forms that represent the two mechanisms associated with the crushed-salt creep consolidation component of the constitutive model.

2.2.1 Creep Consolidation Model Generalization

The creep consolidation constitutive equation for crushed salt includes two operative deformation mechanisms — dislocation creep and grain boundary diffusional pressure solution — and may be written as [Hansen et al., 1998]:

$$\dot{\epsilon}_{ij}^{c} = \left[\dot{\epsilon}_{eq}^{d}\left(\sigma_{eq}^{f}\right) + \dot{\epsilon}_{eq}^{w}\left(\sigma_{eq}^{f}\right)\right] \frac{\partial \sigma_{eq}}{\partial \sigma_{ij}} \tag{2-2}$$

where $\dot{\epsilon}_{ij}^{c}$ is the inelastic strain rate tensor and σ_{eq}^{f} is an equivalent stress measure. The equivalent inelastic strain rate measures for dislocation creep $\left(\dot{\epsilon}_{eq}^{d}\right)$ and pressure solution $\left(\dot{\epsilon}_{eq}^{w}\right)$ are written as functions of the equivalent stress measure. For use in the flow potential, another equivalent stress measure, σ_{eq}, is used to provide a nonassociative type of formulation that provides flexibility in governing the magnitude of the volumetric behavior. The equivalent stress measures are homogeneous of degree one in terms of stress and are given by:

$$\sigma_{eq}^{f} = \left[\eta_0 \Omega_f^{\eta_1} \sigma_m^2 + \left(\frac{2 - D}{D} \right)^{\frac{2n_f}{n_f+1}} \left(\sigma_1 - \sigma_3\right)^2 \right]^{1/2}$$

$$\sigma_{eq} = \left[\kappa_0 \Omega^{\kappa_1} \sigma_m^2 + \left(\frac{2 - D}{D} \right)^{\frac{2n}{n+1}} \left(\sigma_1 - \sigma_3\right)^2 \right]^{1/2} \tag{2-3}$$

$$\Omega_f = \left[\frac{(1 - D)\, n_f}{\left[1 - (1 - D)^{1/n_f}\right]^{n_f}} \right]^{\frac{2}{n_f+1}} \tag{2-4}$$

where:

$$\Omega = \left[\frac{\left(1 - D_v\right) n}{\left[1 - \left(1 - D_v\right)^{1/n}\right]^{n}} \right]^{\frac{2}{n+1}} \tag{2-5}$$

$$D_v = \begin{cases} D_t & D \le D_t \\ D & D > D_t \end{cases} \tag{2-6}$$

D = current fractional density

σ_m = mean stress = $\frac{\sigma_{kk}}{3}$

σ_3 = minimum principal stress

σ_1 = maximum principal stress

η_o, η_1, κ_0, κ_1, n_f, n, and D_t = material parameters.

As crushed salt approaches full consolidation (i.e., $D \rightarrow 1$), Ω_f and Ω approach zero, and the dependence on mean stress diminishes, which is required for an incompressible material matrix. Thus, letting $D = 1$, Equation 2-3 becomes:

$$\sigma_{eq}^{f} = \sigma_1 - \sigma_3 \qquad (2\text{-}7)$$

$$\sigma_{eq} = \sigma_1 - \sigma_3$$

Twice the maximum shear stress or Tresca equivalent stress is used in the equivalent stress measures to describe the shear behavior as is common for intact salt and is given by:

$$\sigma_1 - \sigma_3 = 2\cos\psi J_2 \qquad (2\text{-}8)$$

with the second and third invariants (J_2 and J_3) of the deviator stress $\left(s_{ij}\right)$ defined by:

$$J_2 = \frac{1}{2}s_{ij}s_{ji} \qquad (2\text{-}9)$$

$$J_3 = \frac{1}{3}s_{ij}s_{jk}s_{ki}$$

where the Lode angle (ψ), which is a convenient alternative invariant to J_3, is given by:

$$\psi = \frac{1}{3}\sin^{-1}\left[\frac{-3\sqrt{3}J_3}{2J_2^{3/2}}\right], \left(-\frac{\pi}{6} \le \psi \le \frac{\pi}{6}\right) \qquad (2\text{-}10)$$

The partial derivative given in Equation 2-2 may be determined using the chain rule as:

$$\frac{\partial \sigma_{eq}}{\partial \sigma_{ij}} = \frac{\partial \sigma_{eq}}{\partial \sigma_m}\frac{\partial \sigma_m}{\partial \sigma_{ij}} + \frac{\partial \sigma_{eq}}{\partial J_2}\frac{\partial J_2}{\partial \sigma_{ij}} + \frac{\partial \sigma_{eq}}{\partial \psi}\frac{\partial \psi}{\partial J_3}\frac{\partial J_3}{\partial \sigma_{ij}} \tag{2-11}$$

The derivatives of the invariants in Equation 2-11 are the same regardless of the invariant stress and strain measures selected. These derivatives are:

$$\frac{\partial \sigma_m}{\partial \sigma_{ij}} = \frac{\delta_{ij}}{3}$$

$$\frac{\partial J_2}{\partial \sigma_{ij}} = s_{ij} \tag{2-12}$$

$$\frac{\partial \psi}{\partial J_3}\frac{\partial J_3}{\partial \sigma_{ij}} = -\frac{\sqrt{3}}{2J_2^{3/2}\cos 3\psi} t_{ij}$$

where:

$$\delta_{ij} = \text{Kronecker delta}$$

$$t_{ij} = s_{ip}s_{pj} - \frac{2}{3}J_2\delta_{ij}.$$

Equation 2-11, defining the flow potential, also requires the partial derivatives of the equivalent stress measure (Equation 2-3) with respect to stress. Performing the required differentiation yields:

$$\frac{\partial \sigma_{eq}}{\partial \sigma_m} = \frac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{\sigma_{eq}}$$

$$\frac{\partial \sigma_{eq}}{\partial J_2} = \frac{2}{\sigma_{eq}}\left(\frac{2-D}{D}\right)^{\frac{2n}{n+1}} \frac{\cos\psi \cos 2\psi}{\cos 3\psi} \tag{2-13}$$

$$\frac{\partial \sigma_{eq}}{\partial \psi} = -\frac{4}{\sigma_{eq}}\left(\frac{2-D}{D}\right)^{\frac{2n}{n+1}} \cos\psi \sin\psi J_2$$

Substituting Equations 2-11, 2-12, and 2-13 into Equation 2-2 provides the tensorial strain-rate components for the creep consolidation portion of the crushed-salt model, which is given by:

$$\dot{\epsilon}_{ij}^{c} = \frac{\dot{\epsilon}_{eq}^{d} + \dot{\epsilon}_{eq}^{w}}{\sigma_{eq}} \left\{ \frac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{3} \delta_{ij} + \left(\frac{2 - D}{D} \right)^{\frac{2n}{n+1}} 2\sqrt{J_2} \cos\psi \left(\left[\frac{\cos 2\psi}{\cos 3\psi} \right] \frac{s_{ij}}{\sqrt{J_2}} + \left[\frac{\sqrt{3} \sin\psi}{J_2 \cos 3\psi} \right] t_{ij} \right) \right\} \tag{2-14}$$

Equation 2-14 is seen to be undefined as the Lode angle approaches $\pm\pi/6$. In other words, the flow potential forms corners at $\psi = \pm\pi/6$, and the direction of straining is not unique. To eliminate this problem computationally, the flow potentials on either side of the corner are averaged, which produces an indeterminant form that is examined in the limit as $\psi \rightarrow \pm\pi/6$. Performing this limiting operation, Equation 2-14 becomes:

$$\dot{\epsilon}_{ij}^{c} = \frac{\dot{\epsilon}_{eq}^{d} + \dot{\epsilon}_{eq}^{w}}{\sigma_{eq}} \left\{ \frac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{3} \delta_{ij} + \left(\frac{2 - D}{D} \right)^{\frac{2n}{n+1}} \sqrt{3 J_2} \left(\frac{s_{ij}}{\sqrt{3 J_2}} \mp \frac{t_{ij}}{2 J_2} \right) \right\} \tag{2-15}$$

The flow potential contains four material parameters (κ_0, κ_1, D_t, and n) that need to be determined from laboratory experiments. To complete the crushed-salt creep consolidation description, the kinetic equations describing dislocation creep and pressure solution in crushed salt need to be defined. In general, these kinetic equations could be a form of any specific model that captures the desired characteristics of the material deformation. Discussion of these specific forms is included in Sections 2.2.3 and 2.2.4 following presentation of Equation 2-15 reduced to specific laboratory test conditions.

2.2.2 Evaluation of Laboratory Test Equation Forms

To compare the crushed-salt constitutive equations to laboratory experiments, one needs to reduce the equations to the applicable test conditions. In particular, tests of interest are the hydrostatic compression, triaxial compression, and triaxial extension tests. To derive these forms, one simply needs to substitute the applicable test conditions into the constitutive equations and reduce them to their simplest forms. The hydrostatic compression test conditions can be easily obtained from the triaxial compression test conditions by letting the stress difference $\Delta\sigma = \sqrt{3J_2}$ equal zero. The directions $\{zz, yy, xx\}$ are taken as $\{33, 22, 11\}$, and the $\{zz\}$ direction is taken to be the axial direction. For convenience, the following variables are defined:

$$\alpha = \frac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{3}$$

$$\beta = \left[\frac{2 - D}{D}\right]^{\frac{2n}{n+1}} \sqrt{3 J_2} \qquad (2\text{-}16)$$

Fitting of the constitutive model can be conveniently separated into two separate stages. The first step includes fitting the ratio of the lateral strain rate to the axial strain rate defined as $\mathbb{R}$ and written as:

$$\mathbb{R} = \frac{\dot{\epsilon}_l^c}{\dot{\epsilon}_a^c} \qquad (2\text{-}17)$$

Fitting the strain-rate ratio allows the parameter values associated with the flow potential (i.e., κ_0, κ_1, D_t, and n contained in α and β in Equation 2-16) to be determined independently of the other material parameter values. Obviously, the test data must contain experiments where the stress triaxiality conditions lie between zero and infinity for the fitting to be successful. This can be accomplished with the shear consolidation tests.

Reduction to Triaxial Compression Creep Test ($\psi = \pi/6$)

The triaxial compression creep test is prescribed by controlling a constant stress state defined by $\sigma_{zz} < \sigma_{xx} = \sigma_{yy}$. The axial ($a$), lateral ($l$), and volumetric ($v$) strain components and strain-rate ratio for the creep consolidation portion of the model may be determined from Equations 2-15, 2-16, 2-17, and the applied stress condition as:

$$\dot{\epsilon}_a^c = [\alpha - \beta] \frac{\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w}{\sigma_{eq}}$$

$$\dot{\epsilon}_l^c = \left[\alpha + \frac{\beta}{2}\right] \frac{\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w}{\sigma_{eq}}$$

$$\dot{\epsilon}_v^c = 3\alpha \frac{\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w}{\sigma_{eq}} \qquad (2\text{-}18)$$

$$\mathbb{R} = \frac{\alpha + \frac{\beta}{2}}{\alpha - \beta}$$

Reduction to Triaxial Extension Test ($\psi = -\pi/6$)

The triaxial extension creep test is prescribed by controlling a constant stress state defined by $\sigma_{zz} > \sigma_{xx} = \sigma_{yy}$. The axial ($a$), lateral ($l$), and volumetric ($v$) strain components and strain-rate ratio for the creep consolidation portion of the model may be determined from Equations 2-15, 2-16, 2-17, and the applied stress conditions as:

$$\dot{\epsilon}_a^c = \left[\alpha + \beta\right] \frac{\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w}{\sigma_{eq}}$$

$$\dot{\epsilon}_l^c = \left[\alpha - \frac{\beta}{2}\right] \frac{\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w}{\sigma_{eq}} \qquad (2\text{-}19)$$

$$\dot{\epsilon}_v^c = 3\,\alpha \frac{\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w}{\sigma_{eq}}$$

$$\mathbb{R} = \frac{\alpha - \frac{\beta}{2}}{\alpha + \beta}$$

2.2.3 Equivalent Inelastic Strain-Rate Form for Dislocation Creep

Dislocation creep of intact salt has been characterized by the Multimechanism Deformation (M-D) model [Munson, 1979; Munson and Dawson, 1979]. Thus, the equivalent inelastic strain rate measure for the dislocation creep portion of the crushed-salt model is taken to be the M-D material model. The only modification for application of the M-D model to crushed salt is replacing the intact salt effective stress measure with the effective stress measure given for crushed salt in Equation 2-3.

The model is written as:

$$\dot{\epsilon}_{eq}^d = F\,\dot{\epsilon}_s \qquad (2\text{-}20)$$

where $\dot{\epsilon}_{eq}^d$ is the kinetic equation and $\dot{\epsilon}_s$ is the steady-state strain rate. The transient function F consists of three branches — a work-hardening branch, an equilibrium branch, and a recovery branch and is written in that order as:

$$F = \begin{cases} \exp\left[\Delta\left(1 - \dfrac{\zeta}{\epsilon_t^f}\right)^2\right] & \zeta < \epsilon_t^f \\ 1 & \zeta = \epsilon_t^f \\ \exp\left[-\delta\left(1 - \dfrac{\zeta}{\epsilon_t^f}\right)^2\right] & \zeta > \epsilon_t^f \end{cases} \tag{2-21}$$

Δ and δ are the work-hardening and recovery parameters, respectively, and ϵ_t^f is the transient strain-rate limit. The internal variable ζ is governed by the evolution equation:

$$\dot{\zeta} = (F - 1)\,\dot{\epsilon}_s \tag{2-22}$$

and the transient strain limit is given by:

$$\epsilon_t^f = K_0 e^{cT}\left(\frac{\sigma_{eq}^f}{\mu}\right)^m \tag{2-23}$$

where:

T = absolute temperature

μ = shear modulus

K_0, c, and m = material parameters.

The work-hardening parameter is defined as a function of stress:

$$\Delta = \alpha + \beta \log\left(\frac{\sigma_{eq}^f}{\mu}\right) \tag{2-24}$$

where α and β are material parameters. Because of insufficient data, the recovery parameter (δ) is taken to be a constant. However, functional forms similar to Equation 2-24 are sometimes used for recovery; viz:

$$\delta = \alpha_r + \beta_r \log\left(\frac{\sigma_{eq}^f}{\mu}\right) \tag{2-25}$$

where α_r and β_r are material parameters.

The steady-state strain rate is the sum of the three individual strain-rate mechanisms acting together:

$$\dot{\epsilon}_s = \sum_{i=1}^{3} \dot{\epsilon}_{s_i} \tag{2-26}$$

The three contributing mechanisms — dislocation climb, an undefined mechanism, and slip — are written respectively as:

$$\dot{\epsilon}_{s_1} = A_1 \left(\frac{\sigma_{eq}^f}{\mu} \right)^{n_1} \exp\left(-\frac{Q_1}{RT} \right) \tag{2-27}$$

$$\dot{\epsilon}_{s_2} = A_2 \left(\frac{\sigma_{eq}^f}{\mu} \right)^{n_2} \exp\left(-\frac{Q_2}{RT} \right) \tag{2-28}$$

$$\dot{\epsilon}_{s_3} = \left(B_1 e^{-Q_1/RT} + B_2 e^{-Q_2/RT} \right) \sinh\left[q \left(\frac{\sigma_{eq}^f - \sigma_0}{\mu} \right) \right] H\left(\sigma_{eq}^f - \sigma_0 \right) \tag{2-29}$$

where:

μ = shear modulus

q = activation volume

A_1, A_2, B_1, B_2, n_1, n_2, Q_1, Q_2, and σ_0 = experimental constants

R = universal gas constant

$H(.)$ = Heaviside step function.

2.2.4 Equivalent Inelastic Strain-Rate Form for Pressure solution

Spiers and Brzesowsky [1993] presented a grain boundary diffusional pressure solution model for wet crushed salt as:

$$\dot{e}_v^w = A V_m \frac{\exp\left(-\frac{Q_s}{RT}\right)}{T} \left(\frac{\sigma_m - P}{d^p}\right) \left(\frac{(1 + e_v)^{r_3}}{|e_v|^{r_4}}\right) \Gamma \tag{2-30}$$

where $\dot{e}_v^w$ is the volumetric consolidation strain rate, A, V_m, Q_s, p, r_3, and r_4 are material constants; T is absolute temperature; R is the universal gas constant; d is the grain size; and P is the pore pressure. The model consists of two functional forms — one for small strain and one for large strain, which are invoked depending on the prescribed value for Γ given as:

$$\Gamma = \begin{cases} 1 & \text{small strain } (e_v > -15\%) \\ \left[\dfrac{e_v + \phi_0}{\phi_0(e_v + 1)}\right]^{n_s} & \text{large strain } (e_v < -15\%) \end{cases} \tag{2-31}$$

where ϕ_0 is the initial porosity and n_s is a material parameter. Spiers and Brzesowsky [1993] developed the function Γ to account for increasing surface contact (increasing area and decreasing stress) as the strains become large. This geometrically interpreted variable serves to decrease the magnitude of the driving force.

Spiers and Brzesowsky's model is used to represent the equivalent inelastic strain-rate form for pressure solution with modifications. The functional form given in Equation 2-30 is modified by changing the stress-dependent term (using the equivalent stress measure defined in Equation 2-3) and adding the effect of moisture (w is the moisture fraction by weight). The moisture function (simply w raised to a power, a) eliminates any strain-rate contribution to the crushed-salt consolidation model when moisture content is zero. In addition, the pore pressure dependency (parameter P in Equation 2-30) has been dropped from the model because insufficient test data are available to include pore pressure as a state variable. With these modifications, the modified Spiers' model used to define the kinetic equation becomes:

$$\dot{e}_{eq}^w = \frac{r_1 w^a}{d^p} \frac{e^{-\frac{Q_s}{RT}}}{T} \left(\frac{(1 + e_v)^{r_3}}{|e_v|^{r_4}}\right) \Gamma \sigma_{eq}^f \tag{2-32}$$

Notice that material constants A and V_m appearing in Equation 2-30 have been combined into one parameter, r_1, in Equation 2-32 defined as:

$$r_1 = AV_m = \text{material constant} \left[\frac{\text{m}^p \cdot K}{\text{MPa} \cdot \text{s}}\right] \tag{2-33}$$

Moisture content and grain size are not implemented specifically in numerical models since their distributions are generally not known and they are assumed to be constants. However, the moisture and grain size effects are incorporated through the leading coefficient, which may be corrected for changes in grain size and moisture. Thus, the corrected leading coefficient is

$$r_1^* = \frac{r_1 w^a}{d^p} \tag{2-34}$$

To express the pressure solution model in terms of true strain (ϵ), consider the following relationships:

$$\begin{aligned} \epsilon_v &= \ln\left(\frac{\rho_0}{\rho}\right) \\ \epsilon_v &= \ln\left(1 + e_v\right) \\ \dot{\epsilon}_v &= \frac{\rho}{\rho_0}\dot{e}_v = e^{-\epsilon_v}\dot{e}_v \end{aligned} \tag{2-35}$$

Using Equation 2-35, Equation 2-32 may be written as:

$$\dot{\epsilon}_{eq}^w = r_1^* e^{-\epsilon_v}\left(\frac{e^{r_3\epsilon_v}}{\left|e^{\epsilon_v} - 1\right|^{r_4}}\right)\frac{e^{-\frac{Q_s}{RT}}}{T}\,\Gamma\,\sigma_{eq}^f \tag{2-36}$$

which is the form incorporated into SPECTROM-32, a thermomechanical finite element stress analysis program [Callahan et al., 1989], with the geometric factor written as:

$$\Gamma = \begin{cases} 1 & \text{small strain } \left(e^{\epsilon_v} - 1 > -15\%\right) \\ \left[\dfrac{e^{\epsilon_v} + \phi_0 - 1}{\phi_0 e^{\epsilon_v}}\right]^{n_s} & \text{large strain } \left(e^{\epsilon_v} - 1 < -15\%\right) \end{cases} \tag{2-37}$$

A problem is evident in Spiers' model at time zero. Equation 2-30 or 2-36 can be indeterminate since when $\sigma_{eq}^{f} = 0$, the initial volumetric strain is zero. To eliminate this problem during computations, some initial value must be assumed for the volumetric strain. Typically, this initial strain value will be computed based on an original fractional density of 0.64, which is the approximate fractional density for random-dense packing of single size spheres (Fischmeister and Arzt [1983] and Helle et al. [1985]), and the fractional density at the beginning of creep consolidation. The pressure solution model has seven material constants — a, p, Q_s, r_1, r_3, r_4, and n_s, excluding those that appear in the effective stress measure.

2.3 SUMMARY OF THE CRUSHED-SALT CONSOLIDATION MODEL

The equation describing the combined-mechanism, crushed-salt constitutive model, which includes dislocation creep and pressure solution, is summarized in this section. The final equation for the total creep consolidation strain rate is obtained by substituting Equations 2-20 and 2-36 into Equation 2-14:

$$\dot{\epsilon}_{ij}^{c} = \frac{1}{\sigma_{eq}} \left\{ \frac{r_1 w^{a}}{d^{p}} e^{-\epsilon_v} \left(\frac{e^{r_3 \epsilon_v}}{\left| e^{\epsilon_v} - 1 \right|^{r_4}} \right) \frac{e^{-\frac{Q_s}{RT}}}{T} \Gamma \sigma_{eq}^{f} + F \dot{\epsilon}_{s} \right\} \times$$

$$\left\{ \frac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{3} \delta_{ij} + \left(\frac{2-D}{D} \right)^{\frac{2n}{n+1}} \left(2 \cos\psi \sqrt{J_2} \right) \left(\left[\frac{\cos 2\psi}{\cos 3\psi} \right] \frac{s_{ij}}{\sqrt{J_2}} + \left[\frac{\sqrt{3} \sin\psi}{J_2 \cos 3\psi} \right] t_{ij} \right) \right\} \tag{2-38}$$

As the material approaches full consolidation, the fractional density approaches 1, and the M-D model creep component becomes the same as that for intact salt. Simultaneously, the pressure solution portion of the model diminishes as the material approaches full consolidation. This decrease is implemented through the geometric Γ function, which becomes zero at full consolidation. Thus, at complete consolidation (i.e., $D = 1$), Equation 2-38 may be written as:

$$\dot{\epsilon}_{ij}^{c} = F \dot{\epsilon}_{s} \left(\left[\frac{\cos 2\psi}{\cos 3\psi} \right] \frac{s_{ij}}{\sqrt{J_2}} + \left[\frac{\sqrt{3} \sin\psi}{J_2 \cos 3\psi} \right] t_{ij} \right) \tag{2-39}$$

which is identical to the M-D model for intact salt.

3.0 EXPERIMENTAL DATABASE

A database of crushed-salt consolidation laboratory test results was assembled, analyzed, and reported in previous work [Callahan et al., 1995; 1998a]. This previous work initiated the process of formulating the functional form of a constitutive model for crushed salt and assembled existing test data into a database to obtain quantitative estimates for the material parameters appearing in the model. The assembled database consists of a collection of tests conducted for a variety of reasons. Thus, the database contains biases and shortcomings when viewed strictly from the standpoint of developing constitutive models. The crushed-salt constitutive model has deviatoric and mean stress components that drive the strain response, and the database has shear and hydrostatic consolidation tests used for evaluating the parameters within those respective stress components. Since this initial work was completed, additional tests have been conducted to fill gaps in the database. Two additional shear consolidation tests [RE/SPEC Inc., 1996; Callahan et al., 1998a] were conducted and added to the database following compilation of the initial database. These two tests represent the first tests with high initial fractional densities (near 0.8) that emulate intact salt behavior accompanied by volumetric consolidation. Subsequently, four additional tests were conducted to add test data to the shear consolidation portion of the extant database because that portion of the database was relatively sparse, particularly in the higher initial fractional density range expected at WIPP. These four additional shear consolidation tests on dynamically compacted crushed salt are summarized by Hansen et al. [1998] and Mellegard et al. [1999].

Two new shear consolidation tests were conducted in parallel with the current study to add test data to the shear consolidation portion of the database and verify earlier test results. In addition, three constant strain-rate tests were performed to provide experimental results and load paths outside of the fitted database for verification of the constitutive model. The remainder of this chapter is divided into two sections; the first section summarizes the status of the database used for evaluation of material parameter values and the second section presents details on the two new shear consolidation tests. The three constant strain-rate tests that were performed in parallel with the current effort are discussed in chapter 5.0.

3.1 SUMMARY OF EXISTING TEST DATA

Creation of the database was initiated with an extensive library search and compilation of potentially useful test results [Pfeifle, 1995]. The test data were compiled from the original studies conducted by Holcomb and Hannum [1982], Pfeifle and Senseny [1985], Holcomb and Shields [1987], Zeuch et al. [1991], and Brodsky [1994]. That compilation was reviewed to document those tests deemed inappropriate for parameter estimation and the surviving tests formed the database for parameter estimation work [Callahan et al., 1995]. Subsequently, six shear consolidation tests were added to the database for constitutive model evaluation and

parameter estimation in two different studies: Callahan et al. [1998a] — two tests and Hansen et al. [1998] — four tests. The database is constructed from two types of tests: hydrostatic consolidation and shear consolidation. The two parts of the database are shown separately in Tables 3-1 and 3-2, which summarize the tests for the hydrostatic and shear consolidation groupings, respectively.

Table 3-1 lists 40 tests contained in the hydrostatic consolidation portion of the database. All of the testing was performed in a drained condition; i.e., the pore pressure was zero. The database discussed by Callahan et al. [1995] contained 45 tests. Five of the hydrostatic consolidation tests were eliminated from the database, as recommended by Callahan et al. [1995]. These tests were performed under saturated conditions and were not very well drained, which resulted in the generation of pore pressures with reduced deformation. The maximum and minimum principal stresses are listed under the columns titled σ_1 and σ_3. The principal stresses are equal for the hydrostatic case, but the formatting of the table has been maintained for both types of tests. The initial dry density of the specimens, the density at the beginning of the consolidation stage, and the final density at the end of the test are given under the respective column headings titled ρ_o, ρ_i, and ρ_f.

Table 3-2 lists the shear consolidation tests in the database and is formatted the same as Table 3-1. The table contains the 16 tests that were used in previous work and two additional tests that were conducted in parallel with the current work. As with the hydrostatic consolidation tests, all of the shear consolidation tests were performed in a drained condition.

The tests listed in Tables 3-1 and 3-2 represent 58 tests (40 hydrostatic consolidation tests and 18 shear consolidation tests) and comprise the entire database used for parameter estimation discussed in Chapter 4.0. The original data files often contained thousands of data points, which presented an impractical size for regression analyses. Each data file was reduced in size to create representative data sets containing only 100 data points with the first and last data points always being retained and the remaining data points uniformly sampled. This sampling technique is the same as was used in previous work. Tables 3-1 and 3-2 present the nominal or target test conditions for temperature and stress. The actual test conditions achieved are shown in Tables 3-3 and 3-4. The values for temperature and stress in these tables were determined by computing the time-weighted averages from the 100-point data files. As can be seen, the actual test conditions are moderately different than the targeted test conditions.

Table 3-1. Summary of Hydrostatic Test Conditions (Page 1 of 3)

Test I.D.	Test Type	T (K)	σ_1 (MPa)	σ_3 (MPa)	Mean Grain Size (mm)	Added Water (%)	Test Duration (days)	ρ_o (kg/m^3)	ρ_i (kg/m^3)	ρ_f (kg/m^3)	Source[(a)]
CS1	1	298	-1.72	-1.72	2.30	0	4.0	1,430	1,490	1,548	4
CS2	1	298	-1.72	-1.72	1.36	0	4.3	1,480	1,570	1,720	4
CS3	1	298	-1.72	-1.72	0.77	0	4.0	1,410	1,480	1,552	4
CS4	1	298	-1.72	-1.72	0.42	0	4.0	1,290	1,400	1,485	4
CS5	1	298	-1.72	-1.72	2.30	4.44	3.8	1,360	1,440	1,697	4
CS6	1	298	-1.72	-1.72	1.36	4.28	4.0	1,440	1,500	1,775	4
CS7	1	298	-1.72	-1.72	0.77	4.57	4.3	1,420	1,470	1,572	4
CS8	1	298	-1.72	-1.72	0.42	4.61	4.0	1,400	1,430	1,822	4
CS9	1	298	-1.72	-1.72	2.30	0	37.0	1,480	1,530	1,759	4
CS10	1	298	-3.45	-3.45	2.30	0	34.2	1,470	1,570	1,648	4
HC1A	1	298	-1.72	-1.72	1.56	Sat	28.8	1,462	1,539	1,921	1
HC2A	1	298	-1.72	-1.72	1.56	Sat	98.7	1,388	1,574	2,026	1
HC3A	1	298	-3.45	-3.45	1.56	Sat	49.9	1,448	1,550	2,042	1
HC4A	1	298	-3.45	-3.45	1.56	Sat	110.8	1,409	1,610	2,065	1
HC5A	1	298	-6.90	-6.90	1.56	Sat	53.0	1,496	1,741	2,124	1
HC6A	1	298	-6.90	-6.90	1.56	Sat	77.9	1,395	1,721	2,125	1
27JUL82	1	294	-1.72	-1.72	2.5	0	2.7	1,273	1,390	1,440	2

[(a)]1–Brodsky [1994], 2–Holcomb and Hannum [1982], 3–Holcomb and Shields [1987], and 4–Pfeifle and Senseny [1985]

Table 3-1. Summary of Hydrostatic Test Conditions (Page 2 of 3)

Test I.D.	Test Type	T (K)	σ_1 (MPa)	σ_3 (MPa)	Mean Grain Size (mm)	Added Water (%)	Test Duration (days)	ρ_o (kg/m^3)	ρ_i (kg/m^3)	ρ_f (kg/m^3)	Source[a]
04MAY82	1	313	-1.72	-1.72	2.5	0	2.8	1,396	1,563	1,621	2
30APR82	1	333	-1.72	-1.72	2.5	0	3.0	1,448	1,605	1,677	2
07MAY82	1	353	-1.72	-1.72	2.5	0	2.9	1,240	1,415	1,492	2
12MAY82	1	373	-1.72	-1.72	2.5	0	4.8	1,371	1,621	1,738	2
05FEB82	1	294	-3.44	-3.44	2.5	0	3.4	1,263	1,432	1,466	2
09APR82	1	313	-3.44	-3.44	2.5	0	3.0	1,330	1,495	1,561	2
26MAR82	1	333	-3.44	-3.44	2.5	0	3.9	1,242	1,393	1,451	2
02APR82	1	353	-3.44	-3.44	2.5	0	2.7	1,249	1,428	1,501	2
13APR82	1	373	-3.44	-3.44	2.5	0	2.8	1,240	1,424	1,522	2
29JAN82	1	294	-6.70	-6.70	2.5	0	3.2	1,279	1,506	1,557	2
26FEB82	1	294	-10.1	-10.1	2.5	0	3.1	1,256	1,538	1,601	2
27JU61	1	293	-0.69	-0.69	1.75	2.5	31.8	1,440	1,493	1,732	3
23JUL51	1	293	-1.72	-1.72	1.75	0.5	19.7	1,498	1,593	1,827	3
14NOV51	1	293	-1.72	-1.72	1.75	1.5	24.1	1,477	1,571	1,860	3
25FEB61	1	293	-1.72	-1.72	1.75	2.0	36.6	1,455	1,548	1,853	3
10MAY51	1	293	-1.72	-1.72	1.75	2.4	28.9	1,412	1,601	1,890	3

[a]1–Brodsky [1994], 2–Holcomb and Hannum [1982], 3–Holcomb and Shields [1987], and 4–Pfeifle and Senseny [1985]

Table 3-1. Summary of Hydrostatic Test Conditions (Page 3 of 3)

Test I.D.	Test Type	T (K)	σ_1 (MPa)	σ_3 (MPa)	Mean Grain Size (mm)	Added Water (%)	Test Duration (days)	ρ_o (kg/m^3)	ρ_i (kg/m^3)	ρ_f (kg/m^3)	Source[(a)]
20AUG51	1	293	-1.72	-1.72	1.75	3.0	20.0	1,348	1,516	1,821	3
16JUL51	1	293	-3.44	-3.44	1.75	0.5	20.6	1,391	1,608	1,920	3
18JUL51	1	293	-3.44	-3.44	1.75	1.0	21.6	1,455	1,668	1,930	3
30OCT51	1	293	-3.44	-3.44	1.75	1.5	13.8	1,477	1,648	1,930	3
16JAN61	1	293	-3.44	-3.44	1.75	2.0	27.9	1,489	1,640	1,950	3
19DEC44	1	293	-3.44	-3.44	1.75	2.4	52.1	1,434	1,566	1,899	3
13AUG51	1	293	-3.44	-3.44	1.75	3.0	21.7	1,370	1,586	1,899	3

[(a)] 1–Brodsky [1994], 2–Holcomb and Hannum [1982], 3–Holcomb and Shields [1987], and 4–Pfeifle and Senseny [1985]

Table 3-2. Summary of Shear Consolidation Test Conditions

Test I.D.	Test Type	T (K)	σ_1 (MPa)	σ_3 (MPa)	Mean Grain Size (mm)	Added Water (%)	Test Duration (days)	ρ_o (kg/m^3)	ρ_i (kg/m^3)	ρ_f (kg/m^3)	Source[a]
SC1B	2	298	-3.45	-4.14	1.56	2.34	62.9	1,449	1,574	2,009	1
SC2A	2	298	-3.45	-4.83	1.56	2.25	61.9	1,479	1,608	2,014	1
SC3A	2	298	-3.45	-5.52	1.56	2.21	61.7	1,448	1,575	2,005	1
SC4A	2	298	-6.90	-7.59	1.56	2.27	60.9	1,428	1,607	2,007	1
SC5A	2	298	-6.90	-8.97	1.56	2.52	61.4	1,522	1,764	2,135	1
SC6A	2	298	-6.90	-10.34	1.56	2.19	67.9	1,375	1,701	2,053	1
SC7A	2	298	-5.17	-6.55	1.56	2.33	66.0	1,455	1,665	2,091	1
SC8A	2	298	-5.17	-7.93	1.56	2.29	60.8	1,423	1,611	2,000	1
SC9B	2	298	-5.17	-9.31	1.56	2.33	60.9	1,415	1,683	2,080	1
SC10	2	298	-1.00	-6.00	1.56	0	28.1	1,531	1,808	1,819	1
SC11	2	298	-1.00	-6.00	1.56	0	17.0	1,483	1,688	1,724	1
120C891	2	298	-3.26	-3.70	2.00	2.40	33.8	1,284	1,516	1,805	3
RS/DCCS/1	2	298	-1.00	-5.00	0.5[b]	1.66	6.2	1,953	2,000	2,035	2
RS/DCCS/3	2	298	-2.00	-6.00	0.5[b]	1.63	37.1	1,954	1,964	2,087	2
RS/DCCS/4	2	298	-3.00	-7.00	0.5[b]	1.59	57.0	1,953	2,011	2,139	2
RS/DCCS/5	2	298	-4.00	-8.00	0.5[b]	1.55	59.1	1,939	1,953	2,093	2
RS/DCCS/10	2	298	-5.00	-9.00	0.5[b]	1.49	47.0	1,958	1,981	2,146	2
RS/DCCS/15	2	298	-1.00	-5.00	0.5[b]	1.77	5.9	1,946	1,960	2,042	2

(a) 1–Brodsky [1994], 2–Mellegard et al. [1999], and 3–Zeuch et al. [1991].

(b) Grain size was assumed to be 0.5 because dynamic compaction reduces grain sizes.

Table 3-3. Time-Weighted Average Test Conditions for the Hydrostatic Consolidation Tests (Page 1 of 2)

Test	Datapoint in File comb.dat	Temp. (K)	Axial Stress (MPa)	Lateral Stress (MPa)
CS1	1 through 100	298	–1.70	–1.70
CS2	101 through 200	298	–1.70	–1.70
CS3	201 through 300	298	–1.70	–1.70
CS4	301 through 400	298	–1.72	–1.72
CS5	401 through 500	298	–1.67	–1.67
CS6	501 through 600	298	–1.70	–1.70
CS7	601 through 700	298	–1.70	–1.70
CS8	701 through 800	298	–1.70	–1.70
CS9	801 through 900	298	–1.73	–1.73
CS10	901 through 1000	298	–3.41	–3.41
HC1A	1001 through 1100	298	–1.72	–1.72
HC2A	1101 through 1200	298	–1.72	–1.72
HC3A	1201 through 1300	298	–3.45	–3.45
HC4A	1301 through 1400	298	–3.46	–3.46
HC5A	1401 through 1500	298	–6.91	–6.91
HC6A	1501 through 1600	298	–6.88	–6.88
27JUL82	1601 through 1700	294	–1.69	–1.69
04MAY82	1701 through 1800	313	–1.72	–1.72
30APR82	1801 through 1900	333	–1.74	–1.74
07MAY82	1901 through 2000	353	–1.76	–1.76
12MAY82	2001 through 2100	373	–1.77	–1.77
05FEB82	2101 through 2200	294	–3.44	–3.44
09APR82	2201 through 2300	313	–3.49	–3.49
26MAR82	2301 through 2400	333	–3.44	–3.44
02APR82	2401 through 2500	353	–3.36	–3.36
13APR82	2501 through 2600	373	–3.39	–3.39
29JAN82	2601 through 2700	294	–6.67	–6.67
26FEB82	2701 through 2800	294	–9.53	–9.53
27JU61	2801 through 2900	297	–0.70	–0.70
23JL51	2901 through 3000	293	–1.81	–1.81
14NV51	3001 through 3100	293	–1.73	–1.73
25FE61	3101 through 3200	293	–1.74	–1.74

Table 3-3. Time-Weighted Average Test Conditions for the Hydrostatic Consolidation Tests (Page 2 of 2)

Test	Datapoint in File comb.dat	Temp. (K)	Axial Stress (MPa)	Lateral Stress (MPa)
10MY51	3201 through 3300	293	–1.74	–1.74
20AU51	3301 through 3400	293	–1.74	–1.74
16JL51	3401 through 3500	293	–3.46	–3.46
18JU51	3501 through 3600	293	–3.47	–3.47
30OC51	3601 through 3700	296	–3.50	–3.50
16JA61	3701 through 3800	295	–3.41	–3.41
19DC44	3801 through 3900	293	–3.44	–3.44
13AU51	3901 through 4000	293	–3.47	–3.47

3.2 DESCRIPTION OF RECENT LABORATORY TESTS

Since the status of the crushed-salt constitutive model was reported by Callahan et al. [1998b] and Hansen et al. [1998], five additional laboratory tests have been completed and are included in the present work. Two of these tests are shear consolidation tests; three of the tests are constant strain-rate tests. These tests have been reported separately by Mellegard et al. [1999]. The shear consolidation tests are included in the crushed-salt database used to determine parameter values for the constitutive model and will be summarized here. The constant strain-rate tests are used to verify the constitutive model and are discussed in chapter 5.0.

The two shear consolidation creep tests were performed on dynamically compacted crushed-salt specimens that were fabricated with a laboratory-scale device following a procedure similar to that used for dynamic compaction of large-scale samples [Hansen and Ahrens, 1998]. This device simulated of the compaction technique envisioned for the shaft sealing design. The laboratory-scale device used two Proctor split compaction molds (American Society for Testing and Materials [1991a, 1991b]) to receive the disaggregated salt. After compaction, the molds were removed and the ends of the cylindrical samples were machined to produce testable specimens with nominal dimensions of 100 millimeters in diameter and 200 millimeters in length. The starting material was wetted with a brine so that the specimen moisture content was nominally 1.6 % by weight. The dry density of the specimens was about 1,950 kg/m^3, which is a fractional density of approximately 0.9 (assuming intact salt density of 2,160 kg/m^3). The energy input to create this density was approximately 2.6 times the modified Proctor energy (American Society for Testing and Materials [1991a, 1991b]). The specimens fabricated with the laboratory-scale device were identified with the unique labels, RS/DCCS/*n*, where *n* took on values of 10 and 15 to designate individual specimens. As shown in Table 3-2, four other shear consolidation tests on dynamically compacted crushed salt were performed previously.

Table 3-4. Time-Weighted Average Test Conditions for the Shear Consolidation Tests

Test	Datapoint in File shear.dat	Temp. (K)	Axial Stress (MPa)	Lateral Stress (MPa)
SC1B	1 through 100	298	–4.15	–3.45
SC2A	101 through 200	298	–4.82	–3.46
SC3A	201 through 300	298	–5.52	–3.45
SC4A	301 through 400	298	–7.58	–6.90
SC5A	401 through 500	298	–8.97	–6.92
SC6A	501 through 600	298	–10.33	–6.91
SC7A	601 through 700	298	–6.54	–5.17
SC8A	701 through 800	298	–7.92	–5.17
SC9A	801 through 900	298	–9.33	–5.17
SC10	901 through 1000	298	–6.01	–1.01
SC11	1001 through 1100	298	–6.00	–1.02
12OC891	1101 through 1200	293	–3.70	–3.26
RS/DCCS/1	1201 through 1300	297	–4.95	–1.01
RS/DCCS/3	1301 through 1400	297	–5.98	–2.00
RS/DCCS/4	1401 through 1500	297	–6.99	–3.00
RS/DCCS/5	1501 through 1600	298	–7.99	–4.00
RS/DCCS/10	1601 through 1700	297	–9.01	–5.00
RS/DCCS/15	1701 through 1800	298	–5.00	–1.01

The two shear consolidation tests were effectively standard triaxial compression creep tests ($\psi = \pi/6$) and typical test procedures have been described previously [Callahan et al., 1995; Brodsky, 1994]. The specimens were initially loaded hydrostatically to the level of specified confining pressure (lateral stress) and allowed to stabilize. The specified confining pressure levels for the two tests were –5 and –1 MPa. Data were collected during the hydrostatic loading phase. Following stabilization, the axial compressive stress for each test was increased by 4 MPa while holding the confining pressure constant so that each specimen was subjected to a stress difference of $\Delta\sigma = 4$ MPa; only the confining pressure was different for the two tests. Data were also acquired when the axial stress difference was applied. After the axial stress difference was imposed, it was held constant while data were acquired during the shear consolidation creep phase. The test matrix for the shear consolidation creep tests is shown in Table 3-5 where the first column contains the specimen identification and the following three columns give the axial stress, lateral stress, and temperature, respectively, based on the time-weighted average of the actual laboratory data. Both tests were performed in a drained condition; i.e., the pore pressure was zero.

Table 3-5. Shear Consolidation Creep Test Matrix

Specimen Identification	Test Conditions		
	Axial Stress (MPa)	Lateral Stress (MPa)	Temperature (°C)
RS/DCCS/10	–9.01	–5.00	24
RS/DCCS/15	–5.00	–1.01	25

Earlier analyses (based on the constitutive model) predicted that a stress state existed where the lateral strain rate would initially be negative (compaction) and then reverse direction and become positive as the specimen density increased. The scheme for finding this stress state was to change the mean stress by testing at different confining pressures while holding the axial stress difference constant, as reported by Hansen et al. [1998]. The four tests completed previously (see Table 3-2) were run at confining pressures of –1, –2, –3, and –4 MPa all with a stress difference of 4 MPa. Thus, Test RS/DCCS/10 is simply the next test in that progression; whereas, Test RS/DCCS/15 is a repeat of the first test. The creep strain results from the two tests are compared in Figure 3-1, which plots axial and lateral creep strains as a function of time.

A very significant phenomenon is observed in Test RS/DCCS/10: *the lateral strain rate was initially negative (specimen diameter decreasing) and after some densification of the specimen, the lateral strain rate decreased and ultimately changed sign and became positive (specimen diameter increasing)*. This observation is important to the work presented in Chapter 4.0, where the parameters of the crushed-salt constitutive model are determined. As stated earlier, this behavior is known to exist because as crushed salt consolidates and approaches full consolidation, its behavior has to become similar to that of intact salt. However, to be able to accurately capture this behavior in a constitutive model, the phenomenon must be included in the database so that the fitted parameter values capture the full range of material behavior.

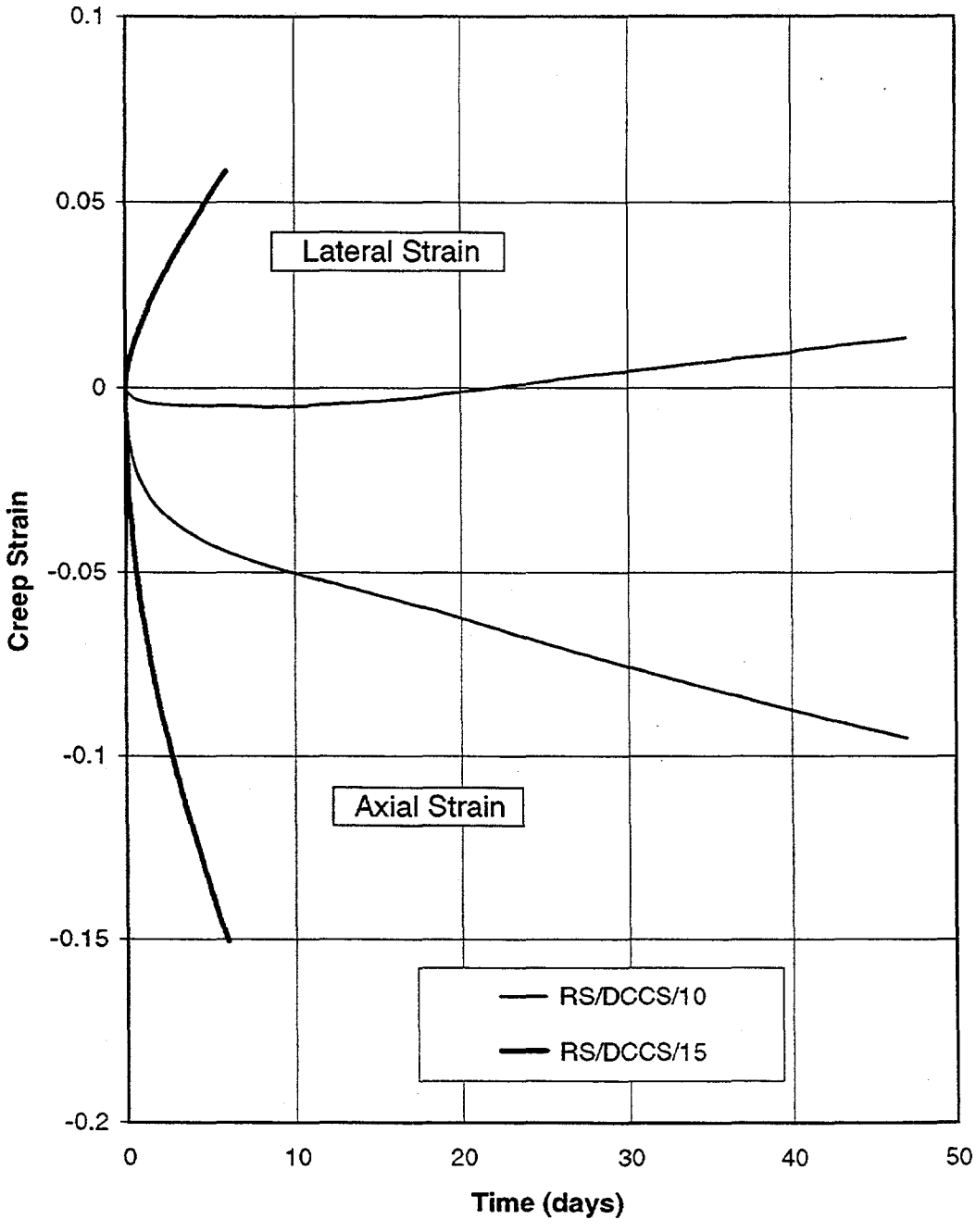

Figure 3-1. Axial and lateral strain as a function of time for two, shear consolidation creep tests on dynamically compacted crushed salt.

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4.0 MODEL FITTING

4.1 INTRODUCTION

The crushed-salt constitutive model given in Equation 2-38 contains 31 material parameters. Seventeen of these material parameters are contained in the dislocation creep (M-D) portion of the model. The M-D model parameters were fixed at the values provided by Munson et al. [1989] for clean salt. The pressure solution portion of the model contains seven material parameters, and the remaining seven material parameters comprise four flow potential material parameters and three equivalent stress measure parameters. These 14 remaining parameters were determined by fitting the equations that define the crushed-salt constitutive model to the laboratory data such that the weighted squared difference between the measured and calculated response was minimized. First, the flow potential parameters (κ_0, κ_1, n, and D_t) were determined by fitting Equation 2-18, which defines the lateral-to-axial strain-rate ratio, to the data measured in the 18 shear consolidation tests. Second, these flow rate parameters were fixed and the ten creep consolidation parameters (η_0, η_1 , n_f, a, p, n_s, r_1, r_3, r_4, and Q_s/R) were determined by fitting the rate equations that define the axial and lateral strains to the data measured in the 18 shear consolidation and 40 hydrostatic consolidation tests. These nonlinear regressions were performed using the personal-computer platform BioMedical Data Processing (BMDP, Version 7.01) statistical software package.

4.2 MODELING PROCEDURE

The *object function* is the mathematical function that is to be minimized in the least-squares sense. For example, when performing a least-squares fit of some data to a straight line, the object function is the squared difference between the measured response (the data) and the predicted response from the equation for the straight line. The equation for the straight line when performing linear regression is called the *response model.*

The object function is evaluated at discrete points. These points are the points where data have been taken or are available. Some of the measurements may be more important than others and should hold more importance or *weight* than other data points. Mathematically, the relative importance of the level of fit to each data point is accommodated through a *weighting function.*

Application of least-squares minimization results in an estimation of the parameters of the response model. In the example cited above, application of least-squares will result in the estimation of the two parameters necessary to specify a straight line under the implicit assump-

tion that the measurements will be distributed about the response model for fixed values of the (hopefully) independent parameters. For complex nonlinear models, the independence of the parameters is not always obvious before fitting. The parameters obtained from a least-squares fit to a nonlinear model may not be appropriate if the parameters are highly correlated.

The response model will almost never reproduce all of the measurements exactly. The difference between the measured data points and the predicted model response is termed the *residual*. When a weighting function is used in the model fitting, the weighted residual is also of interest. The weighted residual is the usual residual multiplied by the weighting function value for the specific observation or data point.

The object function for the crushed-salt constitutive model was developed under the following assumptions and reflects the relative importance associated to individual data points:

- Within a given test, there are an equal number of measurement points (100). Each data point was assumed to have equal weight.
- Within each test, the data are not uniformly distributed with respect to time; the data are more dense early in time when the strain rates are highest. Thus, the weight function that was used in the model fitting reflects the time-step size relative to each data point in each test, such that higher weights are assigned to data points at the end of the test than are assigned to early-time data points.
- Tests of longer duration were assumed to be more important than tests of shorter time duration.
- Residuals were normalized. They are represented as percent deviations from the measured data. Thus, a 10-% deviation from a very small strain results in the same error in the object function as a 10-% deviation from a very large strain.

4.2.1 Response Functions

In the shear consolidation tests, there are two independent measurements (superscript m is used to indicate measurements); namely, the volumetric strain $\left(\epsilon_v^m\right)$ and the axial strain $\left(\epsilon_a^m\right)$. The lateral strain $\left(\epsilon_l^m\right)$ is calculated as:

$$\epsilon_l^m = \frac{\epsilon_v^m - \epsilon_a^m}{2} \tag{4-1}$$

The axial strain rate $\left(\dot{\epsilon}_a^m\right)$ was calculated from the measurement of axial strain and elapsed time as follows. At every data point in the original test data file (some contained thousands of data points), the axial strain rate was calculated as the linear least-square fit to a small interval of data (window) centered on the point in time. The window was then shifted by one data point to

the next point in time and the linear fit was repeated. This process was repeated until a point was reached where the width of the window reached the end of the data file for each test. A 50-point window was used in this process. The lateral strain rate $\left(\dot{\epsilon}_l^m\right)$ was calculated in a similar fashion. The measured lateral-to-axial strain-rate ratio $(\mathbb{R}^m)$ is defined as (cf. Equations 2-17 and 2-18):

$$\mathbb{R}^m = \frac{\dot{\epsilon}_l^m}{\dot{\epsilon}_a^m} \tag{4-2}$$

Following the development in Chapter 2.0, the response function used to determine the flow potential parameters is:

$$\mathbb{R}^p = \frac{\alpha + \frac{\beta}{2}}{\alpha - \beta} \tag{4-3}$$

where:

$\mathbb{R}^p$ = predicted lateral-to-axial strain-rate ratio

$$\alpha = \frac{\kappa_0 \, \Omega^{\kappa_1} \, \sigma_m}{3}$$

$$\beta = \left(\frac{2 - D}{D}\right)^{\frac{2n}{n+1}} \left(\sigma_1 - \sigma_3\right)$$

$$\Omega = \left\{\frac{\left(1 - D_v\right)n}{\left[1 - \left(1 - D_v\right)^{1/n}\right]^n}\right\}^{\frac{2}{n+1}}$$

$$D_v = \begin{cases} D_t & D \le D_t \\ D & D > D_t \end{cases}$$

D = current fractional density

σ_m = mean stress = $(\sigma_3 + 2\sigma_1)/3$

σ_3 = minimum principal stress

σ_1 = maximum principal stress

and

κ_0, κ_1, n, and D_t = flow potential parameters.

The response function (λ) used to determine the creep consolidation parameters is:

$$\lambda = 1 - \left\{\left[(1 - R_1)^2 + (1 - R_2)^2\right] wt\right\}^{1/2} \tag{4-4}$$

where:

$R_1 = \epsilon_a^p / \epsilon_a^m$

$R_2 = \epsilon_l^p / \epsilon_l^m$

$wt = \Delta t / \bar{t}$ = weighting function

Δt = time-step size

$\bar{t}$ = normalizing time = 10^6(s)

ϵ_l^p = predicted lateral strain = $\int_o^t \dot{\epsilon}_l^p \, dt$

ϵ_a^p = predicted axial strain = $\int_o^t \dot{\epsilon}_a^p \, dt$

$\dot{\epsilon}_l^p$ = predicted lateral strain rate = $(\alpha + \beta/2) \dfrac{\dot{\epsilon}_{eq}}{\sigma_{eq}}$

$\dot{\epsilon}_a^p$ = predicted axial strain rate = $(\alpha - \beta) \dfrac{\dot{\epsilon}_{eq}}{\sigma_{eq}}$

$\dot{\epsilon}_{eq}$ = equivalent inelastic strain rate = $\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w$

σ_{eq} = equivalent stress measure = $\left[\kappa_o \, \Omega^{\kappa_1} \, \sigma_m^2 + \left(\dfrac{2 - D}{D}\right)^{\frac{2n}{n+1}} (\sigma_1 - \sigma_3)^2\right]^{1/2}$

$\dot{\epsilon}_{eq}^d$ = Munson-Dawson dislocation creep strain-rate model given in Equations 2-20 to 2-29

$\dot{\epsilon}_{eq}^w$ = Spiers pressure-solution inelastic strain-rate model given in Equations 2-36 and 2-37

and:

η_0, η_1, n_f, a, p, n_s,
r_1, r_3, r_4, and Q_s/R = creep consolidation parameters.

The Munson-Dawson dislocation creep model has 17 parameters, which are given in Table 4-1 for clean WIPP salt.

Table 4-1. M-D Model Parameter Values for Clean Salt

Parameter	Units	Clean Salt
A_1	yr^{-1}	$2.645 \cdot 10^{30}$
	s^{-1}	$8.386 \cdot 10^{22}$
A_2	yr^{-1}	$3.050 \cdot 10^{20}$
	s^{-1}	$9.672 \cdot 10^{12}$
Q_1/R	K	12,581
Q_1	cal/mol	25,000
Q_2/R	K	5,033
Q_2	cal/mol	10,000
n_1	—	5.5
n_2	—	5.0
B_1	yr^{-1}	$1.919 \cdot 10^{14}$
	s^{-1}	$6.0856 \cdot 10^{6}$
B_2	yr^{-1}	$9.568 \cdot 10^{5}$
	s^{-1}	$3.034 \cdot 10^{-2}$
q	—	5,335
σ_o	MPa	20.57
μ	MPa	12,400
m	—	3.0
K_o	—	$6.275 \cdot 10^{5}$
c	K^{-1}	$9.198 \cdot 10^{-3}$
α	—	–17.37
β	—	–7.738
δ	—	0.58

4.2.2 Object Function

The object function is the sum-of-squared errors (SS_E). In determining the flow rate parameters, the sum-of-squared error is defined as:

$$SS_E = \sum_{i=1}^{N} \left(\mathbb{R}_i^p - \mathbb{R}_i^m \right)^2 \tag{4-5}$$

where:

R_i^p = predicted lateral-to-axial strain rate ratio for the ith data point (Equation 4-3)

R_i^m = measured lateral-to-axial strain rate ratio for the ith data point (Equation 4-2)

N = number of data points in test database.

To determine the creep consolidation parameters, the sum-of-squared error is defined as:

$$SS_E = \sum_{i=1}^{N} \left(1 - \lambda_i \right)^2 \tag{4-6}$$

where:

λ_i = response function defined in Equation 4-4 for the ith data point.

4.3 STATISTICAL MEASURES

One key aspect of the model-fitting effort is deciding if the model fit to one database is better than the fit to the other database. In this section, the statistical measures for evaluating and comparing fits to the crushed-salt constitutive model are discussed.

4.3.1 Weighted Residual

In all types of regression, the summation of weighted, squared residuals is the function that is minimized, where the residual is defined as the difference between the observed and predicted functional values. The sum-of-squared error term defined in Equation 4-6 was used in evaluating the model fits to two databases: (1) the shear consolidation tests only and (2) the combined shear and hydrostatic consolidation tests.

The specific weighting function associated with the sum-of-squared error is equal to the reciprocal of the measured axial strain squared $\left(\epsilon_a^m\right)^2$, the reciprocal of the measured lateral strain squared $\left(\epsilon_l^m\right)^2$, the time increment (Δt), and the reciprocal of a normalizing time $(10^6\ s)$. Thus, if the response model (Equation 4-4) predicts zero axial strain and zero lateral strain over the duration of all tests in the database, the term SS_E in Equation 4-6 will have a value of twice the number of million seconds in the database. This is termed the maximum value of the sum-of-squared error $\left(SS_E^{max}\right)$. The 40 hydrostatic consolidation tests constitute a total of $76.02(10^6)\ s$. The 18 shear consolidation tests total $73.93(10^6)\ s$. Therefore, $SS_E^{max} = 147.86$ in the fit to the shear tests, and $SS_E^{max} = 299.90$ in the fit to the combined test database.

In a similar fashion, if the response model is a perfect predictor for all of the tests in the database, the sum-of-squared error will be exactly zero. This is the minimum value of the sum-of-squared error.

For each model fit, the sum-of-squared error was normalized as follows:

$$0 \le \overline{SS_E} \le 1 \tag{4-7}$$

where:

$$\overline{SS_E} = SS_E / SS_E^{max}$$

The normalized sum-of-squared error is used to compare the model fits to the two databases.

4.3.2 Parameter Multicollinearity

When fitting a mathematical relation to a set of laboratory-measured data, it is desirable to have enough information in the measured database to ensure that each of the parameters can be uniquely determined. Two possibilities can occur that will not allow for a unique determination of each parameter in a mathematical relation. First, the mathematical relation may inherently include parameters that are dependent upon one another. For example, in the relation:

$$F = A + B \tag{4-8}$$

the parameters A and B cannot be determined uniquely.

Second, there may not be sufficient data in the database to uniquely determine the magnitude of certain model parameters. For example, there is minimal variation in grain size (d), moisture content (w), and temperature (T) in the shear consolidation tests ($\Delta\sigma \neq 0$). Thus, in fitting the crushed-salt constitutive model to these tests, the parameters p, a, and Q_s/R contained in the product of the functional forms containing them; i.e.,

$$\xi(d,w,T) = \frac{w^{a}}{d^{p}T} \exp\left(-Q_s/RT\right) \tag{4-9}$$

cannot be uniquely determined.

When either of the two aforementioned conditions exist, a condition of multicollinearity is said to exist [Montgomery and Peck, 1982]. An examination of the parameter covariance matrix illustrates the degree to which the material parameters are correlated to each other. The higher the parameter covariance, the higher the parameter collinearity. When a multicollinearity situation exists, one must (1) expand the database of measurements or (2) modify the functional form of the model.

The elements of the correlation matrix (C_{ij}) can be expressed as [Montgomery and Peck, 1982]:

$$C_{ij} = \frac{q_{ij}}{\sqrt{q_{ii}\, q_{jj}}} \tag{4-10}$$

where:

$q_{ij} = \left[z_{ip}\ z_{pj}\right]^{-1}$

$z_{ij} = \dfrac{\partial\ \epsilon^{m}\left(x_j, \overline{p}\right)}{\partial p_i}$

$\overline{p}$ = set of parameters taken at their mean values

p_i = i^{th} parameter

x_j = j^{th} model variable

ϵ^{m} = measured response.

If the parameters are uncorrelated, then $C_{ij} = 0$. Conversely, the correlation coefficient is one if the parameters are totally correlated. The parameters are highly correlated if $|C_{ij}| \geq 0.90$ and a state of parameter multicollinearity may exist.

A scalar quantity, termed the parameter correlation measure (pcm), was used in this study as a global measure of the parameter correlations associated with each model's fit to each database.

This measure is defined as:

$$\text{pcm} = \frac{\frac{1}{2}\left(\sum_{i=1}^{p}\sum_{j=1}^{p} C_{ij}^2 - p\right)}{\sum_{i=1}^{p-1} i} = \frac{2\sum_{i=2}^{p}\sum_{j=1}^{i-1} C_{ij}^2}{p^2 - p} \tag{4-11}$$

where p is the number of parameters in the model and $0 \leq \text{pcm} \leq 1$. The numerator in Equation 4-11 is the sum of the squares of the lower triangular components of the parameter correlation matrix (Equation 4-10), and the denominator simply normalizes the result by the number of components in the sum. Obviously, the lower the parameter correlations, the lower the magnitude of the parameter correlation measure. Finally, an average parameter correlation $(\bar{c})$ can be quantified as:

$$\bar{c} = \sqrt{pcm} \tag{4-12}$$

4.3.3 Parameter Variation Among Fits

The crushed-salt constitutive model was fit to two databases: (1) the shear consolidation tests only and (2) the combination of shear and hydrostatic consolidation tests. If a specific model is the true constitutive law for representing the consolidation of crushed salt, the material parameters in each of the different fits should be the same or nearly the same. To evaluate the parameter variation obtained in the fits, the ratio of the parameter values obtained in the two fits (combined database parameter values divided by shear database parameter values) are examined. If the parameter values change less than the one order of magnitude, the resulting ratio should be between 0.1 and 10.

4.3.4 Predictive Capability

The aptness of the crushed-salt constitutive model (predictive capability) can be demonstrated using the parameter values determined by fitting to the individual test databases. The material parameters determined in the fit to the shear consolidation tests were used to predict each of the hydrostatic consolidation tests. A quantitative measure of the predictive capability is simply the sum-of-squared error (Equations 4-5 and 4-6). This measure was calculated using the

BMDP Program AR (Section 4.4) by fixing the parameter values at those determined in the fit to the shear consolidation tests and fitting (predicting) the hydrostatic consolidation tests.

4.4 BMDP STATISTICAL SOFTWARE

This section describes the BioMedical Data Processing (BMDP) nonlinear regression Programs 3R and AR used in the model fitting. BMDP is a statistical software package developed at the University of California at Berkeley supported by grants from the Biotechnology Resources Branch of the National Institutes of Health and the National Science Foundation.

BMDP Program AR is a nonlinear regression program that estimates the parameters of a nonlinear function by least squares using a pseudo Gauss-Newton algorithm. The response model can be specified as a system of coupled rate equations. The response model derivatives are evaluated numerically based on the initial parameter estimates and are not updated during the regression. In addition to calculating the weighted sum-of-squared error (SS_E), the program calculates the coefficient of multiple determination (R_p^2), the residual mean-squared error (MS_E), and the coefficients of the parameter correlation matrix (C_{ij}). The various program features and supporting documentation of AR are provided in various BMDP technical reports. AR was used in determining the creep consolidation parameters.

BMDP Program 3R is identical to AR with the following exceptions: (1) the model function cannot be expressed as a system of coupled rate equations and (2) the response model derivatives are updated continuously during the regression. 3R was used to determine the flow potential parameters.

The input files required to execute an AR or 3R analysis are described in detail by Dixon et al. [1985] and in the BMDP Users' Digest [Hill, 1984]. The BMDP input files for the model fits are given in Appendix A.

4.5 RESULTS

This section presents the results of the model fits. The results are discussed in terms of the model parameters and the statistical measures defined in Section 4.3.

The crushed-salt constitutive model contains a total of 14 fitted parameters. Four of these parameters are termed the flow potential parameters (κ_0, κ_1, n, and D_v). These parameters were determined by fitting the crushed-salt constitutive model to the lateral-to-axial strain-rate ratios measured in the 18 shear consolidation tests. The remaining 10 parameters in the crushed-salt constitutive model are termed the creep consolidation parameters (η_0, η_1, n_f, a, p, n_s, r_1, r_3, r_4, and Q_s/R). Two sets of creep consolidation parameters were determined; namely, one set each resulting from fits to a database composed of 18 shear consolidation tests and to a combined database composed of the 18 shear and 40 hydrostatic consolidation tests. The parameters were determined by fitting the crushed-salt constitutive model to the axial and lateral strains measured

in each of the tests. The parameters η_0, η_1, and n_f define the stress measure σ_{eq}^f (Equation 2-3). Moisture dependence, grain-size dependence, and temperature dependence are defined by the parameters a, p, and Q_s/R, respectively (Equations 2-34 and 2-36). The remaining parameters (r_1, r_3, and r_4) are for the pressure-solutioning portion of the model (Equations 2-36 and 2-37).

4.5.1 Flow Potential Parameters

The flow potential parameters are given in Table 4-2. Plots of the predicted and measured lateral-to-axial strain-rate ratios as a function of density for each of the 18 shear consolidation tests are given in Appendix B.

Table 4-2. Flow Potential Parameters

Parameter	Magnitude	Units
κ_0	10.119	—
κ_1	1.005	—
n	1.331	—
D_t	0.896	—

4.5.2 Creep Consolidation Parameters

The creep consolidation parameters for each of the two model fits are given in Table 4-3. Plots of the predicted and measured lateral and axial strains for each of the 18 shear consolidation tests and 40 hydrostatic consolidation tests are given in Appendix C.

Table 4-3. Creep Consolidation Parameters (Page 1 of 2)

Parameter	Units	Shear Tests	Combined Tests
η_0	—	0.1029	0.0140
η_1	—	3.9387	3.3881
n_f	—	3.5122	3.9660
a	—	0.3147	$1.0(10^{-5})$
p	—	1.6332	1.0341

Table 4-3. Creep Consolidation Parameters (Page 2 of 2)

Parameter	Units	Shear Tests	Combined Tests
n_s	—	0.5576	1.5318
r_1	m^p·K/(MPa·s)	$1.041(10^{-6})$	$2.663(10^{-5})$
r_1^*	K/(MPa·s)	0.0194	0.3369
r_3	—	15.1281	0.1286
r_4	—	0.1678	0.1680
Q_s/R	K	1,077.46	2,897.08

r_1^* assumes grain size (d) = 1 mm and moisture content (w) = 1 %.

4.6 STATISTICAL MEASURES

4.6.1 Sum-of-Squared Error

The sum-of-squared error (SS_E) was calculated using Equation 4-6 for each of the model fits to the shear test database and the combined test database. Using these results and Equation 4-7, the normalized sum-of-squared error ($\overline{SS}_E$) was calculated for each of the model fits. These results are given in Table 4-4.

Table 4-4. Sum-of-Squared Error, SS_E

Test Database	SS_E	$\overline{SS}_E$
Shear	23.52	0.159
Combined	46.76	0.156

These results indicate that the model fit to the two databases are qualitatively about the same; i.e., about 16-% relative error.

4.6.2 Parameter Multicollinearity

The parameter correlation coefficient matrices for each of the model fits to the two databases are given in Tables 4-5 and 4-6. High parameter correlations ($>|\pm 0.9|$) are indicative of possible parameter multicollinearity. As pointed out in Section 4.3.2, high parameter correlations are indicative of either (1) deficiencies in the functional form of the crushed-salt constitutive model or (2) deficiencies (or gaps) in the test database.

In general, most of the parameter correlations are low ($<|\pm 0.9|$) for both fits. However, three sets of parameters in the fit to the shear test database ($a - p$, $r_3 - Q_s/R$, and $r_4 - Q_s/R$) and one set of parameters in the fit to the combined test database ($n_f - \eta_1$) have correlation coefficients greater than $|\pm 0.90|$. As discussed in Section 4.3.2, the shear test database parameter correlations were expected (cf. Equation 4-9).

The parameter correlation measure (pcm) and the average correlation coefficient ($\overline{c}$) were evaluated using Equations 4-11 and 4-12, respectively. These results are given in Table 4-7 for each of the model fits.

These results indicate that the parameters are slightly less correlated in the fit to the combined test database. However, the average correlation coefficient is less than $|\pm 0.5|$ in both fits, which indicates that the possibility of parameter multicollinearity is low.

4.6.3 Parameter Variation Among Fits

A quantitative measure of the parameter variation between the crushed-salt constitutive model fits to the two databases is defined in Section 4.3.3. The ratio simply indicates the magnitude of the change in each of the parameter values between the fits to the combined test database and the shear consolidation test database. The ratios of the parameter values from the two fits are given in Table 4-8. As can be seen in the table, parameters a, r_1, and r_3 varied by more than one order of magnitude (i.e., parameter ratio <0.1 or >10). This is a significant improvement over earlier work (e.g., Callahan et al. [1995]) where the parameter values were seen to change by several orders of magnitude between the different database fits. Qualitatively, the parameters did not change appreciably overall in the two model fits.

Table 4-5. Parameter Correlation Coefficient Matrix — Model Fit to Shear Consolidation Tests

	η_0	η_1	η_f	a	p	n_s	r_1	r_3	r_4	Q_s/R
η_0	1.0									
η_1	0.1454	1.0								
η_f	–0.8584	–0.6289	1.0							
a	0.0063	0.1278	–0.0724	1.0						
p	–0.0036	–0.0525	0.0295	0.9199	1.0					
n_s	0.0542	0.5542	–0.3274	0.4195	0.1507	1.0				
r_1	–0.0096	0.0100	0.0026	–0.0027	0.0051	–0.1039	1.0			
r_3	–0.0481	–0.1704	0.1242	0.1430	0.3079	–0.6258	0.1888	1.0		
r_4	0.0476	–0.1819	0.0535	–0.2545	–0.2196	0.1028	–0.1882	–0.7864	1.0	
Q_s/R	0.0451	–0.0605	–0.0051	–0.0731	–0.1263	0.3782	–0.1892	–0.9115	0.9516	1.0

Table 4-6. Parameter Correlation Coefficient Matrix — Model Fit to Combined Test Database

	η_0	η_1	η_f	a	p	n_s	r_1	r_3	r_4	Q_s/R
η_0	1.0									
η_1	–0.3350	1.0								
η_f	0.0103	–0.9388	1.0							
a	0.0532	0.2820	–0.3276	1.0						
p	0.3415	–0.5970	0.5266	–0.1563	1.0					
n_s	–0.2313	0.3124	–0.2501	0.1854	–0.0169	1.0				
r_1	–0.0742	0.0442	–0.0207	–0.0070	–0.0174	–0.0906	1.0			
r_3	0.2468	–0.4138	0.3495	–0.2035	0.3888	–0.8495	0.2795	1.0		
r_4	0.4188	–0.3070	0.1607	–0.4692	0.3324	–0.3722	–0.4033	0.3078	1.0	
Q_s/R	0.1698	0.0489	–0.1124	–0.0133	–0.2102	0.2801	–0.0826	–0.5790	0.2697	1.0

The value for the exponent on moisture content, a, given in Table 4-3 for the combined database fit is 10^{-5}, which is the smallest value allowed during the fitting process. During the fitting, the value of a was driven to zero. In other words, the moisture function was driven to act like a Heaviside function turning the pressure solution portion of the model on and off, depending on whether or not moisture was present. However, when moisture content is zero (i.e., $w = 0$) and the exponent is zero, an indeterminate form is created. Thus, the value of the exponent a was limited to the small number to avoid the indeterminate form. Thus, the same conclusion is arrived at as discussed by Hansen et al. [1998] — no improvement in goodness of fit could be achieved by accounting for moisture variation once moisture was present. Further pertinent discussion on moisture is included in Chapter 6.0 of Hansen et al. [1998]. The other two parameter values exhibiting a significant change (r_1 and r_3) are also strongly correlated to the temperature parameter (Q_s/R) as shown in Tables 4-5 and 4-6. The combination of these three parameters can be examined with the function:

$$\chi(r_1,\ r_3,\ Q_s/R) = r_1 \exp\left(\frac{Q_s}{RT}\right) \exp(r_3 \epsilon_v) \tag{4-13}$$

Table 4-7. Parameter Correlation Measure

Test Database	pcm	$\bar{C}$
Shear	0.133	0.365
Combined	0.115	0.339

Table 4-8. Parameter Variation

Parameter	Parameter Set Ratio
η_0	0.14
η_1	0.86
n_f	1.13
a	0.00
p	0.63
n_s	2.75
r_1	17.37
r_3	0.01
r_4	1.00
Q_s/R	2.69

If a temperature of 298 K is assumed, the ratios of χ computed with the combined database parameters to the shear database parameters for volumetric strains of –0.10 and –0.15 are found to be 0.173 and 0.367. Thus, the combined effect of the significant change in the individual parameters is not significant. The cause of these changes is probably the lack of temperature variation in the shear consolidation database resulting in correlation of the parameter values. Overall, the change in parameter values from the two database fits is relatively minor.

4.6.4 Predictive Capability

The predictive capability of the crushed-salt constitutive model is measured qualitatively by how well the model fits to the shear consolidation tests are able to predict the hydrostatic consolidation tests. In other words, the shear consolidation test parameter values given in Table 4-3 were used to predict the hydrostatic consolidation tests with the goodness of fit determined by the sum-of-squared error. For comparison, the combined database parameter values given in Table 4-3 were also used to predict the same sets of tests. Different subsets of the hydrostatic tests were considered to see if the shear consolidation parameter values predicted any specific group of tests better than others. The hydrostatic test database subsets include: (1) dry (tests without any added moisture), (2) wet (test with added moisture), and (3) hydrostatic (the entire hydrostatic test database, including tests with and without added moisture). The sum-of-squared error was computed for each of these databases and are presented in Table 4-9. The shear and combined test databases are also included in Table 4-9 for comparison. Each of these databases exclude two tests: 29JAN82 and 26FEB82. These tests were excluded because they lie outside of the predictive range for the shear test-derived parameter values. This occurs because of the high mean stress and relatively low initial fractional densities for these two tests, which are outside of the shear test database. Table 4-9 shows that the shear test parameter set predicts the wet tests much better than the dry tests. Figures comparing the predicted results with the test data from the hydrostatic tests are given in Appendix C; specifically, Figures C-1 through C-40.

Table 4-9. Sum-of-Squared Error in Hydrostatic Consolidation Tests

Database Parameter Set	SS_E for Predicted Database				
	Shear	Dry[(a)]	Wet[(a)]	Hydrostatic[(a)]	Combined[(a)]
Shear	23.52	49.20	22.00	71.20	94.72
Combined	23.59	15.22	7.22	22.44	46.04

[(a)] Database excludes tests 29JAN82 and 26FEB82.

Upon visual examination of Figures C-1 through C-4, the shear database parameter value set appears to predict the dry tests better than the combined database parameter value set. However,

examination of Figures C-17 to C-28 shows that the model fit to the shear test database does not predict the hydrostatic tests that are dry very well, particularly as the mean stress increases. As can be seen in Table 4-9, the sum-of-squared error from predicting the wet hydrostatic tests (22.00) is about the same as the combined database parameter set fit to all of the hydrostatic tests (22.44).

These results suggest that the crushed-salt constitutive model (with parameter values determined from the shear consolidation tests) has reasonable predictive ability. As evidenced in Table 4-9, the model predicts the wet hydrostatic tests nearly as well as the model fits all of the hydrostatic tests. However, since the shear consolidation test database only includes two dry tests, the prediction of the dry hydrostatic consolidation tests is not as good. As further evidenced in the figures in Appendix C, visual comparison of the two fits shows qualitative sameness, even though the parameter values themselves might appear to be quite different (Table 4-3). The model contains both a volumetric (hydrostatic) component and a deviatoric (shear) component, both of which are present in the shear consolidation tests. Thus, the model not only characterizes (fits) the shear data well, it can reproduce (predict) simpler conditions nearly as well. This provides strong evidence that the model has the potential for predicting the consolidation of crushed salt in other, more complex, conditions as well, including the behavior of the shaft seal. This is explored further in Chapter 5.0, which presents the model predictions of constant strain-rate tests.

5.0 MODEL VERIFICATION

After a material model has been developed, the question remains as to how well it represents real-world problems. Constitutive model verification is best accomplished through the prediction of carefully conducted in situ experiments. When these in situ experiments do not exist, confidence in the model and partial verification can be accomplished by predicting bench-scale and other laboratory tests outside of the database upon which the model development relied. This was demonstrated in Chapter 4.0 where the shear consolidation parameter value set was used to predict the hydrostatic consolidation tests. In this chapter, model verification is pursued further by predicting three constant strain-rate tests using both the shear and combined database parameter value sets. The constant strain-rate tests provide an excellent verification test of the constitutive model since these tests provide a constant strain-rate and varying stress rate; whereas, the constitutive model was developed based on tests that included a constant stress and a varying strain rate. Since the constant strain-rate tests were not included in the model fitting database and represent a totally different load path than the creep consolidation tests, they are ideal for testing the predictive ability of the constitutive model.

5.1 DESCRIPTION OF CONSTANT STRAIN-RATE TESTS

Three constant strain-rate tests were performed on laboratory-scale specimens. The specimens were dynamically compacted using the same technique and raw crushed-salt materials that were employed for fabrication of the shear consolidation specimens. Thus, the constant strain-rate specimens had nominal lengths of 200 millimeters, nominal diameters of 100 millimeters, and nominal fractional densities of 0.9. All three tests were performed at a confining pressure of –1 MPa, a temperature of 20°C, and a constant axial strain rate. Essentially, the test procedure included applying a –1 MPa confining pressure, monitoring the axial strain rate, and initiating the constant axial strain rate when the monitored rate was less than the targeted test axial strain rate. The constant axial strain rate was different for each test, as shown in Table 5-1.

Specimen RS/DCCS/6 was used to perform the first constant strain-rate test on crushed salt, and this first test served to refine the test procedure as stated above. The first two attempts at performing this test were aborted, but the third attempt was successful. The first attempt was aborted because the constant strain-rate phase of the test was entered before the consolidation rate in the preceding hydrostatic phase had slowed to a value less than -1×10^{-7} s^{-1}. This caused

the test system to unload. The second attempt was aborted by failure of an electronic power supply in the test system shortly after the constant strain-rate phase had begun. After determining new specimen dimensions (there was some deformation induced during the first two aborted attempts), a third attempt was successful. At the start of the third attempt, the specimen had a length of 190.3 millimeters, a diameter of 101.6 millimeters, and a fractional density of about 0.92. The test duration was about 1 week, and the controlled test variables were maintained. The radial strain rate was initially compressive and eventually changed sign and became extensile as the specimen density increased. The other two constant strain-rate tests, RS/DCCS/11 and RS/DCCS/21, were performed without incident at axial strain rates of one-half and double, respectively, the strain rate used for RS/DCCS/6. Additional details of the constant strain-rate test equipment, procedures, and results can be found in Mellegard et al. [1999].

Table 5-1. Test Matrix for Constant Strain-Rate Experiments

Specimen I.D.	Initial Fractional Density	Axial Strain Rate (10^{-7} s^{-1})	Confining Pressure (MPa)	Temperature (°C)
RS/DCCS/11	0.912	–0.5	–1	20
RS/DCCS/6	0.921	–1.0	–1	20
RS/DCCS/21	0.907	–2.0	–1	20

5.2 PREDICTION OF CONSTANT STRAIN-RATE TESTS

The crushed-salt constitutive model described in Chapter 2.0 was incorporated into the thermomechanical finite element stress analysis program SPECTROM-32 [Callahan et al., 1989], Version 4.10. Thus, prediction of the constant strain-rate tests was performed using the finite element program with one element. For each test simulation, an element was initially subjected to the time-weighted average axial and lateral stress conditions realized in each test. The stress condition was designed to be a hydrostatic load of –1 MPa; however, the actual test conditions achieved were slightly different than the design condition. The stress conditions were maintained for the *hydrostatic* duration realized in the tests. Then, time-weighted average, time-wise kinematic boundary conditions were applied to the element that matched the constant strain-rate conditions achieved in the tests. The actual time-weighted test conditions for confining pressure

and axial strain rate, as well as the duration of the hydrostatic phase for each of the tests, are given in Table 5-2.

Table 5-2. Time-Weighted Average Test Conditions for Constant Strain-Rate Experiments

Specimen I.D.	Hydrostatic Duration (s)	Axial Stress (MPa)	Lateral Stress (MPa)	Axial Strain Rate (10^{-7} s^{-1})
RS/DCCS/11	93,150	–1.025	–0.998	–0.504
RS/DCCS/6	13,127	–0.999	–0.987	–1.008
RS/DCCS/21	55,870	–1.047	–0.985	–2.040

Thus, the constant strain-rate test simulations used the average actual test conditions. Simulations were performed using both the shear database and combined database parameter sets given in Table 4-3.

Axial and lateral strain simulation results obtained for the three constant strain-rate tests are shown in Figures 5-1 through 5-3 plotted with the laboratory data.

Predicted results are shown for the two different parameter value sets given in Table 4-3. In all three figures, the axial and lateral strain simulation results reproduce the laboratory data reasonably well; however, an offset is noticeable in the strains that appears to be generated by the hydrostatic portion of the tests. The laboratory data exhibit a curious lateral and axial strain response during the presumed hydrostatic portion of the tests. Normally, one would expect the axial and lateral strain to be the same during hydrostatic compression of a homogeneous material. However, the axial and lateral strains are noticeably different in all three of the constant strain-rate tests during the hydrostatic loading phase of the tests. There are three possible explanations for this anomalous behavior related to (1) stress difference, (2) other modes of deformation, and (3) specimen inhomogeneity. Each of these items is briefly discussed separately.

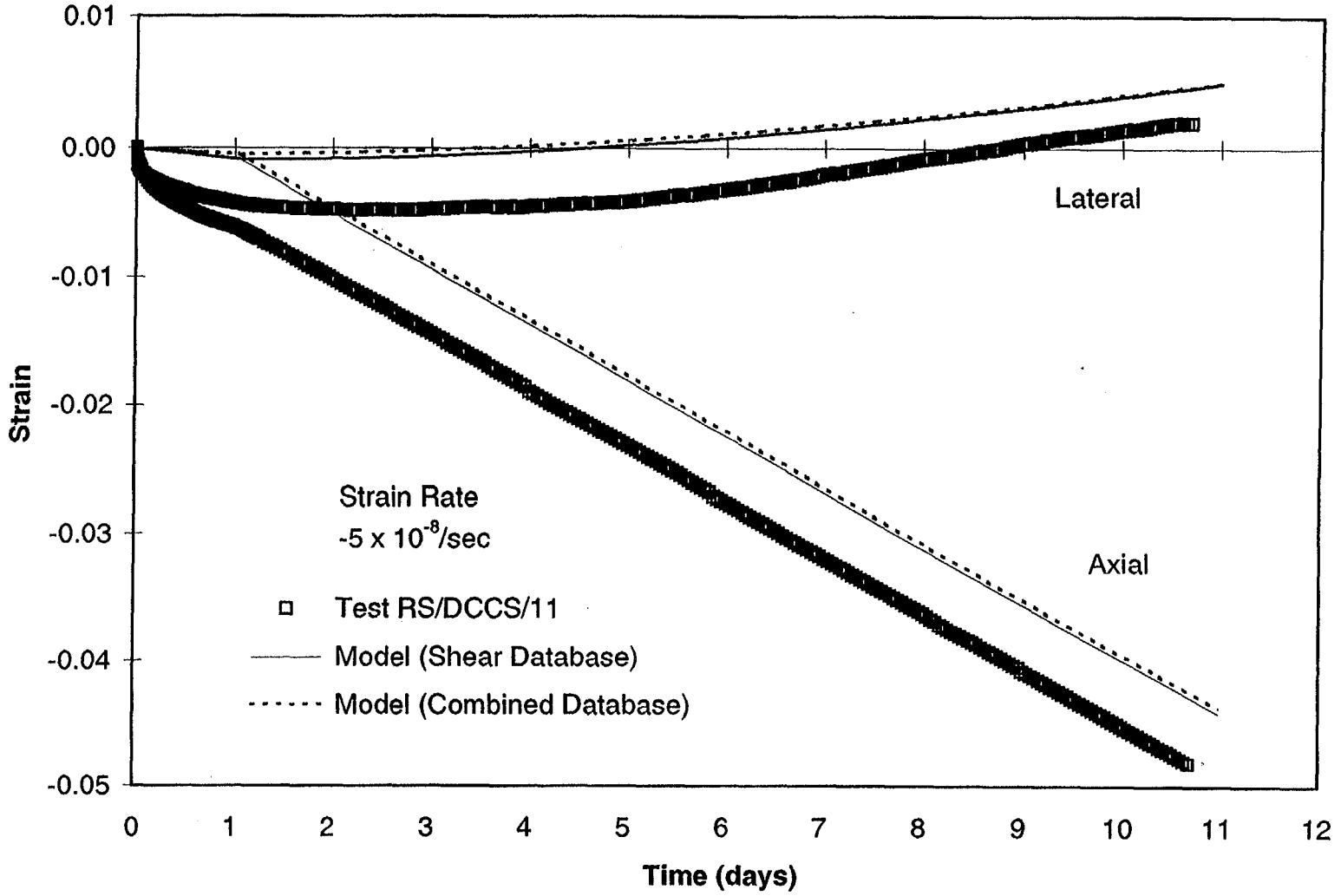

Figure 5-1. Comparison of predicted strains and laboratory data for test RS/DCCS/11 ($-0.5 \cdot 10^{-7} s^{-1}$).

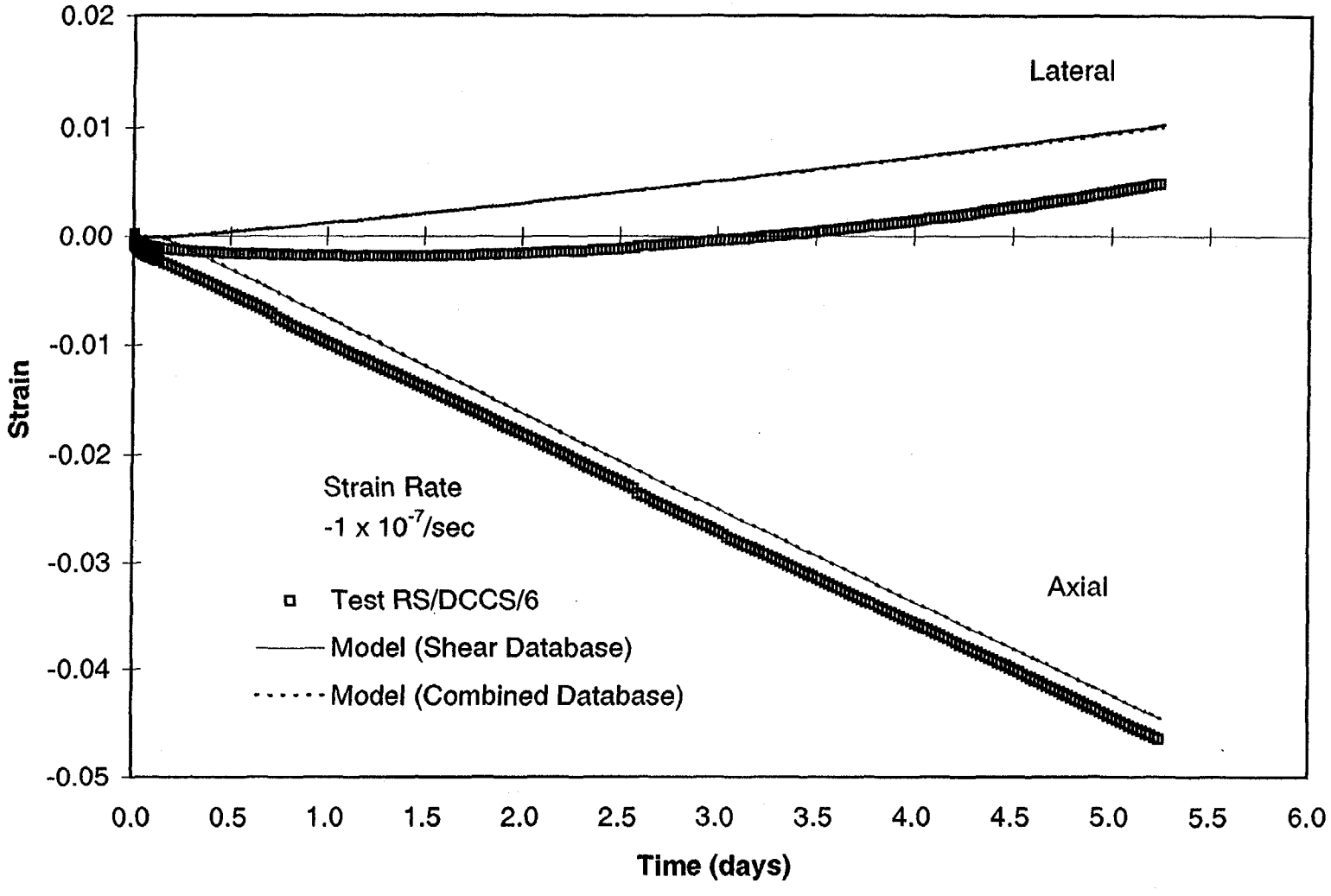

Figure 5-2. Comparison of predicted strains and laboratory data for test RS/DCCS/6 ($-1.0 \cdot 10^{-7} s^{-1}$).

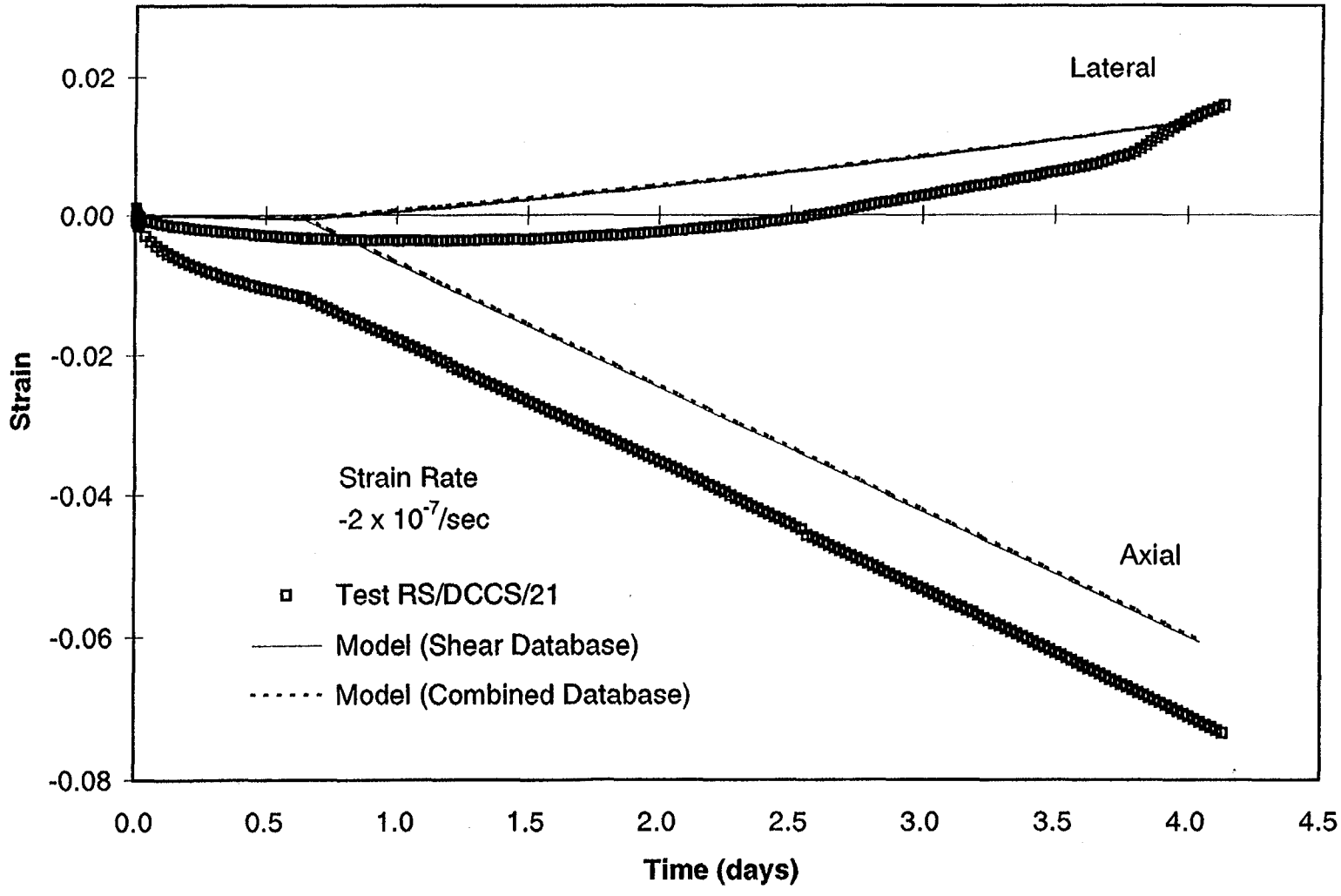

Figure 5-3. Comparison of predicted strains and laboratory data for test RS/DCCS/21 ($-2.0 \cdot 10^{-7} s^{-1}$).

Stress Difference: As given in Table 5-2, the actual axial and lateral stresses applied during the *hydrostatic* portion of the test are not equal as desired. In all three tests, the time-weighted average axial stress is greater than the lateral stress. However, the largest stress difference is only 0.0619 MPa for Test Specimen RS/DCCS/21. While this stress difference contributes to the larger axial strains, it does not appear to be large enough to be solely responsible for the differences in axial and lateral strains. This judgment is made based on the predicted test results which show almost no difference between the axial and lateral stresses. The constitutive model predicts the shear consolidation tests reasonably well; however, these tests involve larger stress differences. This leads one to believe other factors are involved in the axial and lateral strain differences.

Deformation Modes: Upon loading the specimen, there is a certain amount of cataclastic deformation and sliding along the particle interfaces. These deformation mechanisms could create axial and lateral strain differences, which would be amplified by the stress difference.

Specimen Inhomogeneity: Preparation of the dynamically compacted crushed-salt specimens is discussed in detail by Mellegard et al. [1999]. Basically, a laboratory-scale compaction device that approximates the envisioned shaft seal compaction method was used to fabricate the specimens. The specimens were fabricated in three lifts, which created layers of finely pulverized salt about 10 millimeters thick at one-third and two-thirds of the specimen height. These bands of fines, perpendicular to the specimen axis, form significant specimen inhomogeneities that may have contributed to the anisotropic deformation behavior of the specimens. These bands would not affect the axial deformation significantly but could have acted as stiffeners restricting the lateral compaction of the specimens.

With the data available, the importance of these three factors' impact on the specimen deformation cannot be quantified. All three factors may be contributing to the observed deformation behavior of the specimens.

Figures 5-4 through 5-6 plot only the constant strain-rate portion of the tests. This portion of the test begins after the hydrostatic portion ends, as given in Table 5-2. In Figures 5-4 through 5-6, the axial and lateral strains and time have been translated so that the values are all zero at the beginning of the constant strain-rate portion for each test. These results show that the simulation results reproduce the laboratory data quite well. Of course, the axial strain rate is an imposed condition that should be reproduced exactly, and the fact that the axial strain simulation results overlay the axial laboratory data provides a check that the correct strain rate was used in the simulations. Figures 5-7 through 5-9 plot the lateral strains only for the constant strain-rate portion of the tests so that comparison of the computed results and laboratory data can be made

more readily. These figures show decreasing agreement between computed results and laboratory data as the strain rate increases. However, the prediction of the lateral strains is still quite good even at the highest strain rate when one considers the fact that both the test data and load path for the constant strain-rate tests are outside of the database upon which the constitutive model parameters are based. Figures 5-1 through 5-9 show minor differences between the predicted results for the shear and combined database parameter value sets even though some of the parameter values in the two sets appear to be quite different.

The predicted axial stress results for the three constant strain-rate tests are compared in Figures 5-10 through 5-12. The lateral stresses (or confining pressures) are constant throughout the duration of the tests at the values given in Table 5-2. The predicted stress magnitudes are in the range of the laboratory results but consistently over predict the laboratory data following application of the constant strain rate. The over prediction is amplified as the constant strain rate increases. The discontinuities in the axial stress measurement were traced back to a test system control problem, as discussed by Mellegard et al. [1999]. This problem was eliminated, but not until after all three constant strain-rate tests had been conducted. As seen in Figures 5-10 through 5-12, the laboratory measured axial stresses do not increase significantly as the strain rate increases, despite RS/DCCS/21 strain rate being four times that of RS/DCCS/6; whereas, the increase of the predicted axial stresses is significant with increasing strain rate. A rapid rise in axial stress is seen in each of the test simulation results following application of the constant strain rate. There are undoubtedly cataclastic deformation mechanisms operative in these crushed-salt specimens. These mechanisms, which are not included in the crushed-salt constitutive model, are most likely responsible for the moderate stress rises observed in the laboratory tests as compared to the rapid rise in the stress seen in the predictions.

The numerical prediction of the constant strain-rate tests shows that the crushed-salt constitutive model is able to predict the strains quite well. The prediction of the stresses is not as good as the strain predictions and indicates that deficiencies remain in the model. These deficiencies are believed to be embodied in the lack of cataclastic deformation mechanisms in the model. However, the importance of the cataclastic deformation will not be as important in the actual crushed-salt seal components where the strain rates will be more than an order of magnitude less than the slowest strain rate used in the laboratory tests.

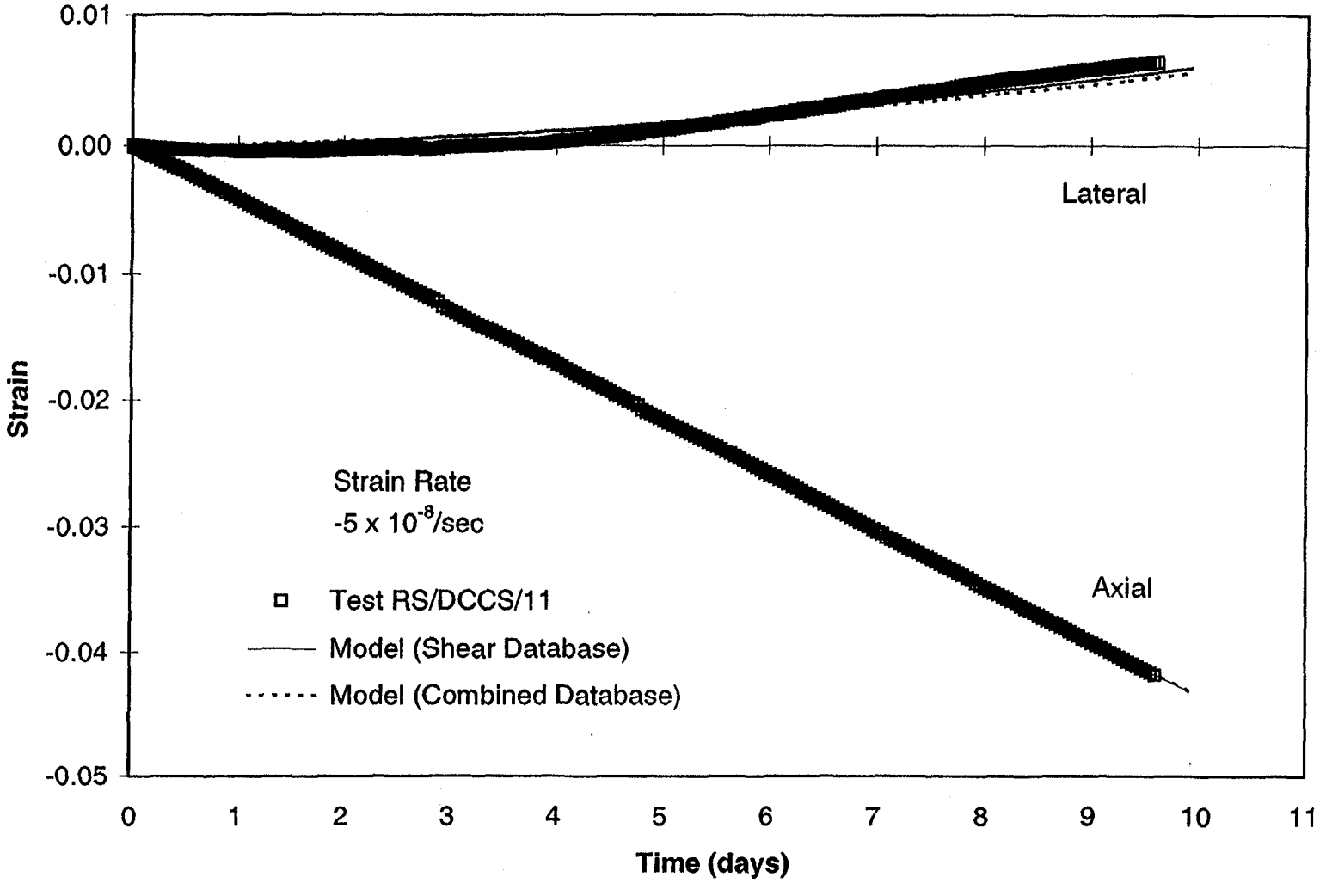

Figure 5-4. Comparison of predicted strains and laboratory data for the constant strain-rate portion of test RS/DCCS/11 ($-0.5 \cdot 10^{-7} s^{-1}$).

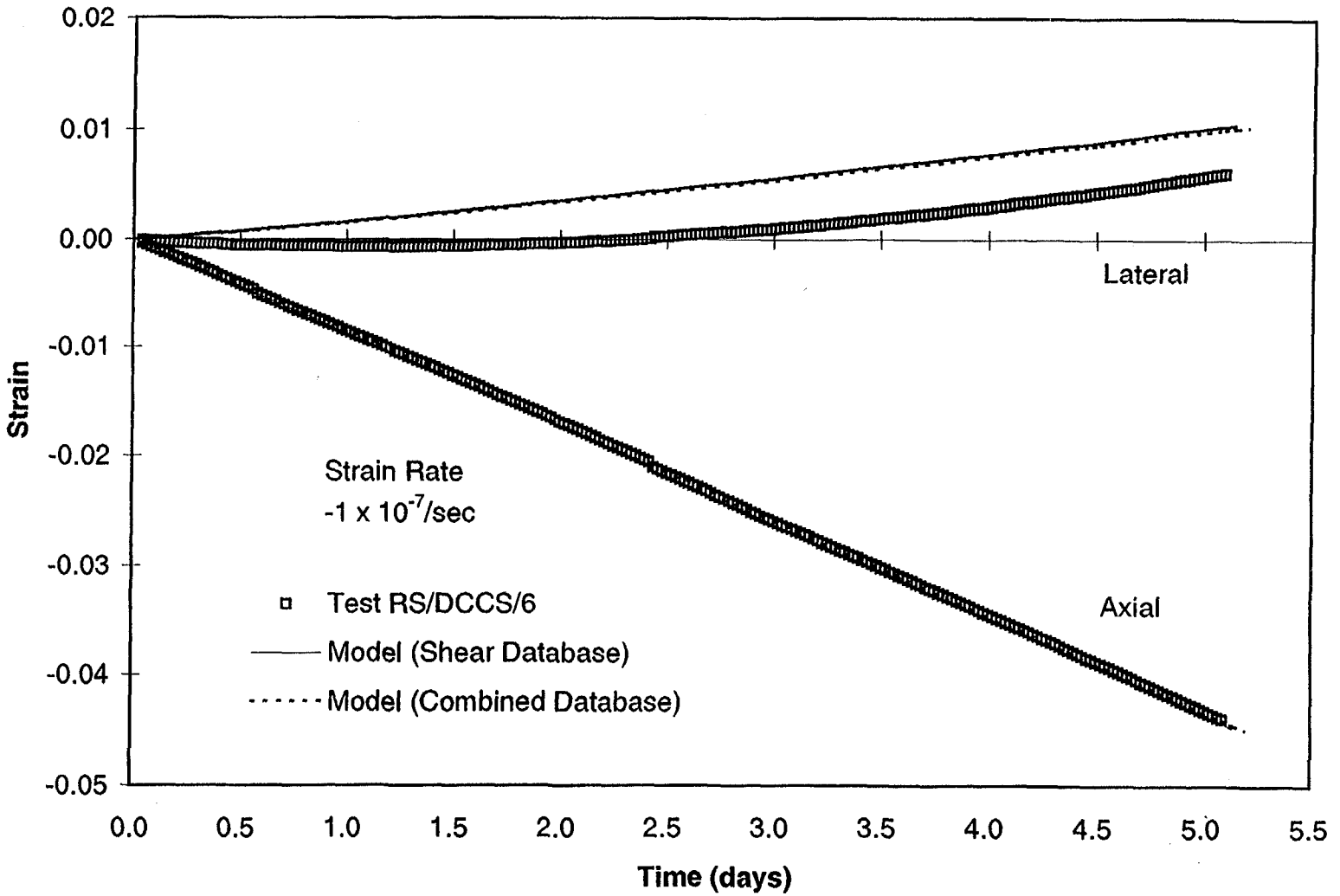

Figure 5-5. Comparison of predicted strains and laboratory data for the constant strain-rate portion of test RS/DCCS/6 ($-1.0 \cdot 10^{-7} s^{-1}$).

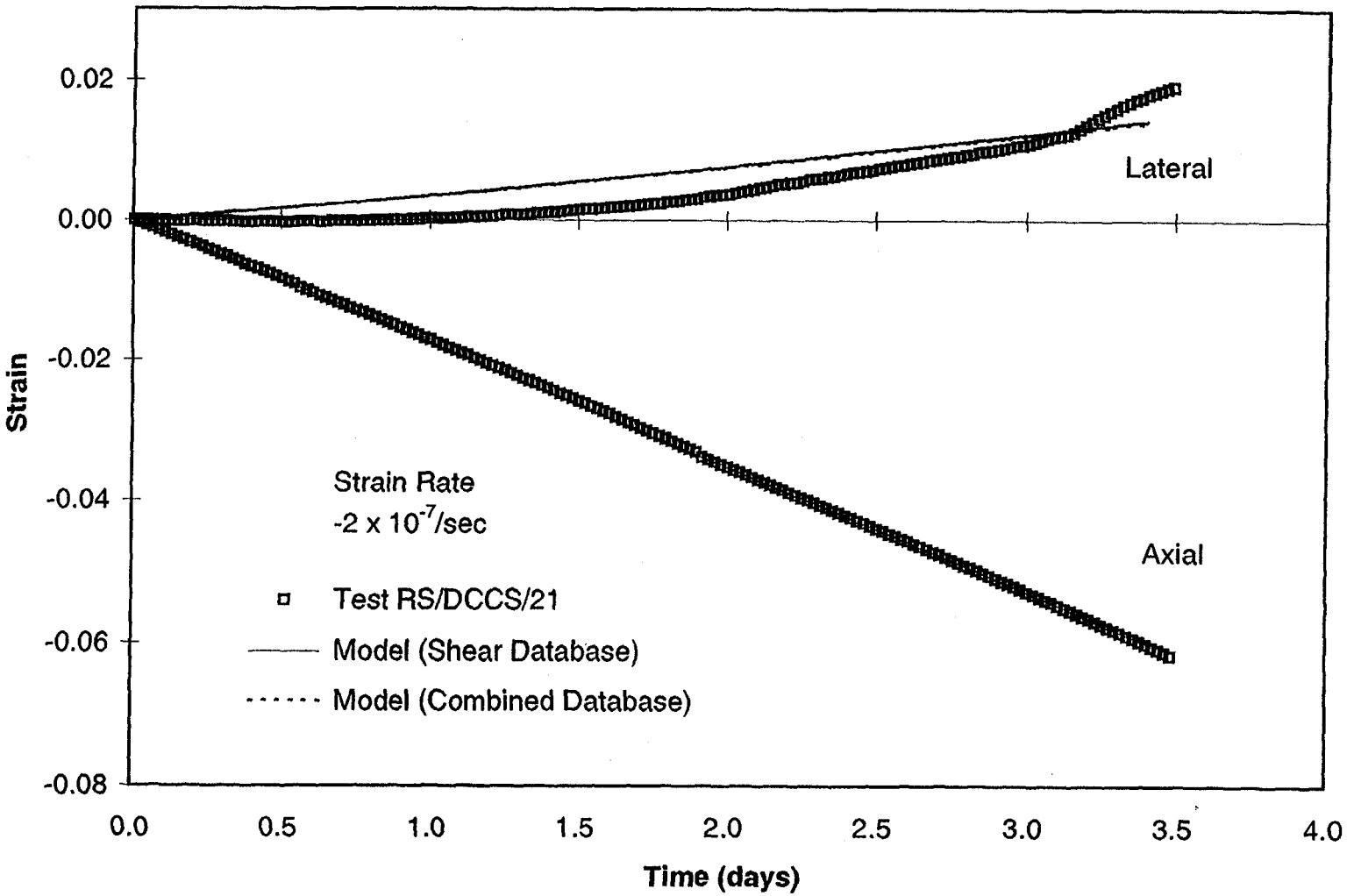

Figure 5-6. Comparison of predicted strains and laboratory data for the constant strain-rate portion of test RS/DCCS/21 ($-2.0 \cdot 10^{-7} s^{-1}$).

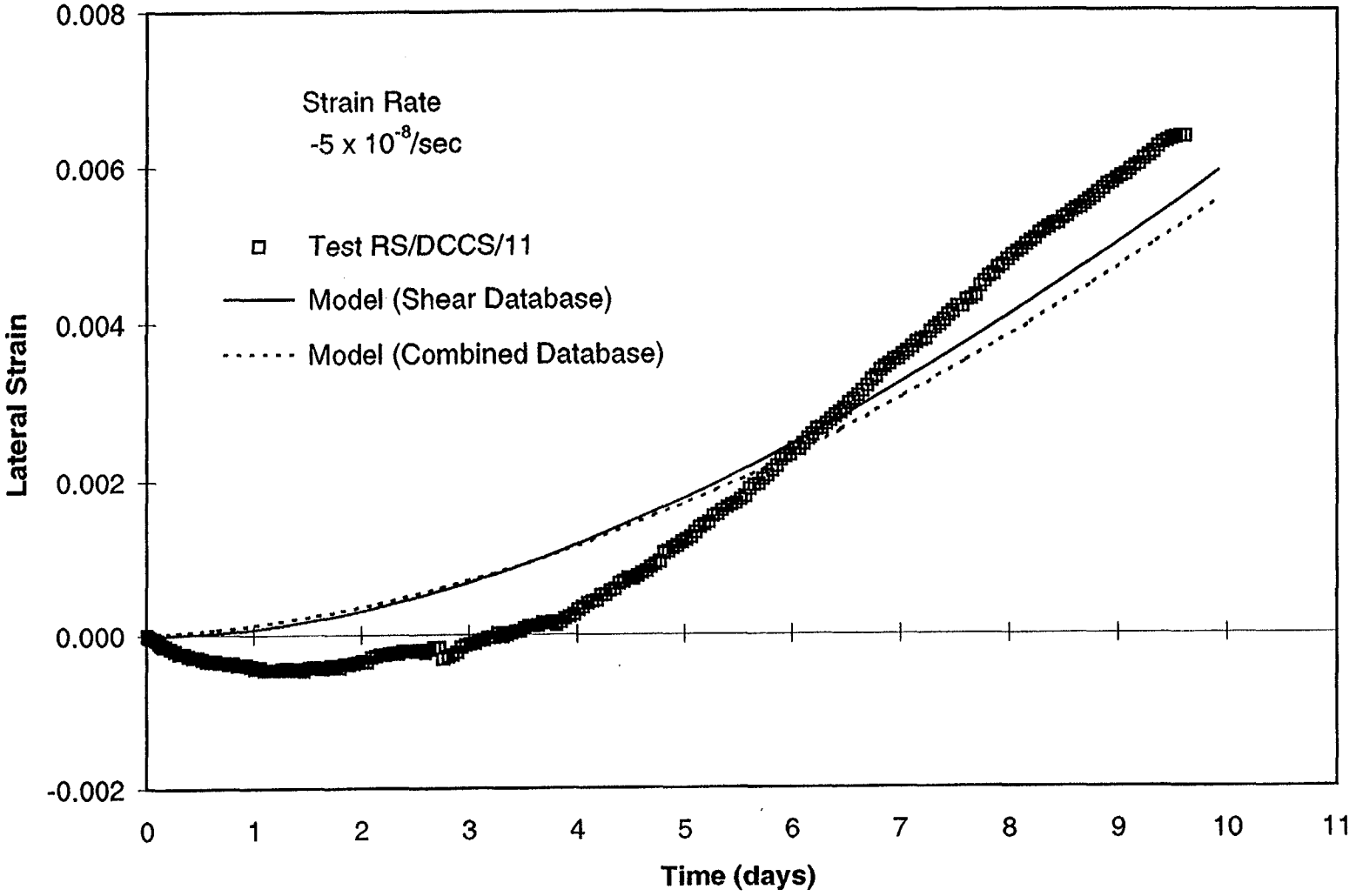

Figure 5-7. Comparison of predicted lateral strains and laboratory data for the constant strain-rate portion of test RS/DCCS/11 ($-0.5 \cdot 10^{-7} s^{-1}$).

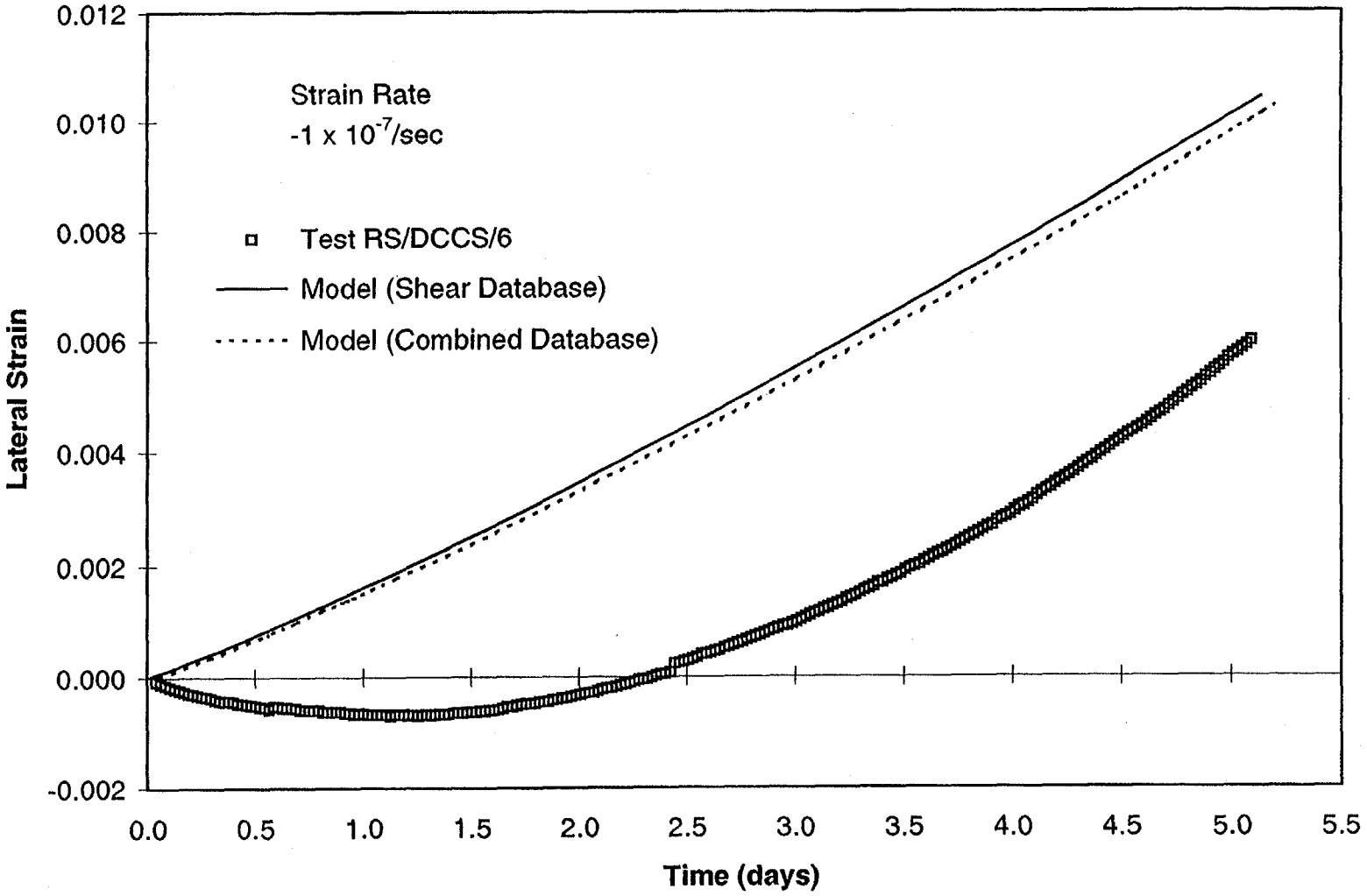

Figure 5-8. Comparison of predicted lateral strains and laboratory data for the constant strain-rate portion of test RS/DCCS/6 ($-1.0 \cdot 10^{-7} s^{-1}$).

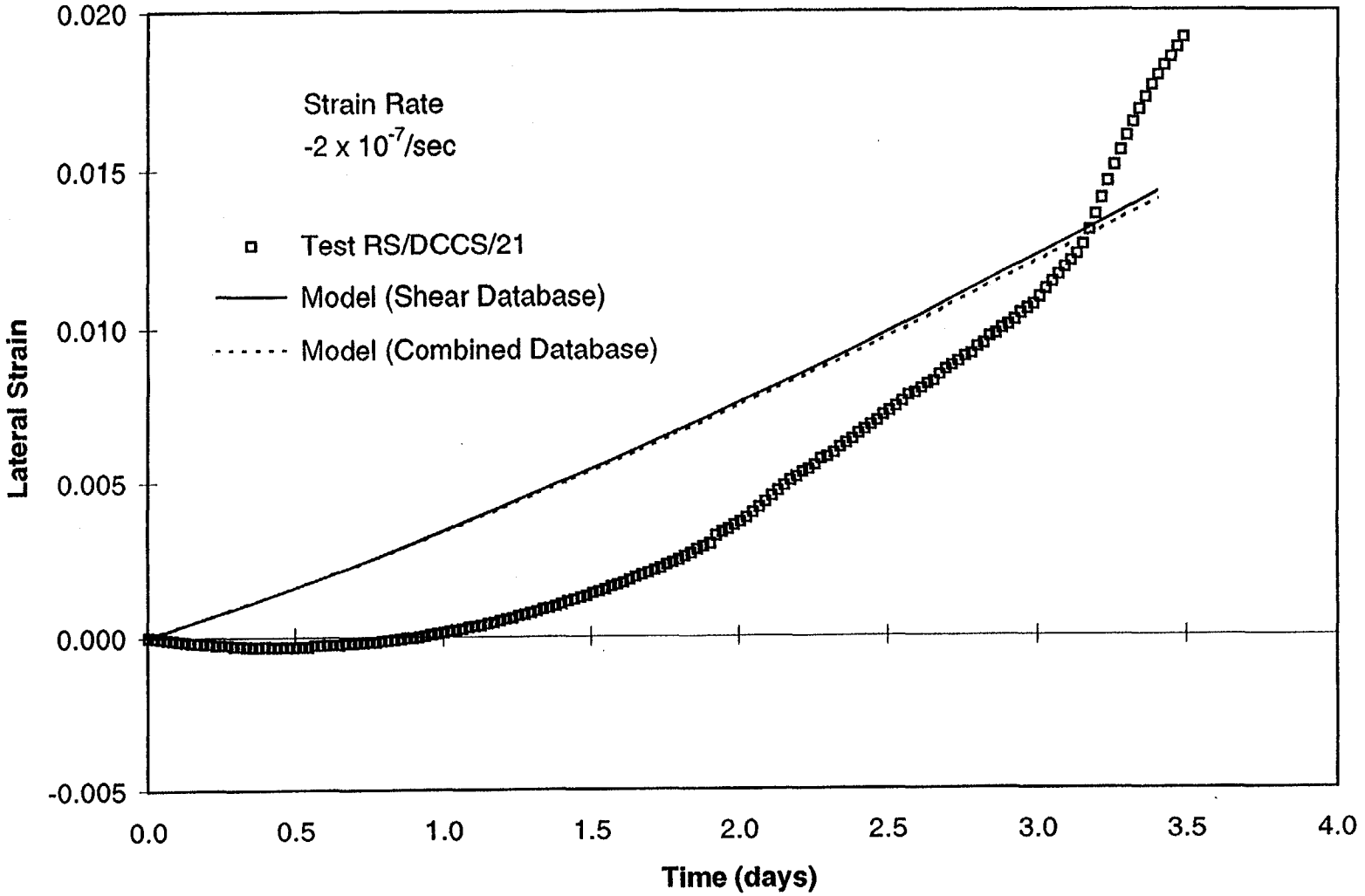

Figure 5-9. Comparison of predicted lateral strains and laboratory data for the constant strain-rate portion of test RS/DCCS/21 ($-2.0 \cdot 10^{-7} s^{-1}$).

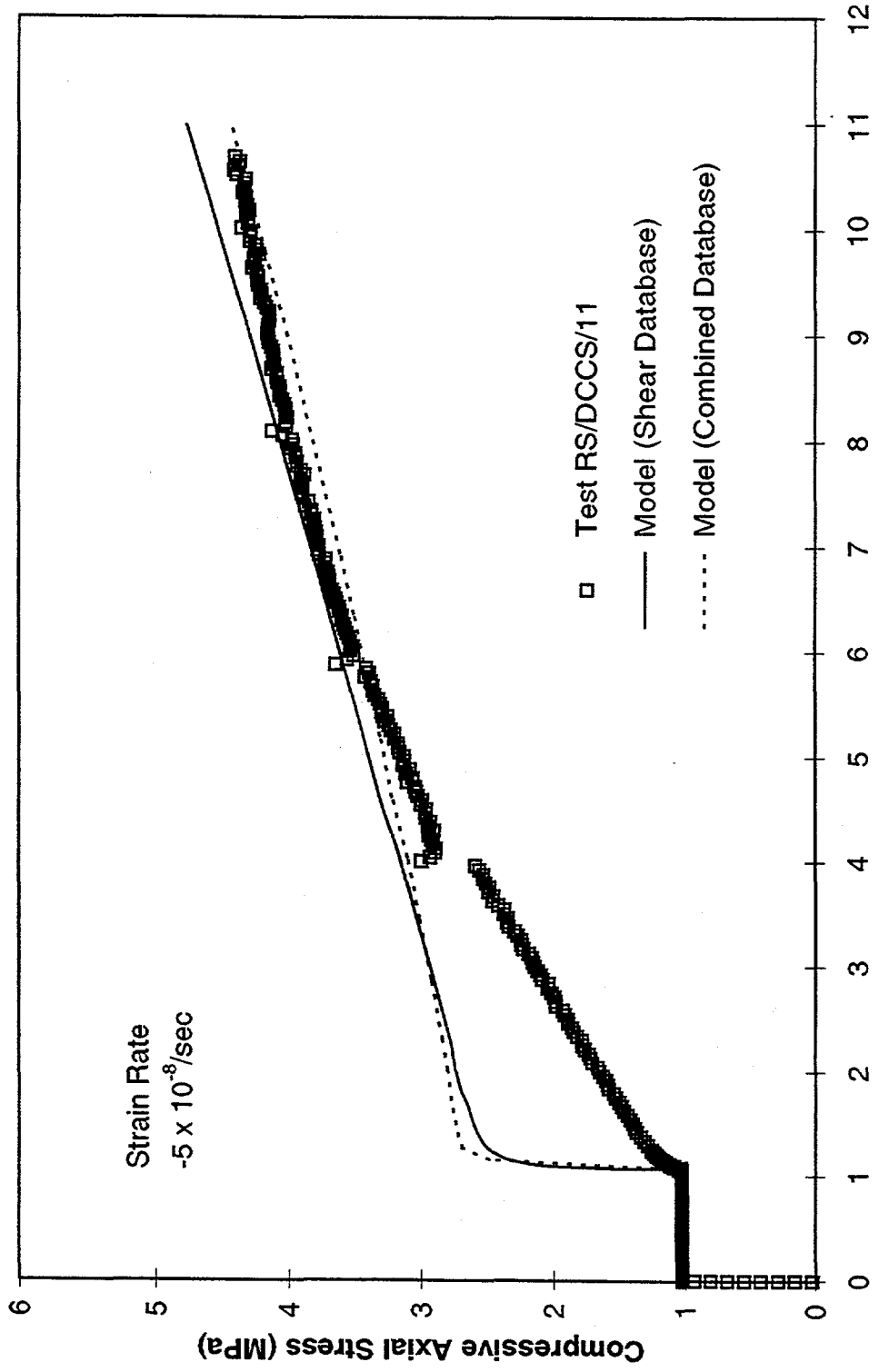

Figure 5-10. Comparison of predicted axial stress and laboratory data for test RS/DCCS/11 ($-0.5 \cdot 10^{-7} s^{-1}$).

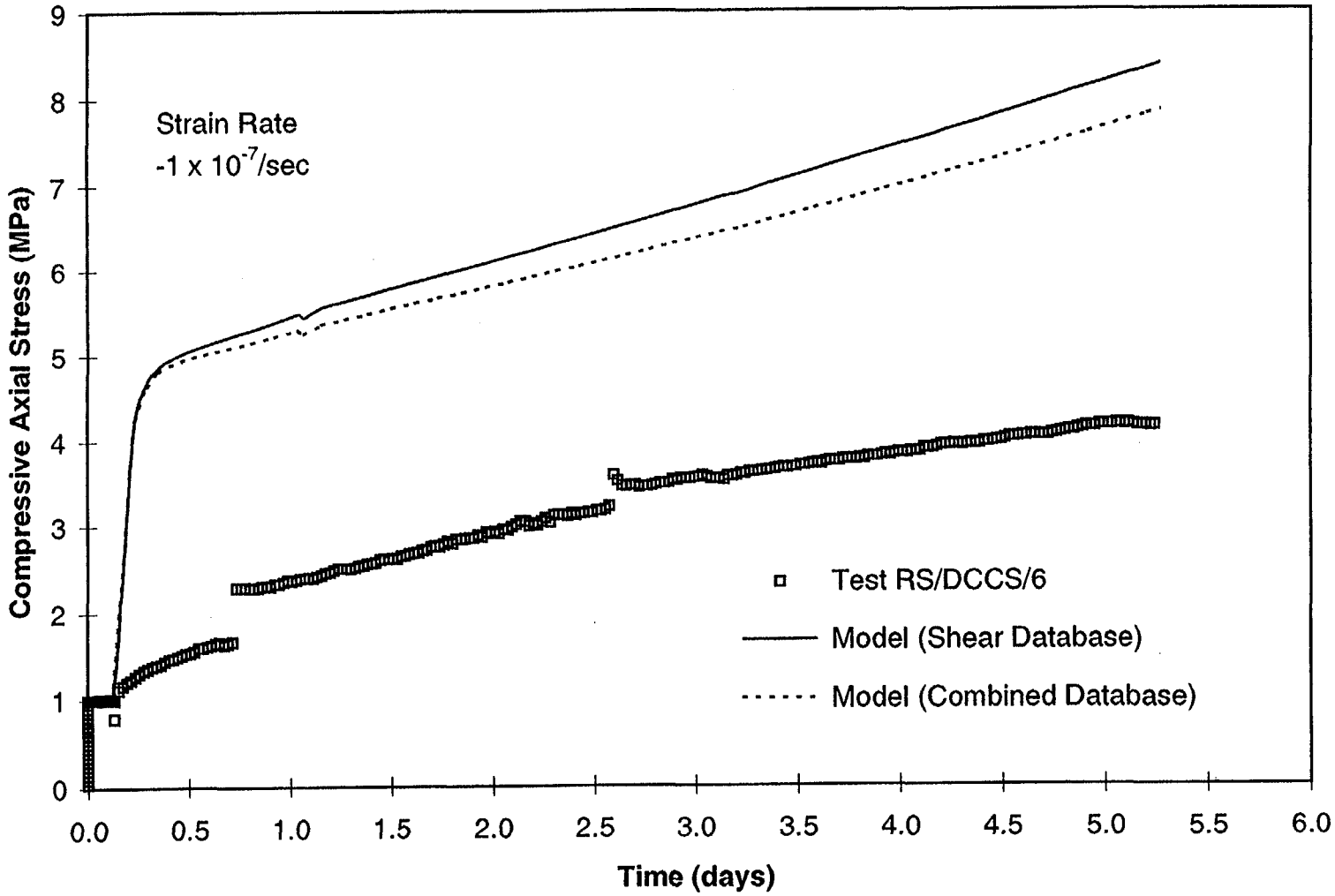

Figure 5-11. Comparison of predicted axial stress and laboratory data for test RS/DCCS/6 ($-1.0 \cdot 10^{-7} s^{-1}$).

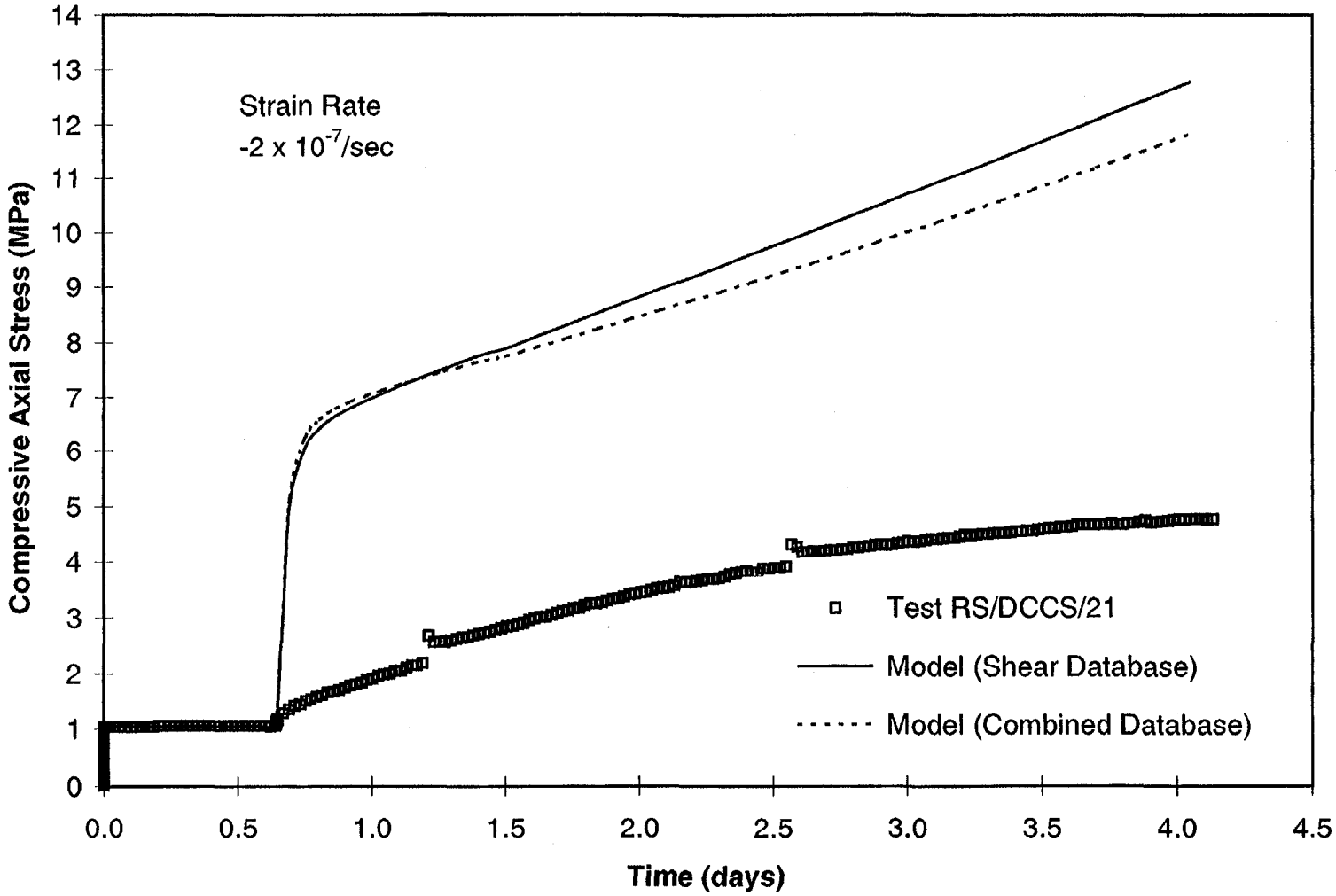

Figure 5-12. Comparison of predicted axial stress and laboratory data for test RS/DCCS/21 ($-2.0 \cdot 10^{-7} s^{-1}$).

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6.0 SHAFT SEAL CALCULATIONS

The current seal designs for the WIPP specify the emplacement of various materials (asphalt, compacted clay, concrete, and crushed salt) in the shafts from the earth's surface to the repository horizon. Crushed salt will be emplaced within the shafts at depths ranging from 430 meters to 600 meters and dynamically compacted to a fractional density of about 0.9. The flow characteristics of the crushed-salt seal are of primary importance since the long-term function of the seal is to prevent the flow of water into the repository from overlying aquifers and to prevent the flow of gas out of the repository. Closure of the shaft resulting from creep of the surrounding intact salt will consolidate the crushed salt over time. The consolidation process reduces the permeability of the crushed salt from its emplaced state to its intact state, creating an effective long-term seal.

The purpose of this chapter is to demonstrate the creep consolidation behavior of a typical crushed-salt shaft seal problem using the model and material parameter values described in Chapters 2.0 and 4.0. The problem selected is identical to the one presented by Loken [1998]. In this earlier study, Loken [1998] compared the combined-mechanism, crushed-salt constitutive model shaft seal simulation results using material properties from Hansen et al. [1998] to shaft seal simulation results obtained using three earlier candidate crushed-salt constitutive models described by Callahan et al. [1995]. Thus, the results obtained in this chapter are compared with the results generated by prior versions of the crushed-salt model.

6.1 SHAFT PROBLEM DESCRIPTION AND ASSUMPTIONS

The shaft configuration chosen to demonstrate the crushed-salt seal behavior is the simplest configuration that can be used to evaluate the seal system. The model is an axisymmetric representation of the shaft and host rock at a fixed depth. By changing the initial stress and temperature conditions, different depths may be examined. The following assumptions apply to the selected model and govern the simulation procedure:

- A condition of plane strain is assumed to exist with respect to the axial (vertical) direction.
- The stratigraphy at the WIPP is ignored. The intact salt surrounding the shaft is assumed to be composed entirely of argillaceous salt governed by the multimechanism deformation creep fracture (MDCF) model [Chan et al., 1998].
- The initial stress state before shaft excavation is lithostatic.
- The shaft is excavated into the lithostatic stress field at time zero.
- The shaft is assumed to be open for 50 years and then instantaneously filled with crushed salt dynamically compacted to a fractional density of 90-%.
- The weight of the crushed-salt backfill is ignored.

- The shaft is assumed to be sufficiently isolated to exclude the influence from other excavations and shafts.
- The deformation and strains predicted during the simulation period are sufficiently large such that finite strain analysis is required.

Figure 6-1 provides a schematic representation of the shaft seal problem. The radius of the shaft was taken as unity, and the outer boundary was placed at 100 radii to be far enough removed so as not to influence the results. For time $t < 0$ years, the shaft is not present and an initial lithostatic stress field exists in the host rock such that the three principal stresses are identical. At time $t = 0$ years, the cylindrical shaft is excavated and the surrounding host salt formation creeps into the shaft for a period of 50 years. At time $t = 50$ years, crushed salt with an initial density of 1,944 kg/m^3 (90-% of intact salt density) is emplaced within the shaft. The salt surrounding the shaft continues to creep and transfers load to the crushed-salt seal, causing the crushed-salt to consolidate. The total simulation period is 500 years.

A representative depth of 550 meters is used to compare the results predicted by the crushed-salt combined mechanism model with those predicted using previous models. Three additional depths (430 meters, 515 meters, and 600 meters) are used to illustrate the magnitude of consolidation as a function of depth for the combined mechanism model. Temperature and initial stress conditions consistent with the host rock at the four depths considered in the calculations are given in Table 6-1.

6.2 MATERIAL MODELS AND PARAMETER VALUES

Two types of material models are required to solve the shaft seal problem based on the problem definition given in Section 6.1. Material models include: (1) a material model to describe the creep behavior of the host salt formation and (2) material models to describe the consolidation of the crushed-salt seal material. The host salt material model used for all of the comparative analyses was the same so that differences in the material models used for the crushed-salt seal could be observed. In all of the crushed-salt consolidation models, the average grain size and moisture content was assumed to be 1 millimeter and 1-% by weight, respectively. The constitutive models used in this study are described briefly in Section 6.2.1.

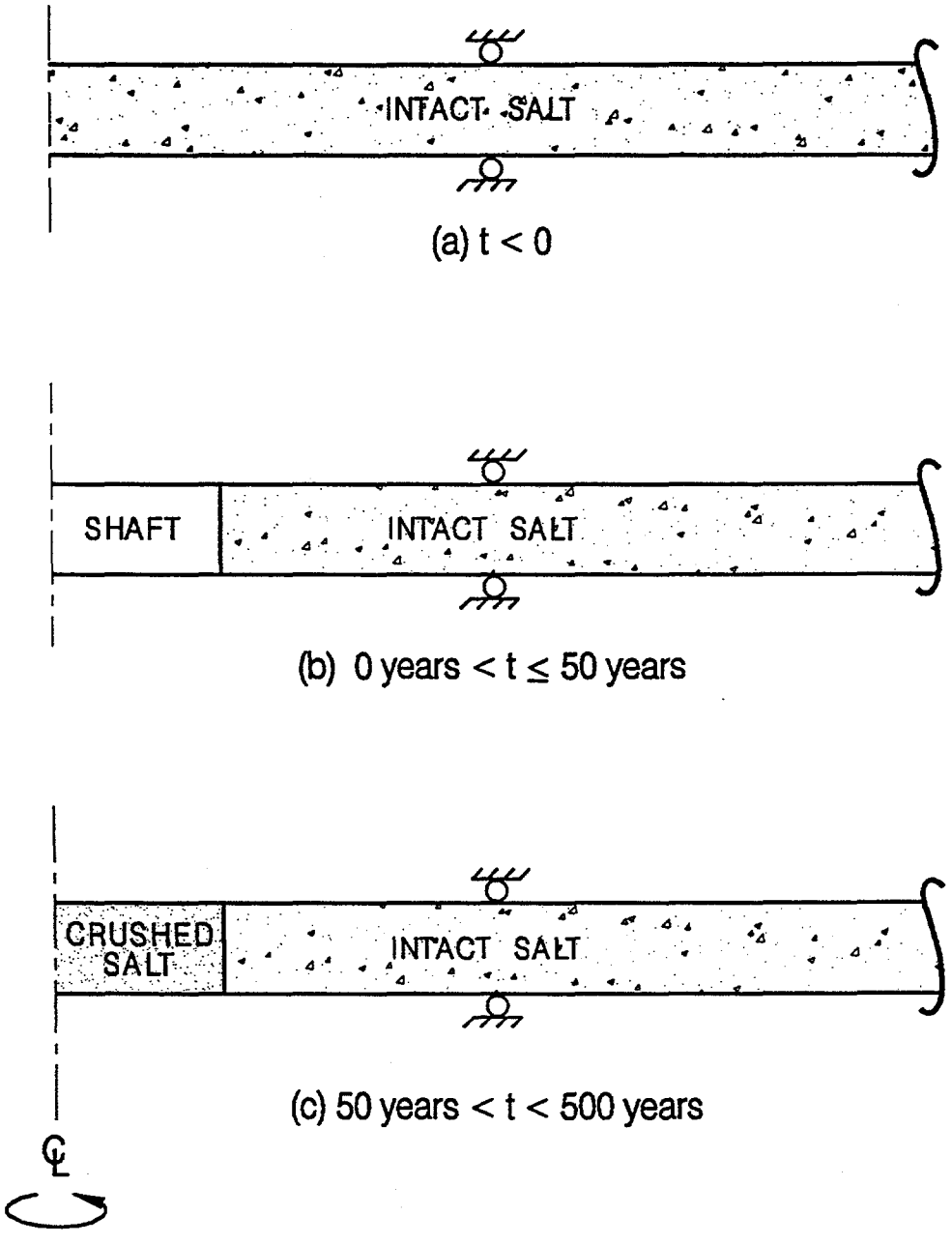

Figure 6-1. Schematic representation of the shaft seal problem.

6.2.1 Intact Salt Model

The material behavior of intact salt was modeled using the MDCF model for argillaceous halite. A description of the MDCF model is given by Chan et al. [1998], along with associated parameter values for WIPP argillaceous salt. Loken [1998] provides additional discussion of the parameters used in the analyses. The same intact salt model was used regardless of the constitutive model used to represent the crushed-salt seal. Thus, the host salt formation's driving force on the seal was identical in all analyses until host salt-seal interaction became important.

Table 6-1. Initial Temperature and Stress Conditions at WIPP for Various Depths within the Salado Formations

Depth (m)	Initial Conditions	
	Temperature[a] (°C)	Stress[b] (MPa)
430	24.8	9.85
515	25.65	11.76
550	26.0	12.57
600	26.5	13.68

[a] Based on a temperature of 27° at 650-m depth and a geothermal gradient of 10°C/km [Sass et al., 1971].

[b] Based on an in situ stress of 14.8 MPa at 650-m depth [Bailey et al., 1992] and an average overburden density in the Salado Formation of 2,300 kg/m^3 [Krieg, 1984].

6.2.2 Previous Consolidation Models

Loken [1998] used parameter values derived from an earlier crushed-salt database and compared the combined-mechanism crushed-salt model results to those obtained from three earlier creep consolidation models developed for crushed salt. These three earlier creep consolidation models are described by Callahan et al. [1995] and include the modified Sjaardema-Krieg model, the modified Zeuch model, and the modified Spiers model. The Sjaardema-Krieg model is an empirical model. The Zeuch model was derived from a hot-isostatic pressing model for dry crushed salt. The Spiers model is a grain boundary diffusional pressure solution model, appropriate for wet crushed salt. The parameter values that define each of these models are given by Callahan et al. [1998a]. Each of these models also contain a nonlinear elastic model proposed by Sjaardema and Krieg [1987] and described by Callahan et

al. [1995]. Mellegard et al. [1999] show reasonable agreement of additional test data compared with the bulk modulus functional form used by Sjaardema and Krieg [1987]. Finally, each of the creep consolidation models contain a Munson-Dawson (M-D) deviatoric portion using the parameter values given in Table 4-1.

6.2.3 Combined Mechanism Model

The combined mechanism model comprises two mechanisms, dislocation creep and grain boundary diffusional pressure solution, and is described in detail in Chapter 2.0. The same nonlinear elastic model is used with this model as described for the previous consolidation models. Three different sets of parameter values were used for the combined mechanism model for analyses of the shaft seal problem. The first set of parameters, reported by Hansen et al. [1998], was determined from the least-squares fit to the database that includes both the shear and hydrostatic consolidation tests but excludes the recent tests discussed in Chapter 3.0. The results of the shaft analyses using these parameter values are documented in Loken [1998]. The other two sets of parameter values, used in the current analyses, are given in Table 4-3 and are referred to as the *shear parameters* and *combined parameters*. The flow potential parameter values are given in Table 4-2.

6.3 CALCULATION RESULTS

Finite element program SPECTROM-32 [Callahan et al., 1989], Version 4.10, was used to predict the creep deformation of the host rock and the consolidation of the crushed-salt seal material. The finite element model used in solving this problem comprises a single row of 51 isoparametric elements. Fifteen elements were used to represent the shaft and 36 elements were used to model the surrounding intact salt. The outer boundary condition consisted of a constant traction boundary condition consistent with the initial stress level for each respective depth analyzed. Kinematic constraints were applied along the horizontal boundaries to prevent axial displacements.

Eight shaft seal analyses were performed, which resulted from using the shear and combined parameter values sets for the combined mechanism model at each of the four depths. The results of these eight calculations are compared with the results of Loken [1998] for shaft analyses using the modified Sjaardema-Krieg, modified Zeuch, and modified Spiers consolidation models and the combined mechanism model with a different combined database parameter value set. Figure 6-2 presents a comparison of the fractional densities predicted by four creep consolidation models at a depth of 550 meters.

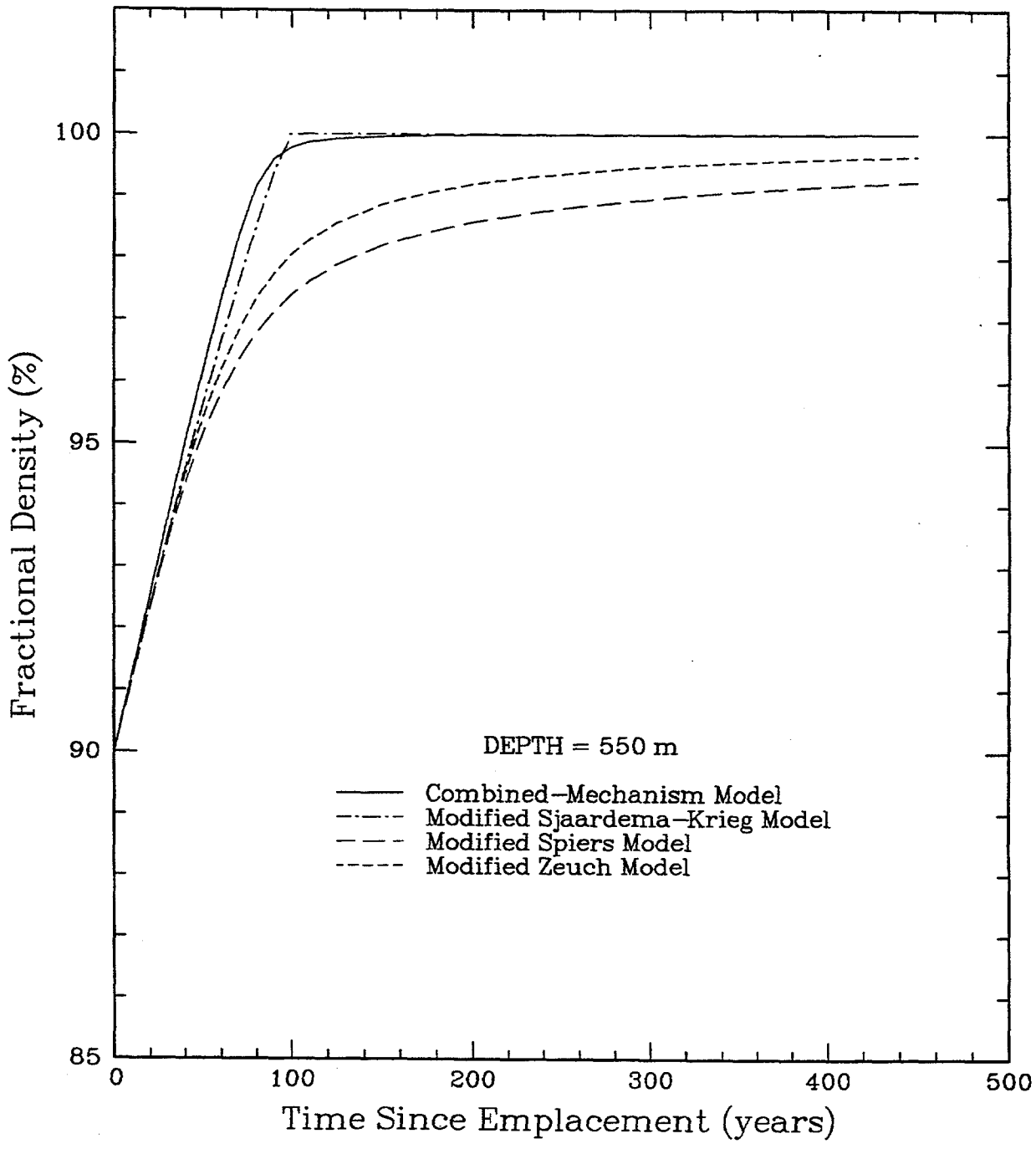

Figure 6-2. Comparison of four creep consolidation models for prediction of crushed-salt fractional density as a function of time at a depth of 550 meters.

These results indicate that the responses are similar for all four models up to a fractional density of 95-%. For this representative depth, approximately 50 years are required to consolidate the crushed salt from 90 to 95-% for all four models. At higher fractional densities, the model results diverge. The results shown in this figure also indicate that the combined mechanism model predicts the fastest consolidation rate when the fractional density is less than 98-%. A relative ranking of the four models in terms of their predicted consolidation rates (from fastest to slowest) is: (1) the combined mechanism model, (2) the modified Sjaardema-Krieg model, (3) the modified Zeuch model, and (4) the modified Spiers model. The results show that the predicted fractional density is nearly a linear function of time for the modified Sjaardema-Krieg model; whereas, the responses of the combined mechanism, modified Zeuch, and modified Spiers models are nonlinear. The Sjaardema-Krieg model predicts full consolidation within 100 years; the other models do not predict that the crushed salt will reach the density of intact salt during the 450-year simulation period following emplacement of the crushed salt. This occurs because the empirical Sjaardema and Krieg model does not stop consolidating when the density of intact salt is reached. The consolidation is simply stopped numerically when the fractional density reaches 100-%.

For comparison, the times required to achieve fractional densities of 92, 94, 96, and 98-% for all four models are given in Table 6-2. Table 6-2 also includes the associated times predicted by the combined mechanism model using the parameter estimates obtained from the fit to the database consisting of 18 shear consolidation tests.

Table 6-2. Time (Years) Required to Reach Fractional Densities for Four Consolidation Models at a Depth of 550 Meters

Fractional Density (%)	Combined Mechanism Model		Modified Sjaardema-Krieg Model	Modified Zeuch Model	Modified Spiers Model
	Shear Parameters	Combined Parameters			
92	16	16	17	17	17
94	32	32	35	35	37
96	49	49	55	57	65
98	67	66	75	100	135
100	—	—	100	—	—

Figure 6-3 shows the calculated fractional densities as a function of time at depths of 430, 515, and 600 meters using the combined mechanism model with the three different parameter sets. The results indicate that the crushed salt will reach 99-% of the density of intact salt within 300 years after emplacement, regardless of depth. The transition from deformation dominated by grain boundary diffusional pressure solution to dislocation creep at very high fractional densities (fractional densities greater than 99-%) is slower for the current parameter estimates than those predicted by Loken [1998] with an earlier derived combined database parameter set.

Figure 6-3 shows that the consolidation rate using the shear and combined test parameters deviates from Loken's results at a fractional density of approximately 98-%. As a result, the time required to consolidate crushed salt to the density of intact salt (fractional density of one) is greater for the shear and combined test parameter values than Loken [1998] computed. Specifically, the times predicted by the combined mechanism model to reach the density of intact salt at a depth of 600 meters are approximately 60 years and 170 years for the Loken [1998] calculations and shear test parameter values, respectively; whereas, the new combined test parameters did not predict full consolidation during the 450-year simulation period. Similar differences are observed at the shallower depths, as illustrated in Figure 6-3.

Figure 6-4 illustrates the time to reach 99.9-% of the intact density of salt predicted by the combined mechanism model as a function of depth for the three parameter sets. As shown in this figure, the time to compact the crushed salt is a nonlinear function of depth. The difference in the model predictions illustrated in this figure is caused by the different consolidation rates determined by the combined mechanism model for fractional densities greater than 98-%. For fractional densities less than 98-%, all models consolidate at approximately the same rate for a given depth, with higher consolidation rates calculated at greater depths as shown in Figure 6-3.

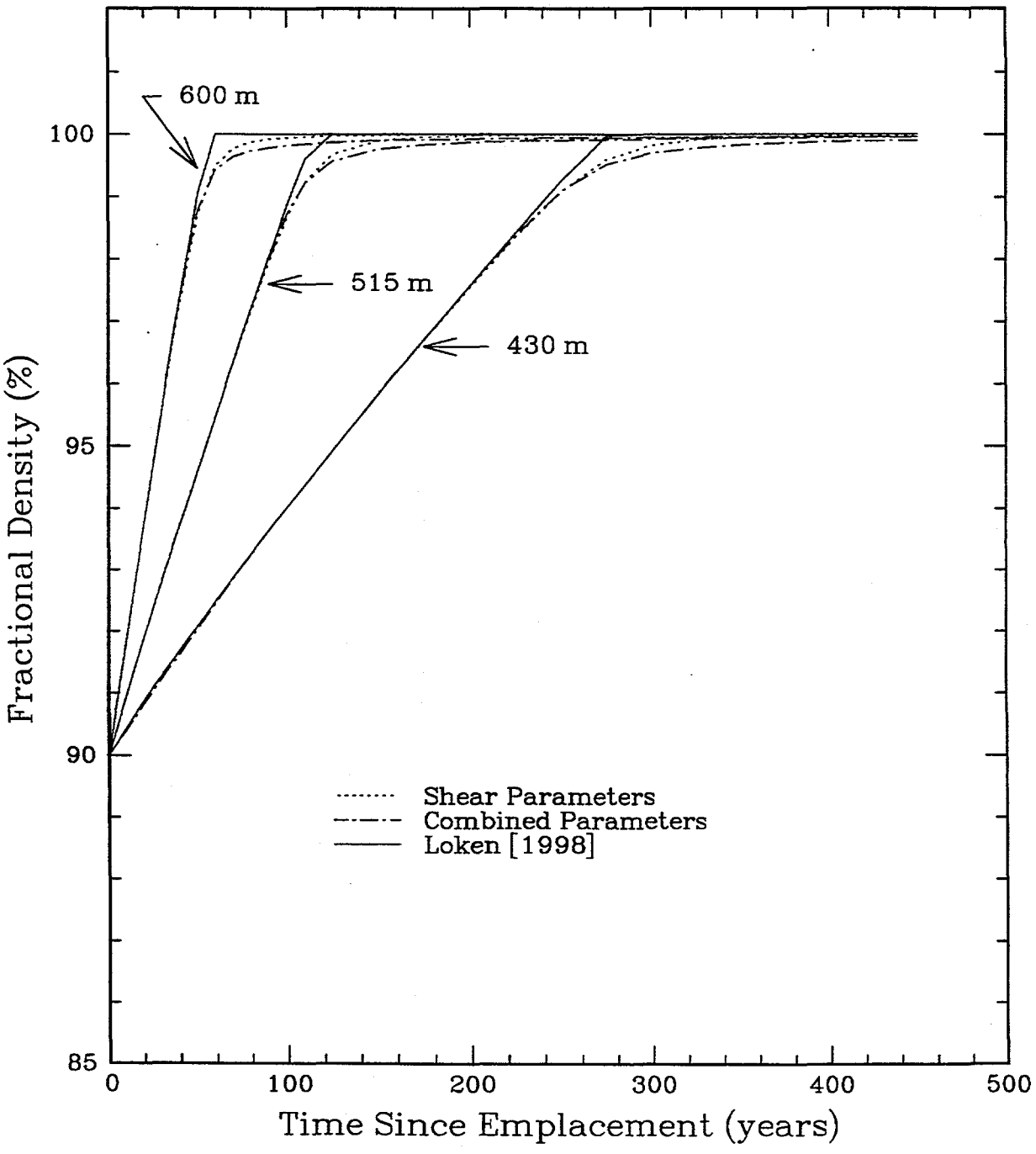

Figure 6-3. Fractional density as a function of time at depths of 430, 515, and 600 meters using the combined mechanism model.

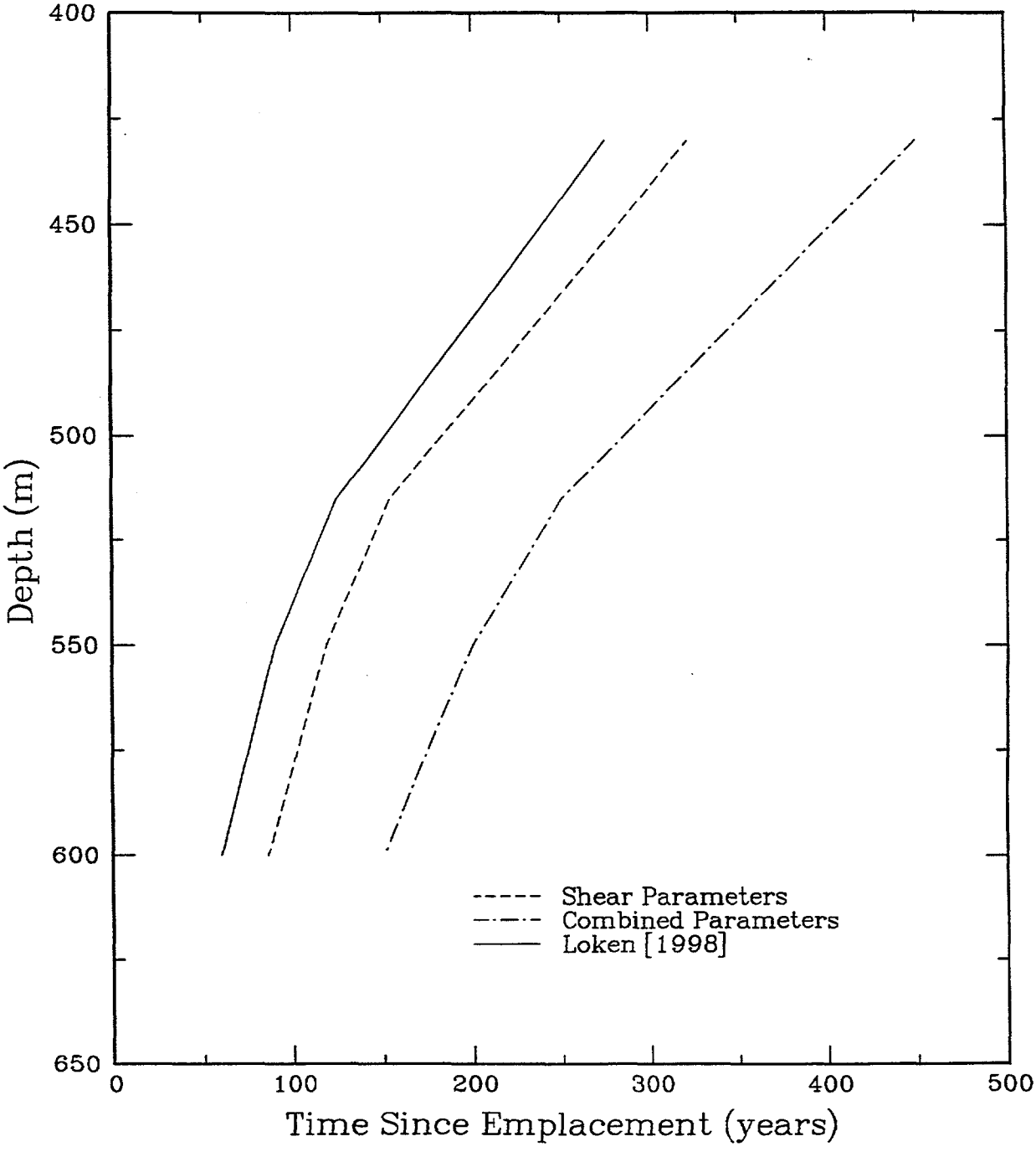

Figure 6-4. Time to consolidate to 99.9 percent fractional density as a function of depth using the combined mechanism model.

In summary, the consolidation rates predicted by the combined mechanism model for a shaft seal problem are nearly the same using the shear and combined parameter values as those predicted using the earlier derived combined parameter values for fractional densities less than 98 -%. For fractional densities above 98-%, significantly slower consolidation rates are predicted using the new parameter values, resulting in a smooth transition to intact salt behavior at full consolidation. Based on the results shown in these analyses, the consolidation rates at high fractional densities (densities greater than 98-% of the density of intact salt) are slightly greater using the shear database values than those predicted using the combined database values. Additionally, the consolidation rates predicted using the combined mechanism model are greater than the consolidation rates predicted using the modified Zeuch and Spiers models. The consolidation rate of the combined mechanism model can either be greater than or less than that predicted by the modified Sjaardema-Krieg model, depending on the fractional density. The modified Sjaardema-Krieg model predicts a nearly linear consolidation rate for all fractional densities; whereas, the consolidation rate predicted by the combined mechanism model is initially greater than that predicted by the modified Sjaardema-Krieg model but is significantly reduced at fractional densities greater than 98-%, which is more representative of observed laboratory data.

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7.0 SUMMARY AND CONCLUSIONS

Crushed salt is planned to be a major long-term component of the shaft seal system at the WIPP site. The crushed-salt seal gradually becomes effective over time as consolidation, caused by creep of the surrounding intact salt, produces shaft closure and loading of the crushed salt. The ability to predict creep consolidation of crushed salt has been important to the design and evaluation of WIPP seals and will undoubtedly be useful in the pending recertification required of the WIPP site. The work reported here represents a culmination of several laboratory and analytical studies devoted to constitutive models for crushed-salt reconsolidation. These earlier studies provided the theoretical bases and laboratory data that support the crushed-salt, combined-mechanism constitutive model. The prior studies, discussed in Section 1.2, have been documented in publications and reports and are summarized by Hansen et al. [1998].

In this study, additional laboratory tests were added to the crushed-salt database. Two new laboratory shear consolidation experiments were conducted with fractional densities near the initial fractional density expected in the dynamically compacted crushed-salt seal (approximately 0.9). These tests expand the database in the fractional density ranges expected in situ and provide information on the crushed-salt flow behavior as its density increases. The expanded database was fit to obtain material parameter values for the crushed-salt constitutive model. The results of the model fitting produced material parameter values representative of the entire database. Two separate fits were performed. The first fit used only the shear consolidation tests in the database, and the second fit used both the shear and hydrostatic consolidation tests. In our previous studies before development of the combined-mechanism model, dramatic changes in the parameter values were observed when the different tests were fit. In the present study, these separate fits produced similar parameter values, which indicates that the constitutive model is more representative of the physics of creep consolidation of crushed salt than were the previous models. These parameter values were used to validate the model against tests outside of the database with different load paths. Three constant strain-rate tests were predicted with the crushed-salt model and compared to the laboratory data. The predicted strains were found to compare quite well with laboratory results; whereas, the predicted axial stress was generally greater than the laboratory measured stresses. Application of the model was demonstrated for typical shaft sealing analysis problems, which illustrate the expected change in fractional density with time for different depths of the shaft seals.

As a result of this study, a constitutive model for crushed salt is available that contains the observed mechanisms for crushed-salt consolidation. When consolidation is complete, the model

predicts intact salt behavior. The model characterizes the experimental data quite well over a wide range of porosities and stress triaxialities and performs reasonably well for stress conditions and load paths outside of the database used for its development.

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APPENDIX A

INPUT FILES TO BMDP, NONLINEAR REGRESSION PROGRAMS 3R AND AR

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APPENDIX A

INPUT FILES TO BMDP, NONLINEAR REGRESSION PROGRAMS 3R AND AR

A.1 DESCRIPTION

The input files required to execute BMDP Program AR and 3R analyses are included in this appendix; specifically, three input files are included. The first file (FLOW.INP) is the input file to the BMDP Program 3R, which was used to determine the flow rate parameters. The second and third files (SHEAR.INP and COMB.INP) are the input files to BMDP Program AR. The input files were used to determine two sets of creep consolidation parameters fit to the shear consolidation database (SHEAR.INP) and the combined shear and hydrostatic consolidation database (COMB.INP).

Basically, the input files can be thought of as a series of paragraphs which are further subdivided into sentences using keywords. Each paragraph is activated by a backslash (/) followed immediately by a keyword. Each of these sentences is activated by keywords and ended with periods. All comment cards are noted using the pound symbol (#). These input files are composed of 12 paragraphs. The first paragraph (/INPUT) contains the title card, the database file name, the format to be used in reading the data, and the number of variables in the database. The second paragraph (/VARIABLES) names each of the 18 variables contained in the database file. The third paragraph (/TRANS) identifies the defined variables (or functions of variables) that are specific to the response model. Specifically, MS and DS are the mean stress and stress difference, respectively. Similarly, D0 and DI are the emplaced and initial fractional density, respectively. The variable USE identifies which test database is to be used in the fit, and the variable WT is the weight function. The fourth paragraph (/REGRESS) identifies the dependent variable (DEPEND), the number of parameters in the model, which variable is the weight function (WEIGHT), which variable number is the integration variable (ITIME) in the rate equations, the number of differential equations (NEQN), the number of iterations (ITER), the number of interval halvings for each iteration (HALVINGS), and the maximum number of integration steps (MAXC). The fifth paragraph (/PARAMETER) identifies the parameter names and the initial estimates, as well as the maximum and minimum values for each of the parameters. The sixth paragraph (/DIFIN) identifies the initial values for each of the dependent variables in the rate equations (Z(i),i=1,NEQN). The seventh paragraph (/DIFEQ) specifies the functional form of the rate equations (DZ(i), i=1,NEQN). The eighth paragraph (/FUN) identifies the dependent variable (response) function (F). The ninth through eleventh paragraphs (/SAVE, /PRINT, and /PLOT) specify output options for the program. The last paragraph (/END) identifies the end of the input file.

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```
#    file = M:\325\fit98\flowp\flow.inp
#
#          fit to shear consolidation tests only (itype = 2)
#
# ================================================================
#
#    This code uses the BMDP routine 3R to fit the equations
#    that describe the axial-to-lateral strain rate ratios and
#    determine parameter values for the flow potential.
#    The following variables are used:
#       1.  mean stress                              (MS)
#       2.  stress difference                        (DS)
#       3.  current density                          (RHO)
#       4.  axial stress                             (AS)
#       5.  lateral stress                           (LS)
#       6.  fractional density                       (D)
#       7.  axial strain rate                        (EAR)
#       8.  lateral strain rate                      (ELR)
#       9.  lateral-to-axial strain rate ratio       (RAT)
#
# ================================================================
#
# ------  INPUT PARAGRAPH
#
/INPUT
    TITLE = 'COMBINED MECHANISM MODEL FIT TO SHEAR LAT/AX STRAIN RATE'.
    FILE = 'M:\325\fit98\flowp\flow.dat'.          # Data file name
    FORMAT = '(2F10.2, E12.6, 2e15.5)'.
    VARIABLES = 5.
#
# ------  VARIABLES PARAGRAPH  ------
#
/VARIABLE
  NAMES=AS,LS,D,EAR,ELR.
#
# ------  TRANSFORMATION PARAGRAPH ------
#
/TRANS
     MS = (2.0*LS+AS)/3.0.     # mean stress, as=axial stress, ls=conf. pres.
     DS = LS - AS.             # stress difference
    RHO = D*2160.              # CURRENT density
    RAT = ELR/EAR.             # regression function

#    FIXED FLOW PARAMETERS

      KAP2 = 1.00.
      WT = 1.                   # uniform weight function
#
# ------  REGRESS PARAGRAPH  ------
#
/REGRESS
      DEPEND = RAT.             # Dependent variable
      PARAMETERS=4.             # Number of regression parameters
      WEIGHT = WT.              # WEIGHT VARIABLE
      ITER = 20.                # NUMBER OF ITERATIONS
      HALVINGS = 3.             # NUMBER OF INTERVAL HALVINGS
```

```
#
# ------  PARAMETERS PARAGRAPH  ------
#
#    Specify the names, initial estimates, and the range of the FOUR
# regression parameters, where KAP0, KAP1, DDT, AND NK determine the
# the equivalent stress measure for the flow potential.  KAP2 is fixed
# at a value of one so that the flow potential reproduces intact salt
# at complete consolidation (D=1).
#
/PARAMETER
     NAMES =   KAP0,KAP1,DDT,NK.

   INITIAL =   10.11891, 1.005131, .896281, 1.331212.

MINIMUM =   4 * 0.0.
MAXIMUM =   4 * 50.0.
#
# ------  SPECIFY FUNCTION  ------
#
/FUN
     IF(D LE DDT) THEN VAR = DDT.
     IF(D GT DDT) THEN VAR = D.
     NUM = (1 - VAR)*NK.
     DEN = (1 -(1-VAR)**(1/NK) ) ** NK.
     OMEGAK = (NUM/DEN) ** (2/(NK+1)).
     KAP = KAP0 * OMEGAK**KAP1.
    TERMK = ( (2-D)/D )**( 2*NK/(NK+1) ).

   ALPHA2 = KAP * MS/3.
    BETA2 = KAP2 * TERMK * DS.

     F2A = (ALPHA2 -     BETA2).
     F2L = (ALPHA2 + 0.5*BETA2).
       F = F2L/F2A.
#
# ------  SPECIFY VARIOUS PRINTING AND PLOTTING OPTIONS  ------
#
/SAVE
      FILE = 'M:\325\fit98\flowp\flow.SAV'.
      NEW.
      KEEP = rho,RAT.
      FORMAT = '(f10.3,5E12.3)'.
/PRINT
         FORMAT = E.
/PLOT
         RESIDUAL.
/END
```

```
#    file = m:\325\fit98\shear\SHEAR.inp
#
#          fit to shear consolidation tests only (itype = 2)
#
# ================================================================
#
#    This code uses the BMDP routine AR to fit the differential
#    equations that describe the axial and lateral strain in the
#    shear consolidation tests to determine the parameter values
#    for the crushed-salt, combined-mechanism constitutive model.
#    The parameter values for the flow potential are determined
#    first and then fixed during the fitting in this routine.
#    The parameter values for M-D consitutitve model are fixed at
#    the values for clean intact salt.  Ten parameter values
#    remain to be determined that describe the effective stress
#    measure (ETA0, ETA1, NA) with ETA2 fixed=1, the moisture and
#    grain size parameters (AA1, PP), and the pressure solutioning
#    parameter values (R1, R3, R4, QSR, NSP).   The independent
#    parameters are:
#       1.  mean stress                              (MS)
#       2.  stress difference                        (DS)
#       3.  emplaced fractional density              (D0)
#       4.  initial fractional density               (DI)
#       5.  grain size                               (DD)
#       6.  absolute temperature                     (T)
#       7.  moisture content                         (W)
#
# ================================================================
#
# ------  INPUT PARAGRAPH
#
/INPUT
    TITLE = 'Combined-Mechanism Model fit to shear consolidation tests'.
    FILE = 'm:\325\fit98\shear\shear.dat'.        # Test data file name
    FORMAT = '(2I3,3F10.0,F6.1,2F9.4,4F9.5,F9.3,F9.6,2F9.3,F5.2,F7.2)'.
    VARIABLES = 18.
#
# ------  VARIABLES PARAGRAPH  ------
#
/VARIABLE
  NAMES=ICASE,ITEST,TIME,DT,TF,TEMP,AS,LS,EVT,EVC,EAT,EAC,RHO,D,RHO0,RHOI,DD,W.
#
# ------  TRANSFORMATION PARAGRAPH ------
#
/TRANS
      MS = (2.0*LS+AS)/3.0.     # mean stress, as=axial stress, ls=conf. pres.
      DS = LS - AS.             # stress difference
     ELC = (EVC - EAC)/2.       # lateral strain, evt=vol. strain, eat=ax.strain
      D0 = 1382.4/2160.         # emplaced fractional density
      DI = RHOI/2160.           # initial fractional density
     ONE = 1.0.                 # regression function

#    FLOW POTENTIAL PARAMETER VALUES

     KAP0 = 10.119.
     KAP1 =  1.005.
```

```
      KAP2 =  1.0.
        NK =  1.3312.
       DDT =  0.8963.

#   17 MUNSON-DAWSON CREEP PARAMETERS FOR CLEAN SALT (FIXED)

      A1 = 8.386E+22.
      A2 = 9.672E+12.
     Q1R = 12581.
     Q2R = 5033.
      N1 = 5.5.
      N2 = 5.0.
      B1 = 6.0856E+6.
      B2 = 3.034E-2.
       Q = 5335.
      S0 = 20.57.
       M = 3.
      K0 = 6.275E+5.
       C = 9.198E-3.
   ALPHA = -17.37.
    BETA = -7.738.
   DELTA = 0.58.
      MU = 12400.                  # SHEAR MODULUS

#   FIX VALUE OF KAP2 AT ONE

    ETA2 = 1.0.

#    WEIGHT FUNCTIONS

      WT1 = DT/1.E+6.
      WT = 1.0.                    # uniform weight function

#    ESTIMATE GRAIN SIZE FOR DCCS TESTS

      DC = DD.
      IF(KASE GT 1200) THEN DC = 0.5.
#
# ------  REGRESS PARAGRAPH  ------
#
/REGRESS
       DEPEND = ONE.               # Dependent variable
       PARAMETERS=10.              # Number of regression parameters
       WEIGHT = WT.                # WEIGHT VARIABLE
       ITIME = 3.                  # INTEGRATION VARIABLE NUMBER
       NEQN = 3.                   # Number of differential equations
       ITER = 20.                  # NUMBER OF ITERATIONS
       HALVINGS = 3.               # NUMBER OF INTERVAL HALVINGS
       MAXC = 300000.              # MAXIMUM NUMBER OF TIMES 'DIFEQ' IS USED
       PRINT = 0.                  # SUPPRESS PRINT ASSOCIATED WITH VARIABLES
#
# ------  PARAMETERS PARAGRAPH  ------
#
#    Specify the names, initial estimates, and the range of the ten
# regression parameters, where R1 is the over all leading parameter; R3, R4,
# and N are strain dependent parameters; KAPPA0, KAPPA1, KAPPA2, N determine
```

```
# the equivalent stress measure for the flow-rule; ETA0, ETA1, ETA2, and Nf
# determine the equivalent stress measure in strain rate measure; A
# is water-content dependent parameters; P defines grain size dependence;
# and QSR defines temperature effect.
#
/PARAMETER

     NAMES =     ETA0,         ETA1,       NA,
                 AA1,           PP,       NSP,
                  R1,           R3,        R4,       QSR.

   INITIAL =  .102854,       3.9387,    3.5122,
               0.3147,       1.6332,   .557621,
              8.69760,      15.1281,   .167765,    2897.09.

     FIXED = QSR.

MINIMUM =     3 * 0.0,    0.3147,    6 * 0.0.
MAXIMUM =    10 * 5000.0.
DELTA   =     9 * 0.001,  1.0.

# ------  INITIAL VALUES FOR DIFERENTIAL EQUATIONS  ------
#
/DIFIN
      Z1 = EAC.
      Z2 = ELC.
      Z3 = 0.
#
# ------  SPECIFY THE DIFFERENTIAL EQUATION  ------
#
/DIFEQ
     IF(TIME NE 0) THEN (

      VOL = Z1 + 2*Z2.
     VOLT = VOL + LN(0.64/DI).
      DEN = DI / EXP(VOL).

  IF(DEN GE 1.0) THEN (
       MD = 0.
       SP = 0. ).

  IF(DEN LT 1.0) THEN (

     IF(DEN LE DDT) THEN VAR = DDT.
     IF(DEN GT DDT) THEN VAR = DEN.
     OMEGAA = ((1.-DEN)*NA / (1-(1-DEN)**(1/NA))**NA)**(2/(NA+1)).
     OMEGAK = ((1.-VAR)*NK / (1-(1-VAR)**(1/NK))**NK)**(2/(NK+1)).
        ETA = ETA0 * OMEGAA**ETA1.
        KAP = KAP0 * OMEGAK**KAP1.
       TERMA = ((2-DEN)/DEN)**(2*NA/(NA+1)).
       TERMK = ((2-DEN)/DEN)**(2*NK/(NK+1)).
        SEQF = SQRT(ETA * MS**2 + ETA2 * TERMA * DS**2).
        SEQ  = SQRT(KAP * MS**2 + KAP2 * TERMK * DS**2).

     ALPHA2 = KAP * MS/3.
      BETA2 = KAP2 * TERMK * DS.
```

```
      F2A = (ALPHA2 -     BETA2) / SEQ.
      F2L = (ALPHA2 + 0.5*BETA2) / SEQ.

      ES1 = A1*(SEQF/MU)**N1 * EXP (-Q1R / TEMP).
      ES2 = A2*(SEQF/MU)**N2 * EXP (-Q2R / TEMP).
      ES3 = 0.

      IF(SEQF GT S0) THEN (
        ARG = Q * (SEQF-S0)/MU.
        ES3 = 0.5*( B1*EXP(-Q1R/TEMP) + B2*EXP(-Q2R/TEMP) )
            * ( EXP(ARG) - EXP(-ARG) ) .).

       ESS = ES1 + ES2 + ES3.

       EFT = K0*EXP(C*TEMP)*(SEQF/MU)**M.
      BIGD = ALPHA + BETA * LOG(SEQF/MU).

      IF(Z3 LT EFT) THEN FU = EXP(  BIGD*(1-Z3/EFT)**2).
      IF(Z3 EQ EFT) THEN FU = 1.
      IF(Z3 GT EFT) THEN FU = EXP(-DELTA*(1-Z3/EFT)**2).

      MD = FU * ESS.

      CR = ABS(EXP(VOLT)-1).

      IF(CR LE 0.15) THEN GAMMA = 1.0.
      IF(CR GT 0.15) THEN (
         GAMMA = (ABS((D0-EXP(VOLT))/((1-D0)*EXP(VOLT))))**NSP. ).

      X3 = EXP((R3-1)*VOLT)/(ABS(1-EXP(VOLT)))**R4.

      IF(W EQ 0) THEN M2 = 0.
      IF(W GE 0) THEN M2 = W**AA1.
      G2 = 1/DC**PP.
      T2 = EXP(-QSR/TEMP)/TEMP.

      SP = R1*M2*G2*T2*X3*GAMMA*SEQF.).

     DZ1 = (MD + SP) * F2A.
     DZ2 = (MD + SP) * F2L.
     DZ3 = (FU-1) * ESS.    ).

     IF(TIME EQ 0) THEN (

     DZ1 = 0.
     DZ2 = 0.
     DZ3 = 0.    ).
#
#  ------  SPECIFY THE DEPENDENT VARIABLE FUNCTION
#
/FUN
  IF(TIME NE 0.) THEN (
     AA = Z1/EAC.
     BB = Z2/ELC.
      F = 1.0- SQRT(((1-AA)**2 + (1-BB)**2)*WT1). ).
```

```
    IF(TIME EQ 0.) THEN (
       NEW = 0.
        Z1 = EAC.
        Z2 = ELC.
        Z3 = 0.
         F = 1.0. ).
#
# ——— SPECIFY VARIOUS PRINTING AND PLOTTING OPTIONS ———
#
/SAVE
      FILE = 'm:\325\fit98\shear\shear.SAV'.
      NEW.
      KEEP = TIME,ONE.
      FORMAT = '(5E15.4)'.
#/PRINT
#          FORMAT = E.
#/PLOT
#          RESIDUAL.
/END
```

```
#     file = m:\325\fit98\comb\comb.inp
#
#     Fit to hydrostatic and shear consolidation tests (icase = 1 & 2)
#
# ================================================================
#
#     This code uses the BMDP routine AR to fit the differential
#     equations that describe the axial and lateral strain in the
#     both the hydrostatic consolidation tests and the
#     shear consolidation tests to determine the parameter values
#     for the crushed-salt, combined-mechanism constitutive model.
#     The parameter values for the flow potential are determined
#     first and then fixed during the fitting in this routine.
#     The parameter values for the M-D consitutitve model are fixed
#     at the values for clean intact salt.  Ten parameter values
#     remain to be determined that describe the effective stress
#     measure (ETA0, ETA1, NF) with ETA2 fixed=1, the moisture and
#     grain size parameters (AA1, PP), and the pressure solutioning
#     parameter values (R1, R3, R4, QSR, NSP).   The independent
#     parameters are:
#        1.  mean stress                              (MS)
#        2.  stress difference                        (DS)
#        3.  emplaced fractional density              (D0)
#        4.  initial fractional density               (DI)
#        5.  grain size                               (DC)
#        6.  absolute temperature                     (T)
#        7.  moisture content                         (W)
#
# ================================================================
#
# ------  INPUT PARAGRAPH
#
/INPUT
    TITLE = 'Combined-Mechanism Model fit to combined consolidation tests'.
    FILE = 'm:\325\fit98\comb\comb.dat'.        # Test data file name
    FORMAT = '(2I3,3F10.0,F6.1,2F9.4,4F9.5,F9.3,F9.6,2F9.3,F5.2,F7.2)'.
    VARIABLES = 18.
#
# ------  VARIABLES PARAGRAPH  ------
#
/VARIABLE
  NAMES=ICASE,ITEST,TIME,DT,TF,TEMP,AS,LS,EVT,EVC,EAT,EAC,RHO,D,RHO0,RHOI,DC,W.
#
# ------  TRANSFORMATION PARAGRAPH ------
#
/TRANS
      MS = (2.0*LS+AS)/3.0.     # mean stress, as=axial stress, ls=conf. pres.
      DS = LS - AS.             # stress difference
     ELC = (EVC - EAC)/2.       # lateral strain, evt=vol. strain, eat=ax.strain
      D0 = 1382.4/2160.         # emplaced fractional density
      DI = RHOI/2160.           # initial fractional density
     ONE = 1.0.                 # regression function

#    FLOW POTENTIAL PARAMETER VALUES

     KAP0 = 10.119.
```

```
      KAP1 =  1.005.
      KAP2 =  1.0.
        NK =  1.3312.
       DDT =  0.8963.

#   17 MUNSON-DAWSON CREEP PARAMETERS FOR CLEAN SALT (FIXED)

      A1 = 8.386E+22.
      A2 = 9.672E+12.
     Q1R = 12581.
     Q2R = 5033.
      N1 = 5.5.
      N2 = 5.0.
      B1 = 6.0856E+6.
      B2 = 3.034E-2.
       Q = 5335.
      S0 = 20.57.
       M = 3.
      K0 = 6.275E+5.
       C = 9.198E-3.
   ALPHA = -17.37.
    BETA = -7.738.
   DELTA = 0.58.
      MU = 12400.                  # SHEAR MODULUS

#   FIX VALUE OF KAP2 AT ONE

    ETA2 = 1.0.

#    WEIGHT FUNCTIONS

      WT1 = DT/1.E+6.
      WT = 1.0.                    # uniform weight function
#
# ------  REGRESS PARAGRAPH  ------
#
/REGRESS
       DEPEND = ONE.               # Dependent variable
       PARAMETERS=10.              # Number of regression parameters
       WEIGHT = WT.                # WEIGHT VARIABLE
       ITIME = 3.                  # INTEGRATION VARIABLE NUMBER
       NEQN = 3.                   # Number of differential equations
       ITER = 1.                   # NUMBER OF ITERATIONS
       HALVINGS = 3.               # NUMBER OF INTERVAL HALVINGS
       MAXC = 300000.              # MAXIMUM NUMBER OF TIMES 'DIFEQ' IS USED
       PRINT = 0.                  # SUPPRESS PRINT ASSOCIATED WITH VARIABLES
#
# ------  PARAMETERS PARAGRAPH  ------
#
#    Specify the names, initial estimates, and the range of the ten
# regression parameters, where R1 is the over all leading parameter; R3, R4,
# and N are strain dependent parameters; KAPPA0, KAPPA1, KAPPA2, N determine
# the equivalent stress measure for the flow-rule; ETA0, ETA1, ETA2, and Nf
# determine the equivalent stress measure in strain rate measure; A
# is water-content dependent parameters; P defines grain size dependence;
# and QSR defines temperature effect.
```

```
#
/PARAMETER

     NAMES =     ETA0,          ETA1,        NF,
                  AA1,           PP,        NSP,
                   R1,           R3,         R4,        QSR.

   INITIAL =   0.01399,       3.38812,    3.96597,
               0.00001,       1.03407,    1.53176,
               0.33690,       0.12857,    0.16797,    2897.087.

MINIMUM =     0.01,  2 * 0.0,  1.0E-6,  3 * 0.0, 1.E-5,  0.10,   0.0.
MAXIMUM =    10 * 5000.0.
DELTA   =     9 * 0.001,  1.0.

#
# ------  INITIAL VALUES FOR DIFERENTIAL EQUATIONS  ------
#
/DIFIN
      Z1 = EAC.
      Z2 = ELC.
      Z3 = 0.
#
# ------  SPECIFY THE DIFFERENTIAL EQUATION  ------
#
/DIFEQ
     IF(TIME NE 0) THEN (

      VOL = Z1 + 2*Z2.
     VOLT = VOL + LN(0.64/DI).
      DEN = DI / EXP(VOL).

  IF(DEN GE 1.0) THEN (
       MD = 0.
       SP = 0. ).

  IF(DEN LT 1.0) THEN (

      IF(DEN LE DDT) THEN VAR = DDT.
      IF(DEN GT DDT) THEN VAR = DEN.
      OMEGAA = ((1.-DEN)*NF / (1-(1-DEN)**(1/NF))**NF)**(2/(NF+1)).
      OMEGAK = ((1.-VAR)*NK / (1-(1-VAR)**(1/NK))**NK)**(2/(NK+1)).
         ETA = ETA0 * OMEGAA**ETA1.
         KAP = KAP0 * OMEGAK**KAP1.
       TERMA = ((2-DEN)/DEN)**(2*NF/(NF+1)).
       TERMK = ((2-DEN)/DEN)**(2*NK/(NK+1)).
        SEQF = SQRT(ETA * MS**2 + ETA2 * TERMA * DS**2).
        SEQ  = SQRT(KAP * MS**2 + KAP2 * TERMK * DS**2).

      ALPHA2 = KAP * MS/3.
       BETA2 = KAP2 * TERMK * DS.

       F2A = (ALPHA2 -     BETA2) / SEQ.
       F2L = (ALPHA2 + 0.5*BETA2) / SEQ.

       ES1 = A1*(SEQF/MU)**N1 * EXP (-Q1R / TEMP).
```

```
        ES2 = A2*(SEQF/MU)**N2 * EXP (-Q2R / TEMP).
        ES3 = 0.

        IF(SEQF GT S0) THEN (
          ARG = Q * (SEQF-S0)/MU.
          ES3 = 0.5*( B1*EXP(-Q1R/TEMP) + B2*EXP(-Q2R/TEMP) )
              * ( EXP(ARG) - EXP(-ARG) ) .).

         ESS = ES1 + ES2 + ES3.

         EFT = K0*EXP(C*TEMP)*(SEQF/MU)**M.
        BIGD = ALPHA + BETA * LOG(SEQF/MU).

        IF(Z3 LT EFT) THEN FU = EXP(  BIGD*(1-Z3/EFT)**2).
        IF(Z3 EQ EFT) THEN FU = 1.
        IF(Z3 GT EFT) THEN FU = EXP(-DELTA*(1-Z3/EFT)**2).

        MD = FU * ESS.

        CR = ABS(EXP(VOLT)-1).

        IF(CR LE 0.15) THEN GAMMA = 1.0.
        IF(CR GT 0.15) THEN (
           GAMMA = (ABS((D0-EXP(VOLT))/((1-D0)*EXP(VOLT))))**NSP. ).

        X3 = EXP((R3-1)*VOLT)/(ABS(1-EXP(VOLT)))**R4.

        IF(W EQ 0) THEN M2 = 0.
        IF(W GE 0) THEN M2 = W**AA1.
        G2 = 1/DC**PP.
        T2 = EXP(-QSR/TEMP)/TEMP.

        SP = R1*M2*G2*T2*X3*GAMMA*SEQF.).

       DZ1 = (MD + SP) * F2A.
       DZ2 = (MD + SP) * F2L.
       DZ3 = (FU-1) * ESS.    ).

       IF(TIME EQ 0) THEN (

       DZ1 = 0.
       DZ2 = 0.
       DZ3 = 0.    ).
#
#  ------  SPECIFY THE DEPENDENT VARIABLE FUNCTION
#
/FUN
  IF(TIME NE 0.) THEN (
     AA = Z1/EAC.
     BB = Z2/ELC.
      F = 1.0- SQRT(((1-AA)**2 + (1-BB)**2)*WT1). ).
  IF(TIME EQ 0.) THEN (
     NEW = 0.
      Z1 = EAC.
      Z2 = ELC.
      Z3 = 0.
```

```
        F = 1.0. ).
 #
 # ------  SPECIFY VARIOUS PRINTING AND PLOTTING OPTIONS  ------
 #
 /SAVE
       FILE = 'm:\325\fit98\comb\comb.sav'.
       NEW.
       KEEP = TIME,ONE.
       FORMAT = '(5E15.4)'.
 #/PRINT
 #           FORMAT = E.
 #/PLOT
 #           RESIDUAL.
 /END
```

APPENDIX B

LATERAL-TO-AXIAL STRAIN-RATE RATIO MODEL FITS TO THE SHEAR CONSOLIDATION TESTS

This appendix contains the plots of the model fits to the 18 shear consolidation tests used to determine the flow potential parameters. Each plot shows the measured and predicted lateral-to-axial strain-rate ratios as a function of density for each of the 18 tests. Test conditions included on the figures correspond to the target test conditions given in Table 3-2.

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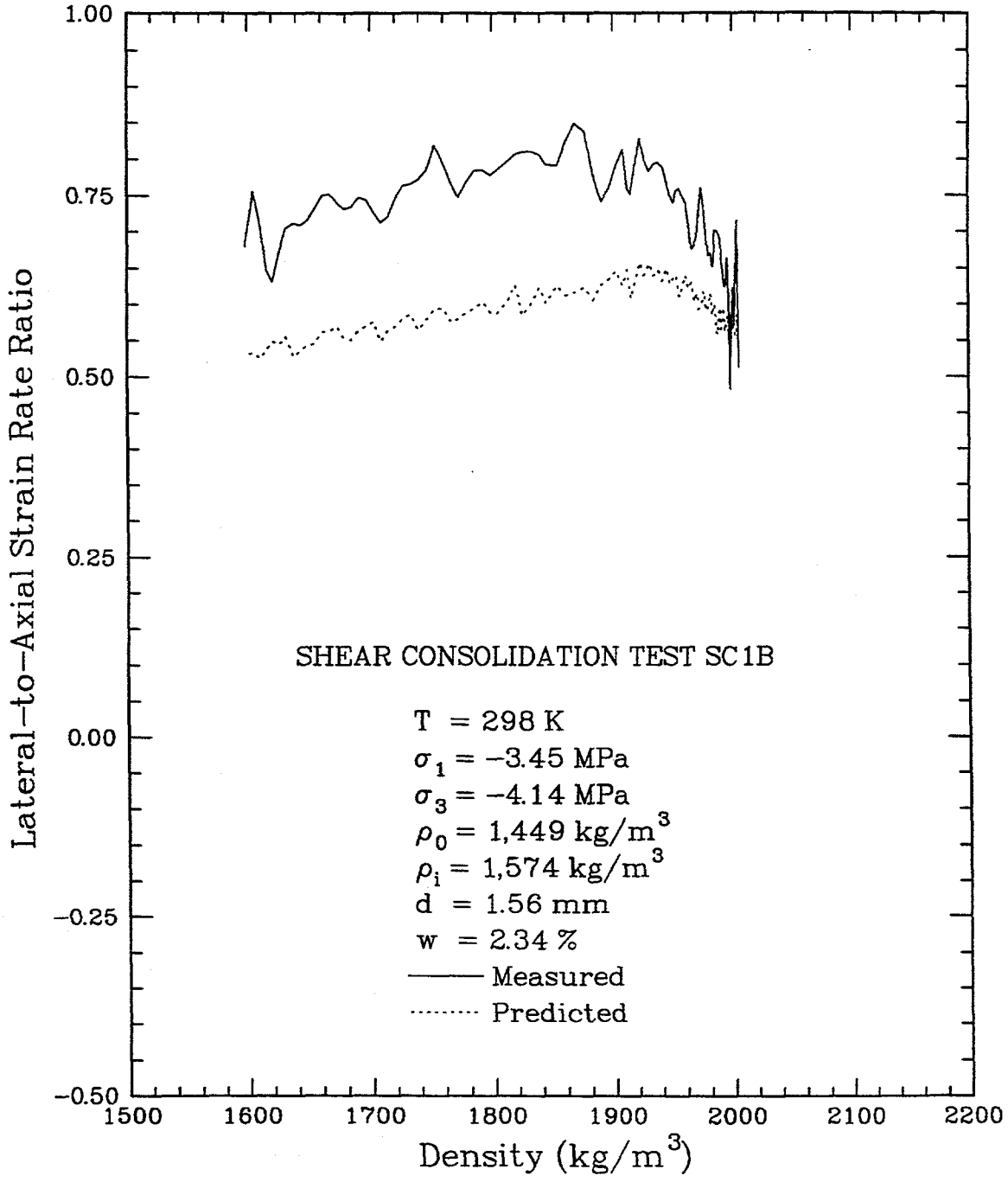

Figure B-1. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test SC1B.

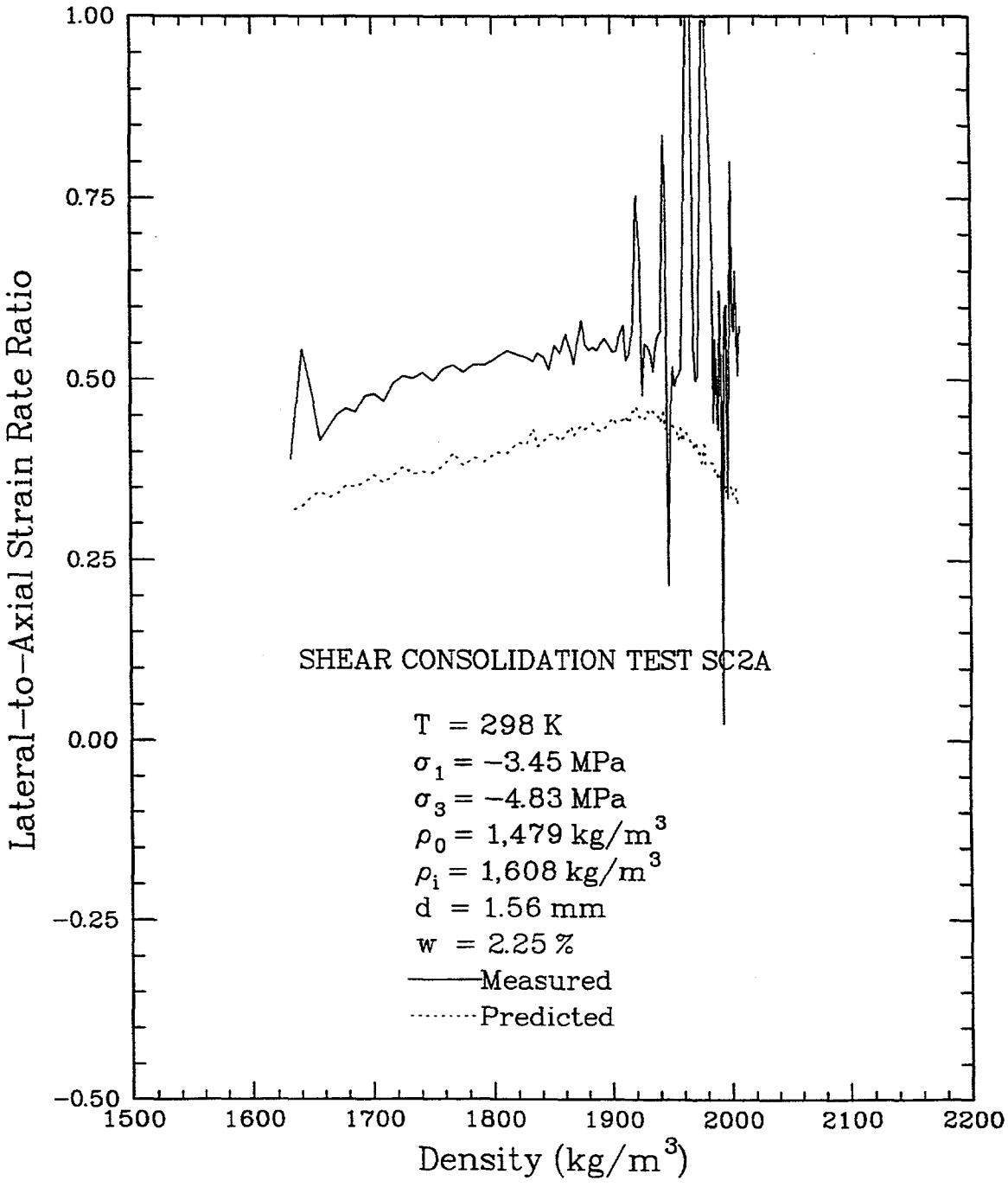

Figure B-2. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test SC2A.

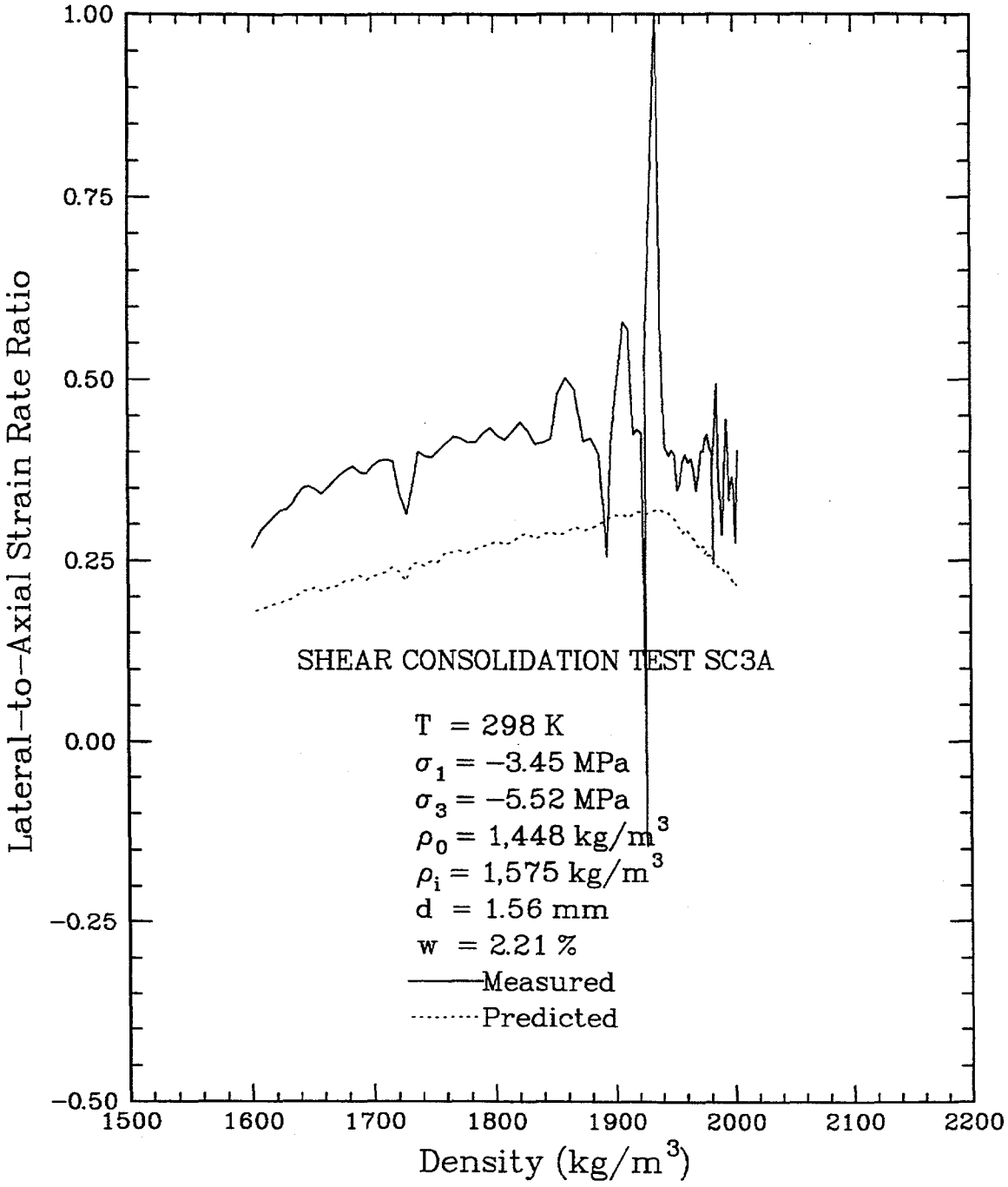

Figure B-3. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test SC3A.

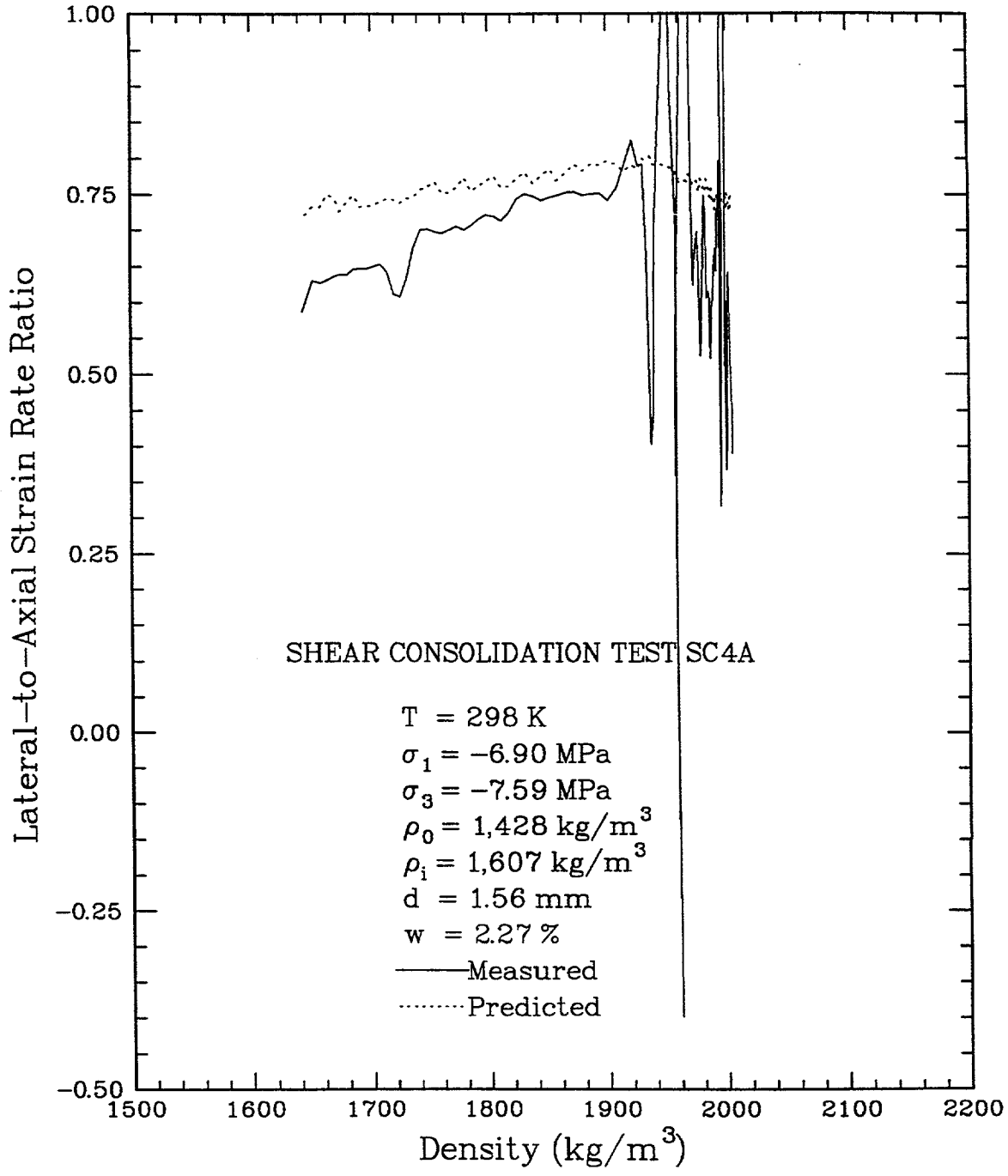

Figure B-4. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test SC4A.

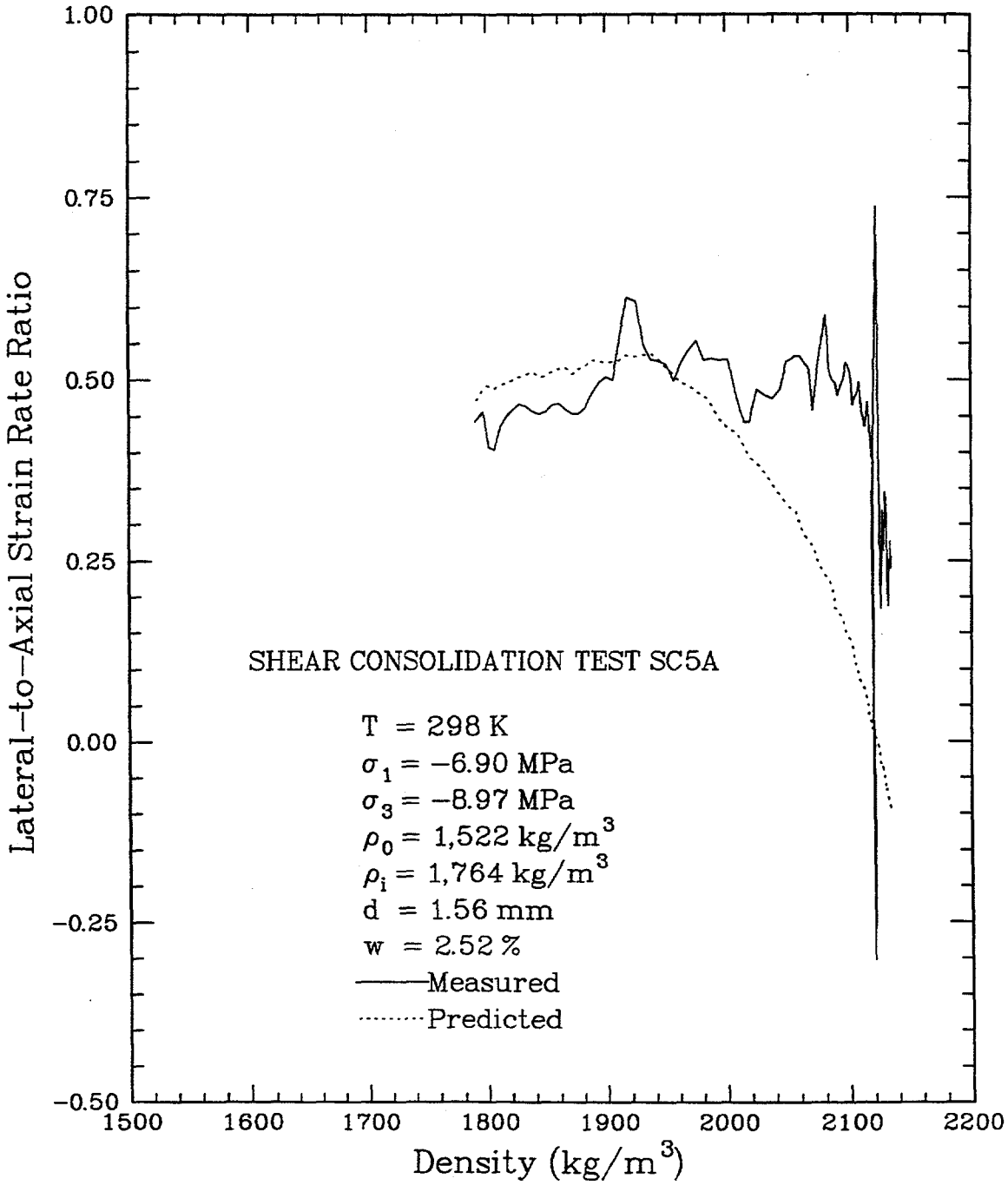

Figure B-5. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test SC5A.

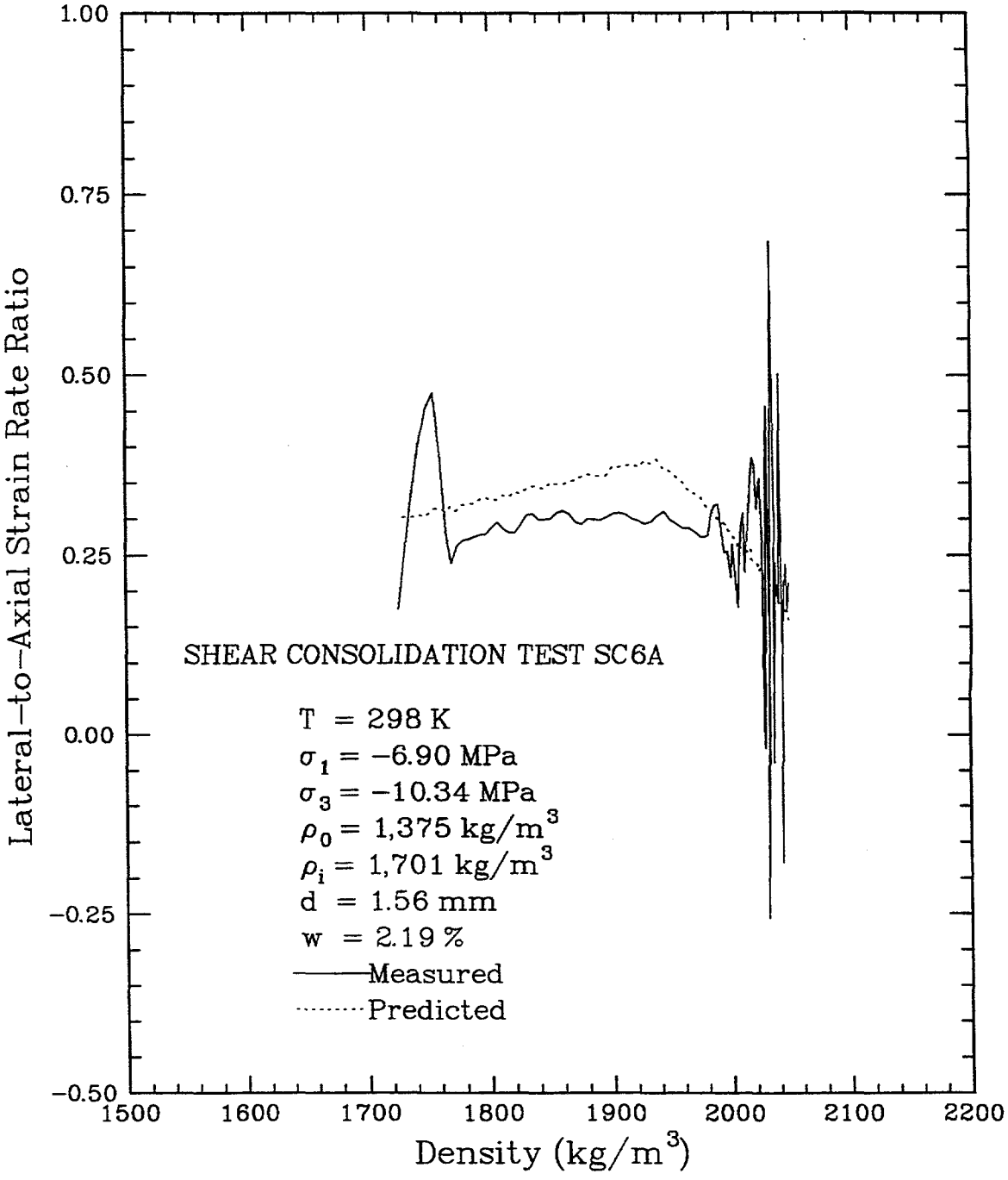

Figure B-6. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test SC6A.

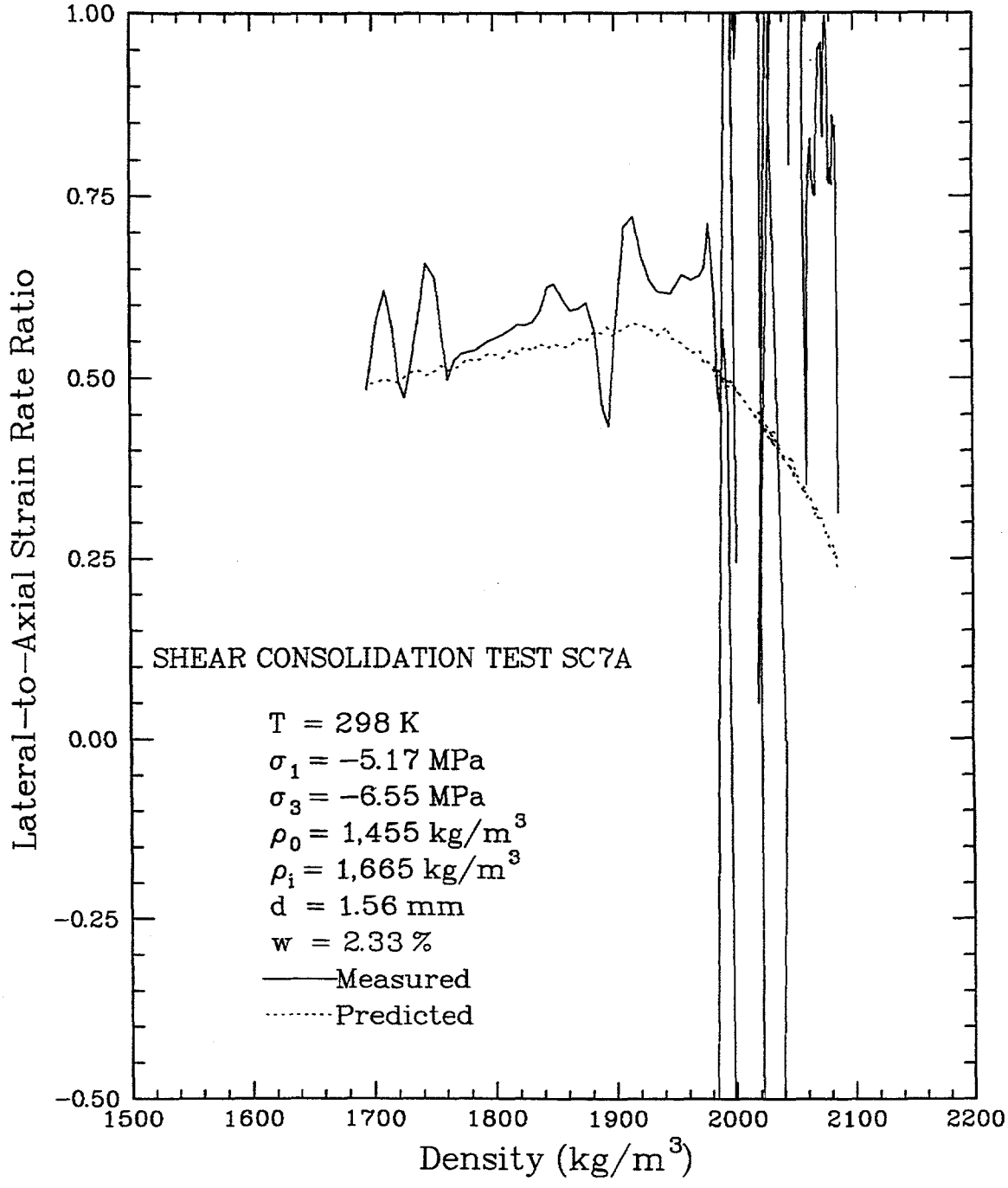

Figure B-7. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test SC7A.

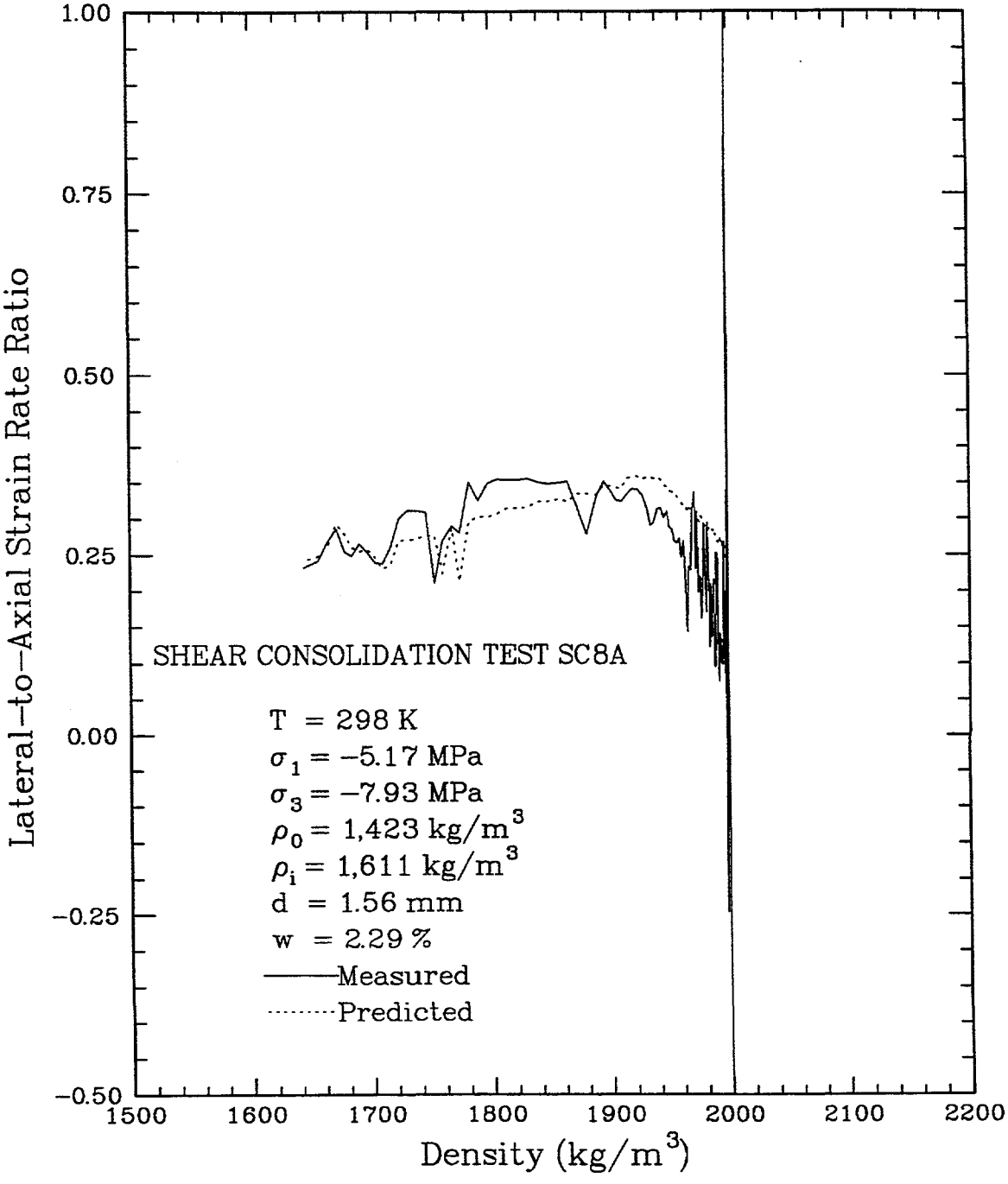

Figure B-8. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test SC8A.

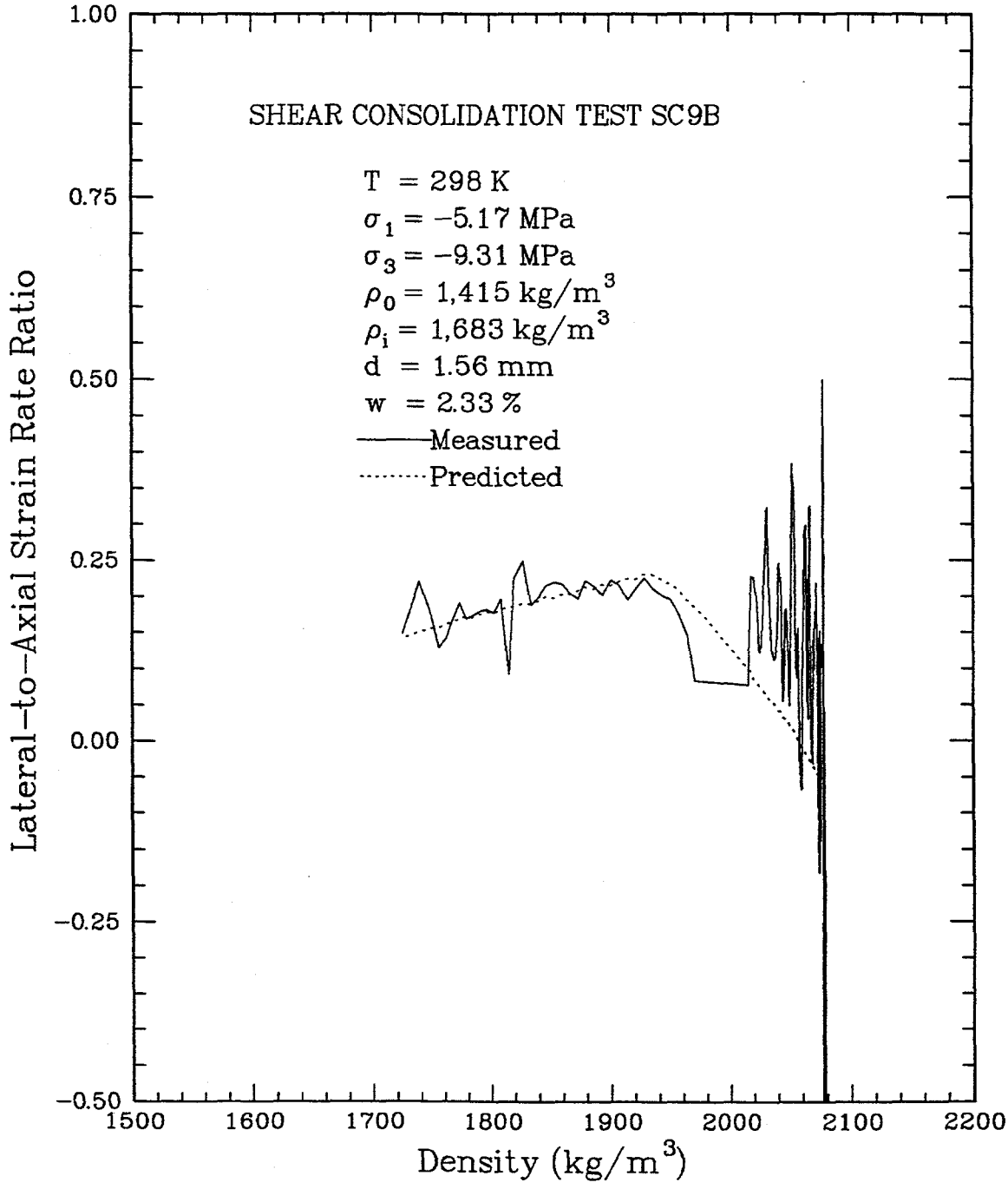

Figure B-9. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test SC9B.

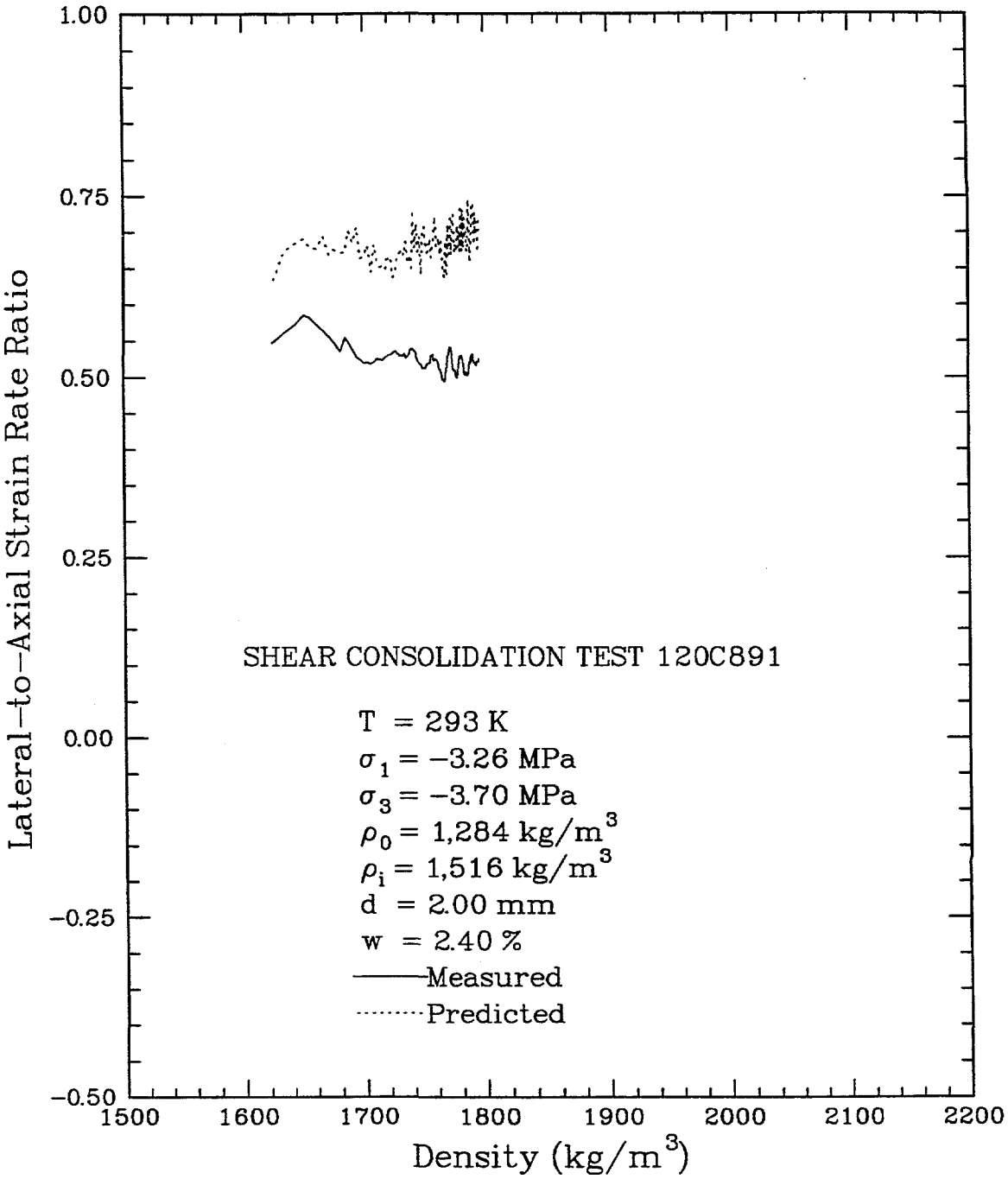

Figure B-10. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test 120C891.

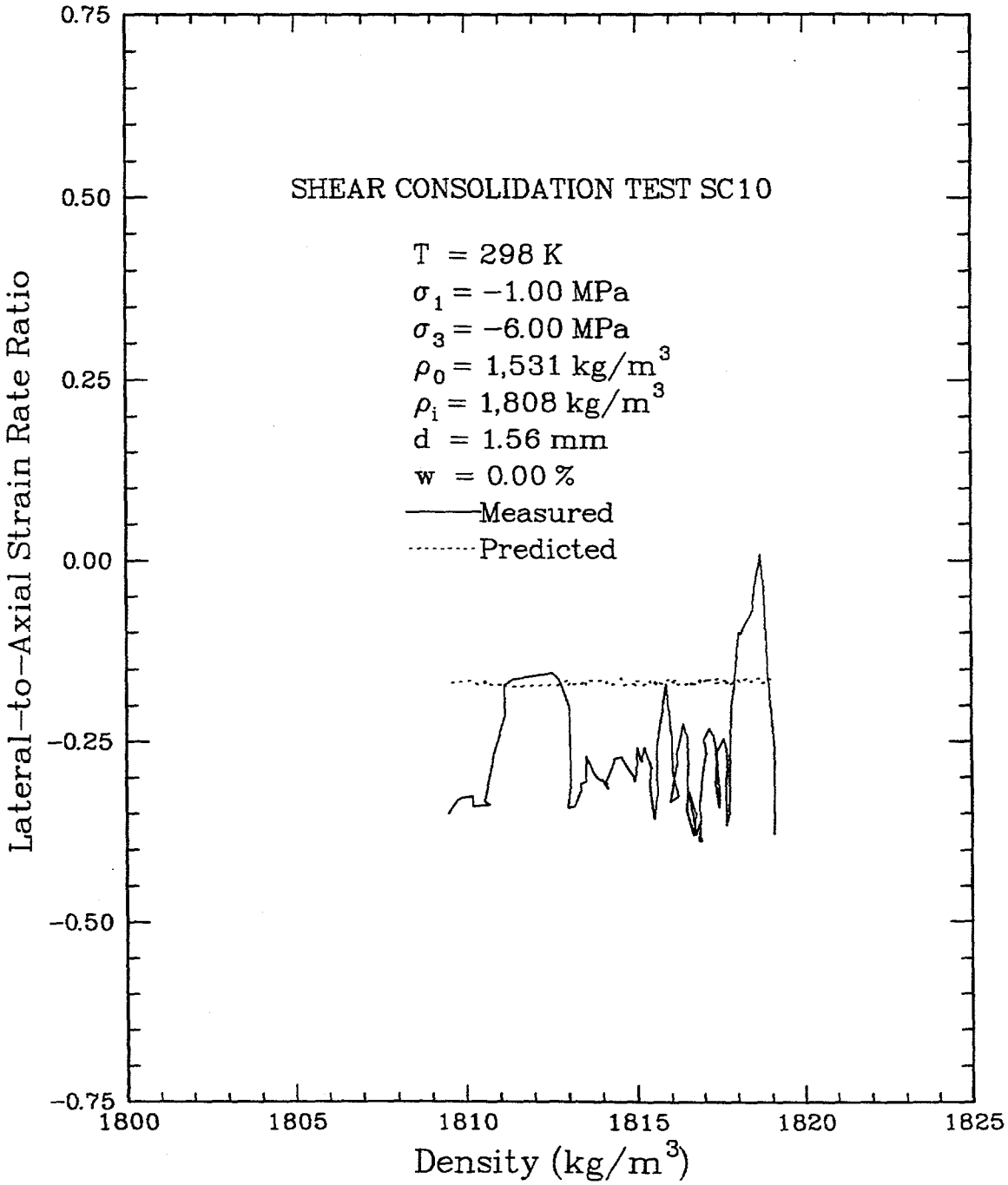

Figure B-11. **Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test SC10.**

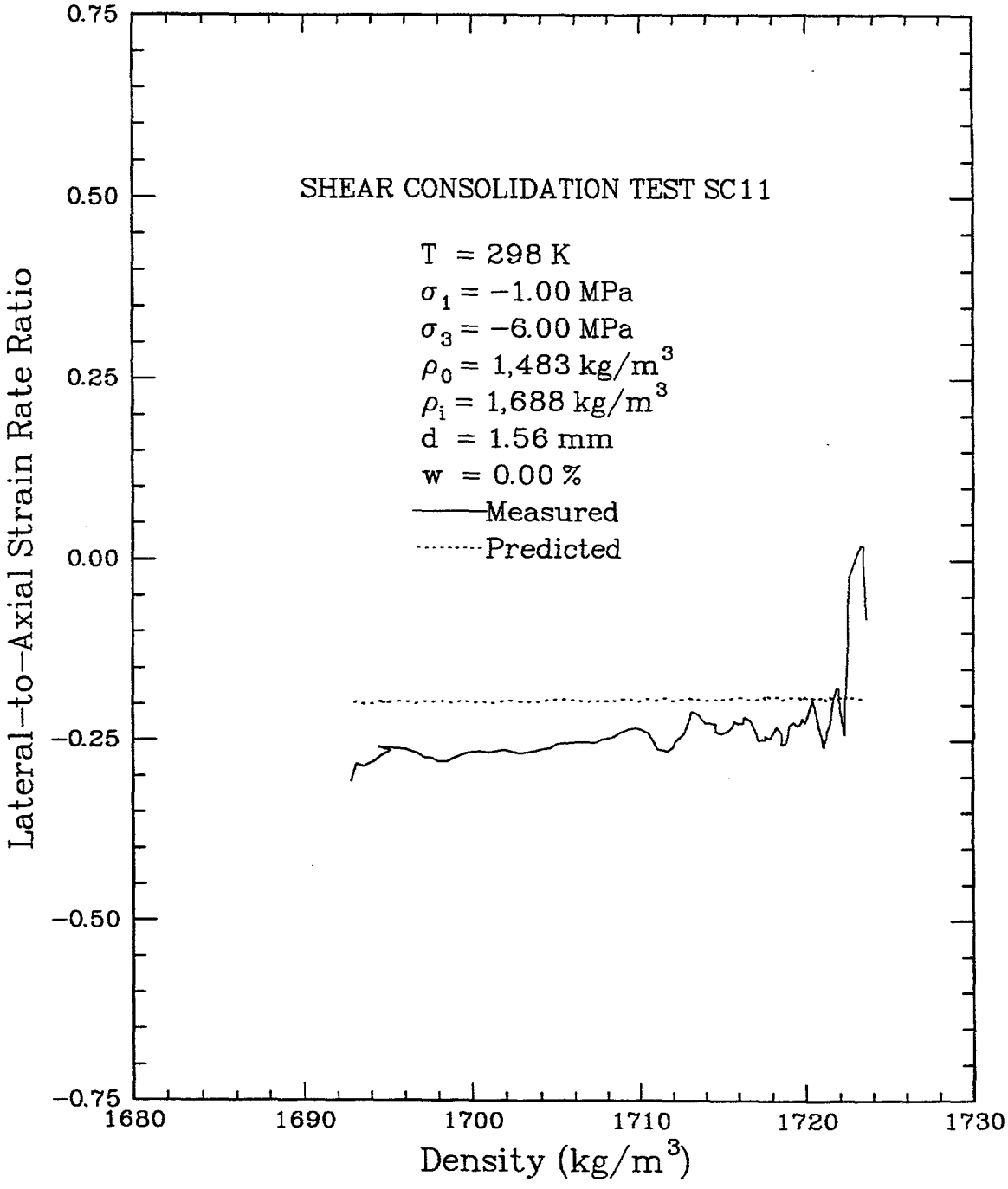

Figure B-12. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test SC11.

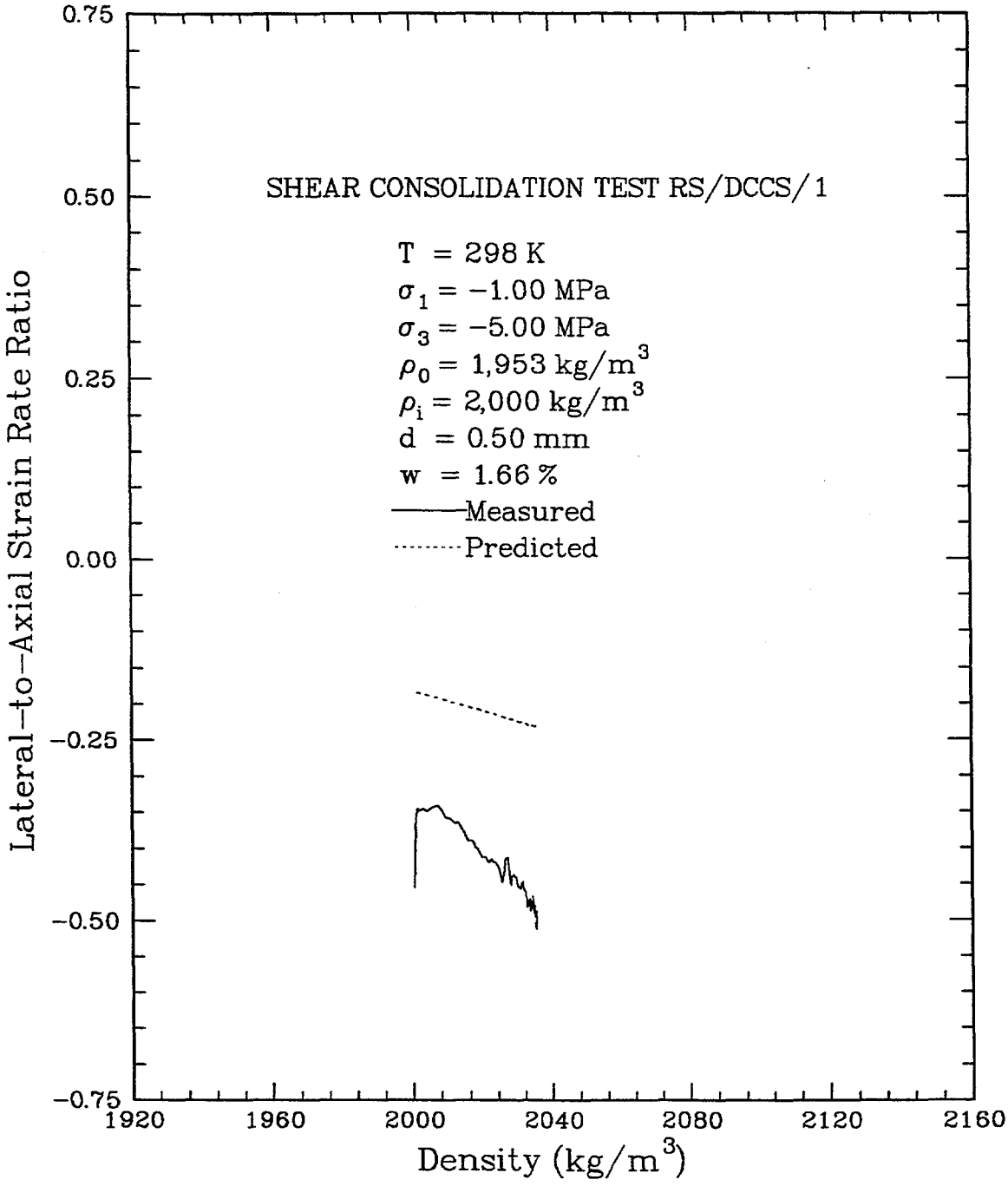

Figure B-13. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test RS/DCCS/1.

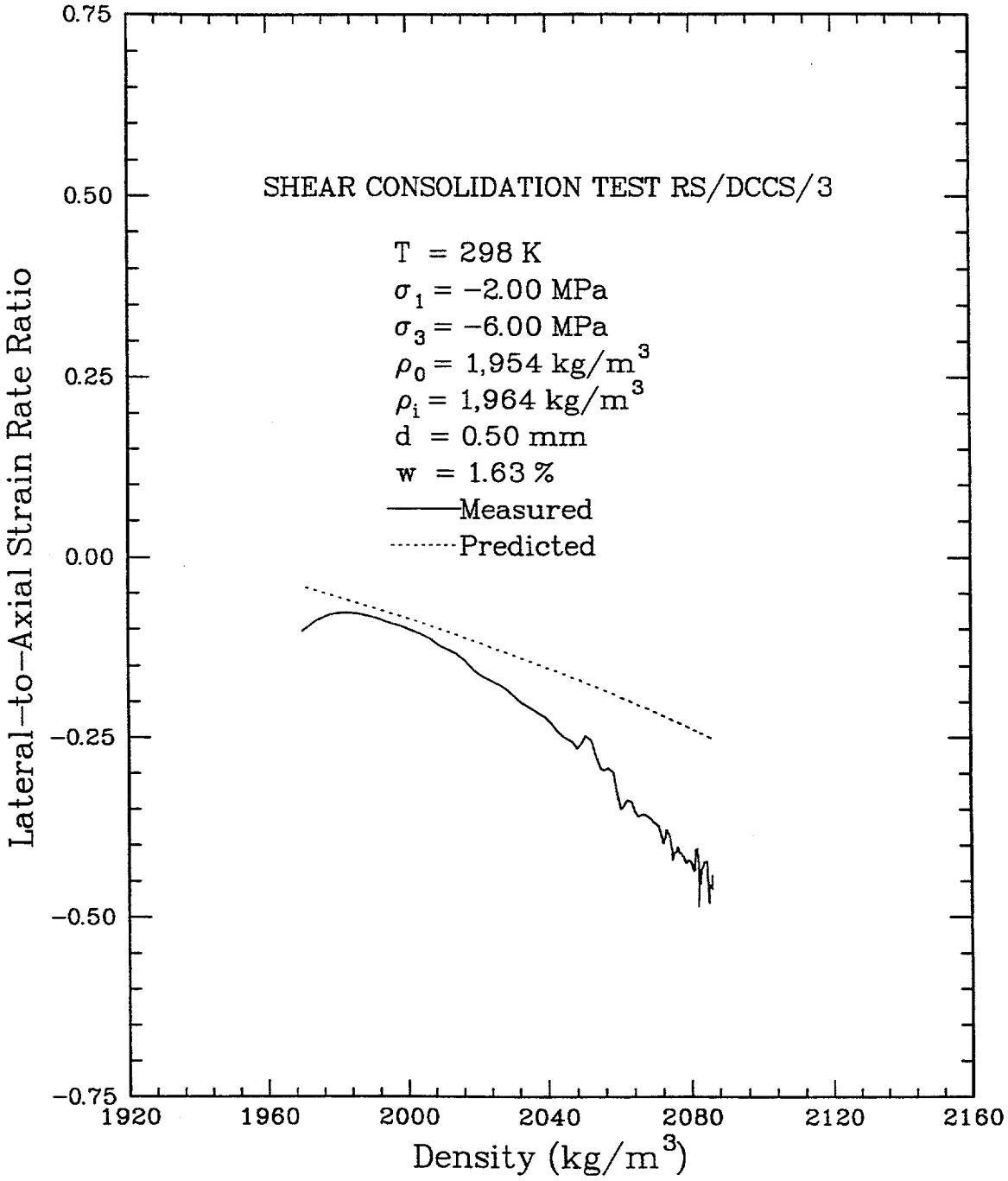

Figure B-14. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test RS/DCCS/3.

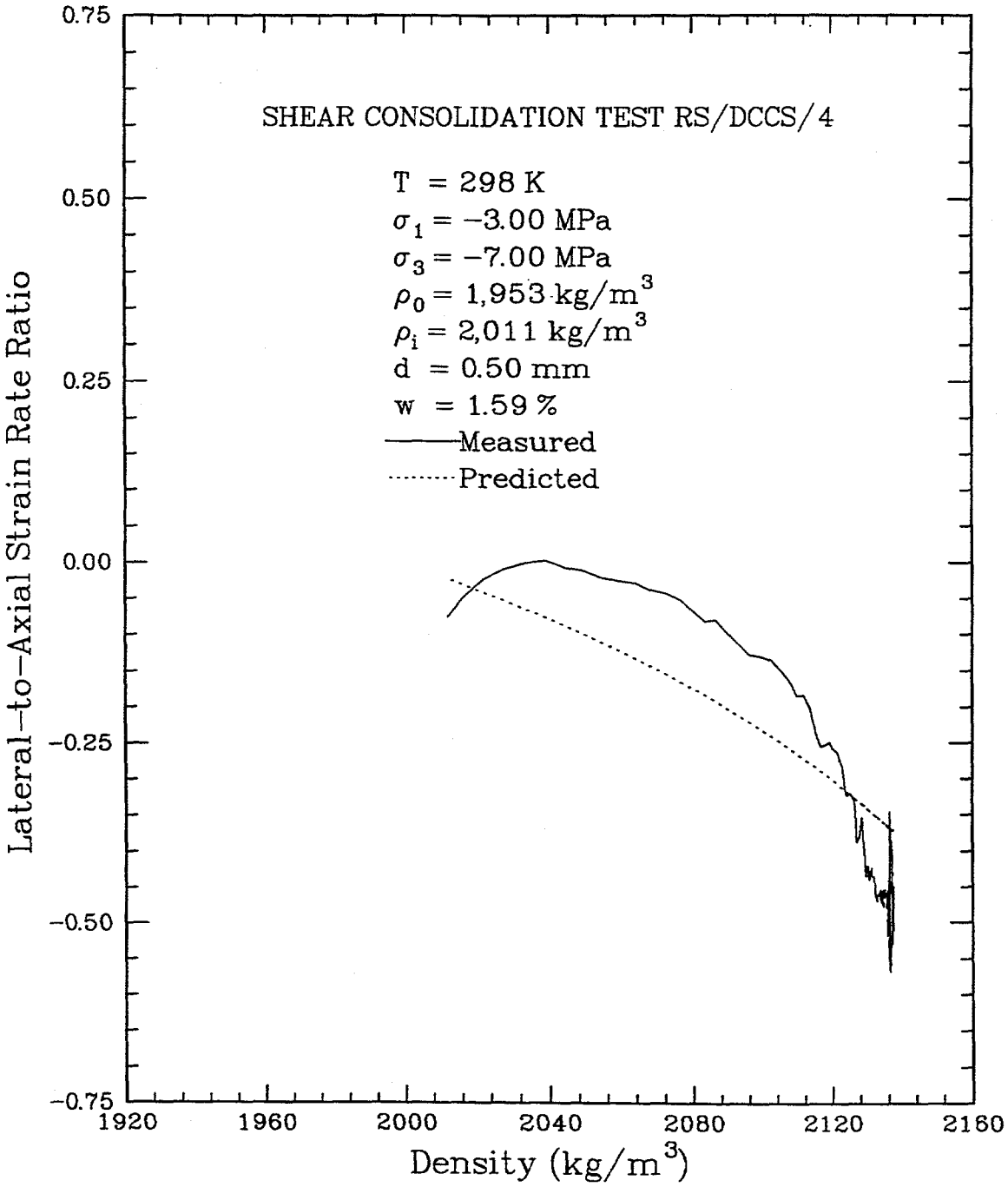

Figure B-15. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test RS/DCCS/4.

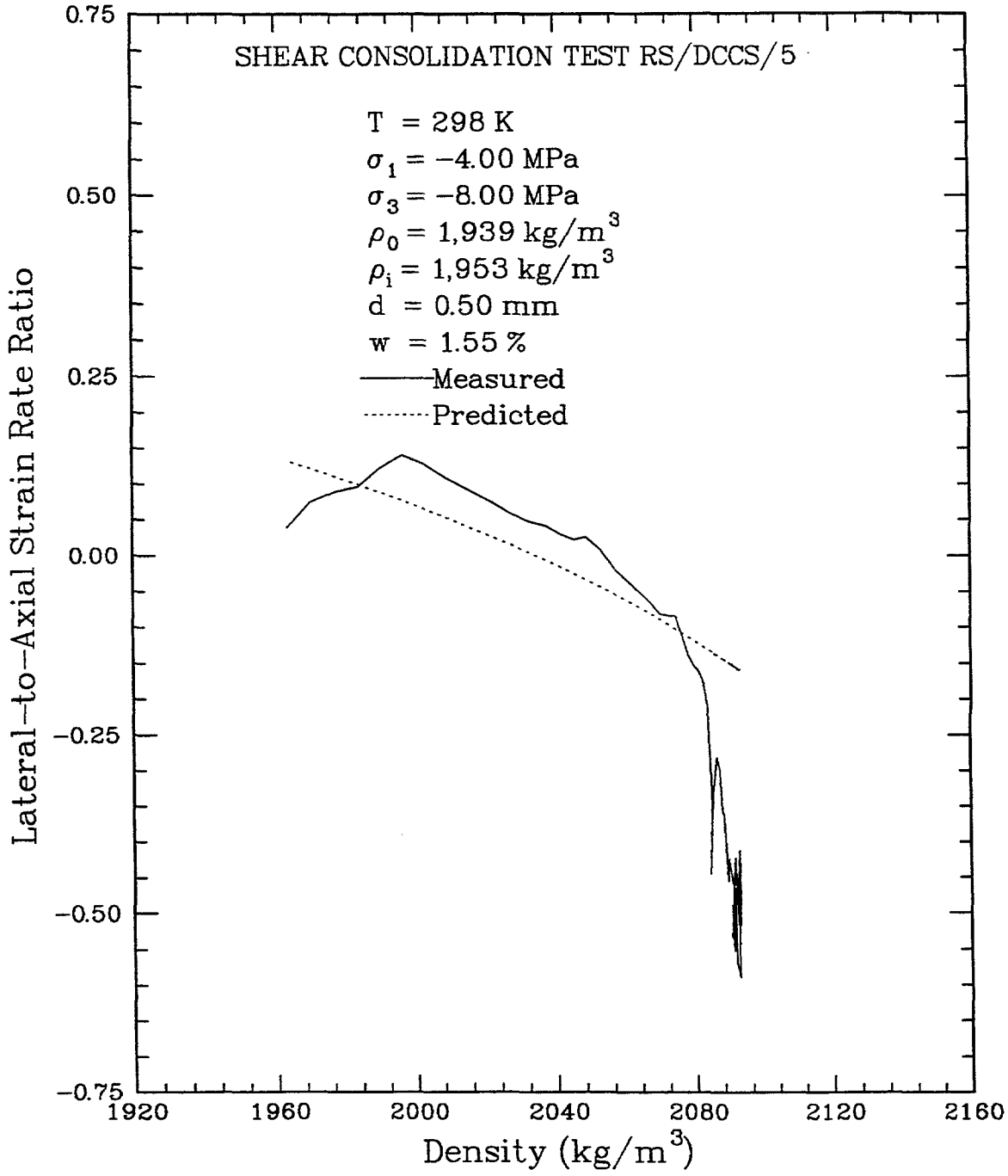

Figure B-16. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test RS/DCCS/5.

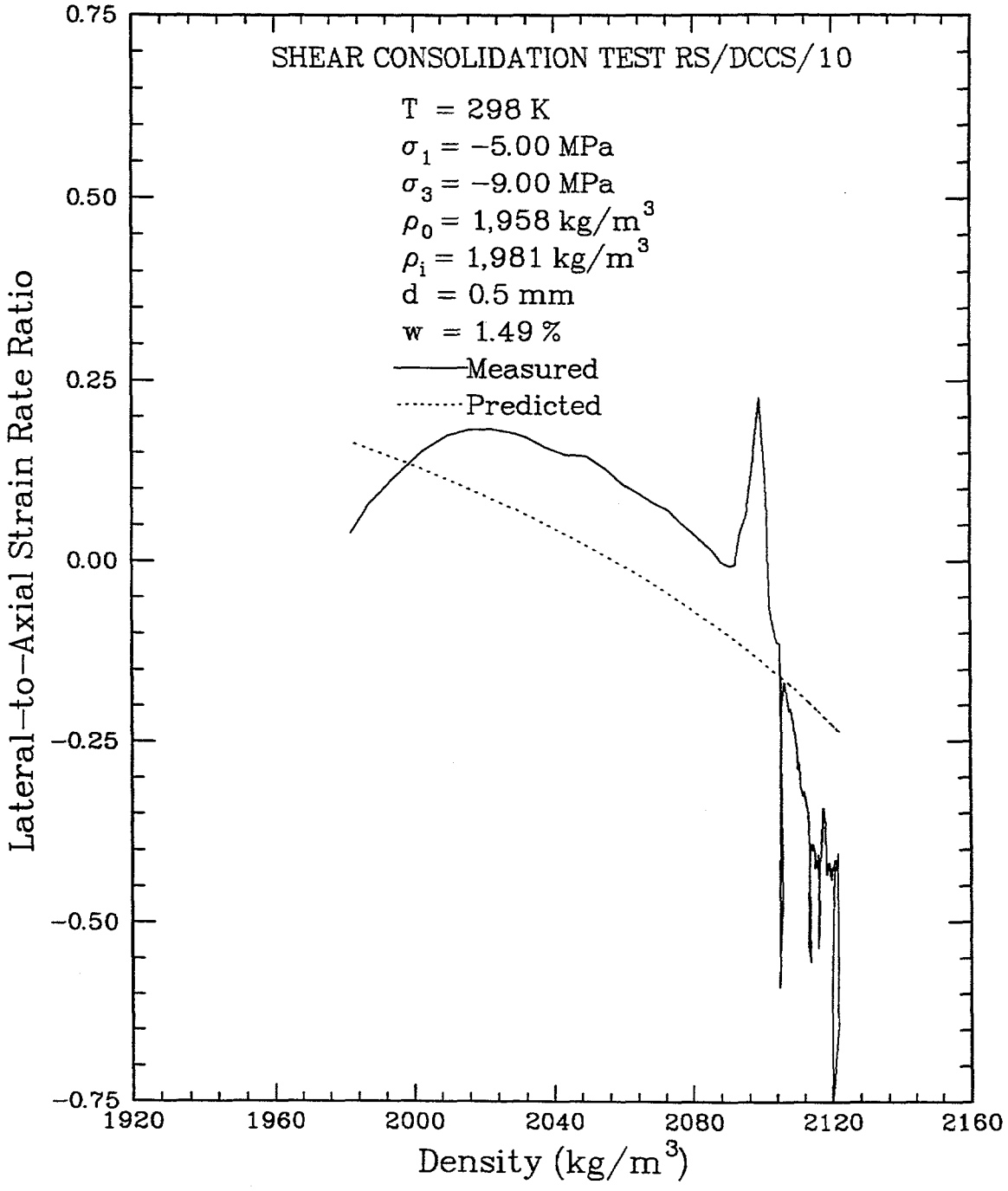

Figure B-17. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test RS/DCCS/10.

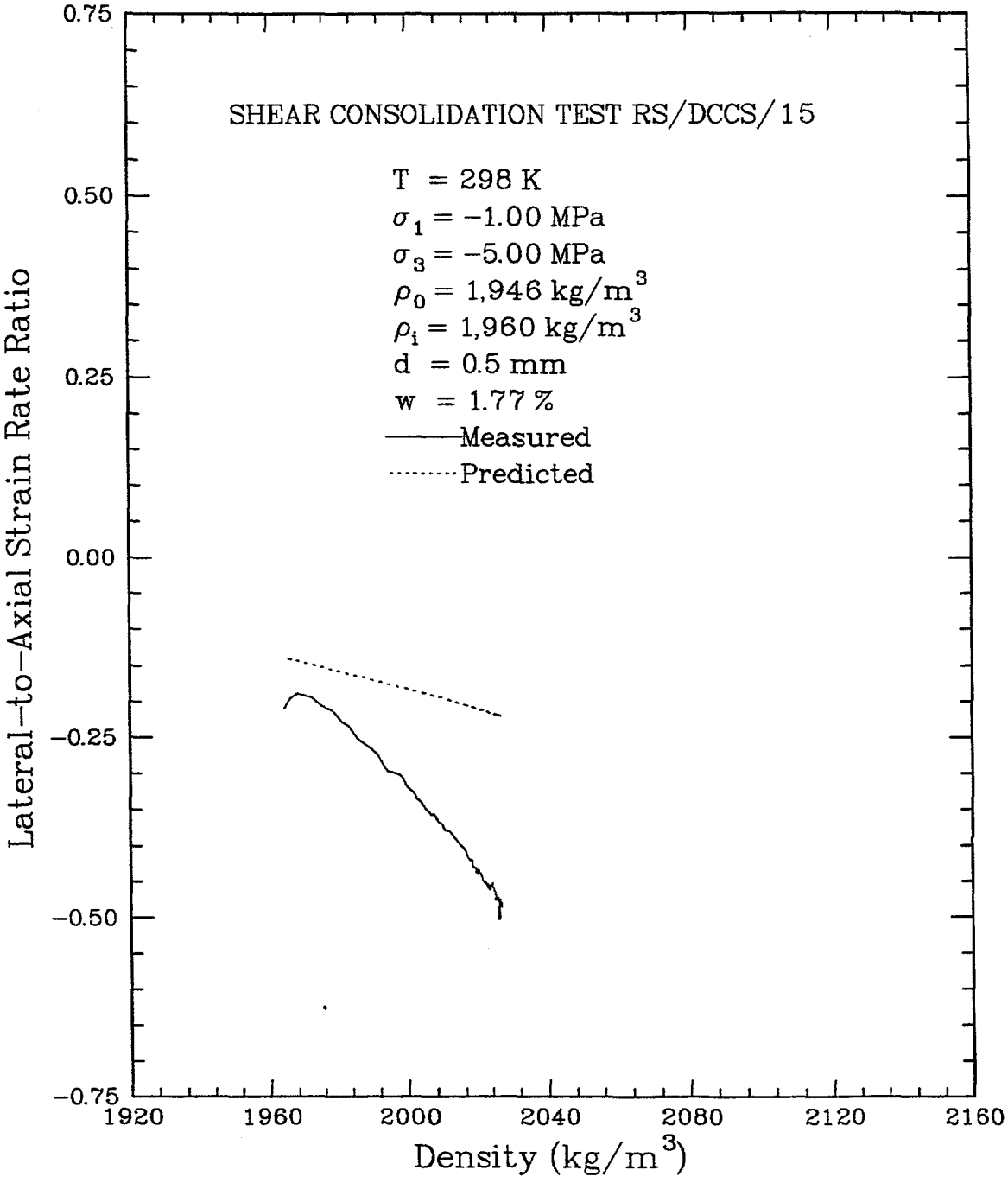

Figure B-18. Lateral-to-Axial Strain-Rate Ratio as a Function of Density for Shear Consolidation Test RS/DCCS/15.

APPENDIX C

CRUSHED-SALT CONSTITUTIVE MODEL FITS TO THE HYDROSTATIC AND SHEAR CONSOLIDATION TESTS

This appendix contains plots of the crushed-salt, combined-mechanism constitutive model fits to the 40 hydrostatic consolidation tests and the 18 shear consolidation tests. Two plots are included for each test depicting the fits to two test databases; namely, (1) a database containing the 18 shear consolidation tests only and (2) a database containing the combined 58 shear and hydrostatic consolidation tests.

The appendix contains 58 figures. Each figure shows the two model fits to each particular laboratory test; either a hydrostatic consolidation test (Figures C-1 through C-40) or a shear consolidation test (Figures C-41 through C-58). The plots labeled *Shear Database* represent the crushed-salt constitutive model fit to the shear test database, and the plots labeled *Combined Database* represent the crushed-salt constitutive model fit to the combined test database. As discussed in Section 4.6.4, shear database curve fits do not appear for Figures C-27 and C-28 because the tests are outside the range of the shear database parameter values.

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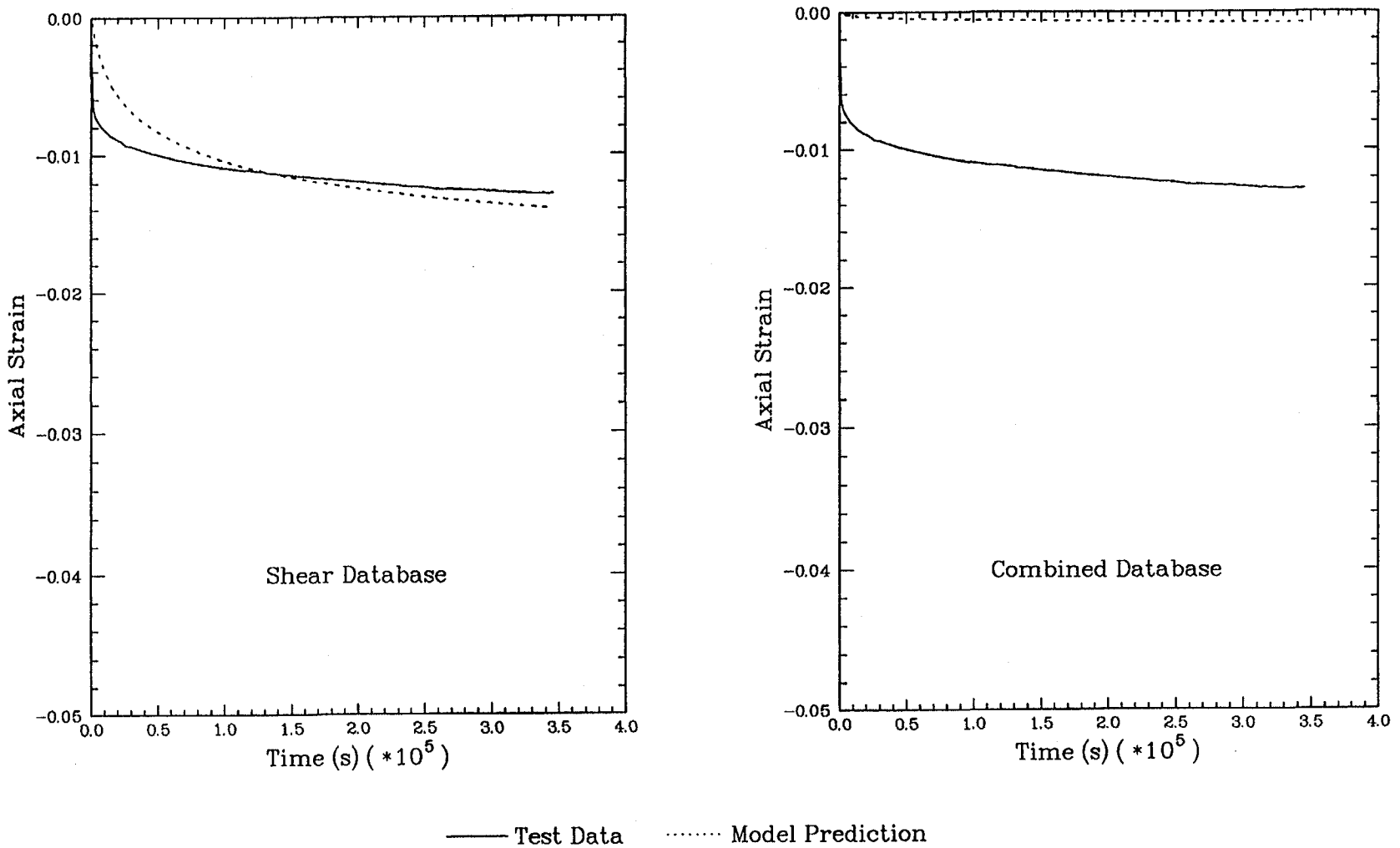


Figure C-1. Hydrostatic Consolidation Test CS1.

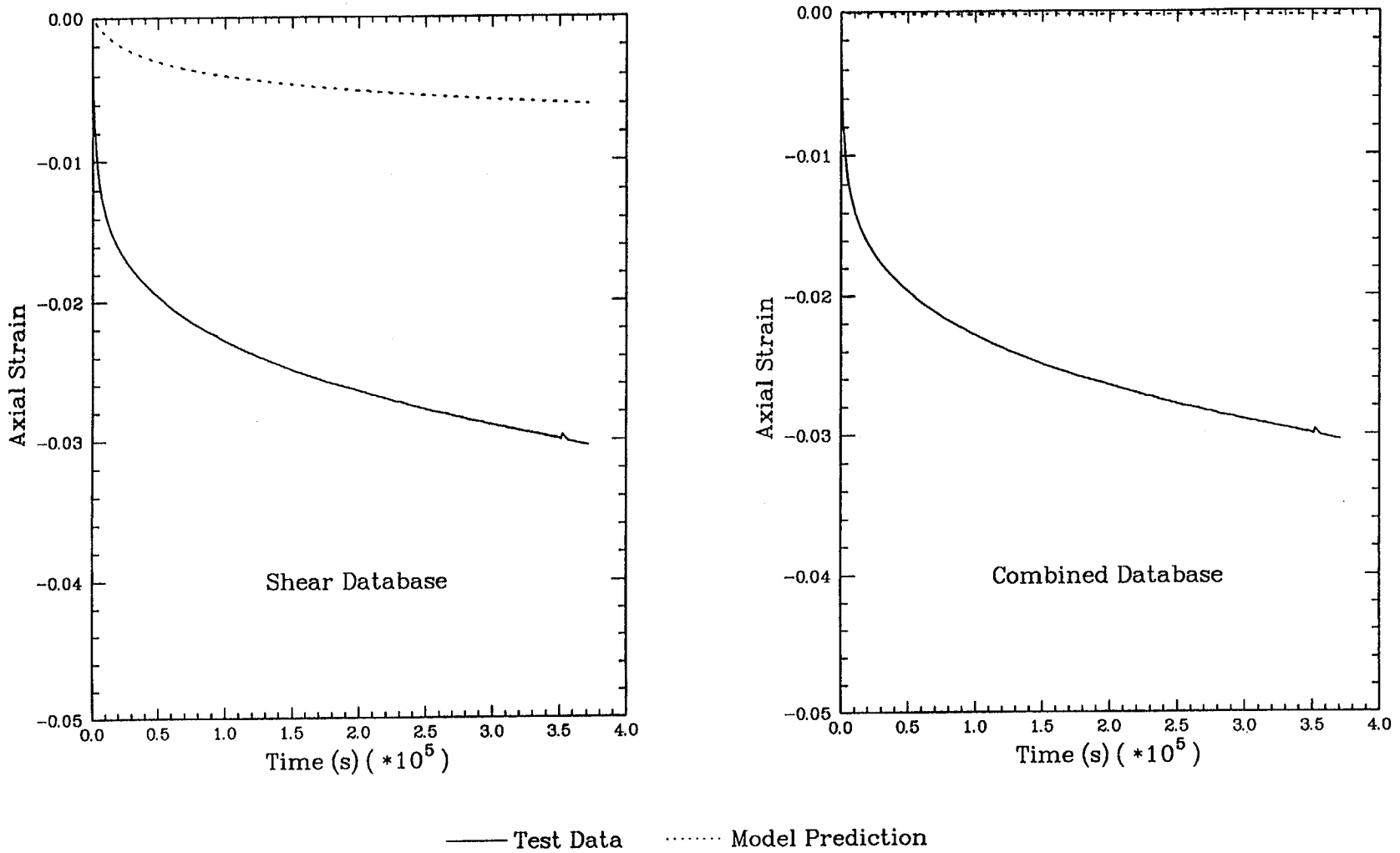


Figure C-2. Hydrostatic Consolidation Test CS2.

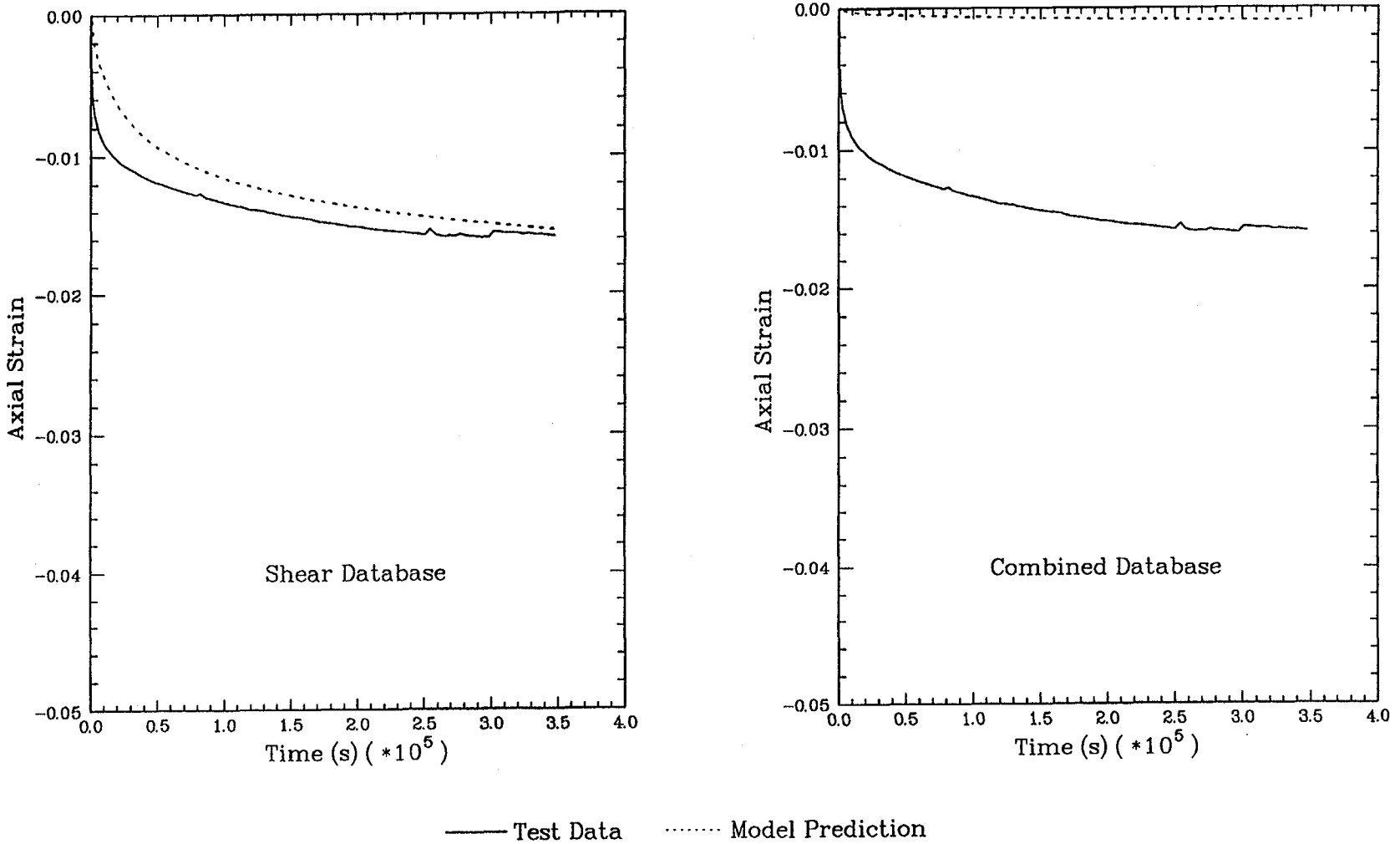


Figure C-3. Hydrostatic Consolidation Test CS3.

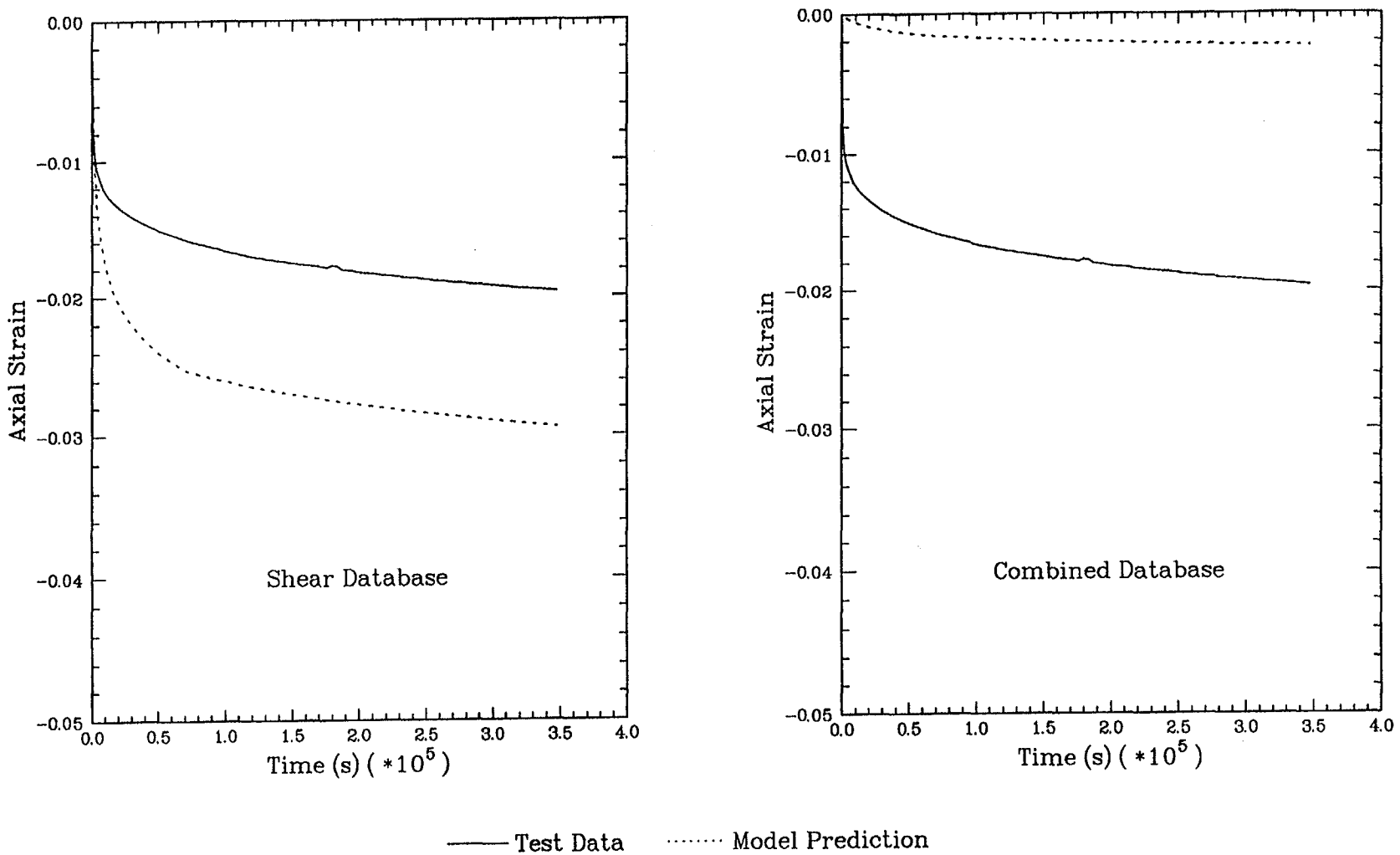


Figure C-4. Hydrostatic Consolidation Test CS4.

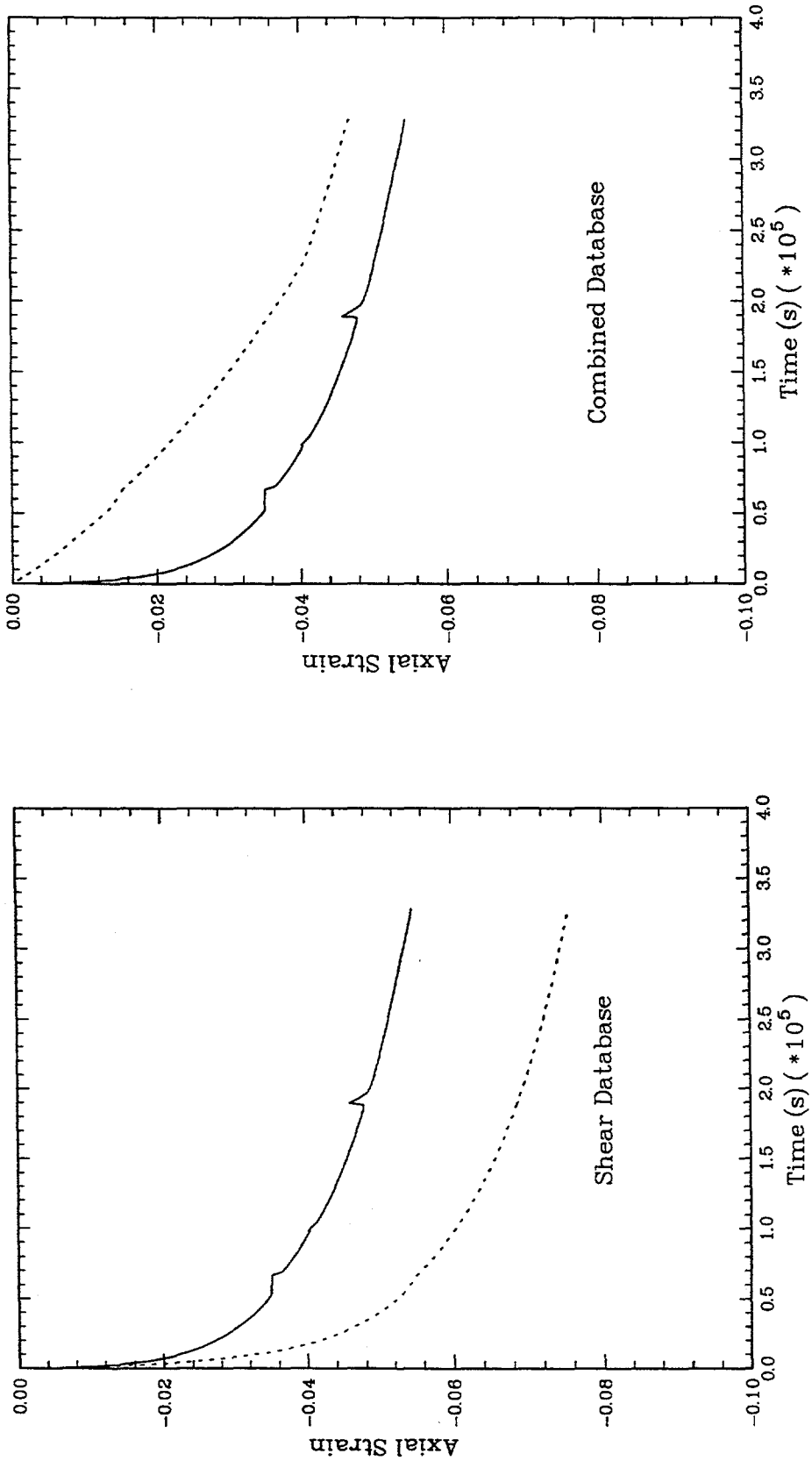


Figure C-5. Hydrostatic Consolidation Test CS5.

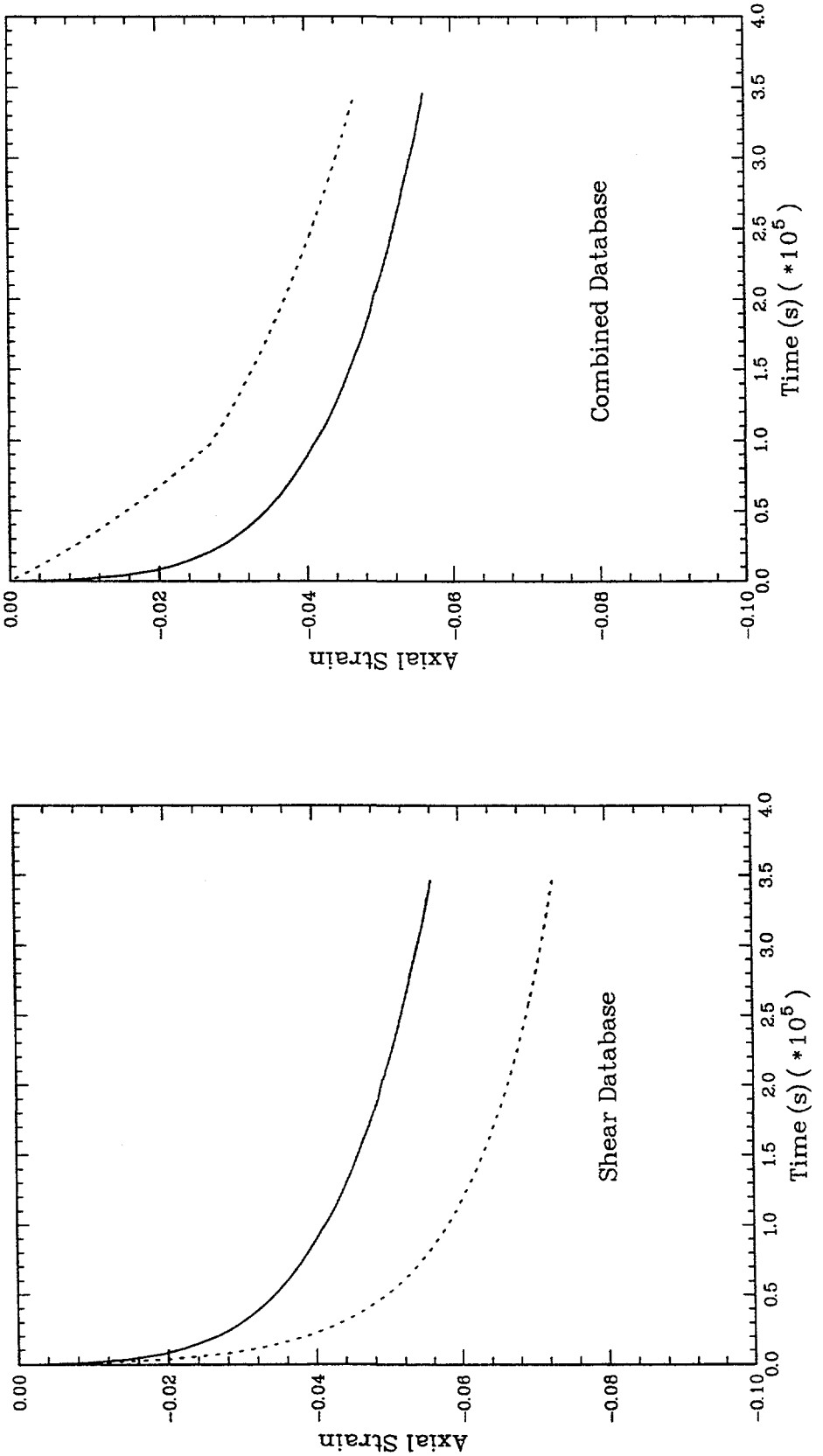


Figure C-6. Hydrostatic Consolidation Test CS6.

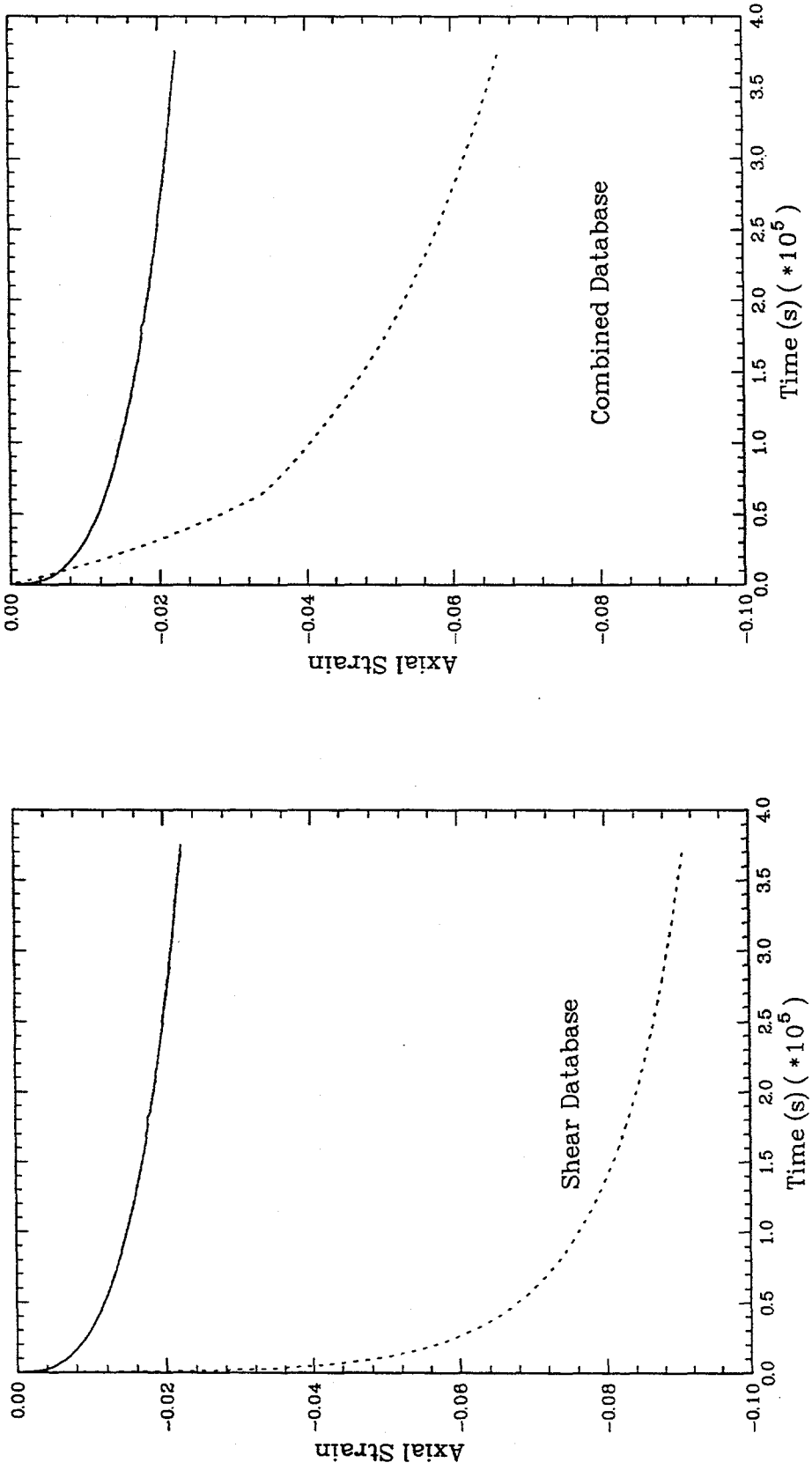


Figure C-7. Hydrostatic Consolidation Test CS7.

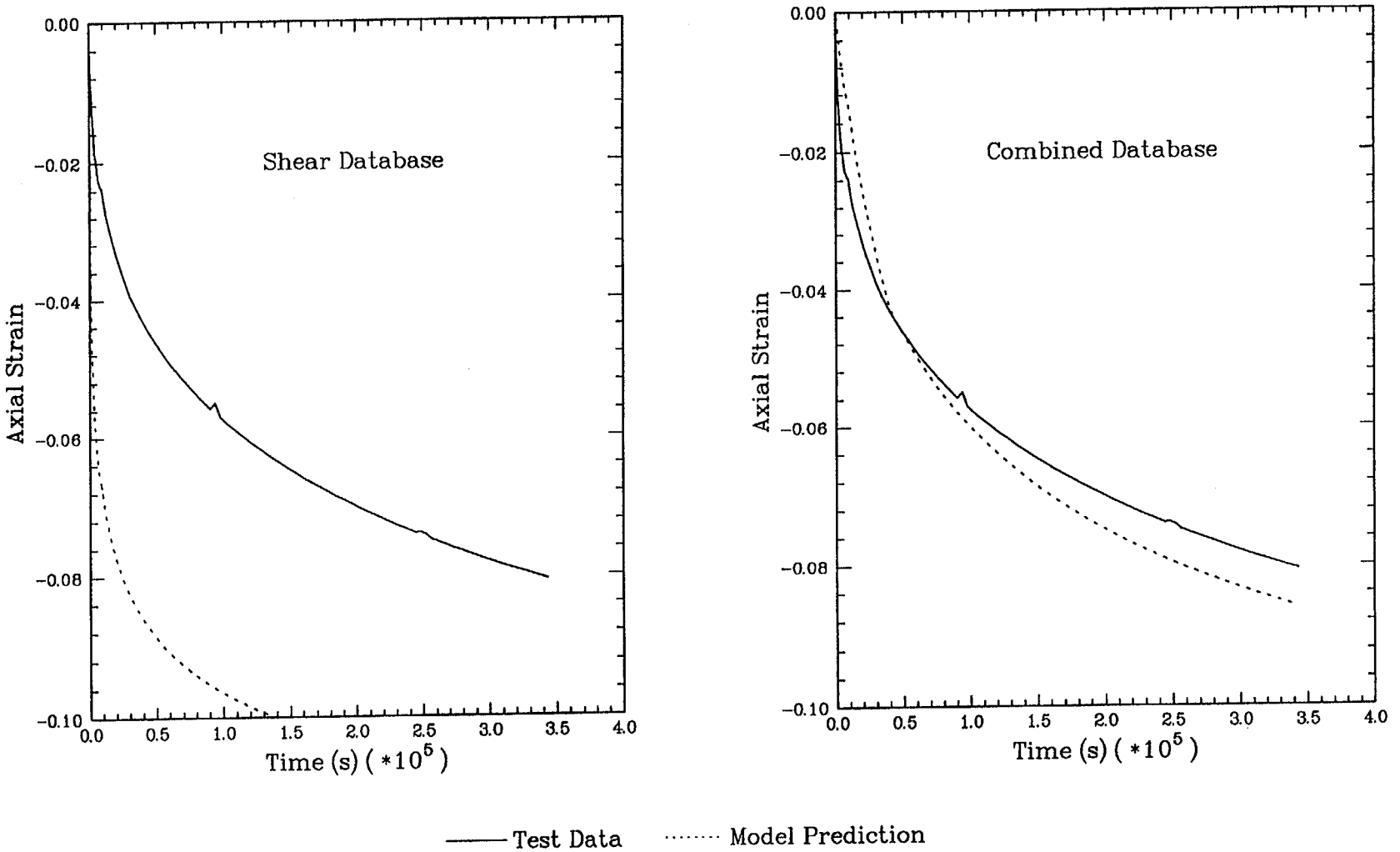


Figure C-8. Hydrostatic Consolidation Test CS8.

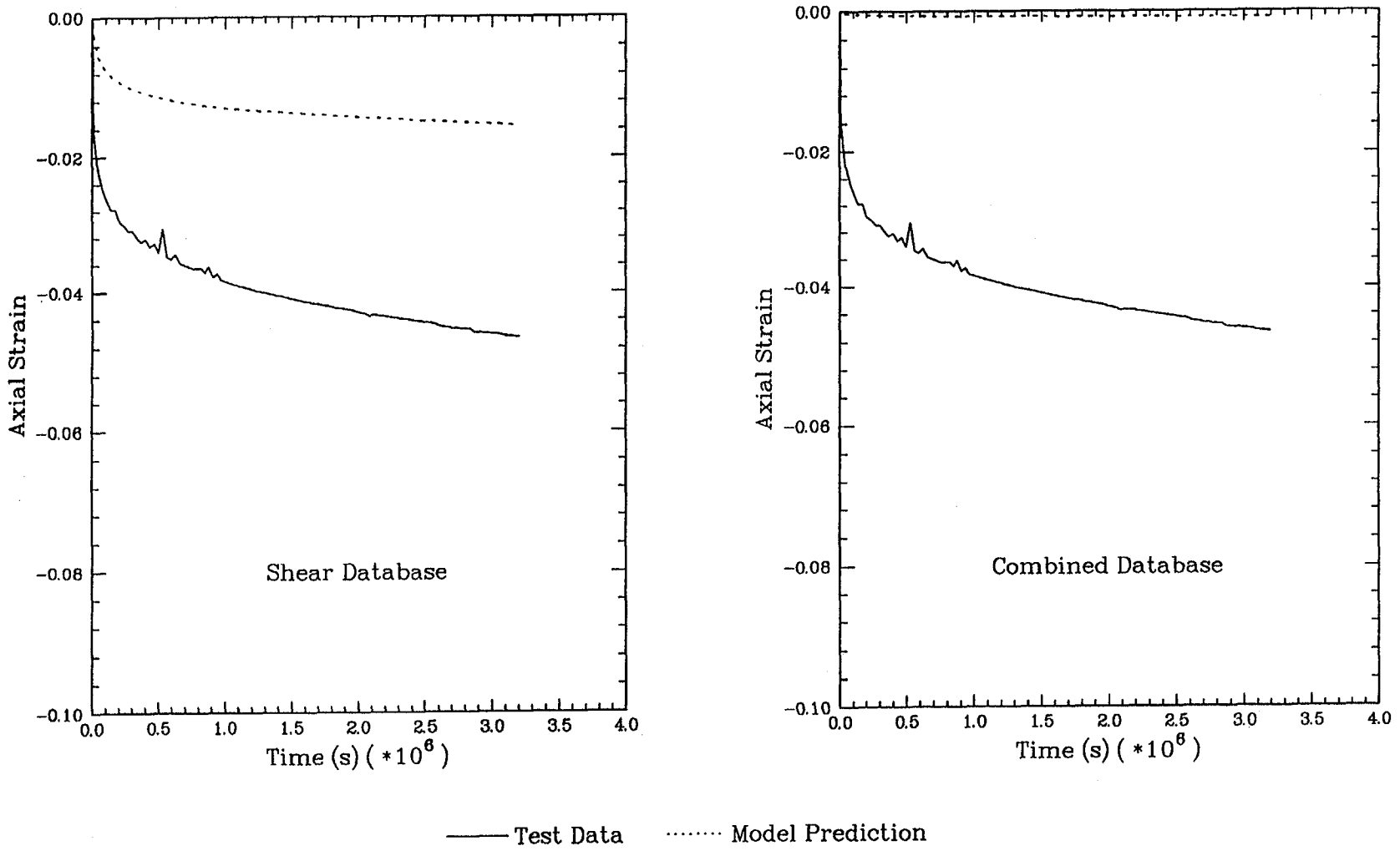


Figure C-9. Hydrostatic Consolidation Test CS9.

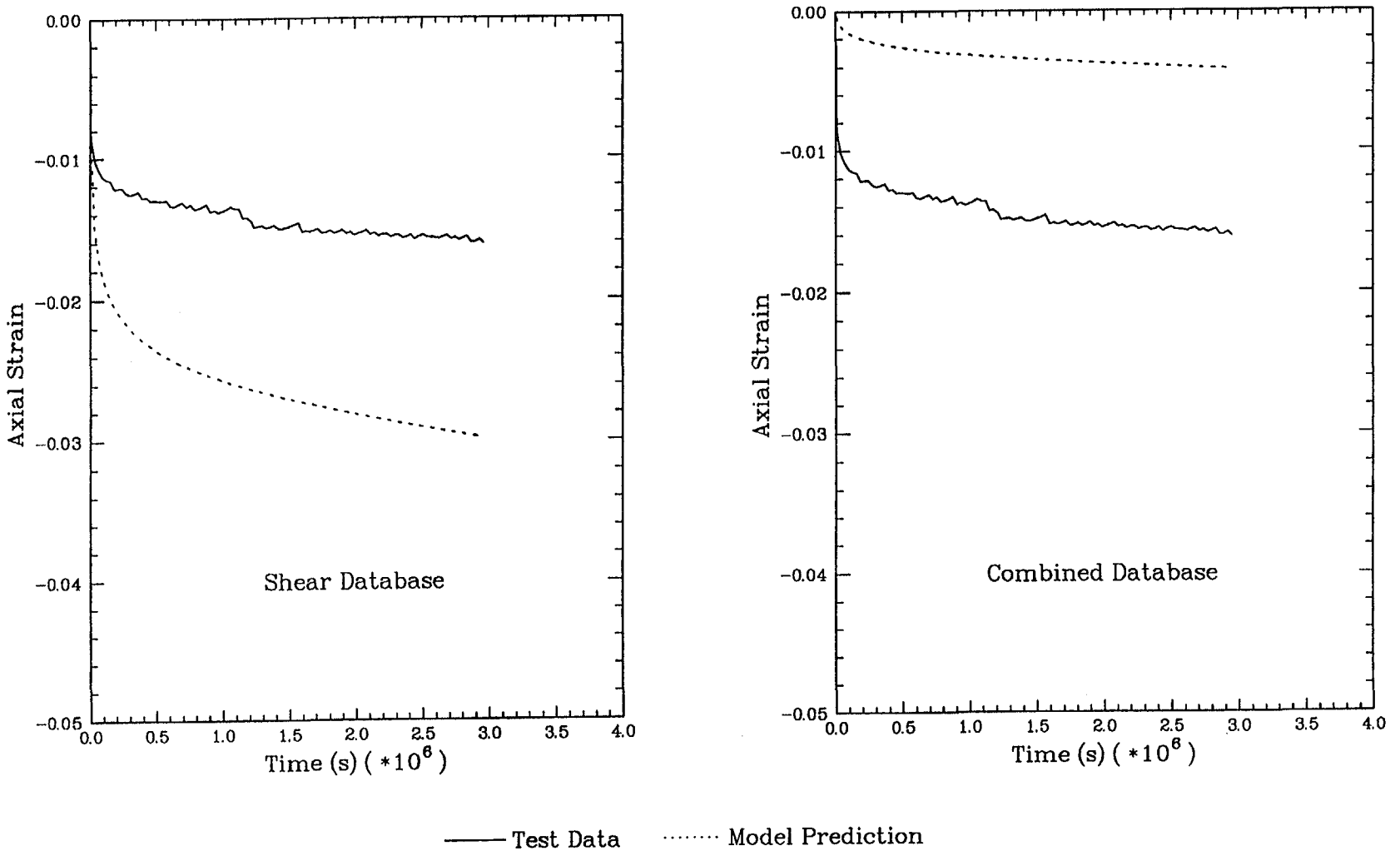


Figure C-10. Hydrostatic Consolidation Test CS10.

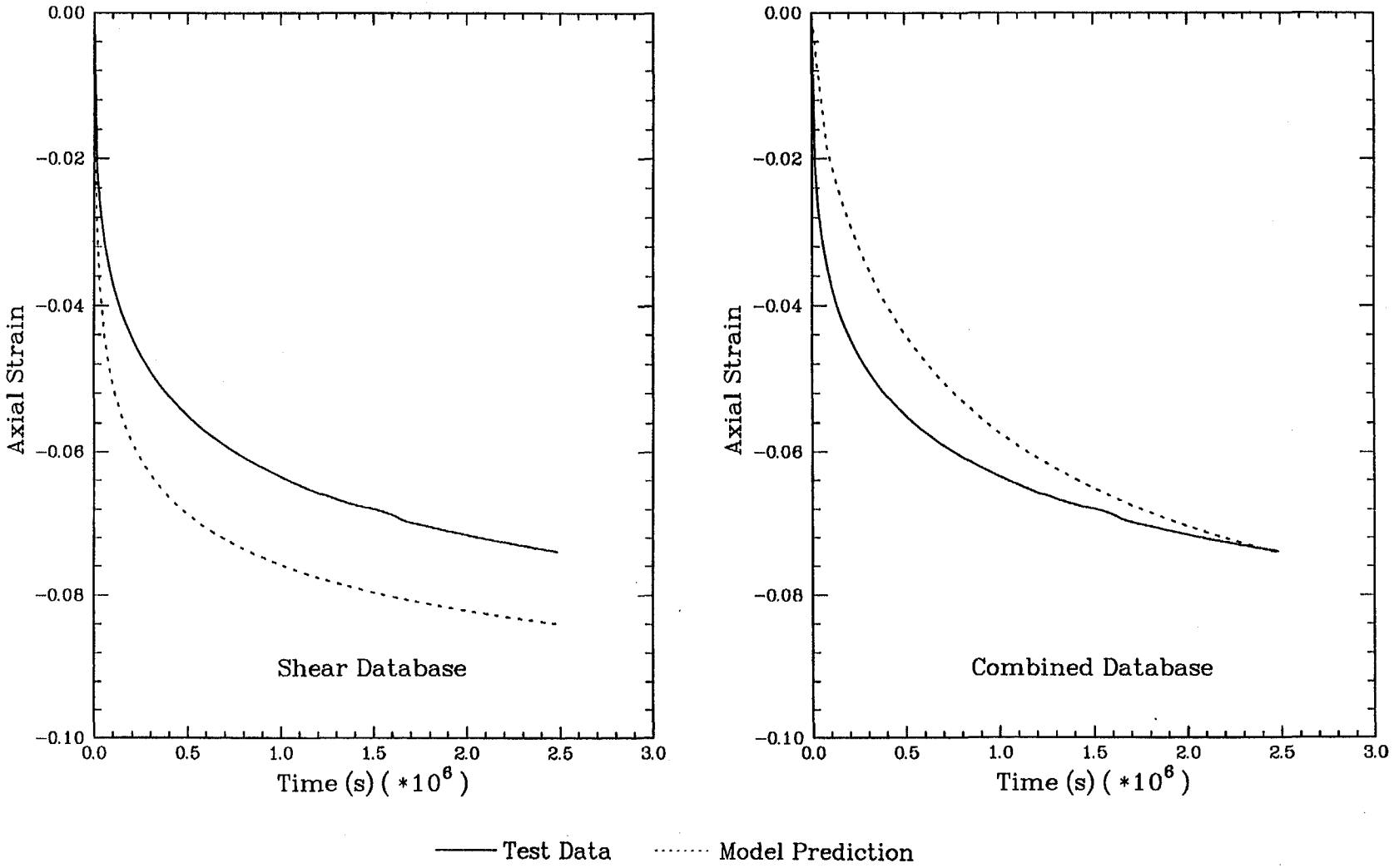


Figure C-11. Hydrostatic Consolidation Test HC1A.

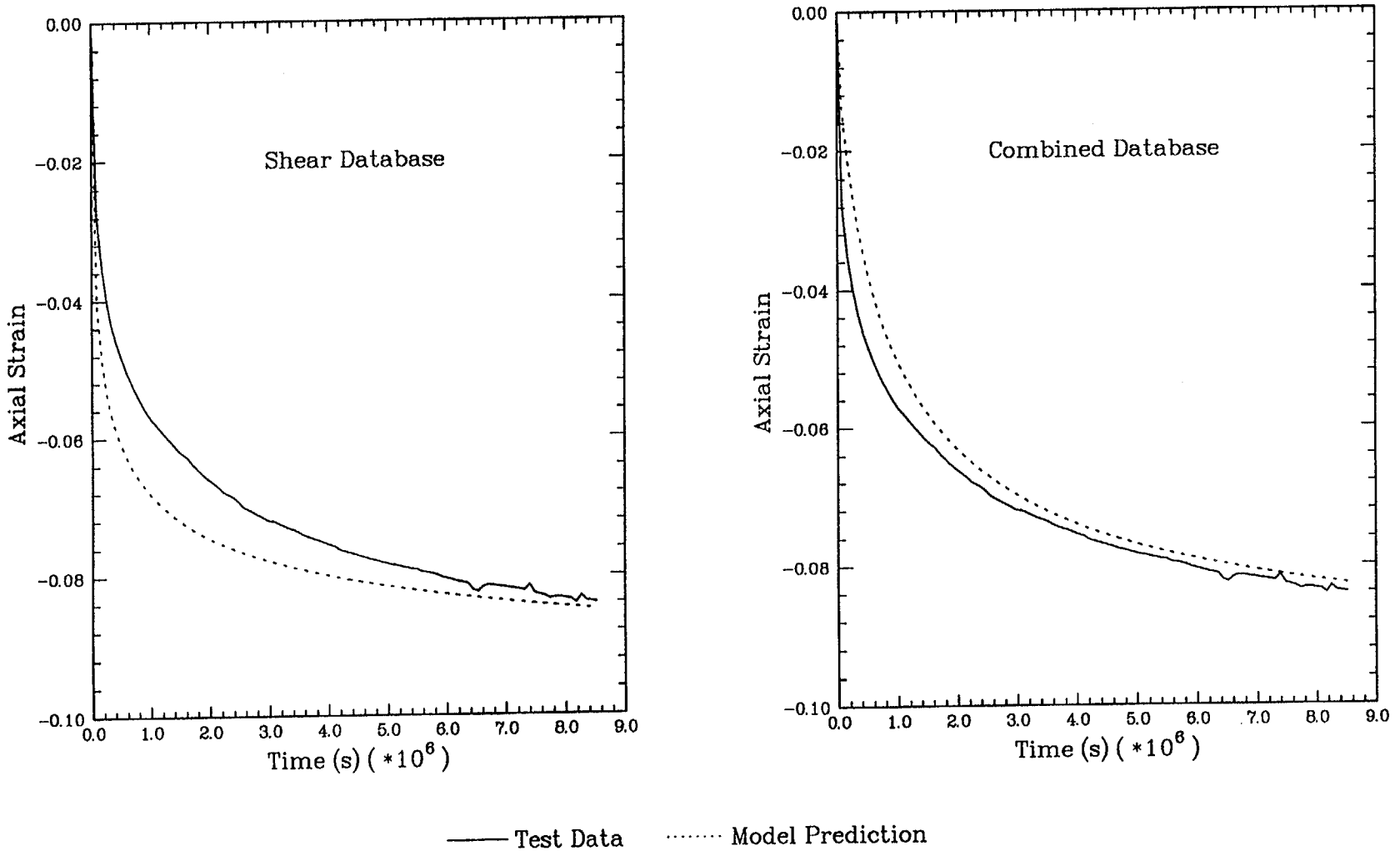


Figure C-12. Hydrostatic Consolidation Test HC2A.

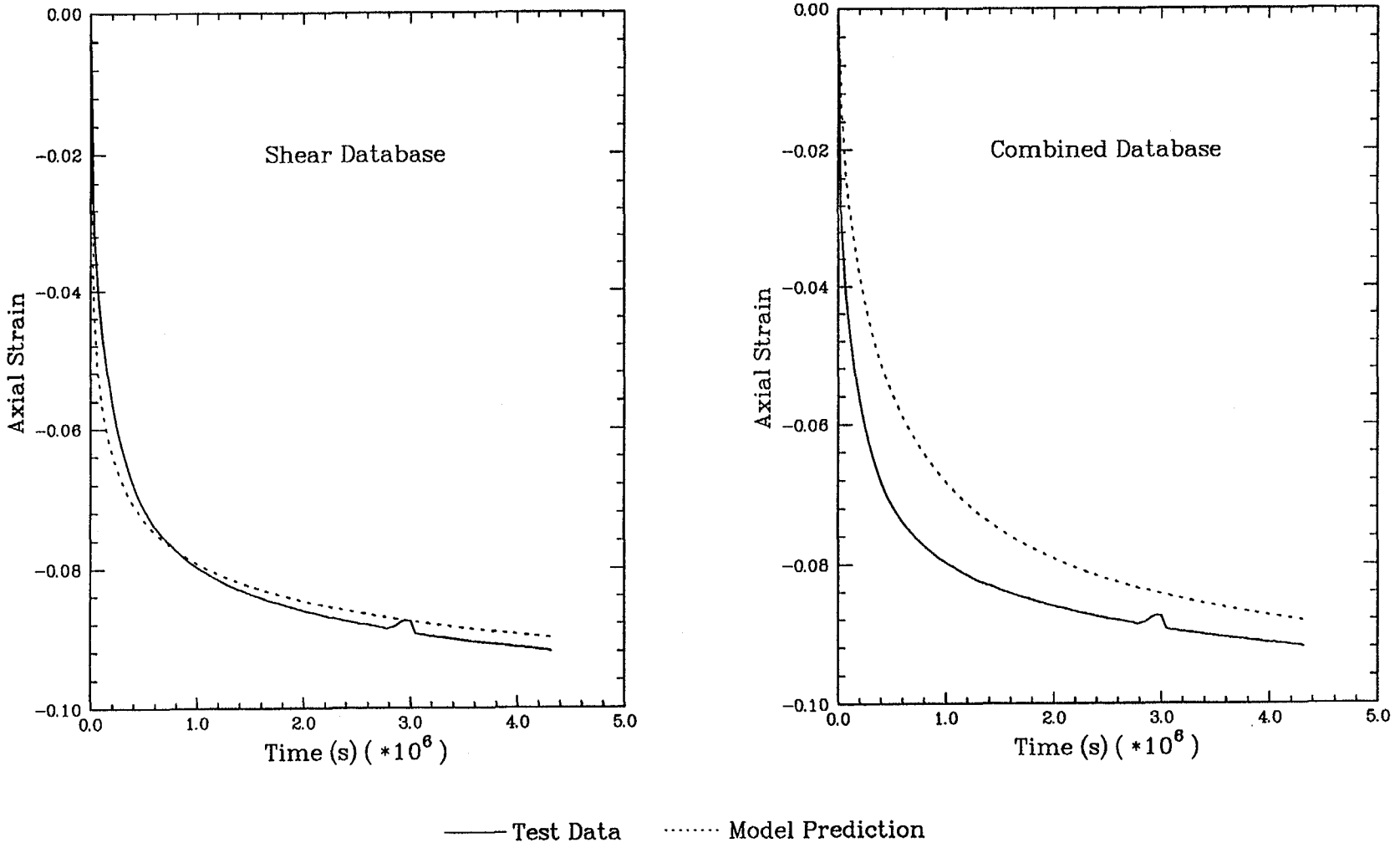


Figure C-13. Hydrostatic Consolidation Test HC3A.

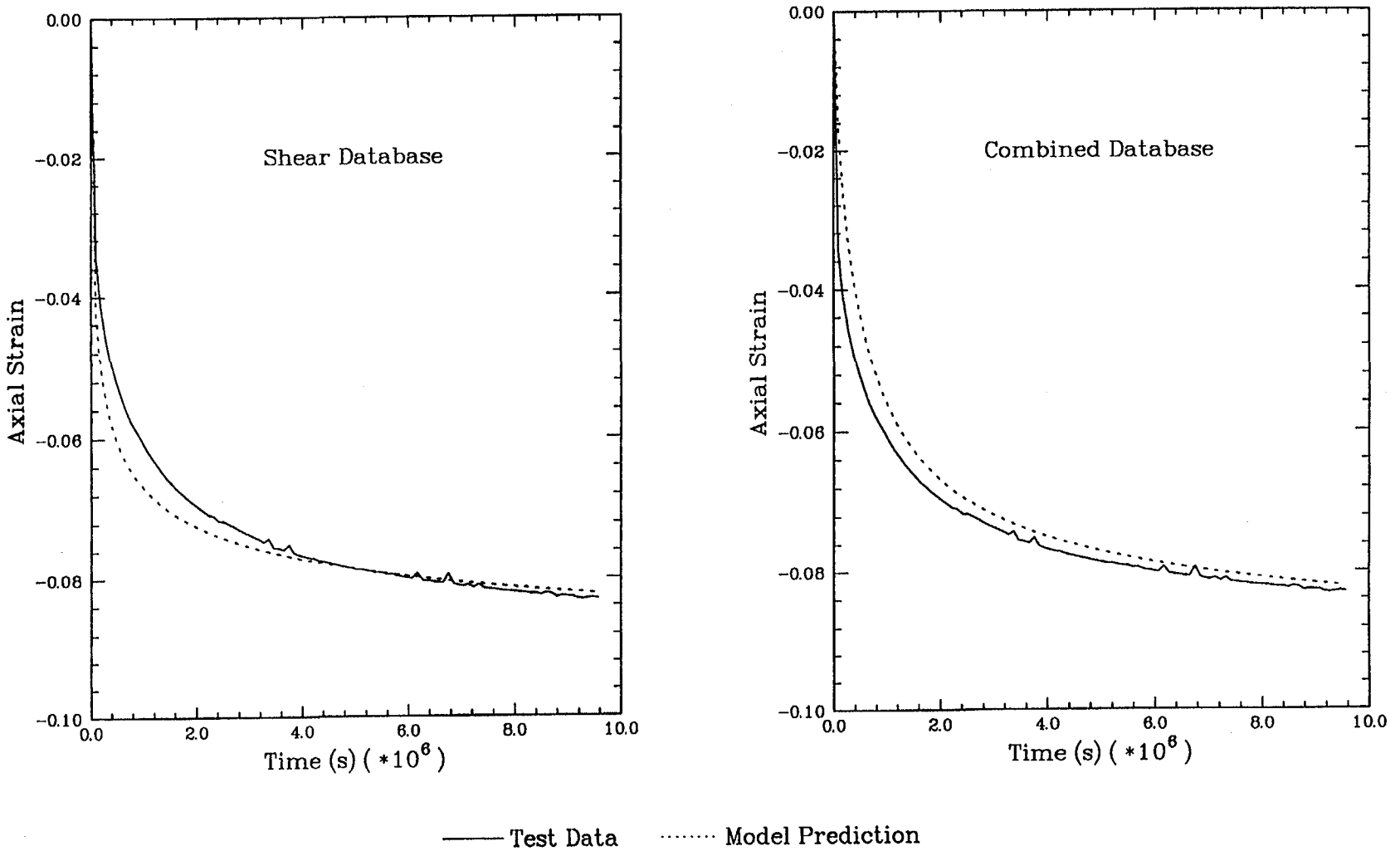


Figure C-14. Hydrostatic Consolidation Test HC4A.

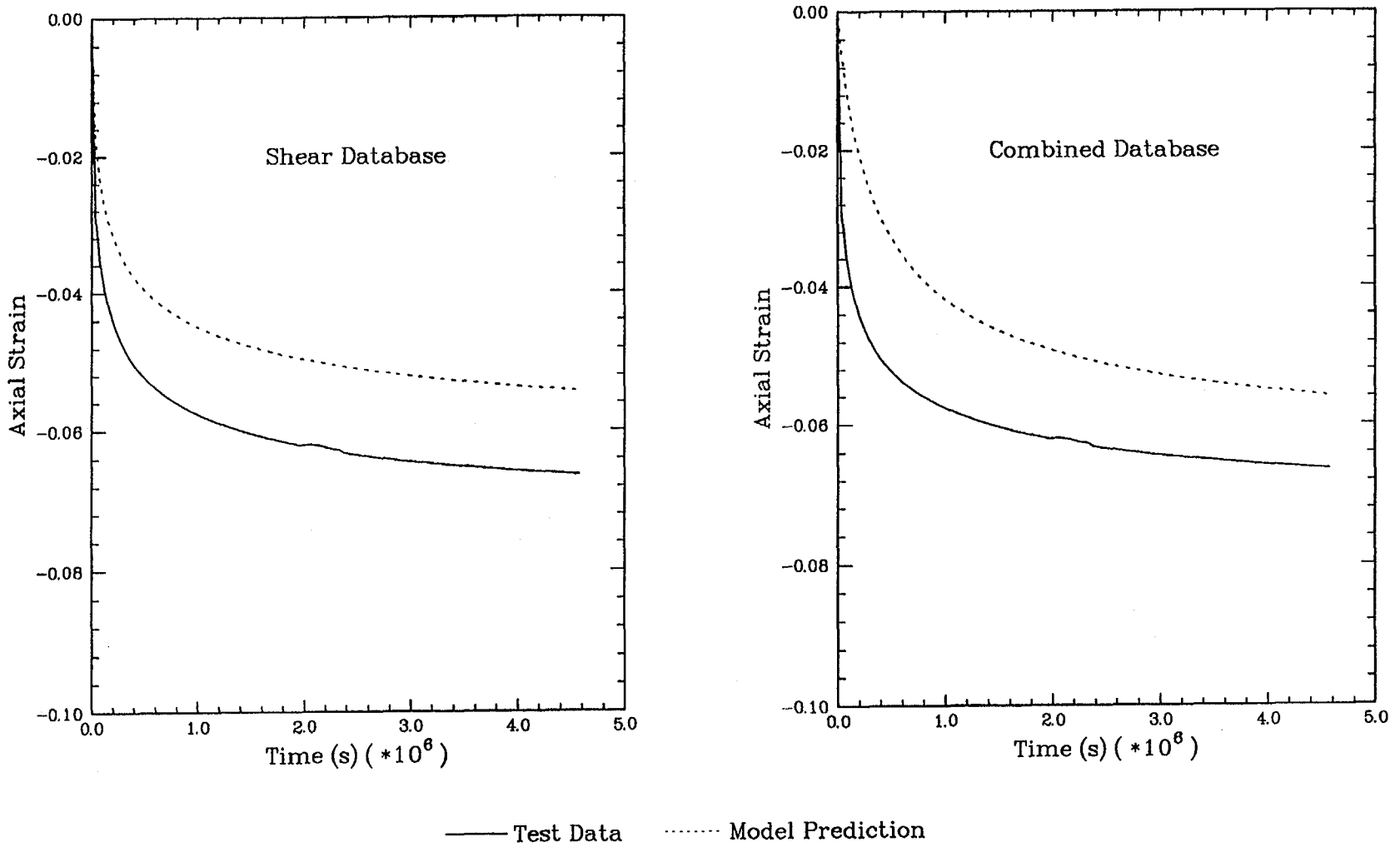


Figure C-15. Hydrostatic Consolidation Test HC5A.

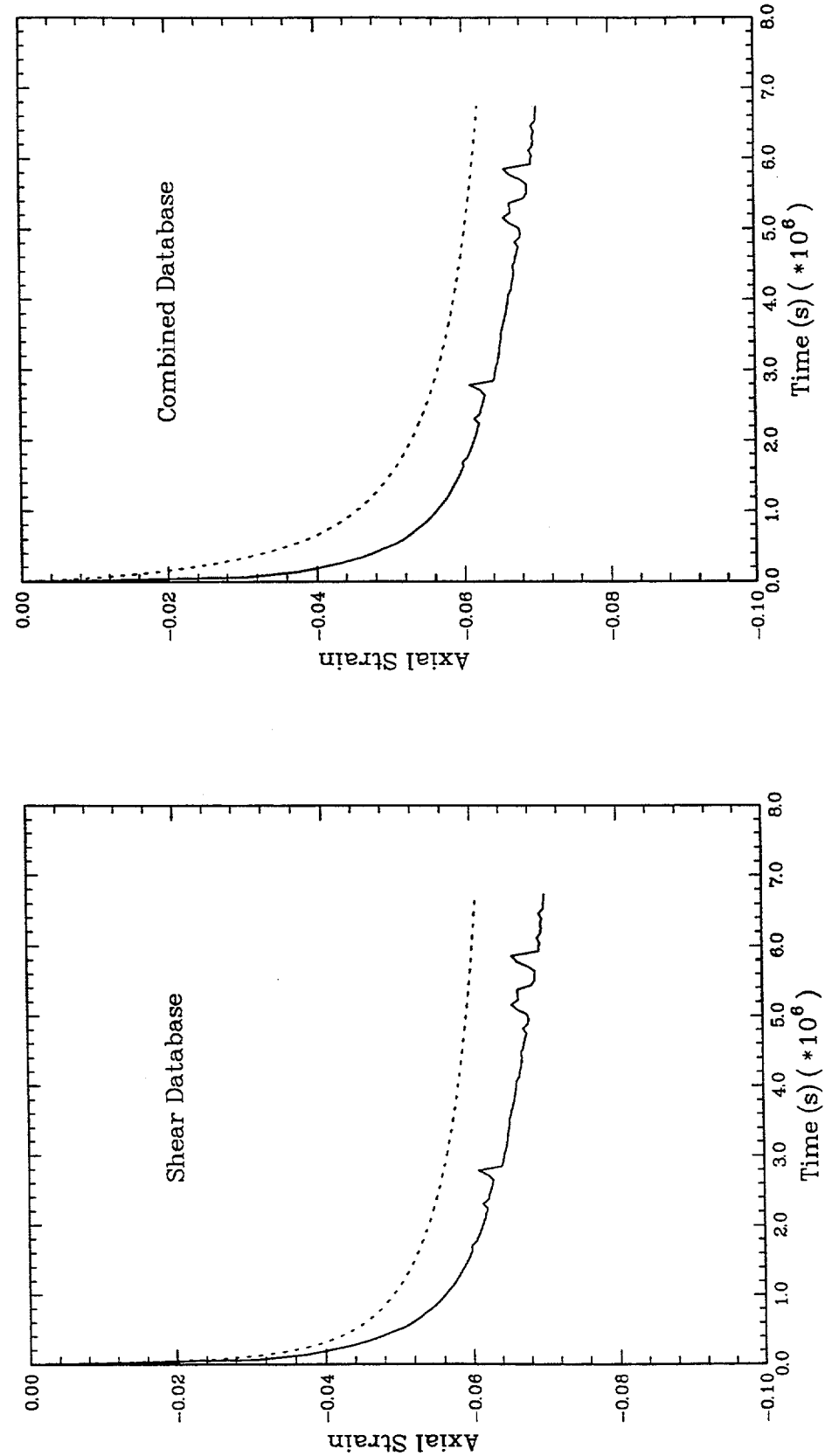


Figure C-16. Hydrostatic Consolidation Test HC6A.

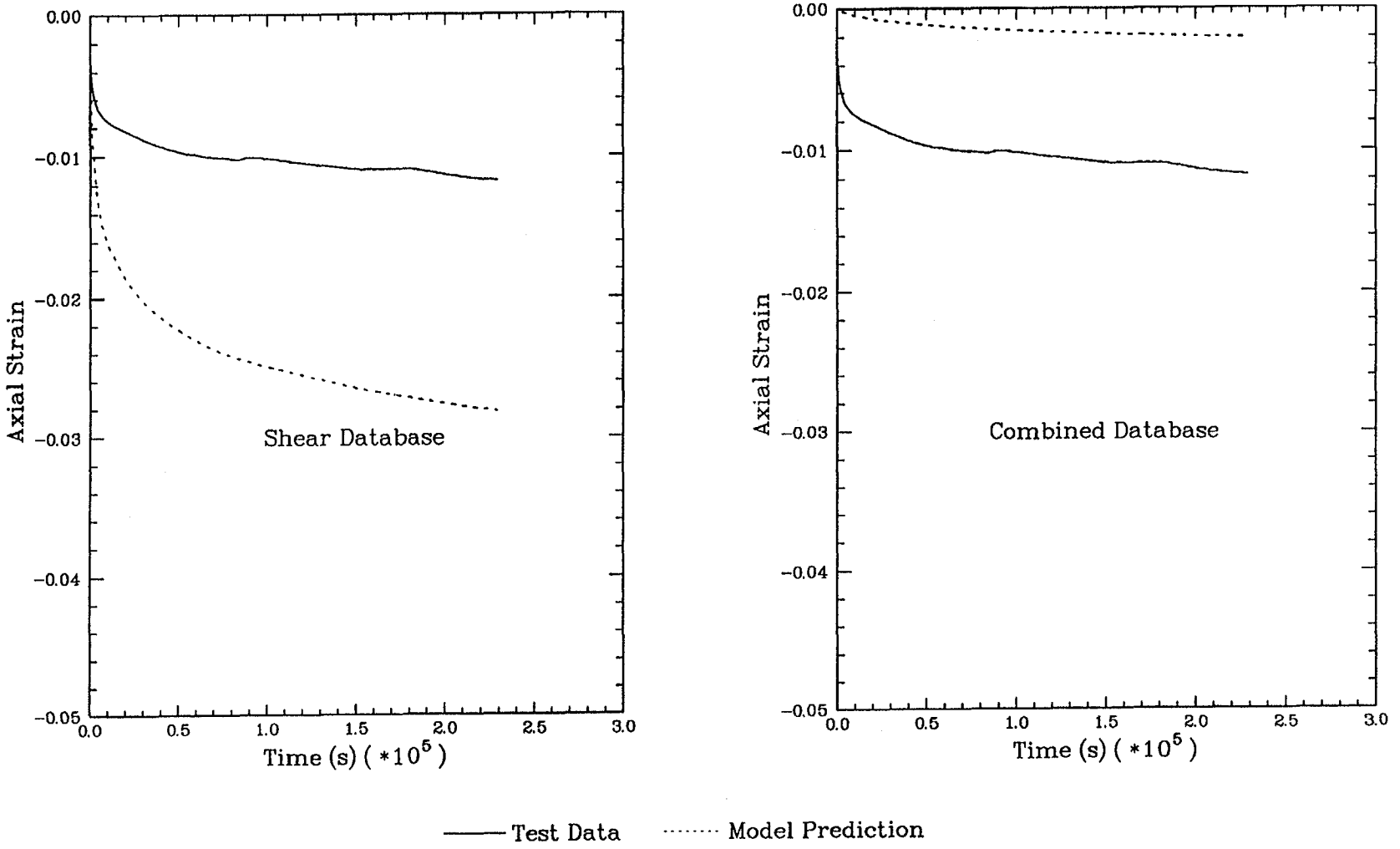


Figure C-17. Hydrostatic Consolidation Test 27JUL82.

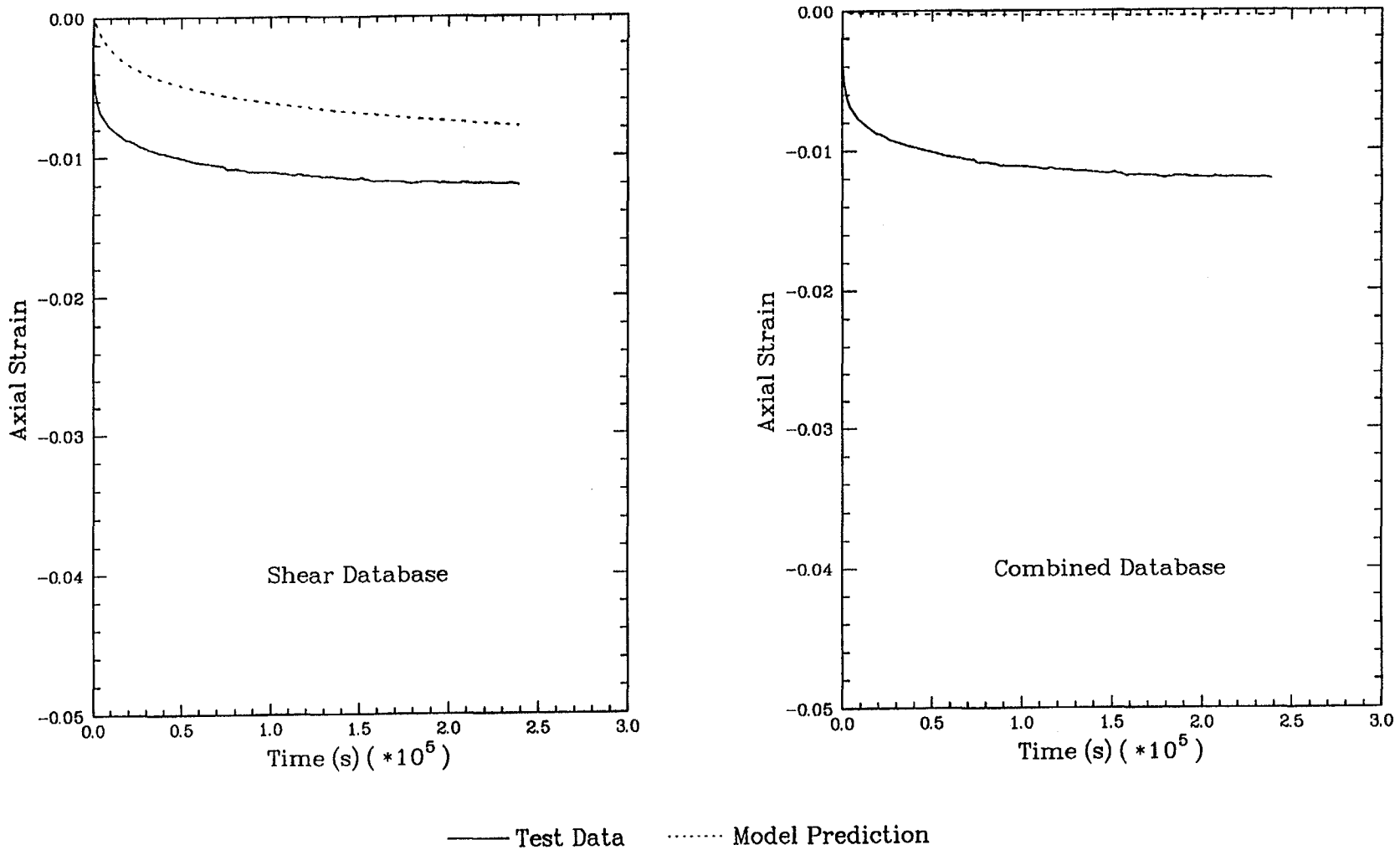


Figure C-18. Hydrostatic Consolidation Test 04MAY82.

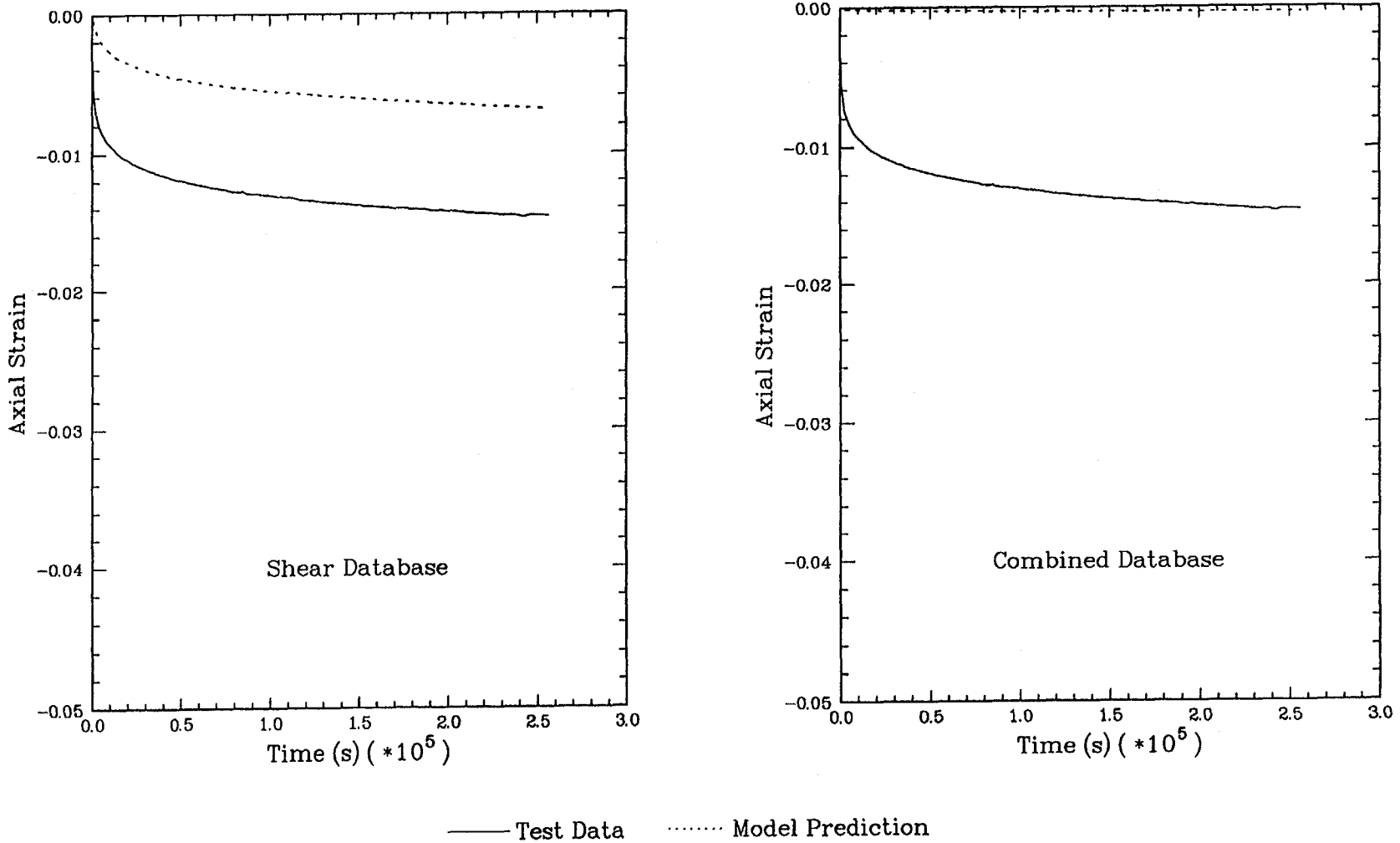


Figure C-19. Hydrostatic Consolidation Test 30APR82.

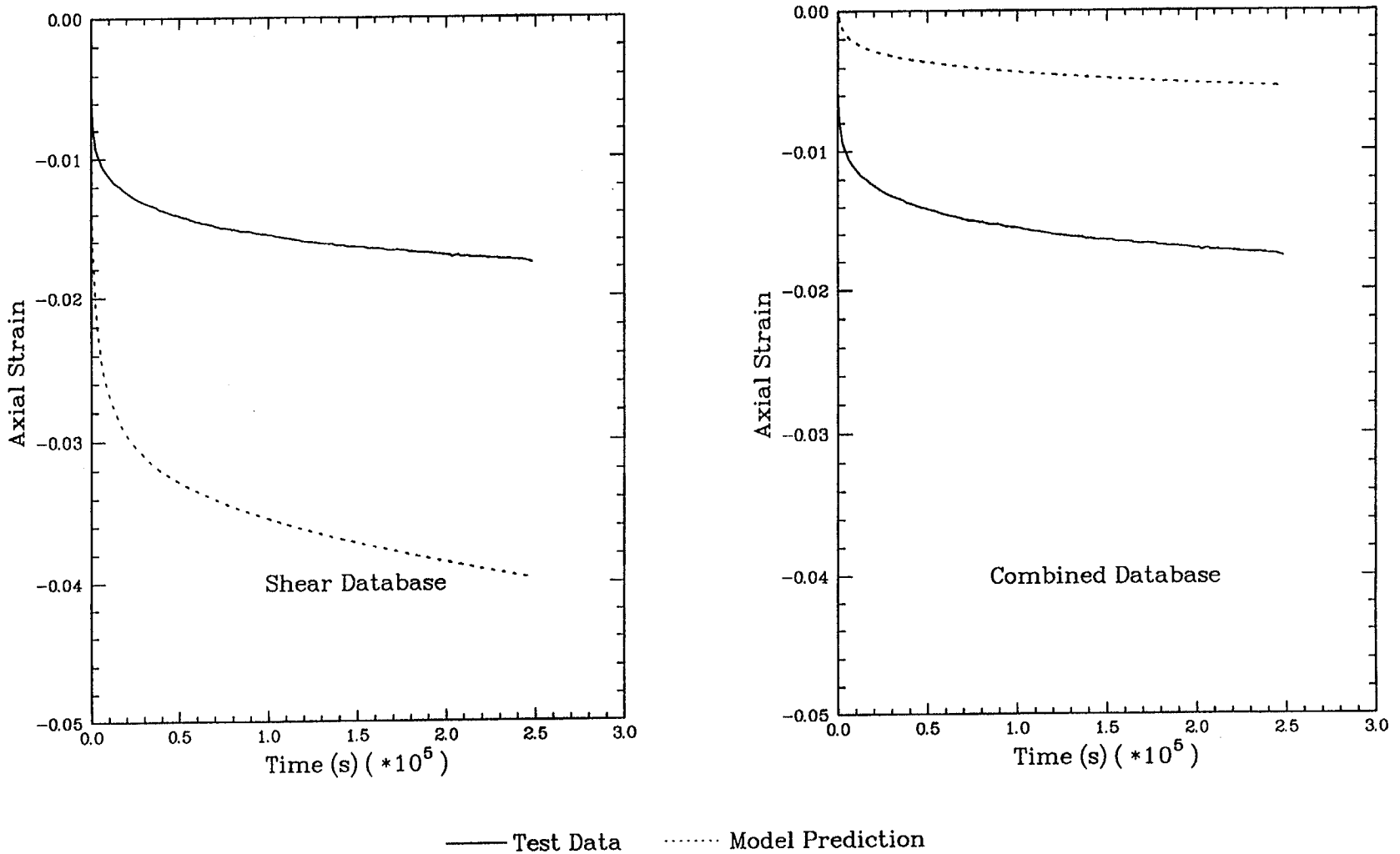


Figure C-20. Hydrostatic Consolidation Test 07MAY82.

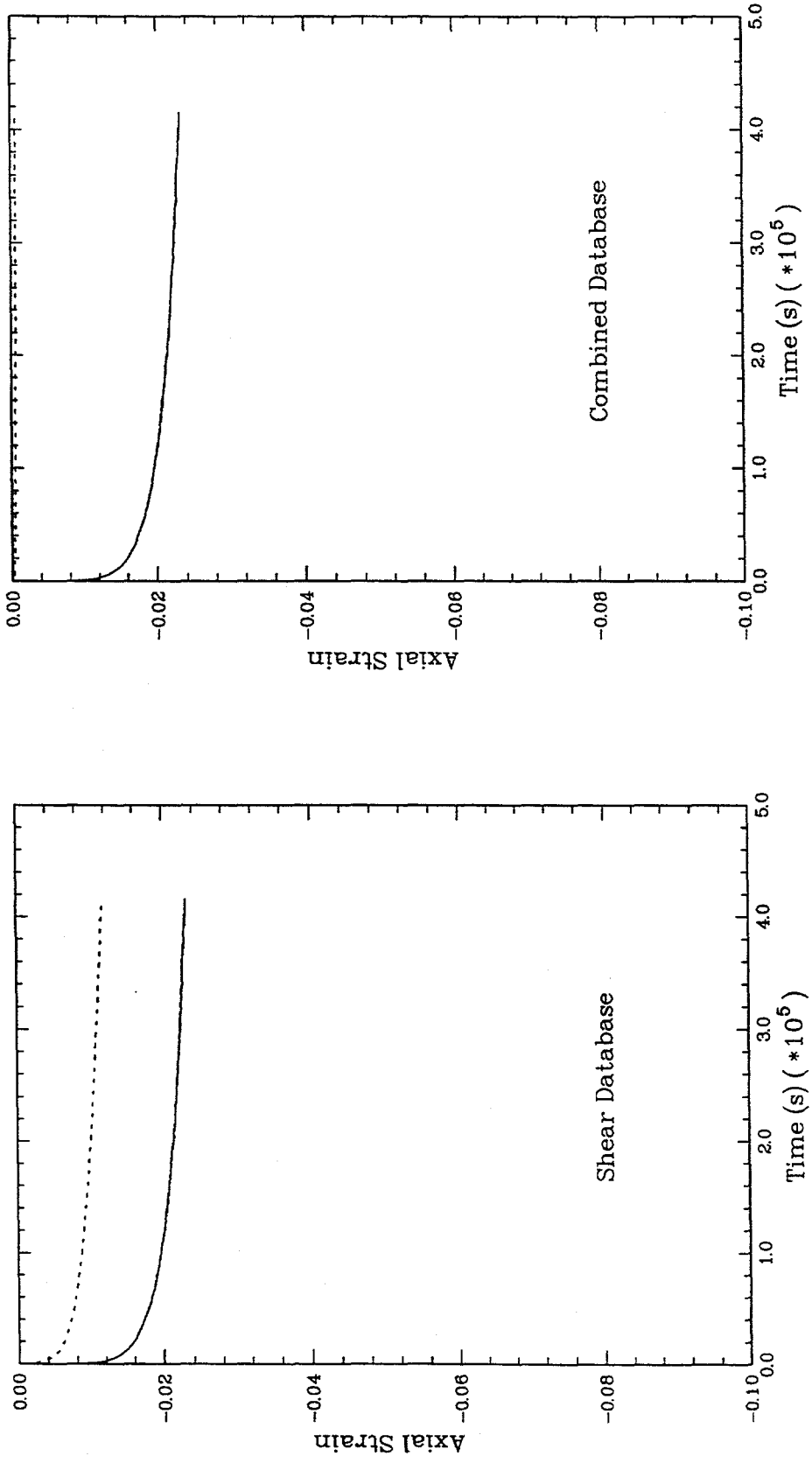
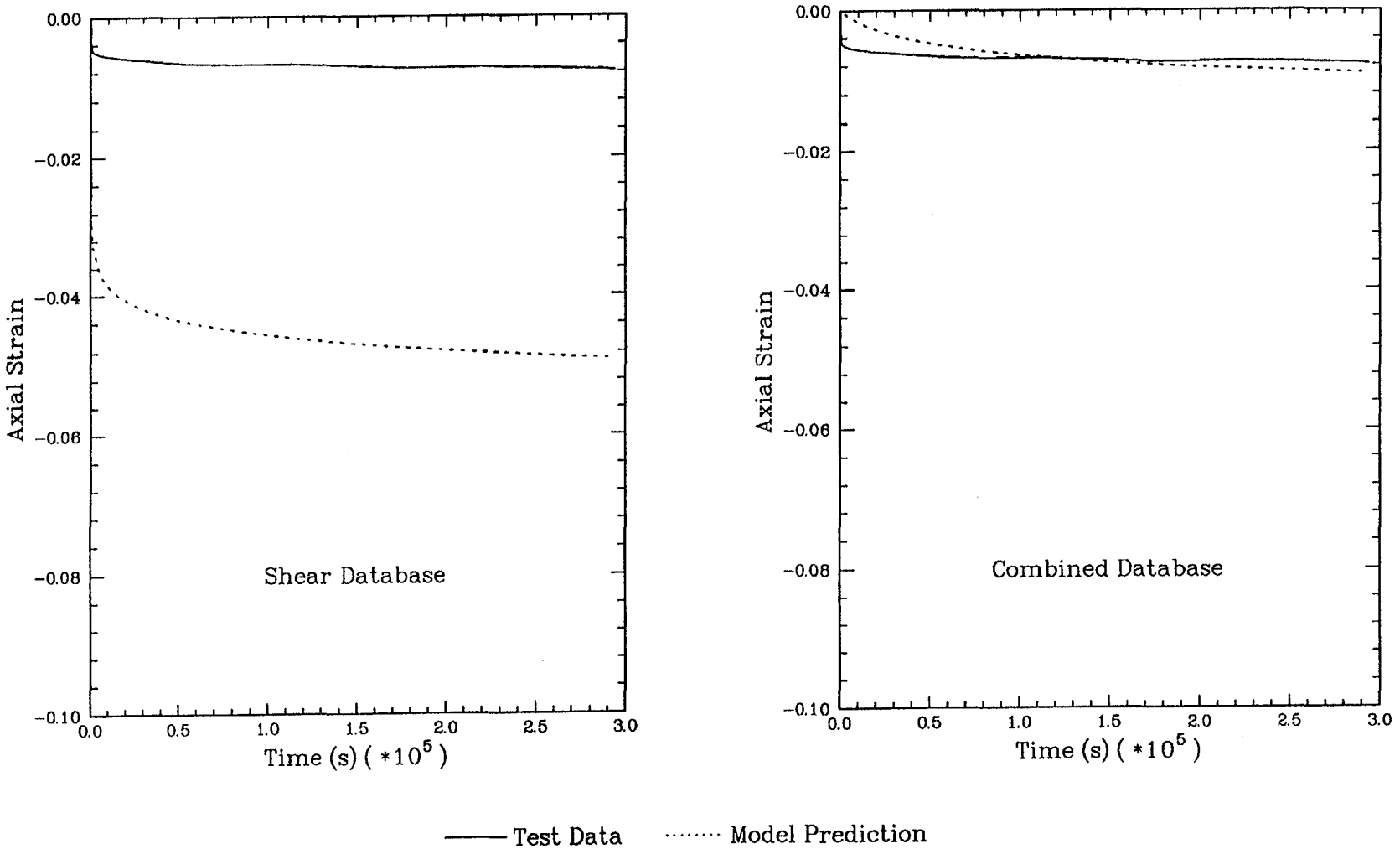


Figure C-21. Hydrostatic Consolidation Test 12MAY82.



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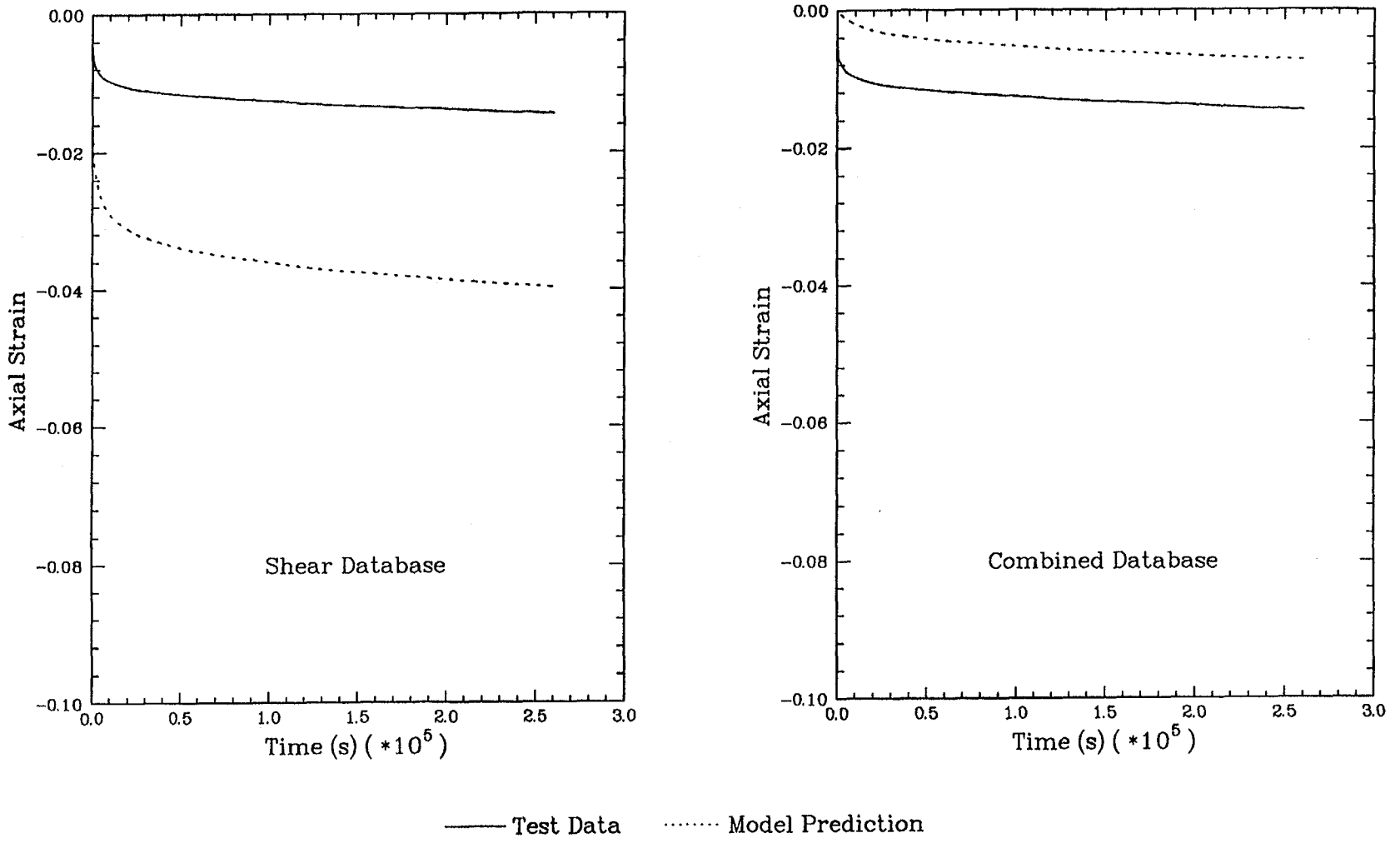


Figure C-23. Hydrostatic Consolidation Test 09APR82.

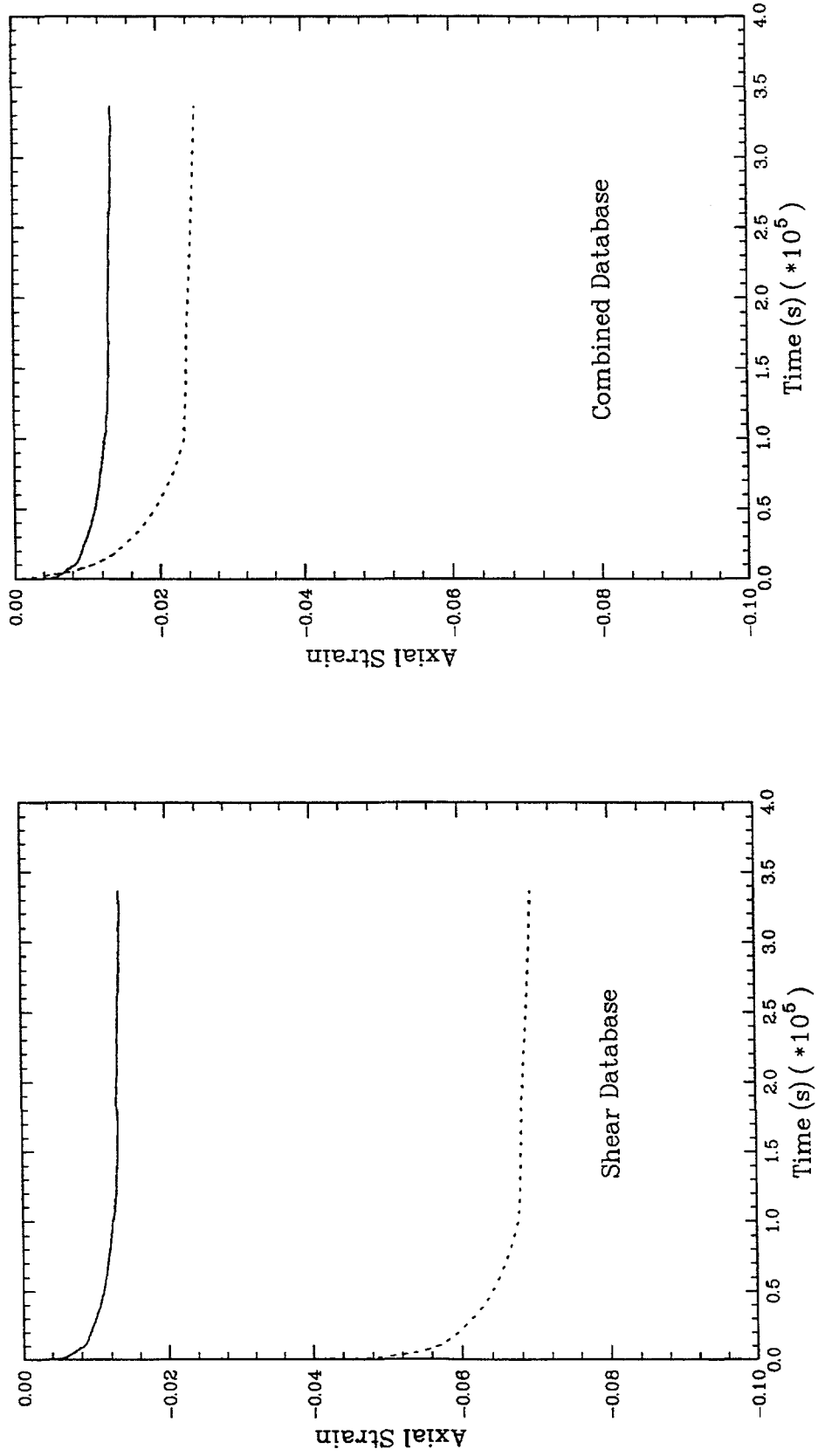
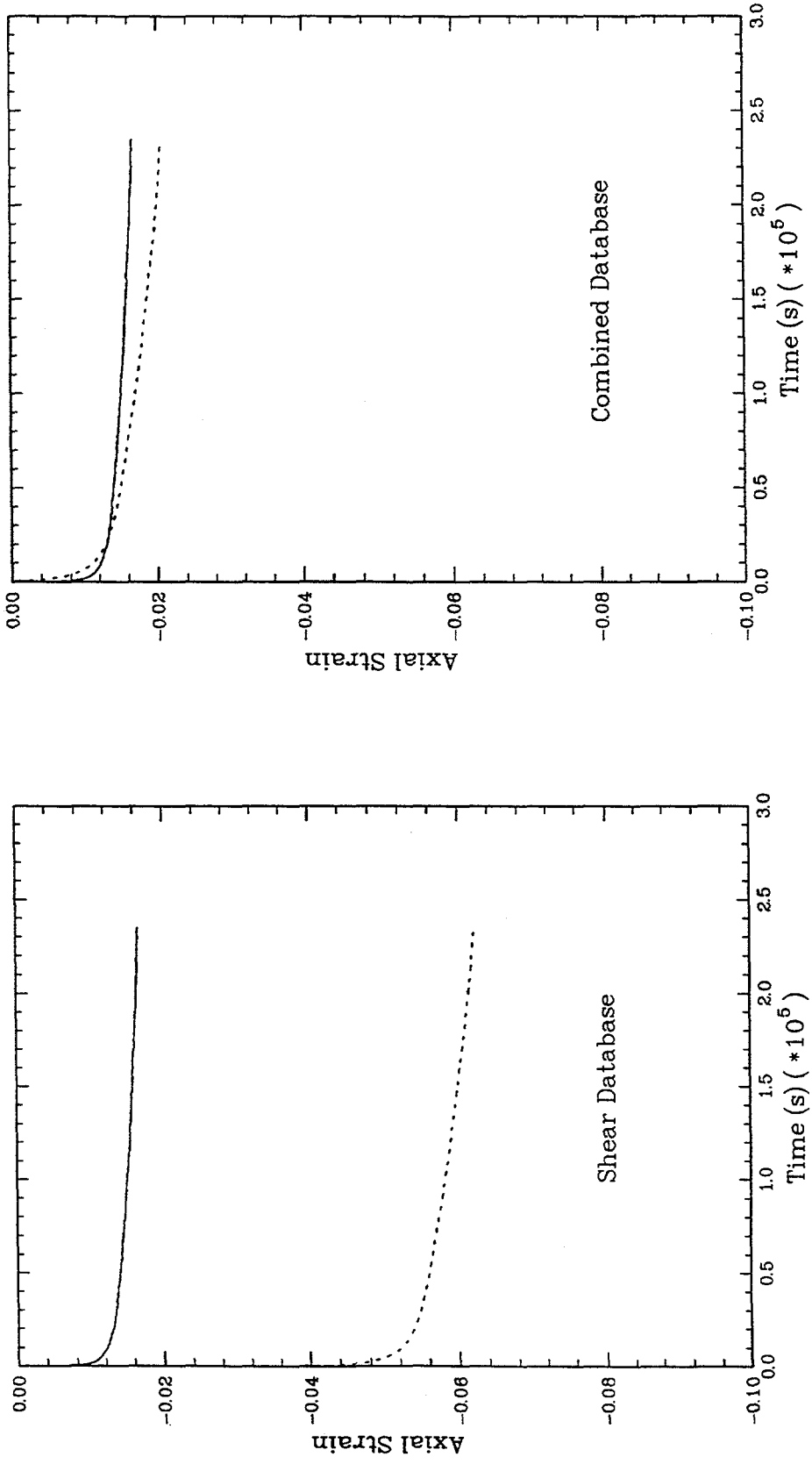


Figure C-24. Hydrostatic Consolidation Test 26MAR82.



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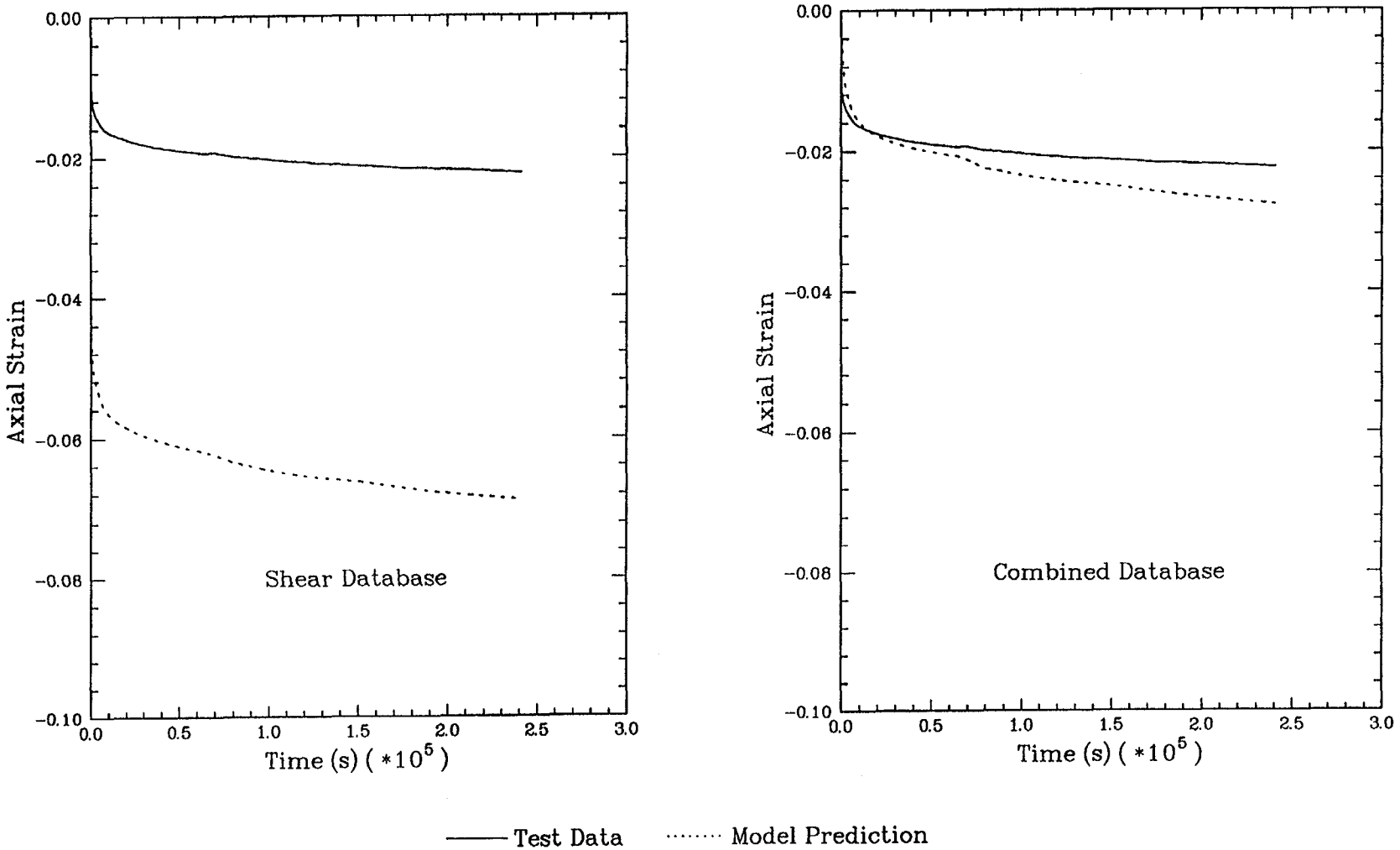


Figure C-26. Hydrostatic Consolidation Test 13APR82.

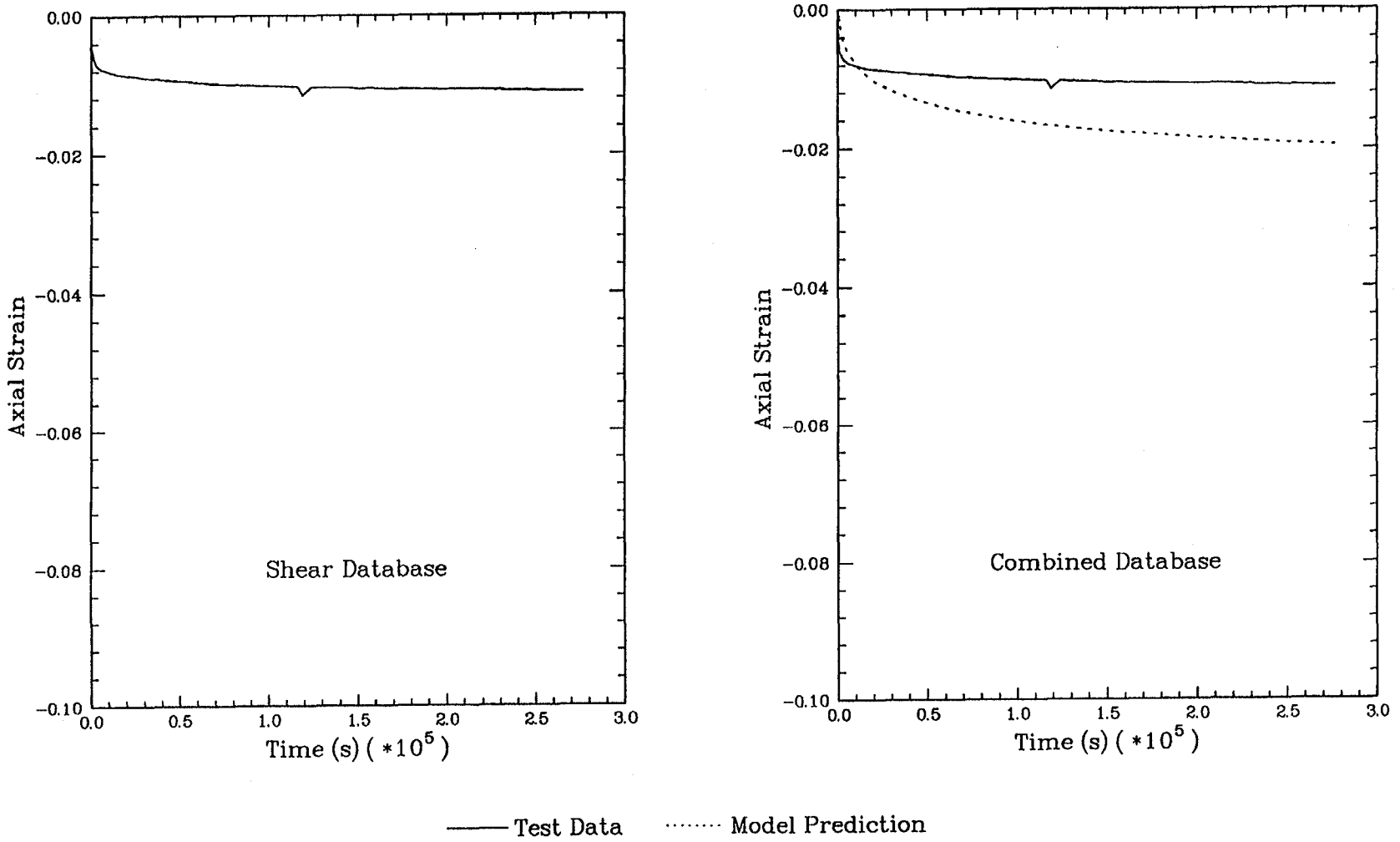


Figure C-27. Hydrostatic Consolidation Test 29JAN82.

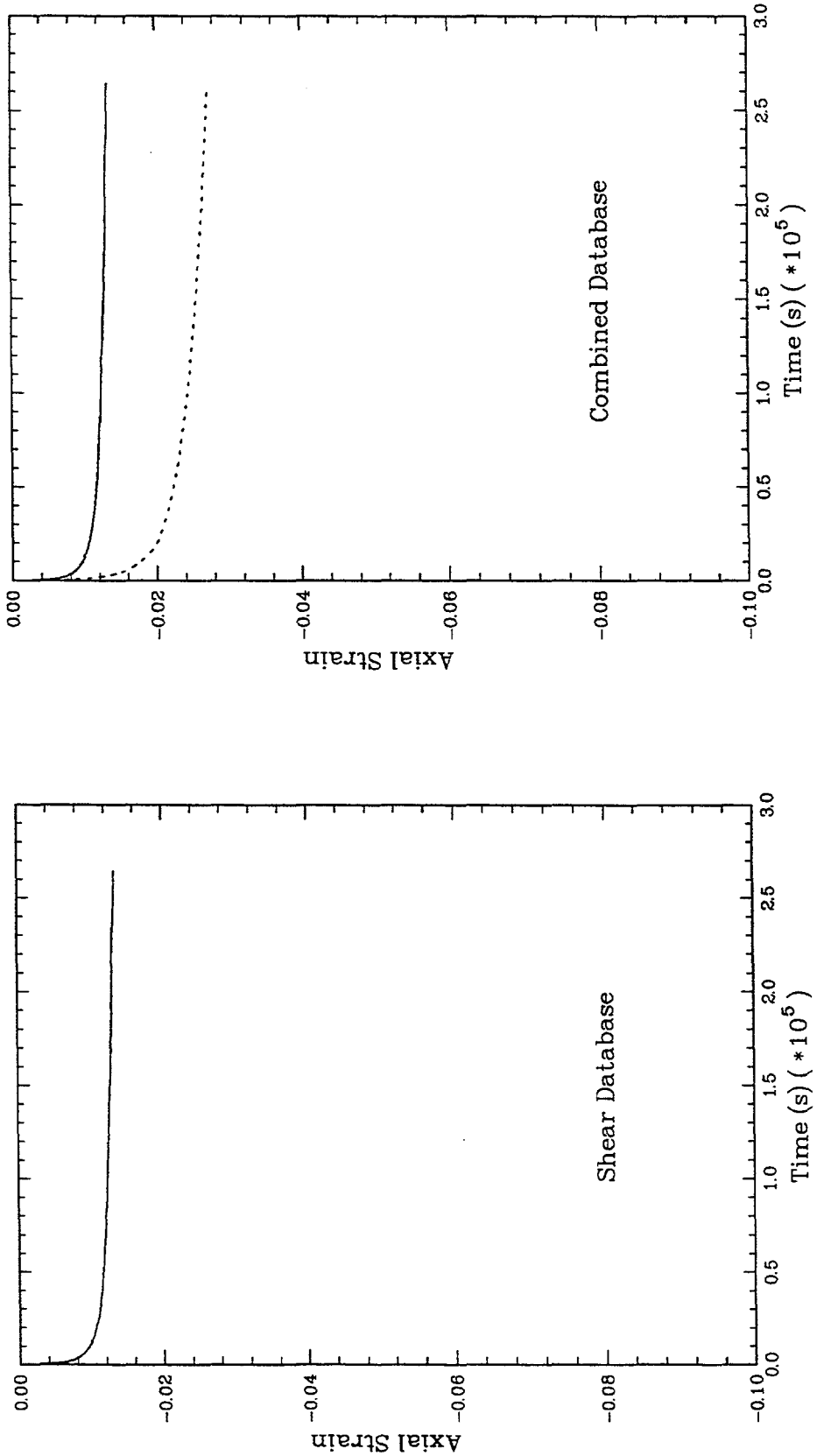


Figure C-28. Hydrostatic Consolidation Test 26FEB82.

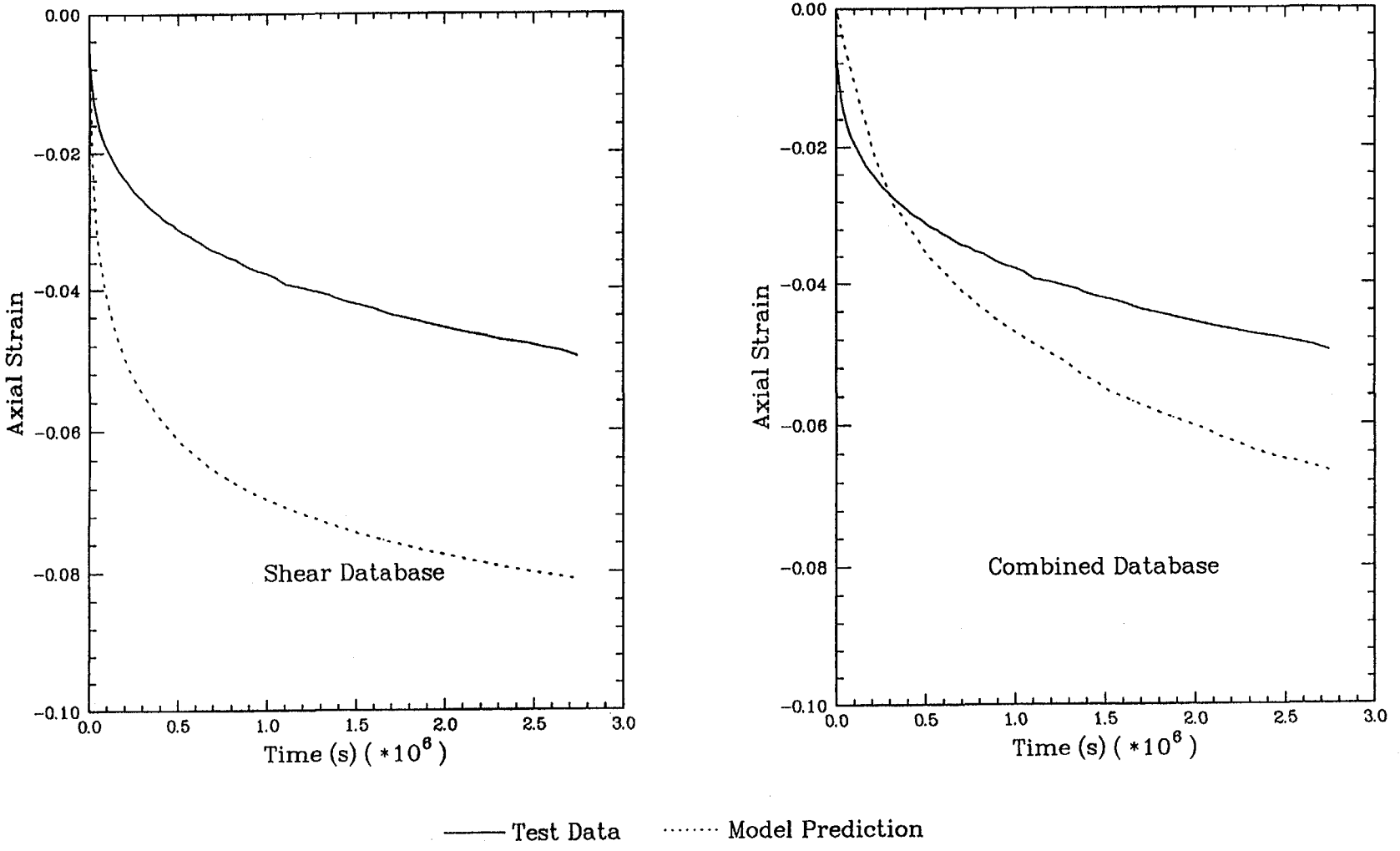


Figure C-29. Hydrostatic Consolidation Test 27JU61.

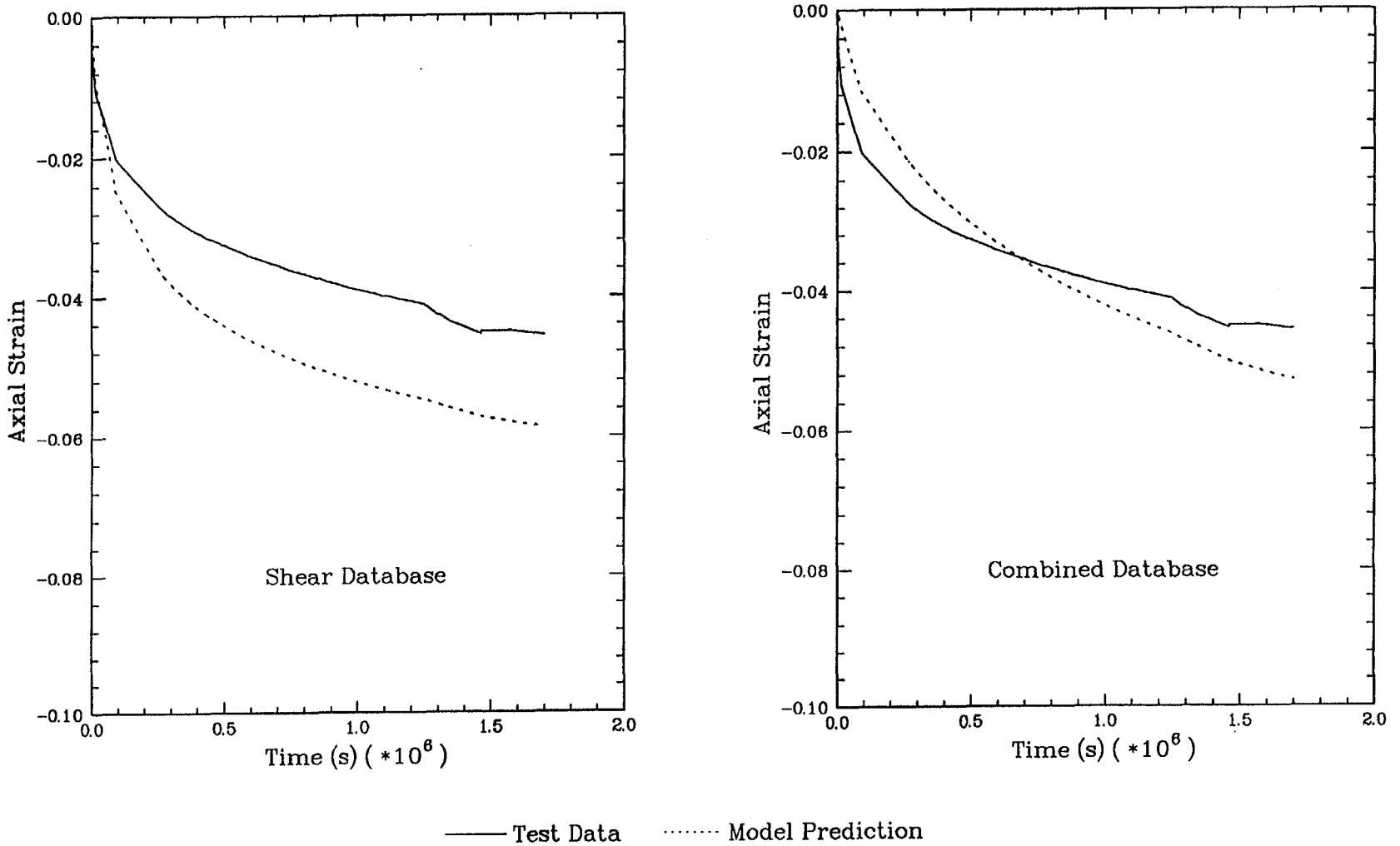


Figure C-30. Hydrostatic Consolidation Test 23JL51.

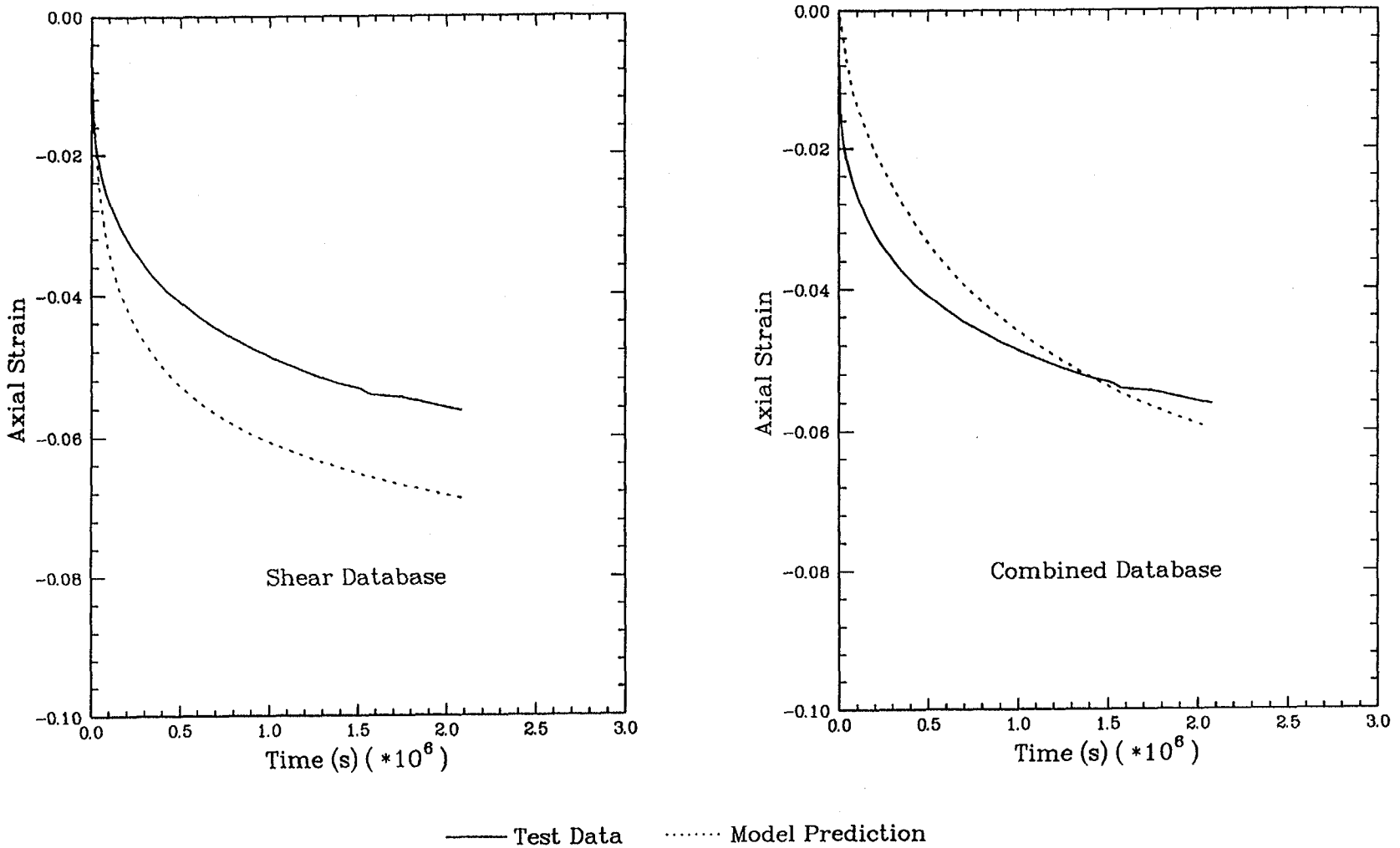


Figure C-31. Hydrostatic Consolidation Test 14NV51.

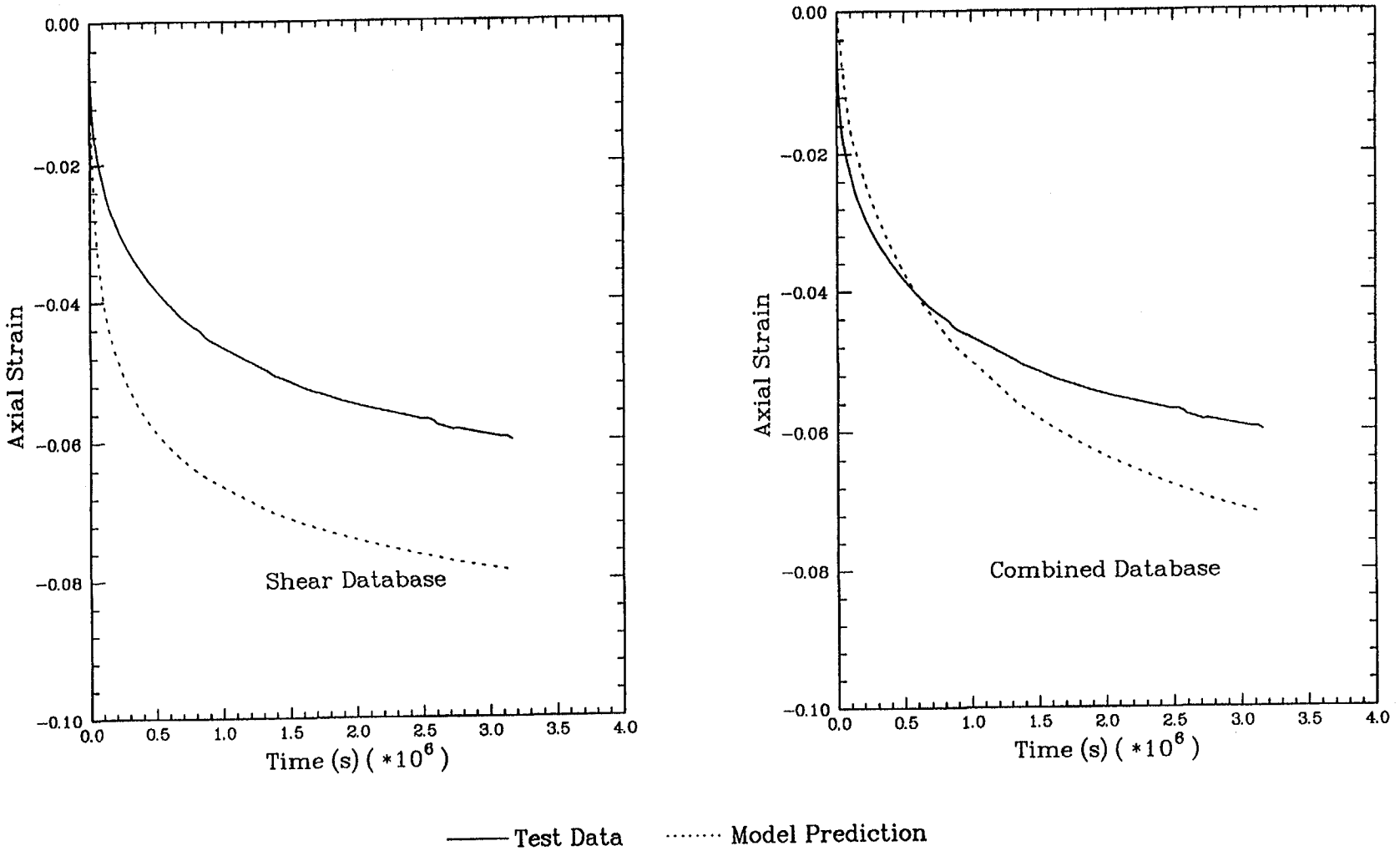


Figure C-32. Hydrostatic Consolidation Test 25FE61.

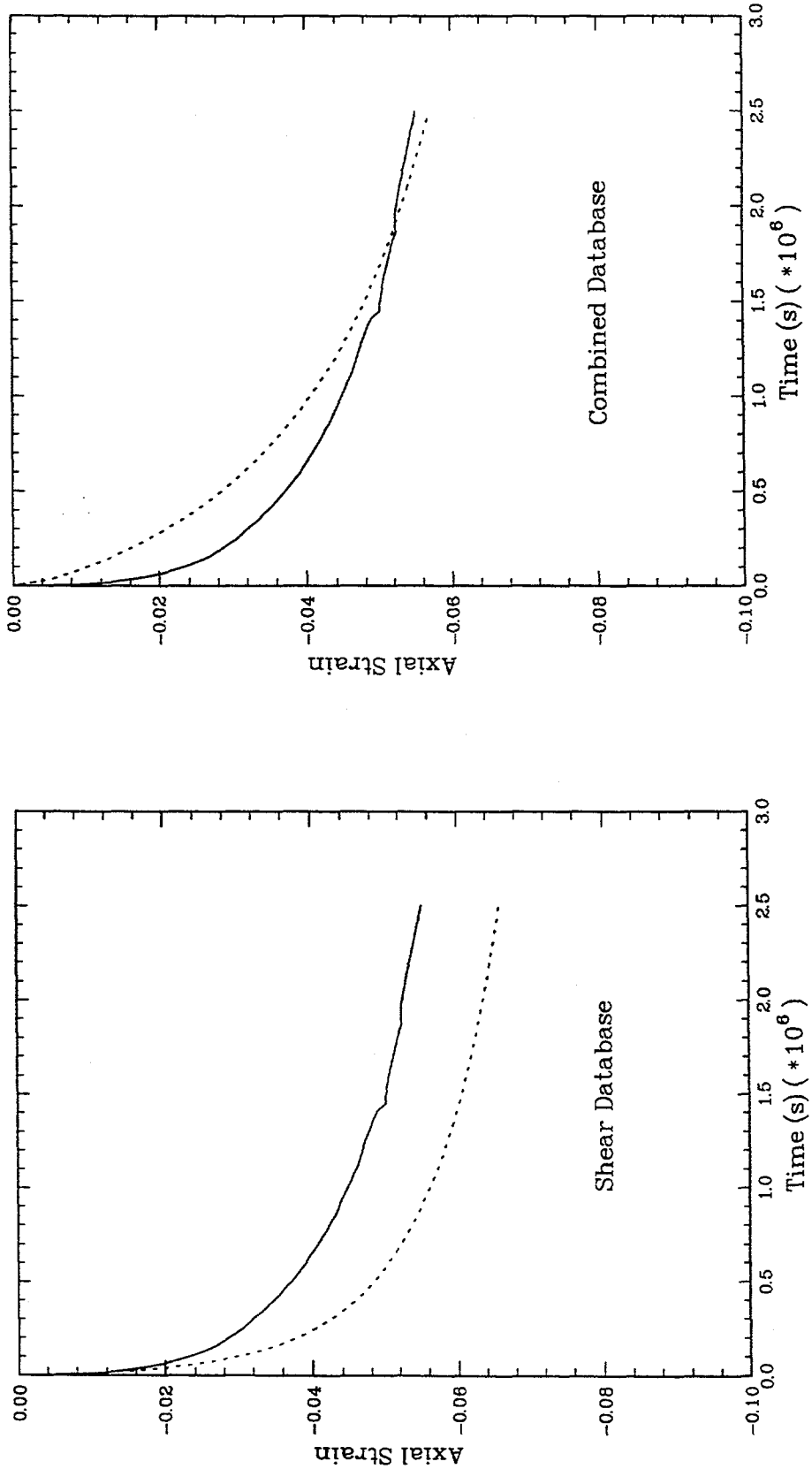


Figure C-33. Hydrostatic Consolidation Test 10MY51.

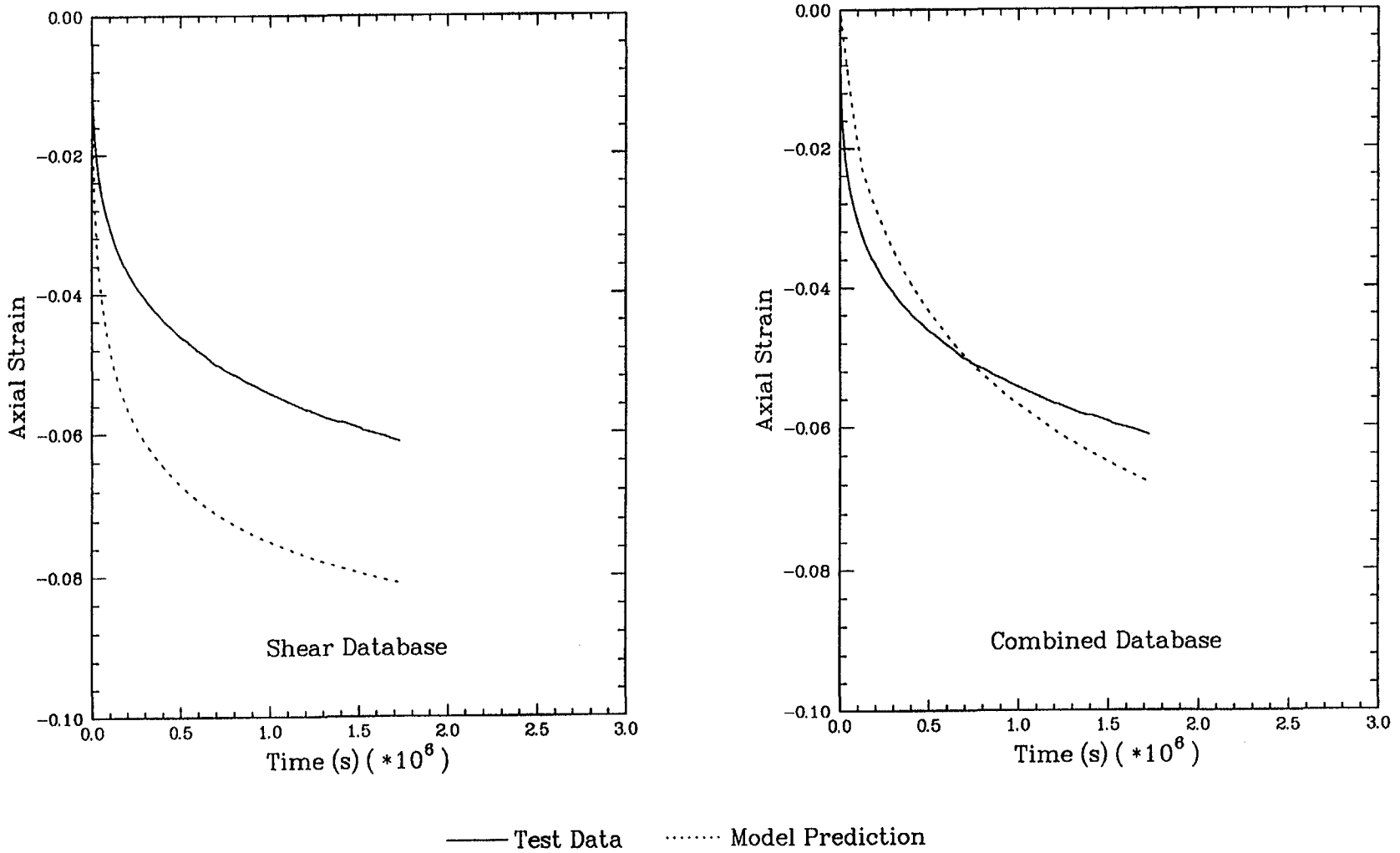


Figure C-34. Hydrostatic Consolidation Test 20AU51.

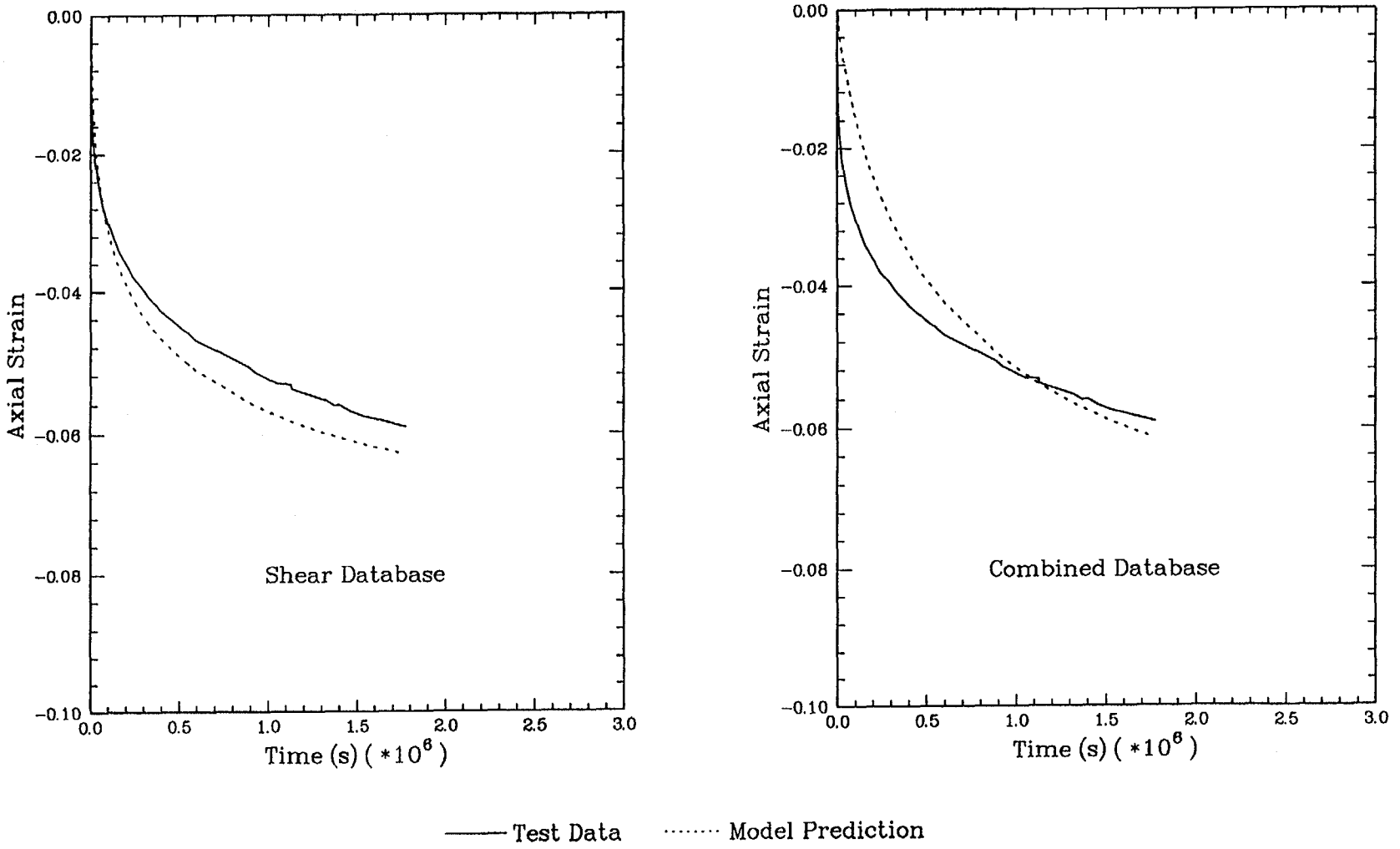


Figure C-35. Hydrostatic Consolidation Test 16JL51.

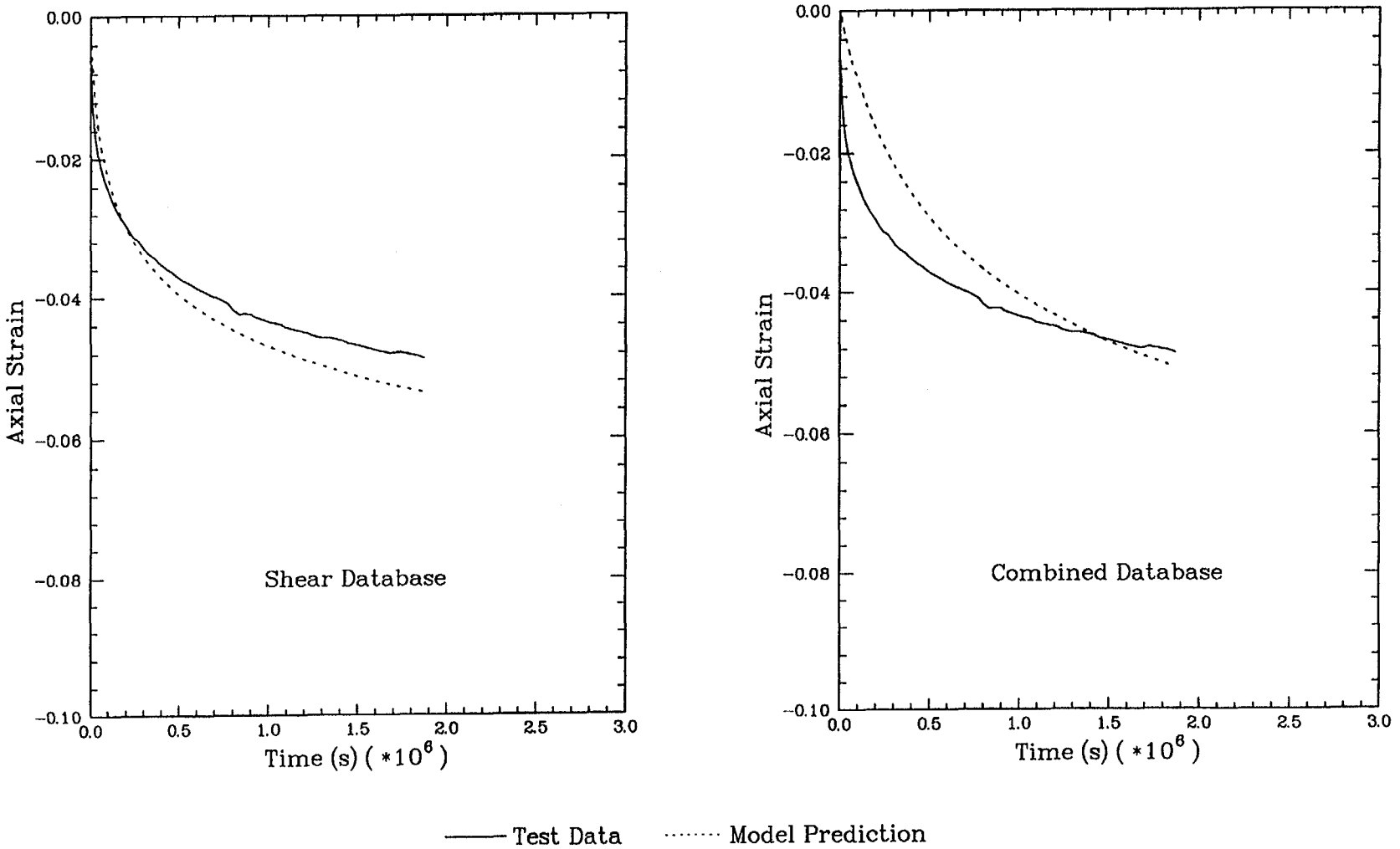


Figure C-36. Hydrostatic Consolidation Test 18JU51.

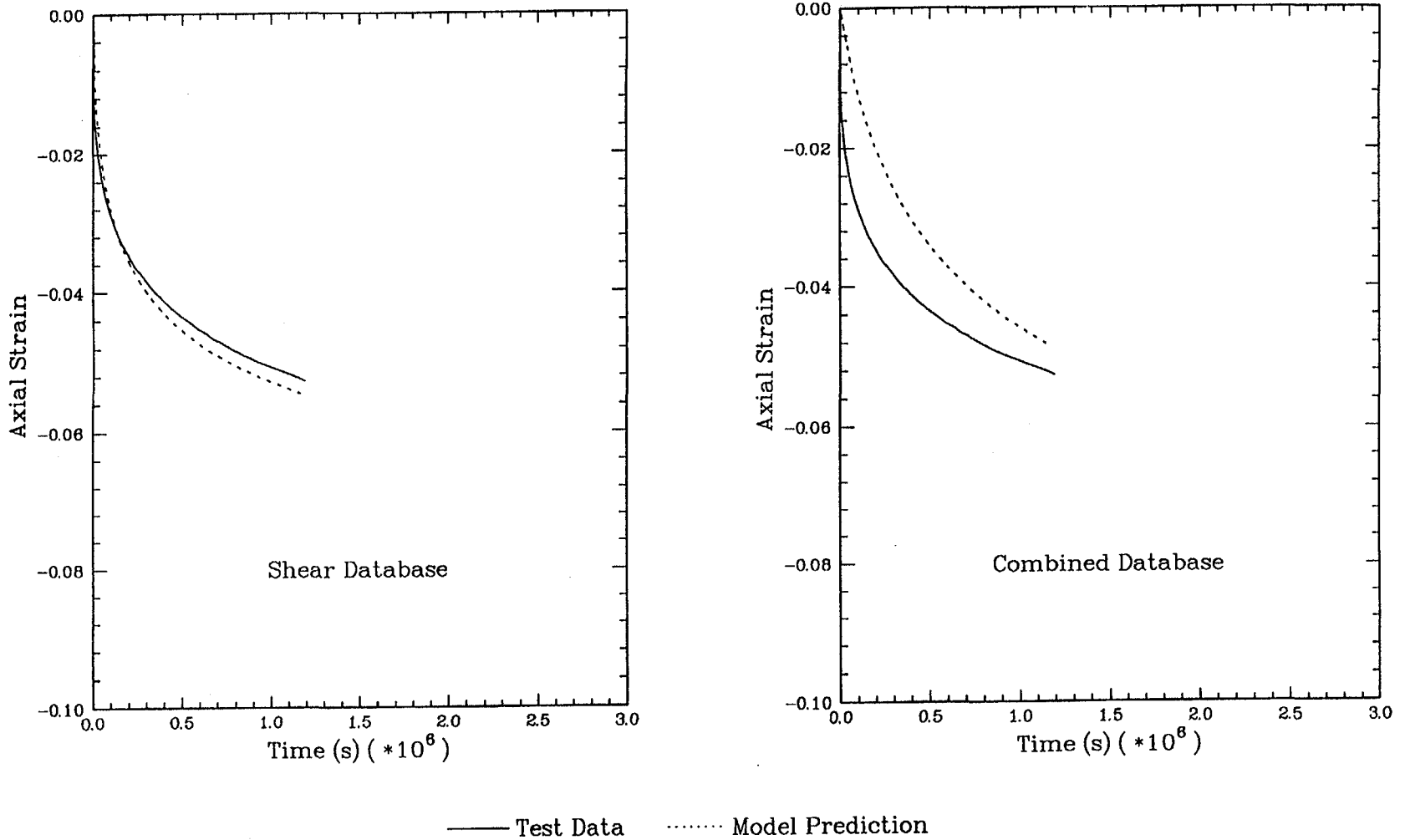


Figure C-37. Hydrostatic Consolidation Test 30OC51.

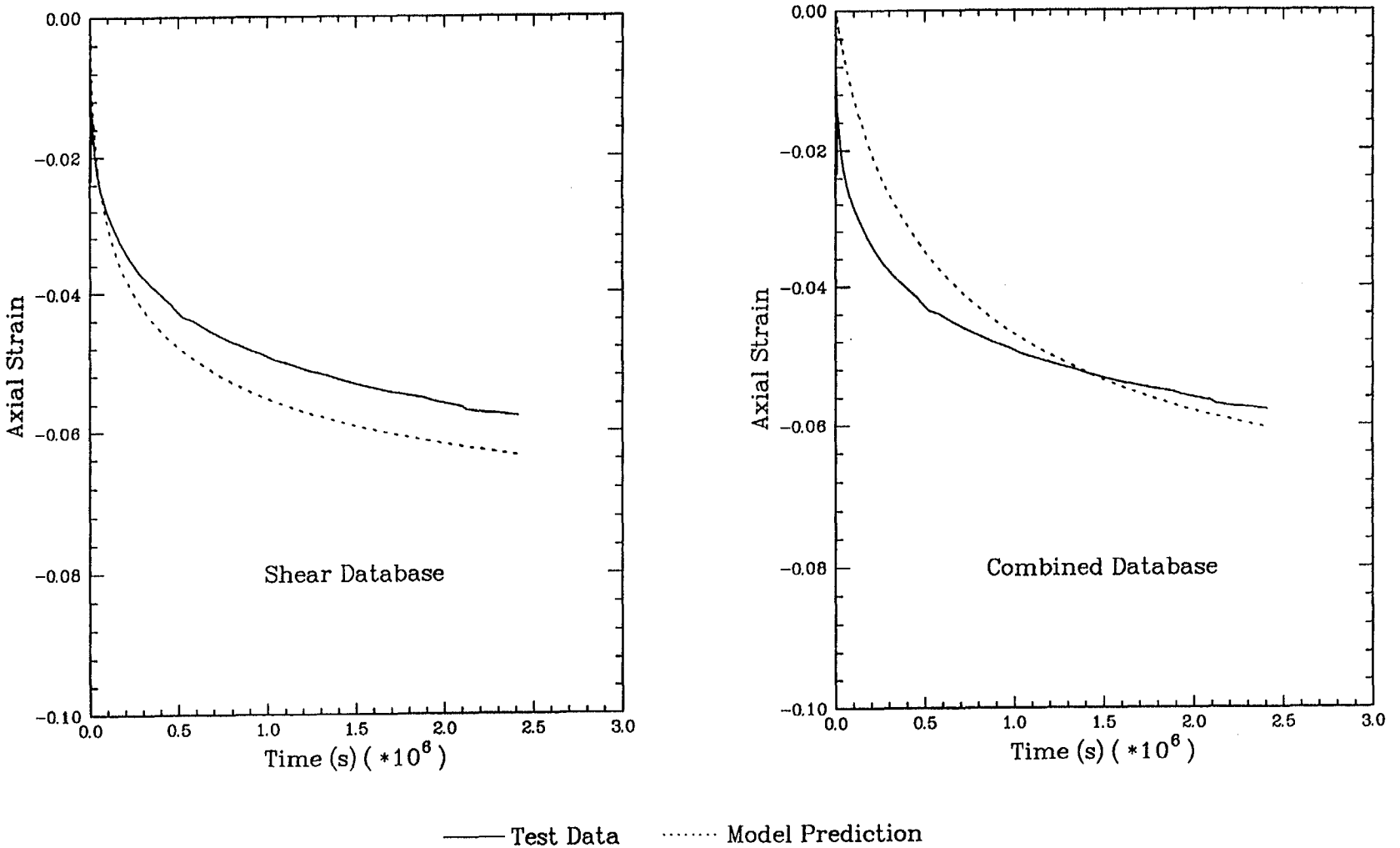


Figure C-38. Hydrostatic Consolidation Test 16JA61.

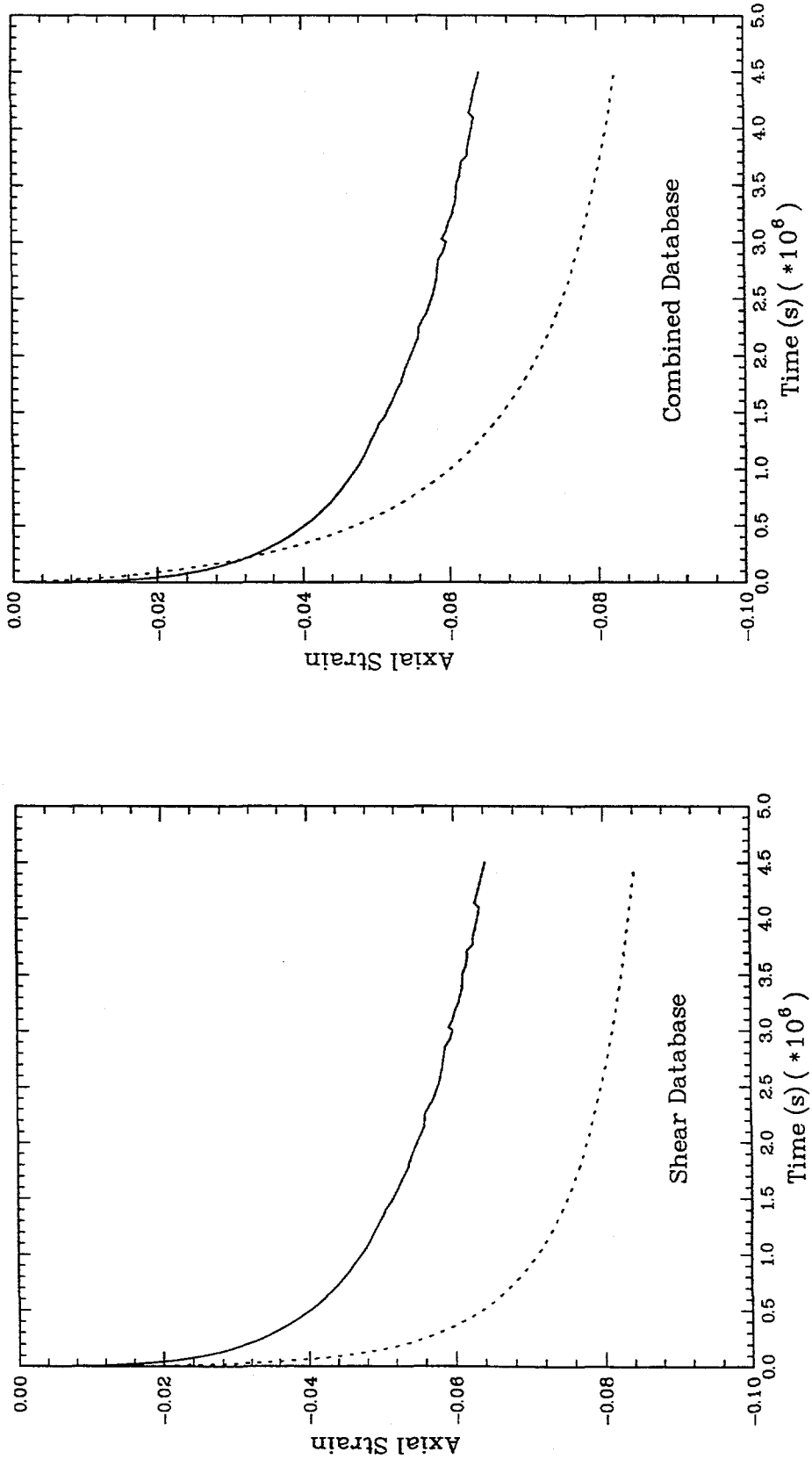


Figure C-39. Hydrostatic Consolidation Test 19DC44.

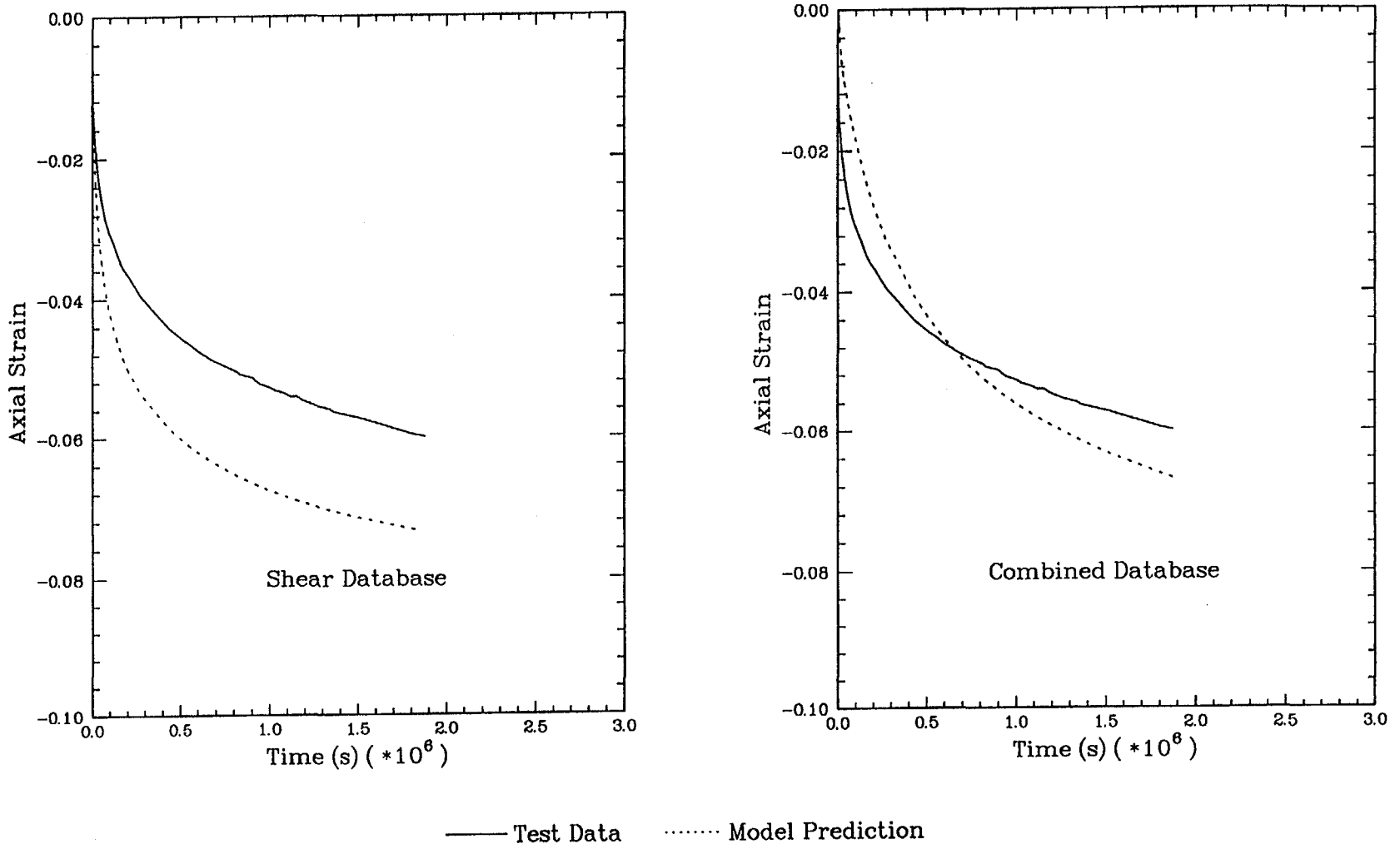


Figure C-40. Hydrostatic Consolidation Test 13AU51.

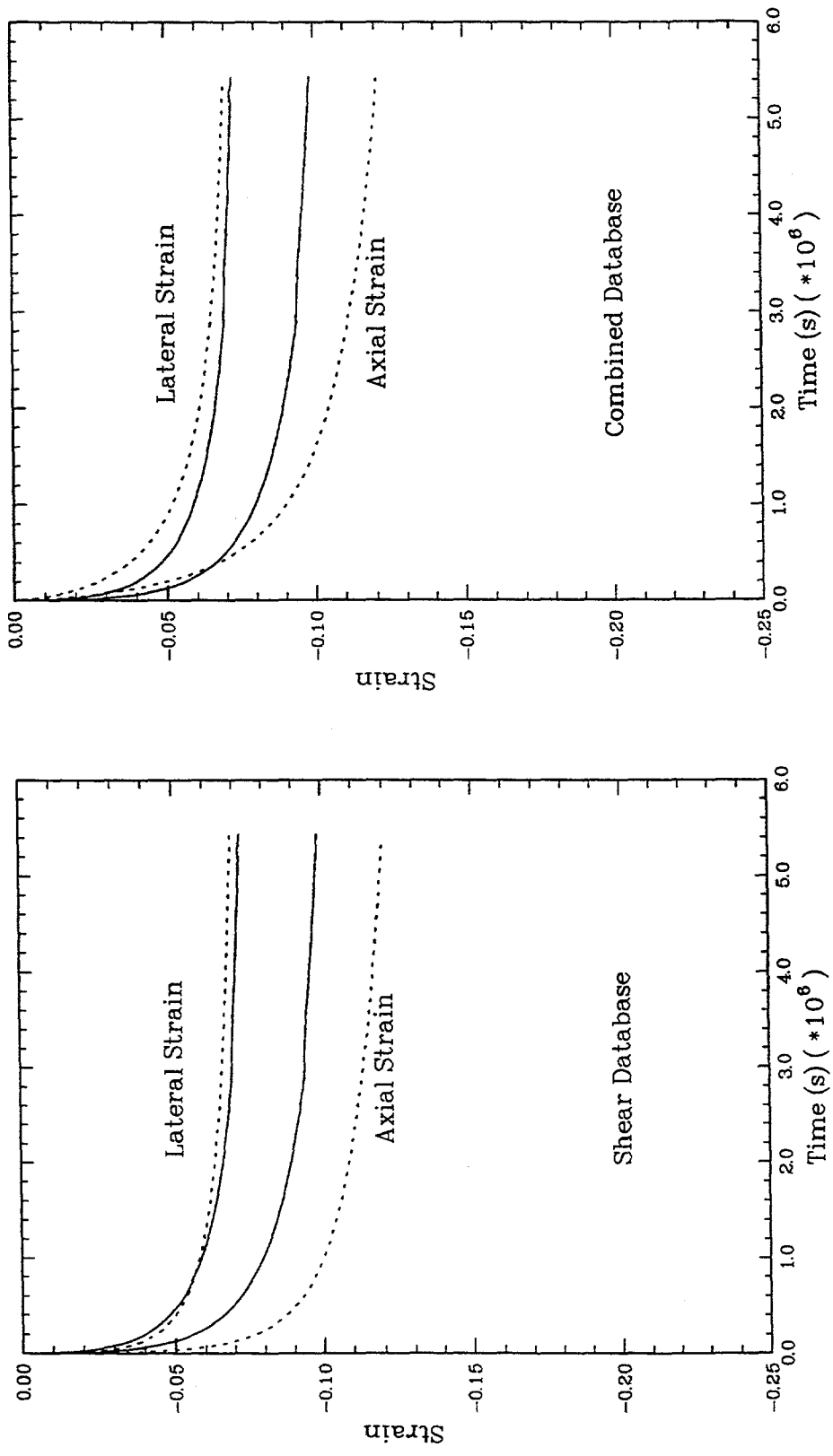


Figure C-41. Shear Consolidation Test SC1B.

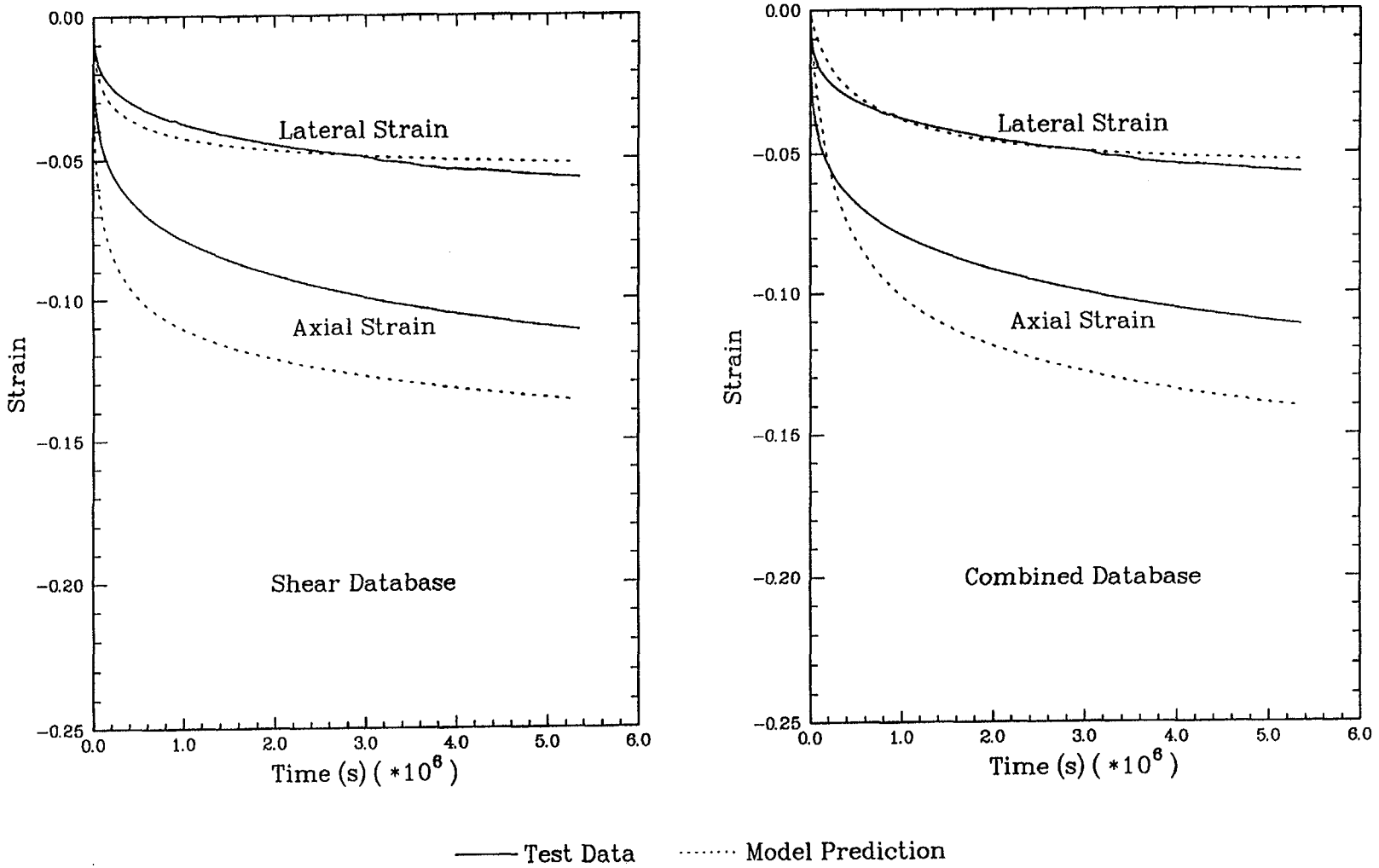


Figure C-42. Shear Consolidation Test SC2A.

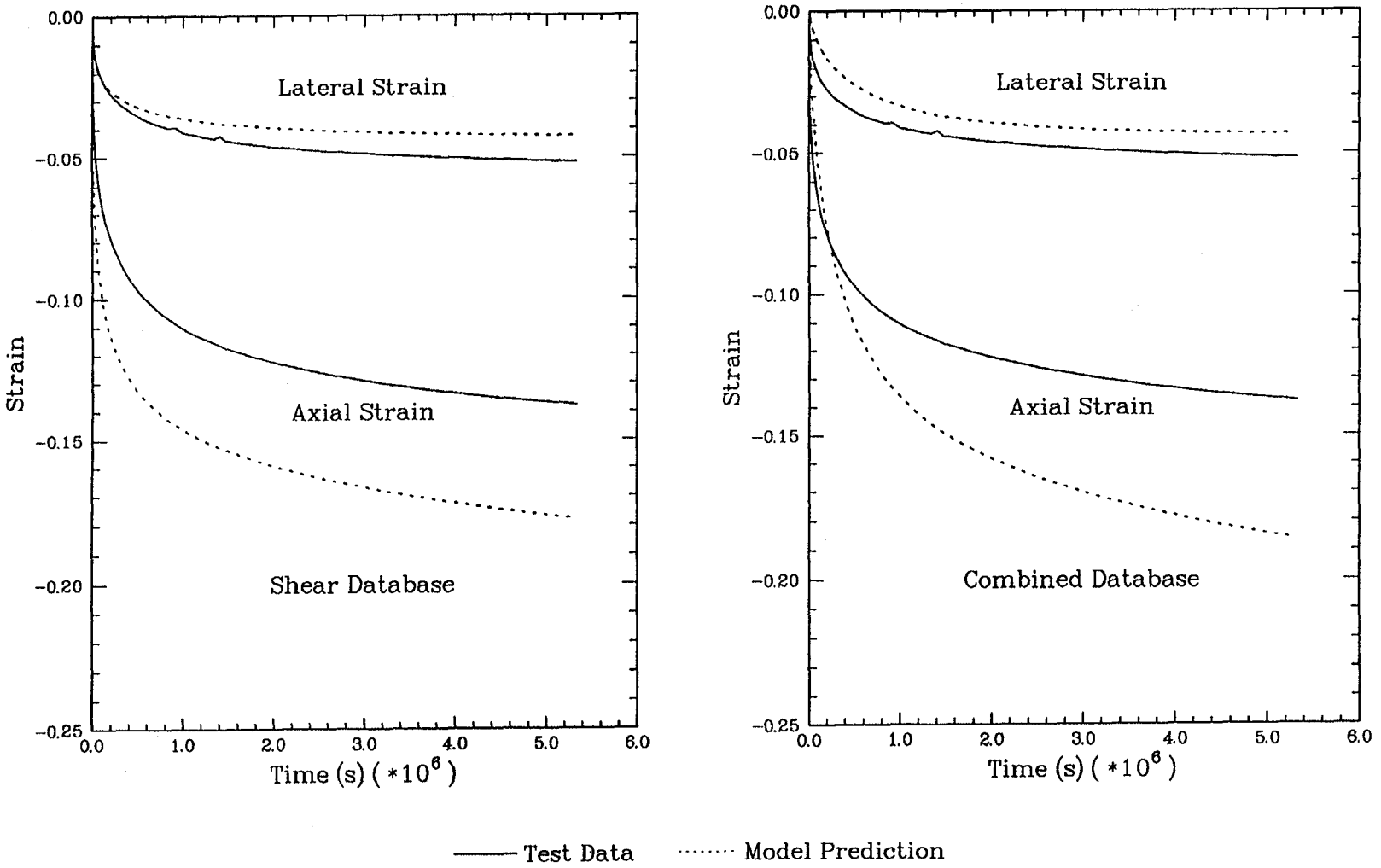
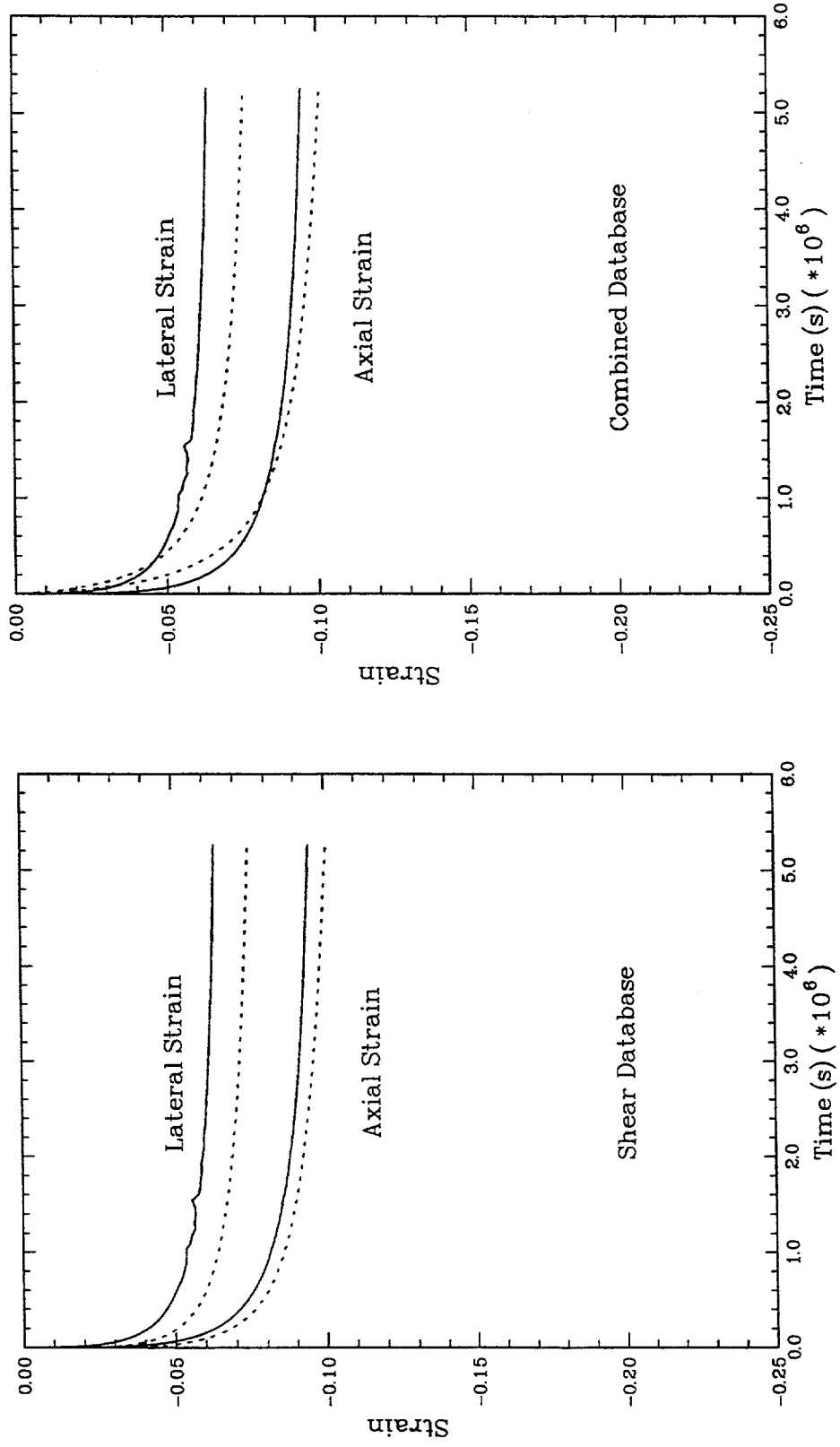


Figure C-43. Shear Consolidation Test SC3A.



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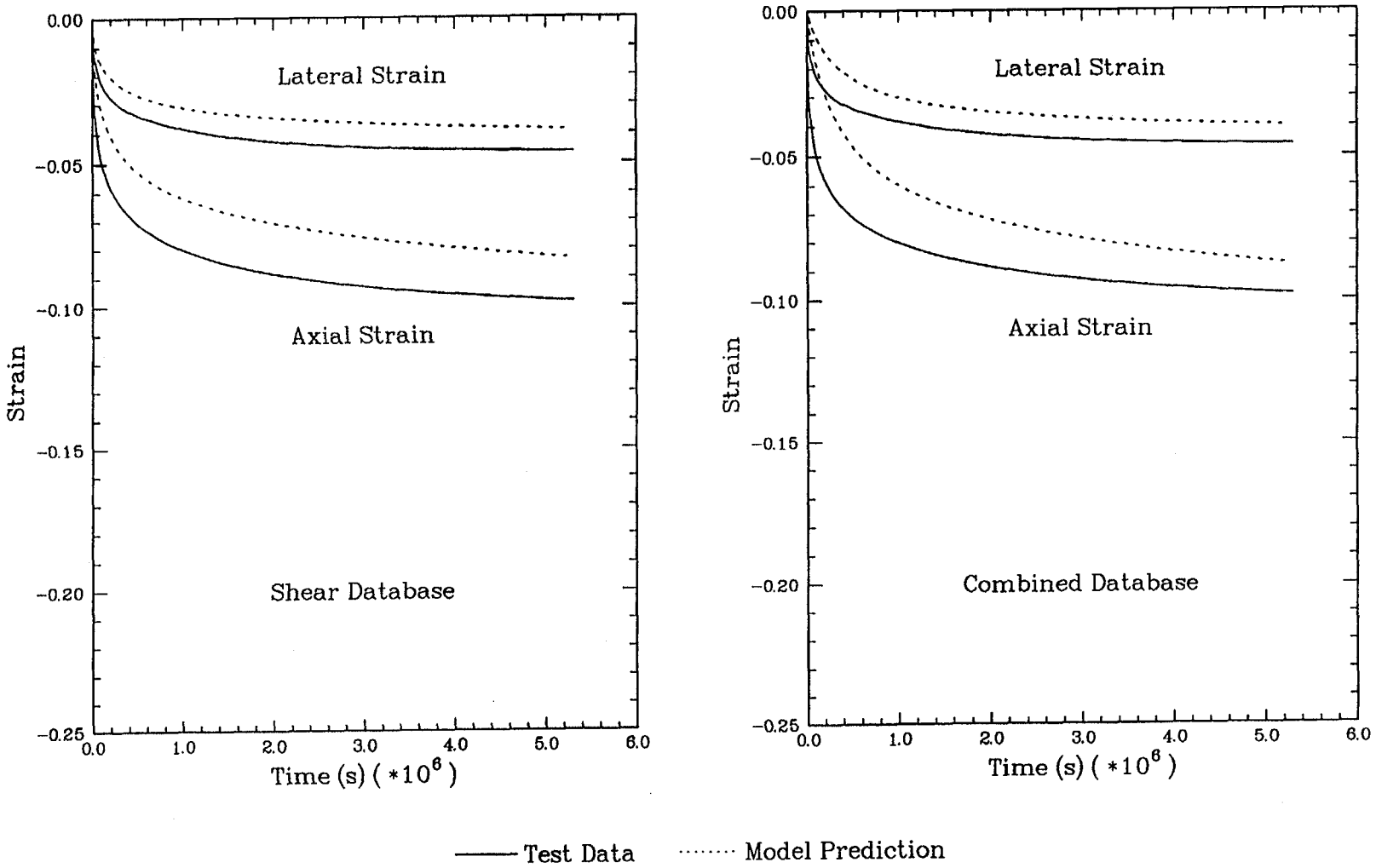

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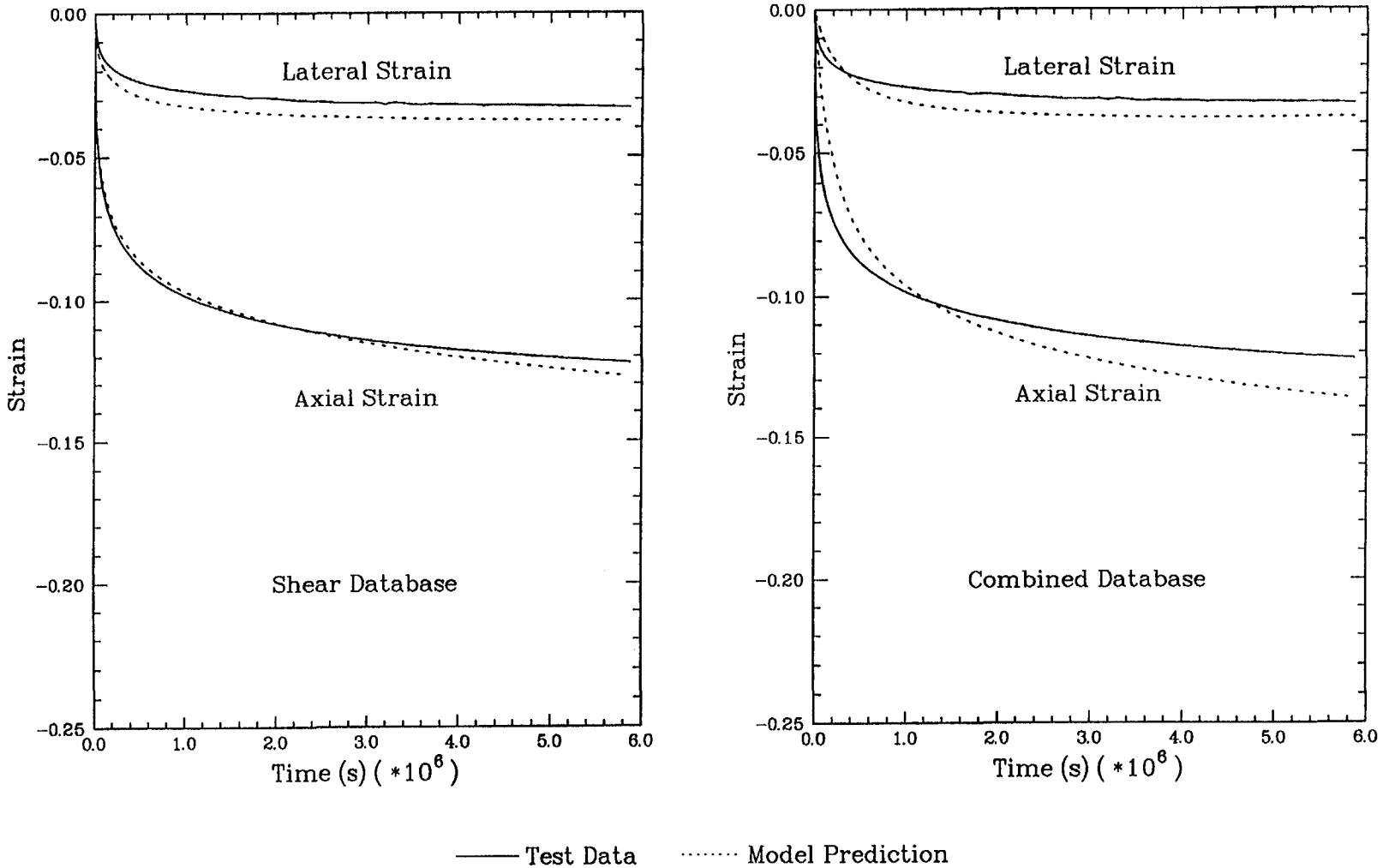

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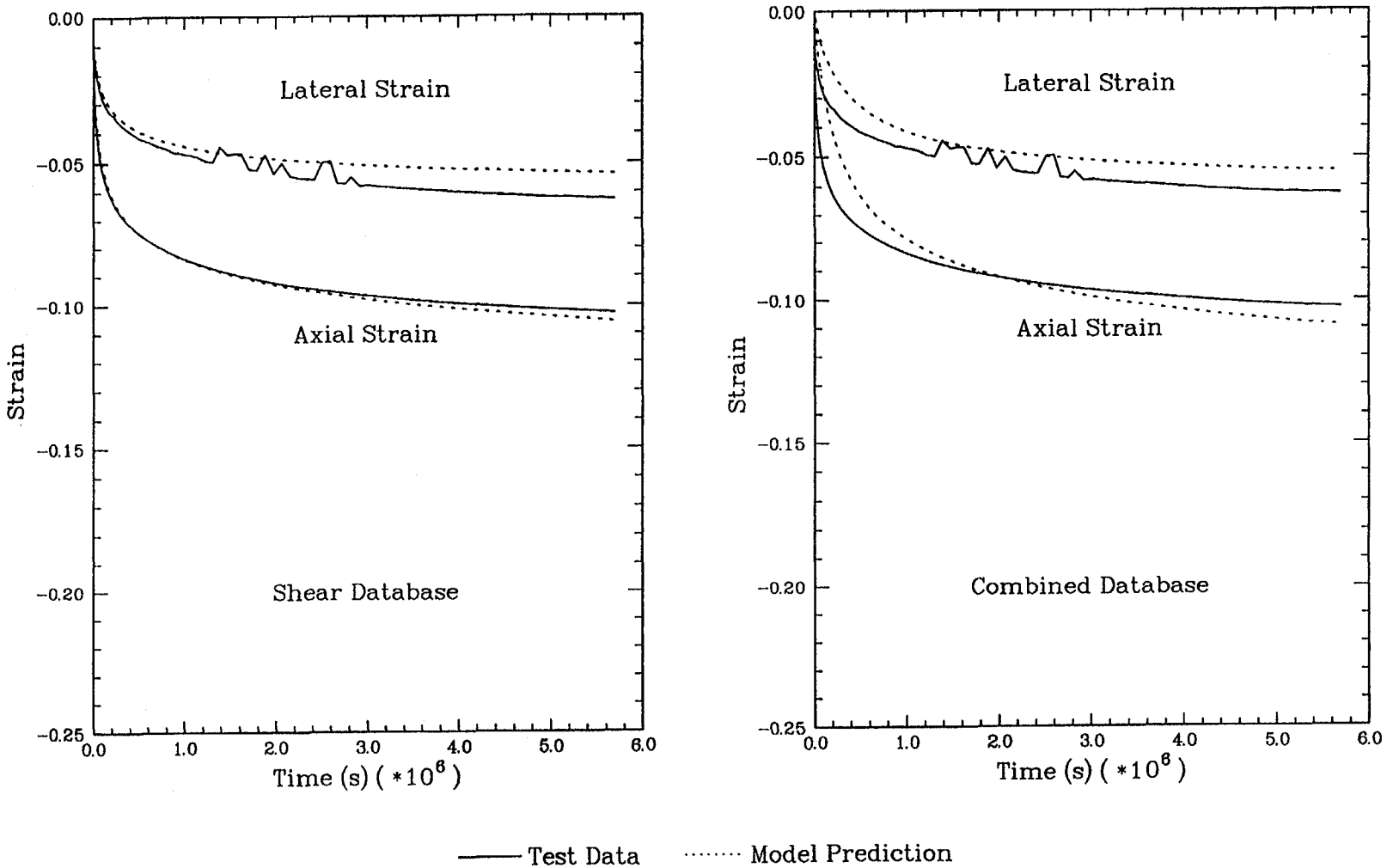

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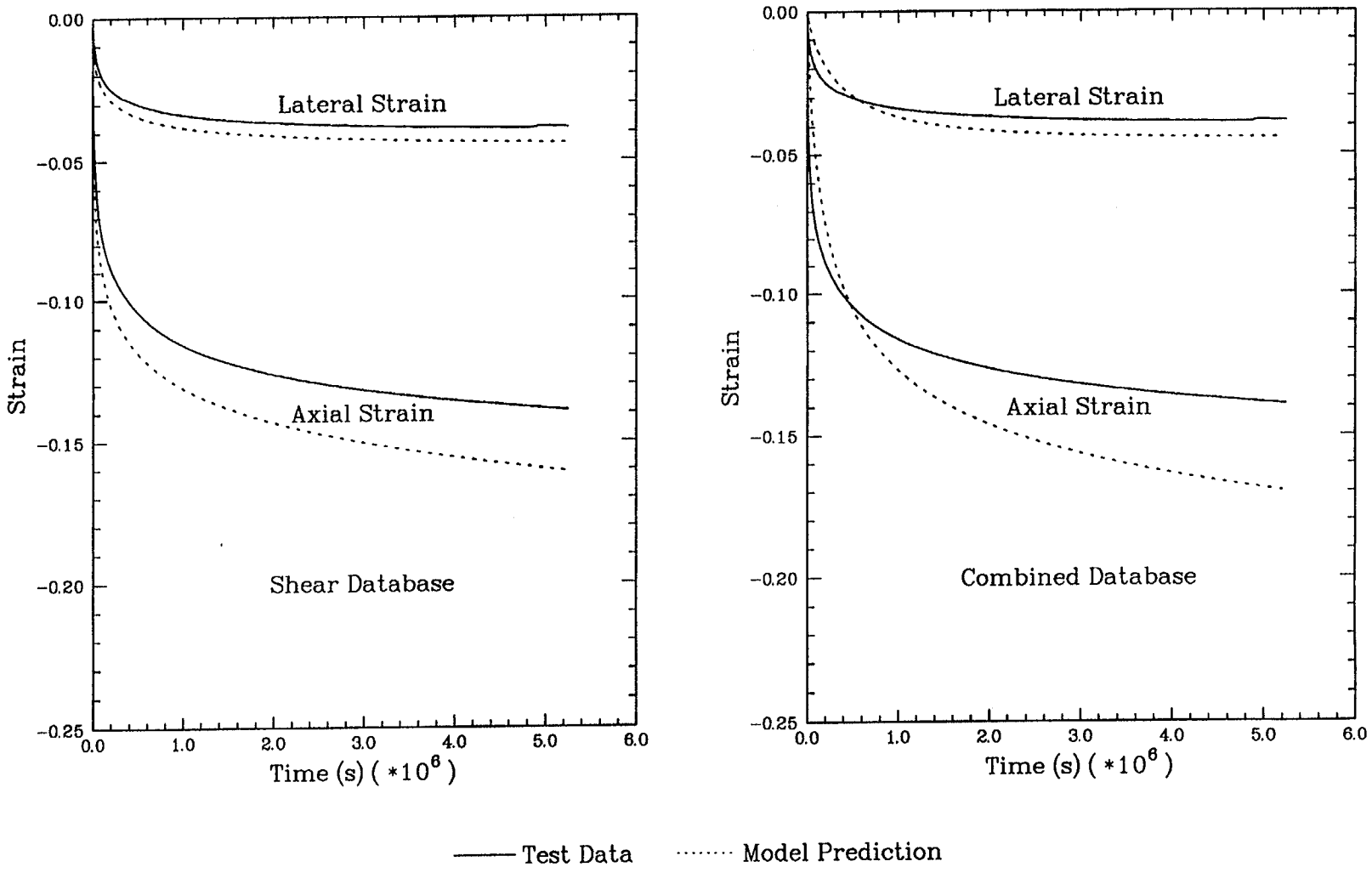

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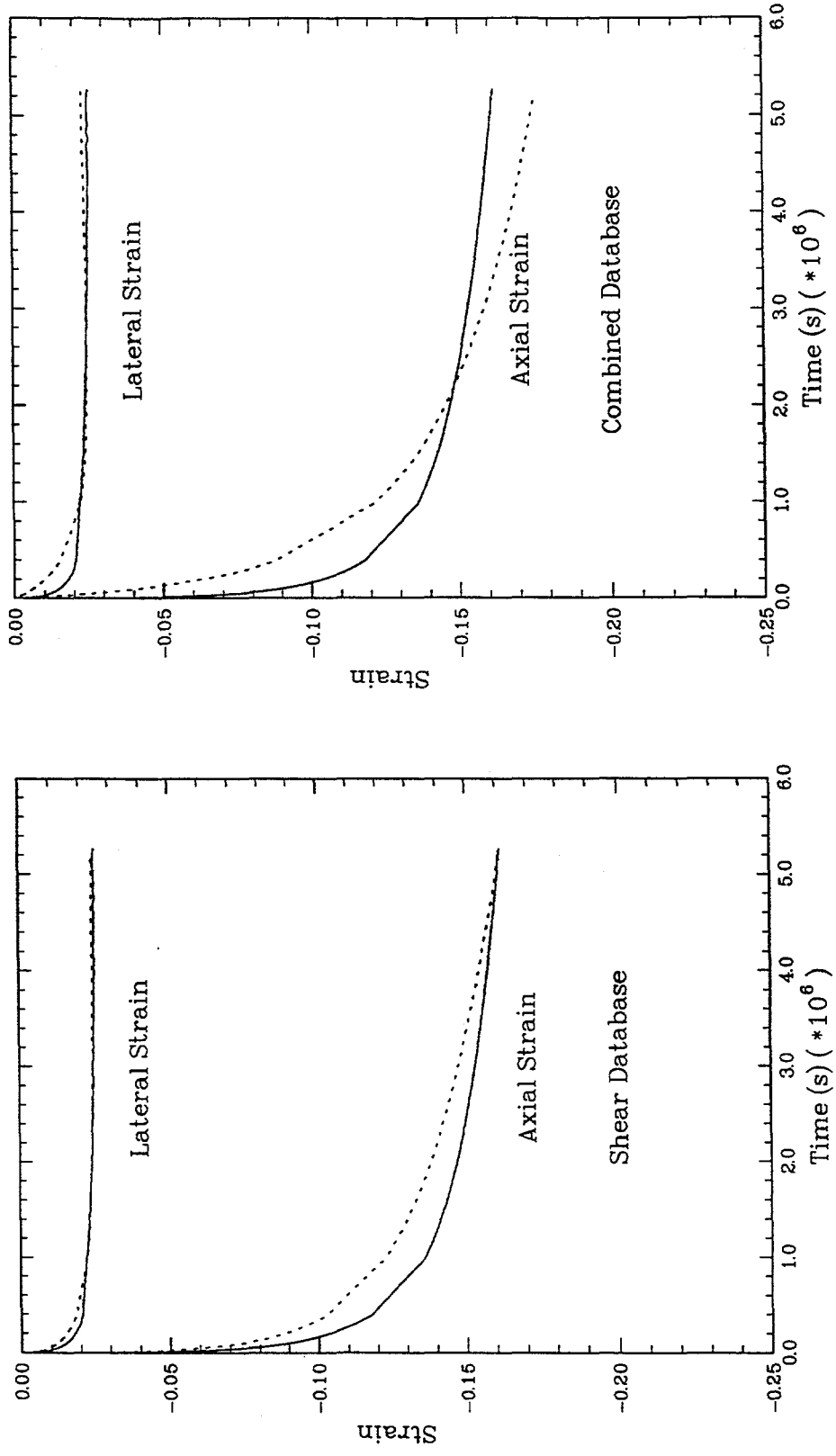

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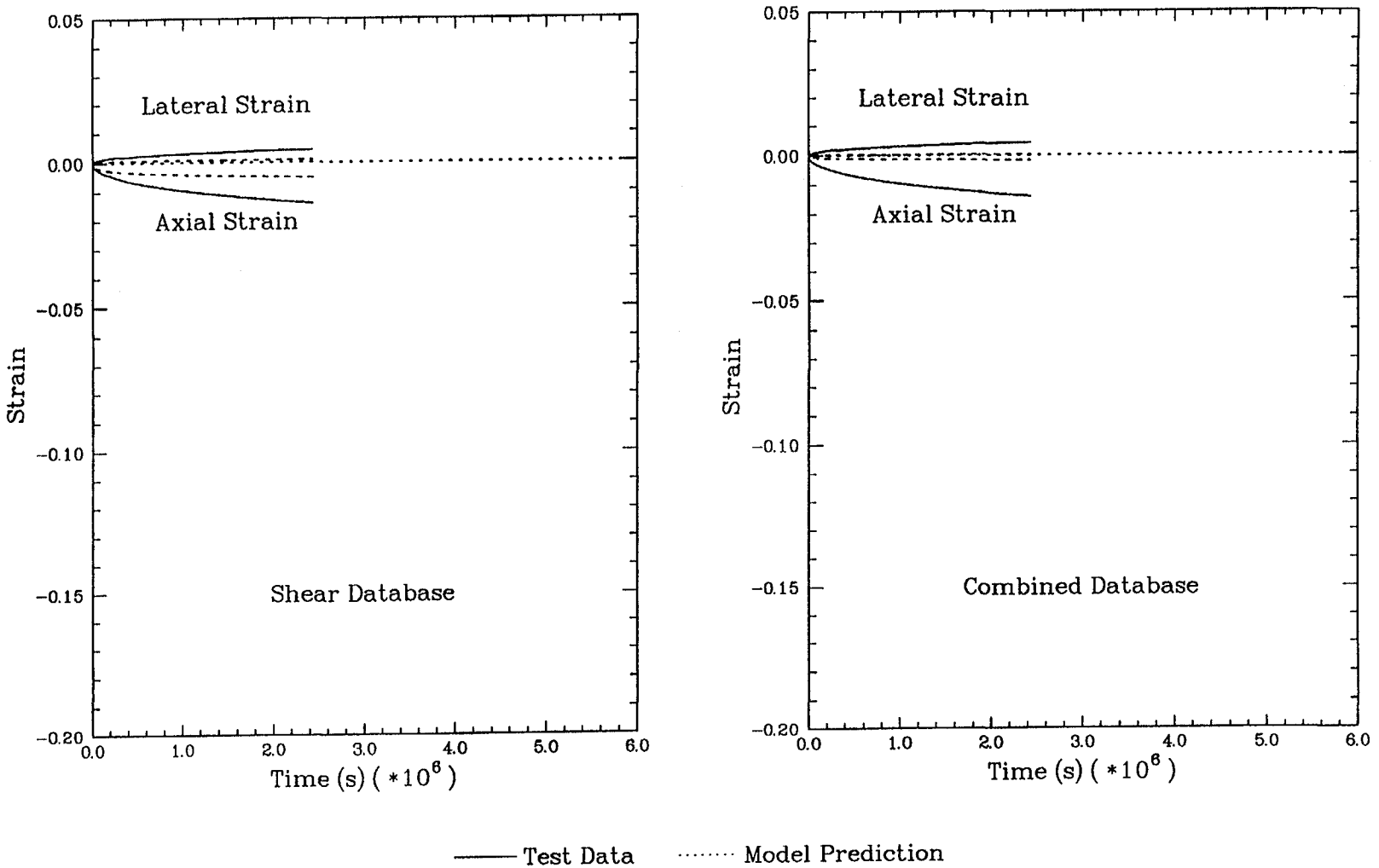

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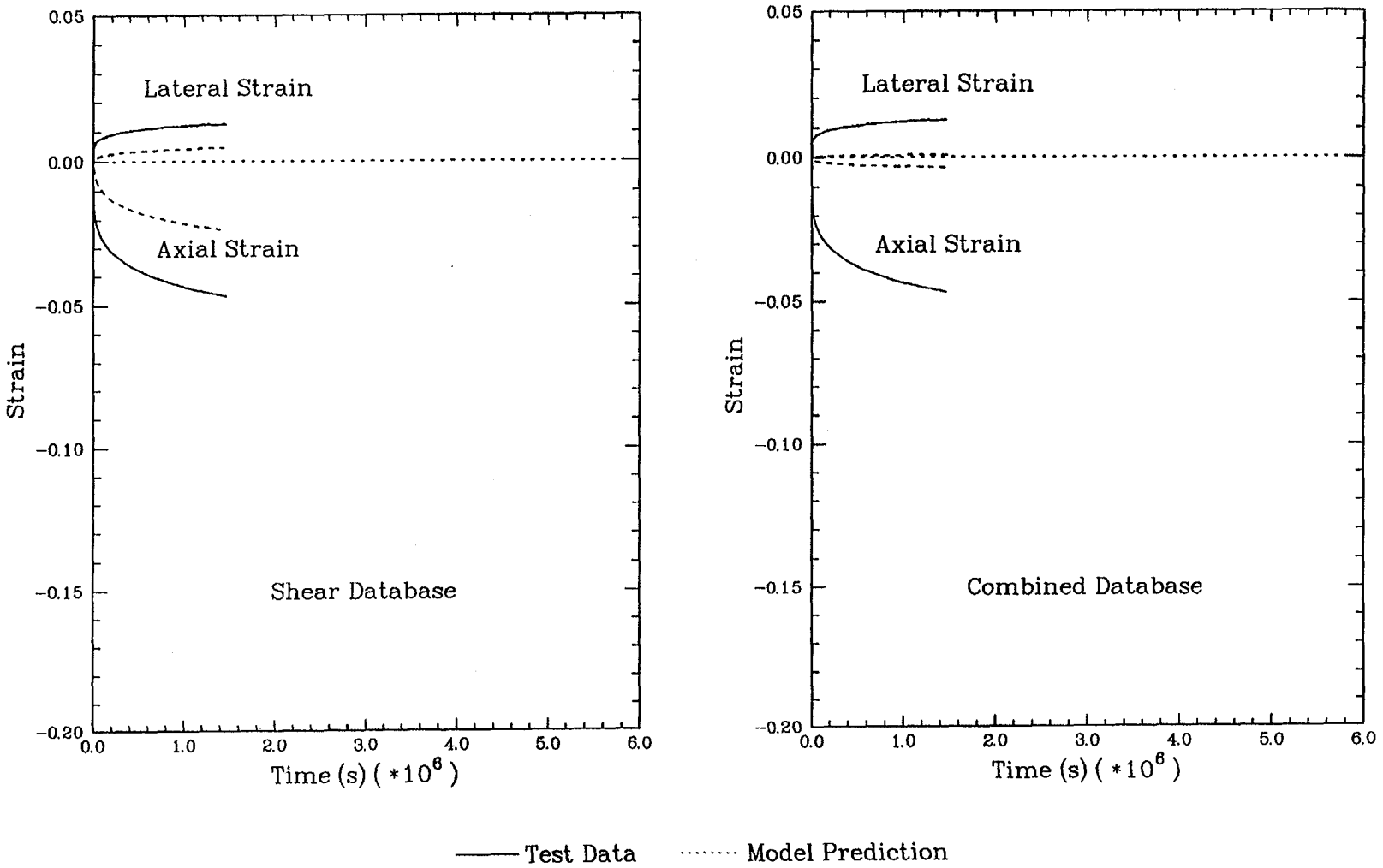

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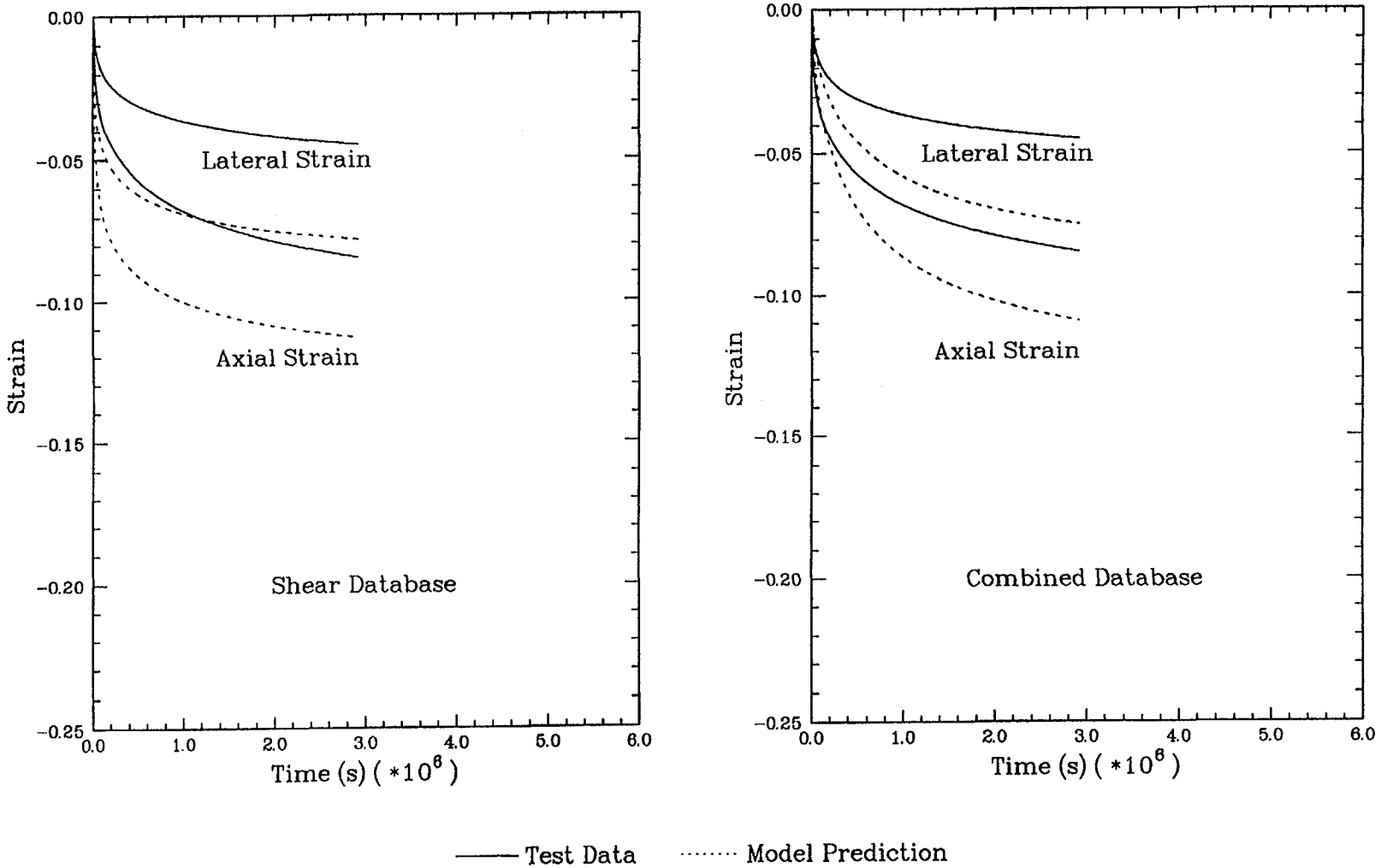

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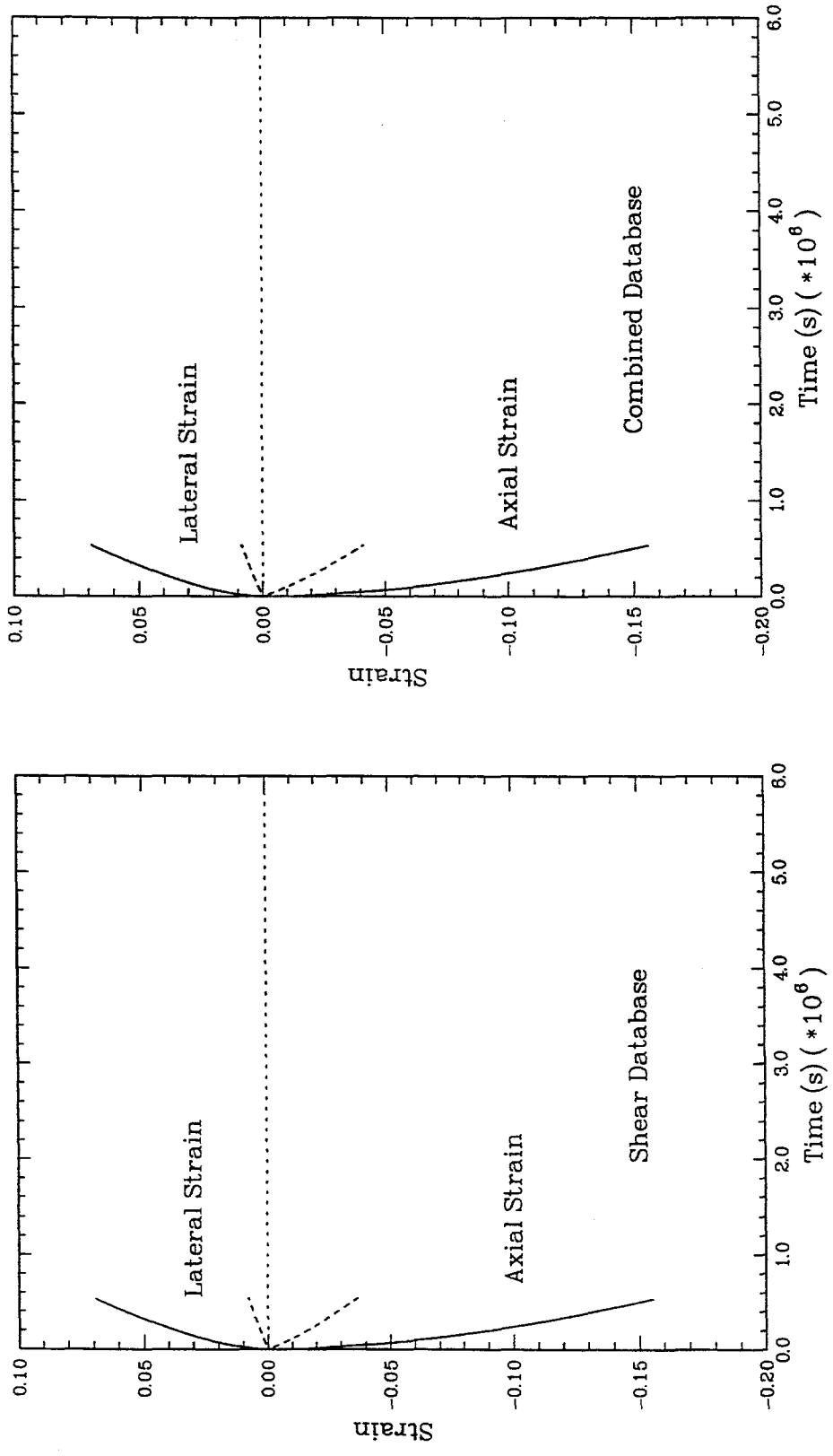

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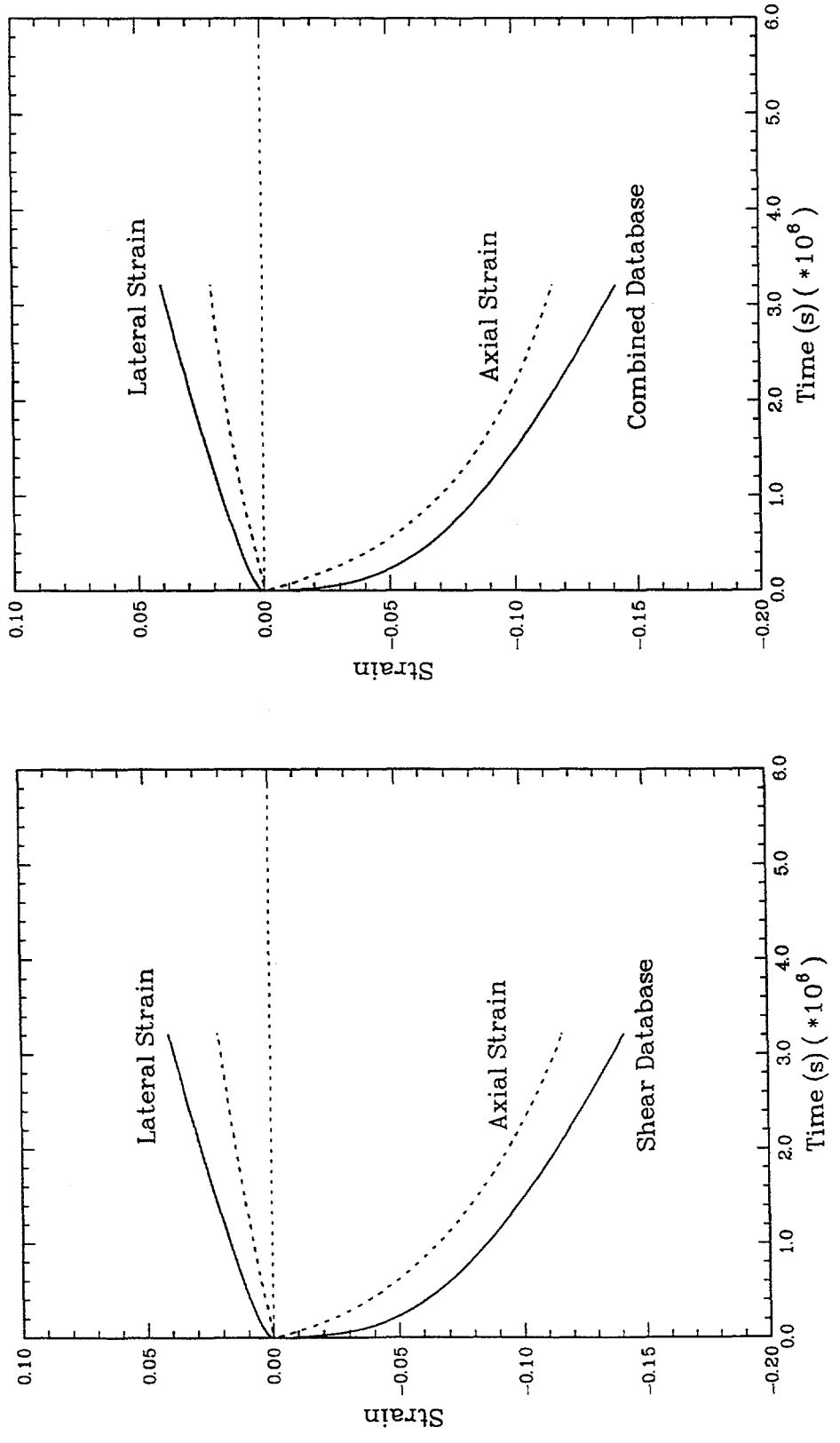

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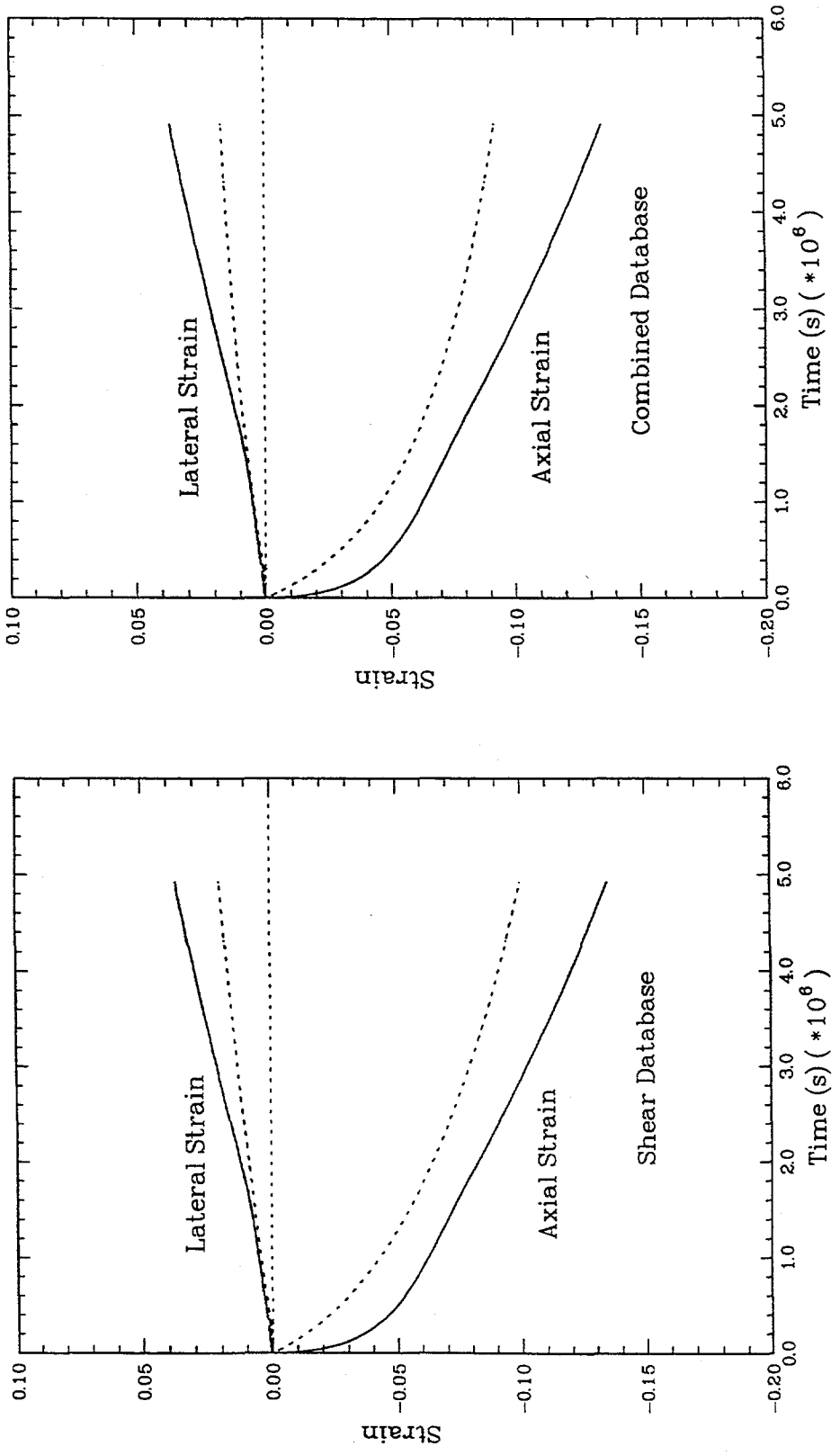

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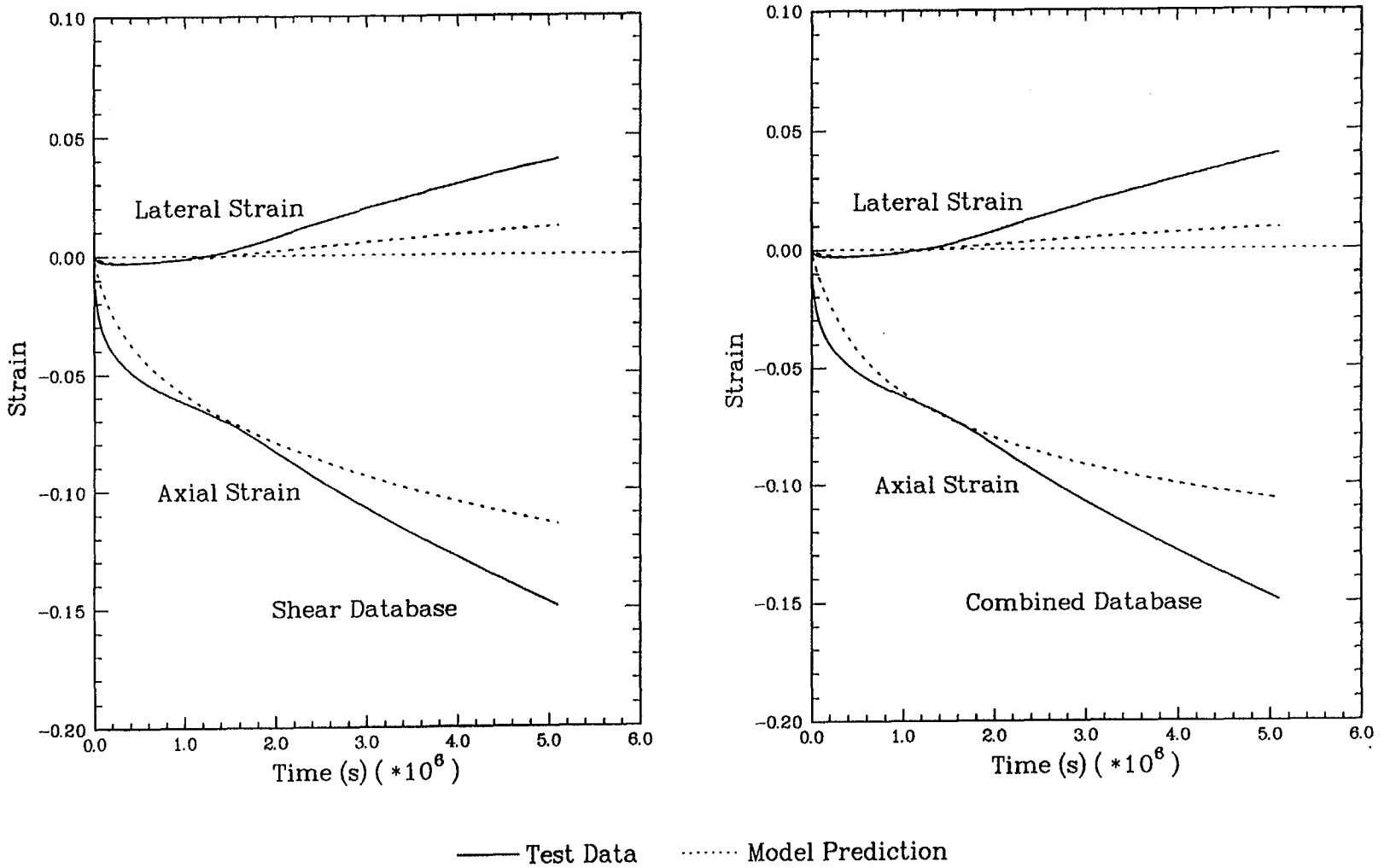

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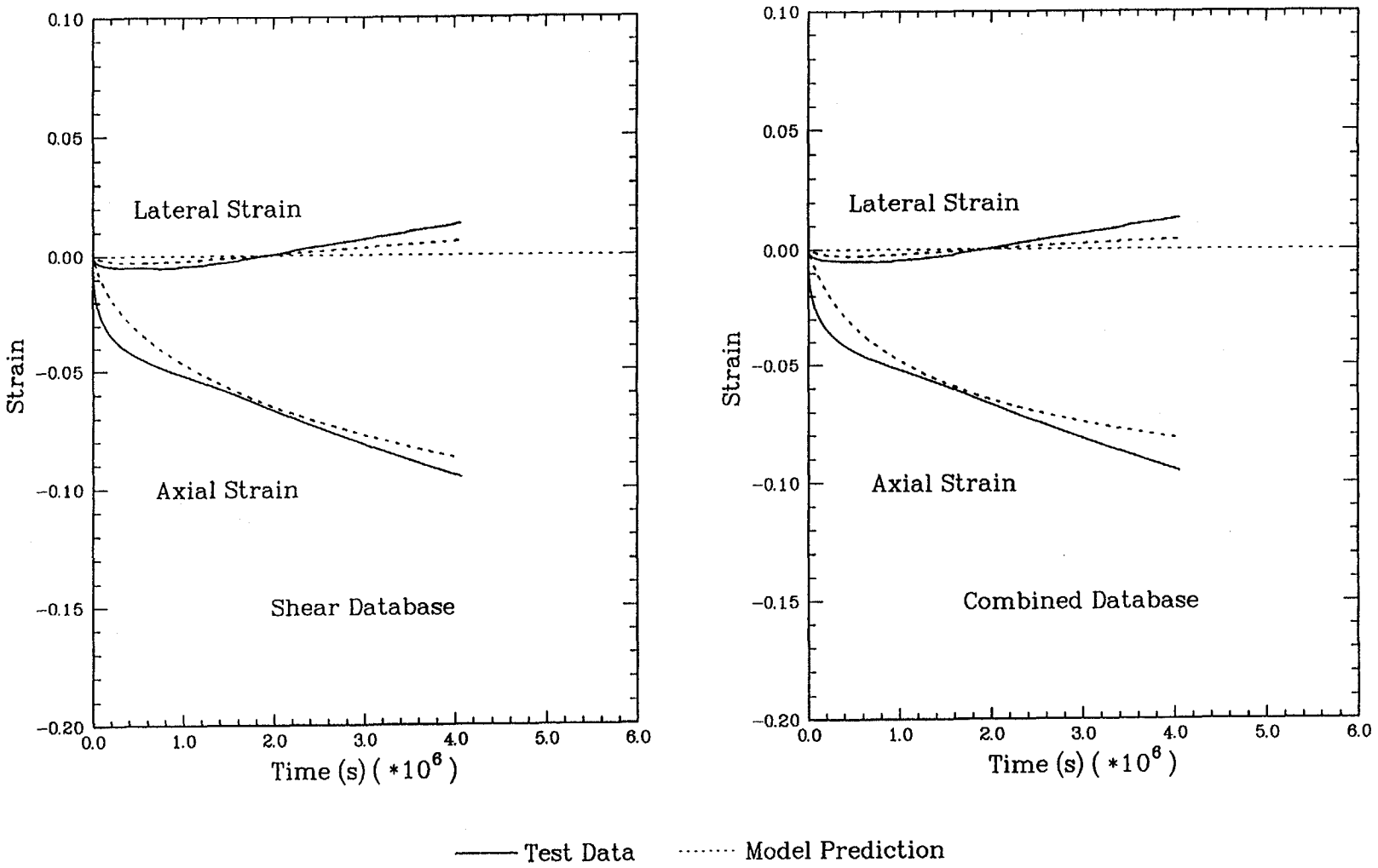

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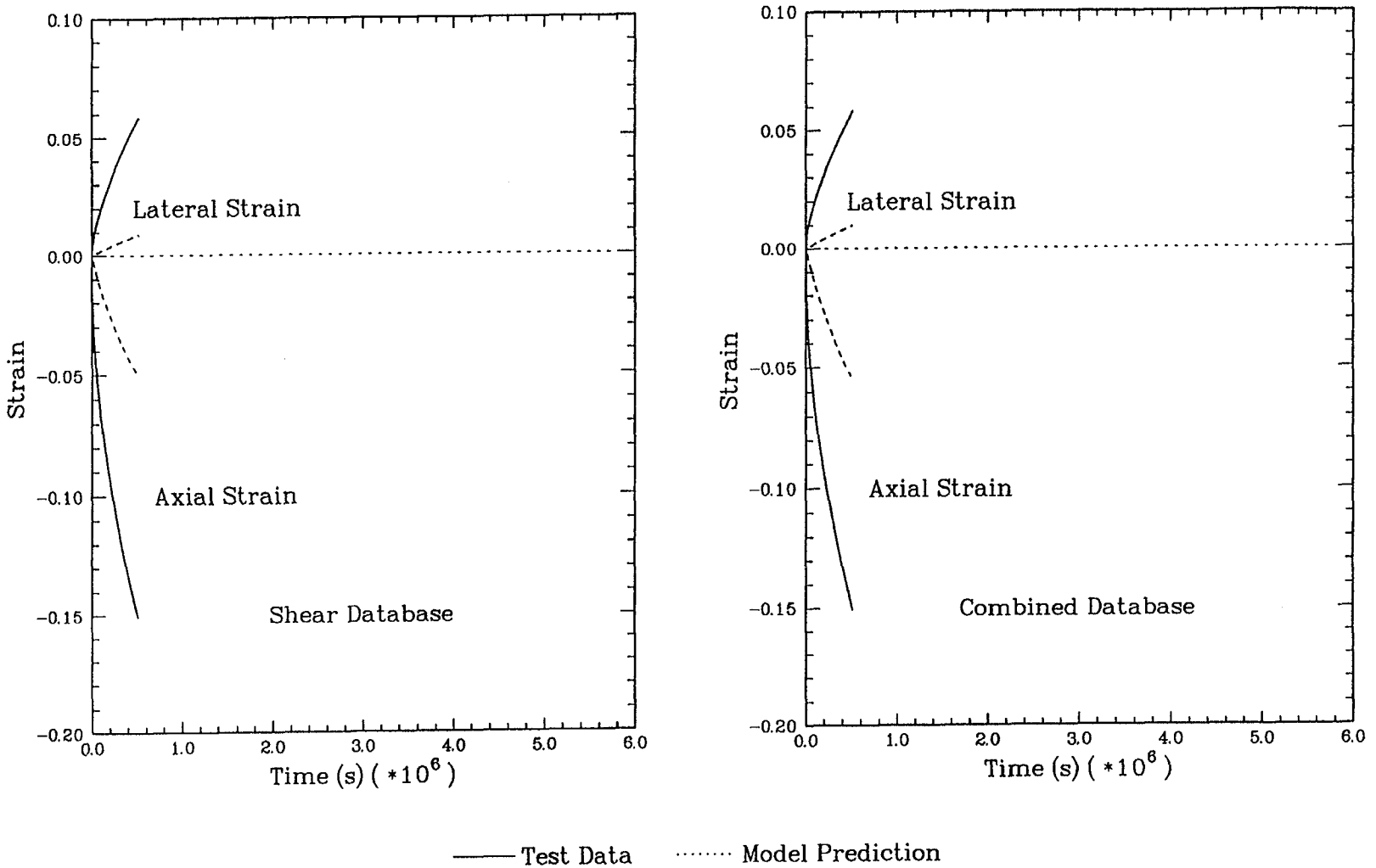

Figure C-58. Shear Consolidation Test RS/DCCS/15.

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BRINE SAMPLING AND EVALUATION PROGRAM
PHASE I REPORT

DOE-WIPP-87-008

DOE/WIPP--87-008

DE88 000631

15 JUNE 1987

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BRINE SAMPLING AND EVALUATION PROGRAM PHASE I REPORT

DOE-WIPP-87-008

EXECUTIVE SUMMARY

This report presents preliminary data obtained in the course of the WIPP Brine Sampling and Evaluation Program. The investigations focus on the brine present in the near-field environment around the WIPP underground workings that flows under existing pressure gradients. Most of the data reported in this document were acquired in the 600 days after January 1, 1985.

Although the WIPP underground workings are considered "dry," small amounts of brine are present, probably on the order of 0.1 to 0.5 percent by weight of the surrounding rocks. This amount of brine is not unexpected in rocks of marine sedimentary origin. Part of that brine can and does migrate into the repository in response to pressure gradients, at essentially isothermal conditions. These small volumes of brine have little effect on the day-to-day operations, but are pervasive throughout the repository. Enough moisture may accumulate over a period of years to affect both operations and planning during the life of the project and the behavior of repository during resaturation and repressurization after sealing and closure.

The preliminary observations made during Phase I of the Brine Sampling and Evaluation Program (BSEP) began informally as an extension of the weep observations in 1983, and included observations made during 1984 of localized weeps and the growth of tubular salt stalactites at various locations in the WIPP underground. Brine occurrences manifested by salt efflorescences, moist areas, and fluid accumulations were also commonly observed in association with drill holes and at some locations on the floors of the workings. The studies were organized in 1984 and formalized in 1985. Moist areas and locations of brine inflows have been observed in all parts of the WIPP underground. The list of 70 drill holes included in Appendix B is not all-inclusive, but illustrates the widespread distribution of the occurrences.

Very small volumes of brine have been observed to "weep" from newly excavated surfaces in the WIPP underground workings. They appear as irregular moisture patches on the ribs and back. Some become visible immediately after excavation, while others may take up to several weeks to become noticeable. As the brine evaporates into the repository atmosphere, halite and very minor amounts of other evaporite minerals are precipitated, usually in the form of finely crystalline encrustations, mounds, and knobs. Individual accumulations are generally less than two centimeters in diameter, but sometimes coalesce to form small masses or ridges. Weeps are pervasive throughout the underground workings and occur on the surfaces of all exposed lithologic units. They appear to develop more quickly and occur more frequently on the units that contain some clay.

Small quantities of gas are associated with some weeps. Slowly bubbling wet areas, usually about 2 or 3 centimeters in diameter, are occasionally very noticeable within a few minutes of mining. The bubbling usually decreases

within an hour or two after mining, and the rate of inflow to freshly mined surfaces of both brine and gas decreases rapidly. Most of the moisture appears slowly over periods of hours or days, and associated gas inflows are so small as to go unnoticed and be difficult to detect. Some of the weeps remain visibly moist for fairly long periods of time, but most appear dry after several months. Manually probing the halite encrustations often reveals that many of the "dry" encrustations are damp within, indicating that the inflow of brine has only decreased in flow rate, not ceased entirely.

More than 1400 holes aggregating over 14 kilometers in total length have been drilled from the WIPP underground excavations. Mostly vertical and horizontal holes, most are 15 meters or less in length. The majority are 15 centimeters (six inches) or less in diameter, although holes almost a meter (36 inches) in diameter and 6 meters long have been drilled. A preliminary listing of those holes drilled before July 1985 is included as Appendix A of this report. Fifty-four of these holes were used as observation locations during Phase I of the BSEP and are listed in Appendix B of this report.

Encrustations of halite on the sides and at the collars of the holes indicate that small volumes of brine have seeped into nearly all of them. Measurable volumes of brine have accumulated in some holes.

In the fall of 1984, at the time the BSEP was initiated, it was realized that many of the more noticeable brine occurrences were found in drill holes that had been in existence for some time and that little or nothing was known about the rate of initial brine inflow. Seventeen new holes that were drilled as part of already-planned stratigraphic data collection became available for brine observations.

Some of the then-existing brine occurrences were scheduled to be disrupted by planned experiments, especially in Room J and Experimental Rooms A1, A2, A3, and B. As a result, initial emphasis was to obtain expeditiously some baseline data prior to such disruptions, with the realization that the BSEP would evolve as the nature of the brine inflows became more apparent.

Measured occurrences have inflow rates that range from less than the rate at which surface moisture is evaporated into the repository atmosphere to approximately 0.5 liters per day. Individual occurrences vary greatly and some drill holes separated by less than a meter have inflows that contrast dramatically, making the discussion of "averages" or "typical occurrences" difficult or misleading. The reasons for this variability are still poorly understood. The inflow at any specific location is influenced by a number of factors, including local stress distribution, local brine sources, variations in local fracturing and permeability, and local variability in the geology. Most occurrences displayed a brief, initial no-flow or low-flow period, followed by maximum inflow. Brine inflow then decreased over a period of several months to relatively steady-state conditions over the 600 days of monitoring. Some occurrences had increased inflows and some ceased entirely. Most of the measurable inflow rates range between a few tenths and a few hundredths of a liter per day. The largest individual production measured during this reporting period produced an aggregate over 235 liters of brine, and continues

to produce approximately 0.2 liters per day. It was clearly an unusual and exceptional occurrence and was associated with excavation-induced fracturing. Inflow rates into that drill hole have declined markedly over the observation period.

It should be noted that the brine occurrences discussed here are small and are clearly distinguished from the "brine reservoirs" found in the underlying, stratigraphically lower, and geologically older, Castile Formation in the Delaware Basin. "Brine reservoirs" are measured in hundreds of thousands of liters, flow readily into boreholes that penetrate them, and have been the subject of other investigations.

The BSEP is focused on the brine, not the gas, occurrences noted at WIPP. One important observation made during Phase 1 of the BSEP is that gas flow and brine flow appear to be intimately related. Gas is associated with many weep occurrences on freshly-mined faces. Gas commonly exsolves from solution as the brine is poured from one container to another. Gas is observed bubbling up through many of the brine occurrences. Fractures, commonly measured in fractions of a millimeter in width and a few meters in length, contain gas and brine in sufficient volume and under sufficient pressure to keep the fractures at least slightly open under lithostatic pressure.

The observations document that salt creep closure and two-phase fluid flow are occurring simultaneously, at least in the immediate vicinity of the repository excavations. It is still not clear what effect the coupling of these processes have on brine inflow or repository behavior. The resaturation of the openings which include the spaces within the waste storage areas (between and within waste containers and between any backfill), the access drifts, and the fractures in the salt, are presently being considered in light of the coupling of these processes. Data collected as part of the BSEP will continue to feed those modeling efforts.

It is clear from the preliminary data that significant pressure-driven brine inflows that are not the result of brine migration in a thermal gradient may occur after sealing and closure of the repository. Brine flow systems are not well understood at this time, but it is likely that the observed inflows are dominated by the response to transient pressure gradients resulting from the excavation of the repository. A component due to regional hydraulic head cannot be ruled out at this time, but if it exists, appears to be relatively small.

Brine chemistry data have been collected, but are not reported in this document. Characterization of the near-field brine chemistry continues, and will be included in a future BSEP report.

The major observations may be summarized as:

- Brine inflows are small, and are not related to large brine reservoirs in the Castile Formation.

- Brine occurrences, particularly those evidenced as halite efflorescence, are pervasive throughout the WIPP underground workings.

- Brine inflow rates are low, usually on the order of a few hundredths of a liter per day or less.

- Although small when measured in terms of liters per day at any given location, cumulative inflow volumes may be significant when measured in terms of the entire repository over periods of many years.

- There is a considerable variation in brine inflow between locations, even when locations are only a few meters (or, in some instances, less than a meter) apart.

- Holes that penetrate the roof and floor generally show a pattern of an initial, maximum flow rate that reduces to a fairly steady flow rate over the time period during which measurements have been made.

- Several flow systems and conditions are possible, but insufficient data exist to select the system and conditions (or combination of several systems and conditions) that best describe the phenomena at WIPP.

BRINE SAMPLING AND EVALUATION PROGRAM PHASE I REPORT

DOE-WIPP-87-008

ABSTRACT

This interim report presents preliminary data obtained in the course of the WIPP Brine Sampling and Evaluation Program. The investigations focus on the brine present in the near-field environment around the WIPP underground workings that is easily moved under existing pressure gradients. Observations began in 1983 and were expanded in 1984 and 1985. Most of the data reported in this document were acquired in the 600 days after January 1, 1985.

Although the WIPP underground workings are considered "dry," small amounts of brine are present, probably on the order of 0.1 to 0.5 percent by weight of the surrounding rocks. This amount of brine is not unexpected in rocks of marine sedimentary origin. Part of that brine can and does migrate into the repository in response to pressure gradients, at essentially isothermal conditions. These small volumes of brine have little effect on the day-to-day operations, but are pervasive throughout the repository and may contribute enough moisture over a period of years to affect resaturation and repressurization after sealing and closure.

The inflows occur as "weeps" on the exposed surfaces and as very small inflows of brine at various locations, most noticeably in holes drilled outward from the underground workings. Over 1400 underground drill holes, most 15 meters or less in length, exist at WIPP. Gas is usually associated with the brine inflows. Gas bubbles are observed in many of the brine occurrences. Gas is also known to exsolve from solution as the brine is poured from container to container.

Measured brine occurrences have inflow rates that range from less than surface evaporation rates to approximately 0.5 liters per day. Most range between a few tenths and a few hundredths of a liter per day. Individual occurrences vary greatly and some drill holes less than a meter apart have brine inflows that contrast dramatically, making the discussion of "averages" or "typical occurrences" difficult or misleading. Most occurrences have initial peak inflow rates that decline to steady rates over the observation period. Some have ceased entirely, and a few have increased inflows.

The largest individual production that was measured during this reporting period produced an aggregate of over 235 liters of brine. It was clearly an unusual and exceptional occurrence, and inflow rates for that occurrence have declined over the observation period.

It is clear from these preliminary data that the brine, gas, and salt creep phenomena are intimately associated. Pressure-driven brine inflows that are not the result of brine migration in a thermal gradient may occur at any time a pressure difference exists, including after sealing and closure of the repository. It is likely that the observed inflows into the repository excavations are dominated by the response to transient-pressure gradients

resulting from the excavation of the repository itself. A component due to regional hydraulic head cannot be ruled out at this time, but if it exists, it appears to be relatively very small.

Investigations of the occurrence and chemistry of the brines are continuing.

1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is a Department of Energy (DOE) research and development facility to demonstrate the safe disposal of radioactive wastes derived from the defense activities of the United States. The WIPP project's mission consists of two parts. The first is to demonstrate the safe handling and disposal of transuranic (TRU) waste in bedded salt. The second is to create a research facility for the examination of the technical issues related to the emplacement of defense-related radioactive waste in bedded salt.

The WIPP facility is located approximately 42 kilometers east of Carlsbad, New Mexico, in an area known as Los Medanos (Figure 1-1). The underground portion of the facility is located at a depth of approximately 655 meters in the bedded salt deposits of the Salado Formation, part of an evaporite sequence over 1000 meters thick (Figure 1-2). An extensive program of site characterization and validation has been conducted for the past ten years (1976-1986). The results of these studies are summarized in the WIPP "Geological Site Characterization Report" (Powers et al., 1978), the WIPP "Safety Analysis Report" (US DOE, 1986), the WIPP "Preliminary Design Validation Report" (Bechtel National, Inc., 1983), and the WIPP "Results of Site Validation Experiments" (Black et al., 1983). Additional site investigations are being conducted as part of an ongoing program to further refine the understanding of the site-specific geology. The hydrogeological activities of the Brine Sampling and Evaluation Program, as outlined in the Brine Testing Program Plan (Morse and Hassinger, 1985), are part of these investigations.

The purpose of the Brine Sampling and Evaluation Program (BSEP) is to investigate the origin, hydraulic characteristics, extent, and composition of brine occurrences in the excavations for the WIPP repository in the Salado Formation. Although considered dry workings, brine is observed to weep from exposed surfaces in the repository horizon and seep into drill holes in the underground excavations.

These brine occurrences become visible shortly after excavation or drilling. The more noticeable occurrences produce brine at the rate of a few tenths or a few hundredths of a liter per day or less. In locations where evaporation is very slow, a total of a few liters to several hundred liters of brine have been observed to accumulate over a period of weeks or months.

Although individual occurrences are small and not particularly noticeable on a day-to-day basis, they are pervasive throughout the repository. Over a period of months and years they may contribute enough moisture to merit consideration from the standpoint of long-term repository performance. During present operations, virtually all of the moisture entering the workings from the host rock is evaporated and removed in the air circulated by the underground ventilation system. The assessment and understanding of the brine occurrences becomes especially important when considering what their long-term impacts might be on operations during the demonstration and retrieval period and the rates of resaturation and repressurization of the excavations after closure of the facility.

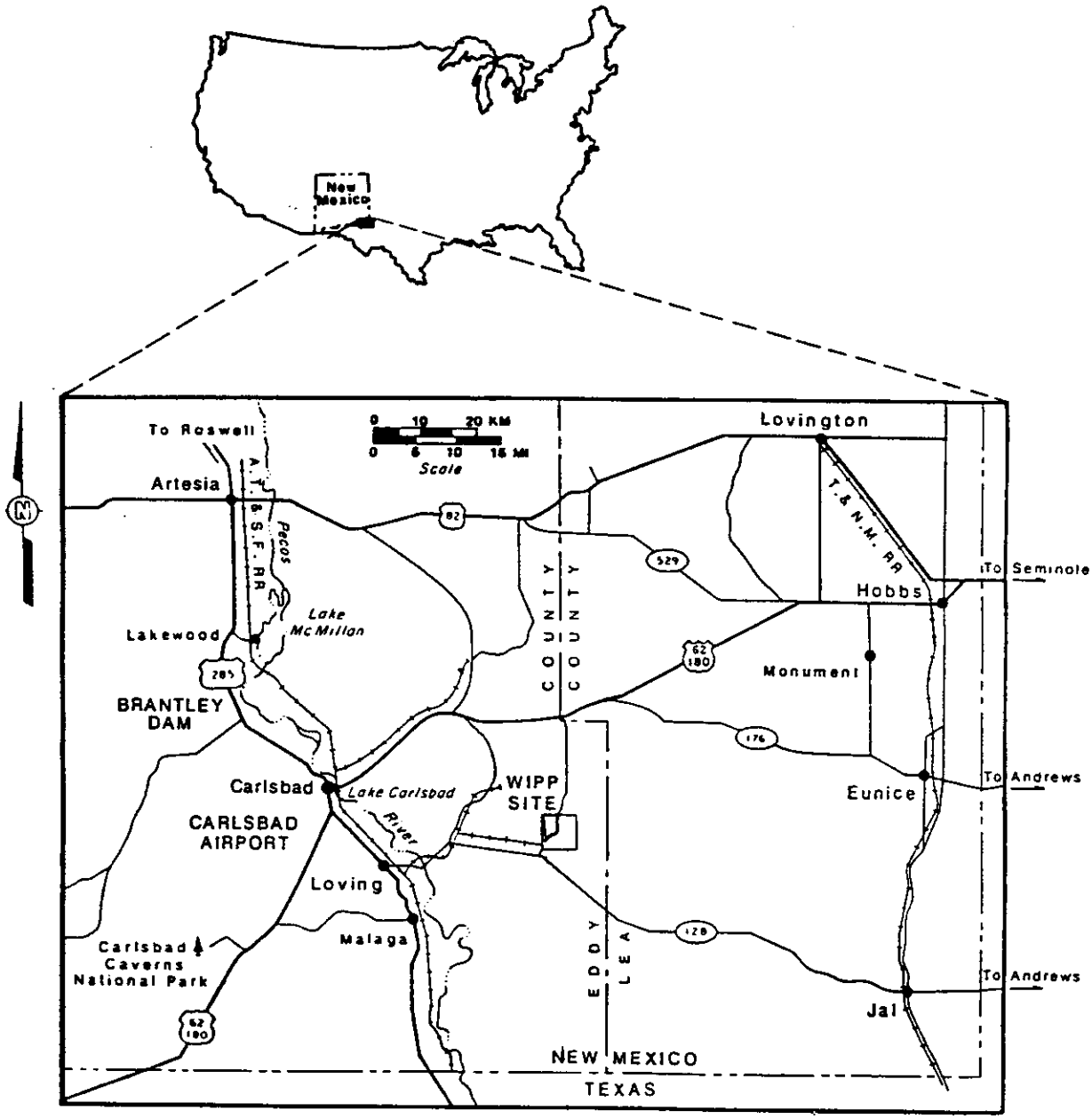


Figure 1-1.
Location Map of the WIPP Site

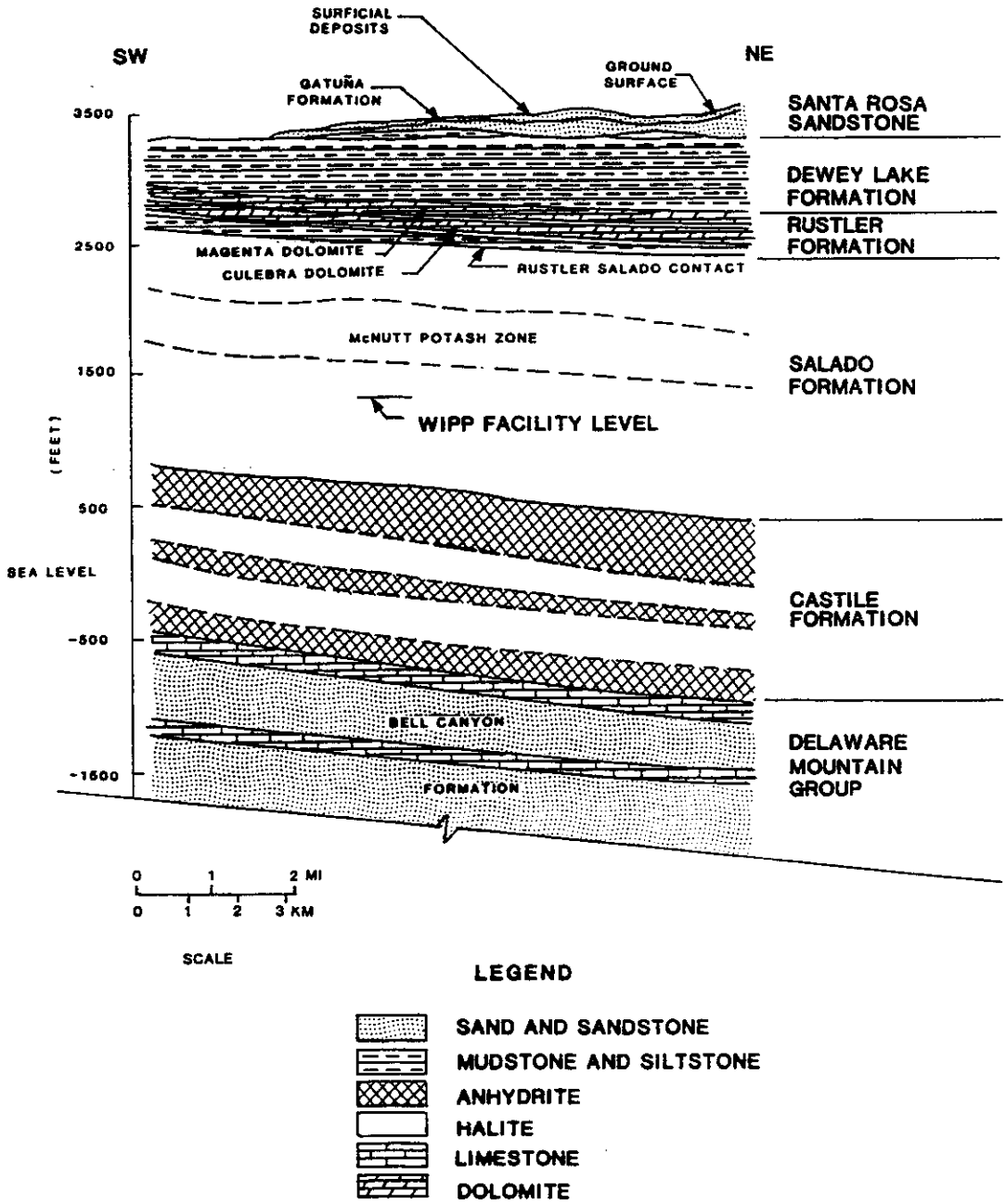


Figure 1-2.

Generalized Stratigraphic Cross Section

1.1 OBJECTIVES OF THE BRINE SAMPLING AND EVALUATION PROGRAM

The objectives of the BSEP are to characterize the hydraulics, extent, and composition of the brine occurrences in the excavations for the WIPP repository. The emphasis of this program is on those aspects of the brine occurrences that are likely to affect operations, resaturation and repressurization, and overall facility performance. The following topics are being investigated and an assessment of their relative importance is being made:

- Brine sources
- Paths for brine movement
- Mechanisms of brine movement
- Aerial extent and volume of existing and potential sources of brine
- Relationship between brine and gas occurrences
- Long-term behavior of known brine occurrences (self-limiting, persistent, etc.)
- Inflow to be anticipated during the demonstration and retrievability period
- Inflow to be anticipated after closure
- Brine composition as it might relate to the above concerns, with emphasis on the anticipated aggregate composition of brines that might enter the repository after closure.

1.2 PHASED APPROACH

This program is being conducted in three phases. Phase I was initiated in the Fall of 1984, and continued throughout 1985 and into 1986. This phase was designed to initiate the program, make preliminary observations, and to provide sufficient data on the characteristics and distribution of the brine near the repository so that a detailed and coordinated investigation could be carried out in Phase II. This document is an interim status report for Phase I.

Phase II continues selected Phase I investigations. It includes additional instrumentation and testing to further refine the understanding of brine occurrences and their chemistry and hydrology, and to identify long-term testing needs and techniques. Phase II was initiated in early 1986 and will continue into early 1987. A Phase II interim report will be issued in 1987.

Phase III monitoring will continue throughout 1987, and is intended to lead directly into a long-term monitoring program expected to continue for the operational life of the facility. A Brine Sampling and Evaluation Program final report will be issued in 1988.

The long-term brine monitoring program, which will continue throughout the life of the facility, will be coordinated with other WIPP monitoring programs.

1.3 PHASE I TASKS

Phase I of the Brine Sampling and Evaluation Program includes five specific tasks that are outlined in Appendix A of the "Brine Testing Program Plan" (Morse and Hassinger, 1985). This report covers Task 1 and Task 2 activities.

- Task 1 included the development of an inventory of drill holes in the WIPP underground with the objective of identifying those open holes that might be locations where preliminary observations could be made for the BSEP. Task 1 also included the review of literature concerning similar low-flow and weeping brine occurrences both at WIPP and other mines. Task 1 activities are described in more detail in Section 1.3.1.

- Task 2 involved the collection of preliminary data from existing, accessible brine occurrences within the underground workings at WIPP. Encountering these occurrences provided insight into the complex nature of the brine inflows. Some test installations were made specifically for the purpose of brine inflow observations as part of Task 2. Task 2 activities are described in more detail in Section 1.3.2.

- Task 3 was the development of a sampling and testing plan for Phase II of the BSEP. Task 3 included the testing of techniques, the refinement of the criteria for the identification of brine sampling locations, and the refinement of sampling procedures and rationale.

- Task 4 focuses on the assessment of the feasibility of using geophysical techniques to define source horizons and the aerial extent of brine occurrences at the repository level. This task is continuing.

- Task 5 was to be the coordination of Phase I tasks with the Gas Testing Program (GTP) (Torres, 1985). However, the GTP was delayed and no coordination was necessary.

1.3.1 TASK 1 ACTIVITIES

The Brine Testing Program Plan (Morse and Hassinger, 1985) stated that this task would consist of the following activities:

- Review literature pertaining to similar low-flow and weeping conditions in other mines to develop an understanding of brine occurrences.

- Review and evaluate previous WIPP brine characterization and gas testing methodology, data, and reports, in view of their applicability to this program.

- Assemble a master inventory and map of underground boreholes from current lists available from Sandia National Laboratories (SNL), Bechtel, Westinghouse, and the mining contractor.

- Verify locations and determine the status, condition, and accessibility of these holes.

- Develop a separate inventory of accessible boreholes in which a determination of the presence or absence of brine can be made, and monitor all of these holes periodically through the duration of the program.

- Develop criteria for identifying boreholes suitable as test sites for the BSEP.

- Identify boreholes suitable as future test sites for the BSEP.

- Evaluate the applicability of available equipment on hand for pressure-transient testing in boreholes.

1.3.2 TASK 2 ACTIVITIES

The goal of Task 2 was to acquire preliminary data for the BSEP, concentrating on the sampling and evaluation of known, easily accessible brine occurrences in the WIPP underground workings. The overall objective was to obtain an initial understanding of the rate at which brine flows into open drill holes and to make a preliminary assessment of the volume of brine likely to be involved in an individual occurrence.

In order to attain this goal, Task 2 is comprised of the following activities (Morse and Hassinger, 1985):

- Removal of brine from accessible boreholes in the floor, using compressed air or other evacuation techniques such as bailing.

- Monitor additional boreholes to be drilled for the Materials Interface Interaction Test (MIIT) and Drum Durability Test (DDT) programs in Room J.

- Initiate brine sampling for preliminary chemical analysis for major and minor ions to identify analyses that will provide useful results. (Sampling for brine chemistry is continuing. The results will be included in a later report.)

- Drill boreholes in an appropriate grid pattern around selected known occurrences. Use isolation techniques and varying depth holes to determine the stratigraphic zones contributing to brine inflow.

- Drill horizontal boreholes in selected areas along ribs to assess spatial distribution of weeps.

- Attempt pressure transient testing in holes with existing equipment, if appropriate.

2.0 INVENTORY OF UNDERGROUND DRILL HOLES

2.1 Objectives

One part of the Task 1 activities was to assemble a master inventory of underground boreholes from lists available from SNL, Bechtel, Westinghouse, and the mining contractor. Most of the holes that were drilled in the WIPP underground were intended to have instrumentation installed in them. The primary objective of compiling the inventory of underground drill holes was to assist in locating those few holes that remain open (not filled with liners, casing, or instrumentation) and to document the suitability of those open holes for use in the BSEP.

2.2 Methodology

Available lists of underground drill holes were obtained and compiled into a computerized inventory, maintained on an IBM XT microcomputer utilizing dBase III software. Twenty-two sources of information were used. Locations, directions, and hole dimensions are either from as-planned or as-built data, or are approximated. Where possible, as-built data was utilized. Selected holes were located underground and visually inspected. Field observations were added to the location data contained in the computerized listing.

2.3 Accomplishments

The borehole inventory compilation resulted in a listing of 1439 holes that are known to have been drilled in the WIPP underground prior to July 1985. Most of these holes are less than 15 meters in length.

That list is attached to this report as Appendix A. It should be noted that this appendix is a preliminary listing that is based in part on unchecked information and should not be used as a definitive reference for the location or existence of underground drill holes. It does, however, serve the intended purpose of the BSEP in identifying almost all of the open holes that are accessible in the WIPP underground that might serve as points for observations of brine, fractures, or other geological occurrences or conditions. Fifty-four of these holes were used as observation locations during Phase I of the BSEP. They are listed in Appendix B.

Most of the drill holes have been made for the purpose of installing some sort of instrumentation. As a result, the vast majority were not accessible for brine inflow observations. Additionally, some holes were known to have been destroyed by subsequent mining activities. A preliminary designation of the status of each hole was made during the compilation of Appendix A. Those designations were:

Abandoned hole or instrument
Collar destroyed by mining
Closed hole
Hole used for experiment
Filled with grout
Lined with inclinometer guide-tube

Instrument in hole
Mined out
Rock bolt in hole

A preliminary underground field check was made of those holes listed with the status of abandoned or containing a failed instrument. Additional observations of other holes were made during routine underground work. If a hole was field checked and known to be open, it was designated as having an open status.

A preliminary listing of those holes known to be open or possibly open, (as indicated either as a status of "abandoned hole or instrument location" or "status unknown," has been abridged from Appendix A. That list contains references to 365 holes and was used as a tool to help locate holes that might be suitable for use as observation or sampling points for Phase I of the BSEP. For such use, a hole had to meet the following criteria. It had to be:

Open
Not used for a conflicting purpose
Accessible for repeated, periodic observations

The suitability of existing holes for use in transient-pressure testing was also a criteria that was initially considered.

As Phase I proceeded, it became apparent that if a hole had been in existence for a long enough period of time and had received sufficient brine inflow to be of interest for transient-pressure testing, significant salt buildups had formed on the sidewalls and, in the case of upholes, at the collar. These salt buildups will interfere with the proper seating of packers and the holes will have to be reamed before there is a chance of success in any transient-pressure testing. It also became obvious that there was enough variation in brine inflow between holes located less than a meter apart, that considerable effort needed to be expended to define probable inflow locations within holes before attempting pressure transient testing. Phase I has concentrated on acquiring accurate information as to the general nature (including stratigraphic controls, if any) of the brine weeps and inflows.

Seventeen new drill holes, sixteen of which were 15 meters (50 feet) deep, were drilled in early 1985 for stratigraphic information. The sixteen 15-meter (50-foot) holes consisted of eight pairs of upholes and downholes which span the northern end of the WIPP underground, a distance of approximately 1300 meters, east to west (Figure 2-1). These holes were available for use in the BSEP and have been monitored for brine inflow since they were drilled.

These seventeen holes, coupled with some observations from several existing holes elsewhere in the workings, provided the data base for Phase I investigations without additional drilling (Appendix B).

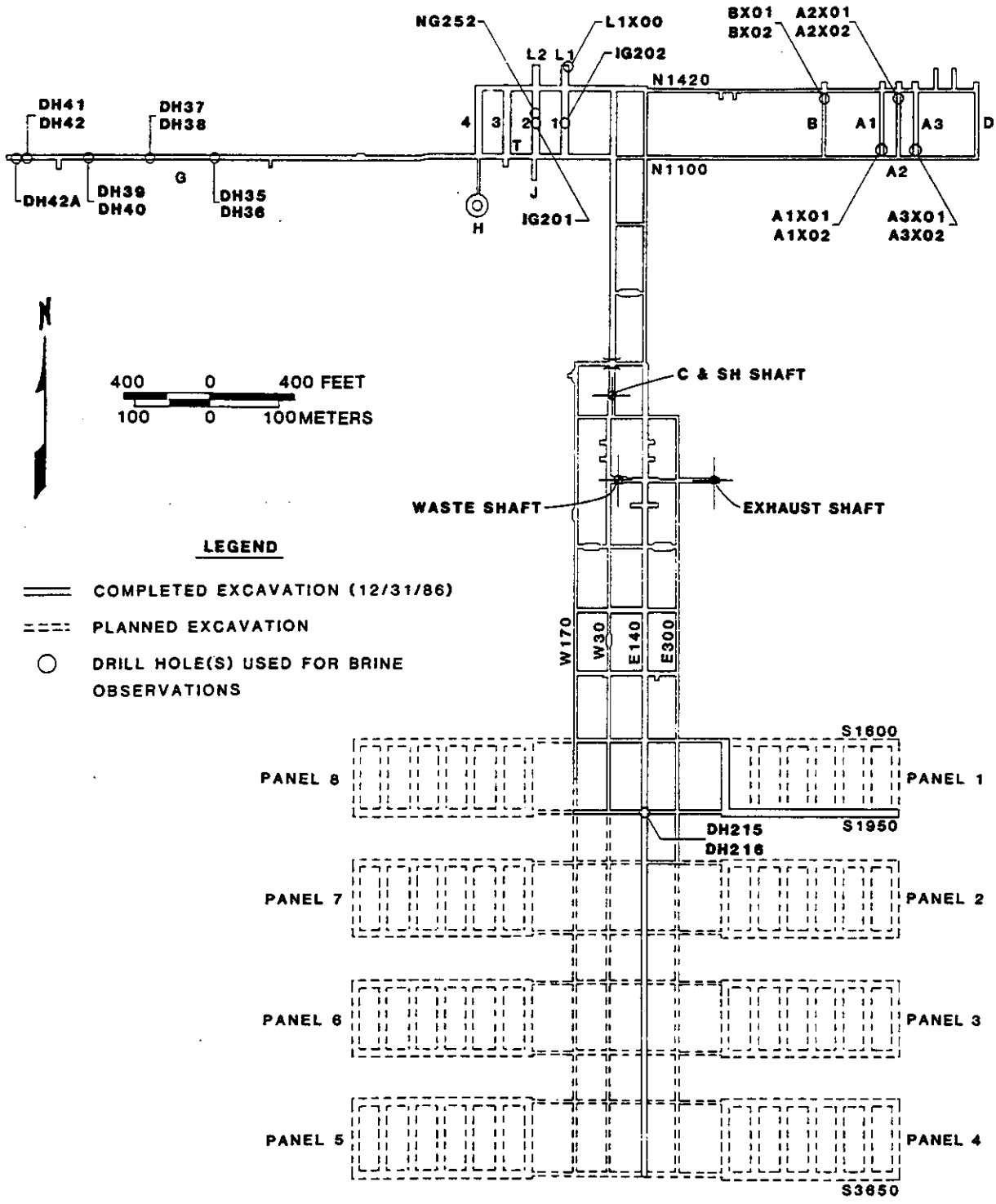


Figure 2-1.

Map of the WIPP Underground Workings

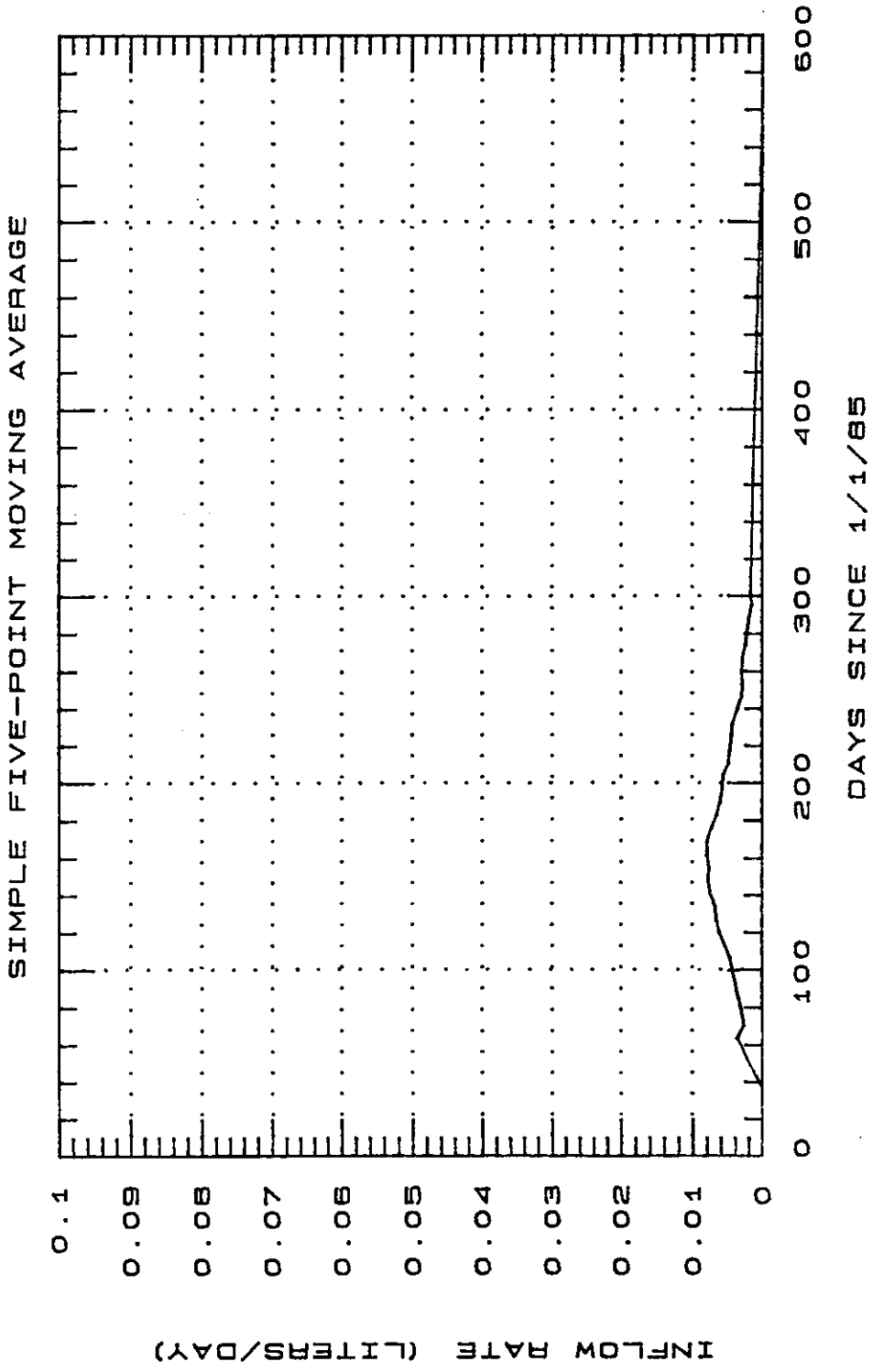
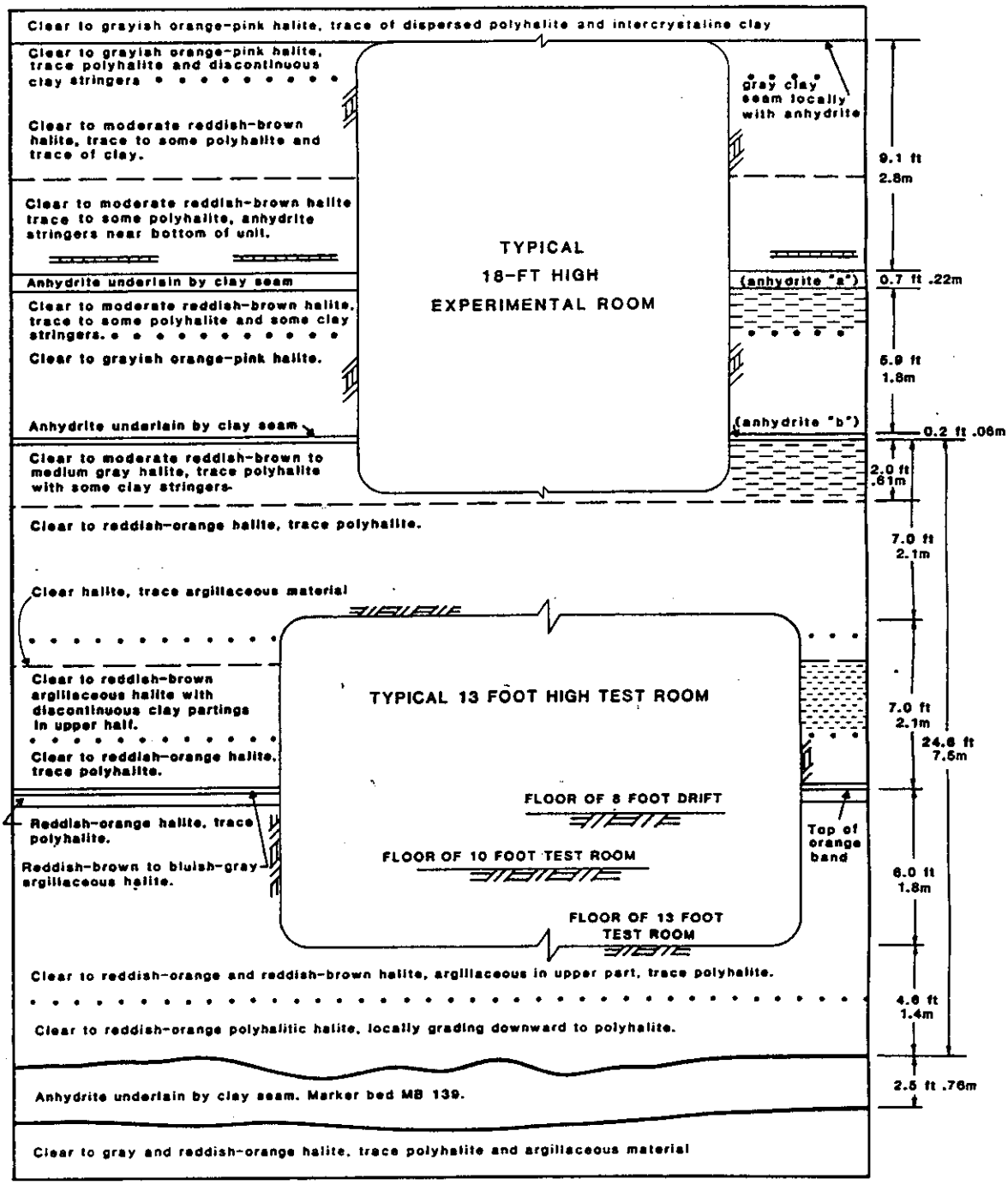


Figure D-23.

DH37 Inflow Rates

Figure 3-1.
Brine Weeps in the WIPP Facility Excavation



NOTES:

1. Dimensions and lithologic descriptions are derived primarily from corehole and geologic mapping data from the four test rooms and experimental area supplemented by geologic information from the remaining SPDV excavation.
2. Unit thicknesses are approximate and vary slightly.
3. Room dimensions have changed with time due to salt-creep closure.

Figure 3-2.

Geologic Cross Section of the Facility and Experimental Level in the Vicinity of the SPDV Test Rooms and the Experimental Rooms

the weeps remain visibly moist for fairly long periods of time, but most appear dry after several months. Manually probing the halite encrustations often reveals that many of the "dry" encrustations are damp within, indicating that the inflow of brine has only decreased in volume, not ceased entirely.

Several factors are hypothesized to cause the decreased inflow rates observed to occur in the weeps noticed shortly after mining. As the transient effects of mining (discussed in more detail in Section 4.2) affect a zone ever farther from the excavated openings, local pressure gradients within a half-meter or so of the excavations probably lessen and the driving mechanism for brine and gas inflow decreases. With time, the moisture in the salt in immediate proximity to the underground openings has been driven to the surface, requiring that additional brine migrate over longer distances for inflow to continue. As evaporation into the repository atmosphere continues, more and more crystal growth takes place. This may well result in partial sealing of the surface by new halite crystals and probably results in a reduction of the permeability at the rock-air interface. Converseley, this sealing affect may be offset by an increased porosity, permeability, and fracturing in the "disturbed zone" close to the excavation, as discussed in Section 4.2.1.1. The cumulative effect of the transient conditions and the changes that take place in the physical and hydrological properties of the salt close to the mine openings is not completely understood at this time.

3.1.2 BRINE IN DRILL HOLES

More than 1400 holes aggregating over 14 kilometers in total length have been drilled from the WIPP underground excavations. They extend in all directions, and most are 15 meters or less in length. The majority are 15 centimeters (six inches) or less in diameter, although holes almost a meter (36 inches) in diameter and 6 meters long have been drilled. A preliminary listing of those holes drilled before July 1985 is included as Appendix A of this report.

Encrustations of halite on the sides and at the collars of the holes indicate that small amounts of brine have seeped into nearly all of them. Noticeable amounts of brine have accumulated in some holes.

In the fall of 1984, at the time the BSEP was initiated, it was realized that many of the more noticeable brine occurrences were found in drill holes that had been in existence for some time and that little or nothing was known about the rate of initial brine inflow. Seventeen new holes that were drilled as part of already-planned stratigraphic data collection became available for brine observations.

Some of the then-existing brine occurrences were scheduled to be disrupted by planned experiments, especially in Room J and Experimental Rooms A1, A2, A3, and B. As a result, initial emphasis was to obtain expeditiously some baseline data prior to such disruptions, with the realization that the BSEP would evolve as the nature of the brine inflows became more apparent (Morse and Hassinger, 1985).

The locations where Phase I brine observations were made are listed in Appendix B, which also contains the drill-hole data (depth, diameter, etc.). The locations of the drill holes that are described in more detail in the following sections of this report are shown on Figure 2-1, a map of the WIPP underground workings. Details of the results of Phase I preliminary brine sampling and evacuation of the drill holes in the WIPP repository horizon is presented in Appendix D. Appendix E consists of tabulation of the data discussed in Appendix D.

3.1.2.1 Downholes

Fluid has collected in a number of the vertical downholes drilled in the floor of the underground workings. At the time the BSEP was initiated, it was noted that some holes were filled or nearly filled with fluid, with individual accumulations occasionally totaling many liters. Brine from one hole flowed onto the floor of the East 140 drift at South 850 (TSC-D'Appolonia, 1983b, Part II; Morse and Hassinger, 1985). This hole was plugged during the excavations that lowered the floor of the East 140 drift.

During construction and experimentation, some brine and water has been introduced into the facility. At the time the BSEP was initiated, it was not known how much of the brine found in the downholes was a result of natural inflow from the surrounding salt and how much was a result of intentional or inadvertent introduction of water, whether for dust control, from leaking water pipes, inflow from water-bearing units in the Rustler Formation above the salt down the shafts prior to grouting, or from other construction or experiment related activities (Morse and Hassinger, 1985).

Plugs inserted below the collar of many of these holes have created a restricted environment within them, which reduces the amount of moisture lost by evaporation. As a result, the observations made in plugged downholes may be more representative of inflow conditions in general than those made in upholes or horizontal holes.

One objective of Phase I of the BSEP was to obtain some preliminary figures for naturally-occurring flow from the surrounding salt beds by making systematic observations at existing holes. The following is a summary of the more detailed discussion contained in Appendix D and the data tables in Appendix E.

Brine collection and inflow measurements were made as described in Procedure WP-07-410 (WIPP BSEP: Brine Collection and Inflow Measurements). The general procedure was simply to provide for the accumulation of the small brine inflows, to collect those accumulations on a periodic basis (approximately once a week for initial collections), and to measure the volume that had accumulated since the previous sampling. These measurements were then recorded and tabulated as the average fractions of liters per day collected from each location.

A variety of field techniques were used, depending upon the specifics of each occurrence. They can be divided into the following groups:

- Initial volume measurements, experimental pumping techniques, and water-level measurements
- Vacuum-assisted sampling probe for brine removal from downholes
- Hand-operated rotary suction pump
- Continuous, gravity-driven collecting installations
- Pressure-vacuum and vacuum moisture-sampler installations

Sampling of the downholes was done with a variety of bailing devices, most of which relied on check valves to retain collected brine while the bailer was raised to the surface (the floor of the repository workings). After bailing, the deeper downholes were plugged just below the collar with a piece of plastic foam which was covered, in turn, by a metal lid. The plug and lid prevented the inadvertent introduction of foreign solids into the hole and reduced moisture loss by evaporation to the repository atmosphere.

It should be noted that the northeast part of the repository (Figure 2-1), including Rooms A1, A2, A3, and B, is excavated at a different stratigraphic level, seven meters higher than the rest of the repository (Figure 3-2). The effects of the stress redistribution in the disturbed zone around the repository on the porosity and permeability of the rocks is discussed in Section 4. The fact that anhydrite Marker Bed 139 is seven meters farther below the repository excavations in holes A1X01, A2X01, A3X01, and BX01 than it is in the other downholes monitored for the BSEP, means that brine inflows from this horizon may be occurring through different stress-relieved zones.

A summary of the preliminary data for the downholes sampled during Phase 1 of the BSEP is given in Table 3-1.

General observations are:

- Immediately after drilling of a new hole, there is a short period of time (typically a few days) during which only small brine inflows are observed. This might be the result of damage done to the formation by the drilling itself.
- After the initial no-flow or low-flow period, brine inflows quickly reached maximum inflow rates and began to decline.
- Inflow rates then decreased over a period of several months to relatively steady-state conditions.
- The amount of brine that flowed into drill holes in close proximity to each other varied drastically.

TABLE 3-1

BRINE INFLOW SUMMARY FOR DOWNHOLES

Hole	Room	Date Room Excavated	Date Hole Drilled	Date First Observed	Approx. Maximum Inflow (l/day)	Approx. Inflow 8/86 (l/day)	Inflow Trend (I,S,D)*	Approx. Total Vol. Removed By 8/86 (l)	Assoc. Gas ?
A1X01	A1	10/84	2/85	3/85	0.05	0.026	S	15	
A2X01	A2	7/84	2/85	2/85	0.06	0.025	S	17	G
A3X01	A3	11/84	1/85	2/85	0.03	0.022	S	14	G
BX01	B	6/84	1/85	1/85	0.12	0.05	S	32	G
DH36	G	12/84	1/85	1/85	0.25	0.21	S	125	G
DH38	G	12/84	1/85	1/85	0.18	0.06	S	34	G
DH40	G	12/84	1/85	1/85	0.04	0.01	S	4	
DH42	G	12/84	1/85	1/85	0.05	0.03	S	19	G
DH42A	G	12/84	1/85	1/85	0.2	0.1	S	75	G
IG201	2	3/83	3/83	11/84	0.05	0.017	D	81	G
IG202	1	4/83	4/83	11/84	0.05	0.014	S	71	G
L1X00	L1	4/84	5/84	5/85	0.03	0.03	I	24	
NG252	2	3/83	3/83	12/84	0.5	0.27	D	235	G

Data summarized and rounded from Appendices D and E.

* I = Increasing
S = Steady
D = Decreasing

Table 3-1.

The data for Hole DH42A in Room G departs from the above observations in several ways. Perhaps most significantly, after the initial brief period of little or no inflow, inflow rates, although high, were not at a maximum, Inflow gradually increased for about three months before reaching a maximum rate. The decline in inflow also took place more slowly and over a longer period of time when compared to the other downholes. The inflow behavior noted at this location is especially interesting when contrasted to that exhibited in Hole DH42 (Figures D-20 and D-21), located two meters to the east and drilled 3.3 meters deeper, which produced approximately one-fourth as much brine.

One of the most important observations is the extreme variation in inflow that was observed between closely spaced locations. In addition to the contrast seen between DH42 and DH42A discussed above, the variations documented in Room 2, Room J, Room L1, and elsewhere are even more striking.

The holes in Room J drilled for the Materials Interface Interactions Test (MIIT) have been described by Morse and Hassinger (1985) and in Appendix D of this report. Over 40 closely spaced shallow drill holes were made and subsequent brine levels within them varied dramatically. Holes partially or completely filled with brine were interspersed with dry or nearly dry holes, often less than a meter away. Deeper drillhole arrays in Room L1 exhibited similar, though less extreme, variations in inflow. The great variation in inflow characteristics between locations only a short distance (a few meters, or in some instances, less than a meter) apart make the discussion of "averages" or "typical occurrences" difficult or misleading. These variations might be explained in part by the effects of mining-induced stress redistributions on porosity and permeability, which are discussed in Section 4.2.

The largest brine production that was observed occurred in Hole NG252 in Room 2, which is discussed at length in Appendix D. NG252 is located close to the west rib (wall) of Room 2 and is 38 millimeters in diameter and 2 meters deep. It is one of the physically smallest of the holes observed and appears to be something of an anomaly. The hole penetrates through anhydrite MB 139, and the brine and gas flowing into this hole appears to enter from a fracture close to the base of MB 139. A dry hole exists, approximately 4.7 meters east of NG252 and on the centerline of Room 2, that is 15 centimeters in diameter, and penetrates into the top of MB 139.

3.1.2.2 Upholes

If the brine inflow into upholes is sufficient to flow down the sides of the hole, moist areas may form on the back (roof). Highly visible salt crust buildups and salt stalactites can also form at the collar of the hole.

Many of the upholes are now inaccessible, usually because they contain installed instruments, and it is not possible to determine the extent of salt buildup within them. If there is enough brine entering the upholes to run down the sides, it will usually flow around the instruments and be evident at the collar. The inflow, coupled with the normally high evaporation rate into the repository atmosphere may cause some stalactites to grow 15 to 30 centimeters per week, but the longer ones are usually quite fragile and break

easily under their own weight or in response to vibrations from the underground equipment. As a result, long stalactites are fairly rare except in undisturbed locations (Figure 3-3). Moisture entering open upholes tends to evaporate readily, as the air can circulate more freely within them. Several techniques were used to seal the collars of the upholes, but none of the techniques completely controlled evaporation (Appendix D). As a result, it is reasonable to assume that the open, accessible holes show heavier internal salt buildup and less buildup and dripping from the collar than equivalent holes which contain instruments or for some other reason have a restricted opening. The data from the upholes should be considered as providing only minimum inflow data.

The data from the upholes is summarized in Table 3-2. As discussed in more detail in Appendix D, the generally much lower and more irregular inflow values for the upholes may reflect the fact that brine was lost by dispersion from the hole collar and evaporation into the repository atmosphere. It is uncertain at this time, however, if all the differences in inflow between the upholes and the downholes can be explained by this mechanism. Further modifications have been made to the collecting techniques used for upholes in order to resolve this question.

The upholes intersect different stratigraphic horizons than those intersected by the downholes. In addition, holes A1X02, A2X02, A3X02, and BX02 are drilled in the back (roof) of rooms at a stratigraphic level approximately 9 meters higher than in the rest of the repository workings. Hole A1X02 is 18 meters long. As a result, the last 3 meters penetrate beds that are not encountered in the other three upholes in Rooms A2, A3, and B. This includes an anhydrite interbed about 2 meters from the end of the hole.

Inflow data from Hole DH215, located at the intersection of E140 and S1950 drifts almost certainly reflect changes in the stress distribution in the disturbed zone in the immediate vicinity of the repository excavations. The effects of mining-induced stress redistribution on porosity and permeability are discussed in more detail in Section 4.2. Inflow increased approximately three hundred percent when additional excavation took place at that intersection and then declined to very small amounts (Section 9.0, Appendix D).

3.1.2.3 Horizontal Holes

Horizontal holes tend to behave much like small versions of the mine drifts, with weeps and halite encrustations forming on the sides and the end. Small stalactites can grow from the top side of the holes, and occasionally brine accumulates on the bottom. In those circumstances where the openings to the holes are restricted and a saturated or partially saturated atmosphere develops in the hole, brine may accumulate on the bottom and eventually seep out at the collar, where salt buildup may develop.

3.1.3 DAMP OR WET AREAS ON FLOORS

Moist areas have been observed on the floor of the workings, but most have been associated with dust-control or other operational activities. Rare occurrences in which brine has seeped from the Salado Formation have been noted. In most

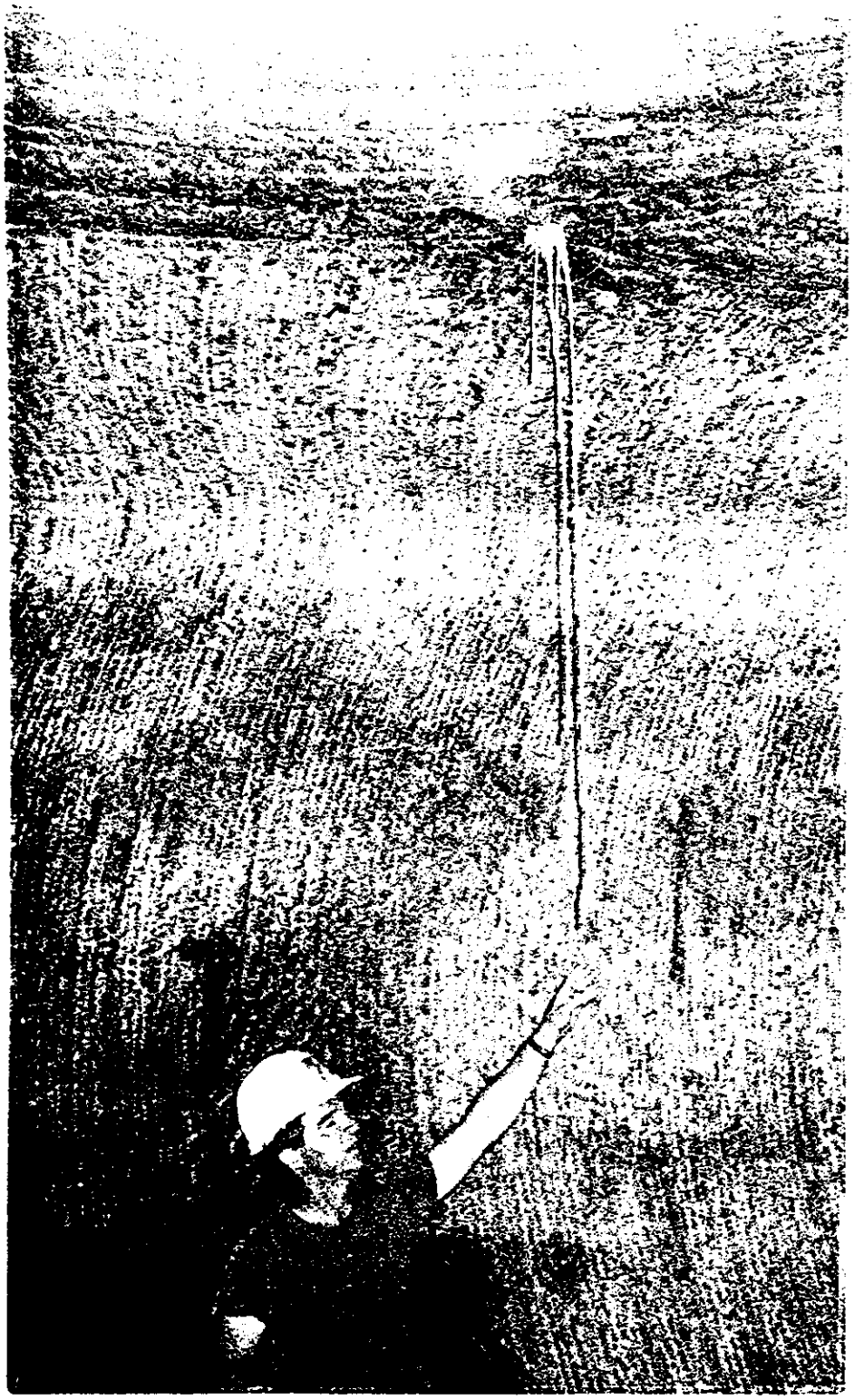


Figure 3-3.

Halite "Stalactites" in the WIPP Facility Excavation

TABLE 3-2

BRINE INFLOW SUMMARY FOR UPHOLES

Hole	Room	Date Room Excavated	Date Hole Drilled	Date First Observed	Approx. Maximum Inflow (l/day)	Approx. Inflow 8/86 (l/day)	Inflow Trend (I,S,D)*	Approx. Total Vol. Removed By 8/86 (l)
A1X02	A1	10/84	3/85	3/85	0.04	0.037	I	9
A2X02	A2	7/84	2/85	2/85	0.03	0.015	S	3
A3X02	A3	11/84	1/85	2/85	0.02	0	NA	4
BX02	B	6/84	2/85	2/85	0.02	0	NA	2
DH35	G	12/84	1/85	2/85	0.02	Trace	NA	4
DH37	G	12/84	1/85	2/85	0.01	0	NA	1
DH39	G	12/84	1/85	2/85	Trace	0	NA	0
DH41	G	12/84	1/85	2/85	Trace	0	NA	0
DH215		1/83	2/83	4/84	0.06	0.01	D	15

Data summarized and rounded from Appendices D and E.

* I = Increasing
S = Steady
D = Decreasing

Table 3-2.

instances, such damp areas have been associated with fractures that provide pathways for brine movement. Small puddles, apparently naturally occurring, were observed on the floors of Room J and Room G. The puddles were quickly limited in size by evaporation into the air circulating through the workings and rapidly became crusted over with crystallizing salt. Where the floor is covered with a layer of partially consolidated salt muck, saturation of the layer of muck below the salt crust can exist, but usually goes undetected. The occurrences of damp or wet areas on floors may be considered a special subset of the occurrences in vertical downholes.

3.1.4 ASSOCIATED GAS OCCURRENCES

The BSEP (as discussed in Section 1.3 of this report) is focused on the brine, not the gas, occurrences noted at WIPP. One important observation that has been made during Phase 1 of the BSEP is that gas flow and brine flow appear to be intimately related. As described in Section 3.1.1, small amounts of gas are associated with many weep occurrences on freshly-mined faces. Gas commonly exsolves from solution as the brine is poured from one container to another. Gas is observed bubbling up through many of the brine occurrences. Fractures, commonly measured in fractions of a millimeter in width and a few meters in length (Appendix C), contain gas and brine in sufficient volume and under sufficient pressure to keep the fractures at least slightly open under lithostatic pressure.

The observations document that salt creep closure and two-phase fluid flow are occurring simultaneously, at least in the immediate vicinity of the repository excavations. It is still not clear what effect the coupling of these processes have on brine inflow or repository behavior. The resaturation of the openings which include the spaces within the waste storage areas (between and within waste containers and between any backfill), the access drifts, and the fractures in the salt, are presently being considered in light of the coupling of these processes. Data collected as part of the BSEP will continue to feed those modeling efforts.

3.2 BRINE INFLOWS INTO MINES IN EVAPORITE FORMATIONS

Small volumes of brine are frequently encountered in mines in evaporite formations including both dome salt and bedded evaporites. A literature review was conducted to provide additional background information on the occurrence of brine. This section briefly reviews these occurrences, most of which cause no disruption of mining operations. The focus of this section is on brine occurrences other than those at WIPP. A discussion of sources of brine in the Salado Formation near WIPP is presented in Section 4.1.

3.2.1 Dome Salt

Many mines in Gulf Coast dome salt have experienced brine and gas seeps or inflows. These occurrences have been reviewed by Kelsall and Nelson (1983). Most occurrences of brine or gas in mines in dome salt are small and have had no effect on mining operations. The initial flow rates are generally the maximum flows noted, and they simply decrease until flow ceases. In rare cases, however, brine inflows have required grouting of brine-emitting zones

or caused major floods which sometimes caused the abandonment of drifts or mines. Brine originates in overlying strata, (including the caprock), surrounding formations (intruded by the salt diapir), porous zones in the salt, and overlying bodies of surface water. The brine inflows or seeps reach the mines through boreholes drilled for mining or exploration purposes, fractures in the salt (particularly near the top or edges of the dome), and through structurally controlled permeable zones, such as brecciated fault zones. Movement of brine through the salt may be enhanced by fracturing of the salt and high hydraulic gradients that may exist near dome edges or the caprock.

During brine migration experiments at Avery Island, Krause (1983) reported brine inflows into an unheated site on the same order of magnitude as the brine inflows into heated holes. He measured approximately 0.026 grams of moisture per day flowing into unheated site AB.

Small quantities of gas are probably ubiquitous in dome salt and occur as intragranular or intergranular bubbles. In most cases, gas occurrences in dome salt are associated with argillaceous salt or inclusions of clastic sediment, suggesting the gases were contained within pieces of other sedimentary rocks incorporated into the salt during the rise and intrusion of the salt diapir. More rarely, large, highly pressurized occurrences result in "blowouts" which violently emit large volumes of gas and salt. Blowouts of salt and gas probably occur because of the loss of confining pressure as the result of mining activities (Kelsall and Nelson, 1983).

3.2.2 Bedded Salt

Brine seeps and leaks into mines have occasionally been encountered in the Salado Formation during potash mining operations in the Carlsbad District. Griswold (1977) indicated that the average brine inflow into mines in the area is probably on the order of 40 to 400 liters per occurrence, although he did report an account of one occurrence that yielded over 400,000 liters of brine. Small brine inflows of the magnitude of those in the WIPP excavations are rarely, if ever, reported because they neither present a hazard to personnel nor cause difficulties in routine mining operations. The McNutt potash ore zone, the principal ore-bearing unit in the basin, lies about 200 meters stratigraphically above the WIPP facility horizon. The seeps are allowed to flow until depleted and do not affect mining operations (Register, 1981).

Well-documented data on brine occurrence in bedded salt from the Mississippi Chemical Mine, east of Carlsbad, NM, resulted from experiments investigating brine movement under thermal gradients (brine migration). Some of these experiments recorded data for brine releases in unheated (ambient) conditions. Hohlfelder (1980) reported brine releases occurring during the Salt Block II Experiment prior to heating. Ewing (as reported by Shefelbine, 1982) recorded average inflows ranging between 0.077 and 0.21 grams/day during ambient conditions prior to heating in the three-heater experiment.

Minor gas releases from pressure relief holes drilled into the roof of potash mines, gas flows lasting several months, and work-disrupting blowouts are also recorded in potash mines and in drilling operations in the Carlsbad District (Rutledge and Morgan, 1963, 1964a, 1964b, 1964c; Rutledge, 1964; Rutledge and

Kennedy, 1964a, 1964b; Rutledge et al., 1964; TSC-D-Appolonia, Part II, 1983b; and Chaturvedi, 1984). Some gas releases are also accompanied by brine. Most of these occurrences do not affect mining operations and minor gas inflows such as those described in this report are rarely, if ever, reported. Blowouts are often associated with an obvious, vertical fracture.

Considerable attention was attracted by a series of three gas releases that occurred in the Kerr-McGee (now New Mexico Potash) mine near Carlsbad, New Mexico, in 1983 and 1984, one of which involved a fatality (Cavanaugh and Davidson, 1983; Chaturvedi, 1984). This occurred at a location approximately 15 kilometers north of the WIPP site in the McNutt potash zone in the upper part of the Salado Formation, 200 meters stratigraphically above the WIPP facility horizon. A very small amount of brine, sufficient to dampen the trace of the fracture, was associated with this release. After the release of pressurized gas, an open fracture 5 to 10 millimeters wide and more than 8 meters long was left (Chaturvedi, 1984). This release occurred at a depth of approximately 500 meters below surface. The question of how wide and how long the fracture was prior to the explosive release of gas remains unanswered.

Investigations of the gas occurrences cited above have concluded that most of the occurrences are small and that most of the gas present in the bedded evaporites near Carlsbad resides in clay or argillaceous beds in the salt, with far less residing in polyhalite beds or in the halite. In these studies, gas was most frequently encountered in boreholes drilled upward through the back (roof) at the intersection of drifts. This result supports the idea that the gas accumulates locally in response to the excavation-induced stress redistributions and increased near-field permeability caused by the mining operations. These effects are discussed in more detail in Section 4.2.

No other accounts of brine inflows into salt mines in North America were found in the literature search. Some potash mining has occurred in the Paradox Basin bedded evaporites in the Four Corners area. The Cane Creek Mine was the site of a disruptive, mining-related gas (not brine) release that caused the mine to be converted to a solution mining operation (Westfield et al., 1963). The gas may have originated in a dolomite interbed.

3.3 BRINE OCCURRENCES IN SALADO FORMATION DRILL HOLES NEAR WIPP

Brine and/or gas has also been encountered in the Salado Formation in the vicinity of the WIPP site during drilling for potash evaluations, oil and gas exploration, and various WIPP site characterization studies (Griswold, 1977; Powers et al., 1978; Register, 1981; Popielak et al., 1983; Mercer, 1983; and Mercer, 1987). These occurrences are distinctly separate from those encountered in the Rustler Formation overlying the Salado, and from the "brine reservoirs" in the underlying Castile Formation mentioned in Section 4.1.4 of this report. They are also separate from, but may be more closely related to, the small inflows into the mined repository that are the focus of the BSEP.

Mercer (1987, p. 15) summarizes this data, observing:

> "Very few hydraulic data are available for the Salado Formation. In the halites, the presence of water is restricted because halite does not readily maintain primary porosity, solution channels, or open fractures. Investigations to-date of the Salado Formation at the WIPP site do not indicate an active, circulating, ground-water system."

4.0 PRELIMINARY HYDROLOGIC - GEOMECHANICAL EVALUATIONS

The observations and measurements (summarized in Section 3.1, and presented in detail in Appendices D and E) suggest that multiple brine sources may be involved at the WIPP site and that complex flow induced by excavation is taking place. The potential sources of brine and the flow mechanisms that may be involved are described and evaluated in this section as to applicability at the WIPP repository horizon. Where appropriate, previous relevant scientific investigations are referenced. We emphasize that the observations and measurements have been made in the near-field environment of the underground excavations, which is to be distinguished from the far-field, overall WIPP site hydrogeologic environment.

Moisture does occur in the Salado Formation at the WIPP site. In discussing short-term mining-induced transient flow systems and the rate at which brine flows into the excavations, it may not be important whether the moisture in the Salado is residual from the Permian Sea (connate water), is the result of diagenetic or other processes including dehydration of hydrated minerals, or was introduced into the rocks by some past or present regional flow system. However, the source characteristics (moisture content, permeability, and extent of porous zone) will influence cumulative volume of brine reaching the repository.

Several investigators have measured the moisture content of salt in the Salado Formation. Black et al. (1983) measured a moisture content of 0.59 percent by weight at the repository horizon by heating the salt samples to a temperature of 400°C. The BSEP investigations focus on the water that can and does migrate into the underground openings, which are at atmospheric pressure and approximately 27°C. The migration of brine is probably in response to pre-existing or transient pressure gradients. As a result, the fluid which is locked within unfractured crystals, which is tightly bound to clays or other minerals, or which requires higher than repository temperatures to be liberated, is of lesser concern. Preliminary measurements of the fluid content present in 26 samples from the repository level heated to 250°C is on the order of 0.1 percent by weight, ranging from undetected to a maximum of 0.27 percent (Black et al., 1983). Since heating to 250°C liberates some water of hydration, the actual amount of fluid free to migrate under repository conditions is probably some fraction of those values. Additional measurements of the fluid content of rocks exposed in or occurring close to the repository excavations are presently being made and will be described in a later report.

Similar results were obtained by Hohlfelder (1981), who tested nine samples obtained from the McNutt potash zone exposed in the Mississippi Chemical Mine 19 kilometers northwest of the WIPP site. This is a mineralogically more complex horizon in the Salado Formation that contains more polyhalite than the facility horizon salts. At 200°C, he found that the weight loss ranged from 0.010 percent to 0.044 percent, with the average being 0.028 percent. At 425°C, he found that the weight loss ranged from 0.25 percent to 1.21 percent, with the average being 0.51 percent.

4.1 SOURCES OF BRINE IN THE SALADO FORMATION AT WIPP

Many occurrences of water and brine in evaporite formations, consisting mainly of halite, anhydrite, and gypsum, have been documented. They appear to occur principally as:

- o Hydrous minerals (gypsum, clays),
- o Fluid inclusions in bedded salt (intragranular and intergranular)
- o Intergranular porosity and open fractures
- o Larger porous zones often referred to as "brine reservoirs"

Occurrences of fluid inclusions and hydrous minerals are particularly well-described in the literature. Brine reservoirs have not been as well described, but the literature concerning them is increasing due to the importance of salt formations for siting nuclear waste repositories.

The Salado Formation (described in Powers et al., 1978, and U.S. DOE, 1986) has a complex mineralogy. It is composed of bedded halite with lesser amounts of anhydrite, gypsum, and polyhalite. A detailed geologic description of the repository horizon of alternating layers of halite, polyhalitic halite, and slightly argillaceous halite is provided by Holt and Powers (1986). The halite is generally white to clear, but may be tinted orange, reddish-brown, or gray by interstitial polyhalite or clay. The argillaceous halite is usually reddish-brown in color, with the clay occurring as matrix, interstitial, and intercrystalline material. Halite also occurs as large replacement crystals (pseudomorphs) after gypsum swallowtail crystals and, less commonly, as displacement crystals in some beds of argillaceous halite and anhydrite. Penecontemporaneous dissolution pits, often reaching depths greater than 3 feet, are locally abundant (Powers and Hassinger, 1985) and contain large (1-2 cm), clear halite crystals with frequent fluid inclusions. The halite and anhydrite mineralogy of the WIPP repository horizon has been described by Grim, et. al. (1960) and Stein (1985a). Stein (1985a) reports that the non-NaCl components consist of quartz, anhydrite, gypsum, magnesite, polyhalite, and clays, with traces of alkali feldspar and possibly zeolites. The salt itself contains, on the average, less than 5 percent by weight mineral impurities, except in areas of well-defined anhydrite or clay interbeds.

4.1.1 HYDROUS MINERALS

The most common hydrous minerals (i.e., minerals containing bound water) in evaporite sequences include:

- o Gypsum ($CaSO_4 \cdot 2H_2O$),
- o Clays in mudstone partings and layers, and disseminated in evaporite beds,
- o Several minor hydrous chlorides, sulfates, and carbonates.

Gypsum is a common evaporite mineral that usually dehydrates to anhydrite during consolidation and diagenesis. Most evaporite sequences older than

Tertiary contain anhydrite only, with gypsum being a rehydration product or occurring locally where dehydration was impeded by entrapped brine. One kilogram of gypsum contains over 200 grams (over 1/5 total mass) of water. Clays may be detrital or authigenic and, like gypsum, may release water to the salt when less water-rich clays are produced during diagenesis (Collins, 1975). The hydrous phases in evaporite formations are usually concentrated in individual interbeds, partings, or zones, but they may be dispersed through the salt (Holser, 1979). Gypsum veins may be common locally (Pettijohn, 1975).

The bound water in hydrous minerals is located in specific sites in the minerals' crystal structure. As such, bound water is not a significant source for brine flows. Dehydration of these minerals during burial, heating, compaction, and diagenesis may be a source of water that, if retained in the sediments, may be entrapped in inclusions and brine reservoirs.

4.1.2 FLUID INCLUSIONS

Bedded salt is known to contain up to 1.7 percent water in the form of fluid inclusions (Roedder and Belken, 1979; Roedder, 1984). Fluid inclusions are isolated pockets of brine measuring up to several millimeters in diameter occurring within (intragranular) or between (intergranular) halite crystals. Intragranular occurrences are usually crystallographically controlled and are frequently cubic in shape. Large inclusions tend to be more irregular. The enclosed brine is generally a saturated aqueous NaCl solution that usually includes other cations (Ca, Mg, K) as well as organic compounds and dissolved or exsolved gasses (Roedder, 1984).

An extensive review of the occurrences and geochemistry of fluid inclusions in salt is given by Roedder (1984). Fluid inclusions may be primary (i.e., trapped during the original deposition of the enclosing halite) or secondary, forming after original deposition. Secondary fluid inclusions may form either under near-surface sedimentary conditions, during diagenesis or recrystallization of the primary halite, or during deformation of the evaporite beds. The secondary fluid inclusions may enclose connate brine (syngenetic interstitial water), but the brine may be altered by mixing with other water sources. These sources include both waters of dehydration of hydrated mineral phases and groundwater introduced into the salt. Inclusions may be concentrated in certain horizons or may occur in thin (10's to 100's of micrometers) bands within the salt. Intergranular inclusions probably indicate recrystallization of the salt sometime following original deposition (Roedder, 1984).

The origin of fluid inclusions may be indicated by the geochemistry of the trapped fluid as well as by petrographic details. Disparate fluid compositions among trapped brines in a given unit are frequently noted even between inclusions in close proximity. Some fluid inclusions may contain connate brines while others really contain brines that are the product of mixing or rock-brine interactions (Roedder, 1984). Stein (1985a), and Stein and Krumhansl (1986) have made preliminary studies of fluid inclusions present in the Salado Formation at the WIPP site. Most of the inclusion fluids studied were extracted from the larger, recrystallized halite crystals described in Section 4.1.

Estimates of the amount of brine contained in fluid inclusions at the repository level range from 0.22 weight-percent (Black et al., 1983) to about 0.6 weight-percent (Stein, 1985b). Stein and Krumhansl (1986), came to the preliminary conclusion that the chemistry of the fluid inclusions and the chemistry of the weep and drill hole fluids differed sufficiently to suggest different origins. Additionally, the brines contained within fluid inclusions are not free to migrate into underground openings under a pressure gradient until such inclusions are intersected by fractures, hence the inclusion fluids are not a primary focus of the BSEP.

4.1.3 INTERGRANULAR POROSITY AND OPEN FRACTURES

Brine occurs in the salt of the repository horizon both in hairline fractures, along grain boundaries, and in larger fractures that cut through grains. The latter are much more significant in terms of brine movement through the salt, as some have been observed to be in locations where brine seeps into the underground openings. Fractures up to a few millimeters in width have been observed in freshly excavated surfaces at the facility horizon, 655 meters beneath the surface (Appendix C). The brine is associated with gas, both of which are pressurized and may be responsible for keeping the fractures open prior to mining. It is difficult to obtain good values for the permeability of the porous zones and open fractures in the Salado Formation.

Conventional drill-stem tests performed at WIPP-associated wells generally found that the permeability of the Salado Formation in the vicinity of WIPP was less than the sensitivity limit of the system, i.e., less than 1×10^{-7} darcy. Beauheim et al. (1983) reported field permeability values for the Salado Formation at Cabin Baby-1 of about 9×10^{-9} and 8×10^{-8} darcies, but expressed concern over data interpretations. Specialized testing obtained qualified values in the range of 2.1×10^{-5} to 2.5×10^{-5} darcies for the bulk permeability of the Salado (Peterson et al., 1981; Mercer, 1987).

Peterson et al. (1985) report the results of permeability tests made in the facility horizon at WIPP using pressurized gas. The interpreted data indicated permeabilities ranging from about 10^{-6} to less than 10^{-9} darcies for undisturbed salt. It should be noted that these values were calculated assuming an unsaturated pore volume. As the authors pointed out, "If the volume were partially or fully saturated, so that fluid migration and/or threshold pressure effects were important, the intrinsic formation permeability would be larger than reported."

As discussed in more detail in Section 4.2 below, excavation-induced stress redistributions may cause the permeability of the Salado Formation to increase or decrease with time. The Peterson et al. (1985) field data from the repository level also supports the theoretical prediction that a disturbed zone with increased permeability will develop adjacent to the repository excavations. Conversely, it is possible that at depths comparable to the waste repository and at some distance from the excavation itself, the high lithostatic pressure in combination with brine moisture will likely result in the healing or sintering of open fractures and in the isolation of zones that might yield moisture to the repository excavations. Such fracture healing may also occur after repository closure, sealing, and repressurization. This is discussed further in Section 4.2.1.1.

Brine inflows into the local potash mines were discussed in Section 3.2.2, and are generally of greater total volume than those observed at WIPP. These occurrences are associated with the McNutt potash zone, stratigraphically higher and more complex mineralogically than the WIPP facility level. These inflows occur at shallower depths than at WIPP; it would be expected that the rocks in those mines are subjected to lower lithostatic stress. Greater values for porosity and permeability would be expected in the potash zone in those mines than at the repository horizon at WIPP. The possibility of recharge from the surface may also be more likely near some of the mines.

As previously described, the bedded salt deposits at WIPP contain relatively thin interbeds of anhydrite and clay. These interbeds contain brine in porous zones or open fractures as described above for the salt. They probably have different permeabilities and porosities from the salt and have a strong local effect on both the volume of brine available and the brine flow path.

Brine may occur in interstitial porosity in interbeds or in a fracture system within brittle interbeds, such as anhydrite. Hydrogeologic evidence for brine occurrence in anhydrite Marker Bed 139 was developed by Borns (1985) who described the structure of the marker bed in several zones. In one zone where anhydritic laminae were present, horizontal fractures were found. These fractures were in-filled with polyhalite and halite, indicating past movement of brine through them.

4.1.4 LARGE FRACTURED ZONES ("BRINE RESERVOIRS")

Large fractured zones capable of producing large volumes of brine (millions of liters), referred to as "brine reservoirs," have been encountered while drilling through evaporites in the Permian Basin. A comprehensive study (TSC-D'Appolonia, 1983c) of brine reservoirs in the underlying Castile formation at the WIPP site concluded that the reservoirs occurred in massive anhydrite layers approximately 100 meters thick that had been deformed upward by the underlying salt. The brine-producing zones encountered during drilling are interpreted as a lateral system of open fractures that provide an initially vigorous flow or pressure buildup response, combined with a system of microfractures that provide a slower sustained response.

There is no evidence to indicate that large fractured zones such as these occur in the Salado Formation in proximity to the repository horizon to affect the small, near-field brine inflows discussed in this report. Additionally, the Castile brine reservoirs are stratigraphically isolated from the WIPP repository by more than 230 meters of intervening evaporite beds. At the repository horizon the anhydrite beds in the Salado are much thinner than those in the underlying Castile Formation. There is also no evidence of salt anticline development at the repository horizon that seems to be associated with the large brine producing zones. It is concluded that the source of brine at the repository horizon is not a large-scale brine reservoir.

4.2 BRINE FLOW MECHANISMS

The observations of brine and the brine inflow measurements made previously (Section 3.0) are related to the excavation of an underground repository.

Flow may occur under a hydraulic gradient or under a thermal gradient. Flow may develop through salt and through the anhydrite and clay interbeds. The preliminary data from the BSEP indicate that no single simple set of conditions exists. The observed brine inflows almost certainly reflect a combination of the mechanisms discussed below. The combination of these mechanisms varies in both time and space.

4.2.1 FLOW UNDER A HYDRAULIC GRADIENT

In describing the fluid-flow systems operational under a hydraulic gradient, several stages in the development of the repository are identified by Freeze (1983) (Figure 4-1):

- Undisturbed flow regime prior to excavation (Stage 1)
- Transient flow regime during repository excavation and operations (Stage 2)
- Steady-state flow regime during repository operations (Stage 3)
- Transient flow regime during repository resaturation (Stage 4)
- Restoration of hydraulic gradients (Stages 5 and 6)

The first three stages are described below.

Prior to repository construction, there will be an initial steady-state hydraulic potential distribution in the vicinity of the repository (Stage 1). The flow in the undisturbed state could occur both vertically and laterally through the salt, clay interbeds, and interbeds of fractured anhydrite.

The quantity and rate of fluid movement through the Salado Formation under pre-excavation regional hydraulic gradients is small to nonexistent, and is probably not a significant factor in the mechanisms causing the observed inflows into the repository. Moisture does, however, occur in the Salado Formation (Section 4.1). For the purposes of the following discussions of short-term mining-induced transient flow systems, the source of that moisture may not be important, although it may have implications on reservoir characteristics that might determine the total volume of brine that is available for migration into the repository.

During repository construction and operation, a transient flow system (Stage 2) will be set up with flow towards the repository in response to the constant pressure drawdown that occurs at the excavation surface and the increase in permeability caused by stress redistribution near the excavation. Inflows may be evaporated and removed from the excavations by the ventilation system. If the repository is in operation long enough, inflows may become steady-state (Stage 3). If hydraulic gradients become smaller, the flow becomes non-Darcian, or a region develops around the repository where permeability is reduced from pre-excavation values, then inflow may be reduced or cease completely.

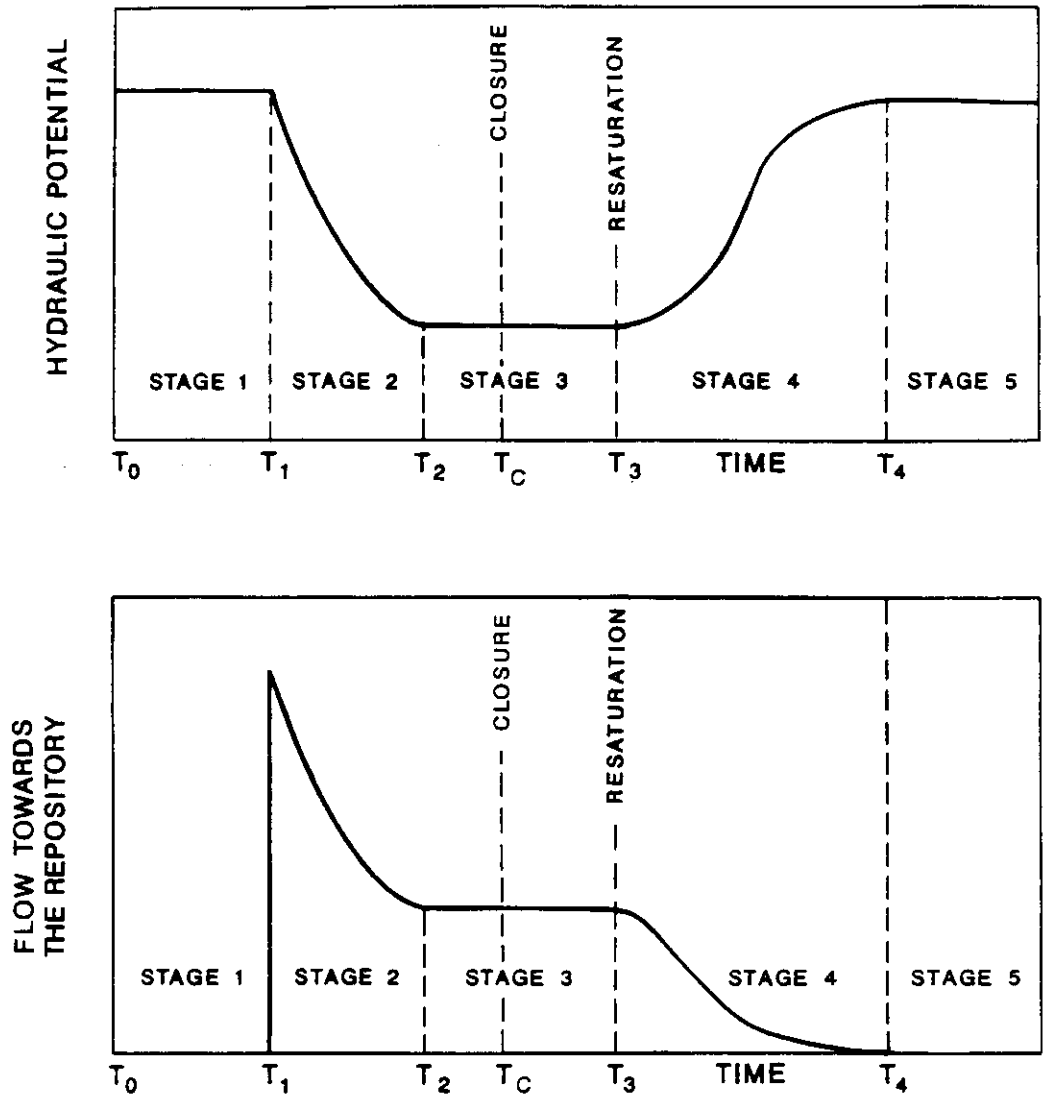


Figure 4-1.

Conceptual Model for Brine Flow Towards a Repository
(Modified From Freeze, 1983)

The following discussion addresses flow during repository operations through both undisturbed salt and interbeds (Stage 1) and flow through disturbed salt and interbeds in the vicinity of the excavation (Stages 2 and 3). Disturbance encompasses both the effects of constant pressure drawdown and lithostatic stress relief. Several fluid-flow systems under a pressure gradient are then described.

4.2.1.1 Flow Through Salt

Brine may flow through either the intercrystalline or intracrystalline structure of salt. Owing to the relatively low permeability of individual salt crystals, fluid inclusions within individual crystals may move very slowly, whereas fluid movement occurs more rapidly in the intercrystalline structure of the salt. Case and Kelsall (1985) compiled laboratory and field data which show that the permeability of salt under a wide range of confining pressure ranges from 1 md to 10^{-6} md, while the measurement of the permeability of a single salt crystal was 10^{-9} md (Sutherland and Cave, 1980). It is noted by some investigators (Remson, 1984) that flow rates calculated using traditional transport equations may be too high. We suggest that this may be because the brine exists as a thin film surrounded by a massive salt matrix and that surface forces may become dominant in affecting interstitial flow. The proportionality between flux rate and hydraulic gradient (Darcy's Law) may no longer apply and the flow will occur at a much slower rate. For practical purposes, the brines may be immobile [as suggested by geochemical analysis (Popielak, et al, 1983)], although this immobility has not been proven by hydrologic observation or analysis.

During excavation of the underground facility, the local hydraulic gradient is increased, resulting in brine flow from the adjacent strata to the excavation. Stresses are redistributed in the salt fabric resulting in an increase in permeability. Both these processes would result in an increased brine flow rate. Conversely, as interstitial pressures are relieved, there is compression of the pore space and accelerated creep due to increased effective stress[1]. This, in conjunction with the reduction of the hydraulic gradient with time, will tend to reduce brine inflow rates.

Theoretical studies (Kelsall et al., 1982 and Case and Kelsall, 1985), and field measurements (Peterson et al., 1985) support the existence of a zone of increased permeability as illustrated in Figure 4-2. In the radial direction from the room, the stress has been relieved, resulting in an increase in permeability normal to this direction (Figure 4-3). In the tangential direction, the stresses may increase initially at the room boundary due to the elastic response, and then decrease due to inelastic creep deformations. The permeability may increase or decrease normal to this direction (Figure 4-3).

[1] Effective stress is used in this context as the difference between total stress and pore pressure.

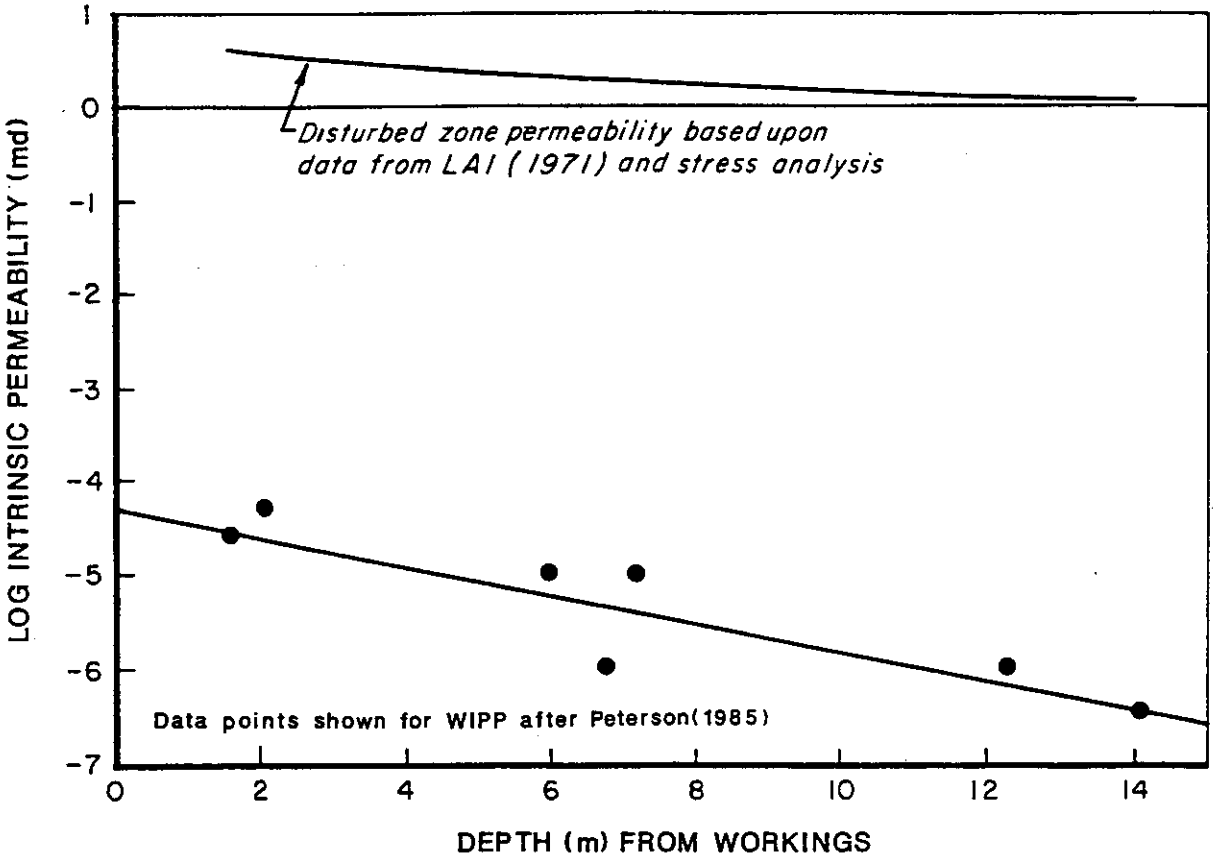


Figure 4-2.

Relationship of Salt Permeability and Depth Near an Excavation
(From Case and Kelsall, 1985)

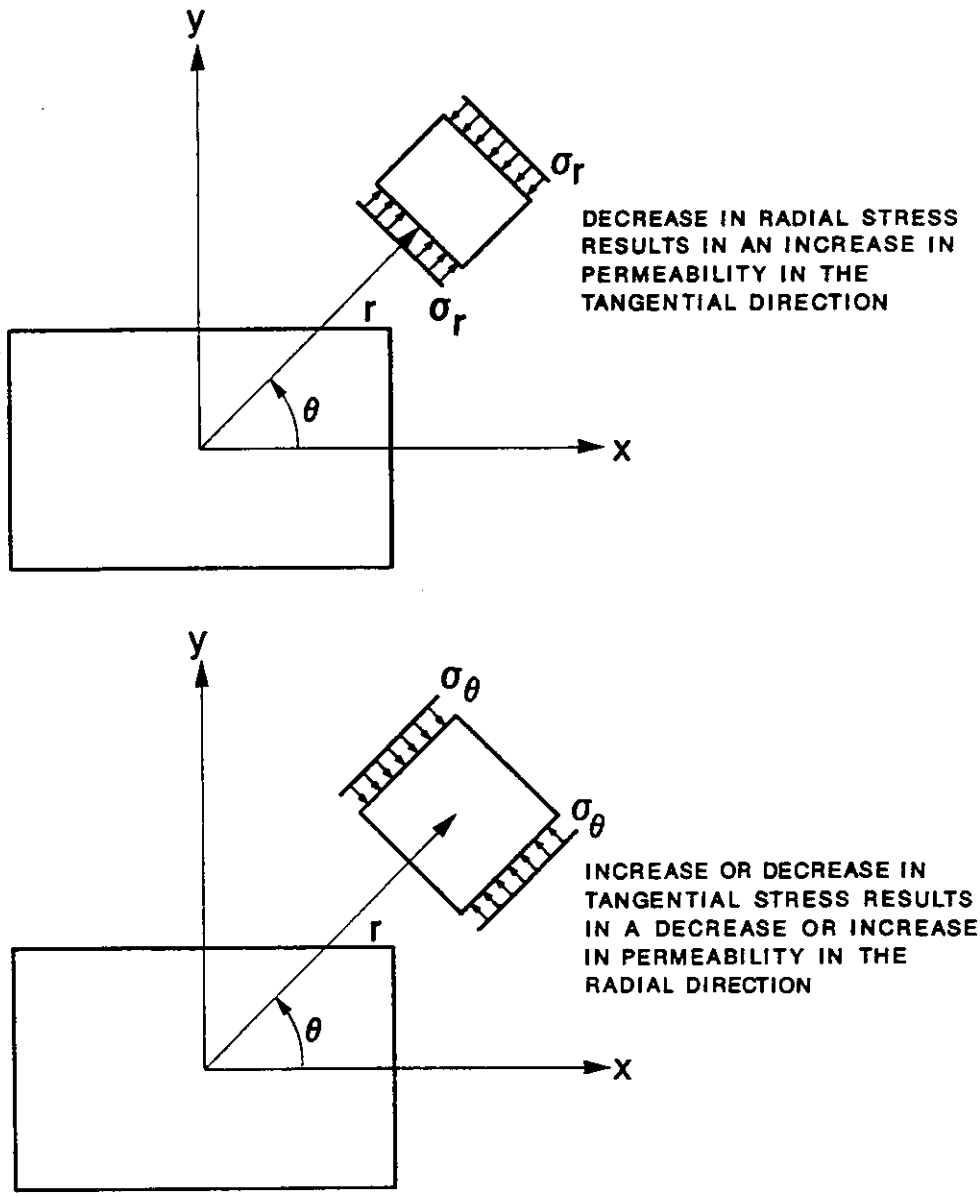


Figure 4-3.
Modification of Permeability in the Radial and Tangential Directions

This modified permeability zone ("disturbed zone") occurs in the immediate vicinity of the excavations and has a width that increases with time, beginning immediately with the excavation of a new opening and continuing until repressurization after closure. In a practical sense, this zone may extend from a few meters to a few tens of meters away from the repository. Evidence regarding this change in permeability around an entry has been obtained using a guarded straddle packer system (Peterson et al., 1985). The tests were performed to determine the permeability of salt, the variation with distance from the mined surface, and the influence of interspersed anhydrite and clay seams. The combined permeability measurements indicate that there is a relationship of permeability with test interval depth. The data indicate that permeability is increased from undisturbed values by two orders of magnitude (10^{-6} to 10^{-4} md) within one to 14 meters of the excavation. This trend is similar to that predicted by Kelsall et al. (1982). Since measurements are made for flow normal to the direction of stress relief, the results are not unexpected.

Predictions of the zone of increased permeability at WIPP are made using the stress-permeability relations developed by Lai (1971). Estimates of the amount of stress relief as a function of depth from the rectangular entry may be made using the relationships developed by Chabannes (1982). Assumptions or simplifications include: 1) that the stress distribution is steady-state, and is based upon the steady-state creep law; 2) that the cross-section of the excavation is circular in a homogeneous stress field; and 3) that the far-field stress is hydrostatic. The predicted results show a trend similar to the in situ data; the calculated values of permeability are four to five orders of magnitude higher. The in situ test results indicate steeper changes in permeability with depth than the predictive analysis. Because the actual stress distribution is probably not steady-state, the excavations are not cylindrical, and other assumptions made for the calculations only approximate actual repository conditions, this difference is not unexpected.

Permeability will also increase due to localized fracturing of intact salt, especially in the disturbed zone (Bechtel National, 1986). In Room 2, a single hole NG252 (Appendix D, Section 3.2.2) which was drilled downward for geomechanical instrumentation has produced a relatively large amount of brine. Brine and gas flow into the hole from a fracture located near the base of the anhydrite Marker Bed 139. As described by Bechtel National (1986), the fractures intersect the interbeds and the salt in the disturbed zone. This fracture or a related fracture is observed in the floor of Room 2, approximately 15 meters from the geomechanics instrument array. It is exposed approximately two meters from the west wall of Room 2 and is observed to extend to almost a meter below the surface to the east. It is expected that this type of fracturing will result in a fracture porosity and permeability in the disturbed zone in the immediate vicinity of the repository that is higher than the laboratory or field measurements described above.

Owing again to the relatively low permeability of individual salt crystals, fluid inclusions within individual crystals may move very slowly, whereas fluid movement occurs more rapidly in the intercrystalline structure. It is postulated that intercrystalline brine flow is primarily responsible for the efflorescence that is common throughout the repository.

Tests to evaluate healing of fractured WIPP salt under renewed confining stress have been conducted by Costin and Wawersik (1980) and by Withiam et al. (1984). Costin and Wawersik took short rod specimens fabricated from intact WIPP salt and loaded these specimens to failure creating a fracture along the axis of the specimen. After fracturing, the specimens were pieced together and subjected to higher temperatures (up to 100°C) and pressures (up to 35MPa) in order to "heal" the fractures. The specimens were then retested to determine the degree of fracture healing. The results indicated that 70 to 80 percent of the original strength was recovered within several days. In more recent permeability tests, Withiam et al. (1984) recovered samples from one foot below the repository horizon and created fractures either by sawing or tensile splitting. The fractures created with a bandsaw were smooth, with no discernible roughness. Fractures created by splitting followed crystal boundaries and cleavage faces, and had a typical roughness amplitude in the range of 5 to 10 mm. Permeability tests were conducted at hydrostatic pressures up to 3,000 psi at room temperature. It was concluded that the reduction of permeability with time, under constant confining pressure, suggested fracture healing.

Laboratory investigations have also established the stress dependency of permeability for intact salt through microfracture healing and reduction in porosity (Sutherland and Cave, 1980). A reduction in porosity and permeability due to salt creep could be a significant factor in limiting the inflow of brine into the repository. We hypothesize that flow of brine and gas toward the repository from the interstitial voids and fractures in undisturbed salt will reduce interstitial pressure, allowing salt creep to close void spaces and increase the tendency for fractures to heal. This may result in lowered porosity and permeability in a zone around the repository outside of the zone of increased permeability discussed above. These effects may, in time, reduce or limit the brine inflow. If this occurs, and a permeability barrier develops naturally around the repository, then it follows that air circulating for a sufficiently long period of time during operations prior to closure of the repository will dry out the workings and slow down the process of resaturation after closure.

The establishment of steady-state flow (Stage 3) through salt would be dependent on the hydrologic characteristics of the salt. Owing to its low permeability, the time frame that the repository is operational, and the nature of recharge, steady-state flow might not be established. The occurrence of brine with dissolved gas in isolated fractures or porous zones in salt may also affect the development of steady-state flow. Before excavation, the fluid pressures in fractures is theoretically equal to the lithostatic state of stress, which at the WIPP repository horizon is approximately 15 MPa. During excavation, the state of stress in the salt near the brine occurrence is relieved. The reduction in stress may result in microfracturing of salt at the excavation-brine/gas occurrence boundary and a flow of brine (and gas) into the underground workings can occur. In such a situation, the brine/gas flow is reduced as the fracture or porous zone is drained.

4.2.1.2 Flow Through Interbeds

Because most interbeds create nearly planar discontinuities, flow paths along or through them tend to be less tortuous than flow paths through massive halite. As a result, flow paths associated with interbeds may provide relatively high permeability zones that may effectively collect intercrystalline fluids and provide a route for brine movement toward the repository. During excavation, a high hydraulic pressure gradient is established and flow may occur where an interbed is intersected by a borehole in the repository. Adjacent to an excavation, the permeability of interbeds may be increased by stress relief, especially if flow is occurring in fractures. Fracturing in the disturbed zone in the immediate proximity to the workings could also occur and provide a route for flow through the salt from an interbed (above the roof or below the floor) to the excavation. Separations on the order of several centimeters have developed in and along interbeds (especially associated with brittle anhydrite zones), many months after excavation (Bechtel National, 1986). Considering flow to a borehole, flow may be greater from interbeds which are close to the roof or floor of the excavation in the zone of maximum stress relief.

Indirect evidence for the effects of excavation may be found by comparing the borehole flow measurements in Rooms A1, A2, A3, 1B, and G. As mentioned previously, the anhydrite Marker Bed 139 is located at a greater depth (seven meters) in Rooms A1 through B. The flow measurements in four floor holes in these rooms form a consistent set of measurements, suggesting that the source of the flow for the four holes is the same relatively undisturbed stratum or series of strata. In contrast, the range of recorded inflow rates in Room G is much wider, perhaps reflecting disturbance, different sources of flow, different flow systems, or more local variability in the geology. For example, the two floor holes that are two meters apart, DH42 and DH42A, exhibit distinctly different flow rates and time rates of change in flow rate.

4.2.2 FLOW UNDER A THERMAL GRADIENT

The migration of brine fluid inclusions may develop along a thermal gradient. In this mechanism, the solubility of salt is temperature-dependent with dissolution occurring on the high temperature side and precipitation on the low temperature side. The fluid inclusion moves toward the higher temperature. In general, migration rates are controlled by temperature, temperature gradient, inclusion shape and size, and the salt crystal microstructure (Olander; 1984, 1985).

There is much experimental evidence for brine migration toward a high temperature source (comparable to a radioactive heat source) [Hohlfelder and Hadley (1979); Gnirk et al., (1981); Jenks and Claiborne (1981); Pigford (1982); Olander (1984, 1985); Olander et al (1982); Roedder (1984) and Clark (1985)]. Roedder (1984) states that there is no evidence of brine migration under normal geothermal gradients. In the underground repository, there is an approximate equilibrium between rock temperature and the repository air temperature, with perhaps a slight rise of temperature into the rock. Any tendency for brine to migrate up-gradient would be overshadowed by relatively high hydraulic gradients resulting in flow toward the repository.

5.0 BRINE SAMPLING AND EVALUATION PROGRAM: CONTINUING EFFORTS

The following investigations are continuing as part of the Brine Sampling and Evaluation Program at WIPP. The results will be presented in later BSEP reports.

- Additional delineation of stratigraphic variations in the brine occurrences.
- Additional delineation of horizontal variations of brine content in the rocks exposed at the facility level.
- Refinement of the data on the loosely-bound brine available for non-thermal migration into the repository.
- Characterization of the chemistry of the naturally-occurring brine that is likely to migrate into the repository.
- Continued monitoring of brine inflow into selected drill holes.
- Continued assessment of the feasibility of using geophysical techniques to define source horizons and the aerial extent of brine occurrences at the repository level.

6.0 SUMMARY

Although the WIPP underground constitutes "dry" workings, small amounts of brine are present, probably on the order of 0.1 to 0.5 percent by weight of the surrounding rocks. Part of that brine can and does migrate into the repository openings in response to transient or pre-existing pressure gradients, independent of thermal gradients. These small volumes of brine have little effect on the day-to-day operations, but are pervasive throughout the repository and may contribute enough moisture over a period of years to merit consideration with regard to resaturation and repressurization.

The inflows that occur as "weeps" on the exposed surfaces have been observed since the initial excavations in 1983. "Weeps" are very small inflows of brine that occur on almost all exposed surfaces and are evidenced by halite efflorescence. Small brine inflows also occur in drill holes. Over 1400 drill holes, most 15 meters or less in length, exist in the WIPP underground. Small quantities of gas are often associated with brine inflows. Gas bubbles are observed in many of the brine occurrences. Gas is also known to exsolve from solution as the brine is poured from container to container.

Measured occurrences have inflow rates that range from less than the rate at which surface moisture is evaporated into the repository atmosphere to approximately 0.5 liters per day. Individual occurrences vary greatly and some drill holes separated by less than a meter have inflows that contrast dramatically, making the discussion of "averages" or "typical occurrences" difficult or misleading. The reasons for this variability are still poorly understood. The inflow at any specific location is influenced by a number of factors, including local stress distribution, local brine sources, variations in local fracturing and permeability, and local variation in the geology. Most occurrences displayed a brief, initial no-flow or low-flow period, followed by maximum inflow. Brine inflow then decreased over a period of several months to relatively steady-state conditions. Some occurrences had increased inflows and some ceased entirely. Most of the noticeable inflow rates range between a few tenths and a few hundredths of a liter per day. The largest individual production measured during this reporting period produced an aggregate over 235 liters of brine, and continues to produce over 0.2 liters per day. It was clearly an unusual and exceptional occurrence and was associated with excavation-induced fracturing. Inflow rates in that drill hole have declined markedly over the observation period.

It should be noted that the brine occurrences discussed here are small and are clearly distinguished from the "brine reservoirs" found in the underlying, stratigraphically lower, and geologically older, Castile Formation in the Delaware Basin. "Brine reservoirs" are measured in hundreds of thousands of liters, flow readily into boreholes that penetrate them, and have been the subject of other investigations (Section 4.1.4).

It is clear from the preliminary data that brine inflow, gas inflow, and salt creep into the workings are intimately associated with each other and that significant pressure-driven brine inflows that are not the result of brine migration in a thermal gradient may occur after sealing and closure of the

repository. Brine flow systems are not well understood at this time, but it is likely that the observed inflows are dominated by the response to transient pressure gradients resulting from the excavation of the repository. A component due to regional hydraulic head cannot, at this time, be ruled out.

Brine chemistry data has been collected, but is not reported in this document. Characterization of the near-field brine chemistry continues, and will be included in a future BSEP report.

The major observations may be summarized as:

- Brine inflows are small, and are not related to large brine reservoirs in the Castile Formation.
- Brine occurrences, particularly those evidenced as halite efflorescence, are pervasive throughout the WIPP underground workings.
- Brine inflow rates are low, usually on the order of a few hundredths of a liter per day or less.
- Although small when measured in terms of liters per day at any given location, cumulative inflow volumes may be significant when measured in terms of the entire repository over periods of many years.
- There is a considerable variation in brine inflow between locations, even when locations are only a few meters (or, in some instances, less than a meter) apart.
- Holes that penetrate the roof and floor generally show a pattern of an initial, maximum flow rate that reduces to a fairly steady flow rate over the time period during which measurements have been made.
- Several flow systems and conditions are possible, but insufficient data exist to select the system and conditions (or combination of several systems and conditions) that best describe the phenomena at WIPP.

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APPENDIX A

PRELIMINARY INVENTORY OF UNDERGROUND DRILL HOLES AT WIPP

EXPLANATION OF FIELDS USED IN THE DATA BASE FOR APPENDIX A and B

Hole Number

This is the designation number that was assigned to the drill hole. A question mark in the hole number field indicates that the number used was an arbitrary number used on a temporary basis by field personnel for a drill hole actually located underground. Additional checking is necessary to unambiguously determine the assigned number.

Room

Room name or number, if the hole is located in a test or experimental room.

North-South and East-West Coordinates

Mine coordinates of the drill hole collar, in feet, referenced to the center of the C&SH Shaft.

Elevation

Elevation of the drill hole collar, in feet, referenced to mean sea level.

Accuracy

Accuracy of the coordinates and elevation data

- A = Approximate
- B = As-Built survey data
- P = As-Planned location data
- D = Duplicate hole record or record of a hole number that should be deleted from the listing of holes. This is usually the result of both a hole number and a separate instrument number being assigned to the same location.

Purpose

The reason the hole was drilled.

- Ae Acoustic Emission
- C Core

CON Construction-related drilling

CS Clay-seam sample

DD Demonstration drilling

EX Experiment

GT Gas Testing

HF Hydrofrac Experiment

HTR Heater installation

I Instrument

ID Instrument demonstration

LT Lab-testing sample

O Observation hole

P Pilot hole

Pr Pressure-relief hole

RM Rock mechanics

ST Stratigraphic analysis

US Ultra-sonic experiment

WO Water observation

Direction

General direction of the hole from the underground workings: up, down, north, south, east, or west.

Angle

Angle from the horizontal

Depth

Depth of hole in feet, referenced to the collar.

Diameter

Diameter of the hole in inches.

References

A1 TSC-D'Appolonia, 1983a (WIPP-DOE-163)

A2 Bechtel National, 1984 (WIPP-DOE-202)

A3 Bechtel National, 1985 (WIPP-DOE-213)

B Brine Sampling and Evaluation Program File

C Record of Special Drill Holes, WIPP Facility Horizon, 9/12/83: BSEP Files

D Room A1, A2, A3, and J As-Built Survey Data, Survey Calculation Sheets: BSEP Files

E Field Notes, J. Gallerani, Bechtel: BSEP Files

F Field Notes, D. Deal, IT Corp.: BSEP Files

G Room J Brine Survey: BSEP Files

H Room L1 and L2 Field Notes: BSEP Files

J Geotechnical Instrument List, 11/02/83: BSEP Files

APPENDIX A
PRELIMINARY INVENTORY OF UNDERGROUND DRILL HOLES AT WIPP
1439 Records of Holes Drilled Before July 1985
(NOTE: This List Contains Unchecked Information)

Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
1		N1440	W0557.0	1298.5	A	DD	N	0	16.8	36
2		N1440	W0548.5	1298.5	A	DD	N	0	2.8	36
3		N1440	W0540.7	1298.5	A	DD	N	0	3.0	36
3?1		N1092.5	W0410	1306	A	?	U,S	45?	25+	3
3?2		N1093	W0410	1306	A	?	U,S	45?	25+	4
4		N1440	W0530.7	1298.5	A	DD	N	0	10.4	36
4PD01	4	N1177	W0630.5	1294	A	DD	D	90	9.1	5.12
4PD02	4	N1187	W0630.5	1294	A	DD	D	90	9.1	5.12
4PU	4	N1120	W0630.5	1304	A	DD	U	90	9.3	5
4PU01	4	N1177	W0646	1304	A	DD	U,W	60	14.1	5.12
4PU02	4	N1177	W0630.5	1304	A	DD	U	90	16.2	5.12
4PU03	4	N1187	W0630.5	1304	A	DD	U	90	9.7	5.12
A		S1250	E0140	1262	A	Ae	E	0	15.15	3
A	L2	N1515	W0365	1312.5	A	WO	D	90	12.8	1
A1041	A1	N1190.70	E1258.00	1313.33	B	HTR	D	90	19.9	30
A1042	A1	N1343.30	E1258.01	1313.78	B	HTR	D	90	19.5	30
A1043	A1	N1187.29	E1258.05	1313.10	B	HTR	D	90	20.6	30
A1044	A1	N1349.56	E1258.29	1313.81	B	HTR	D	90	19.2	30
A1045	A1	N1177.97	E1257.96	1313.09	B	HTR	D	90	19.8	36
A1046	A1	N1356.05	E1258.19	1313.60	B	HTR	D	90	19.2	36
A1061	A1	N1199.27	E1257.79	1313.22	B	HTR	D	90	19.8	16
A1062	A1	N1210.58	E1257.99	1313.58	B	HTR	D	90	19.8	16
A1063	A1	N1221.82	E1258.02	1313.54	B	HTR	D	90	19.9	16
A1064	A1	N1233.13	E1258.01	1313.73	B	HTR	D	90	19.9	16
A1065	A1	N1244.38	E1258.03	1313.57	B	HTR	D	90	19.8	16
A1066	A1	N1255.70	E1257.97	1313.33	B	HTR	D	90	20.4	16
A1067	A1	N1266.98	E1258.00	1313.41	B	HTR	D	90	19.8	16
A1068	A1	N1278.28	E1258.00	1313.49	B	HTR	D	90	19.8	16
A1069	A1	N1289.63	E1257.98	1313.80	B	HTR	D	90	19.8	16
A1070	A1	N1300.94	E1257.98	1314.21	B	HTR	D	90	19.8	16
A1071	A1	N1312.25	E1257.99	1314.34	B	HTR	D	90	19.8	16
A1072	A1	N1323.65	E1257.97	1314.06	B	HTR	D	90	20.3	16
A1073	A1	N1334.81	E1258.01	1313.99	B	HTR	D	90	20.1	16
A1095	A1	N1421	E1258.0	1322.3	D,A	I	S	0	172.5	1.88
A1303	A1	N1207.9	E1258.0	1313.5	P	I	U	90	50.75	1.875
A1304	A1	N1207.51	E1258.76	1313.83	B	I	D	90	50.3	1.875
A1305	A1	N1237.49	E1258.73	1331.69	B	I	U	90	50.45	3
A1306	A1	N1237.49	E1258.73	1313.88	B	I	D	90	50.3	3
A1307	A1	N1269.45	E1258.43	1331.50	B	I	U	90	50.4	1.875
A1308	A1	N1269.47	E1258.73	1313.82	B	I	D	90	49	1.875
A1309	A1	N1297.47	E1258.72	1331.83	B	I	U	90	50.5	1.875
A1310	A1	N1297.47	E1258.69	1314.46	B	I	D	90	49.7	1.875
A1311	A1	N1327.42	E1258.73	1331.90	B	I	U	90	50.5	1.875
A1312	A1	N1327.44	E1258.69	1314.41	B	I	D	90	49.1	1.875
A1313	A1	N1364.85	E1258.79	1331.61	B	I	U	90	50.25	1.875
A1314	A1	N1364.96	E1258.78	1313.94	B	I	D	90	49.65	1.875
A1315	A1	N1207.48	E1267.65	1322.64	B	I	E	0	29.8	1.875
A1316	A1	N1207.45	E1249.87	1322.62	B	I	W	0	50.6	1.875
A1316	A1	N1369.45	E1249.73	1322.53	B	I	W	0	47	1.875
A1317	A1	N1269.48	E1267.65	1322.53	B	I	E	0	28	1.875
A1319	A1	N1327.5	E1267.57	1323.02	B	I	E	0	50.3	1.875
A1320	A1	N1327.47	E1249.96	1323.00	B	I	W	0	50.5	1.875
A1321	A1	N1267.54	E1267.71	1328.48	B	I	E	0	59	1.875
A1322	A1	N1267.46	E1249.92	1328.47	B	I	W	0	50.0	1.875
A1323	A1	N1267.50	E1267.50	1316.52	B	I	W	0	50.15	1.875
A1324	A1	N1237.50	E1267.66	1322.90	B	I	E	0	29.65	3
A1325	A1	N1237.45	E1249.87	1322.87	B	I	W	0	49.75	3
A1703	A1	N1218.67	E1258.77	1331.42	B	I	U	90	50.75	1.875
A1704	A1	N1218.70	E1258.77	1313.81	B	I	D	90	50.65	4.875
A1705	A1	N1251.48	E1258.76	1331.62	B	I	U	90	50.0	1.875
A1706	A1	N1251.47	E1248.76	1313.71	B	I	D	90	50.6	1.875
A1707	A1	N1267.41	E1258.77	1331.49	B	I	U	90	50.45	1.875
A1709	A1	N1283.45	E1258.76	1331.54	B	I	U	90	50.25	1.875
A1710	A1	N1283.46	E1258.74	1313.98	B	I	D	90	50.65	1.875

APPENDIX A
PRELIMINARY INVENTORY OF UNDERGROUND DRILL HOLES AT WIPP
1439 Records of Holes Drilled Before July 1985
(NOTE: This List Contains Unchecked Information)

Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
A1711	A1	N1316.25	E1258.74	1332.15	B	I	U	90	50.75	1.875
A1712	A1	N1316.26	E1258.77	1314.50	B	I	D	90	50.53	1.875
A1713	A1	N1352.85	E1258.72	1331.61	B	I	U	90	50.4	1.875
A1714	A1	N1352.96	E1258.75	1313.96	B	I	D	90	49.8	1.875
A1717	A1	N1218.67	E1367.68	1322.62	B	I	E	0	29.75	1.875
A1718	A1	N1218.65	E1249.92	1322.65	B	I	W	0	50.4	1.875
A1719	A1	N1251.49	E1267.65	1322.73	B	I	E	0	16.6	1.875
A1721	A1	N1267.50	E1267.62	1330.01	B	I	E	0	16.2	1.875
A1722	A1	N1267.45	E1267.81	1314.94	B	I	E	0	16.0	1.875
A1723	A1	N1267.51	E1250.01	1330.00	B	I	W	0	50.0	1.875
A1724	A1	N1267.43	E1250.25	1314.96	B	I	W	0	50.15	1.875
A1725	A1	N1283.50	E1267.46	1322.83	B	I	E	0	16.0	1.875
A1727	A1	N1316.28	E1267.71	1323.31	B	I	E	0	16.0	1.875
A1728	A1	N1316.27	E1249.90	1323.29	B	I	W	0	50.1	1.875
A1729	A1	N1352.99	E1267.72	1322.68	B	I	E	0	16.55	1.875
A1730	A1	N1352.89	E1249.94	1322.72	B	I	W	0	50.25	1.875
A1731	A1	N1251.43	E1267.24	1331.20	B	I	U,E	45	38	1.875
A1732	A1	N1251.46	E1267.38	1313.87	B	I	D,E	45	37.9	1.875
A1735	A1	N1283.44	E1267.25	1331.18	B	I	U,E	45	37.9	1.875
A1736	A1	N1283.46	E1267.32	1314.22	B	I	D,W	45	37.15	1.875
A1751	A1	N1272.48	E1258.04	1313.62	B	I	D	90	21.5	1.875
A1752	A1	N1275.72	E1258.21	1313.66	B	I	D	90	21.44	1.875
A1753	A1	N1278.17	E1259.24	1313.76	B	I	D	90	21.29	1.875
A1754	A1	N1278.30	E1260.48	1313.75	B	I	D	90	21.27	1.875
A1755	A1	N1278.34	E1263.72	1313.85	B	I	D	90	21.23	1.875
A1756	A1	N1279.66	E1258.01	1313.75	B	I	D	90	21.23	1.875
A1757	A1	N1280.86	E1258.07	1313.86	B	I	D	90	21.48	1.875
A1758	A1	N1283.93	E1258.11	1313.96	B	I	D	90	21.63	1.875
A1759	A1	N1287.04	E1258.03	1313.98	B	I	D	90	21.60	1.875
A1760	A1	N1288.07	E1258.02	1313.99	B	I	D	90	21.60	1.875
A1761	A1	N1289.65	E1252.33	1314.03	B	I	D	90	21.65	1.875
A1762	A1	N1289.60	E1255.47	1314.03	B	I	D	90	21.69	1.875
A1763	A1	N1289.69	E1256.68	1314.02	B	I	D	90	21.73	1.875
A1?1	A1	N1273	E1259	1314	A	I	D	90	21.4	2
A1?2	A1	N1276.5	E1259	1314	A	I	D	90	21.4	2
A1?3	A1	N1278	E1259.8	1313.5	A	I	D	90	21.3	2
A1?4	A1	N1278	E1261.3	1313.5	A	I	D	90	21.3	2
A1?5	A1	N1278	E1264.8	1313.5	A	I	D	90	21.4	2
A1?6	A1	N1260.3	E1258	1313.3	A	I	D	90	1.6	6
A1F41	A1	N1261.39	E1258.01	1313.28	B	C,I	D	90	1.5	6
A1F91	A1	N1295.24	E1258.10	1314.09	B	C,I	D	90	1.5	6
A1X01	A1	N1147.02	E1254.40	1313.26	B	C	D	90	49.75	4
A1X02	A1	N1146.88	E1254.24	1331.29	B	C	U	90	59.0	4
A2001	A2	N1237.49	E1326.65	1328.31	B	I	W	0	59.6	4.0
A2002	A2	N1237.54	E1326.70	1312.28	B	I	W	0	59.9	4.0
A2003	A2	N1237.48	E1344.88	1328.28	B	I	E	0	59.5	4.0
A2004	A2	N1237.55	E1344.74	1312.27	B	I	E	0	59.8	4.0
A2005	A2	N1327.50	E1327.08	1329.15	B	I	U,W		84.1	4.0
A2006	A2	N1237.48	E1326.97	1311.43	B	I	D,W		83.2	4.0
A2007	A2	N1237.56	E1344.75	1329.01	B	I	U,E		93.8	4.0
A2008	A2	N1237.49	E1344.42	1311.57	B	I	D,E		83.6	4.0
A2009	A2	N1275.06	E1326.66	1328.29	B	I	W	0	62.2	4.0
A2010	A2	N1275.02	E1326.76	1312.36	B	I	W	0	59.7	4.0
A2011	A2	N1275.05	E1344.86	1328.43	B	I	E	0	59.7	4.0
A2012	A2	N1275.10	E1344.61	1312.45	B	I	E	0	59.7	4.0
A2013	A2	N1274.99	E1327.10	1329.27	B	I	U,W		84.3	4.0
A2014	A2	N1275.17	E1326.95	1311.71	B	I	D,W		84.0	4.0
A2015	A2	N1275.03	E1344.60	1329.37	B	I	U,E		84.2	4.0
A2016	A2	N1275.10	E1344.53	1311.91	B	I	D,E		83.7	4.0
A2017	A2	N1357.46	E1326.67	1327.77	B	I	W	0	59.3	4.0
A2018	A2	N1357.48	E1326.91	1311.90	B	I	W	0	59.0	4.0
A2019	A2	N1357.49	E1344.89	1327.88	B	I	E	0	58.8	4.0
A2020	A2	N1357.50	E1344.69	1311.96	B	I	E	0	59.6	4.0
A2021	A2	N1357.56	E1327.02	1326.60	B	I	U,W		84.0	4.0

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Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
A2022	A2	N1357.55	E1327.10	1311.22	B	I	D,W		83.3	4.0
A2023	A2	N1257.50	E1344.64	1328.78	B	I	U,E		83.4	4.0
A2024	A2	N1357.47	E1344.47	1311.35	B	I	D,E		83.1	4.0
A2031	A2	N1217.90	E1331.24	1311.38	B	HTR	D	90	20.0	30
A2032	A2	N1218.32	E1338.79	1311.91	B	HTR	D	90	20.5	30
A2033	A2	N1225.44	E1331.20	1311.32	B	HTR	D	90	20.8	30
A2034	A2	N1225.78	E1338.93	1311.23	B	HTR	D	90	20.8	30
A2035	A2	N1233.16	E1331.15	1312.01	B	HTR	D	90	20.1	30
A2036	A2	N1233.03	E1338.80	1312.10	B	HTR	D	90	20.2	30
A2037	A2	N1240.66	E1331.21	1311.55	B	HTR	D	90	20.2	30
A2038	A2	N1240.64	E1338.74	1311.61	B	HTR	D	90	20.2	30
A2039	A2	N1248.10	E1331.26	1311.59	B	HTR	D	90	20.1	30
A2040	A2	N1248.17	E1338.78	1311.76	B	HTR	D	90	20.8	30
A2041	A2	N1255.63	E1331.21	1311.70	B	HTR	D	90	20.6	30
A2042	A2	N1255.68	E1338.79	1311.88	B	HTR	D	90	20.6	30
A2043	A2	N1263.04	E1331.28	1311.86	B	HTR	D	90	20.5	30
A2044	A2	N1263.15	E1339.23	1311.93	B	HTR	D	90	20.4	30
A2045	A2	N1270.79	E1331.39	1311.81	B	HTR	D	90	20.2	30
A2046	A2	N1270.77	E1338.78	1312.06	B	HTR	D	90	20.3	30
A2047	A2	N1278.23	E1331.27	1311.89	B	HTR	D	90	20.5	30
A2048	A2	N1278.14	E1338.82	1311.96	B	HTR	D	90	20.5	30
A2049	A2	N1285.73	E1331.22	1311.90	B	HTR	D	90	21.0	30
A2050	A2	N1285.60	E1338.73	1312.04	B	HTR	D	90	21.0	30
A2051	A2	N1292.97	E1331.27	1311.76	B	HTR	D	90	20.2	30
A2052	A2	N1293.34	E1338.72	1311.94	B	HTR	D	90	20.1	30
A2053	A2	N1300.84	E1331.23	1311.78	B	HTR	D	90	20.7	30
A2054	A2	N1300.54	E1338.81	1311.79	B	HTR	D	90	19.8	30
A2055	A2	N1308.30	E1331.22	1311.60	B	HTR	D	90	20.4	30
A2056	A2	N1308.21	E1338.82	1311.82	B	HTR	D	90	21.0	30
A2057	A2	N1315.72	E1331.18	1311.39	B	HTR	D	90	19.8	30
A2058	A2	N1315.69	E1338.79	1311.91	B	HTR	D	90	20.5	30
A2076	A2	N1210.76	E1331.21	1310.69	B	HTR	D	90	20.7	16
A2077	A2	N1210.66	E1338.80	1311.26	B	HTR	D	90	20.4	16
A2078	A2	N1323.35	E1331.23	1311.83	B	HTR	D	90	20.2	16
A2079	A2	N1323.32	E1338.76	1311.99	B	HTR	D	90	20.1	16
A2085	A3	N1420.19	E1348.67	1315.48	B					
A2086	A2	N1420.13	E1353.74	1315.39	B					
A2095	A2	N1421	E1335	1322	D,A	I	S	0	202	1.88
A2331	A2	N1175.45	E1335.74	1328.79	B	I	U	90	50.1	1.875
A2331A	A2				D					
A2332	A2	N1175.58	E1335.77	1310.55	B	I	D	90	50.35	1.875
A2332A	A2				D					
A2333	A2	N1207.44	E1335.76	1329.06	B	I	U	90	50.1	1.875
A2334	A2	N1207.54	E1335.78	1310.75	B	I	D	90	50.1	1.875
A2335	A2	N1237.50	E1335.77	1329.31	B	I	U	90	50.3	3.0
A2336	A2	N1237.50	E1335.77	1311.11	B	I	D	90	50.37	3.0
A2337	A2	N1269.06	E1335.73	1330.39	B	I	U	90	50.3	1.875
A2338	A2	N1269.51	E1335.80	1311.85	B	I	D	90	50.3	1.875
A2339	A2	N1297.47	E1335.73	1329.44	B	I	U	90	50.2	1.875
A2340	A2	N1297.53	E1335.73	1311.02	B	I	D	90	49.4	1.875
A2341	A2	N1327.61	E1335.81	1329.61	B	I	U	90	50.2	1.875
A2342	A2	N1327.56	E1335.82	1311.84	B	I	D	90	50.4	1.875
A2343	A2	N1357.49	E1335.75	1328.73	B	I	U	90	50.4	1.875
A2344	A2	N1357.42	E1335.85	1311.10	B	I	D	90	47.1	1.875
A2345	A2	N1207.50	E1344.69	1319.92	B	I	E	0	30.4	1.875
A2346	A2	N1207.50	E1326.80	1319.85	B	I	W	0	29.8	1.875
A2347	A2	N1269.52	E1344.63	1320.63	B	I	E	0	30.1	1.875
A2348	A2	N1269.52	E1326.89	1320.64	B	I	W	0	30.1	1.875
A2349	A2	N1327.61	E1344.62	1320.58	B	I	E	0	30.1	1.875
A2350	A2	N1327.58	E1335.86	1320.67	B	I	W	0	29.8	1.875
A2351	A2	N1204.50	E1344.73	1319.43	B	I	E	0	55.8	1.875
A2352	A2	N1204.48	E1326.91	1326.91	B	I	W	0	56.3	1.875
A2353	A2	N1267.53	E1344.55	1320.64	B	I	E	0	56.1	1.875
A2354	A2	N1267.45	E1326.85	1320.69	B	I	W	0	56.0	1.875

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Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
A2355	A2	N1329.49	E1344.64	1320.62	B	I	E	0	56.5	1.875
A2356	A2	N1329.48	E1326.88	1320.65	B	I	W	0	56.5	1.875
A2357	A2	N1237.52	E1344.62	1320.30	B	I	E	0	30.1	3.0
A2358	B	N1237.56	E1326.82	1320.24	B	I	W	0	30.3	3.0
A2393	A2	N1267.59	E1344.57	1314.65	B	I	E	0	68.4	1.875
A2394	A2	N1267.53	E1326.75	1314.64	B	I	W	0	68.6	1.875
A2531	A2	N1265.96	E1335.77	1329.38	B	I	U	90	50.3	1.875
A2532	A2	N1263.06	E1335.76	1329.39	B	I	U	90	16.2	1.875
A2533	A2	N1264.43	E1335.76	1329.38	B	I	U	90	4.8	1.875
A2534	A2	N1266.10	E1335.76	1311.91	B	I	D	90	50.3	1.875
A2535	A2	N1263.07	E1335.74	1311.93	B	I	D	90	16.4	1.875
A2536	A2	N1264.54	E1335.77	1311.80	B	I	D	90	4.10	1.875
A2537	A2	N1326.06	E1335.79	1329.55	B	I	U	90	50.0	1.890
A2538	A2	N1323.08	E1335.80	1329.54	B	I	U	90	16.3	1.890
A2539	A2	N1324.59	E1335.79	1329.58	B	I	U	90	4.10	1.890
A2540	A2	N1326.04	E1335.78	1311.68	B	I	D	90	48.5	1.875
A2541	A2	N1323.05	E1335.79	1311.94	B	I	D	90	16.5	1.875
A2542	A2	N1324.55	E1335.79	1311.84	B	I	D	90	4.3	1.875
A2543	A2	N1209.09	E1344.67	1319.80	B	I	E	0	32.6	1.50
A2546	A2	N1209.01	E1326.81	1319.88	B	I	W	0	33.0	1.50
A2549	A2	N1266.00	E1344.56	1320.61	B	I	E	0	29.8	1.875
A2550	A2	N1262.97	E1344.63	1320.68	B	I	E	0	16.6	1.875
A2551	A2	N1264.63	E1344.64	1319.62	B	I	E	0	4.9	1.875
A2552	A2	N1265.98	E1326.78	1320.67	B	I	W	0	29.9	1.875
A2553	A2	N1262.99	E1326.85	1320.63	B	I	W	0	16.4	1.875
A2554	A2	N1264.50	E1326.88	1320.62	B	I	W	0	4.7	1.875
A2555	A2	N1326.06	E1344.52	1320.66	B	I	E	0	29.0	1.875
A2556	A2	N1323.07	E1344.58	1320.71	B	I	E	0	16.5	1.875
A2557	A2	N1324.52	E1344.61	1320.67	B	I	E	0	5.2	1.875
A2558	A2	N1326.04	E1326.90	1320.63	B	I	W	0	30.0	1.875
A2559	A2	N1323.06	E1326.86	1320.61	B	I	W	0	16.0	1.875
A2560	A2	N1324.57	E1326.86	1320.67	B	I	W	0	4.9	1.875
A2803	A2	N1218.75	E1335.80	1329.14	B	I	U	90	50.5	1.875
A2804	A2	N1218.71	E1335.72	1311.32	B	I	D	90	50.4	1.875
A2805	A2	N1251.50	E1335.83	1329.23	B	I	U	90	50.3	1.875
A2806	A2	N1251.59	E1335.76	1311.60	B	I	D	90	50.3	1.875
A2807	A2	N1267.52	E1335.79	1329.28	B	I	U	90	50.4	1.875
A2808	A2	N1267.61	E1335.80	1311.85	B	I	D	90	50.25	1.875
A2809	A2	N1283.43	E1335.79	1329.31	B	I	U	90	50.2	1.875
A2810	A2	N1282.97	E3894.28	1312.32	B	I				
A2810	A2	N1283.53	E1335.79	1311.86	B	I	D	90	50.5	1.875
A2811	A2	N1316.42	E1335.79	1324.60	B	I	U	90	50.2	1.875
A2812	A2	N1316.41	E1335.77	1311.71	B	I	D	90	50.35	1.875
A2813	A2	N1349.43	E1335.81	1328.86	B	I	U	90	50.3	1.875
A2814	A2	N1349.49	E1335.79	1311.20	B	I	D	90	50.8	1.875
A2817	A2	N1218.72	E1344.53	1320.22	B	I	E	0	30.0	1.875
A2818	A2	N1218.74	E1326.93	1320.19	B	I	W	0	29.9	1.875
A2819	A2	N1251.51	E1344.64	1320.47	B	I	E	0	29.85	1.875
A2820	A2	N1251.50	E1326.84	1320.49	B	I	W	0	29.9	1.875
A2821	A2	N1267.47	E1344.60	1328.10	B	I	E	0	29.7	1.875
A2822	A2	N1267.55	E1344.39	1313.13	B	I	E	0	30.02	1.875
A2823	A2	N1267.49	E1326.87	1328.14	B	I	W	0	29.8	1.875
A2824	A2	N1267.53	E1326.90	1313.12	B	I	W	0	30.0	1.875
A2825	A2	N1283.58	E1344.66	1320.52	B	I	E	0	29.9	1.875
A2826	A2	N1287.47	E1326.87	1320.59	B	I	W	0	30.0	1.875
A2827	A2	N1316.29	E1344.57	1320.55	B	I	E	0	29.87	1.875
A2828	A2	N1316.39	E1326.79	1320.58	B	I	W	0	29.8	1.875
A2829	A2	N1349.51	E1344.48	1320.03	B	I	E	0	30.1	1.875
A2830	A2	N1289.29	E1338.89	1321.09	B	I				
A2830	A2	N1349.50	E1326.94	1319.95	B	I	W	0	29.7	1.875
A2831	A2	N1251.50	E1344.35	1329.08	B	I	U,E		50.3	1.875
A2832	A2	N1251.63	E1344.27	1312.15	B	I	D,E		50.1	1.875
A2833	A2	N1251.50	E1327.41	1329.02	B	I	U,W		50.25	1.875
A2834	A2	N1251.58	E1327.19	1311.94	B	I	D,W		50.25	1.875

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Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
A2835	A2	N1283.52	E1344.41	1329.13	B	I	U,E		50.02	1.875
A2836	A2	N1283.73	E1344.12	1312.30	B	I	D,E		49.8	1.875
A2837	A2	N1283.57	E1327.32	1329.07	B	I	U,W		50.25	1.875
A2838	A2	N1283.55	E1327.28	1312.06	B	I	D,W		50.1	1.875
A2839	A2	N1251.58	E1339.45	1311.61	B	I	D,E		49.08	1.875
A2840	A2	N1267.99	E1339.47	1314.51	B	I	D,E		49.0	1.875
A2841	A2	N1282.93	E3902.96	1311.32	B	I				
A2841	A2	N1283.55	E1339.40	1312.00	B	I	D,E		50.3	1.875
A2851	A2	N1278.26	E1333.15	1312.17	B	I				
A2852	A2	N1278.32	E1336.77	1312.01	B	I				
A2854	A2	N1278.33	E1340.80	1312.10	B	I				
A2855	A2	N1278.38	E1342.46	1311.96	B	I				
A2857	A2	N1280.29	E1336.77	1312.24	B	I				
A2858	A2	N1280.34	E1331.20	1312.04	B	I				
A2859	A2	N1280.27	E1338.83	1312.19	B	I				
A2860	A2	N1288.96	E1334.84	1317.05	B	I				
A2861	A2	N1282.10	E1334.97	1312.16	B	I				
A2862	A2	N1282.05	E3903.21	1312.15	B	I				
A2863	A2	N1283.85	E1331.21	1312.05	B	I				
A2864	A2	N1283.84	E1338.81	1312.22	B	I				
A2865	A2	N1283.86	E1333.19	1312.02	B	I				
A2866	A2	N1283.71	E1336.82	1312.10	B	I				
A2868	A2	N1285.77	E1333.17	1312.10	B	I				
A2869	A2	N1285.87	E1334.94	1312.09	B	I				
A2870	A2	N1285.85	E1336.84	1312.21	B	I				
A2873	A2	N1285.74	E1340.83	1312.21	B	I				
A2874	A2	N1285.75	E1342.48	1312.26	B	I				
A2877	A2	N1287.88	E1331.20	1313.48	B	I				
A2878	A2	N1287.76	E1338.85	1321.05	B	I				
A2879	A2	N1289.62	E1331.26	1313.47	B	I				
A2F41	A2	N1274.65	E1334.77	1311.85	B	C,I	D	90	1.5	6
A2F45	A2	N1278.40	E1334.95	1311.93	B	C,I	D	90	1.5	6
A2F91	A2	N1274.43	E1338.76	1311.83	B	C,I	D	90	1.5	6
A2F95	A2	N1281.89	E1329.68	1311.88	B	C,I	D	90	1.5	6
A2US1	A2	N1300.02	E1343.81	1314.54	B	US				
A2X01	A2	N1393.72	E1338.88	1311.20	B	C	D	90	50.15	4
A2X02	A2	N1393.65	E1338.89	1328.86	B	C	U	90	52.75	4
A2X50	A2	N1177.41	E1335.76	1329.04	B	I	U	90	50.6	1.875
A2X51	A2	N1177.37	E1335.67	1310.31	B	I	D	90	50.2	1.875
A3082	A3	N1176.74	E1411.97	1309.65	B	HTR	D	90	20.4	16
A3083	A3	N1188.14	E1411.97	1309.77	B	HTR	D	90	20.0	16
A3084	A3	N1199.33	E1411.96	1309.54	B	HTR	D	90	21.6	16
A3085	A3	N1210.61	E1412.03	1309.31	B	HTR	D	90	20.8	16
A3085D		N1421	E1426	131.5	A	Ae	S	0	127.1	3.88
A3086	A3	N1221.79	E1411.95	1309.32	B	HTR	D	90	20.8	16
A3086D		N1421	E1431	1317.5	A	Ae	S	0	127.2	3.88
A3087	A3	N1233.07	E1411.96	1309.46	B	HTR	D	90	20.8	16
A3087D	A3	N1421	E1436	1317.5	A	Ae	S	0	127.2	3.88
A3088	A3	N1244.36	E1411.92	1309.59	B	HTR	D	90	21.0	16
A3089	A3	N1255.71	E1411.94	1309.49	B	HTR	D	90	20.6	16
A3090	A3	N1266.91	E1411.90	1309.74	B	HTR	D	90	20.0	16
A3091	A3	N1278.36	E1411.91	1309.99	B	HTR	D	90	20.3	16
A3092	A3	N1289.72	E1411.99	1309.77	B	HTR	D	90	20.1	16
A3093	A3	N1300.86	E1412.00	1310.01	B	HTR	D	90	20.2	16
A3094	A3	N1312.15	E1411.90	1309.73	B	HTR	D	90	20.2	16
A3095	A3	N1323.40	E1411.96	1309.70	B	HTR	D	90	20.5	16
A3095D	A3	N1421	E1412	1322	D,A	I	S	0	115.2	1.88
A3096	A3	N 334.55	E1411.91	1309.64	B	HTR	D	90	20.3	16
A3097	A3	N1345.77	E1411.97	1309.54	B	HTR	D	90	20.7	16
A3098	A3	N1357.10	E1411.97	1309.16	B	HTR	D	90	20.6	16
A3363	A3	N1207.41	E1412.76	1327.19	B	I	U	90	50.0	1.875
A3364	A3	N1307.45	E1412.71	1309.64	B	I	D	90	50.2	1.875
A3365	A3	N1237.51	E1412.66	1327.21	B	I	U	90	50.1	3
A3366	A3	N1237.47	E1412.81	1309.65	B	I	D	90	50.0	3

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A3367	A3	N1267.48	E1412.75	1327.55	B	I	U	90	60.2	1.875
A3368	A3	N1267.41	E1412.76	1310.03	B	I	D	90	50.0	1.875
A3369	A3	N1397.44	E1412.75	1327.78	B	I	U	90	50.4	1.875
A3370	A3	N1397.46	E1412.78	1310.19	B	I	D	90	49.3	1.875
A3371	A3	N1327.43	E1412.70	1327.47	B	I	U	90	50.6	1.875
A3372	A3	N1327.41	E1412.78	1309.77	B	I	D	90	51.5	1.875
A3373	A3	N1363.38	E1412.74	1327.01	B	I	U	90	50.9	1.875
A3374	A3	N1363.38	E1412.77	1309.36	B	I	D	90	50.2	1.875
A3375	A3	N1207.45	E1421.66	1318.49	B	I	E	0	50.2	1.875
A3376	A3	N1207.43	E1403.86	1318.43	B	I	W	0	29.8	1.875
A3377	A3	N1269.54	E1421.61	1318.82	B	I	E	0	50.2	1.875
A3378	A3	N1269.50	E1403.90	1318.94	B	I	W	0	30.0	1.875
A3379	A3	N1327.54	E1421.20	1318.97	B	I	E	0	51.3	1.875
A3380	A3	N1327.49	E1403.87	1318.93	B	I	W	0	30.8	1.875
A3381	A3	N1269.48	E1421.52	1312.77	B	I	E	0	50.1	1.875
A3382	A3	N1267.52	E1403.96	1324.81	B	I	W	0	58.8	1.875
A3383	A3	N1237.5	E1403.81	1318.48	B	I	W	0	29.9	3
A3384	A3	N1237.44	E1421.50	1318.54	B	I	E	0	50.2	3
A3579	A3	N1265.97	E1421.63	1318.68	B	I	E	0	50.3	1.5 s
A3580	A3	N1262.98	E1421.59	1318.70	B	I	E	0	19.6	1.5 s
A3581	A3	N1264.51	E1421.57	1318.66	B	I	E	0	7.8	1.5 s
A3583	A3	N1262.98	E1403.85	1318.63	B	I	W	0	19.5	1.5 s
A3584	A3	N1264.51	E1403.85	1318.70	B	I	W	0	7.8	1.5 s
A3903	A3	N1218.63	E1412.70	1327.07	B	I	U	90	50.4	1.875
A3904	A3	N1218.67	E1412.74	1309.59	B	I	D	90	50.0	1.875
A3905	A3	N1251.52	E1412.74	1327.23	B	I	U	90	50.2	1.875
A3906	A3	N1251.46	E1412.77	1309.72	B	I	D	90	50.4	1.875
A3907	A3	N1267.50	E1412.72	1327.59	B	I	U	90	50.3	1.875
A3909	A3	N1283.47	E1412.71	1327.76	B	I	U	90	50.4	1.875
A3910	A3	N1283.49	E1412.74	1310.23	B	I	D	90	50.1	1.875
A3911	A3	N1316.24	E1412.77	1327.55	B	I	U	90	50.5	1.875
A3912	A3	N1316.24	E1412.77	1309.97	B	I	D	90	50.4	1.875
A3913	A3	N1349.50	E1412.92	1326.92	B	I	U	90	50.4	1.875
A3914	A3	N1349.40	E1412.71	1309.51	B	I	D	90	50.8	1.875
A3917	A3	N1218.67	E1421.61	1318.37	B	I	E	0	50.2	1.875
A3918	A3	N1218.62	E1403.82	1318.37	B	I	W	0	30.1	1.875
A3919	A3	N1251.52	E1403.91	1318.55	B	I	E	0	50.4	1.875
A3920	A3	N1251.54	E1403.96	1318.54	B	I	W	0	16.4	1.875
A3921	A3	N1268.46	E1421.40	1326.34	B	I	E	0	50.5	1.875
A3922	A3	N1267.42	E1421.50	1311.36	B	I	E	0	50.4	1.875
A3923	A3	N1267.50	E1404.01	1326.36	B	I	W	0	29.0	1.875
A3924	A3	N1267.53	E1403.90	1311.34	B	I	W	0	29.9	1.875
A3925	A3	N1283.48	E1421.60	1318.95	B	I	E	0	51.5	1.875
A3926	A3	N1283.48	E1403.97	1319.01	B	I	W	0	16.3	1.875
A3927	A3	N1316.24	E1421.60	1318.90	B	I	E	0	50.0	1.875
A3928	A3	N1316.30	E1403.88	1318.88	B	I	W	0	30.2	1.875
A3929	A3	N1349.41	E1421.59	1318.34	B	I	E	0	50.0	1.875
A3930	A3	N1349.51	E1404.02	1318.31	B	I	W	0	29.1	1.875
A3931	A3	N1253.50	E1420.87	1326.89	B	I	D,E	45	50.0	1.875
A3931A	A3				D					
A3931A	A3				D					
A3932	A3	N1251.52	E1421.18	1310.16	B	I	D,E	45	50.9	1.875
A3933	A3	N1253.55	E1404.28	1326.98	B	I	U,W	45	38.1	1.875
A3934	A3	N1251.43	E1404.28	1310.07	B	I	D,W	45	37.4	1.875
A3935	A3	N1283.49	E1421.12	1327.36	B	I	U,E	45	50.3	1.875
A3936	A3	N1287.51	E1421.18	1310.44	B	I	D,E	45	50.3	1.875
A3937	A3	N1283.54	E1404.28	1327.38	B	I	U,W	45	38.3	1.875
A3938	A3	N1283.53	E1404.27	1310.50	B	I	D,E	45	37.8	1.875
A3939	A3	N1251.42	E1409.12	1309.66	B	I	D,W	62.5	50.2	1.875
A3940	A3	N1267.39	E1409.10	1309.91	B	I	D,W	62.5	50.7	1.875
A3941	A3	N1282.96	E1408.36	1310.13	B	I	D,W	62.5	50.5	1.875
A3951	A3	N1272.57	E1411.98	1310.10	B	I	D	90	22.92	1.875
A3952	A3	N1275.80	E1411.98	1310.28	B	I	D	90	23.04	1.875
A3953	A3	N1277.14	E1411.87	1310.23	B	I	D	90	22.77	1.875

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Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
A3954	A3	N1278.26	E1406.56	1310.31	B	I	D	90	22.20	1.875
A3955	A3	N1278.18	E1409.53	1310.23	B	I	D	90	22.20	1.875
A3956	A3	N1278.21	E1410.76	1310.21	B	I	D	90	21.23	1.875
A3957	A3	N1277.93	E1413.14	1310.23	B	I	D	90	22.93	1.875
A3958	A3	N1278.29	E1414.39	1310.20	B	I	D	90	23.08	1.875
A3959	A3	N1278.25	E1417.64	1310.24	B	I	D	90	22.00	1.875
A3960	A3	N1279.52	E1411.99	1310.14	B	I	D	90	23.07	1.875
A3961	A3	N1280.78	E1411.87	1310.11	B	I	D	90	23.05	1.875
A3962	A3	N1283.82	E1411.83	1310.07	B	I	D	90	22.20	1.875
A3963	A3	N1287.09	E1412.05	1310.20	B	I	D	90	22.34	1.875
A3964	A3	N1288.01	E1411.88	1310.07	B	I	D	90	22.54	1.875
A3965	A3	N1289.43	E1406.41	1310.11	B	I	D	90	22.44	1.875
A3966	A3	N1289.49	E1409.48	1310.11	B	I	D	90	22.60	1.875
A3967	A3	N1289.52	E1410.65	1310.15	B	I	D	90	22.54	1.875
A3968	A3	N1289.59	E1413.24	1310.12	B	I	D	90	22.65	1.875
A3969	A3	N1289.59	E1414.40	1310.15	B	I	D	90	22.65	1.875
A3970	A3	N1289.55	E1417.59	1310.20	B	I	D	90	22.73	1.875
A3971	A3	N1290.86	E1411.99	1310.20	B	I	D	90	22.58	1.875
A3972	A3	N1292.24	E1411.94	1310.08	B	I	D	90	22.50	1.875
A3973	A3	N1295.39	E1411.99	1310.13	B	I	D	90	22.48	1.875
A3974	A3	N1283.85	E1406.35	1310.32	B	I	D	90	22.94	1.875
A3975	A3	N1283.91	E1417.59	1310.11	B	I	D	90	22.59	1.875
A3981A	A3				D					
A3US1	A3	N1300.31	E1420.92	1312.22	B	US				
A3US2	A3	N1298.03	E1420.96	1313.92	B	US				
A3US3	A3	N1296.06	E1420.99	1313.85	B	US				
A3X01	A3	N1125	E1408	1309	A	C	D	90	50.5	4
A3X02	A3	N1125	E1408	1327	A	C	U	90	50.75	4
A3X57	A3	N1351.49	E1421.06	1329.04	B	I	U,E	45	50.3	1.875
A3X58	A3	N1251.49	E1404.19	1327.07	B	I	U,W	45	37.3	1.875
A3X59	A3	N1267.48	E1421.61	1312.84	B	I	E	0	50.3	1.875
B		S1246	E0140	1266	A	Ae	E	0	15.1	3
B	L2	N1515	W0365	1312.5	A	WO	D	90	13.0	1
B001	B	N1259.21	E0969.63	1334.72	B	I	W	0	50.4	4.0
B002	B	N1259.27	E0969.88	1318.72	B	I	W	0	50.3	4.0
B003	B	N1258.79	E0989.88	1334.66	B	I	E	0	50.25	4.0
B004	B	N1259.26	E0987.84	1318.71	B	I	E	0	50.2	4.0
B005	B	N1259.23	E0970.00	1335.41	B	I	U,W	45	50.35	4.0
B006	B	N1259.24	E0970.09	1318.06	B	I	D,W	45	50.15	4.0
B007	B	N1259.26	E0987.40	1335.31	B	I	U,E	45	50.5	4.0
B008	B	N1259.21	E0987.45	1318.01	B	I	D,E	45	50.4	4.0
B009	B	N1276.53	E0969.77	1334.57	B	I	W	0?	50.1	4.0
B010	B	N1276.53	E0969.92	1318.59	B	I	W	0?	50.4	4.0
B011	B	N1276.63	E0987.62	1334.62	B	I	E	0?	50.6	4.0
B012	B	N1276.55	E0988.06	1318.62	B	I	E	0?	50.2	4.0
B013	B	N1276.49	E0970.08	1335.29	B	I	U,W	45	50.1	4.0
B014	B	N1276.52	E0970.22	1318.10	B	I	D,W	45	50.2	4.0
B015	B	N1276.53	E0987.53	1335.43	B	I	U,E	45	50.4	4.0
B016	B	N1276.61	E0987.53	1317.84	B	I	D,E	45	54.97	4.0
B020	B	N1232.57	E0977.97	1317.93	B	HTR	D	90	18.0	16
B021	B	N1242.79	E0978.01	1317.66	B	HTR	D	90	18.5	16
B022	B	N1252.38	E0977.94	1317.78	B	HTR	D	90	18.4	16
B023	B	N1262.45	E0977.94	1317.73	B	HTR	D	90	18.4	16
B024	B	N1272.30	E0978.01	1317.73	B	HTR	D	90	18.0	16
B025	B	N1282.28	E0977.96	1317.84	B	HTR	D	90	17.9	16
B026	B	N1292.31	E0977.99	1317.90	B	HTR	D	90	18.2	16
B027	B	N1302.18	E0977.94	1317.93	B	HTR	D	90	18.1	16
B030	B	N1227.20	E0977.93	1318.00	B	HTR	D	90		16
B031	B	N1237.38	E0978.01	1317.86	B	HTR	D	90	18.3	16
B032	B	N1247.56	E0978.00	1317.77	B	HTR	D	90		
B033	B	N1257.43	E0978.02	1317.70	B	HTR	D	90		16
B034	B	N1267.43	E0977.99	1317.79	B	HTR	D	90	18.5	16
B035	B	N1277.29	E0977.94	1317.83	B	HTR	D	90	18.0	16
B036	B	N1287.37	E0977.98	1317.73	B	HTR	D	90	18.0	16

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Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
B037	B	N1297.27	E0977.94	1318.00	B	HTR	D	90	18.3	16
B038	B	N1307.09	E0978.07	1317.89	B	I	D	90	18.3	16
B041	B	N1220.36	E0974.20	1317.86	B	I	D	90	18.7	16
B042	B	N1314.33	E0974.18	1317.78	B	I	D	90	18.4	36
B043	B	N1220.91	E0981.69	1317.93	B	I	D	90	18.5	36
B044	B	N1314.21	E0981.83	1317.96	B	I	D	90	17.4	36
B045	B	N1212.44	E0974.16	1317.58	B	I	D	90	17.7	36
B046	B	N1322.32	E0974.24	1317.84	B	I	D	90	18.3	36
B047	B	N1212.69	E0981.67	1317.80	B	I	D	90	18.3	36
B048	B	N1322.56	E0981.75	1317.93	B	I	D	90	17.2	36
B049	B	N1200.03	E0981.50	1317.83	B	I	D	90	17.5	36
B050	B	N1335.03	E0974.19	1317.60	B	I	D	90	18.0	36
B051	B	N1199.43	E0981.77	1317.92	B	I	D	90	17.8	36
B052	B	N1335.08	E0981.86	1317.76	B	I	D	90	19.1	36
B061	B	N1204.17	E0974.24	1317.63	B	I	D	90	18.2	30
B062	B	N1330.51	E0974.18	1317.80	B	I	D	90	18.8	30
B063	B	N1204.25	E0981.25	1317.88	B	HTR	D	90	18.4	30
B064	B	N1330.26	E0981.82	1317.87	B	HTR	D	90	18.9	30
B090D	B	N1430.92	E0970.33	1318.44		I	D	90	100?	6
B090U		N1431.59	E0970.48	1330.63	B	I	U	90	100?	6
B099	B	N1419.47	E0896.01	1325.46	B	I	N	0	306	1.5
B301	B	N1202.23	E0978.79	1335.83	B	I	U	90	50.13	1.875
B302	B	N1202.19	E0978.74	1318.10	B	I	D	90	49.29	1.875
B303	B	N1250.42	E0978.77	1335.64	B	I	U	90	50.21	1.875
B304	B	N1250.45	E0978.76	1318.02	B	I	D	90	47.85	1.875
B305	B	N1275.38	E0978.78	1335.91	B	I	U	90	50.38	1.875
B305A	B				D	I				
B306	B	N1275.25	E0978.77	1317.61	B	I	D	90	50.35	1.875
B306A	B				D	I				
B307	B	N1285.34	E0978.70	1335.65	B	I	U	90	50.1	1.875
B308	B	N1285.32	E0978.70	1317.99	B	I	D	90	50.4	1.875
B309	B	N1310.27	E0978.69	1335.66	B	I	U	90	50.4	1.875
B310	B	N1310.4	E0970	1300	P	I	D	90	48.9	1.875
B310A	B	N1311.31	E0978.71	1318.09	B	I	D	90	50.0	1.875
B311	B	N1353.27	E0978.78	1335.35	B	I	U	90	50.06	1.875
B312	B	N1353.26	E0978.78	1317.84	B	I	D	90	49.71	1.875
B313	B	N1202.22	E0987.61	1326.95	B	I	E	0	50.0	1.875
B314	B	N1202.26	E0969.99	1326.97	B	I	W	0	49.7	1.875
B315	B	N1250.37	E0987.60	1326.67	B	I	E	0	50.2	1.875
B316	B	N1250.47	E0969.83	1326.66	B	I	W	0	50.4	1.875
B317	B	N1270.42	E0987.73	1326.79	B	I	E	0	50.4	1.875
B318	B	N1270.40	E0969.87	1327.15	B	I	W	0	50.33	1.875
B319	B	N1285.35	E0987.63	1326.76	B	I	E	0	50.2	1.875
B320	B	N1285.38	E0969.99	1326.72	B	I	W	0	50.2	1.875
B321	B	N1310.38	E0987.75	1326.73	B	I	E	0	50.1	1.875
B322	B	N1310.42	E0970.04	1326.68	B	I	W	0	50.2	1.875
B323	B	N1353.23	E0987.67	1326.59	B	I	E	0	49.1	1.875
B324	B	N1353.46	E0970.08	1326.52	B	I	W	0	49.0	1.875
B327	B	N1270.36	E0987.89	1331.38	B	I	E	0	50.0	1.875
B327B	B				D	I				
B328	B	N1270.38	E0989.81	1322.68	B	I	W	0	50.75	1.875
B329	B	N1272.41	E0987.52	1335.36	B	I	U,E	45	51.15	1.875
B329A	B				D					
B330	B	N1270.42	E0970.32	1335.22	B	I	U,W	45	50.0	1.875
B331	B	N1270.41	E0987.22	1318.35	B	I	D,E	45	49.0	1.875
B332	B	N1270.41	E0970.30	1318.30	B	I	D,W	45	50.4	1.875
B333	B	N1259.97	E0978.76	?	B	I	U	90	50.5	3.0
B334	B	N1259.97	E0978.76	1317.88	B	I	D	90	50.1	3.0
B335	B	N1260.02	E0987.81	1326.64	B	I	E	0	50.1	1.875
B336	B	N1259.90	E0969.75	1326.65	B	I	W	0	49.6	1.875
B507	B	N1265.39	E0977.29	1335.58	B	I	U	0	52.8	1.50
B508	B	N1265.45	E0980.26	1335.59	B	I	U	0	27.85	1.50
B509	B	N1265.46	E0978.78	1335.59	B	I	U	0	15.7	1.50
B510	B	N1265.56	E0977.20	1317.95	B	I	D	0	66.6	1.50

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B511	B	N1265.46	E0980.26	1318.03	B	I	D	0	27.8	1.50
B512	B	N1265.48	E0978.76	1316.80	B	I	D	0	15.9	1.50
B525	B	N1265.53	E0987.72	1328.65	B	I	D,E	45	53.21	1.50
B526	B	N1265.48	E0987.70	1325.70	B	I	D,E	45	28.2	1.50
B527	B	N1265.47	E0987.74	1327.19	B	I	D,E	45	15.1	1.50
B528	B	N1265.45	E0969.80	1325.68	B	I	D,W	45	53.4	1.50
B529	B	N1265.41	E0969.81	1328.70	B	I	D,W	45	28.1	1.50
B530	B	N1265.44	E0969.84	1327.17	B	I	D,W	45	15.2	1.5
B540	B	N1419.95	E0948.66	1326.42	B	I	S	0	52.4	1.875
B541	B	N1420.06	E0935.67	1326.38	B	I	S	0	53.0	1.875
B542	B	N1420.00	E0896.77	1325.46	B	I	S	0	156.0	1.5
B543	B	N1100	E0896	1325	A	I	N	0	306	1.5
B703	B	N1203.75	E0978.80	1335.68	B	I	U	90	50.11	1.875
B704	B	N1203.69	E0978.81	1318.01	B	I	D	90	50.0	1.875
B705	B	N1267.90	E0978.74	1335.58	B	I	U	90	50.1	1.875
B706	B	N1267.90	E0982.42	1318.07	B	I	D,E		50.6	1.875
B707	B	N1340.30	E0978.59	1335.51	B	I	U	90	50.45	1.875
B708	B	N1339.30	E0978.62	1317.87	B	I	D	90	50.38	1.875
B708A	B				D					
B709	B	N1366.38	E0978.93	1335.31	B	I	U	90	50.16	1.875
B710	B	N1366.47	E0978.88	1317.76	B	I	D	90	50.03	1.875
B713	B	N1203.75	E0987.67	1326.93	B	I			50.2	1.875
B714	B	N1203.71	E0969.98	1326.94	B	I	W	0	50.3	1.875
B715	B	N1250.91	E0987.63	1326.65	B	I	E	0	50.2	1.875
B716	B	N1251.91	E0969.89	1326.08	B	I	W	0	50.2	1.875
B717	B	N1367.94	E0987.48	1334.29	B	I	E	0	50.62	1.875
B718	B	N1267	E0987	1319	A	I	E	0	50	1.875
B718A	B	N1266.94	E0987.35	1319.30	B	I	E	0	50.4	1.875
B719	B	N1267.93	E0969.93	1334.22	B	I	W	0	50.25	1.875
B720	B	N1267.87	E0970.19	1319.22	B	I	W	0	50.15	1.875
B721	B	N1311.87	E0987.76	1326.65	B	I	E	0?	50.2	1,875
B722	B	N1311.89	E0969.99	1326.68	B	I	W	0?	50.6	1.875
B723	B	N1340.14	E0987.78	1326.64	B	I	E	0?	50.0	1.875
B724	B	N1340.37	E0969.67	1326.66	B	I	W	0?	50.3	1.875
B725	B	N1366.33	E0987.85	1326.37	B	I	E	0	50.19	1.875
B726	B	N1366.56	E0970.08	1326.42	B	I	W	0	50.1	1.875
B727	B	N1203.70	E0987.21	1335.32	B	I	U,E	45	50.0	1.875
B728	B	N1203.72	E0987.46	1318.29	B	I	D,E	45	50.08	1.875
B729	B	N1203.74	E0970.31	1335.40	B	I	U,W	45	50.43	1.875
B730	B	N1203.70	E0970.59	1318.66	B	I	D,W	45	50.00	1.875
B731	B	N1251.94	E0987.20	1335.12	B	I	U,E	45	50.04	1.875
B732	B	N1251.97	E0987.24	1318.10	B	I	D,E		50.0	1.875
B733	B	N1251.91	E0970.13	1335.20	B	I	U,W		50.35	1.875
B734	B	N1251.93	E0970.37	1318.28	B	I	D,W		50.5	1.875
B735	B	N1283.9	E0979.85	1317.75	P	I	E,U	45	50	1.875
B735A	B				D	I				
B735B	B				D					
B736	B	N1283.85	E0987.39	1318.07	B	I	D,E		50.04	1.875
B739	B	N1339	E0987	1335	A	I	U,E	45	50	1.875
B739A	B				D					
B740	B	N1342	E0989	1318	A	I	D,E	45	50	1.875
B740A	B	N1341.74	E0988.92	1318.03	B	I	D,E		50.0	1.875
B741	B	N1340.31	E0970.06	1335.17	B	I	U,W		50.0	1.875
B742	B	N1340.33	E0970.40	1318.32	B	I	D,W		50.25	1.875
B743	B	N1251.98	E0978.78	1335.67	B	I	U	90	49.92	1.875
B744	B	N1251.66	E0978.73	1317.92	B	I	D,E		50.0	1.875
B745	B	N1283.92	E0978.73	1335.63	B	I	U	90	50.1	1.875
B746	B	N1284.11	E0978.74	1317.93	B	I	D	90	50.0	1.875
B747	B	N1311.90	E0978.70	1335.67	B	I	U	90	50.5	1.875
B748	B	N1311.85	E0978.75	1317.96	B	I	D	90	50.00	1.875
B749	B	N1251.92	E0982.50	1318.13	B	I	D	90	50.00	1.875
B750	B	N1283.84	E0982.33	1317.98	B	I	D,E		50.1	1.875
B801	B	N1234.90	E0978.02	1318.27	B	I	D	90	21.5	1.8
B802	B	N1236.23	E0978.03	1318.19	B	I	D	90	21.5	1.8

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1439 Records of Holes Drilled Before July 1985
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Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
B803	B	N1236.18	E0978.01	1318.37	B	I	D	90	21.5	1.875
B804	B	N1237.39	E0975.58	1318.22	B	I	D	90	21.5	1.8
B805	B	N1237.38	E0976.74	1318.18	B	I	D	90	21.5	1.9
B806	B	N1237.4	E0977.5	1317.8	A	I	D	90		1.875
B807	B	N1237.4	E0978.5	1317.8	A	I	D	90		1.875
B808	B	N1237.39	E0979.39	1318.19	B	I	D	90	21.5	1.9
B809	B	N1237.42	E0980.50	1318.20	B	I	D	90	21.5	1.9
B810	B	N1238	E0978	1317.8	A	I	D	90		1.875
B811	B	N1238.75	E0977.99	1318.34	B	I	D	90	21.5	1.9
B812	B	N1241.3	E0978	1317.7	A	I	D	90	21.5	1.9
B813	B	N1238.75	E0977.95	1318.18	B	I	D	90		
B814	B	N1242.42	E0975.50	1318.18	B	I	D	90	21.5	1.9
B815	B	N1242.47	E0976.67	1318.23	B	I	D	90	21.5	1.9
B817	B	N1242.8	E0979	1317.7	A	I	D	90		1.875
B818	B	N1242.43	E0979.37	1318.19	B	I	D	90	18.9	1.875
B819	B	N1242.46	E0980.52	1318.17	B	I	D	90	19.6	1.875
B820	B	N1243	E0978	1317.7	A	I	D	90	21.0	1.9
B821	B	N1243.65	E0977.96	1318.25	B	I	D	90	19.6	1.875
B822	B	N1244.99	E0977.97	N1318.21	B	I	D	90	19.6	1.875
B823	B	N1240.01	E0978.02	1318.25	B	I	D	90	19.6	1.875
B824	B	N1234.86	E0980.55	1318.30	B	I	D	90	18.8	1.875
B825	B	N1235.05	E0975.53	1318.11	B	I	D	90	19.6	1.875
B826	B	N1239.90	E0980.48	1318.24	B	I	D	90	19.9	1.875
B827	B	N1239.91	E0975.56	1318.24	B	I	D	90	19.7	1.875
B828	B	N1244.99	E0980.43	1318.15	B	I	D	90	19.5	1.875
B829	B	N1244.81	E0975.48	1318.16	B	I	DO	90	19.8	1.875
B842	B	N1314	E0974	1298	A	I	D	90		
B846	B	N1322	E0974	1298	A	I	D	90		
B850	B	N1335	E0974	1298	A	I	D	90		
BF41	B	N1289.87	E0977.54	1318.46	B	C,I	D	90	1.5	6
BF91	B	N1295.00	E0977.61	1318.26	B	C,I	D	90	6	1.5
BX01	B	N1384.66	E0982.33	1317.44	B	C	D	90	50.15	4
BX02	B	N1384.44	E0982.87	1335.47	B	C	U	90	49.25	4
BX50	B	N1270.40	E0969.85	1299.75	P	I	U	90	50.38	1.875
BX51	B	N1270.40	E0969.85	1299.75	P	I	D	90	50.2	1.875
BX52	B	N1270.4	E0994	1304	P	I	E	0	50.38	1.875
BX53	B	N1270.4	E0994	1304	P	I	E	0	50.3	1.875
BX54	B	N1271.41	E0987.52	1335.36	B	I	U,E	45	50.2	1.875
BX55	B	N1285	E0980	1318	A	I	U,E	45	50.2	1.875
BX56	B	N1282	E0980	1318	A	I	U,E	45	50.3	1.875
BX57	B	N1339	E0978.5	1318	A	I	D	90	49.7	1.875
BX58	B	N1339.11	E0987.28	1335.24	B	I	U,E	45	50.3	1.875
C		S1246	E0140	1262	A	Ae	E	0	15.13	3
C	L2	N1515	W0365	1312.5	A	WO	D	90	12.6	1
CS1		S0994	E0161.5	1258.5	A	CS	N	0	7.8	4
CS2		S0994	E0162.5	1258.5	A	CS	N	-10	10.9	4
CS3		S1000	E0140	1260	A	CS	U	90	31.0	4
D	L2	N1515	W0365	1312.5	A	WO	D	90	10.7	1
D001	D	N1264.9	E1683.63	1317.75	P	I	U	90	51.0	3.8
D002	D	N1264.9	E1699.63	1317.75	P	I	U	90	50	3.8
D003	D	N1264.9	E1683.63	1299.75	P	I	D	90	51.0	3.8
D18	M	N1426.2	E1701.5	1304	A	DD	E	0	12.4	16
D19	M	N1426.2	E1701.5	1308.5	A	DD	E	0	12.4	16
D301	D	N1267.82	E1691.63	1318.17	A	I	U	90	50	3.8
D302	D	N1267.84	E1691.63	1299.97	A	I	D	90	50	3.8
D303	D	N1267.92	E1682.60	1308.72	A	I	W	0	50	3.8
D304	D	N1267.87	E1700.66	1308.77	A	I	E	0	50	3.8
D?01	D	N1155.33	E1691.94	1300.39	A	I	D	90	46.5	1.875
D?02	D	N1156.26	E1691.97	1318.14	A	I	U	90	50?	1.875
D?03	D	N1154.58	E1700.24	1300.86	A	I	D,E	45	50?	1.875
D?04	D	N1156.78	E1683.02	1309.20	A	I	W	90	50?	5
D?05	D	N1156.01	E1683.97	1317.56	A	I	W	90	50?	5
D?06IG	D	N1261.95	E1698.99	1317.76	B	I	U,E	45	50?	
D?07IG	D	N1261.77	E1684.35	1317.77	B	I	U,W	45	50?	

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D?08IG	D	N1261.71	E1684.21	1299.48	B	I	D,W	45	50?	
D?09	D	N1189.94	E1682.50	1313.90	A	I	W	0		5
D?10	D	N1189.39	E1683.33	1308.57	A	I	W	0		4
DH001		N1424	E0439.5	1318.2	A	C	U	90	50.8	3
DH002		N1424	E0440	1307	A	C	D	90	50.2	3
DH002A		N1424	E0435	1307	A	C	D	90	49.2	3
DH002B		N1424	E0442	1306.3	A	C	D	90	53.0	3
DH003		N1112	E0444	1318.1	A	C	U	90	48.8	3
DH003A		N1112	E0450.5	1317.4	A	C	U	90	49.9	3
DH004		N1112.5	E0444	1309.6	A	C	D	90	45.8	3
DH004A		N1113	E0446	1310	A	C	D	90	11.2	3
DH004B		N1112	E0450.5	1309.7	A	C	D	90	51.4	3
DH005		N1463	E0972	1329.9	A	C	U	90	51.0	4.5
DH006		N1463	E0972	1317.9	A	C	D	90	49.75	4.5
DH007		N1112	E0976.5	1326.7	A	C	U	90	49.8	3
DH008		N1112	E0976.5	1318.8	A	C	D	90	38.3	3
DH008A		N1112	E0975	1318	A	C	D	90	50.7	3
DH008B		N1112	E0979.5	1318.0	A	C	D	90	51.4	3
DH009		N1432	E1332.5	1324.5	A	C	U	90	51.4	3
DH010		N1432	E1332.5	1312.1	A	C	D	90	52.0	3
DH011		N1112	E1332.5	1320.5	A	C	U	90	50.9	3
DH012		N1112	E1312.5	1311.1	A	C	D	90	51.3	3
DH013		N1424	E1690	1311.4	A	C	U	90	13.8	3
DH013A		N1424.5	E1691	1311.5	A	C	U	90	49.0	3
DH013B		N1425	E1695	1311.4	A	C	U	90	21.0	3
DH014		N1425	E1695	1299.5	A	C	D	90	49.1	3
DH015		N1104	E1688.5	1318.9	A	C	U	90	51.0	3
DH016		N1104	E1688	1309.3	A	C	D	90	51.0	3
DH017		N1427	E0178	1316.5	A	C	U	90	52.0	3
DH018		N1429	E0181	1305.1	A	C	D	90	50.8	
DH019		N1107	E0206.5	1314.7	A	C	U	90	51.6	3
DH020		N1109	E0206	1306.2	A	C	D	90	51.1	3
DH021		N1421	E0786	1331.0	A	C	U	90	50.4	3
DH022		N1421.5	E0785.5	1318.8	A	C	D	90	51.0	3
DH023		N1112	E0781	1328.0	A	C	U	90	51.0	3
DH024		N1112	E0781	1319.5	A	C	D	90	49.4	3
DH024A		N1112	E0780	1319.5	A	C	D	90	50.4	3
DH025		N1422	E1510	1318.8	A	C	U	90	51.8	3
DH026		N1427	E1510	1307.2	A	C	D	90	53.0	3
DH027	Ge	N1107	W0682	1300.8	A	C	U	90	50.5	3.5
DH028	Ge	N1107	W0682	1289.9	A	C	D	90	50.5	3.5
DH029	Ge	N1099	W0982	1298.3	A	C	U	90	50.4	3.5
DH029A	Ge	N1099	W0987	1298.1	A	C	U	90	35.0	3.5
DH030	Ge	N1099	W0982	1289.2	A	C	D	90	50.1	3.5
DH031	Ge	N1099	W1280	1298.5	A	C	U	90	50.5	3.5
DH031A	Ge	N1099	W1282	1298.5	A	C	U	90	49.2	3.5
DH031B	Ge	N1099	W1265	1298.5	A	C	U	90	4.9	3.5
DH032	Ge	N1099	W1280	1289.6	A	C	D	90	50.0	3.5
DH032A	Ge	N1099	W1265	1289.5	A	C	D	90	5.5	3.5
DH033	Ge	N1099	W1582	1298.6	A	C	U	90	50.5	3.5
DH033A	Ge	N1099	W1570	1297.4	A	C	U	90	4.1	3.5
DH033B	Ge	N1099	W1570.5	1297.4	A	C	U	90	1.2	3.5
DH034	Ge	N1099	W1582	1289.4	A	C	D	90	51.5	3.5
DH034A	Ge	N1099	W1570	1289.2	A	C	D	90	3.6	3.5
DH035	G	N1102	W1882	1294.4	A	C	U	90	52.0	3.5
DH036	G	N1102	W1882	1284.6	A	C	D	90	51.5	3.5
DH037	G	N1101	W2182	1287.0	A	C	U	90	51.5	3.5
DH038	G	N1101	W2182	1297.4	A	C	D	90	47.5	3.5
DH039	G	N1101	W2482	1296.0	A	C	U	90	50.7	3.5
DH040	G	N1101	W2482	1286.1	A	C	D	90	51.0	3.5
DH041	G	N1101	W2782	1295.8	A	C	U	90	49.9	3.5
DH042	G	N1101	W2782	1285.9	A	C	D	90	51.2	3.5
DH042A	G	N1101	W2789	1285.7	A	C	D	90	40.5	3.5
DH207		S0697	E0155	1259.8	A	C,I	U	90	52.8	3

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DH208		S0698	E0150	1251.6	A	C	D	90	42.9	3
DH211		S1320	E0163	1270.5	A	C	U	90	50.0	3
DH212		S1320	E0163	1261.7	A	C	D	90	52.1	3
DH215		S1960	E0153	1272.0	A	C,I	U	90	51.1	3
DH216		S1960	E0153	1262.6	A	C,I	D	90	54.2	3
DH219		S2422	E0162	1266.3	A	C	U	90	51.0	3
DH219A		S2418	E0162	1266.1	A	C	U	90	11.3	3
DH220		S2421	E0162	1257.4	A	C	D	90	51.8	3
DH223		S3114	E0154	1255.1	A	C,I	U	90	52.6	3
DH224		S3114	E0154	1246.6	A	C,I	D	90	52.5	3
DH227		S3656	E0147	1247.0	A	C	U	90	51.7	3
DH228		S3656	E0147	1237.8	A	C	D	90	50.4	3
DH301		N0150	W0170	1276.9	A	C	U	90	50.75	3.5
DH302		N0150	W0170	1264.9	A	C	D	90	50.6	3.5
DH303		S0400	W0170	1267.2	A	C	U	90	51.4	3.5
DH304		S0400	W0170	1254.3	A	C	D	90	50.5	3.5
DH306		S0400	E0140	1244.1	A	C	D	90	52.0	3
DH306A		S0400	E0125	1244.0	A	C	D	90	8.5	3.5
DH307		S0400	E0300	1262.6	A	C,I	U	90	52.0	3
DH309		S0700	E0220	1259.8	A	C,I	U	90	52.3	3
DH311		S1000	E0300	1264.4	A	C,I	U	90	52.0	3
DH313		S1300	E0300	1270.6	A	C	U	90	19.6	3
DH313A		S1300	E0299	1270.9	A	C	U	90	50.2	3
DH314		S1300	E0300	1258.3	A	C	D	90	50.75	3
DH315		S1300	W0170	1272.1	A	C	U	90	50.3	3.5
DH316		S1300	W0170	1259.9	A	C	D	90	50.1	3.5
DH317		S1600	W0030	1271.2	A	C	U	90	50.1	3
DH317A		S1600	W0028.5	1271.2	A	C	U	90	5.0	3
DH317B		S1597	W0027	1271.2	A	C	U	90	51.0	3.5
DH317C		S1600	W0029.5	1271.2	A	C	U	90	5	3
DH318		S1600	W0030	1258.5	A	C	D	90	50.0	3
DH319		S0700	E0300	1260.0	A	C	U	90	51.05	3.5
DH321		S0400	E0000	1261.4	A	C,I	U	90	52.0	3
DH323		S0395.53	E0057.61	1261.2	B	C	U	90	52.5	3
DO045		N0249.5	E0147.13	1286.24	B	C,I	U	90	52.7	3
DO046		N0249.2	E0147	1276.5	A	C	D	90	51.5	3
DO052		N0146	W0002	1280.4	A	C	U	90	50?	3
DO053		N0146	W0004	1266.6	A	C	D	90	49.2	3
DO056		N621	E000	1296.8	A	C,I	U	90	52.1	3
DO057		N0621	E0000	1288.1	A	C	D	90	52.1	3
DO063		N1110	E0000	1310.6	A	C,I	U	90	52.8	3
DO064		N1110	E0000	1301.5	A	C	D	90	52.8	3
DO067	1	N1265	W0231.5	1296.8	A	C,I	D	90	51.7	3
DO069	1	N1265	W0231.5	1310.1	A	C,I	U	90	51.4	3
DO077	2	N1270	W0364.5	1294.6	A	C,I	D	90	53.4	3
DO079	2	N1270	W0364.5	1307.7	A	C,I	U	90	51.8	3
DO088	3	N1265	W0497.5	1305.9	A	C,I	U	90	52.7	3
DO090	3	N1265	W0497.5	1292.1	A	C,I	D	90	53.6	3
DO091	4	N1275	W0630.5	1292.1	A	C,I	D	90	51.8	3
DO093	4	N1275	W0630.5	1304.9	A	C,I	U	90	52.0	3
DO201		S0406	W0019	1262.2	A	C	U	90	51.7	3
DO202		S0406	W0019	1248.6	A	C	D	90	51.4	3
DO203		N0624	E0140	1298.2	A	C,I	U	90	51.75	3
DO204		N0640	E0140	1290.5	A	C	D	90	51.6	3
DO205		N1410	E0000	1316.5	A	C	U	90	50.7	3
DO206		N1410	E0000	1308.0	A	C	D	90	50.6	3
DO229		S0401	E0153	1259.8	A	C	U	90	50.6	3
DPD01		N1433	E1672	1300	A	EX	D,N	45	40.5	5
DT01	4					DD	W	0	13	1.875
DT02	4					DD	W	0	13	1.875
DT03	4					DD	W	0	13	3
DT04	He	N1100	W0646	1296.5	A	DD,C	S	0	3.8	16
DT05		N1095	W0656?		A	DD,C	S	0	2.5	6
DT06	He	N1100	W0646	1296	A	DD,C	S	0	1	4

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DT07		S0750?	E0140		D	DD	E	0	12	1.875
DT08		S0750?	E0140		D	DD	E	0	12	1.875
DT09		S0750?	E0140		D	DD	E	0	7	1.875
DT10		S0750?	E0140		D	DD	E	0	9	1.875
DT11		S0750?	E0140		D	DD	E	0	9	1.875
DT12		S1000	E0176.5	1256	A	DD	E	0	50	1.875
DT13		S1002	E0176.5	1256	A	DD	E	0	50	1.875
DT14		S1002	E0176.5	1257	A	DD	E	0	50	1.875
DX01	D	N1237.9	E1691.63	1317.75	P	I	U	90	50	1.875
DX02	D	N1237.9	E1700.63	1317.75	P	I	E,U	45	50	4
DX03	D	N1237.9	E1700.63	1317.75	P	I	E	0	50	1.875
DX04	D	N1237.9	E1691.63	1299.75	P	I	D	90	50	1.875
DX05	D	N1237.9	E1682.63	1299.75	P	I	W,D	45	50	1.875
DX10	D	N1247.9	E1700.63	1317.75	P	I	E,U	45	50	3.8
DX15	D	N1372.89	E1700.17	1303.97	A	DD	E	0	3.0	16
DX16	D	N1370.06	E1700.54	1304.19	A	DD	E	0	6.8	16
DX17	D	N1371.50	E1700.60	1308.49	A	DD	E	0	7.3	16
DX30	D	N1247.90	E1691.63	1299.75	P	I	D	90	50	1.875
DX50	D	N1247.90	E1700.63	1308.75	P	I	E	0	50	2
DX51	D	N1247.90	E1682.63	1308.75	P	I	W	0	50	2
DX70	D	N1247.90	E1691.63	1317.75	P	I	U	90	50	1.875
DX71	D	N1247.90	E1687.93	1299.75	P	I	E,D	45?	33?	1.875
E	L2	N1515	W0365	1312.5	A	WO	D	90	7.1	5
GA090-D	G	N1100	W1868	1285	A	I	D	90	103.5	1.88
GA090-U	G	N1100	W1868	1296	A	I	U	90	103.4	1.88
GA301	G	N1102.54	W2327.30	1296.71	B	I	U	90	50.9	3.0
GA302	G	N1102.53	W2327.21	1286.74	B	I	D	90	51.00	3.0
GA303	G	N1112.28	W2327.21	1291.73	B	I	N	0	50.67	3.0
GA304	G	N1092.57	W2327.20	1291.76	B	I	S	0	50.75	3.0
GA311-1	G	N1102.54	W2325.33	1296.89	B	I	U	90	50.66	1.875
GA311-2	G	N1102.57	W2321.29	1296.82	B	I	U	90	30.36	1.875
GA311-3	G	N1102.58	W2322.18	1296.78	B	I	U	90	20.41	1.875
GA311-4	G	N1102.54	W2323.29	1296.83	B	I	U	90	10.55	1.875
GA311-5	G	N1102.58	W2324.26	1296.84	B	I	U	90	5.51	1.875
GA312-1	G	N1102.54	W2325.26	1286.27	B	I	D	90	50.50	1.875
GA312-2	G	N1102.51	W2321.25	1286.63	B	I	D	90	30.25	1.875
GA312-3	G	N1102.53	W2322.25	1286.62	B	I	D	90	20.50	1.875
GA312-4	G	N1102.54	W2323.24	1286.71	B	I	D	90	10.44	1.875
GA312-5	G	N1102.53	W2324.26	1286.63	B	I	D	90	5.10	1.875
GA313-1	G	N1112.55	W2325.22	1291.76	B	I	N	0	50.95	1.875
GA313-2	G	N1112.58	W2321.29	1291.75	B	I	N	0	30.4	1.875
GA313-3	G	N1112.53	W2322.29	1291.75	B	I	N	0	20.4	1.875
GA313-4	G	N1112.54	W2323.27	1291.79	B	I	N	0	10.6	1.875
GA313-5	G	N1112.55	W2324.29	1291.77	B	I	N	0	5.7	1.875
GA314-1	G	N1092.37	W2325.25	1291.81	B	I	S	0	50.92	1.875
GA314-2	G	N1092.33	W2321.28	1291.76	B	I	S	0	30.40	1.875
GA314-3	G	N1092.38	W2322.26	1291.79	B	I	S	0	20.36	1.875
GA314-4	G	N1092.33	W2323.27	1291.78	B	I	S	0	10.50	1.875
GA314-5	G	N1092.34	W2324.26	1291.81	B	I	S	0	5.75	1.875
GA333	G	N1112.32	W2730.26	1290.63	B	I	N	0	55.50	3.0
GA334	G	N1092.43	W2730.27	1290.60	B	I	S	0	55.4	3.0
GA501	G	N1092.54	W2335.20	1291.78	B	I	S	0	138.7	2.25
GA503	G	N1092.61	W2331.71	1291.77	B	I	S	0	55.6	1.5
GA505	G	N1092.60	W2330.23	1291.73	B	I	S	0	23.3	1.5
GA507	G	N1092.59	W2328.74	1291.73	B	I	S	0	8.3	1.5
GB1	4	N1400	W0630	1293	A	WO,C	D	90	18	1
GB331	G	N1102.56	W2730.26	1295.62	B	I	U	90	50.62	3.0
GB332	G	N1102.52	W2730.26	1285.90	B	I	D	90	50.0	3.0
GB341-1	G	N1102.53	W2732.21	1295.88	B	I	U	90	50.45	1.875
GB341-2	G	N1102.53	W2736.23	1295.93	B	I	U	90	30.2	1.875
GB341-3	G	N1102.53	W2735.21	1295.89	B	I	U	90	20.4	1.875
GB341-4	G	N1102.53	W2734.22	1295.85	B	I	U	90	10.4	1.875
GB341-5	G	N1102.55	W2733.19	1295.90	B	I	U	90	5.1	1.875
GB342-1	G	N11-2.54	W2732.21	1285.64	B	I	D	90	50.4	1.875

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Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
GB342-2	G	N1102.55	W2736.22	1285.66	B	I	D	90	30.2	1.875
GB342-3	G	N1102.55	W2735.22	1285.64	B	I	D	90	20.4	1.875
GB342-4	G	N1102.56	W2734.23	1285.67	B	I	D	90	10.3	1.875
GB342-5	G	N1102.54	W2733.22	1285.62	B	I	D	90	5.2	1.875
GB343-1	G	N1112.53	W2732.20	1290.17	B	I	N	0	55.17	1.875
GB343-2	G	N1112.58	W2736.21	1290.72	B	I	N	0	35.1	1.875
GB343-3	G	N1112.52	W2735.25	1290.72	B	I	N	0	25.3	1.875
GB343-4	G	N1112.56	W2734.23	1290.77	B	I	N	0	15.25	1.875
GB343-5	G	N1112.56	W2733.20	1290.75	B	I	N	0	10.17	1.875
GB343-6	G	N1112.56	W2737.21	1290.72	B	I	N	0	5.1	1.875
GB344-1	G	N1092.22	W2732.21	1290.73	B	I	S	0	55.2	1.875
GB344-2	G	N1092.26	W2736.17	1290.75	B	I	S	0	35.3	1.875
GB344-3	G	N1092.25	W2735.24	1290.75	B	I	S	0	25.4	1.875
GB344-4	G	N1092.21	W2734.19	1290.75	B	I	S	0	15.3	1.875
GB344-5	G	N1092.22	W2733.20	1290.73	B	I	S	0	10.3	1.875
GB344-6	G	N1092.27	W2737.26	1290.75	B	I	S	0	5.5	1.875
GB522	G	N1112.01	W2717.23	1290.75	B	I	N	0	140.5	1.875
GB522A	G				D					
GB523	G	N1112.22	W2725.00	1290.58	B	I	N	0	64.17	1.875
GB525	G	N1112.28	W2727.26	1290.66	B	I	N	0	25.25	1.875
GB527	G	N1112.27	W2728.76	1290.72	B	I	N	0	10.25	1.875
GBX50	G	N1112.23	W2722.25	1290.64	B	I	N	0	80.0	1.875
GD401	G	N1102.55	W2482.32	1295.18	B	I	U	90	50.63	3.0
GD402	G	N1102.57	E2482.19	1285.32	B	I	D	90	50.28	3.0
GD403	G	N1102.45	W2490.17	1295.06	B	I	U	90	50.28	3.0
GD404	G	N1102.49	W2490.17	1285.28	B	I	D	90	50.1	3.0
GD405	G	N1102.48	W2520.34	1295.73	B	I	U	90	50.5	3.0
GD406	G	N1102.42	W2520.24	1286.11	B	I	D	90	50.3	3.0
GD411-1	G	N1102.51	W2480.31	1295.41	B	I	U	90	50.7	1.875
GD411-2	G	N1102.48	W2476.25	1295.61	B	I	U	90	30.08	1.875
GD411-3	G	N1102.49	W2477.26	1295.59	B	I	U	90	20.5	1.875
GD411-4	G	N1102.53	W2478.25	1295.49	B	I	U	90	10.58	1.875
GD411-5	G	N1102.54	W2478.30	1295.50	B	I	U	90	5.42	1.875
GD412-1	G	N1102.54	W2480.24	1285.28	B	I	D	90	50.58	1.875
GD412-2	G	N1102.50	W2476.25	1285.42	B	I	D	90	30.3	1.875
GD412-3	G	N1102.54	W2477.25	1285.34	B	I	D	90	20.75	1.875
GD412-4	G	N1102.50	W2478.26	1285.23	B	I	D	90	10.60	1.875
GD412-5	G	N1102.53	W2479.24	1285.22	B	I	D	90	5.70	1.875
GD413-1	G	N1102.55	W2475.22	1295.66	B	I	U	90	16.08	1.875
GD413-2	G	N1102.53	W2474.22	1295.71	B	I	U	90	5.42	1.875
GD414-1	G	N1102.52	W2475.23	1285.49	B	I	D	90	10.3	1.875
GD414-2	G	N1102.54	W2474.76	1285.58	B	I	D	90	5.42	1.875
GD415-1	G	N1102.50	W2470.20	1295.88	B	I	U	90	50.55	1.875
GD415-2	G	N1102.49	W2466.20	1295.97	B	I	U	90	30.17	1.875
GD415-3	G	N1105.51	W2467.26	1295.96	B	I	U	90	20.25	1.875
GD415-4	G	N1102.51	W2468.25	1295.92	B	I	U	90	10.50	1.875
GD415-5	G	N1102.51	W2469.23	1295.95	B	I	U	90	5.66	1.875
GD416-1	G	N1102.51	W2466.3	1285.6	B	I	D	90	50.1	1.875
GD416-2	G	N1102.51	W2466.27	1285.59	B	I	D	90	30.8	1.875
GD416-3	G	N1102.51	W2467.29	1285.63	B	I	D	90	20.8	1.875
GD416-4	G	N1102.51	W2468.28	1285.68	B	I	D	90	10.8	1.875
GD416-5	G	N1102.53	W2469.25	1285.56	B	I	D	90	5.6	1.875
GD417-1	G	N1102.56	W2460.27	1296.16	B	I	U	90	50.7	1.875
GD417-2	G	N1102.57	W2456.28	1296.17	B	I	U	90	30.25	1.875
GD417-3	G	N1102.50	W2457.25	1296.21	B	I	U	90	20.6	1.875
GD417-4	G	N1102.54	W2458.27	1296.18	B	I	U	90	9.3	1.875
GD417-5	G	N1102.53	W2459.25	1296.17	B	I	U	90	5.3	1.875
GD418-1	G	N1102.53	W2460.29	1285.94	B	I	D	90	50.5	1.875
GD418-2	G	N1102.55	W2456.26	1285.95	B	I	D	90	30.22	1.875
GD418-3	G	N1102.53	W2457.26	1285.94	B	I	D	90	20.79	1.875
GD418-4	G	N1102.54	W2458.22	1285.91	B	I	D	90	10.83	1.875
GD418-5	G	N1102.55	W2459.23	1285.99	B	I	D	90	5.83	1.875
GD419-1	G	N1102.63	W2440.18	1296.26	B	I	U	90	5.42	1.875
GD419-2	G	N1102.55	W2436.35	1296.32	B	I	U	90	32.67	1.875

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GD419-3	G	N1102.53	W2437.25	1296.31	B	I	U	90	20.17	1.875
GD419-4	G	N1102.52	W2438.24	1296.32	B	I	U	90	10.67	1.875
GD419-5	G	N1102.53	W2439.21	1296.27	B	I	U	90	5.42	1.875
GD420-1	G	N1102.54	W2440.25	1286.18	B	I	D	90	51.0	1.875
GD420-2	G	N1102.51	W2436.26	1286.32	B	I	D	90	30.72	1.875
GD420-3	G	N1102.53	W2437.25	1286.29	B	I	D	90	20.90	1.875
GD420-4	G	N1102.51	W2438.23	1286.19	B	I	D	90	10.77	1.875
GD420-5	G	N1102.53	W2439.25	1286.14	B	I	D	90	5.46	1.875
GD421-1	G	N1102.53	W2420.22	1295.80	B	I	U	90	51.25	1.875
GD421-2	G	N1102.49	W2416.22	1295.93	B	I	U	90	30.50	1.875
GD421-3	G	N1102.58	W2417.23	1295.94	B	I	U	90	21.70	1.875
GD421-4	G	N1102.55	W2418.21	1295.88	B	I	U	90	15.54	1.875
GD421-5	G	N1102.50	W2419.18	1295.87	B	I	U	90	7.55	1.875
GD422-1	G	N1102.54	W2420.26	1285.77	B	I	D	90	50.5	1.875
GD422-2	G	N1102.55	W2416.28	1285.91	B	I	D	90	30.71	1.875
GD422-3	G	N1102.53	W2417.30	1285.87	B	I	D	90	20.25	1.875
GD422-4	G	N1102.54	W2418.26	1285.82	B	I	D	90	10.5	1.875
GD422-5	G	N1102.54	W2419.24	1285.84	B	I	D	90	5.5	1.875
GE206	4	N1275	W0620	1293	A	I	E	0	52.6	3
GE207					D	I				
GE208	4	N1275	W0625	1293	A	I	W	0	52.0	3
GE209					D	I				
GE210					D	I				
GE211	3	N1250	W0490	1302	A	I	E	0	51.75	3
GE212					D	I				
GE213	2	N1275.77	W0348.05	1294.89	B	I	E	0	52.0	3
GE214					D	I				
GE215	2	N1276.19	W0380.82	1301.83	B	I	W	0	52.0	3
GE216					D	I				
GE217	1	N1265.58	W0215.14	1303.88	B	I	E	0	51.5	3
GE218					D	I				
GE219	1	N1265.47	W0248.31	1303.87	B	I	W	0	52.5	3
GE220					D	I				
GE221					D	I				
GE222		N1266.18	E0155.94	1312.94	B	I	E	0	51.5	3
GE223		N0626.83	W0027.46	1292.21	B	I	W	0	51.6	3
GE224		N0624.54	E0010.18	1294.44	B	I	E	0	53.3	3
GE225		N1265.73	E0140.87	1312.96	B	I	W	0	52.5	3
GE226					D	I				
GE226		N0146	W0004	1280.4	A	C,I	U	90	51.6	3
GE227		N0035.37	E0001.25	1272.97	B	I	U	90	52.0	3
GE228		S0065.56	W0007.51	1274.15	B	I	U	90	50.5	3
GE229		N0254.26	E0141.25	1281.61	B	I	W	0	51.3	3
GE230		N0254.27	E0147.19	1285.74	B	I	U	90	52.3	3
GE231		S0410.68	E030.39	1254.03	B	I	S	0	53.0	3
GE232		S0399.65	E0044.9	1261.35	B	I	U	90	51.0	3
GE233		N1263.11	W0002.95	1314.40	B	I	U	90	51.9	3
GE234					D	I				
GE235					D	I				
GE236		N1266.02	E0148.08	1316.71	B	I	U	90	51.0	3
GE237	2	N1276.05	W0372.76	1307.75	B	I	U	90	51.5	3
GE238	2	N1275.85	W0356.49	1294.89	B	I	U	90	51.75	3
GE239	1	N1265.24	W0223.46	1310.15	B	I	U	90	52.0	3
GE240	1	N1265.17	W0239.42	1310.15	B	I	U	90	52.0	3
GE241		N1111.14	W0363.04	1309.72	B	I	U	90	52.5	3
GE242		N1111.14	W0363.09	1295	B	I	D	90	52.0	3
GE243					D	I				
GE244		S0027.98	W0005.89	1276.58	B	I	U	90	46.9	3
GE245		S0395.97	E0009.03	1262.50	B	I	U	90	46.5	3
GE246					D	I				
GE247					D	I				
GE248					D	I				
GE249					D	I				
GE250		S3079.66	E0154.38	1246.29	B	I	D	90	52.5	3

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GE251		S0015.80	W0005.29	1276.78	B	I	U	90	52.0	3
GE252		S0027.5	W0024.79	1268.72	B	I	W	0	36.25	3
GE253		S0028.6	W0004.69	1258.89	B	I	D	90	52.1	3
GE254		S0027.59	E0010.9	1268.35	B	I	E	0	36.0	3
GE255					D	I				
GE256		S0404	E0138	1260.5	A	I	U	90	51.0	3
GE257		S0397	E0141	1260.5	A	I	U	90	51.0	3
GE257A		S0398	E0136	1260.5	A	I	U	90	45	3
GE258		N1099	W0001	1301.4	A	I	D	90	60.0	3
GE259		N1420	W0231	1310	A	I	U	90	50.0	3
GE260		N1420	W0231	1298	A	I	D	90	50.4	3
GE261		N1420	W0365	1308	A	I	U	90	51.75	3
GE262		N1420	W0365	1296	A	I	D	90	49.3	3
GE263					D	I				
GE264		S0400	E0300	1262.5	A	I	U	90	50.4	3
GE265					D	I				
GE266		S0400	E0140	1244	A	I	D	90	52.0	3
GE267					D	I				
GE268		S0400	E0000	1259	A	I	U	90	50.0	3
GE431	G	N1097.56	W2471.28	1295.52	B	I	U	90	50.35	3.0
GE432	G	N1097.49	W2471.25	1285.56	B	I	D	90	50.2	3.0
GE433	G	N1111.57	W2489.26	1294.91	B	I	U	90	55.3	3.0
GE434	G	N1111.47	W2489.22	1285.66	B	I	D	90	50.2	3.0
GE435	G	N1103.13	W2489.89	1290.35	B	I	NW	0	55.7	3.0
GE436	G	N1092.78	W2470.47	1290.24	B	I	SE	0	50.45	3.0
GE584	G	N1112.00	W2495.21	1290.26	B	I	NW	0	41.3	1.875
GE585	G	N1112.02	W2492.79	1290.22	B	I	NW	0	21.6	1.875
GE586	G	N1112.07	W2491.35	1290.25	B	I	NW	0	10.8	1.875
GE588	G	N1092.67	W2464.31	1290.42	B	I	SE	0	85.8	1.50
GE590	G	N1092.70	W2467.38	1290.47	B	I	SE	0	42.8	1.50
GE592	G	N1092.79	W2468.97	1290.38	B	I	SE	0	17.5	1.50
H003	H	N0869.46	W0642.87	1296.90	B	I	U,NE		22.76	4.0
H004	H	N0869.35	W0642.99	1287.61	B	I	D,NE		23.00	4.0
H005	H	N0844.69	W0667.60	1296.71	B	I	U,SW		49.99	4.0
H006	H	N0844.87	W0667.51	1287.42	B	I	D,SW		49.73	4.0
H007	H	N0895.70	W0616.56	1297.21	B	I	U,SW		22.72	4.0
H008	H	N0895.58	W0616.65	1287.91	B	I	D,SW		22.78	4.0
H009	H	N0920.46	W0591.95	1297.26	B	I	NE,U		54.62	4.0
H010	H	N0920.5	W0592	1288	A	I	D,E	45	50	4
H011	H	N0920.41	W0591.99	1287.90	B	I	SW	0	36.4	4.0
H012	H	N0895.32	W0616.92	1288.63	B	I	SW	0	36.31	4.0
H090-D		N1095	W0415	1292	A	I	D	90	103.0	12.00
H090-U		N1095	W0415	1306	A	I	U	90	103.0	12.00
H1SE		S0436	W0011	1258	A	LT,C	E	0	3.7	4
H2SE		S0436	W0011	1257	A	LT,C	E	0	4.0	4
H301	H	N0907.96	W0655.23	1297.74	B	I	U	90	50.2	1.875
H302	H	N0908.02	W0655.22	1288.18	B	I	D	90	50.25	1.875
H303	H	N0857.11	W0655.24	1297.26	B	I	U	90	50.14	3.0
H304	H	N0857.05	W0655.22	1287.44	B	I	D	90	50.0	3.0
H305	H	N0857.04	W0604.32	1297.03	B	I	U	90	50.33	1.875
H306	H	N0857.10	W0604.34	1287.69	B	I	D	90	50.5	1.875
H307	H	N0907.47	W0604.30	1297.66	B	I	U	90	50.62	3.0
H308	H	N0907.99	W0604.26	1287.10	B	I	D	90	50.15	3.0
H309	H	N0895.54	W0642.75	1293.17	B	I	SE	0	18.64	1.875
H310	H	N0920.44	W0667.70	1293.18	B	I	NW	0	50.2	1.875
H311	H	N0869.60	W0642.73	1292.18	B	I	NE	0	17.34	3.0
H312	H	N0844.55	W0667.75	1292.11	B	I	SW	0	50.29	3.0
H313	H	N0869.53	W0616.80	1292.36	B	I	NW	0	18.0	1.875
H314	H	N0844.57	W0591.85	1292.36	B	I	SE	0	50.45	1.875
H315	H	N0895.41	W0616.88	1292.59	B	I	SW	0	17.58	3.0
H316	H	N0920.60	W0591.76	1292.62	B	I	NE	0	50.60	3.0
H317	H	N0900.76	W0629.73	1294.75	B	I	S	0	36.17	1.875
H318	H	N0895.77	W0643.00	1297.46	B	I	U,SE		26.10	1.875
H319	H	N0895.85	W0643.07	1288.58	B	I	D,SE		26.16	1.875

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Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
H320	H	N0920.18	W0667.38	1297.27	B	I	NW,U		50.3	1.875
H321	H	N0920.06	W0667.24	1288.51	B	I	D,NW		50.3	1.875
H326	H	N0869.24	W0616.48	1296.58	B	I	NW,U		25.8	1.875
H327	H	N0869.24	W0616.45	1287.60	B	I	NW,D	25.6	1.875	I
H328	H	N0844.80	W0592.10	1296.83	B	I	SE,U		50.0	1.875
H329	H	N0844.99	W0592.23	1287.81	B	I	SE,D		50.3	1.875
H3SF		S0442	W0018	1257	A,D	LT,C	S	0	3.2	4
H501	H	N0844.54	W0666.13	1297.52	B	I	U	90	28.50	1.50
H502	H	N0880.66	W0665.63	1297.61	B	I	U	90	14.59	1.50
H504	H	N0844.45	W0665.65	1288.03	B	I	D	90	28.35	1.50
H505	H	N0880.62	W0665.67	1287.92	B	I	D	90	28.35	1.50
H513	H	N0880.55	W0593.96	1297.39	B	I	U	90	28.5	1.50
H514	H	N0884.35	W0593.79	1297.59	B	I	U	90	14.3	1.50
H516	H	N0880.59	W0593.99	1287.84	B	I	D	90	27.50	1.50
H517	H	N0884.46	W0593.86	1288.11	B	I	D	90	13.4	1.50
H519	H	N0881.58	W0648.00	1292.65	B	I	SE	0	22.7	1.50
H520	H	N0883.50	W0648.01	1292.81	B	I	SE	0	12.0	1.50
H523	H	N0879.76	W0683.19	1292.67	B	I	W	0	29.0	1.50
H524	H	N0885.34	W0683.28	1292.80	B	I	W	0	14.5	1.50
H532	H	N0820.52	W0611.53	1292.53	B	I		0	15.54	1.50
H533	H	N0881.58	W0611.56	1292.54	B	I		0	9.46	1.50
H535	H	N0885.39	W0576.05	1292.58	B	I	E,NE	0	28.7	1.50
H536	H	N0879.72	W0576.05	1292.62	B	I	E	0	14.4	1.50
H537	H	N0881.96	W0649.40	1297.54	B	I	U,SE		33.38	1.50
H538	H	N0882.58	W0610.76	1296.86	B	I	U,W		23.34	1.50
H543	H	N0881.98	W649.58	1288.07	B	I	D,SE		33.99	1.50
H544	H	N0882.51	W0611.18	1287.99	B	I	D,W		23.85	1.50
H549	H	N0901.24	W0630.72	1291.06	B	I	S	0	24.17	1.875
H550	H	N0901.31	W0628.78	1290.98	B	I	S	0	16.08	1.875
H551	H	N0901.25	W0692.70	1291.09	B	I	S	0	9.25	1.875
H701	H	N1033.35	W0635.43	1295.70	B	I	W	0	50.21	1.875
H702	H	N0900.54	W0660.91	1297.70	B	I	U	90	50.42	1.875
H703	H	N0900.54	W0660.91	1288.18	B	I	D	90	50.10	1.875
H704	H	N0846.51	W0627.97	1297.22	B	I	U	90	50.1	1.875
H705	H	N0846.49	W0627.92	1287.31	B	I	U	90	50.10	1.875
H705A	H				D					
H708	H	N0891.69	W0645.68	1292.92	B	I	SE	0	15.45	1.875
H709	H	N0909.41	W0676.25	1292.93	B	I	NW	0	50.33	1.875
H710	H	N0864.19	W0629.78	1292.12	B	I	N	0	10.5	1.875
H711	H	N0828.67	W0629.81	1292.09	B	I	S	0	50.5	1.875
H712	H	N0891.58	W0614.04	1292.76	B	I	W	0	15.6	1.875
H714	H	N0892.30	W0646.72	1297.58	B	I	SE,U		27.8	1.875
H715	H	N0891.87	W0646.01	1297.27	B	I	U		17.4	1.875
H716	H	N0892.44	W0646.93	1288.13	B	I	D		28.0	1.875
H717	H	N0891.97	W0646.14	1288.34	B	I	D		17.45	1.875
H718	H	N0909.18	W0675.66	1297.18	B	I	U,NW		50.63	1.875
H719	H	N0909.05	W0675.65	1288.39	B	I	D,NW		50.5	1.875
H720	H	N0863.00	W0629.77	1296.76	B	I	N.U		40.0	1.875
H721	H	N0863.75	W0629.76	1296.31	B	I	N,U		23.12	1.875
H722	H	N0862.93	W0629.73	1287.01	B	I	D		39.25	1.875
H723	H	N0863.72	W0629.80	1287.31	B	I	D		23.1	1.875
H724	H	N0829.09	W0629.87	1296.45	B	I	S,U		50.5	1.875
H725	H	N0829.22	W0629.76	1287.28	B	I	S,D		50.0	1.875
H726	H	N0892.35	W0612.66	1297.46	B	I	U,W		28.05	1.875
H727	H	N0892.24	W0613.22	1297.19	B	I	U,W		17.4	1.875
H728	H	N0892.24	W0612.75	1288.09	B	I	D,W		26.9	1.875
H729	H	N0891.44	W0613.51	1288.34	B	I	D,W		17.5	1.875
HF1		N0079	E0167.5	1267	A	HF	E	0	50	4
HF2	Ge	N1110	W0685	1294	A	HF	W	0	512	4
HF3	Ge	N1110	W0685	1294	A	HF	W	0	74	4
HX50	H	N0846.57	W0629.71	1287.09	B	I	D	90	3.0	3.0
HX51	H	N0920.5	W0592	1289	A	I	NE,D	45	50.70	4.0
ID1	4					ID	E	0	100	1.875
ID2	4					ID	E	0	100	1.875

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Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
ID3	4					ID	S	0	100	1.875
ID4	4					ID	E	0	55	3
IG201	2	N1276.07	W0378.75	1294.97	B	I	D	90	54	4.5
IG202	1	N1265.32	W0245.35	1296.49	B	I	D	90	47.5	4.5
IG203	2	N1276.18	W0379.31	1307.30	B	I	U	90	52	4.5
IG204	2	N1275.87	W0349.99	1307.22	B	I	U	90	52	4.5
IG205	1	N1265.47	W0245.94	1310.29	B	I	U	90	56	4.5
IG206	1	N1265.27	W0216.92	1309.52	B	I	U	90	52	4.5
IG211	2	N1275.75	W0348.81	1306.73	B	I	E	0	17	4.5
IG212	2	N1275.97	W0348.53	1296.88	B	I	E	0	17	4.5
IG213	2	N1275.96	W0379.84	1307.07	B	I	W	0	17	4.5
IG214	2	N1276.26	W0380.18	1296.87	B	I	W	0	17	4.5
IG215	1	N1265.39	W0215.88	1309.28	B	I	E	0	16.5	4.5
IG216	1	N1265.39	W0215.71	1298.70	B	I	E	0	16.5	4.5
IG217	1	N1265.4	W0247.18	1309.28	B	I	W	0	16.5	4.5
IG218	1	N1265.59	W0247.51	1298.88	B	I	W	0	16.5	4.5
IG219	3	N1265.63	W0481.94	1305.09	B	I	E	0	17	4.5
IG220	3	N1265.60	W0480.86	1293.53	B	I	E	0	17	4.5
IG221	3	N1265.59	W0513.19	1304.87	B	I	W	0	17	4.5
IG222	3	N1265.86	W0513.33	1293.59	B	I	W	0	17	4.5
IG223	4	N1274.65	W0614.78	1304.20	B	I	E	0	16.5	4.5
IG224	4	N1274.01	W0612.80	1294.35	B	I	E	0	16.5	4.5
IG225	4	N1274.72	W0646.07	1303.93	B	I	W	0	16.5	4.5
IG226	4	N1275.04	W0646.14	1293.91	B	I	W	0	16.5	4.5
IG227	D				D	I				
IG228	D				D	I				
JV1	J	N1004	W0367	1288	A	CON	D	90	8	36
JV2	J	N1008	W0367	1288	A	CON	D	90	7.39	36
JV3	J	N1019	W0367	1288	A	CON	D	90	8	36
JV4	J	N1055	W0367	1289	A	CON	D	90	8	36
JV5	J	N1060	W0367	1290	A	CON	D	90	8	36
JV6	J	N1065	W0367	1290	A	CON	D	90	36	7.5
JV7	J	N1067	W0367	1290	A	CON	D	90	7.5	36
JV8	J	N1067	W0374	1290	A	CON	D	90	8.1	36
JV9	J	N1067	W0378	1290	A	CON	D	90	8.1	36
L1PD01	L1	N1500	W0231.5	1312	A	DD	D	90	45	5
L1PU01	L1	N1500	W0231.5	1325	A	DD	U	90	50	5
L1S02	L1	N1534.1	W0220	1312	A	EX	D	90	12.2	2
L1S03	L1	N1534.1	W0222	1312	A	EX	D	90	12.1	2
L1S04	L1	N1534.1	W0224	1312	A	EX	D	90	12.1	2
L1S05	L1	N1534.1	226	1312	A	EX	D	90	12.0	2
L1S06	L1	N1534.1	W0228	1312	A	EX	D	90	12.0	2
L1S07	L1	N1534.1	W0235	1312	A	EX	D	90	12.0	2
L1S08	L1	N1534.1	W0237	1312	A	EX	D	90	12.0	2
L1S09	L1	N1534.1	W0239	1312	A	EX	D	90	12.0	2
L1S10	L1	N1534.1	W0241	1312	A	EX	D	90	12.0	2
L1X00	L1	N1538.5	W0225	1312	A	C	D	90	12.55	4
L1X11	L1	N1534.1	W0243	1312	A	EX	D	90	12.0	2
L1X12	L1	N1534.1	W0245	1312	A	EX	D	90	12.0	2
L1XS01	L1	N1534.1	W0218	1312	A	EX	D	90	12	2
L2C03	L2	N1510	W0365	1312.5	A	EX	D	90	12?	16
L2C25	L2	N1510	W0365	1312	D	EX,C	D	90	12	5
L2C29	L2	N1515	W0365	1312.5	A	EX,C	D	90	8.0	8
L2C02	L2	N1534.19	W0375.05	1312.5	A	EX	D	90	12	30
L2C04	L2	N1524.19	W0375.05	1312.5	A	EX	D	90	12	30
L2PD01	L2	N1500	W0364.5	1312.4	A	DD	D	90	13.0	5
L2PH01	L2	N1540.19	W0364.5	1317	A	DD	N	0	25.0	5
L2PU01	L2	N1535	W0364.5	1325	A	DD	U	90	25.4	5
L2PU02	L2	N1500	W0364.5	1325	A	DD	U	90	9.2	5
L2S01	L2	1535.8	W0375.3	1312.5	A	EX	D	90	12.0	1.875
L2S02	L2	N1535.6	W0375.6	1312.5	A	EX	D	90	12.0	1.875
L2S03	L2	N1535.3	W0375.9	1312.5	A	EX	D	90	12.0	1.875
L2S04	L2	N1535.0	W0376.2	1312.5	A	EX	D	90	12.0	1.875
L2S05	L2	N1534.7	W0376.5	1312.5	A	EX	D	90	12.0	1.875

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L2S06	L2	N1534.4	W0376.65	1312.5	A	EX	D	90	12.0	1.875
L2S07	L2	N1534.1	W0376.65	1312.5	A	EX	D	90	12.0	1.875
L2S08	L2	N1533.8	W0376.5	1312.5	A	EX	D	90	12.0	1.875
L2S09	L2	N1533.5	W0376.2	1312.5	A	EX	D	90	12.0	1.875
L2S10	L2	N1533.2	W0375.9	1312.5	A	EX	D	90	12.0	1.875
L2S11	L2	N1532.9	W0375.6	1312.5	A	EX	D	90	12.0	1.875
L2S12	L2	N1532.6	W0375.3	1312.5	A	EX	D	90	12.0	1.875
L2S13	L2	N1532.6	W0375.0	1312.5	A	EX	D	90	12.0	1.875
L2S14	L2	N1532.9	W0374.7	1312.5	A	EX	D	90	12.0	1.875
L2S15	L2	N1533.2	W0374.4	1312.5	A	EX	D	90	12.0	1.875
L2S16	L2	N1533.5	W0374.1	1312.5	A	EX	D	90	12.0	1.875
L2S17	L2	N1533.8	W0373.8	1312.5	A	EX	D	90	12.0	1.875
L2S18	L2	N1534.1	W0373.45	1312.5	A	EX	D	90	12.0	1.875
L2S19	L2	N1534.4	W0373.45	1312.5	A	EX	D	90	12.0	1.875
L2S20	L2	N1534.7	W0373.8	1312.5	A	EX	D	90	12.0	1.875
L2S21	L2	N1535.0	W0374.1	1312.5	A	EX	D	90	12.0	1.875
L2S22	L2	N1535.3	W0374.4	1312.5	A	EX	D	90	12.0	1.875
L2S23	L2	N1535.6	W0374.7	1312.5	A	EX	D	90	12.0	1.875
L2S24	L2	N1515.8	W0375.0	1312.5	A	EX	D	90	12.0	1.875
L2S25	L2	N1515	W0365	1312.5	A	EX	D	90	12.0	2
L2S26	L2	N1515	W0365	1312.5	A	EX	D	90	12.0	2
L2S27	L2	N1515	W0365	1312.5	A	EX	D	90	12.0	2
L2S28	L2	N1515	W0365	1312.5	A	EX	D	90	12.0	2
L2S29	L2	N1515	W0365	1312.5	A	C	D	90	7.7	5
L2S30	L2	N1535.8	W0354.43	1312.5	A	EX	D	90	12	4
L2S31	L2	N1534.9	W0354.9	1312.5	A	EX	D	90	12	4
L2S32	L2	N1534.2	W0355.6	1312.5	A	EX	D	90	12	4
L2S33	L2	N1533.8	W0355.6	1312.5	A	EX	D	90	12	4
L2S34	L2	N1533.2	W0354.9	1312.5	A	EX	D	90	12	4
L2S35	L2	N1532.6	W0354.3	1312.5	A	EX	D	90	12	4
L2S36	L2	N1532.6	W0353.7	1312.5	A	EX	D	90	12	4
L2S37	L2	N1533.2	W0353.0	1312.5	A	EX	D	90	12	4
L2S38	L2	N1533.8	W0352.4	1312.5	A	EX	D	90	12	4
L2S39	L2	N1534.2	W0352.4	1312.5	A	EX	D	90	12	4
L2S40	L2	N1534.9	W0353.0	1312.5	A	EX	D	90	12	4
L2S41	L2	N1535.8	W0353.7	1312.5	A	EX	D	90	12	4
L2S42	L2	N1525.8	W0375.3	1312.5	A	EX	D	90	12	4
L2S43	L2	N1525.2	W0375.9	1312.5	A	EX	D	90	12	4
L2S44	L2	N1524.5	W0376.7	1312.5	A	EX	D	90	12	4
L2S45	L2	N1523.9	W0376.7	1312.5	A	EX	D	90	12	4
L2S46	L2	N1523.2	W0375.9	1312.5	A	EX	D	90	12	4
L2S47	L2	N1522.6	W0375.3	1312.5	A	EX	D	90	12	4
L2S48	L2	N1522.6	W0374.7	1312.5	A	EX	D	90	12	4
L2S49	L2	N1523.2	W0374.1	1312.5	A	EX	D	90	12	4
L2S50	L2	N1523.9	W0373.8	1312.5	A	EX	D	90	12	4
L2S51	L2	N1524.5	W0373.8	1312.5	A	EX	D	90	12	4
L2S52	L2	N1525.2	W0374.1	1312.5	A	EX	D	90	12	4
L2S53	L2	N1525.8	W0374.7	1312.5	A	EX	D	90	12	4
L2T01	L2	N1535.8	W0375.05	1312.5	A	EX	D	90	12.0	1.875
L2T02	L2	N1532.6	W0375.05	1312.5	A	EX	D	90	12.0	1.875
L2T03	L2	N1535.8	W0353.95	1312.5	A	EX	D	90	12	1.875
L2T04	L2	N1532.6	W0353.95	1312.5	A	EX	D	90	12	1.875
L2T05	L2	N1525.79	W0375.05	1312.5	A	EX	D	90	12	1.875
L2T06	L2	N1522.59	W0375.05	1312.5	A	EX	D	90	12	1.875
LH1	4	?? New	Number		D	C				
LH2	4	?? New	Number		D	C				
LH3	4	?? New	Number		D	C				
LH4	4	?? New	Number		D	C				
LMG1		S0016	W0006	1277	A	I	U__	90	6.25	1
LMG2		S0028	W0009	1276.5	A	I	U	90	5.9	1
LMG3		S0028	W0003	1276.5	A	I	U	90	6.3	1
LMG4		S0065	W0007	1274	A	I	U	90	8.6	1
MAA01	M	N1425.17	E1688.9	1300	P	EX	D,E	60	11.66	4
MAA11	M	N1453.67	E1688.9	1300	P	EX	D,W	60	12.0	4

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PRELIMINARY INVENTORY OF UNDERGROUND DRILL HOLES AT WIPP
1439 Records of Holes Drilled Before July 1985
(NOTE: This List Contains Unchecked Information)

Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
MAA12	M	N1455.67	E1688.9	1300	P	EX	D,E	60	12.0	4
MAA21	M	N1459.17	E1689.9	1300	P	EX	D,W	60	13.25	4
MAA22	M	N1461.17	E1687.9	1300	A	EX	D,E	60	13.25	4
MAA31	M	N1446.17	E1691.3	1300	A	EX	D,W	60	14.25	4
MAA32	M	N1449.17	E1686.5	1300	P	EX	D,E	60	14.25	4
MAE11	M	N1453.67	E1682.9	1300	P	EX	D	90	10.27	6
MAE12	M	N1455.67	E1694.9	1300	P	EX	D	90	10.27	6
MAE21	M	N1459.17	E1682.9	1300	P	EX	D	90	11.27	16
MAE22	M	N1461.17	E1694.9	1300	P	EX	D	90	11.27	16
MAE31	M	N1446.17	E1682.9	1300	P	EX	D	90	12.27	36
MAE32	M	N1449.17	E1694.9	1300	P	EX	D	90	12.27	36
MAI11	M	N1454.47	E1682.9	1300	P	EX	D	90	6.66	1.87
MAI12	M	N1452.87	E1682.9	1300	P	EX	D	90	6.66	1.87
MAI21	M	N1460.42	E1682.9	1300	P	EX	D	90	7.16	1.87
MAI22	M	N1457.92	E1682.9	1300	P	EX	D	90	7.16	1.87
MAI31	M	N1448.27	E1682.9	1300	P	EX	D	90	7.66	1.87
MAI32	M	N1444.07	E1682.9	1300	P	EX	D	90	7.66	1.87
MAP01	M	N1425.17	E1694.9	1300	P	EX	D	90	10	6
MAP02	M	N1421.17	E1694.9	1300	P	EX	D	90	10	4
MB139-1		N0079	W0006	1264.1	A	C	D	90	10.0	3
MB139-2		S0410	E0150	1251.2	A	C	D	90	15.7	3
MB139-3		S0101	E0157	1260.5	A	C	D	90	16.0	3
MB139-4		S0099	W0017	1258.7	A	C	D	90	16.2	3
MIIT01	J	N1087.99	W0379.09	1290.99	B	EX	D	90	3.1	3.25
MIIT02	J	N1088.03	W0377.02	1290.81	B	EX	D	90	2.9	3.25
MIIT03	J	N1086.02	W0379.09	1290.89	B	EX	D	90	3.2	3.25
MIIT04	J	N1086.05	W0377.13	1290.82	B	EX	D	90	2.77	3.25
MIIT05	J	N1084.07	W0379.04	1290.78	B	EX	D	90	3.07	3.25
MIIT06	J	N1084.06	W0377.15	1290.55	B	EX	D	90	3.12	3.25
MIIT07	J	N1084.07	W0379.04	1290.78	B	EX	D	90	3.12	3.25
MIIT08	J	N1082.08	W0377.24	1290.48	B	EX	D	90	3.05	3.25
MIIT09	J	N1080.02	W0379.05	1290.42	B	EX	D	90	2.97	3.25
MIIT10	J	N1079.98	W0377.23	1290.38	B	EX	D	90	3.08	3.25
MIIT11	J	N1078.43	W0379.31	1290.03	B	EX	D	90	2.92	3.25
MIIT12	J	N1078.11	W0377.21	1290.20	B	EX	D	90	3.05	3.25
MIIT13	J	N1075.91	W0379.10	1289.89	B	EX	D	90	3.20	3.25
MIIT14	J	N1076.18	W0377.30	1289.85	B	EX	D	90	3.05	3
MIIT15	J	N1074.21	W0379.01	1289.25	B	EX	D	90	2.90	3
MIIT16	J	N1074.17	W0377.18	1289.2	B	EX	D	90	2.98	3
MIIT17	J	N1072.03	W0379.10	1290.31	B	EX	D	90	3.25	3
MIIT18	J	N1071.91	W0377.18	1290.25	B	EX	D	90	2.92	3
MIIT19	J	N1069.99	W0379.08	1290.77	A	EX	D	90	6.10	3
MIIT20	J	N1069.84	W0377.22	1290.34	B	EX	D	90	5.98	3
MIIT21	J	N1068.04	W0379.08	1290.60	B	EX	D	90	5.92	3
MIIT22	J	N1067.93	W0377.23	1290.44	B	EX	D	90	5.82	3
MIIT23	J	N1065.74	W0379.22	1260.77	B	EX	D	90	6.35	3
MIIT24	J	N1065.79	W0377.21	1290.74	B	EX	D	90	5.98	3
MIIT25	J	N1074.01	W0361.72	1291	B	EX	D	90	3.0	3
MIIT26	J	N1088.18	W0359.95	1290.77	B	EX	D	90	2.9	3
MIIT27	J	N1076.14	W0361.70	1291.03	B	EX	D	90	3.0	3
MIIT28	J	N1086.16	W0359.89	1290.67	B	EX	D	90	2.8	3
MIIT29	J	N1078.04	W0361.77	1290.98	B	EX	D	90	3.0	3
MIIT30	J	N1084.12	W0359.82	1290.59	B	EX	D	90	3.0	3
MIIT31	J	N1080.18	W0361.86	1291.09	B	EX	D	90	3.0	3
MIIT32	J	N1082.14	W0359.82	1290.80	B	EX	D	90	2.9	3
MIIT33	J	N1082.21	W0361.74	1291.18	B	EX	D	90	3.0	3
MIIT34	J	N1080.08	W0359.88	1291.04	B	EX	D	90	3.0	3
MIIT35	J	N1084.18	W0361.96	1291.22	B	EX	D	90	3.0	3
MIIT36	J	N1078.12	W0359.78	1290.93	B	EX	D	90	3.0	3
MIIT37	J	N1086.18	W0361.87	1291.23	B	EX	D	90	3.0	3
MIIT38	J	N1076.07	W0359.77	1290.71	B	EX	D	90	3.0	3
MIIT39	J	N1088.26	W0361.92	1290.93	B	EX	D	90	2.9	3
MIIT40	J	N1074.06	W0359.61	1290.88	B	EX	D	90	3.0	3
MIITP	J	N1067	W0378	1290.8	A	P	D	90	8.8	1.5

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1439 Records of Holes Drilled Before July 1985
(NOTE: This List Contains Unchecked Information)

Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
N950A		N0949	E0000	1264	A	Gt	U	90	15.5	1
NG252	2	N1277.02	W0380.66	1294.89	B	I	D	90	7	1.5
NG254	2	N1276.39	W0380.29	1294.92	B	I	D	90	7	1.5
NG255	2	N1278.52	W0380.66	1294.89	B	I	D	90	7	1.5
NG256	2	N1276.39	W0382	1295	A	I	D	90	7	1.5
NoNumber		N0079	E0167.5	1267.8	A	?	E	0	25+	2
NoNumber		N0079	E0167.5	1288.5	A	?	E,U	10	25+	2
NoNumber		N0070	E0167.5	1269.9	A	?	E,U	20	25+	2
NoNumber		N1099	E0001	1310.6	A	Dril	U	90	3	8
NoNumber		N1099	E0001	1310.6	A	Dril	U	90	3	2
OH02		S0402	E0143	1260.5	A	O	U	90	20	4
OH03	2	N1265	W0364.5	1307.7	A	O	U	90	20.0	4
OH04		N1115.14	W0363.04	1309.72	A	O	U	90	20.0	4
OH05		S0400	E0045	1261	A	O	U	90	20.0	4
OH06		N1100	W0005	1310.6	A	O	U	90	20.0	4
OH07		S0070	E0000	1274	A	O	U	90	20.0	4
OH08		N0139	W0004	1280.4	A	O	U	90	20.0	4
OH09		N1433	W0231.5	1310	A	O	U	90	15.4	4
OH10		N1420	W0230	1310	A	O	U	90	21.0	4
OH11		N1433	W0364.5	1308	A	O	U	90	19.7	4
OH12		N1420	W0365	1308	A	O	U	90	18	4
OH13		N1433	W0231.5	1298	A	O	D	90	9.5	4
OH14		N1433	W0364.5	1296	A	O	D	90	9.7	4
P4001	4	N1155	W0613	1304	A	EX	U,E	45	34.4	4
P4002	4	N1143	W0613	1304	A	EX	U,E	45	34.4	4
P4003	4	N1151	W0613	1304	A	EX	U,E	45	34.4	4
P4004	4	N1148	W0613	1304	A	EX	U,E	45	34.4	4
P4301	4	N1168.6	W0614.4	1297.1	P	I	E	0	50	1.875
P4351	4	N1165.3	W0614.3	1297.1	P	I	E	90	33	3
P4399	4	N1170.4	W0614.3	1297.1	P	I	E	90	30	1.875
P4511	4	N1265.0	W0614	1298.5	P	I	E	0	48	2.5
P4512	4	N1260.0	W0614.0	1298.5	P	I	E	0	48	2.5
P4513	4	N1255.0	W0614.0	1298.5	P	I	E	0	48	2.5
P4514	4	N1250.0	W0614.0	1298.5	P	I	E	0	48	2.5
P4521	4	N1284	W0614	1298.5	A	I	E	0	48	2.5
P4522	4	N1289	W0614	1298.5	A	I	E	0	48	2.5
P4523	4	N1294	W0614	1298.5	A	I	E	0	48	2.5
P4524	4	N1299	W0614	1298.5	A	I	E	0	48	2.5
P4525	4	N1304	W0614	1298.5	A	I	E	0	49.0	4
P4531	4	N1240.0	W0614.0	1298.5	P	I	E	0	49	2
P4532	4	N1235.0	W0614.0	1298.5	P	I	E	0	49	2
P4541	4	N1309	W0614	1298.5	A	I	E	0	48?	3
P4542	4	N1314	W0614	1298.5	A	I	E	0	48?	3
P4701	4	N1171.0	W0614.2	1297.1	P	I	E	0	50	1.875
P4702	4	N1160.0	W0619.0	1305.0	P	EX	U,E	45?	150	2
P4X01	4	N1395	W0630.5?	1292	A	C	D	90	8	5.25
P4X02	4	N1386.5	W0633.5	1292.0	P	C	D	90	8	5.25
P4X03	4	N1389.8	W0627.5	1292.0	P	C	D	90	8	5.25
P4X04	4	N1373.3	W0633.5	1292.0	P	C	D	90	8	5.25
P4X05	4	N1379.1	W0630.5	1292.0	P	C	D	90	8	5.25
P4X06	4	N1373.9	W0627.5	1292.0	P	C	D	90	8	5.25
P4X15	4				D	RM,D				
P4X16	4	N1358	W0646	1299	A	RM	W	0	10.5	16
P4X17	4	N1358	W0646	1296	A	RM	W	0	10.1	16
P4X18	4	N1148	W0613	1302	A	CS	E	0	5.9	16
P4X19	4	N1143	W0613	1302	A	CS	E	0	6.0	16
P4X20	4					C	D	90	15.0	4
P4X20A	4				A	C	D	90	17.9	16
P4X21		N1440	W0510	1302	A	CS	N	0	3	16
P4X25	4	N1364	W0631	1292	A	C,RM	D	90	50.2	5
P4X26	4	N1364	W0631	1305	A	C	U	90	52.1	5
P4X27	4	N1361	W0631	1292	A	C	D	90	51.05	5
P4X28	4	N1361	W0631	1305	A	C	U	90	50.4	4
P4X29	4	N1362.6	W0627.5	1292	A	C	D	90	49.5	5

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1439 Records of Holes Drilled Before July 1985
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Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
P4X30	4	N1360	W0628.5	1305	A	C	U	90	50.9	4
P4X31	4	N1360	W0628.5	1292	A	C	D	90	50.35	5
P4X32	4	N1346	W0631	1292	A	C	D	90		NX
P4X40		N1122.0	W0582.5	1294.5	A	AE	N	0	11.4	3
P4X41		N1122.0	W0581.5	1295.0	A	AE	N	0	10.5	3
P4X42		N1122.0	W0581.5	1297.0	A	AE	N	0	10.55	3
P4X43		N1122.0	W0581.5	1301.0	P	AE	N	0	10.95	3
P4X44		N1122.0	W0579.5	1295.0	A	AE	N	0	10.88	3
P4X45		N1122.0	W0573.0	1295.0	A	AE	N	0	11.44	3
P4X46		N1122.0	W0580.5	1296.2	A	C,AE	N	0	9.5	4
P4X50	4	N1160.0	W0614.0	1297.0	P	DD	E	0	100	1.875
P4X51	4	N1151.0	W0614.0	1297.0	P	DD	E	0	100	3
P4X52	4	N1160.0	W0619.0	1292.25	P	DD	D	90	50	2
P4X61	4	N1141	W0643.5	1297	A	DD	W	0	50	1.875
P4X81	4	N1141	W0643.5	1294	A	C,DD	D	90	18.7	16
P4X82	4	N1141	W0631	1294	A	C,DD	D	90	17.0	30
P4X83	4	N1155	W0643	1294	A	C,DD	D	90	6.1	16
P4X84	4	N1138	W0644	1294	A	C	D	90	15.7	36
P4X85	4	N1163?	W0643	1294	A	C,DD	D	90	?	36
P4X86	4	N1113	W0613	1302.5	A	DD	E	0	1.9	16.5
P4X?1	4	N1358	W0643	1305	A		U	90	7	6
P4X?2	4	N1143	W0613	1296	A		E	0		
P4X?3	4	N1170	W0646	1294	A		W	0	25+	2.5
P4X?4	4	N1173	W0646	1294	A	I	W	0	13+	2
P4X?5	4	N1177	W0642.5	1292	A		D	90	7	5
P4X?6	4	N1141	W0643.5	1298	A		W	0		1.875
P4X?7	4	N1235	W0625	1293	A		U	90		5?
P4X?9	4					ST	U	90	50	4
P4X?9A	4					C,RM	W	0	10	16
PC1	4	?? New	Number			I	E	0	50	3
PC2	4	?? New	Number			I	E	0	50	3
PC3	4	?? New	Number			I	E	0	50	3
PC4	4	?? New	Number		D	I				
PR01		S1000	E0140	1260	A	PR	U	90	20	2
PR02		S1600	E0140	1271.2	A	PR	U	90	20	2
PR03		S2182	E0140	1263	A	PR	U	90	20	2
PR04		S2748	E0140	1250	A	PR	U	90	20	2
PR05		S3314	E0140	1250	A	PR	U	90	20	2
PR06		S0090	E0140	1274	A	PR	U	90	20	2
PR07		N0460	E0000	1286	A	PR	U	90	20	2
PR08		N0460	E0140	1287	A	PR	U	90	20	2
PR09		N0780	E0000	1298	A	PR	U	90	20	2
PR10		N0780	E0140	1298	A	PR	U	90	20	2
PR11		N1420	W0365	1309	A	PR	U	90	20	2
PR12		N1100	W0620	1305	A	PR	U	90	20	2
PR13		N1420	W0620	1305	A	PR	U	90	20	2
PR14		N1100	E0140	1309	A	PR	U	90	20	2
PR15		N0140	E0140	1280	A	PR	U	90	20	2
PR16		N1420	W0498	1306	A	PR	U	90	20	2
PR17		S0398	E0138	1260.5	A	PR	U	90	20	2
PR?		N1109	E0348	1318	A	PR	U	90	20?	2
PR?		N1109	E0456.5	1318	A	PR	U	90	20?	2
PR?		N1112	E1411	1320	A	PR	U	90	20?	2
RM1	4	?? New	Number		D	C				
RM2	4	?? New	Number		D	C				
RM3	4	?? New	Number		D	C				
RM4	4	?? New	Number		D	C				
RM5	4	?? New	Number		D	C				
RM6	4	?? New	Number		D	C				
RM7	4	?? New	Number		D	C				
S1160A		S1160	E0140	1265	A	Gt	U	90	47	3.5
S2575A		S2575	E0140	1266	A	Gt	U	90	12.9	1
S550A		S0550	E0140	1260	A	Gt	U	90	12.9	1
S850A		S0850	E0140	1259	A	Gt	U	90	8.8	1

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Hole Number	Room	N-S Coord.	E-W Coord.	Elevation	Accuracy	Purp.	Dir.	Angle	Depth (Ft)	Dia. (In)
S850C		S0850	E0140	1251	A	Gt	D	90	16.1	1
SH1	4	?? New	Number			ST	D	90	44	4
SH2	4	?? New	Number			ST	U	90	50	5.25
SH3	4	?? New	Number			ST	D	90	50	5.25
SH4	4	?? New	Number			ST	D	90	50	5.25
SH5	4	?? New	Number			LT,S	W	0	10	16
SM01	4	?? New	Number			I	E	0	50	1.875
SM02	4	?? New	Number			I	E	0	50	1.875
SM03	4	?? New	Number			I	E	0	50	1.875
SM04	4	?? New	Number			I	E	0	50	1.875
SM05	4	?? New	Number			I	E	0	50	1.875
SM06	4	?? New	Number			I	E	0	50	2.25
SM07	4	?? New	Number			I	E	0	50	2.25
SM08	4	?? New	Number			I	E	0	50	2.25
SM09	4	?? New	Number			I	E	0	50	2.25
SM10	4	?? New	Number			I	E	0	50	2.25
SM11		N0237.7	E0153	1280	A	I	E	0	50	3
SM12		N0232.2	E0153	1280	A	I	E	0	50	3
SM13		N0227.2	E0153	1280	A	I	E	0	50	3
SM14		N0222.4	E0153	1280	A	I	E	0	50	3
SM15		N0217.0	E0153	1280	A	I	E	0	50	3
SM16		N0211.8	E0153	1280	A	I	E	0	50	3
T15	T				A	C				
T19	T				A	C				
V1SE		S0436	W0013	1262	A	LT,C	U	90	2.6	4
V2SE		S0437	W0012	1262	A	LT,C	U	90	3.5	4
V3SF		S0438	W0018	1262	A	LT,C	U	90	4.3	4
WG201		S0030	W0004	1276	A	I	U	90	15	1.62
WG202		S0030	E0004	1276	A	I	U	90	15	1.62
WG203		S0065	W0004	1274	A	I	U	90	10	1.62
WG204		S0065	E0004	1274	A	I	U	90	10	1.62

APPENDIX B
LIST OF UNDERGROUND DRILL HOLES WHERE BRINE OCCURRENCES WERE OBSERVED AND MONITORED FOR PHASE I OF THE BRINE SAMPLING AND EVALUATION PROGRAM AT WIPP.

Hole Number	Room	Location Accuracy S=Survey A=Approx	N-S Coord	E-W Coord	Elevation	Dia. (in)	Depth (ft)	Direction	Angle	References	Remarks Brine,gas and general.
A1X01	A1	S	N1147.02	E1254.40	1313.26	4	49.75	D	90	B, D, E	Monitored as part of the BSEP since it was drilled in 3/85.
A1X02	A1	S	N1146.88	E1254.24	1331.29	4	59.0	U	90	B, D, E	Monitored as part of the BSEP since it was drilled in 3/85.
A2X01	A2	S	N1393.72	E1338.88	1311.20	4	50.15	D	90	B, D, E	Monitored as part of the BSEP since it was drilled in 2/85
A2X02	A2	S	N1393.65	E1338.89	1328.86	4	52.75	U	90	B, D, E	Monitored as part of the BSEP since it was drilled in 2/85.
A3X01	A3	S	N1137.94	E1406.84	1309.78	4	50.5	D	90	B, D, E	Monitored as part of the BSEP since it was drilled in 1/85. Drillers did not report any moisture while drilling. Hole started producing brine few weeks later.
A3X02	A3	S	P1138.00	E1406.89	1327.93	4	50.75	U	90	B, D, E	Monitored as part of the BSEP since it was drilled 1/85. Drillers did not encounter moisture while drilling. Hole started producing brine few weeks later.
BX01	B	S	N1384.68	E0982.33	1317.44	4	50.15	D	90	B, E	Monitored as part of the BSEP since it was drilled in 1/85.
BX02	B	S	N1384.44	E0982.87	1335.47	4	49.25	U	90	B, E	Monitored as part of the BSEP since it was drilled in 1/85.
DH035	G	A	N1102	W1882	1294.4	3.5	52.0	U	90	A3, B	Monitored as part of BSEP since 2/85.
DH036	G	A	N1102	W1882	1284.6	3.5	51.5	D	90	A3, B	Monitored as part of BSEP since 1/85.
DH037	G	S	N1101	W2182	1297.4	3.5	51.5	U	90	A3, B	Monitored as part of BSEP since 1/85. At the present no brine is collected because of insufficient inflow.
DH038	G	S	N1101	W2182	1287.0	3.5	47.5	D	90	A3, B	Monitored as part of BSEP since 1/85.
DH039	G	S	N1101	W2482	1296.0	3.5	50.7	U	90	A3, B	Monitored as part of BSEP since 2/85. At the present no brine is collected because of insufficient inflow.
DH040	G	S	N1101	W2482	1286.1	3.5	51.0	D	90	A3, B	Monitored as part of BSEP since 1/85.
DH041	G	S	N1101	W2782	1295.8	3.5	49.9	U	90	A3, B	Monitored as part of BSEP since 2/85. At the present no brine is collected because of insufficient inflow.
DH042	G	S	N1101	W2782	1285.9	3.5	51.2	D	90	A3, B	Monitored as part of the BSEP since 2/85.
DH042A	G	S	N1101	W2789	1285.7	3.5	40.5	D	90	A3, B	Monitored as part of the BSEP since 2/85.
DH215		S	S1960	E0153	1272.0	3	52.0	U	90	A1, B	Gas releases had been observed in this hole. Monitored as part of the BSEP since 1/85.
DH216		S	S1960	E0153	1262.6	3	54.2	D	90	A1, B	Gas releases had been observed in this hole. Monitored as part of the BSEP from 1/85 to 6/85.
DH317		S	S1600	W0033	1271.3	3	50.1	U	90	A2, B	Stalactite growth monitored as part of BSEP from 05/07/85 to 01/31/86.
DH317A		S	S1600	W0030	1271.2	3	5.0	U	90	A2, B	Stalactite growth monitored as part of BSEP from 05/07/85 to 01/31/86.
DH317B		S	S1597	W0030	1271.2	3.5	51.0	U	90	A2, B	Gas pocket at 45.91. Brine seeped from hole after drill rods were broken at end of run at depth of 16.3 ft. Probable source was anhydrite "a". Monitored as part of BSEP from 05/07/85 to 01/31/86.
IG201	2	S	N1275.54	W0379.51	1294.97	2.875	53.83	D	90	A3, B, H, J	Monitored as part of BSEP since 11/84.
IG202	1	S	N1264.79	W0246.11	1296.49	2.875	48.16	D	90	A3, B, H, J	Monitored as part of BSEP since 11/84.
JV8	J	S	N1067	W0374	1290	36	8.1	D	90	D, F, G	Drilled 8/08/85, drillers reported water at 7 ft 10 inches.
JV9	J	S	N1067	W0378	1290.4	36	8.1	D	90	D, G	Brine in bottom of pilot hole on 8/20/85.
L1S25	L1	A	N1524	W0218	1312	4	11.90	D	90	B, H	Monitored as part of BSEP since 12/10/85.
L1S26	L1	A	N1524	W0220	1312	4	11.72	D	90	B, H	Monitored as part of BSEP since 12/10/85.
L1S27	L1	A	N1524	W0222	1312	4	11.93	D	90	B, H	Monitored as part of BSEP since 12/10/85.
L1S29	L1	A	N1524	W0226	1312	4	12.03	D	90	B, H	Monitored as part of BSEP since 12/10/85.
L1S30	L1	A	N1524	W0228	1312	4	12.18	D	90	B, H	Monitored as part of BSEP since 12/10/85.
L1S32	L1	A	N1524	W0237	1312	4	11.95	D	90	B, H	Monitored as part of BSEP since 12/10/85.
L1S33	L1	A	N1524	W0239	1312	4	11.98	D	90	B, H	Monitored as part of BSEP since 12/10/85.

APPENDIX B
LIST OF UNDERGROUND DRILL HOLES WHERE BRINE OCCURRENCES WERE OBSERVED AND MONITORED FOR PHASE I OF THE BRINE SAMPLING AND EVALUATION PROGRAM AT WIPP.

Hole Number	Room	Location Accuracy S=Survey A=Approx	N-S Coord	E-W Coord	Elevation	Dia. (in)	Depth (ft)	Direction	Angle	References	Remarks Brine,gas and general.
L1S36	L1	A	N1524	W0245	1312	4	12.22	D	90	B, H	Monitored as part of BSEP since 12/10/85.
L1X00	L1	A	N1538.5	W0225	1312	4	12.45	D	90	B, H	Drillers reported "found water in hole at 10 ft, 5/13/84", monitored since 10/26/84.
L2C25	L1	A	N1510	W0365	1312	5	11.36	D	90	B, H	Monitored as part of BSEP since 12/17/85.
MIIT02	J	S	N1088.03	W0377.02	1290.81	3.25	2.9	D	90	B, D, G	Brine since drilled, monitored from 10/26/85 to 4/23/85.
MIIT04	J	S	N1086.05	W0377.13	1290.82	3.25	3.275	D	90	B, D, G	Brine since drilled, monitored from 10/26/84 through 4/23/85.
MIIT06	J	S	N1084.16	W0377.15	1290.55	3.25	3.125	D	90	B, D, G	Brine since drilled, monitored from 10/26/84 through 4/23/85.
MIIT08	J	S	N1082.08	W0377.24	1290.48	3.25	3.05	D	90	B, D, G	Brine since drilled, monitored from 10/26/84 to 4/23/85.
MIIT10	J	S	N1079.98	W0377.23	1290.38	3.25	3.075	D	90	B, D, G	Brine since drilled, monitored from 10/26/84 through 4/23/85.
MIIT12	J	S	N1078.11	W0377.21	1290.20	3.25	3.05	D	90	B, D, G	Brine since drilled, monitored from 10/26/84 through 4/23/85.
MIIT14	J	S	N1076.18	W0377.30	1289.85	3	3.05	D	90	B, D, G	Brine since drilled, monitored from 10/26/84 through 4/23/85.
MIIT16	J	S	N1074.17	W0377.18	1289.2	3	2.975	D	90	B, D, G	Brine since drilled, monitored from 10/26/84 through 4/23/85.
MIIT17	J	S	N1072.03	W0379.10	1290.31	3	3.250	D	90	B, D, G	Brine since drilled, monitored from 10/26/84 through 4/23/85, Sandia filled hole with Brine A solution 4/30/85.
MIIT18	J	S	N1071.91	W0377.18	1290.25	3	3.925	D	90	B, D, G	Brine since drilled, monitored from 10/26/84 through 4/23/85, Sandia Experiment filled hole with Brine A 04/20/85 and plugged hole with rubber cork.
MIIT20	J	S	N1069.84	W0377.22	1290.34	3	5.975	D	90	B, D, G	Brine noted 10/26/84, monitored from 10/26/84 through 4/23/85.
MIIT22	J	S	N1067.93	W0377.23	1290.44	3	5.825	D	90	B, D, G	Brine noted 10/26/84, monitored from 10/26/84 through 4/23/85.
MIIT24	J	S	N1065.79	W0377.21	1290.74	3	5.975	D	90	B, D, G	Brine noted 10/26/84, monitored 10/26/84 through 4/23/85, Sandia experiment added Brine A to hole 4/30/85 and capped with rubber cork.
MIITP	J	A	N1067	W0378	1290.8	1.5	8.8	D	90	B, F	Brine since drilled, pilot hole for 36-inch diameter hole that was never completed. Monitored from 4/02/85 through 4/23/85.
NG252	2	S	N1275.86	W0381.05	1294.89	1.5	7.54	D	90	A3, B, H, J	Monitored as part of the BSEP since 11/84. This hole continues to produce gas, first time noticed before 10/84.
PR02		A	S1600	E0140	1271.2	2	20	U	90	B, C	Stalactite growth monitored as part of the BSEP from 05/07/1985 to 02/19/1986.
PR03		A	S2182	E0140	1263	2	20	U	90	B, C	Stalactite growth monitored as part of the BSEP from 05/07/85 to 02/19/86.
PR04		A	S2748	E0140	1250	2	20	U	90	B, C	Stalactite growth monitored as part of the BSEP from 05/07/85 to 02/19/86.

APPENDIX C

GAS OCCURRENCES AT THE MINING FACE IN THE WIPP REPOSITORY EXCAVATIONS, MARCH AND APRIL, 1986

by Richard Deshler
IT Corporation

A review of WIPP mining operations shift reports has been made for any documented occurrences of gas at the mining face which were described as "audible" releases prior to March 21, 1986. Only two such documented occurrences were noted. These were reported on February 6, 1983, in the face at E0, N800, and on April 1, 1984 in the C2 alcove.

There were several reports of gas releases from holes drilled into the roof of the facility. This type of occurrence is not uncommon at WIPP and only those occurrences considered anomalous are reported here.

The only notable cases of gas encountered in the face were those which occurred during mining activities in the S2180 area during March and April of 1986. None of these resulted in any personnel injury or property damage. These encounters are described below:

1. A small release occurred during mining in the S2180 drift at about E233 on March 21, 1986. The same day, a horizontal probe hole drilled ahead of the face also encountered gas.

2. A pressure relief hole drilled into the roof of the S1950 and E300 intersection in December, 1985 began venting <u>during mining</u> to the south of this intersection on April 7, 1985. In addition, a small release was noted in the horizontal probe hole in the E300 drift on April 2, 1986.

3. A small release occurred in the face during mining in the E300 drift at about S2140 on April 9, 1986.

REPORT OF GAS OCCURRENCE

Location: S2180 Drift Between E140 and E300

Date: March 21, 1986

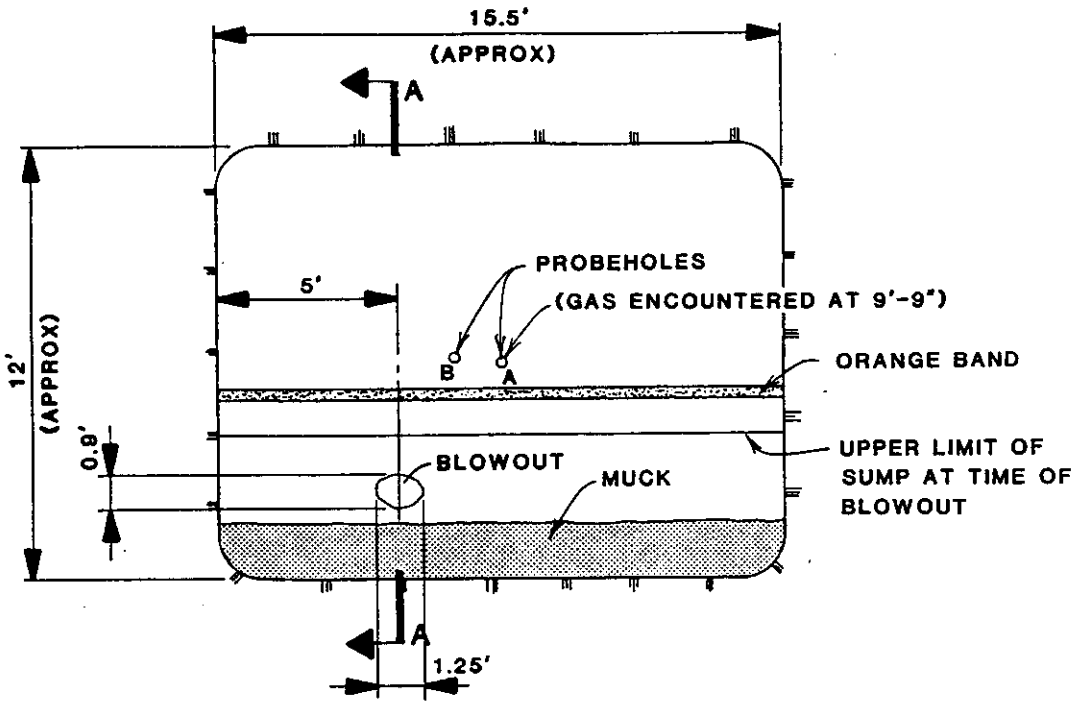
Description:

On Friday, March 21, 1986, at 1:00 p.m. the continuous miner was extending the S2180 drift to the east. While sumping the E233 face, a sudden exfoliation occurred, accompanied by the release of a small quantity of gas. A small slab of rock was thrown into the cutting head of the continuous miner. The miner operators reported hearing a sharp noise which was described as sounding like a shotgun discharge. All personnel were immediately evacuated from the area. All equipment, except the face fan, was shut off, and all appropriate safety and notification procedures were followed. A test was conducted for the presence of CH_4, NO_2, CO, H_2S, and SO_2, none of which were detected.

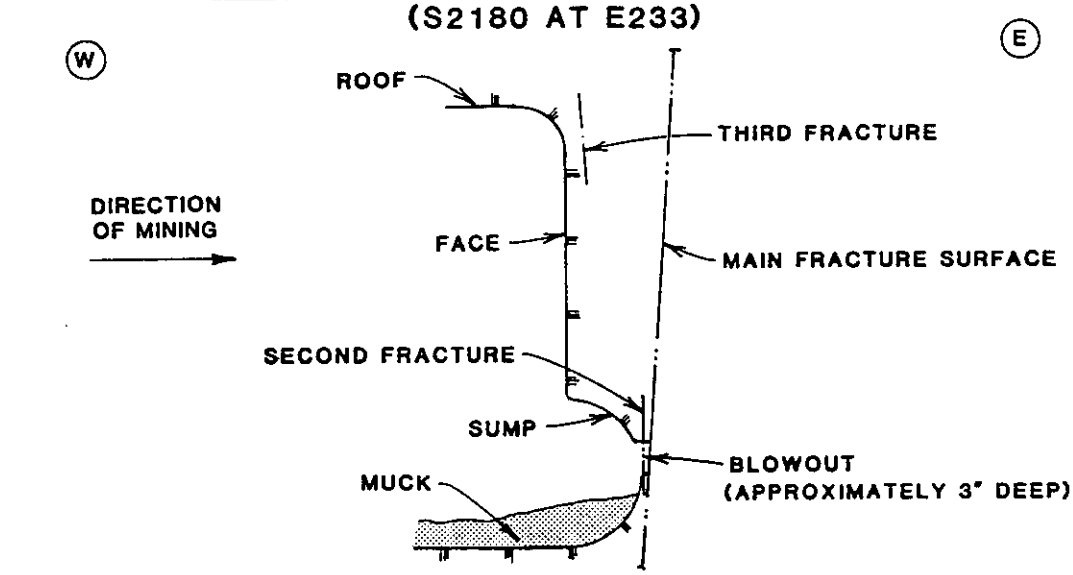
Inspection of the face showed that an oval-shaped slab of salt had exfoliated from the face. The slab was nearly vertical in orientation, 0.9 ft. high, 1.25 ft. long, and 0.25 ft. thick as shown in Figure C.1. The location was approximately 5 feet south of the north rib and 10 feet below the back. The source of the gas appeared to be two sub-parallel fractures oriented roughly north-south and dipping about 85 degrees to the west. The fractures were very clean, had no infilling, and no visible alteration of the surface. No brine was noted during the first examinations. However, on March 26, 1986, the day after mining, the main fractures stood out as a damp outline on the ribs, roof, and floor of the drift. The fractures appeared to be open 1/16 to 1/8 inch in the vicinity of the release, but mining showed them to be very tight away from the location of the gas release.

After mining was discontinued in the drift, mining operations proceeded to drill a horizontal probe hole close to the center of the face (Hole A, Figure C.1). At 5:00 p.m. the same afternoon, when the drill had penetrated to a depth of 9.75 feet, another fracture containing gas was encountered. The drill and 10 feet of drill steel were ejected from the hole accompanied by a brief noise like "a broken air hose." The area was again evacuated and another test was conducted for the presence of H_2S and SO_2 gas, neither of which were detected. Mining operations were suspended over the weekend. A second horizontal probe hole was drilled on Monday, March 24th, parallel to and about 2 feet north of the first hole, to a depth of 60 feet (Hole B, Figure C.1). No additional gas was noted.

Upon resumption of mining in the drift on March 25th, geotechnical personnel monitored the face advance to describe the fractures and any additional gas occurrences. As the face above the location of the exfoliation was mined, an additional gas release was observed. There was a visible "puff" of dust from the upper north corner of the face above and to the west of the exfoliation site. The continuous miner was shut down immediately, but no additional indications of a gas release were noted. This release came from a fracture which



VIEW LOOKING EAST AT WORKING FACE
(S2180 AT E233)



SECTION "A-A"

Figure C.1

Location of Gas Releases at the Working Face
at S2180 and E233

had a similar orientation to the fractures involved in the exfoliation and may have been part of the same fracture system. The fracture was very tight and had no evidence of infilling. However, a small and unmeasurable amount of brine and gas bubbles issued from this fracture. This fracture was not traceable once the area had been mined. The smell of "rotten vegetables" was reported in both of these cases of gas release.

As the mining face was advanced close to the point where the first probe hole encountered gas (9.75 ft.), excavation was carefully monitored. The source of the gas at that location was another near-vertical north-south trending fracture (Figure C.2). This fracture was very tight, hard to see, and not distinguishable in the roof or ribs after the area was mined. Continued mining eastward along S2180 exposed three additional fractures in the upper portion of the face with north-south trends and dips of about 50 degrees east (Figure C.2). It is not known whether these fractures are related to the gas-containing fracture encountered in the first probe hole or not. The fractures in the back have a much shallower dip, and there was no visible evidence of gas.

Careful monitoring of the mining continued, and other very minor, gas releases were noted. Most of the occurrences were in the form of small "weeps" of bubbling brine not associated with any recognizable fracturing, and generally not lasting more than 10 or 15 minutes. At S2180/E255, an audible hiss was noticed at the face. The hiss was only noticed after the continuous miner was shut down for lunch break. It was audible for about seven minutes, and minor amounts of brine and gas bubbles were still seeping from a fracture when mining resumed 20 minutes later. The fracture associated with this release was not as obvious or as well developed as the previous fractures.

In all of the cases listed, the "rotten vegetable" smell was present in various intensities. The odor was also often noted when approaching the face immediately after an area was mined.

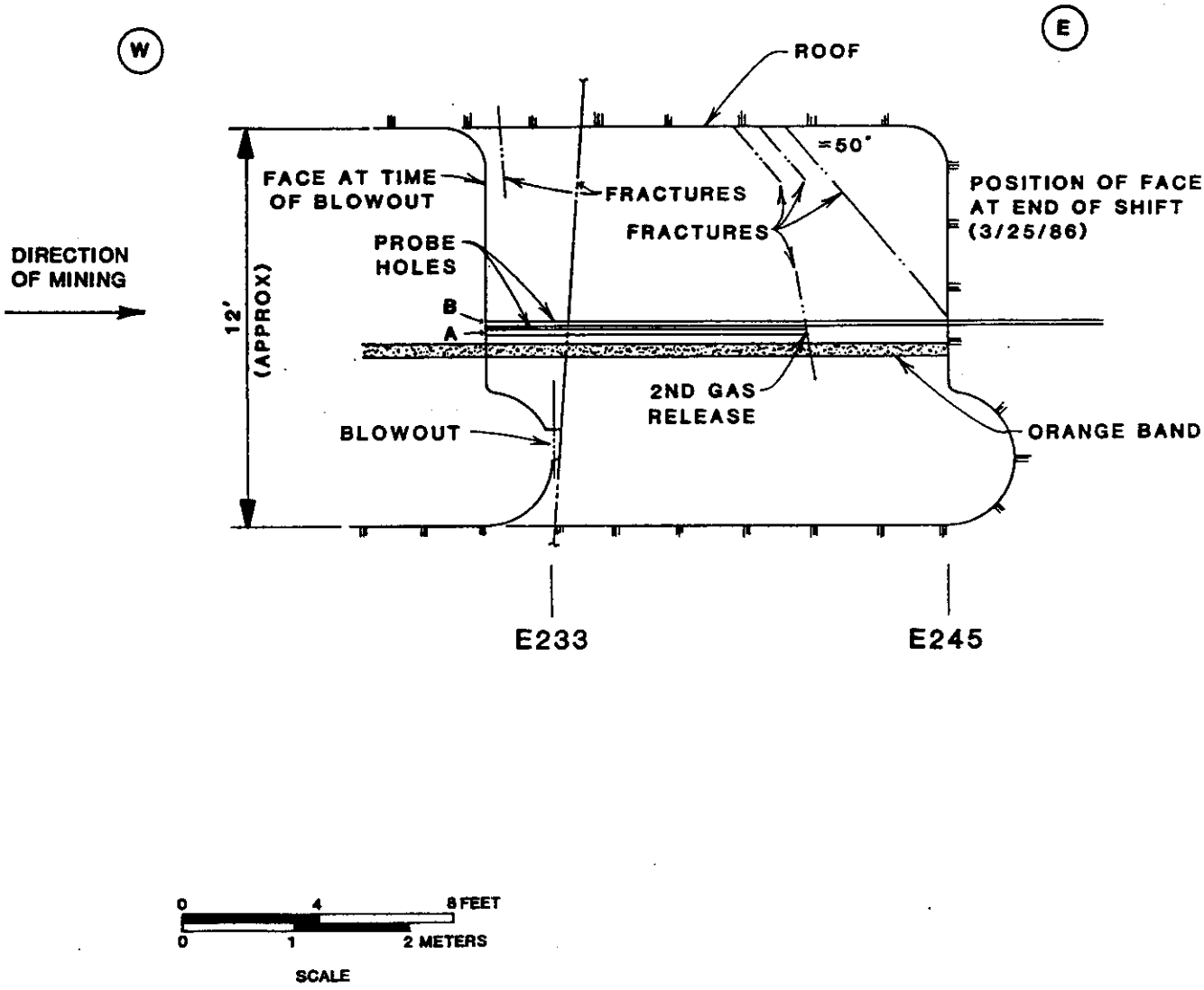


Figure C.2

Cross Section of the S2180 Drift
in the Vicinity of E233

REPORT OF GAS OCCURRENCE

Location: Intersection of S1950 and E300

Date: 3:00 p.m. on Monday, April 7, 1986

Description:

Gas was heard blowing from the vertical pressure release hole drilled into the back at the intersection of S1950 and E300 when the continuous miner was shut down at the end of the shift. Safety was notified and they ran tests for the presence of CH_4, CO, H_2S, NO_2, CO_2, and SO_2, none of which were detected. In addition, they reported being able to feel gas coming from the hole when a hand was placed at the opening and smelling a slight "rotten cabbage" odor. The mining face at the time of the gas release was at about S2090 in the E300 drift. The hole was not blowing when checked at 10:00 a.m. on Tuesday.

REPORT OF GAS OCCURRENCE

Location: E300 Drift at S2140

Date: April 9, 1986

Description:

On Wednesday, April 9, 1986, at about 10:00 a.m., there was a small gas release at S2140 in the E300 drift. A roughly oval-shaped piece of salt was rapidly exfoliated from the working face, accompanied by a small pop. Debris was thrown about 20 feet. This exfoliation left an elongate hole in the salt 2 ft. high, 0.6 ft. wide, and 0.0 to 0.2 ft. deep, increasing in depth from west to east. The release was located in the upper east corner of the face, about 1 foot below the back and 1 foot west of the east rib. The cutting head of the miner was sumping in the lower west corner of the face when the gas release occurred.

There was an obvious fracture at the back of the space left by the exfoliating slab of salt. The fracture was oriented N50E and dipped 53 degrees south. The fracture was open as much as 3/8 inch in the area of the cavity, but was very tight away from that immediate vicinity and disappeared entirely in the clayey zone below. The open part was in the clear halite and no evidence showed infilling or alteration of the surfaces to indicate whether or not there was a cavity there prior to mining.

Tests were conducted to detect the presence of H_2S, SO_2, NO_2, and CH_4, none of which were detected.

Another minor gas occurrence was noted in the E300 drift at about S1960 on April 2 at about 11.30 a.m. The mining machine had been cutting to the south and was shut down for lunch. An audible hiss was noted coming form the horizontal probe hole which had been drilled ahead of the face to the S2180/E300 intersection about a week earlier. No gas releases had been noted during drilling. The intensity of the hiss decreased gradually with time, but continued for at least 50 minutes and was still audible just before the miner started up after lunch.

APPENDIX D

PHASE I PRELIMINARY SAMPLING AND EVALUATION OF BRINE OCCURRENCES AT THE WIPP REPOSITORY HORIZON

This appendix contains a discussion of the Task 2 sampling activities that were part of Phase I of the WIPP Brine Sampling and Evaluation Program (BSEP). Included in this discussion is a description of sampling methodology, the manner in which the data was handled and calculations made, and a location-by-location description of both the sampling and the sampling results. The data obtained during Task 2 of Phase I are presented in tabular form in Appendix E.

1.0 SAMPLING METHODOLOGY AND PROBLEMS

The general procedure for brine collection and inflow measurements was simply to provide for the accumulation of the small brine inflows, to collect those accumulations on a periodic basis (approximately once a week for initial collections), and to measure the volume that had accumulated since the previous sampling. These measurements were then recorded and tabulated as the average fractions of liters per day collected from each location.

A variety of field techniques were used, depending upon the specifics of each occurrence. They can be broken down into the following groups:

- Initial volume measurements, experimental pumping techniques, and water-level measurements
- Vacuum-assisted sampling probe for brine removal from downholes
- Hand-operated rotary suction pump
- Continuous, gravity-driven collecting installations
- Pressure-vacuum and vacuum moisture-sampler installations

Additional details concerning the brine sampling procedures is provided in WIPP Procedure WP 07-410.

Down-hole sampling was done with a variety of bailing devices, most of which relied on check valves to retain collected brine while the bailer was raised to the surface (the floor of the repository workings). These devices occasionally failed when debris (mostly salt crystals and other muck in the holes) prevented the valves from seating properly, allowing some brine to leak from the sampler and flow down the inside of the drill hole. The result was an anomalously small recorded value for brine withdrawn at that time, usually followed the next week by a larger than expected amount. In most cases, the average of those two values was consistent with the trend of earlier and later readings. The result is a "kick" in the data that is not representative of the actual, much more consistent, inflow rates. Such sampling problems were noted on the field data sheets.

The bailing techniques would remove most, but not all of the brine in the hole. The amount of brine remaining in the hole was a fairly consistent amount, so the values obtained for "brine removed" were very close to the amount that actually flowed into the hole during the period between evacuations. After sampling, a visual inspection was made of the bottom of the hole to see if the bottom was at least partially exposed. If a partially-dry bottom was not observed after initial evacuation, the sampler was lowered to the bottom again and the evacuation repeated. After bailing, the downholes were plugged just below the collar with a piece of plastic foam which was covered, in turn, by a metal lid. The plug and lid prevented the inadvertent introduction of foreign solids into the hole and reduced moisture loss by evaporation to the repository atmosphere.

Evaporation has played a significant role in reducing the measured amounts of brine inflow, especially from the upholes. Several techniques were used to seal the collar of the upholes, but none of the techniques completely controlled evaporation. The projected high temperatures that will eventually be reached in Rooms A1, A2, A3, and B required that some of the materials used in the initial phases of the study be removed (they might give off deleterious vapors at high temperatures) and caused the replacement of some plastic items with metal.

Occasionally large "kicks" are observed in the uphole data. Many of these are a result of the clearing of a temporary blockage in the plastic tube leading from the collecting device at the hole collar to the collecting container. It was not uncommon for pieces of clay to slough from the clay seams exposed in the holes and for clay to fall down into the collecting device. The clay, in addition to pieces of salt that either fall from the sides of the hole or accumulate by the evaporation of brine, occasionally completely plugged the devices.

The result of these conditions and disruptions are that the data from the upholes should be considered as providing only minimum inflow data. Additionally, the effects of heat, the presence of metal, and the close proximity of many other holes need to be considered when evaluating the data from the A rooms and Room B.

2.0 DATA HANDLING AND CALCULATIONS

The data collected as part of the BSEP were initially recorded on field data sheets and then transferred to a computerized data base using an IBM XT microcomputer. Standard software programs (dBase III Plus and Lotus 1-2-3) were used for storage and calculations. Samples were collected about once a week except for special circumstances discussed later. The amount of brine removed was measured to the nearest hundredth of a liter and recorded, along with the date and time of collection, on the field data sheets. Brine levels were also measured and recorded. An approximation of the volume of brine in the downholes can be calculated from the height of the column of brine in the hole and the average diameter of the hole. The result of this calculation is less accurate than actually measuring the volume of brine removed, but the brine level was routinely measured prior to attempting evacuation of the accumulated brine. In a few instances, the brine level data were used to resolve apparent anomalies in the brine volume measurements that resulted from equipment failure or human error.

The dates and times at which collections were made were transformed into decimal days since an arbitrary reference date (January 1, 1985) and the elapsed time in decimal days between samples was used to calculate average brine inflow rates in terms of fractions of liters per day.

As described in Section 1.0, much of the variability in the quantity of brine collected resulted from limitations of the collecting techniques rather than variations in the actual inflow of brine from the bedrock into the collecting locations. As a result, plotting of the inflow data from the data tables (Appendix E) results in an irregular plot which implies variations in inflow that, in fact, do not exist. The graphed data included in this report were processed and plotted by a standard computer software program (STSC Statgraphics) on an IBM AT microcomputer, using a simple moving average to smooth the curves. A five-point moving average was used for the majority of the graphs. The smoothed result reflects trends that are representative of the brine inflow rates while still showing variations that are probably the result of collecting problems.

An alternative technique to smooth the data is to plot cumulative inflow against time, fit a curve to that plot, and then differentiate the best-fit equation to determine the flow rate. This technique may be attempted after more data has been acquired.

3.0 OBSERVATIONS

3.1 Room 1, Hole IG202

SPDV Test Room 1 was one of the first rooms excavated in the northern part of the WIPP underground (Figure D-1). Initial mining was finished on April 13, 1983, and a number of instrument holes were drilled in it during the following few weeks. One of those was downhole IG202, located near the west rib in the center of the room, which was drilled for use as an inclinometer observation location. It is lined with a 74 millimeter (2 7/8th inch) I.D. flexible PVC inclinometer guide tube that is not a normal well casing. Leaks may occur into the guide tube. This type of liner has flexible expansion joints that can transmit fluids and a plastic cap on the bottom that was not installed with the intent of preventing brine inflow.

IG202 was drilled using brine as the drilling fluid. On April 21, 1983, the PVC guide tube was installed in the hole and a small-diameter tremie pipe (plastic tubing) was used to grout the liner in place. It is likely that the grouting is incomplete and that vertical movement of fluid takes place in open, ungrouted spaces outside the guide tube. When the guide tube was installed, it was filled with fresh water to assist in sinking the guide tube to the bottom of the hole. The fluid in the guide tube was reportedly blown out with compressed air, but it is not known how complete that removal was. It is probable at least some fluid remained in the partially grouted space outside the guide tube and in pore spaces and fractures in the rock which drained into the bottom of the hole after it was "blown dry."

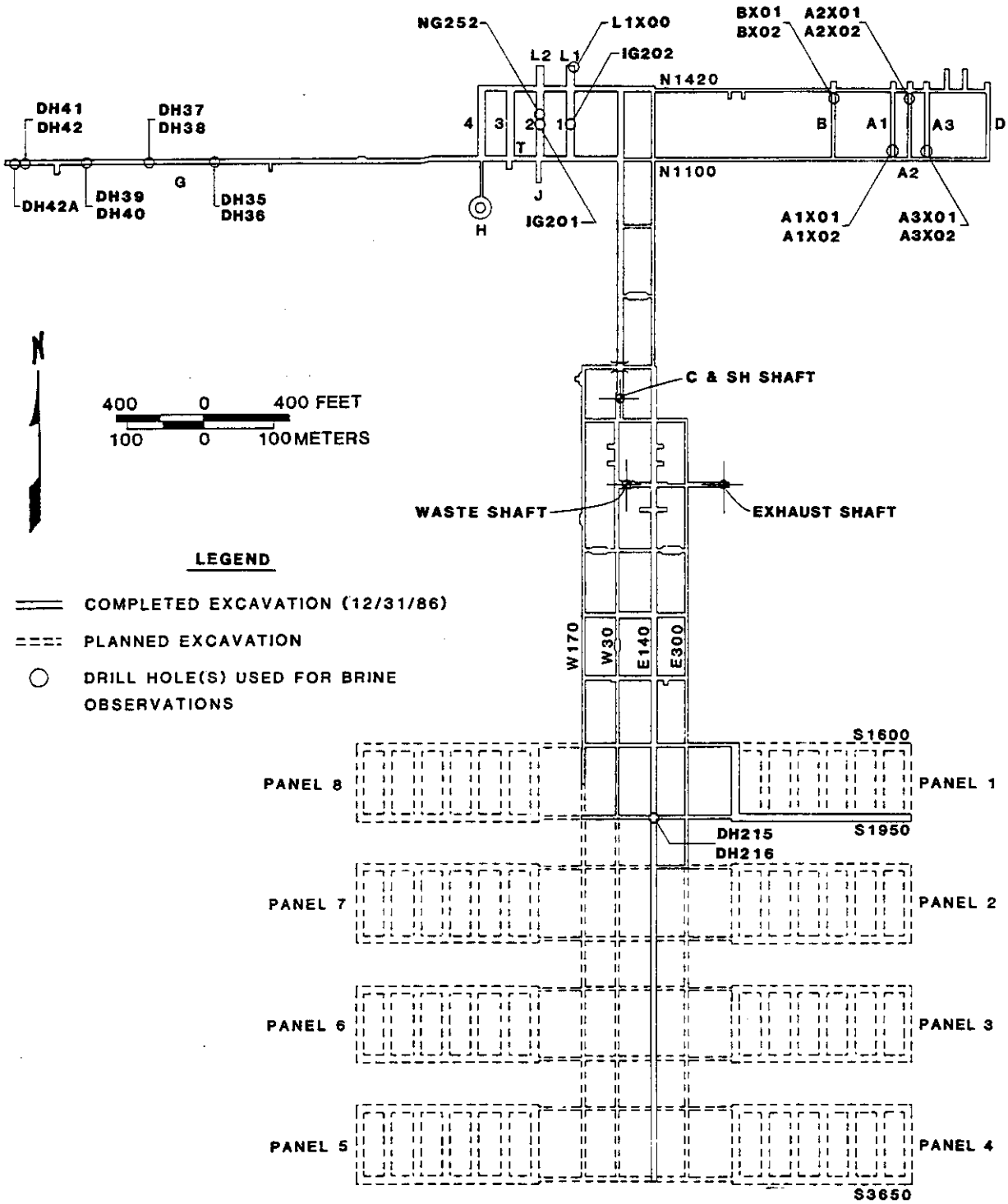


Figure D-1.

Map of the WIPP Underground Workings

On November 30, 1984, fluid filled the hole to within approximately two meters of the collar. It is known that fluids were introduced into this hole on at least two occasions (brine of unknown composition at the time of drilling and fresh water during guide-tube emplacement). The chemistry of fluids in this hole has certainly been affected by the materials and fluids introduced into the hole, especially the grout. Room 1 was also used by the mining contractor as an underground shop and lunchroom. As a result, the origin, quantity, and chemical composition of the fluid in the hole at the time of initial BSEP testing was probably not representative of naturally occurring, spontaneous inflows from the surrounding rocks.

This hole was the location of some of the initial experiments with air-jet pumping techniques. On November 30, 1984, over 52 liters of brine were removed from the hole and the inside of the guide tube was blown as dry as possible with high-pressure air. On January 8, 1985, an additional 12.6 liters was removed and the inside of the guide tube blown dry again. Some brine was lost during both of these evacuations, so those figures, although reasonably accurate, represent minimum figures for the amount of brine actually in the hole. Evacuation using the vacuum-assisted sampling system and measuring technique described in WIPP Procedure WP 07-410 began January 15, 1985, and continued until October 15, 1985, when the guide tube had become so distorted due to shear movement in the bedrock that sampling was discontinued for fear that the sampling device would become wedged in the hole. Most of the displacement is taking place along fractures in anhydrite interbed MB 139, which is about one to two meters below the floor of Room 2 (Figure D-2).

Relatively few data points exist for the inflow data for IG202. As a result, a four-point moving average was used to smooth this data (Figure D-3) instead of the five-point average used for most of the rest of the data.

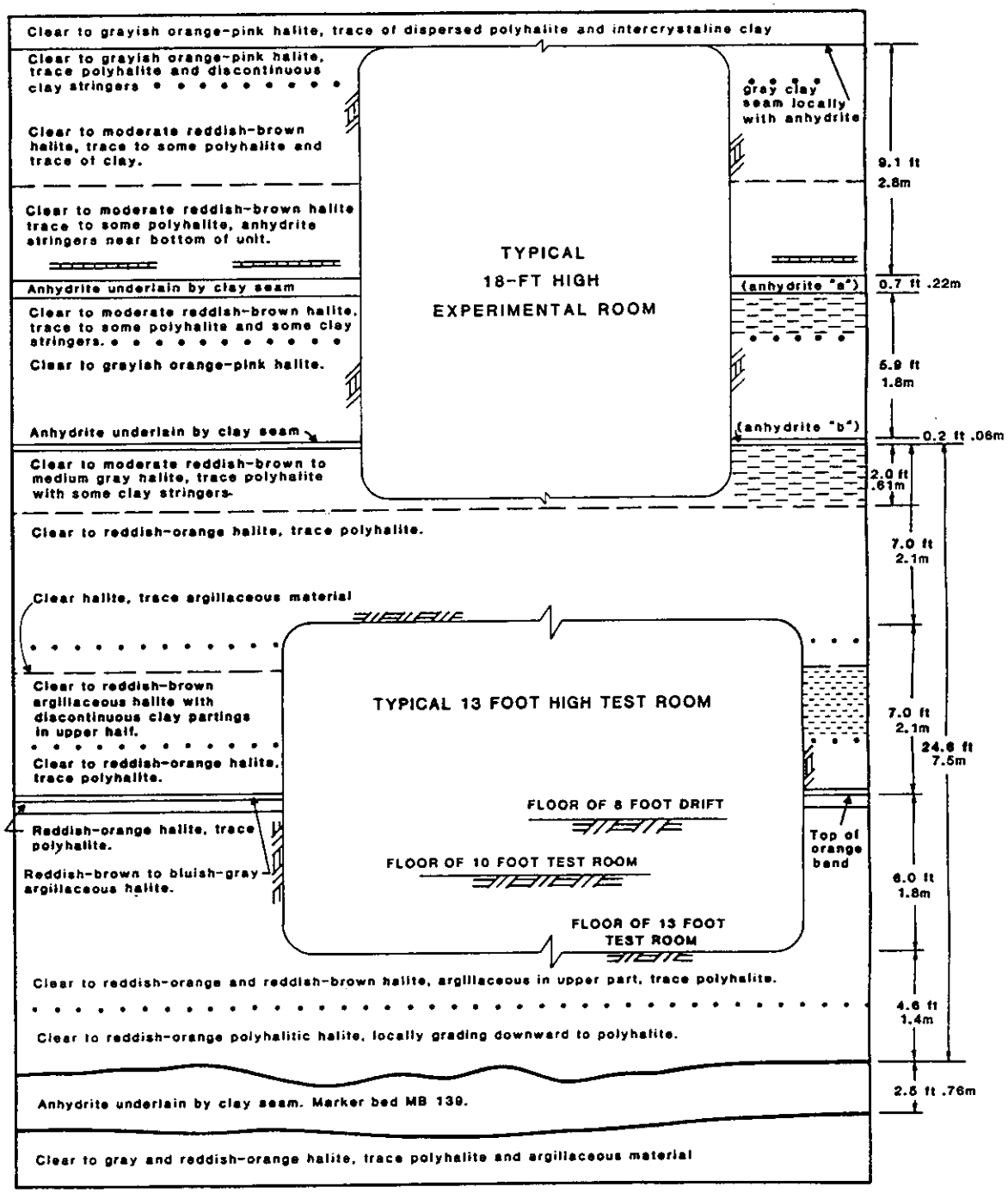
Average inflow rates were on the order of 0.05 liters per day in early 1985, decreasing gradually for about 175 days (Table E.18; Figure D-3). Inflow rates leveled out to between 0.01 and 0.02 liters per day for the remainder of the sampling period with the fluctuations falling within the limit of error of the sampling and measuring techniques. A total of over 71 liters of brine was removed from hole IG202 between November 30, 1984 and August 24, 1986.

3.2 Room 2

SPDV Test Room 2 was also one of the first rooms excavated in the northern part of the WIPP underground (Figure D-1). Initial mining was finished March 17, 1983 and a number of test holes were drilled in it during the following few weeks. Two of these holes were included in Phase I of the BSEP: inclinometer hole IG201 and stressmeter hole NG252.

3.2.1 Hole IG201

IG201 was drilled for use as an inclinometer observation location and is located near the west rib in the center of Room 2. Brine was used as the drilling fluid. On March 28, 1983 a 74 millimeter (2 7/8th inch) I.D. PVC guide tube identical to the one in Hole IG202 was installed in the hole, and a small-diameter tremie pipe (plastic tubing) was used to grout the liner in



NOTES:

1. Dimensions and lithologic descriptions are derived primarily from corehole and geologic mapping data from the four test rooms and experimental area supplemented by geologic information from the remaining SPDV excavation.
2. Unit thicknesses are approximate and vary slightly.
3. Room dimensions have changed with time due to salt-creep closure.

Figure D-2.

Geologic Cross Section of the Facility and Experimental Level

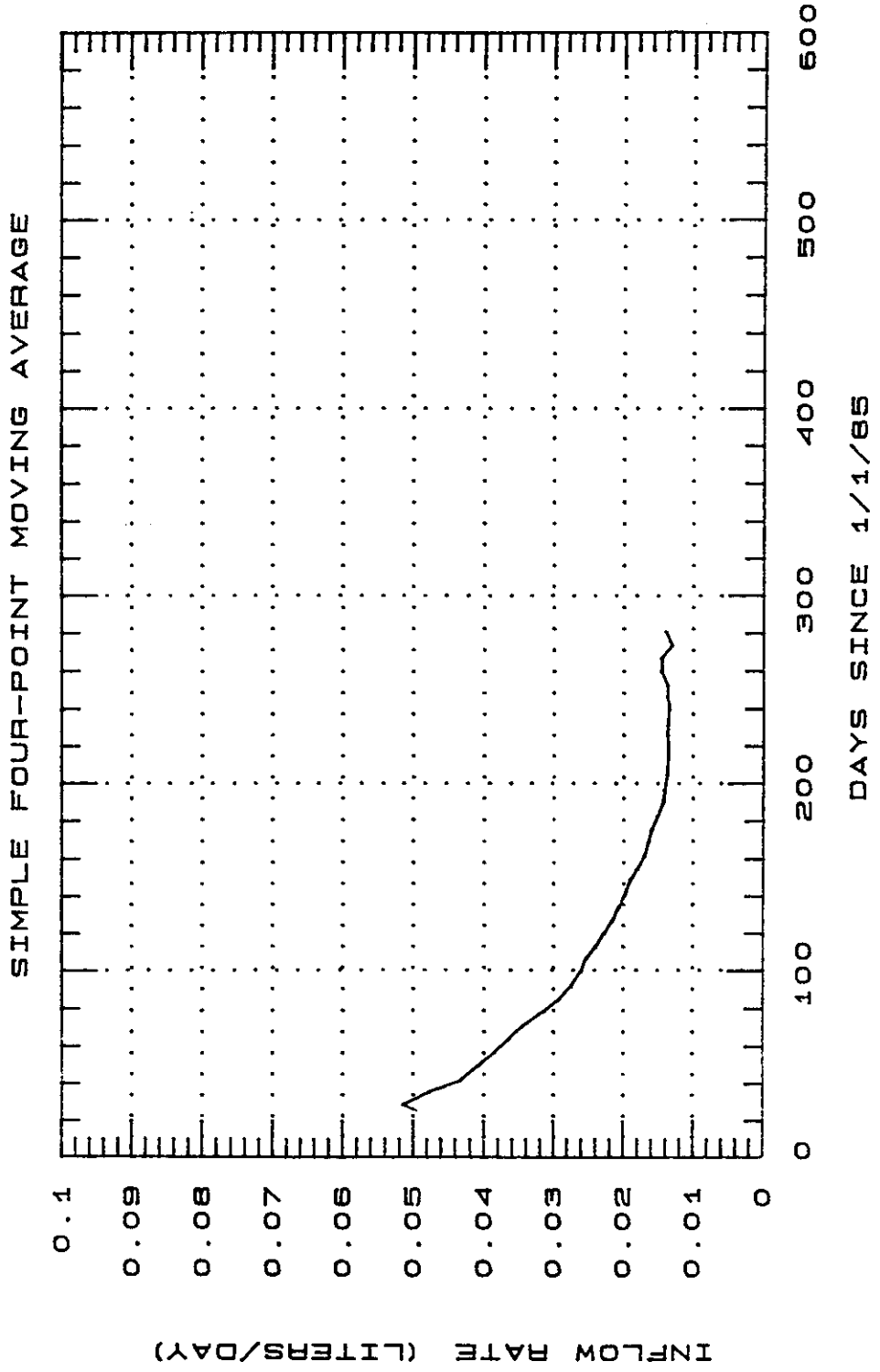


Figure D-3.
IG202 Inflow Rates

place. It is highly likely that the grouting is incomplete and that vertical movement of fluid takes place in open, ungrouted spaces outside the guide tube. When the guide tube was installed, it was filled with fresh water to assist in sinking the guide tube to the bottom of the hole.

On November 21, 1984 fluid filled the hole to within 1.23 meters (4.05 feet) of the collar. It is known that fluids were introduced into this hole on at least two occasions (brine of unknown composition at the time of drilling and fresh water during guide-tube emplacement). The chemistry of fluids in this hole has certainly been affected by the materials and fluids introduced into the hole, especially the grout. Room 2 was also used by the mining contractor as an underground storage area. The origin, quantity, and chemical composition of the fluid in the hole at the time of initial BSEP testing was probably not representative of naturally-occurring, spontaneous inflows from the surrounding rocks.

This hole was the location of some of the initial experiments with air-jet pumping techniques. On November 21, 1984, about 8.4 liters of brine had been removed from the hole when the experimental pumping system failed. On November 30, 1984, an additional 54.7 liters were removed and the inside of the guide tube was blown as dry as possible with high-pressure air. On January 8, 1985, 1.5 liters were removed before the check valve failed on a different experimental sampler. An additional 2.5 liters were removed on January 9, 1985. Some brine was lost during these evacuations, so those figures, although reasonably accurate, represent minimum figures for the amount of brine that was actually in the hole. Evacuation using the vacuum-assisted sampling system and measuring technique described in WIPP Procedure WP 07-410 began January 15, 1985.

Initial brine inflow rates were slightly greater than 0.05 liters per day, decreasing gradually to slightly less than 0.02 liters per day at the end of April, 1986 (Table E.17, Figure D-4). At that time, the guide tube had become so distorted from shear within the bedrock that sampling was discontinued. A total of over 81 liters of brine had been removed from hole IG201 over that period of time.

3.2.2 Hole NG252

Stressmeter downhole NG252 is located about 3 meters north of IG201 in SPDV Test Room 2. This hole has a fairly complicated history (Figure D-5). The initial 38 millimeters (1.5 inch) hole was drilled 2 meters (6.5 feet) deep in March 1983 with brine used as the drilling fluid. The stressmeter failed in December 1983 and on March 4, 1984, the instrument was over-cored with a 152-millimeter (6-inch) core barrel and removed. As a result, the upper 50 centimeters (1.5 feet) of this hole is 152 millimeters (6 inches) in diameter and the bottom 1.5 meters (5 feet) is 38 millimeters in diameter.

On November 21, 1984, this hole was found to be filled with both brine and muck. The top of the brine was 18 centimeters (7 inches) below the collar and the top of the salt muck was 28 centimeters below the collar. Approximately 1.3 liters of brine were removed on November 21, effectively evacuating the hole to the level of the top of the salt muck.

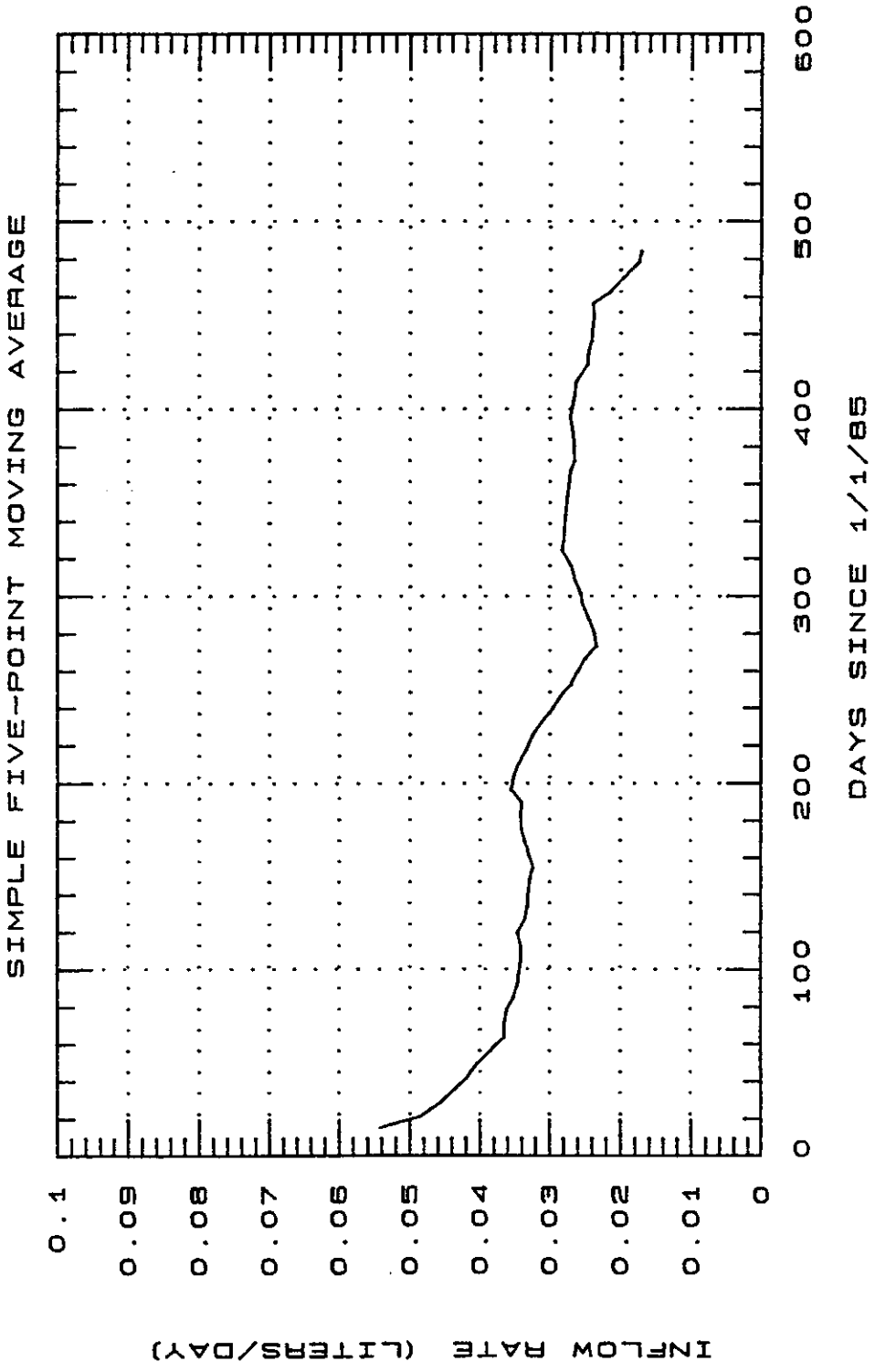


Figure D-4.
IG201 Inflow Rates

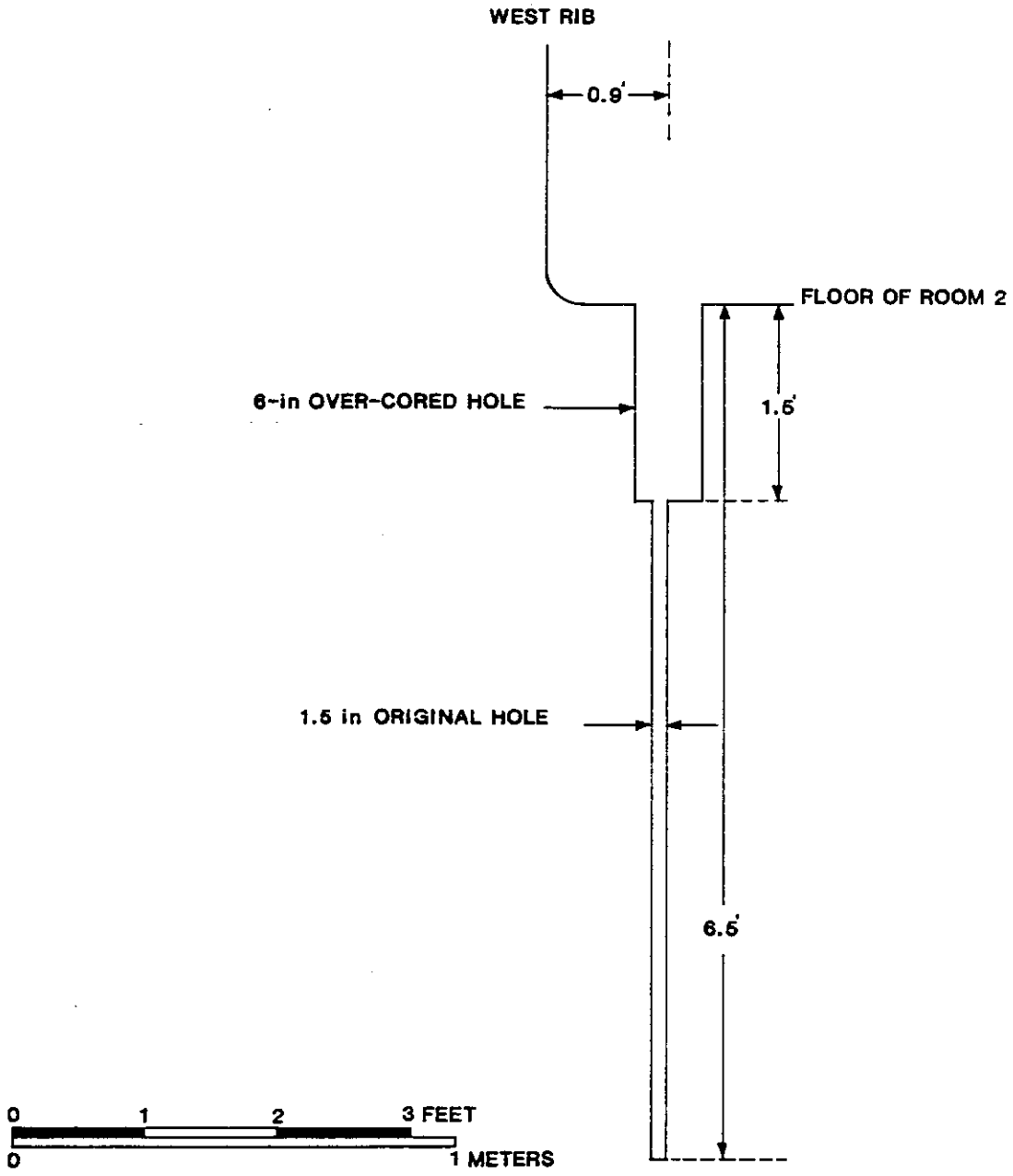


Figure D-5.
NG252 Configuration

Six days later, on November 27, 1984, the brine level had risen to 6.4 centimeters above the salt muck. About 0.76 liters of brine were evacuated, exposing the top of the salt muck. Later that day, the brine level was observed to have risen to completely cover the salt muck.

On November 29, 1984, compressed air was used to blow all the salt muck and accumulated brine out of NG252. The quantity of brine that was blown out was not measured, but it amounted to several liters. PVC casing with a cap was installed to prevent debris from entering and plugging the hole.

Twenty days later, on December 19, 1984, representatives of the Environmental Evaluation Group (EEG) collected a sample of brine from this location. On that date, the level of the brine surface had risen to approximately the level observed on November 21; 18 centimeters below the collar or about 50 centimeters below the top of the new PVC casing.

Since this hole was easily accessible, known to produce brine, and of small diameter, it was selected as the location for initial observations. The hole was evacuated and a short-term inflow test was performed following normal surface-well recovery analysis techniques. Initial brine levels were measured every hour. Intervals between measurements were lengthened as appropriate once initial inflow rates were determined. Measurements continued around the clock until the brine level stabilized (Table E.20).

The diameter of the hole enlarges from 38 to 152 millimeters at a point approximately 1.5 meters above the bottom of the hole. The inflow data was recorded as the increasing level of brine in the hole with time. To correct for the change in hole diameter, brine level was converted to approximate volume of brine in the hole by multiplying by the appropriate cross-sectional area. The calculations were made using Lotus 123 software. This figure is reported as equivalent volume in liters in Table E-20 and on Figures D-6 and D-7.

The data for the rise in static level was plotted both as an X-Y plot (Figure D-6) and as a semi-log plot (Figure D-7), the more conventional form for recovery graphs. These curves are not strictly analogous to "recovery tests," however, since the initial point for the curves probably does not represent a steady-state drawn-down condition. In addition, the distribution of potential energy (hydrologic regime) of the brine in the vicinity of the underground drill holes is still poorly understood.

Brine flowed into the evacuated hole from the fractures and pores close to the hole and, for a while, the hole actually filled faster the fuller it became. This can be seen on Figure D-6 between approximately 35 and 175 hours. Both graphs show an abrupt change-in-slope at a brine level of approximately 1.5 liters, where the hole diameter enlarged from 38 to 152 millimeters. Inflow ceased after the hole became filled with brine to a depth of approximately 6.1 feet. The floor of Room 2 slopes down toward the south, and it is probable that when Hole NG252 is filled to this level, additional inflow ceases because the brine discharges through some undetermined flow path into unconsolidated muck on the floor of Room 2. The conclusion reached was that this type of data, although interesting, is not very useful unless an equilibrium draw-down state is established prior to recording the rising brine level.

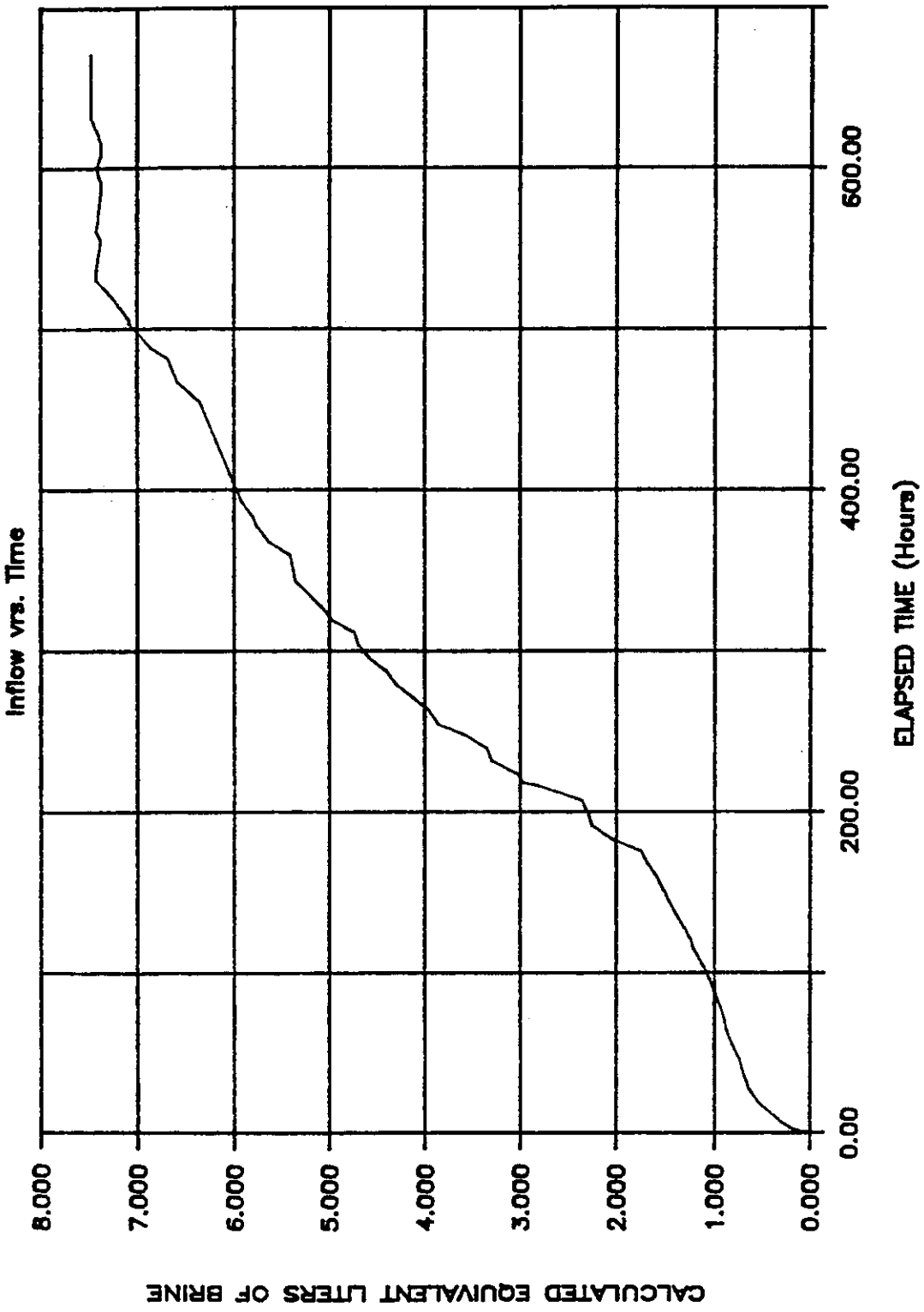


Figure D-6.

NG252 Short Term Inflow

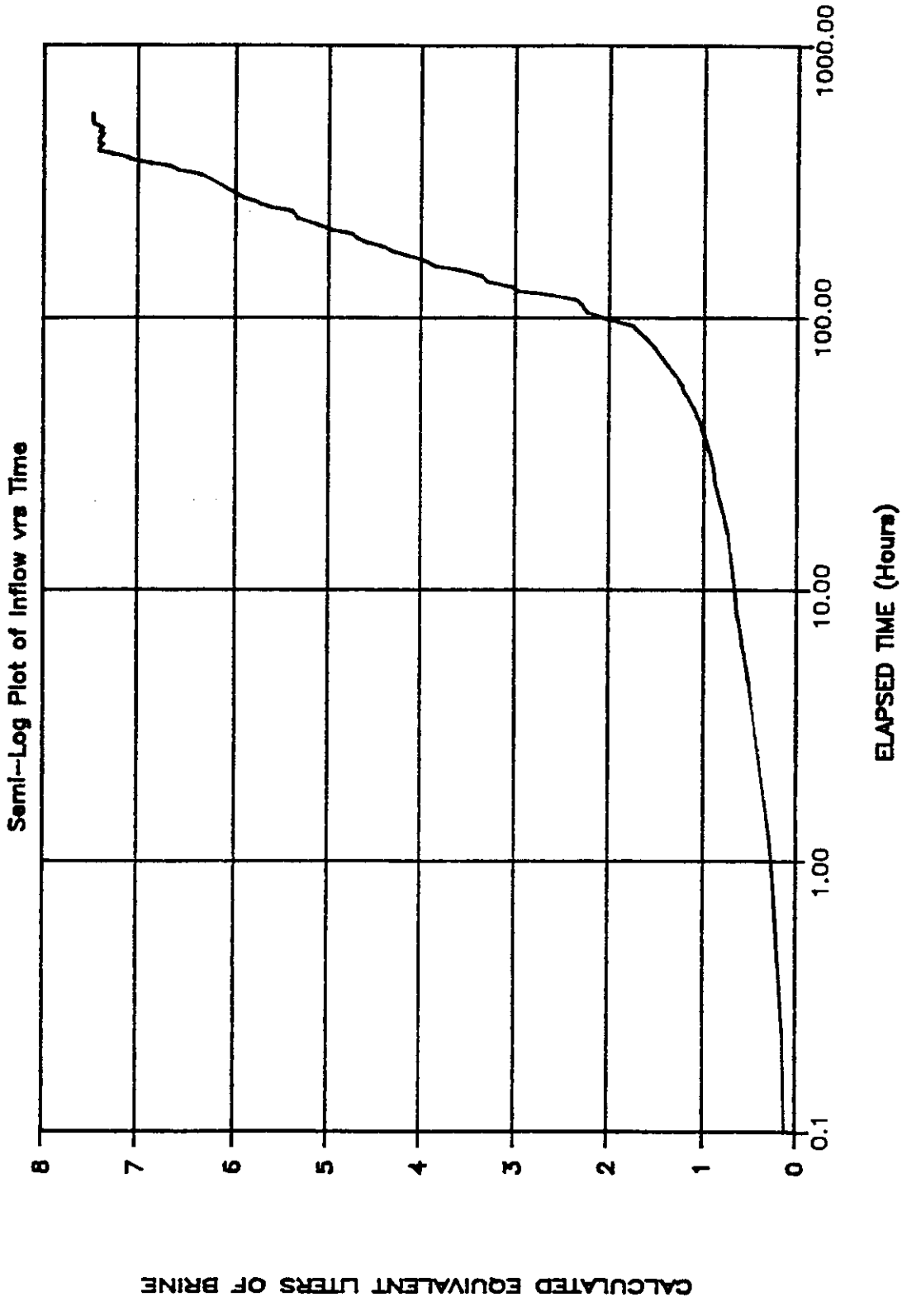


Figure D-7.

Semi-Log Plot of NG252 Short Term Inflow

Starting in February 1985, brine was bailed from NG252 on a regular basis (Table E.21; Figure D-8). Inflow rates were initially close to 0.6 liters per day, gradually declining to about 0.27 liters per day by August 19, 1986. Over 235 liters of brine had been removed from this hole by that date. Significant quantities of gas are associated with the brine inflow into NG252. Gas bubbles are almost always observed. Brine withdrawn from the hole effervesces immediately after bailing as it is poured from one container into another. NG252 penetrates anhydrite Marker Bed 139 and most of the brine flows into this hole from a fracture very close to the bottom of the hole, near the base of Marker Bed 139 (Figure D-2).

NG252 is the largest brine producer of any of the drill holes observed during Phase I of the BSEP, and appears to be something of an anomaly. It is located in close proximity to a completely dry downhole. The dry hole is approximately 4.7 meters east of NG252 on the centerline of Room 2, is 15 centimeters in diameter, is 1.65 meters deep, and penetrates into MB 139. It does not appear to completely penetrate MB 139, which may be the reason it is dry.

3.3 Experimental Rooms A1, A2, A3, and B

Experimental Rooms A1, A2, A3, and B are in the northeastern part of the WIPP underground workings (Figure D-1). Excavation of Room A1 was completed in October 1984, Room A2 in July 1984, Room A3 in November 1984, and Room B in June 1984. They are 5.5 meters (18 feet) high and are excavated in a zone about 6 meters (20 feet) stratigraphically higher than the rest of the workings (Figure D-2). As a result, the drill holes penetrate a slightly different stratigraphy, a fact that results in especially useful data. The end of 15-meter upholes typically penetrate rocks about seven meters stratigraphically above the end of other 15-meter upholes. Hole A1X02 is 18 meters long and penetrates an additional 3 meters, intersecting an anhydrite interbed not present in the other three upholes in Rooms A2, A3, and B. Downholes typically penetrate MB139 at depths of 7 to 7.6 meters. The data from these holes reflects both the sampling of different geological horizons and, perhaps, more importantly, interbeds such as MB 139 under different stress conditions than is encountered elsewhere in the facility.

These rooms all contain many experimental and instrument holes (Appendix A), almost all of which are inaccessible to the BSEP. In early 1985, a pair of stratigraphic observation holes were drilled in each of these rooms. These holes were drilled with air as the drilling fluid. Inflow to these pairs of holes have been monitored from the time they were drilled.

The A and B rooms are the location of the heated room experiments. Canisters containing electric heaters have been emplaced at the stratigraphic level of the facility, below the floor of the rooms. The power was turned on to the heaters in the A rooms on October 2, 1985 (day 274 after 1/01/85), and in Room B on April 23, 1985 (day 112 after 1/01/85). Since that time the rooms have been heating up, a factor that is expected to effect both the inflow of brine and the brine chemistry.

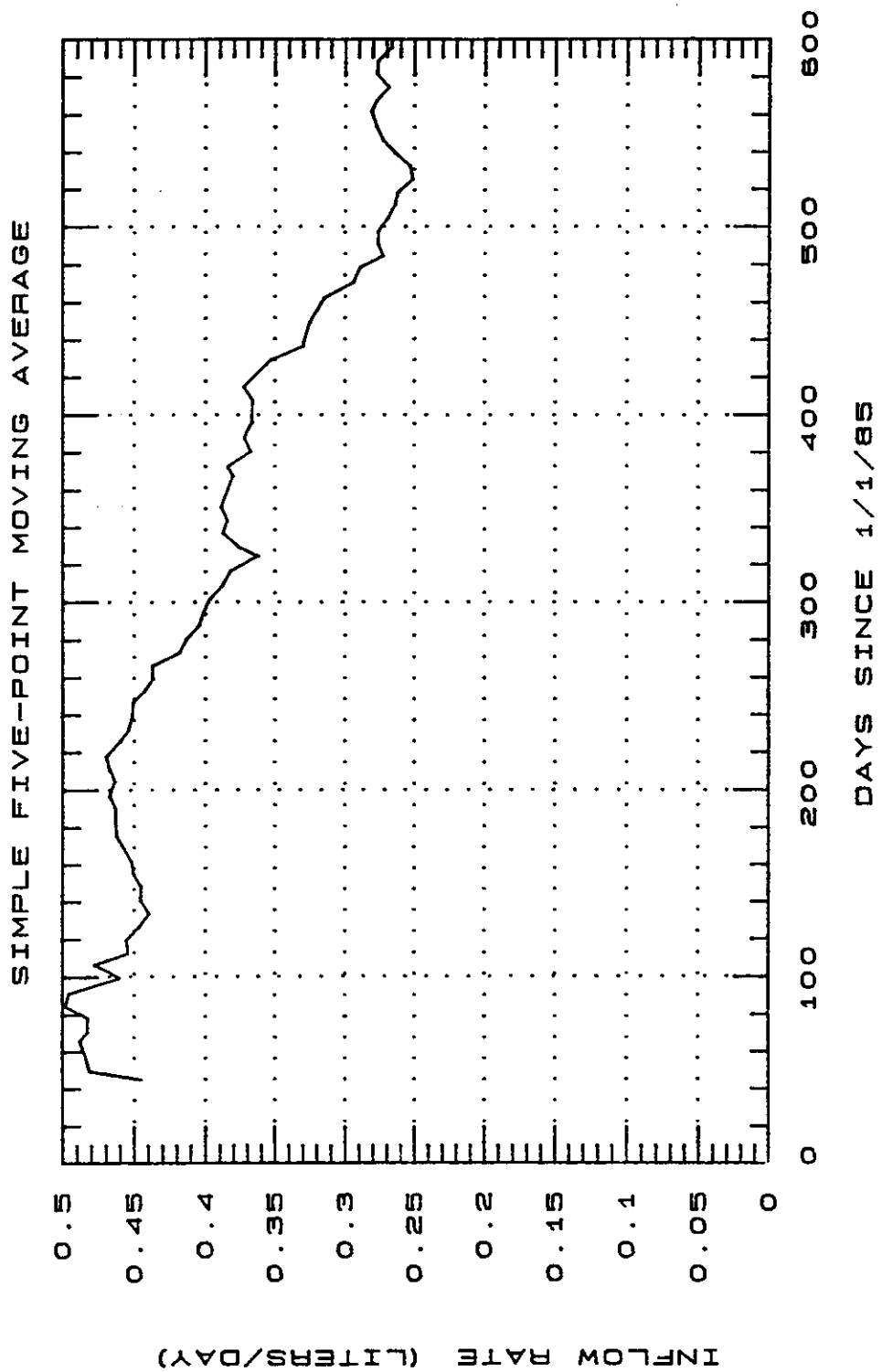


Figure D-8.

NG252 Inflow Rates

3.3.1 Room A1, Hole A1X01

Hole A1X01 is a downhole drilled in the south end of Room A1 on February 26, 1985. No brine or gas was noticed during drilling. Brine accumulations were noticed shortly after drilling. Brine was first removed from this hole on March 12, 1985. Inflow rates in April 1985, were on the order of 0.047 liters per day, gradually decreasing to slightly greater than 0.026 liters per day in October 1985. Inflow appeared to stabilized at that rate and remained quite constant through August 1986 (Table E.1, Figure D-9). A total of approximately 15.3 liters of brine had been removed from A1X01 by August 19, 1986.

3.3.2 Room A1, Hole A1X02

Hole A1X02 is an uphole completed March 7, 1985, in the south end of Room A1, directly over hole A1X01. The end of this hole penetrates beds that are stratigraphically higher than those penetrated by any of the other holes monitored as part of the BSEP, intersecting an additional anhydrite interbed. Drillers noted that brine entered the hole at a depth of 3.55 meters. The hole was reamed on February 28, 1985 to a 12.7 centimeters (5-inch) diameter for the first 3.7 meters to eliminate drilling problems caused by moist cuttings. A moist area was noted developing around the collar on March 7, 1985. On March 12, 1985 the moist area on the back (roof) extended for a third of a meter in all directions from the drill hole.

Several different types of collecting devices were installed, with successful collection of brine first occurring on April 2, 1985. Most of the irregularities in the data (Table E.2) are a result of collecting difficulties and evaporation losses, not real variations in brine inflow. Inflow rates were on the order of 0.02 liters per day between drilling and the end of October 1985, decreasing slightly between November 1985 through June 1986, followed by an increase to almost 0.04 liters per day in August 1986 (Figure D-10). A total of over 8.7 liters of brine had been collected from this hole by August 19, 1986. A significant, additional amount was certainly produced from the hole but lost by dissipation near the borehole collar and evaporation to the repository atmosphere.

3.3.3 Room A2, Hole A2X01

Hole A2X01 is a downhole completed February 9, 1985 in the north end of Room A2. No brine or gas inflows were noted during drilling, but moist, irregular vugs were observed in the core, usually in coarsely crystalline polyhalitic halite, clear halite, and halite containing some brown clay. Brine accumulations were noticed shortly after drilling. Brine-soaked muck containing some oil (contamination from the drilling operations) was first removed from this hole on February 19, 1985. Mixtures of brine and muck were also bailed from the hole on March 7, 1985 and March 12, 1985. On March 20, 1985, 0.52 liters of fairly clear brine were removed from the hole (Table E.3). Initial inflow rates in late March and early April 1985, were slightly greater than 0.05 liters per day, declining fairly rapidly to slightly less than 0.035 liters per day by mid-May. Inflow then remained quite steady, decreasing very gradually to about 0.025 liters per day in late August 1986 (Table E.3, Figure D-11). A total of approximately 16.8 liters of brine had been removed from A2X01 by August 19, 1986.

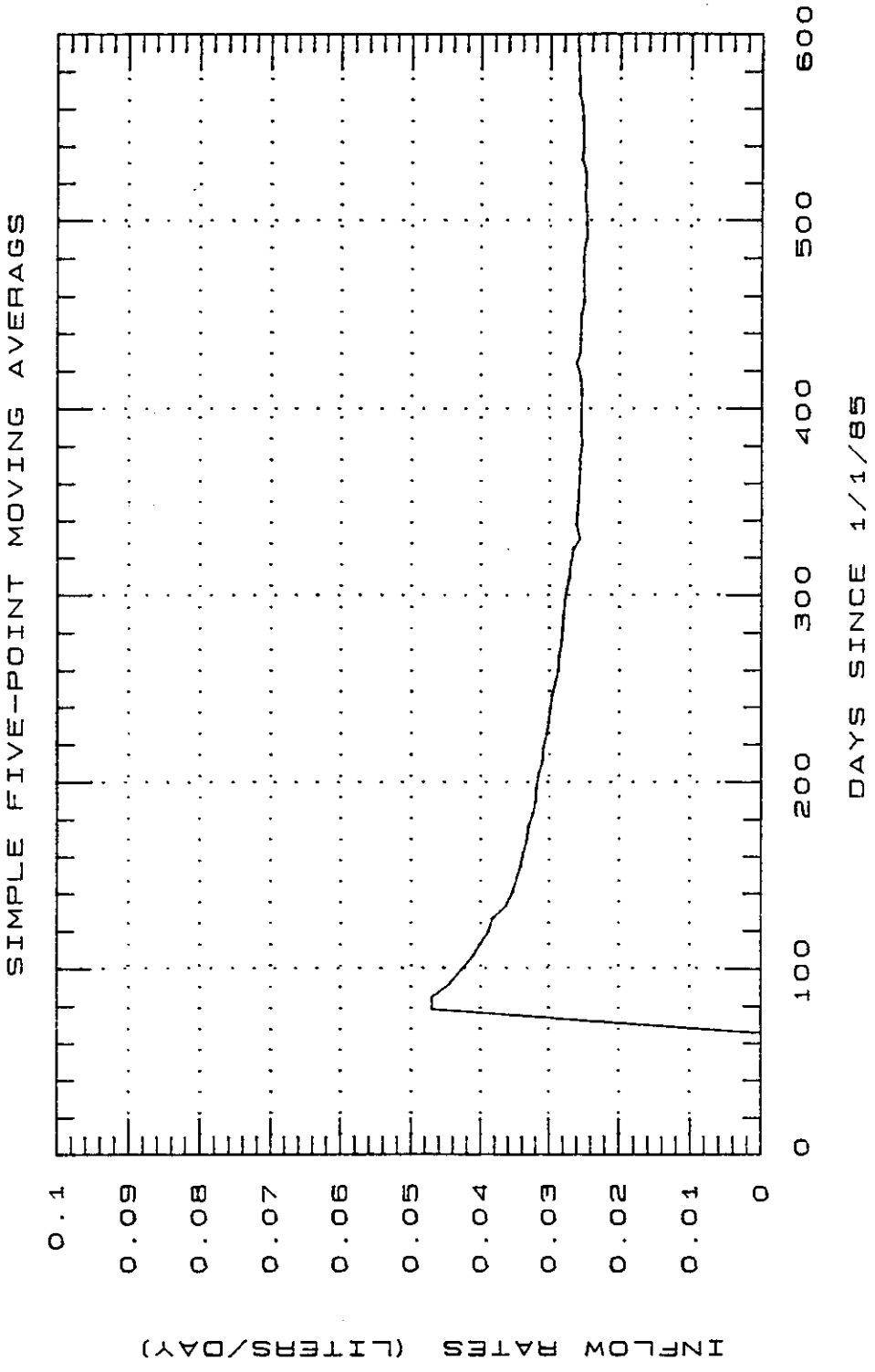


Figure D-9.

A1X01 Inflow Rates

3.3.4 Room A2, Hole A2X02

Hole A2X02 is an uphole completed February 20, 1985, in the north end of Room A2, directly over Hole A2X01. The drillers noted that the hole produced brine during drilling at both 3.5 meters and 7.7 meters. The hole was reamed on February 13, 1985, to a 12.7 centimeter (5-inch) diameter for the first 7.6 meters to eliminate drilling problems caused by moist cuttings.

A collecting device was installed on the hole February 19, 1985. The same difficulties described for Hole A1X02 were encountered, and the same cautions concerning the use of the data are applicable. A moist area immediately developed on the back (roof) around the hole and was about 1.5 meters in diameter on March 12, 1985. The irregularities in the data are mostly the result of problems in collecting the brine. A large amount of brine is known to have been lost by evaporation. Inflow rates were over 0.03 liters per day in March 1985, but then decreased to less than 0.01 liters per day (Table E.4, Figure D-12). Problems with the collecting device from April through August 1985 resulted in most of the brine inflows escaping and not being recorded, so the low readings during that time period do not reflect the fact that considerable brine flowed from Hole A2X02. Flow does appear to have been much lower during the winter of 1985-86, but shows an increase in the summer of 1986 to more than about 0.015 liters per day. Figure D-12 shows trends that roughly parallel the humidity measurements taken in the room, but the above-mentioned collecting uncertainties caution against drawing too strong a correlation.

Approximately 3.35 liters of brine had been collected from Hole A2X02 by August 19, 1986. A significant additional amount was certainly produced from the hole but lost by dissipation near the borehole collar and evaporation to the repository atmosphere.

3.3.5 Room A3, Hole A3X01

Hole A3X01 is a downhole completed on January 14, 1985 in the south end of Room A3. No brine or gas inflows were noted during drilling, but moist, irregular vugs were observed in the core, usually in coarsely crystalline polyhalitic halite, clear halite, and halite containing some brown clay. Brine accumulations were noticed shortly after drilling. Brine-soaked muck was noticed in this hole on February 5, 1985. Approximately 0.3 liters of brine, muck, and oil was removed from the hole on February 19, 1985 (Table E.5). Inflow rates in February and March were on the order of 0.03 liters per day, decreasing gradually through October 1985, and then maintaining a fairly constant inflow slightly greater than 0.02 liters per day through August 1986 (Table E.5, Figure D-13). Over 13.6 liters of brine had been removed from A3X01 by August 19, 1986.

3.36 Room A3, Hole A3X02

Hole A3X02 is an uphole completed January 22, 1985 in the south end of Room A3, directly over Hole A3X01. No brine or gas inflows were noted during drilling, but moist, irregular vugs were observed in the core, usually in coarsely crystalline polyhalitic halite, clear halite, and halite containing some brown clay. Brine accumulations were noticed shortly after drilling. A collecting device was installed February 5, 1985 and on February 19, 1985, over 0.1 liters of brine had accumulated in the collection container. The wet

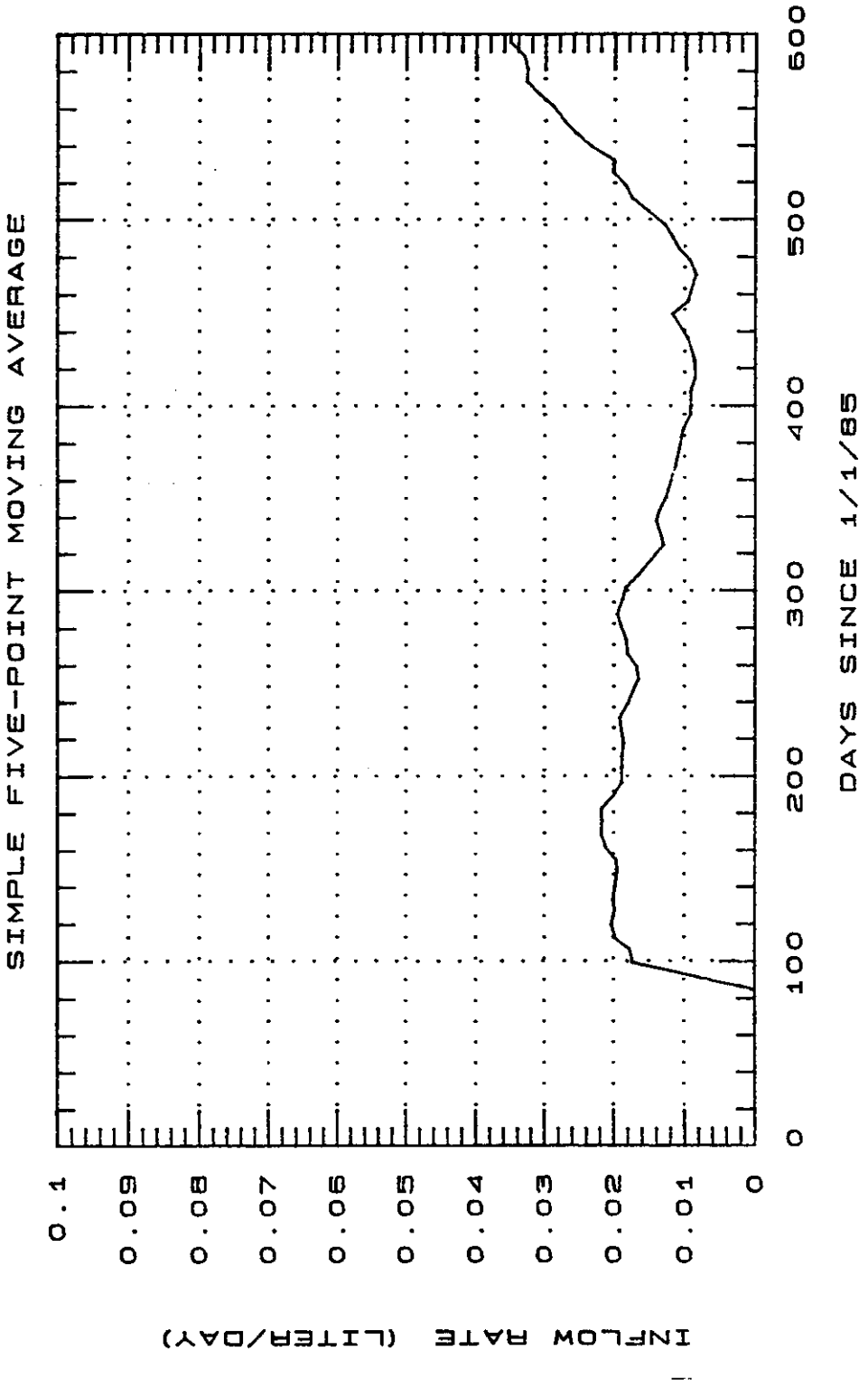


Figure D-10.
A1X02 Inflow Rates

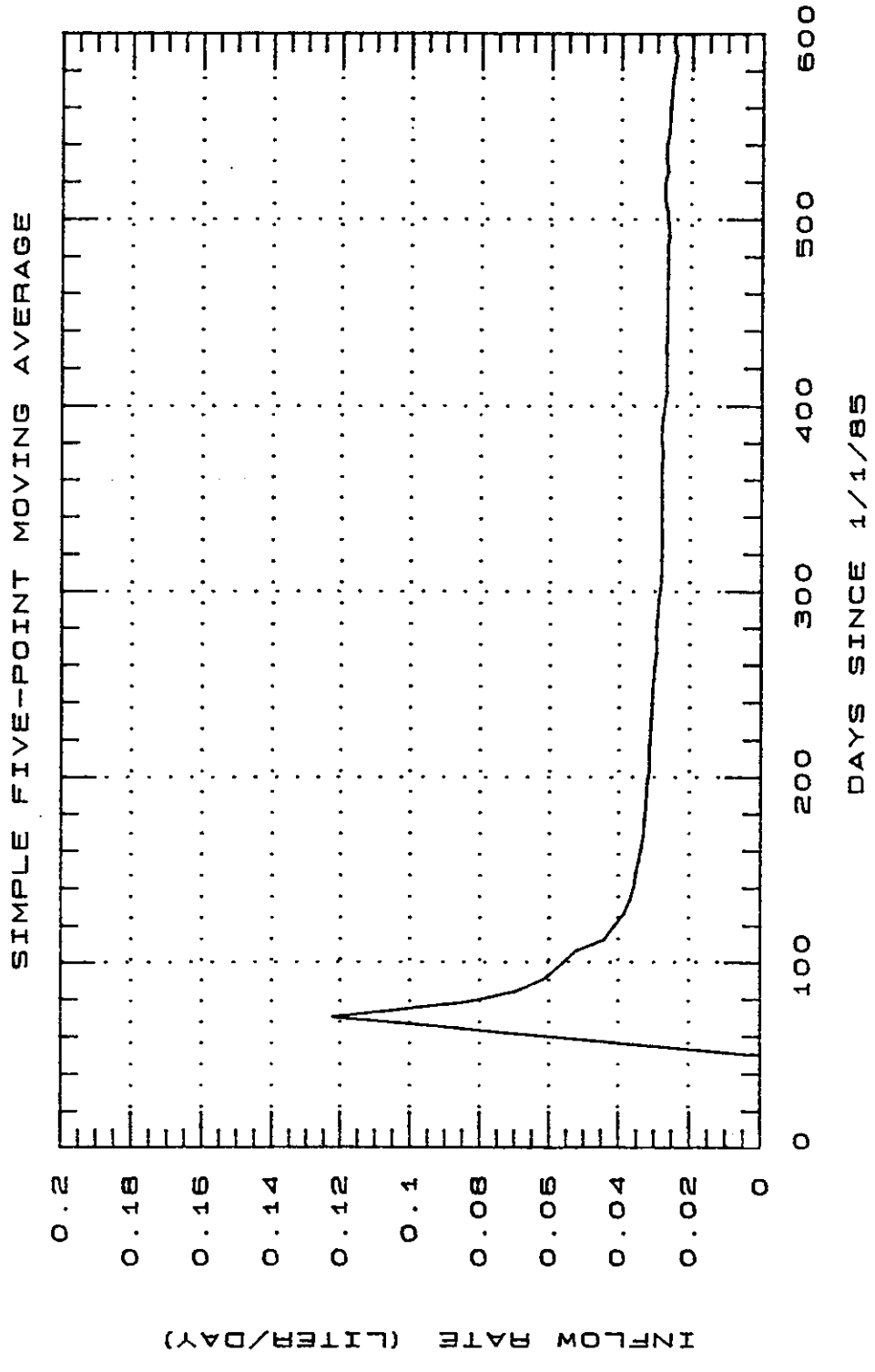


Figure D-11.
A2X01 Inflow Rates

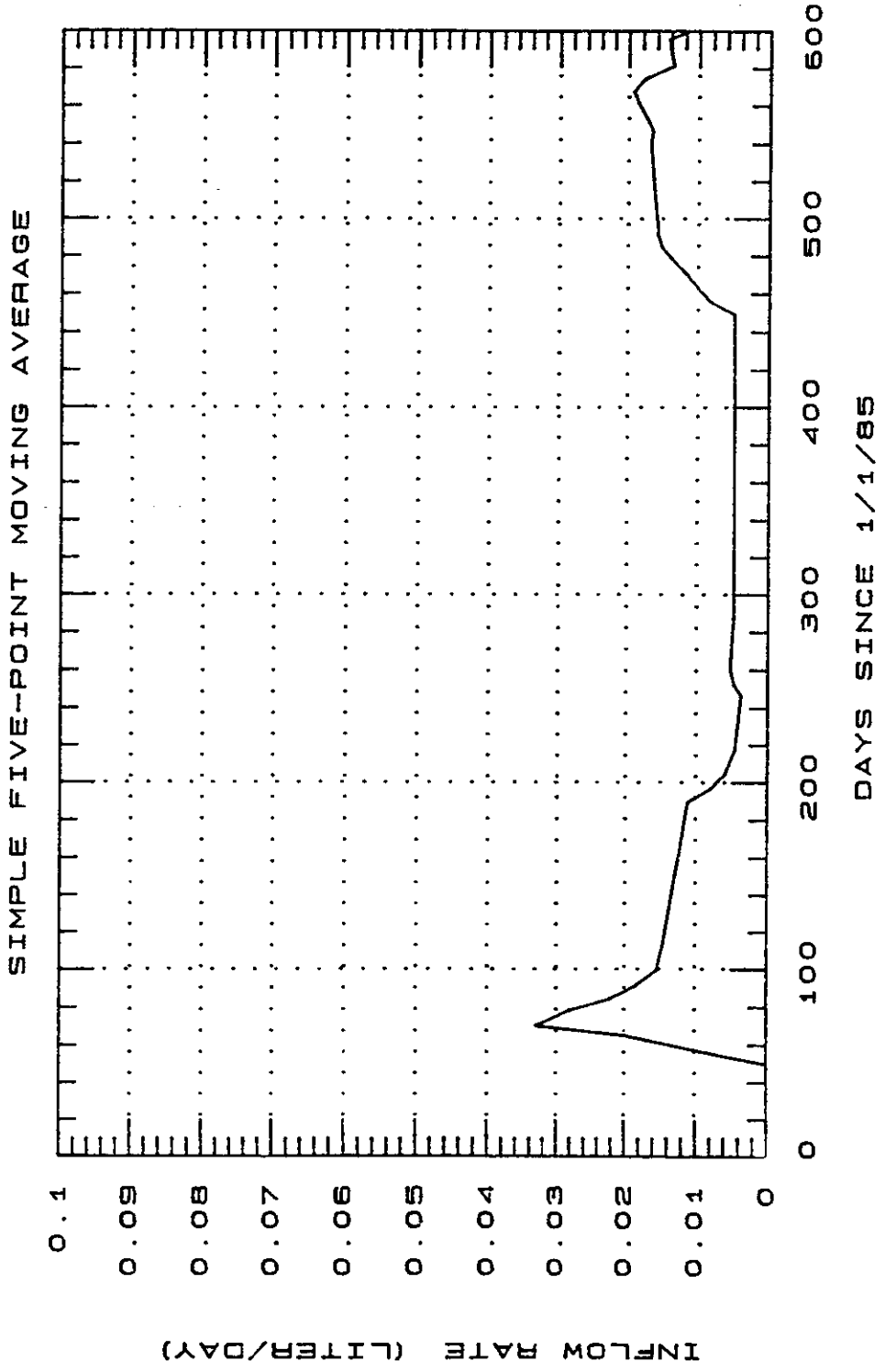


Figure D-12

A2X02 Inflow Rates

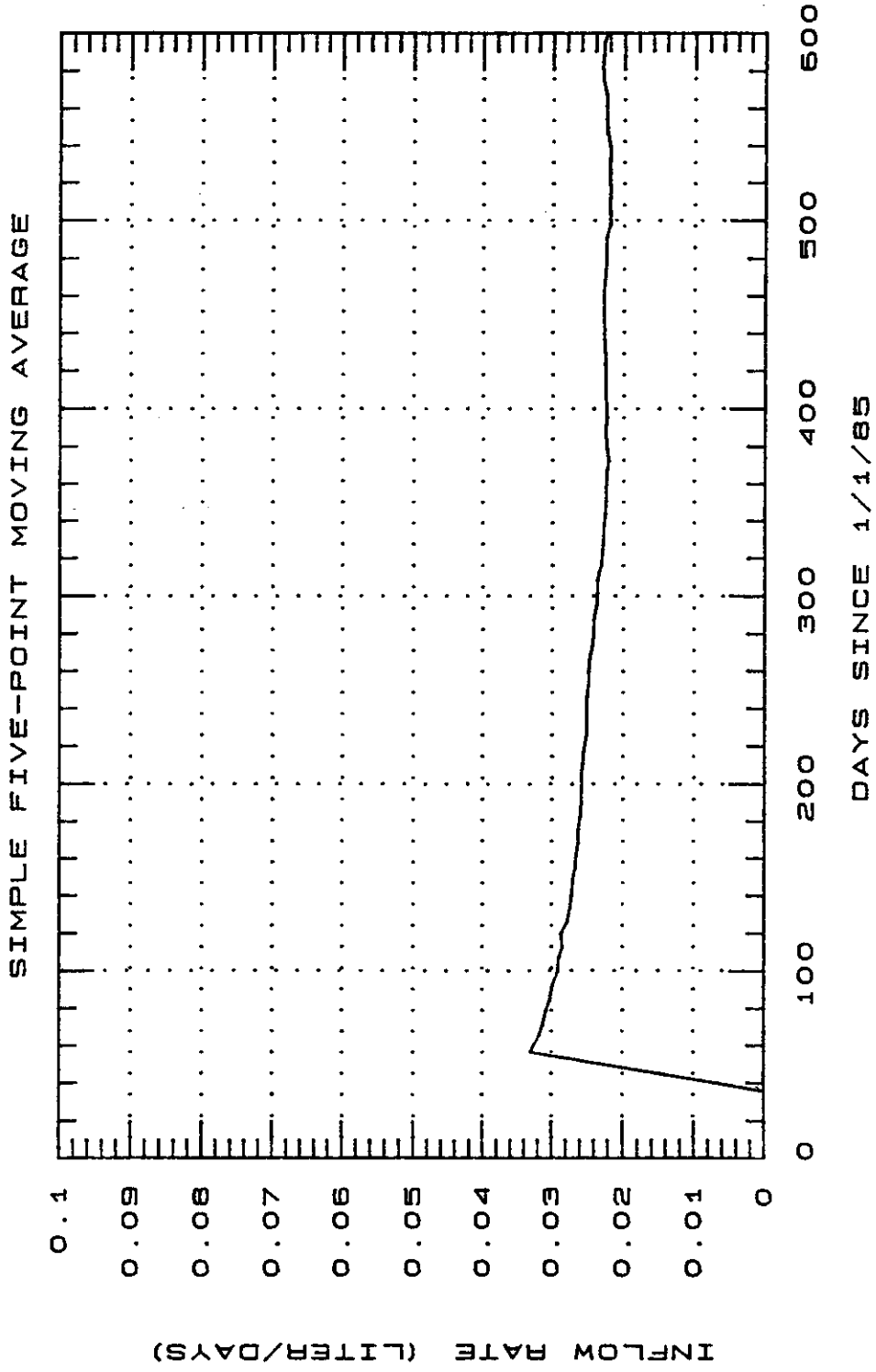


Figure D-13.

A3X01 Inflow Rates

area on the back (roof) was 3 feet in diameter by February 26, 1985. Inflow rates exceeded 0.02 liters per day in March 1985, declined slowly to about 0.01 liters per day in October 1985, and then declined more rapidly to trace amounts (0.01 liters per day or less) by the end of January 1986 (Table E.6, Figure D-14). A total of approximately 4.4 liters of brine had been collected by the end of January 1986, when significant inflows effectively ceased. An additional amount was certainly produced from the hole but lost by dissipation near the borehole collar and evaporation into the repository atmosphere.

3.3.7 Room B, Hole BX01

Hole BX01 is a downhole completed on January 27, 1985 in the north end of Room B. Marker Bed 139 was penetrated from 7.09 to 7.91 meters. When the core from 10.7 to 11.1 meters was removed from the core barrel, it was visibly wet with brine, and brine dripped from the fresh core. This interval consisted of clear to light reddish-orange, coarsely crystalline halite and polyhalitic halite. Moist, irregular vugs were observed in the core, usually in coarsely crystalline polyhalitic halite, clear halite, and halite containing some brown clay. Brine accumulations were noticed shortly after drilling. Approximately 0.4 liters of brine and muck were bailed from the hole on February 5, 1985 (Table E.7). Inflow rates in February 1985, were on the order of 0.1 liters per day, declining to about 0.06 liters per day by the end of April 1985 (Table E.7, Figure D-15). Inflow rates then continued through August 1986, showing only a slight decline to about 0.05 liters per day. A total of over 32 liters had been collected from BX01 by August 19, 1986.

3.3.8 Room B, Hole BX02

Hole BX02 is an uphole completed February 1, 1985 in the north end of Room B, directly over Hole BX01. Some moisture was noted on the core at 2.9 meters, but presented no problems to the drilling operations. The drillers noted that the hole was dry at completion of the drilling. Moist, irregular vugs were observed in the core, usually in coarsely crystalline polyhalitic halite, clear halite, and halite containing some brown clay. A collecting device was attached to the collar of the hole on February 5, 1985, and a few drops of brine were observed in the collecting container on March 12, 1985. On March 20, 1985, about 0.1 liter was removed from the collecting device (Table E.8). In April 1985, the inflow rate was on the order of 0.02 liters per day, declining gradually to about 0.015 liters per day in June 1985 (Table E.8, Figure D-16). Inflow then declined abruptly so that by the end of July 1985, only trace amounts were noticed. The evaporation problem has been exacerbated by the increasing air temperatures that began to develop in this room after the heaters were turned on. A total of about 1.75 liters of brine were collected from BX02 by the middle of January 1986. An additional amount was certainly lost by dissipation near the borehole collar and evaporation to the repository atmosphere, and the hole has been essentially dry since the end of January 1986.

3.4 Room G

Room G extends farther to the northwest than any of the rest of the WIPP underground workings (Figure D-1). It was excavated in November through December 1984. Four pairs of 15-meter up and down, vertical, stratigraphic observation holes were drilled to obtain geologic cores. These holes were

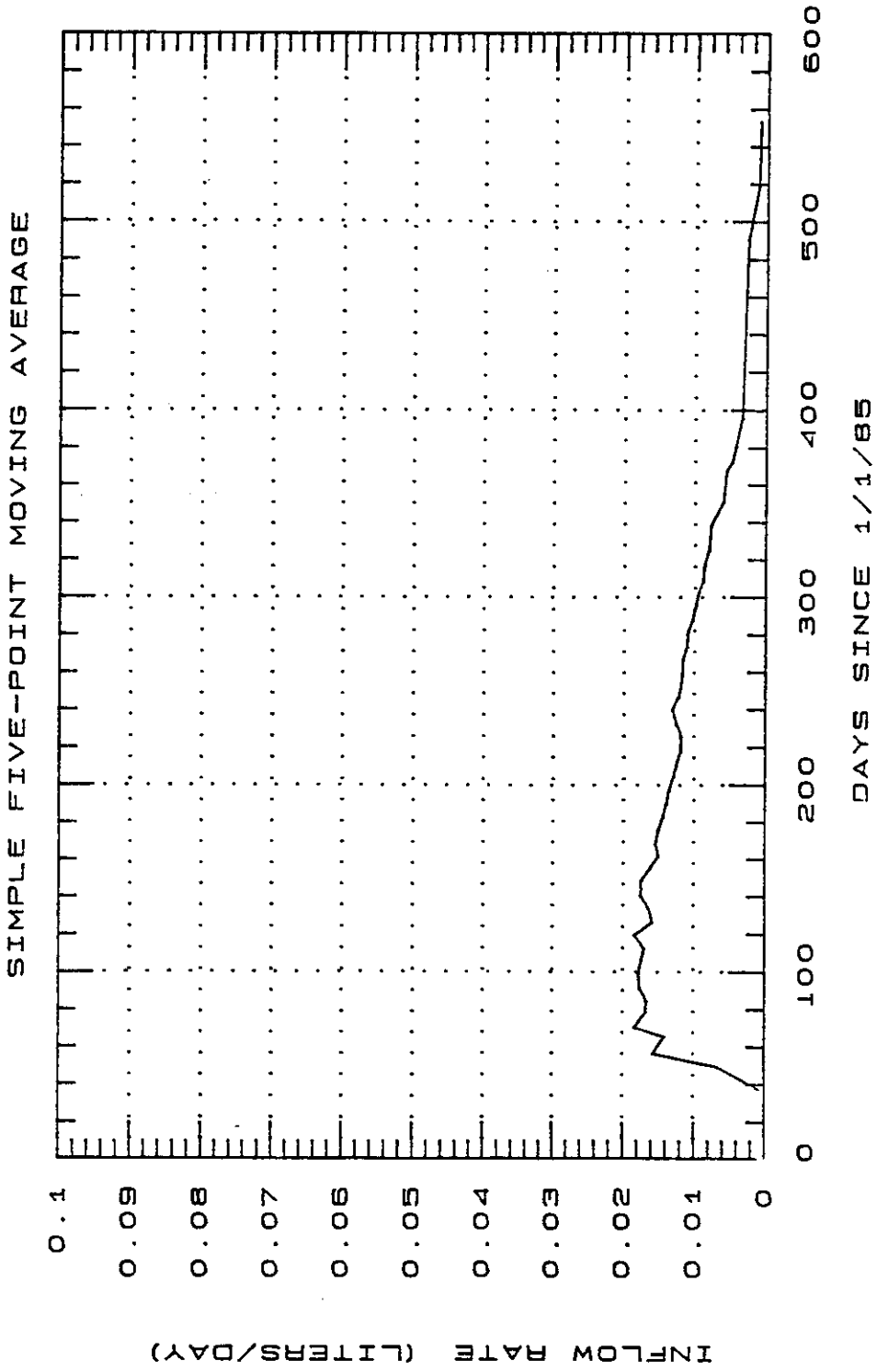


Figure D-14

A3X02 Inflow Rates

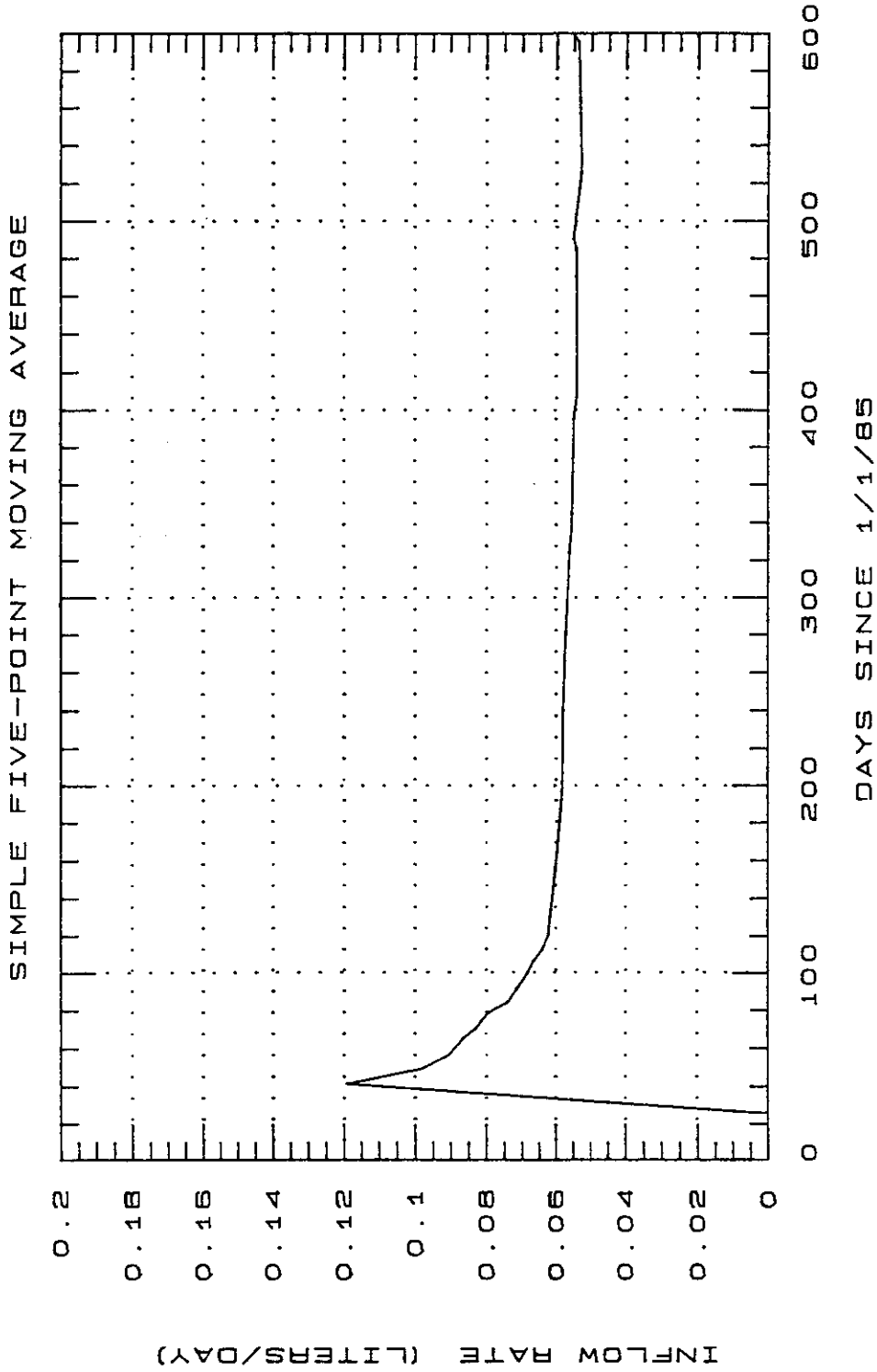


Figure D-15.

BX01 Inflow Rates

drilled with air as the drilling fluid. They were monitored from the time of drilling as part of the BSEP. The numbering system used assigned odd numbers to the upholes (DH35, DH37, DH39, and DH41) and even numbers to the corresponding downholes (DH36, DH38, DH40, and DH42). As a result of poor core recovery from the 6- to 12-meter interval in the westernmost downhole, DH42, an offset hole, DH42A, was drilled 12 meters deep, 2 meters west of DH42. It is interesting to note the striking difference in the inflow into this pair of holes, only 2 meters apart. Marker Bed 139 was generally intersected at depths of about 1.4 to 2 meters below the floor of Room G (Figure D-2).

3.4.1 Hole DH36

Hole DH36 is the easternmost downhole in Room G and was completed January 26, 1985. No brine or gas inflows were noted during drilling, but brine accumulations were noticed shortly after drilling. Moist muck was observed in the bottom of the hole on January 28, 1985 and 2.5 liters of brine, muck, and hydraulic fluid (contamination from drilling) were bailed from the hole on February 5, 1985 (Table E.10). Initial inflow rates were on the order of 0.25 liters per day and remained quite steady, decreasing only slightly through August 1986, when inflow rates still exceeded 0.2 liters per day (Table E.10, Figure D-17). Almost 125 liters of brine had been removed from DH36 by August 19, 1986.

3.4.2 Hole DH38

Hole DH38 is a downhole completed January 26, 1985 just east of the center of Room G. No brine or gas inflows were noted during drilling, but brine accumulations were noticed shortly after drilling. Moist muck was observed in the bottom of the hole on February 5, 1985 and 0.8 liters of brine and muck were bailed from the hole on February 19, 1985 (Table E.12). Initial inflow rates exceeded 0.1 liters per day in February 1985, but by mid-March had declined to less than 0.06 liters per day (Table E.12, Figure D-18). Inflow rates show a slightly increasing trend through October 1985, followed by a slightly decreasing trend through August 1986, but overall the inflow rate has been remarkably steady. Over 34 liters of brine had been removed from DH38 by August 19, 1986.

3.4.3 Hole DH40

Hole DH40 is a downhole completed January 25, 1985 just west of the center of Room G. No brine or gas inflows were noted during drilling, but brine accumulations were noticed shortly after drilling. Moist muck was observed in the bottom of the hole on February 5, 1985 and about a liter of brine, muck, and hydraulic fluid was bailed from the hole on April 17, 1985 (Table E.13). Calculated inflow rates in April 1985 exceeded 0.04 liters per day but quickly decreased to about 0.01 liters per day in May, then decreased only gradually through August 1986 (Table E.13, Figure D-19). A total of slightly more than 4.3 liters had been removed from DH40 by June 3, 1986.

3.4.4 Hole DH42

Hole DH42 is a downhole completed on January 23, 1985 at the west end of Room G. No brine or gas inflows were noted during drilling, but brine accumulations were noticed shortly after drilling. Moist muck was observed in the

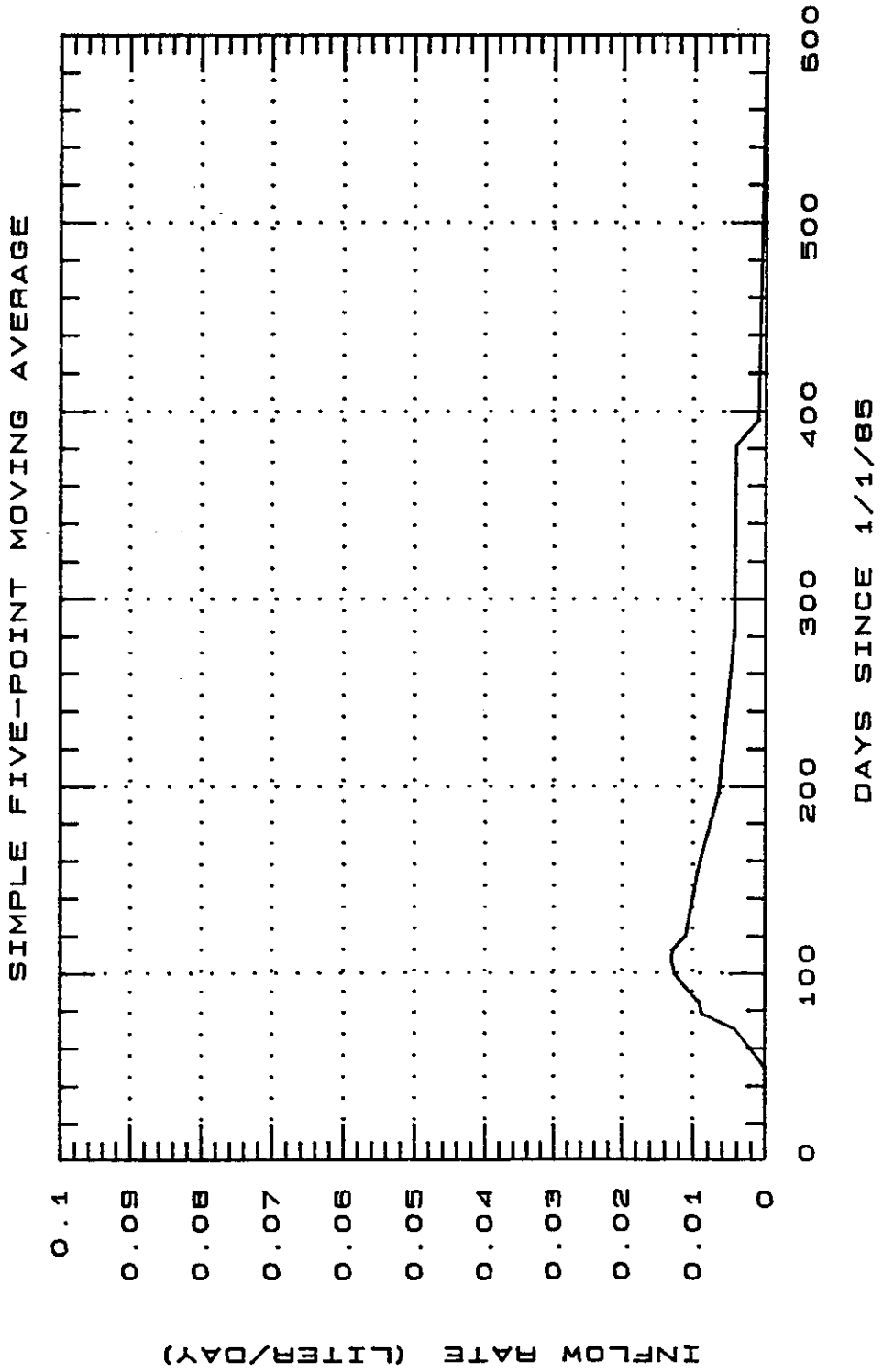


Figure D-16.

BX02 Inflow Rates

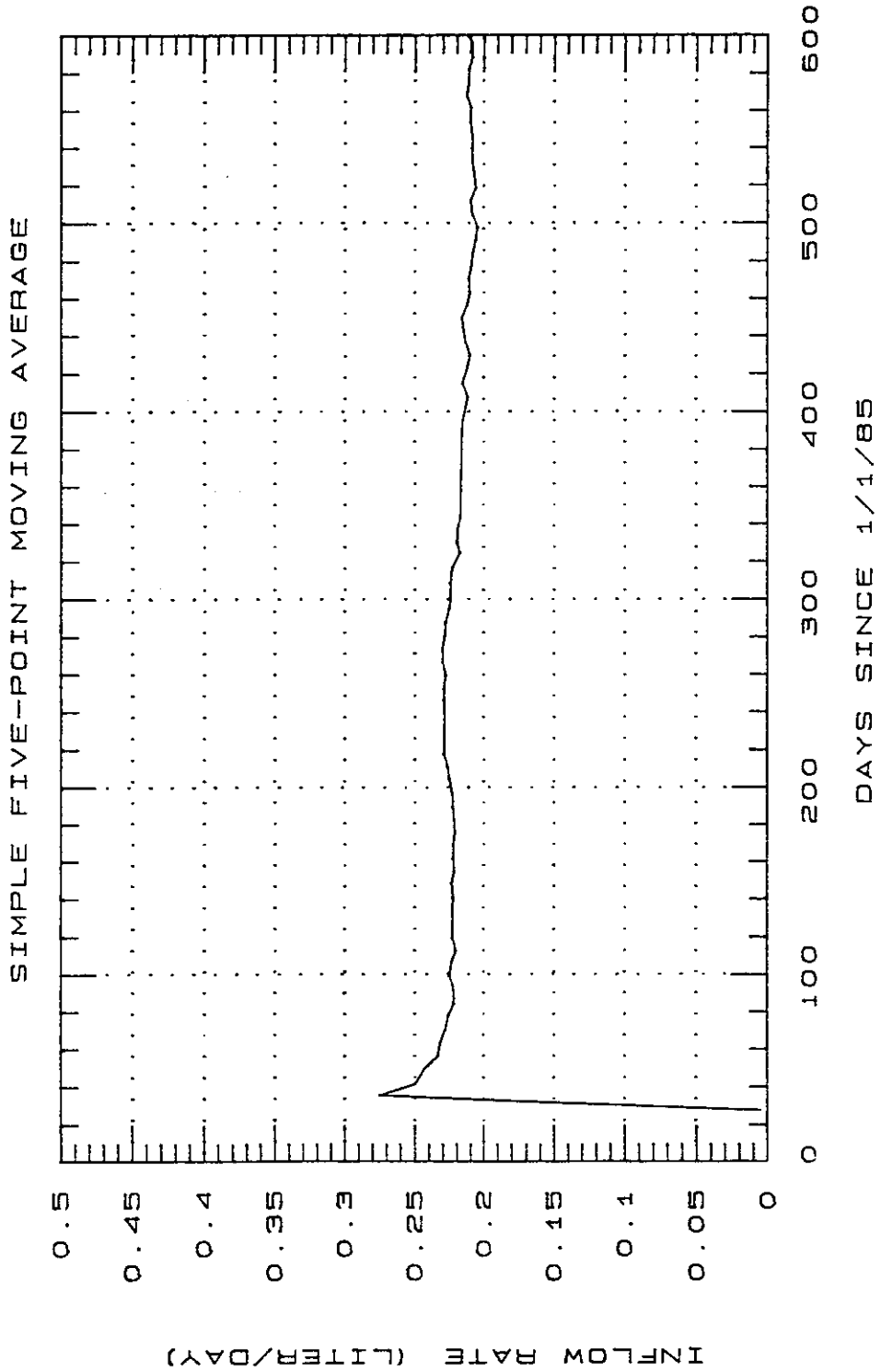


Figure D-17

DH36 Inflow Rates

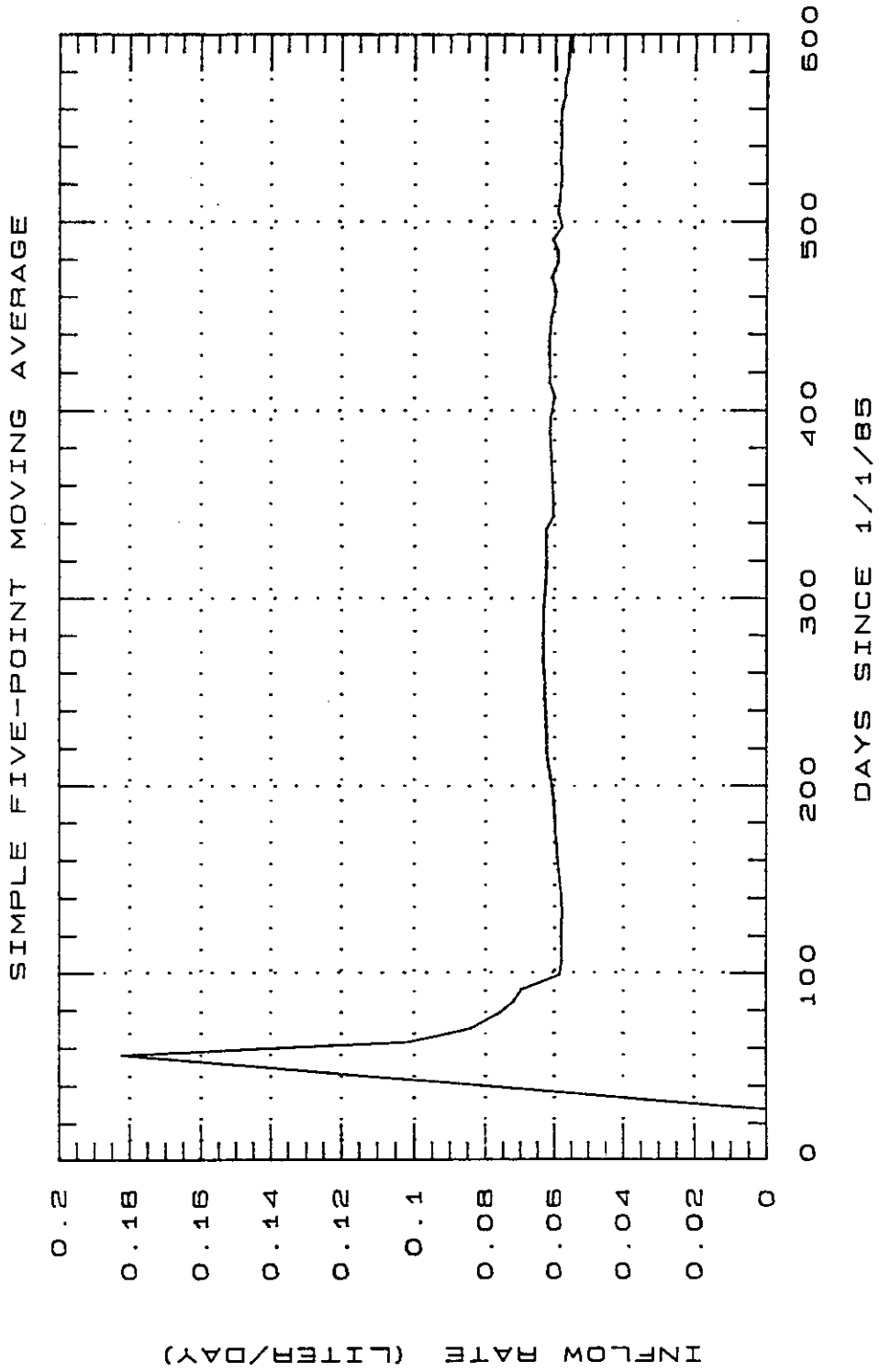


Figure D-18.

DH38 Inflow Rates

bottom of the hole on January 28, 1985 and about 0.3 liters of brine and muck was bailed from the hole on February 5, 1985 (Table E.14). Calculated inflow rates in mid-February 1985, were on the order of 0.05 liters per day and decreased only gradually to about 0.03 liters per day through August 1986 (Table E.14, Figure D-20). A total of approximately 19 liters had been removed from DH42 by August 19, 1986.

3.4.5 Hole DH42A

Hole DH42A is the westernmost downhole at the west end of Room G, 2 meters west of DH42. This hole was drilled because of poor core recovery from the 6- to 12-meter interval in DH42, which is 15.6 meters deep. DH42A was completed January 25, 1985 and is 12.3 meters deep. No brine or gas inflows were noted during drilling, but brine accumulations were noticed shortly after drilling. Brine was observed in the bottom of the hole on January 28, 1985 and 0.85 liters of brine were bailed from the hole on February 5, 1985 (Table E.15).

Calculated inflow rates in mid-February 1985, were on the order of 0.18 liters per day, increased gradually to about 0.2 liters per day in May 1985, and then began decreasing to about 0.1 liters per day in April 1986, where the inflow rate appeared to level out (Table E.15, Figure D-21). A total of approximately 75 liters of brine had been removed from DH42A by August 19, 1986. It is interesting to note that approximately four times as much brine flowed into DH42A than into DH42, which is 2 meters to the east and 3.3 meters deeper.

Most of the downholes studied showed an initial period of little or no inflow followed by a brief maximum inflow period lasting for a few days or a week or two, followed in turn by a decreasing inflow trend. Hole DH42A is the only location studied during Phase I that exhibited an early inflow trend that increased gradually over a much longer period of time (three months). The decreasing trend that followed also took much longer to begin to level out to a fairly steady inflow rate (Figure D-21).

3.4.6 Hole DH35

Hole DH35 was completed January 25, 1985 and is the easternmost uphole at the east end of Room G, above Hole DH36. No brine or gas inflows were noted during drilling, but brine accumulations were noticed shortly after drilling. Brine was observed dripping from the collar on February 5, 1985. A collecting device was installed under the collar on that date, and almost 0.2 liters was collected on March 5, 1985. Inflow rates were in excess of 0.02 liters per day in mid-March 1985, and decreased fairly steadily to 0.01 liters per day in May 1986 (Table E.9, Figure D-22). The lack of brine collected in late May and early April 1986, reflects the fact that the collecting device was broken, not that inflow ceased. However, a marked decrease in inflow did take place about that time. Calculated inflow rates in the summer of 1986 were less than 0.05 liters per day and seemed to be reduced to trace amounts by late August 1986. A total of approximately 4.3 liters was collected from DH35 by August 19, 1986.

3.4.7 Hole DH37

Hole DH37 was completed January 26, 1985 and is located just east of the center of Room G, above Hole DH38. No brine or gas inflows were noted during

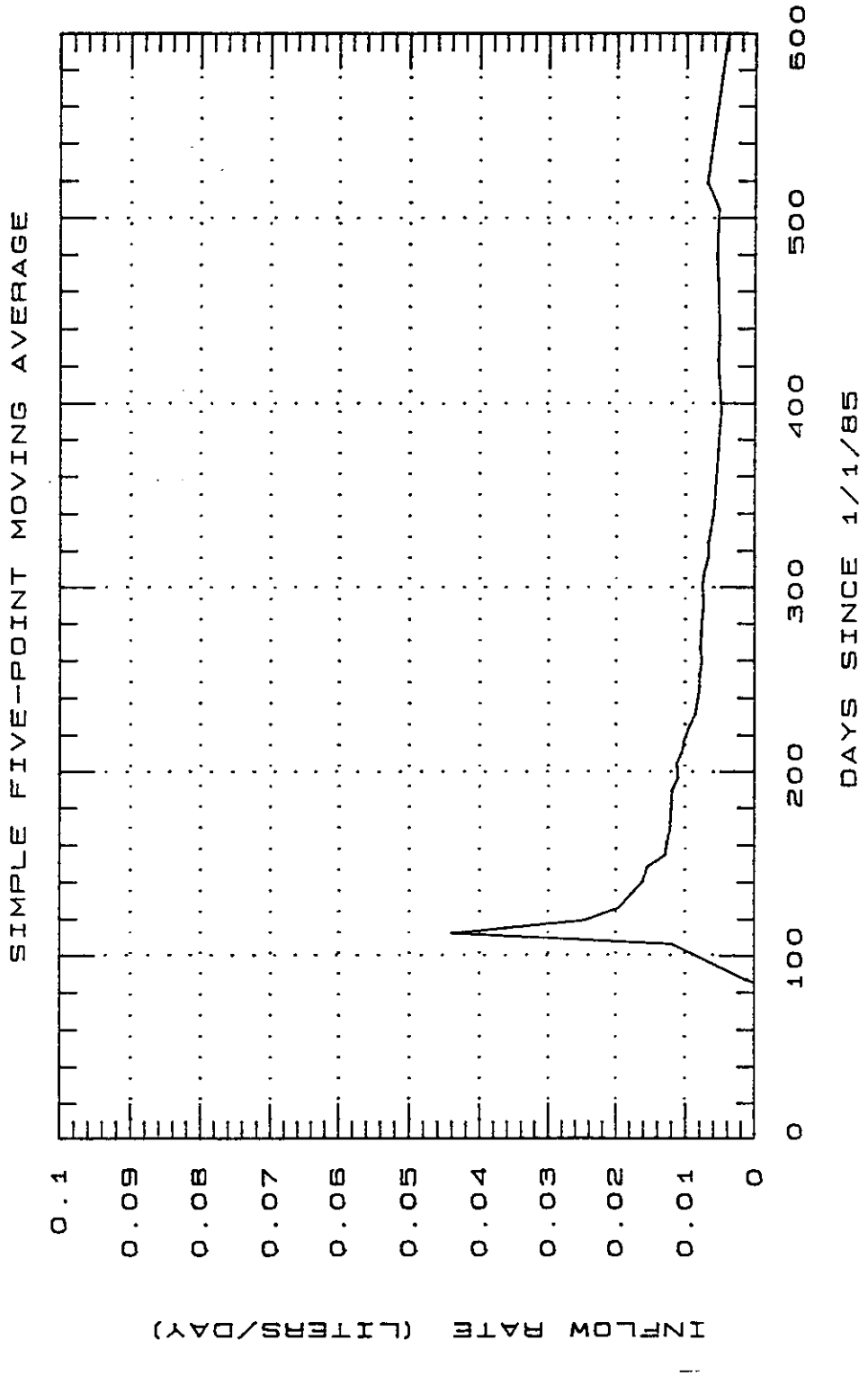


Figure D-19

DH40 Inflow Rates

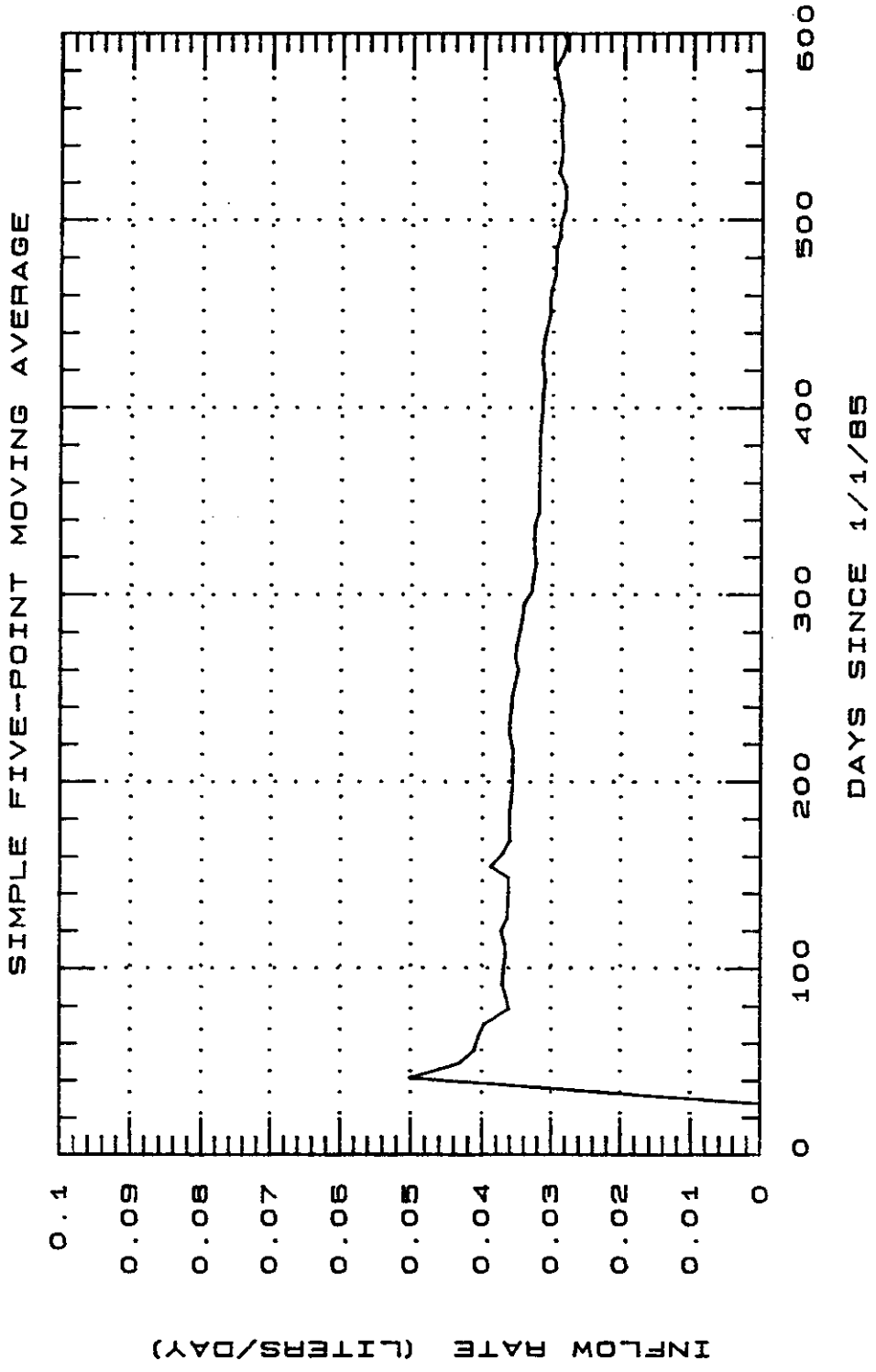


Figure D-20.

DH42 Inflow Rates

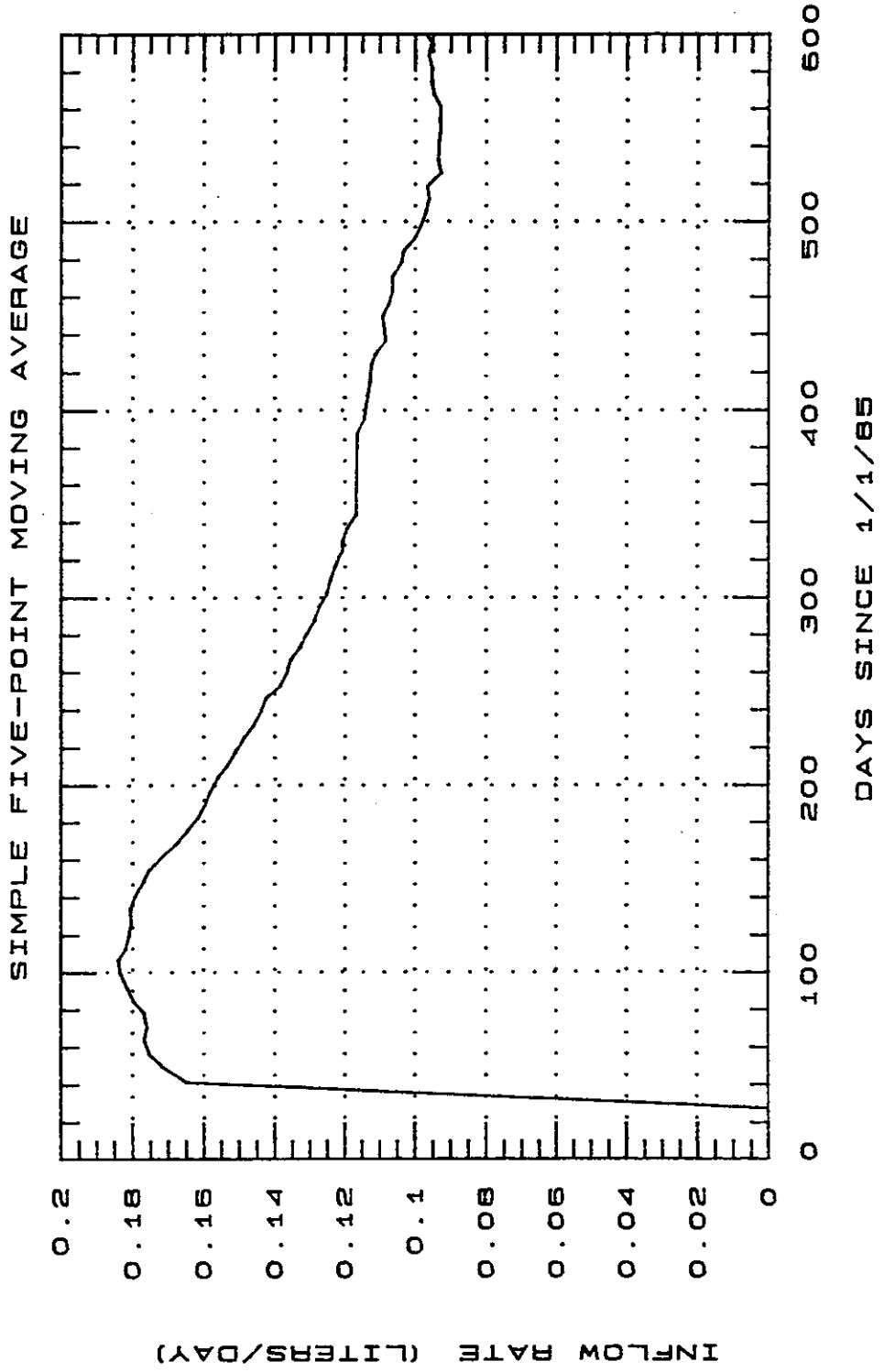


Figure D-21

DH42A Inflow Rates

drilling, but brine accumulations were noticed shortly after drilling. Brine was observed dripping from the collar on February 5, 1985. A collecting device was installed under the collar on that date, and approximately 0.06 liters was collected on March 5, 1985. Inflow rates were on the order of 0.01 liters per day through July 1985, decreasing to less than 0.005 through September 1985, and then decreased further to trace quantities accumulating in the collecting container (Table E.11; Figure D-23). A total of a little over 1.2 liters was collected from DH37 by July 1, 1986.

3.4.8 Hole DH39

Hole DH39 was completed January 24, 1985 and is located just west of the center of Room G, above Hole DH40. No brine or gas inflows were noted during drilling, but brine accumulations were noticed shortly after drilling. A moist area on the back (roof) around the collar was observed on February 5, 1985. A collecting device was installed under the collar on that date, and trace amounts of brine were collected in May 1985. Measurable quantities of brine did not accumulate in the collecting device.

3.4.9 Hole DH41

Hole DH41 was completed January 25, 1985 at the west end of the center of Room G, above Hole DH42. No brine or gas inflows were noted during drilling, but brine accumulations were noticed shortly after drilling. A moist area on the back (roof) around the collar was observed on February 5, 1985. A collecting device was installed under the collar on that date. Measurable quantities of brine did not accumulate in the collecting device.

3.5 Room J

Room J is the site of the Materials Interface Interactions Test (MIIT) and the Drum Durability Test (DDT). Room J was excavated in April 1984. A pit was excavated in the southwest floor of the room and a series of 1- to 2-meter deep drill holes were made in the north end of the room (Figure D-24; Morse and Hassinger, 1985). Brine flowed into Holes MIIT-2 and MIIT-4 during drilling, and began to seep into the pit immediately after excavation. The brine pit was cleaned and blown dry with compressed air on June 27, 1984. Five days later the pit had refilled to about one-half of its previous depth.

Forty shallow drill holes were made for the MIIT program. The fact that the brine levels in these closely-spaced drill holes were dramatically different was observed during the summer and fall of 1984. Holes partially or completely filled with brine were interspersed with dry or nearly dry holes, often less than a meter away. On October 26, 1984, the room and the brine accumulations were surveyed (Figure D-24; Morse and Hassinger, 1985). The brine levels in the drill holes were resurveyed on November 26, 1984. At that time, the floor of the room was observed to be contaminated by a variety of materials and fluids.

On November 29, 1984, the MIIT holes were evacuated and cleaned with compressed air, the DDT pit was cleaned, and the contaminants that were loose on the floor removed. Approximately 75 liters of brine and salt crystals were removed from

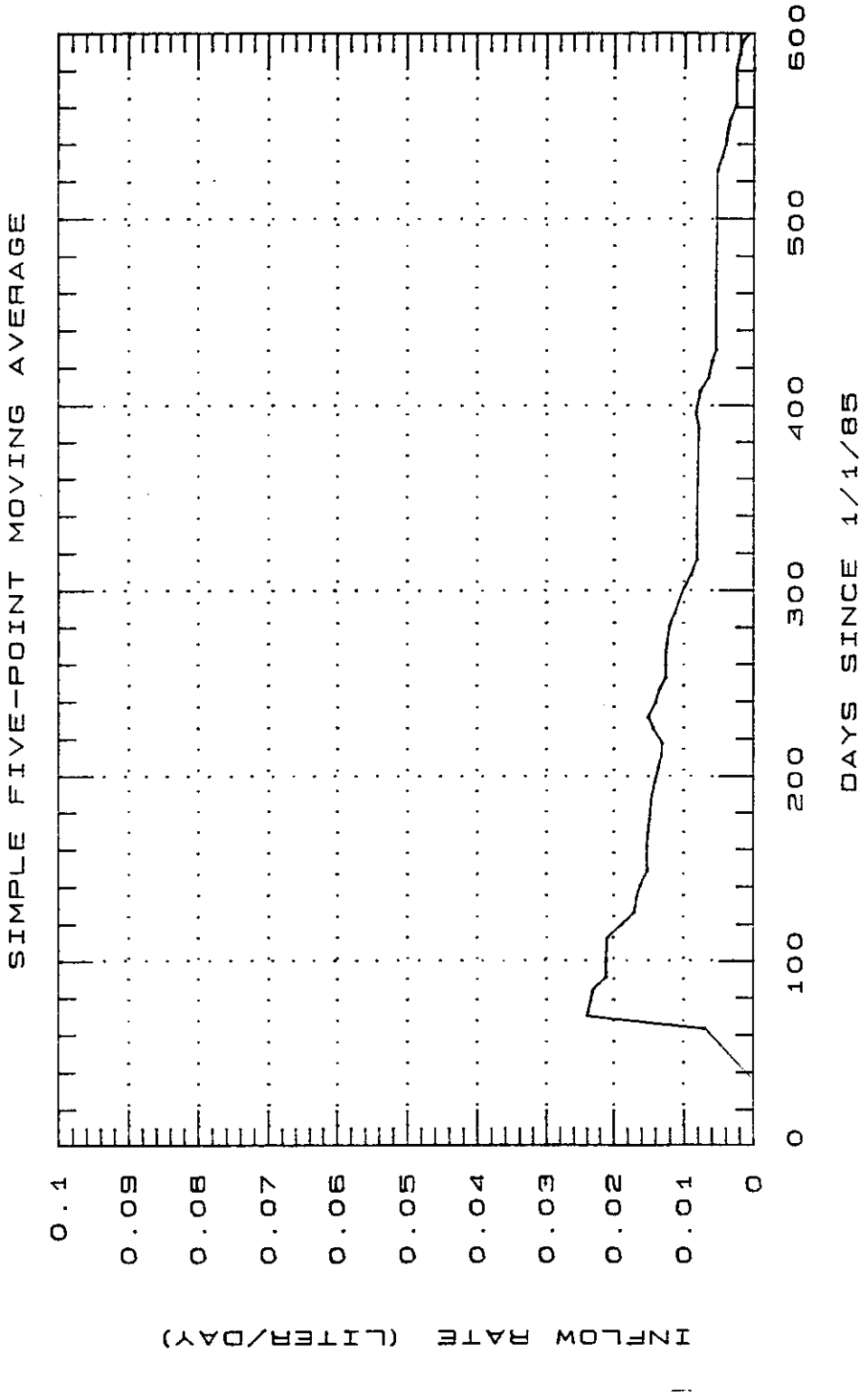


Figure D-22.

DH35 Inflow Rates

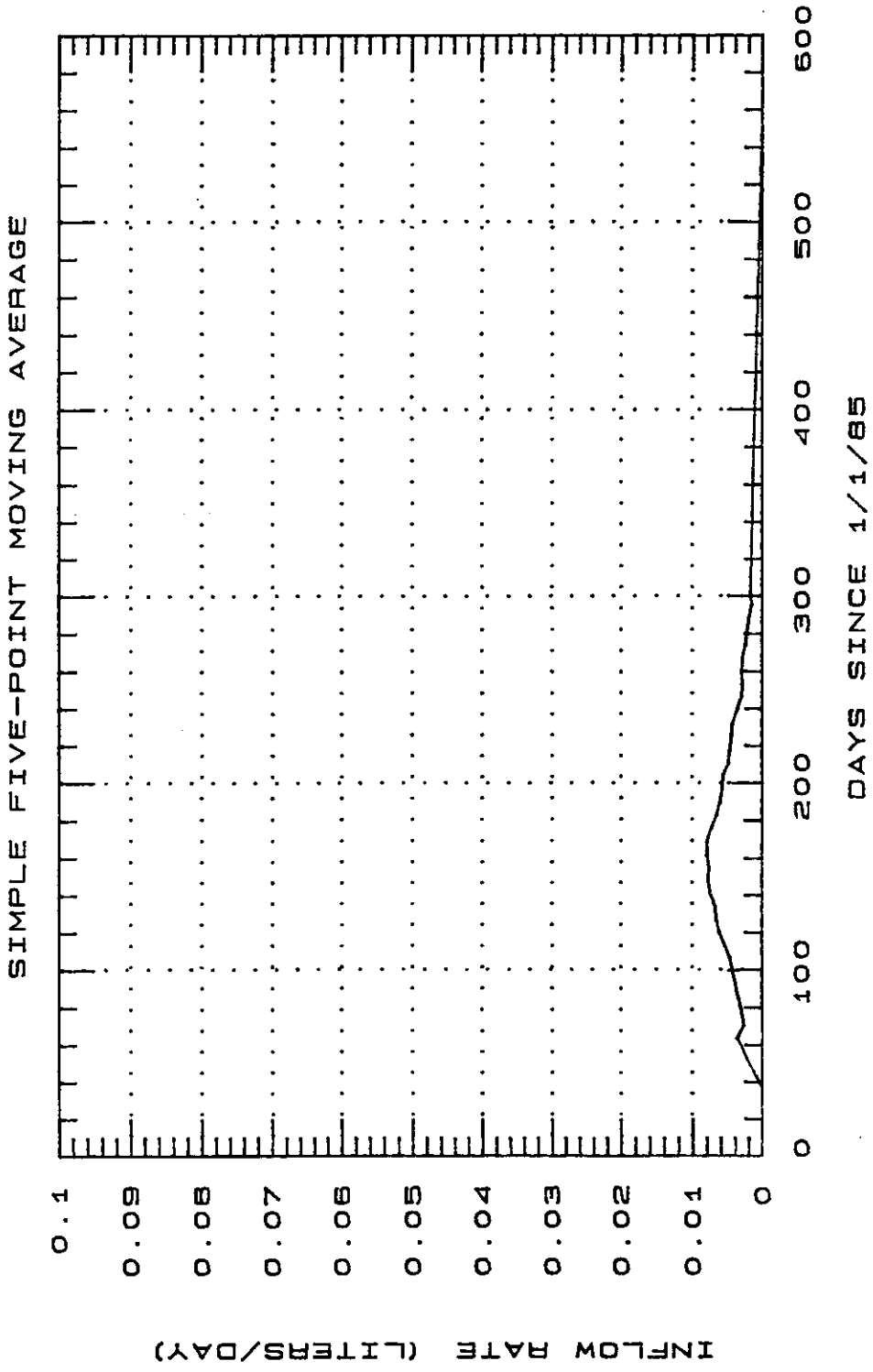


Figure D-23.

DH37 Inflow Rates

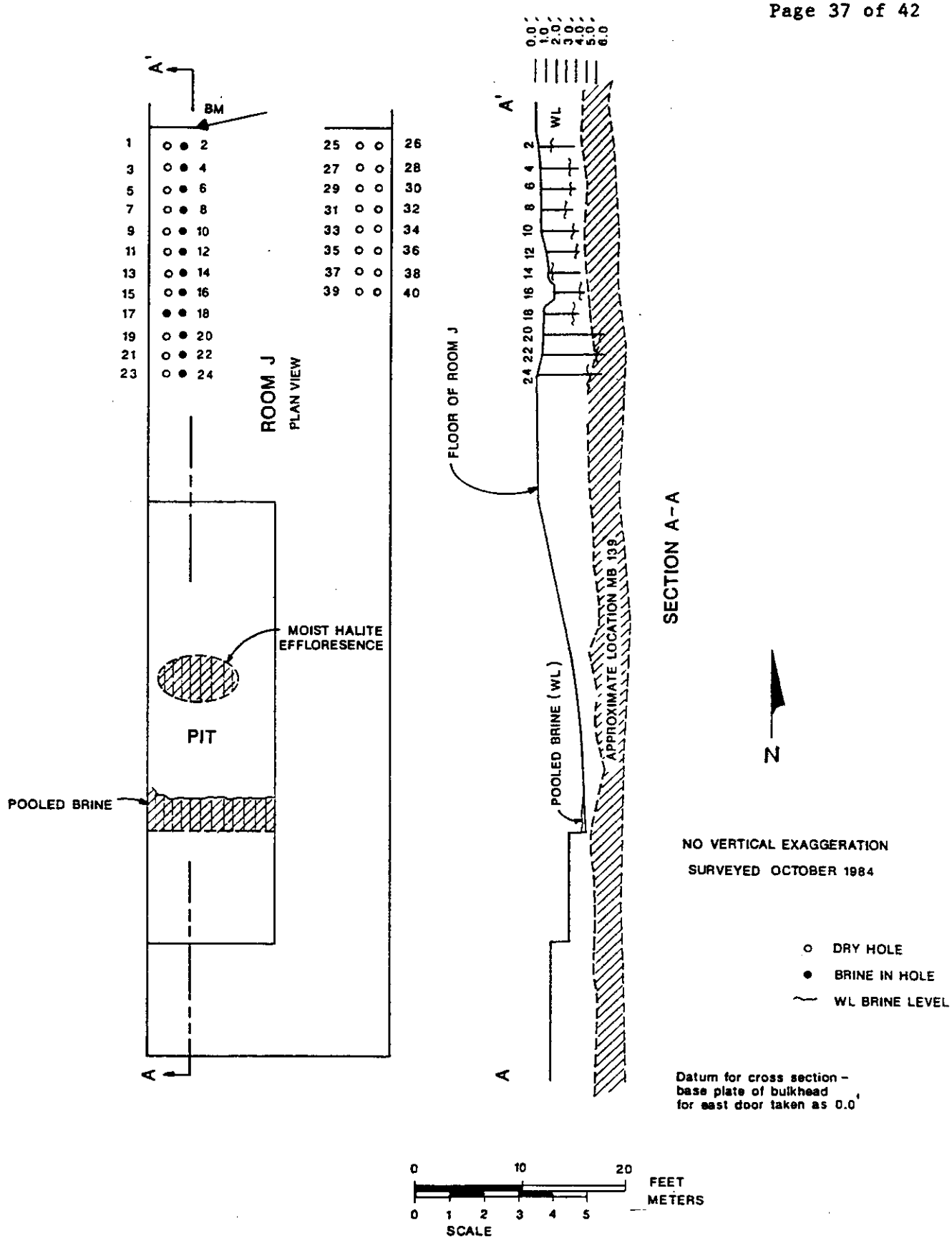


Figure D-24.

Room J Brine Survey, Plan and Cross Section
(After Morse and Hassinger, 1985)

the pit and about 17.5 liters were removed from the MIIT holes. Eighteen days later brine puddles had returned to the floor of the DDT pit and some brine had returned to all except one of the MIIT holes that had previously contained brine.

On January 8, 1985, the brine levels were again surveyed and the holes evacuated. Brine inflows were monitored through April 23, 1985, when Room J was closed to the BSEP in the course of the MIIT experiments.

The significance of the observations that were made in Room J is that drill holes less than a meter apart exhibited strikingly different brine inflows and the brine level in adjacent holes stood at strikingly different levels. Marker Bed 139 was obviously playing a significant role in the migration of brine to the MIIT holes and the brine pit (Figure D-24), and gas bubbles were associated with almost all occurrences. A total of over 18 liters of brine were removed from the MIIT holes.

3.6 Room L1, Hole L1X00

Room L1 was excavated in April 1984. Shortly after excavation, 11 holes were drilled in the floor across the north end of the room and approximately one foot of brine accumulated in each of these holes. On November 27, 1984 it was observed that 10 of the 11 holes had been filled and sealed with grout as part of the Plugging and Sealing test program. The remaining hole, L1X00, was still open and contained brine, and about 11 liters of brine were removed from the hole. On November 30, 1984 compressed air was used to completely evacuate the hole. On May 14, 1985 the hole was found to contain brine and an additional 11.46 liters were removed. Inflow rates at the end of May were calculated to be on the order of 0.03 liters per day, declining gradually to about 0.02 liters per day in early December 1985 (Table E.19, Figure D-25). Inflow rates then gradually increased through August 1986 returning almost to their May 1985, values. A total of over 23.5 liters of brine had been removed from L1X00 by August 19, 1986.

Thirty-six downholes, 10 centimeters in diameter, and 3.6 meters deep were drilled through MB 139 on a 1 meter by 1.5 meter grid in the north end of Room L1. Observations of brine inflows into some of these holes showed variations between holes that were similar to, but somewhat less dramatic than, those described above for the MIIT holes in Room J.

3.7 E140 Drift at S1950, Holes DH215 and DH216

The south exploratory drift was excavated at E140 in 1982 and 1983, reaching the southern end (S3666) of the planned underground facility January 29, 1983. The initial excavation was 2.4 meters high and 7.6 meters wide. The part of the drift at S1950 was mined on January 3, 1983. A pair of uphole and downholes (DH215 and DH216) were drilled shortly after excavation, and sonic-probe extensometers (GE247 and GE248) were installed in them. Both holes were drilled with brine as the drilling fluid and both encountered traces of pressurized gas during drilling. Hole DH215 is the uphole and is 15.8 meters deep. Hole DH216 is the downhole and is 16.5 meters long. Both holes began producing brine shortly after drilling and, partially because they were far removed from the observation holes in the northern, experimental part of the WIPP workings, were the location of early, informal, brine inflow observations.

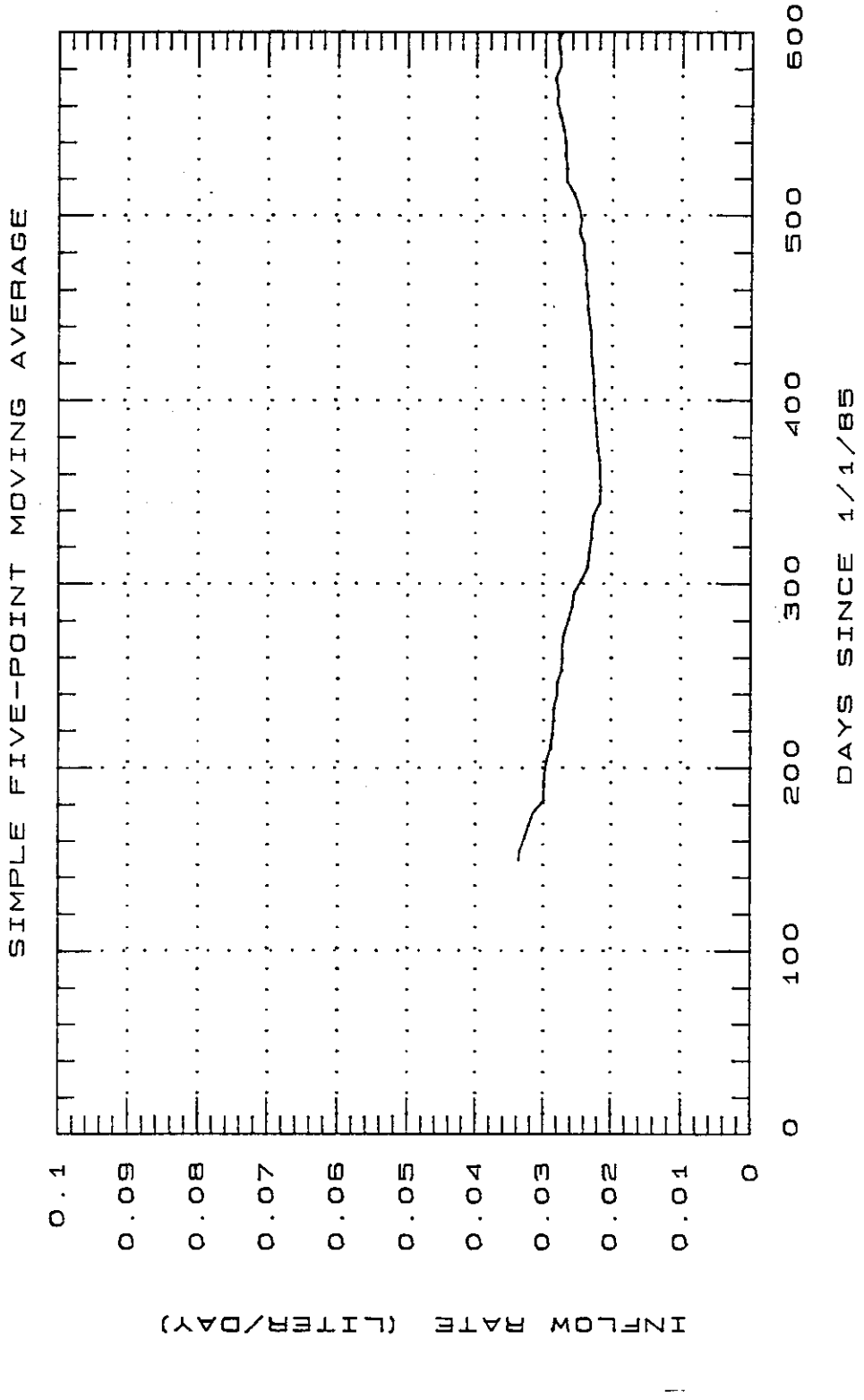


Figure D-25.

L1X00 Inflow Rates

The presence of instrumentation in both holes makes it difficult to obtain good quantitative data and probably effects any chemical data obtained from brine withdrawn from them.

In April 1984, the downhole was observed to be completely filled with brine, and brine was observed dripping into it from the uphole over it. It was not known how much of the 15.8 meters of brine in the downhole had been produced from the rocks exposed in the sides of the hole and how much had dripped into it from the uphole. It was further recognized that both holes had been drilled with brine and that water had been spread on the floor of the drift by the mining contractor for dust control, both possible sources of brine that may have accumulated in the downhole.

On April 20, 1984, a funnel and collecting device was installed on the uphole to collect the brine issuing from it, and the brine that filled the downhole was evacuated down to the level of the instrument head, approximately 0.55 meters below the collar. It was not possible to conveniently extract brine from below the instrument head, so a column of brine more than 15.2 meters long remained in the hole.

Three days later, on April 23, 1984, about an inch of brine had accumulated over the instrument head in the downhole (DH216), but no brine had been collected from the uphole (DH215). Gas bubbles were observed rising around the instrument head in DH216. By the end of April, small amounts of brine were collected from the uphole, and incidental observations throughout the summer and fall of 1984 documented that more brine was being produced from the downhole than from the uphole, but that both did yield brine.

Formal collections were initiated in January 1985, at which time the uphole seemed to be producing more brine than the downhole. Accurate data from the downhole (DH216) was difficult to obtain, and the collar was destroyed and the hole plugged by mining November 19, 1985.

Data from the uphole, DH215, is more complete (Table E.16) and is quite interesting (Figure D-26). Inflow rates in January 1985 were on the order of 0.01 liters per day and showed a gradual increase, almost doubling to 0.02 liters per day by November 1985. On November 19, 1985, the floor of E140 was lowered by 4 feet at S1950. On November 20, 1985, mining of the cross drift S1950 began, with mining to the east, toward E300. On January 29, 1986, the cross drift was extended to the west, toward W30. Hole DH215 was the uphole in the center of what then became the intersection of E140 and S1950. On February 28, 1986, additional mining took place at this intersection as the floor of E140 south of the intersection was lowered 1.2 meters.

Inflow rates increased three-fold, to approximately 0.06 liters per day, immediately following the lowering of the floor and the excavation of the cross drift to the east. It is highly probable that the change in the stress distribution in the vicinity of the intersection resulted in the increased inflow and that the sudden increase shown on Figure D-26 is a mining-induced transient effect. Inflow rates then declined steadily, perhaps beginning coincidentally with the additional mining at the intersection or perhaps related to that mining, through August 1986, to rates below those observed in January 1985.

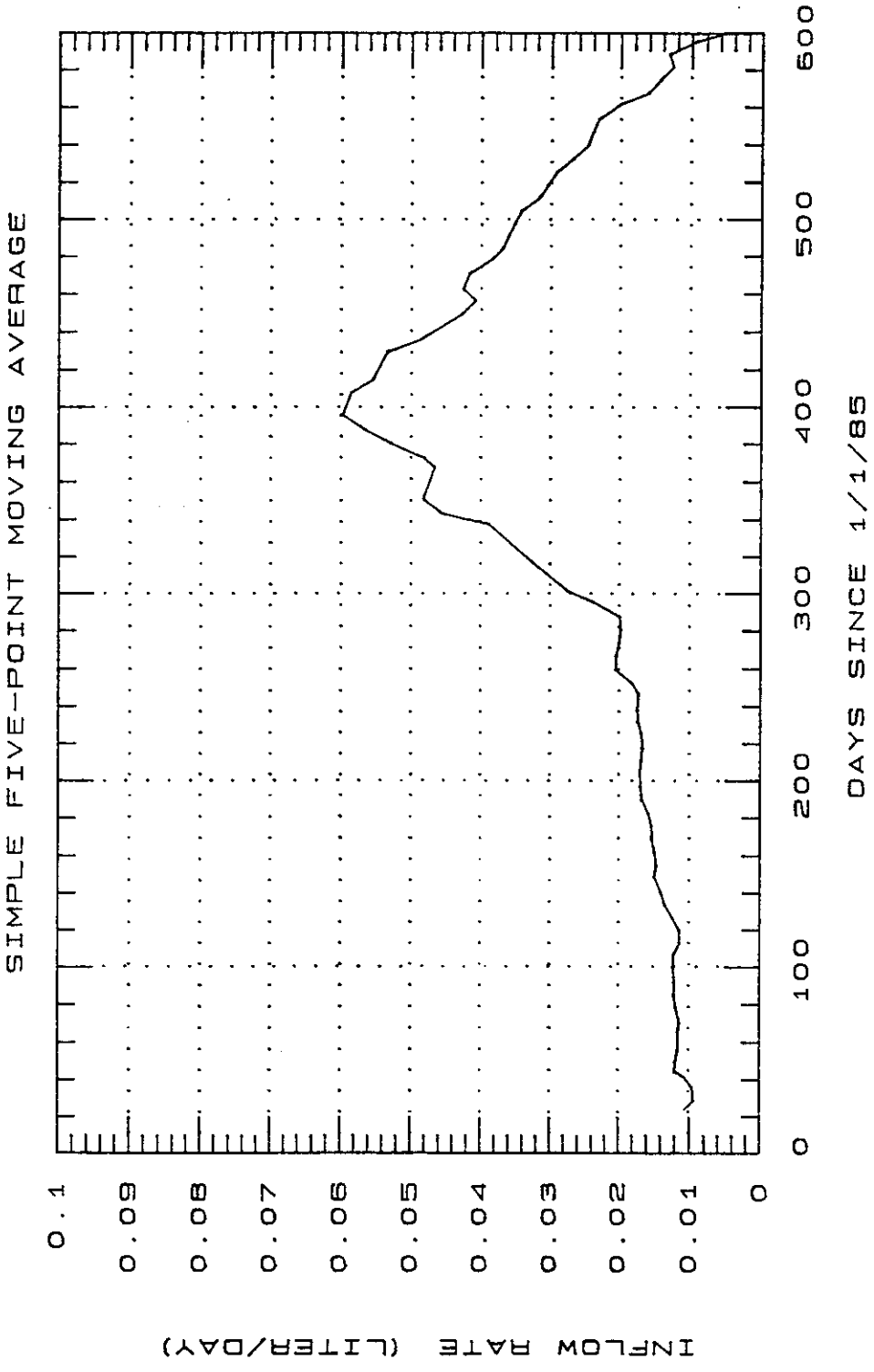


Figure D-26.

DH215 Inflow Rates

Over 15 liters of brine were collected from DH215 over the 600 days of collection. This figure is a minimum figure and much more brine had been produced from the hole, but not collected and measured, prior to January 1985.

APPENDIX E

WIPP BSEP BRINE INFLOW DATA TABLES

TABLE E.1
Inflow Data for Hole A1X01 in Room A1

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
03/12/85	12:20	00.08	70.514	0.08	0.000	First time bailed.
03/20/85	13:30	00.38	78.562	0.46	0.047	Brine plus some muck.
03/26/85	11:25	00.23	84.476	0.69	0.039	Muck in hole. Valved leaked, some brine drained back down hole.
04/02/85	12:15	00.39	91.510	1.08	0.055	
04/10/85	12:20	00.33	99.514	1.41	0.041	
04/17/85	11:30	00.28	106.479	1.69	0.040	
04/23/85	10:50	00.23	112.451	1.92	0.039	
04/30/85	13:26	00.26	119.560	2.18	0.037	
05/07/85	09:10	00.25	126.382	2.43	0.037	
05/14/85	10:06	00.24	133.421	2.67	0.034	
05/21/85	11:40	00.26	140.486	2.93	0.037	
05/29/85	10:00	00.27	148.417	3.20	0.034	
06/04/85	10:20	00.20	154.431	3.40	0.033	
06/11/85	09:40	00.23	161.403	3.63	0.033	
06/18/85	09:34	00.23	168.399	3.86	0.033	
06/25/85	09:40	00.22	175.403	4.08	0.031	
07/02/85	11:00	00.23	182.458	4.31	0.033	
07/09/85	10:00	00.23	189.417	4.54	0.033	
07/16/85	10:55	00.23	196.455	4.77	0.033	
07/24/85	10:00	00.25	204.417	5.02	0.031	
07/30/85	09:32	00.19	210.397	5.21	0.032	
08/06/85	09:37	00.21	217.401	5.42	0.030	
08/14/85	09:48	00.23	225.408	5.65	0.029	
08/20/85	10:18	00.19	231.429	5.84	0.032	
08/28/85	09:13	00.23	239.384	6.07	0.029	
09/04/85	09:46	00.19	246.407	6.26	0.027	
09/10/85	09:30	00.18	252.396	6.44	0.030	
09/17/85	09:10	00.19	259.382	6.63	0.027	
09/24/85	09:11	00.21	266.383	6.84	0.030	
10/01/85	09:23	00.21	273.391	7.05	0.030	
10/08/85	12:24	00.20	280.517	7.25	0.028	Room A1 heaters turned on 10/02/85.
10/15/85	09:43	00.19	287.405	7.44	0.028	
10/23/85	09:55	00.20	295.413	7.64	0.025	
10/29/85	11:05	00.17	301.462	7.81	0.028	
11/05/85	08:50	00.19	308.368	8.00	0.028	
11/13/85	09:15	00.22	316.385	8.22	0.027	
11/21/85	10:40	00.21	324.444	8.43	0.026	
11/26/85	10:10	00.14	329.424	8.57	0.028	
12/04/85	14:13	00.20	337.592	8.77	0.024	
12/10/85	10:40	00.15	343.444	8.92	0.026	
12/17/85	13:59	00.19	350.583	9.11	0.027	
01/03/86	09:40	00.41	367.403	9.52	0.024	
01/08/86	10:20	00.09	372.431	9.61	0.018	
01/16/86	09:50	00.25	380.410	9.86	0.031	
01/23/86	10:10	00.18	387.424	10.04	0.026	
01/31/86	11:05	00.21	395.462	10.25	0.026	
02/12/86	10:10	00.30	407.424	10.55	0.025	
02/19/86	10:55	00.18	414.455	10.73	0.026	
02/28/86	14:05	00.23	423.587	10.96	0.025	
03/06/86	10:00	00.15	429.417	11.11	0.026	
03/13/86	09:30	00.18	436.396	11.29	0.026	
03/26/86	09:20	00.33	449.389	11.62	0.025	
04/02/86	09:00	00.18	456.375	11.80	0.026	

TABLE E.1
Inflow Data for Hole A1X01 in Room A1

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
04/08/86	09:09	00.15	462.381	11.95	0.025	
04/16/86	11:30	00.20	470.479	12.15	0.025	
04/24/86	09:35	00.20	478.399	12.35	0.025	
04/30/86	10:13	00.15	484.426	12.50	0.025	
05/06/86	09:40	00.12	490.403	12.62	0.020	
05/13/86	09:25	00.19	497.392	12.81	0.027	
05/20/86	10:16	00.18	504.428	12.99	0.026	
05/27/86	15:05	00.18	511.628	13.17	0.025	
06/03/86	09:28	00.17	518.394	13.34	0.025	
06/10/86	10:50	00.15	525.451	13.49	0.021	
06/17/86	09:59	00.19	532.416	13.68	0.027	
06/24/86	10:10	00.18	539.424	13.86	0.026	
07/01/86	12:46	00.19	546.532	14.05	0.027	
07/08/86	10:05	00.16	553.420	14.21	0.023	
07/16/86	09:57	00.20	561.415	14.41	0.025	
07/22/86	09:26	00.16	567.393	14.57	0.027	
07/29/86	10:05	00.17	574.420	14.74	0.024	
08/05/86	10:21	00.19	581.431	14.93	0.027	
08/12/86	09:58	00.18	588.415	15.11	0.026	
08/19/86	10:40	00.18	595.444	15.29	0.026	

TABLE E.2
Inflow Data for Hole A1X02 in Room A1

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
03/07/85	09:30	NA	65.396	0.00	0.000	First record, completed drilling 3/07/85. Hit brine at 12 ft. on 2/27/85.
03/12/85	12:00	NA	70.500	0.00	0.000	Trace brine, deepened hole to clay seam. Moisture on back 1 ft radius.
03/20/85	13:00	NA	78.542	0.00	0.000	Trace brine, drip missing funnel.
03/26/85	11:25	NA	84.476	0.00	0.000	Repositioned funnel, collected one cup of salt crystals with trace brine.
04/02/85	12:15	00.21	91.510	0.21	0.008	Some drips missing funnel.
04/10/85	12:20	00.22	99.514	0.43	0.027	Collecting container had leak.
04/17/85	11:30	00.12	106.479	0.55	0.017	Some drips missing funnel.
04/23/85	10:50	00.12	112.451	0.67	0.020	Some drips missing funnel.
04/30/85	13:16	00.12	119.553	0.79	0.017	Some drips missing funnel.
05/07/85	09:05	00.16	126.378	0.95	0.023	
05/14/85	10:04	00.19	133.419	1.14	0.027	
05/21/85	11:35	00.13	140.483	1.27	0.018	Some drips missing funnel.
05/29/85	10:00	00.21	148.417	1.48	0.026	
06/04/85	10:25	00.17	154.434	1.65	0.028	
06/11/85	09:40	00.05	161.403	1.70	0.007	
06/18/85	09:30	00.08	168.396	1.78	0.011	Some missing funnel, big stalactite formed.
06/25/85	09:45	00.16	175.406	1.94	0.023	
07/02/85	11:00	00.10	182.458	2.04	0.014	
07/09/85	09:58	00.15	189.415	2.19	0.022	
07/16/85	10:53	00.24	196.453	2.43	0.034	
07/24/85	09:49	00.24	204.409	2.67	0.030	
07/30/85	09:30	00.15	210.396	2.82	0.025	
08/06/85	09:35	00.14	217.399	2.96	0.020	
08/14/85	09:26	00.05	225.393	3.01	0.006	
08/20/85	10:13	00.09	231.426	3.10	0.015	
08/28/85	09:08	00.06	239.381	3.16	0.008	
09/04/85	09:44	00.07	246.406	3.23	0.010	
09/10/85	09:24	00.12	252.392	3.35	0.020	
09/17/85	09:08	00.13	259.381	3.48	0.019	Some drips missing funnel.
09/24/85	09:07	00.17	266.380	3.65	0.024	
10/01/85	09:21	00.14	273.390	3.79	0.020	
10/08/85	12:19	00.16	280.513	3.95	0.022	Room A1 heaters turned on 10/02/85.
10/15/85	09:41	00.12	287.403	4.07	0.017	
10/23/85	09:43	00.19	295.405	4.26	0.024	
10/29/85	11:02	00.12	301.460	4.38	0.020	
11/05/85	08:46	00.12	308.365	4.50	0.017	
11/13/85	09:16	00.13	316.386	4.63	0.016	Some drips missing funnel.
11/21/85	10:45	00.13	324.448	4.76	0.016	Some drips missing funnel.
12/04/85	14:07	00.14	337.588	4.90	0.011	
12/10/85	10:31	00.08	343.438	4.98	0.014	
12/17/85	13:56	00.03	350.581	5.01	0.004	
01/03/86	09:40	00.01	367.403	5.02	0.001	Some drips missing funnel.
01/23/86	10:10	00.06	387.424	5.08	0.003	New, larger, funnel since 01/17.
01/31/86	11:05	00.23	395.462	5.31	0.029	
02/12/86	10:10	00.22	407.424	5.53	0.018	
02/19/86	10:50	00.07	414.451	5.60	0.010	

TABLE E.2
Inflow Data for Hole A1X02 in Room A1

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
02/28/86	14:00	00.02	423.583	5.62	0.002	
03/13/86	09:30	00.05	436.396	5.67	0.004	
03/26/86	09:20	00.05	449.389	5.72	0.004	
04/02/86	09:00	00.08	456.375	5.80	0.011	
04/16/86	11:30	00.10	470.479	5.90	0.007	
04/24/86	09:35	00.05	478.399	5.95	0.006	
04/30/86	10:10	00.07	484.424	6.02	0.012	
05/06/86	09:40	00.16	490.403	6.18	0.027	
05/13/86	09:25	00.02	497.392	6.20	0.003	
05/20/86	10:16	00.04	504.428	6.24	0.006	
05/27/86	15:05	00.15	511.628	6.39	0.021	
06/03/86	09:28	00.13	518.394	6.52	0.019	
06/10/86	10:50	00.10	525.451	6.62	0.014	
06/17/86	09:59	00.12	532.416	6.74	0.017	
06/24/86	10:10	00.25	539.424	6.99	0.036	
07/01/86	12:44	00.23	546.531	7.22	0.032	
07/08/86	10:05	00.11	553.420	7.33	0.016	
07/16/86	09:54	00.25	561.413	7.58	0.031	
07/22/86	09:26	00.16	567.393	7.74	0.027	
07/29/86	10:05	00.26	574.420	8.00	0.037	
08/05/86	10:19	00.22	581.430	8.22	0.031	
08/12/86	09:58	00.28	588.415	8.50	0.040	
08/19/86	10:38	00.26	595.443	8.76	0.037	

TABLE E.3
Inflow Data for Hole A2X01 in Room A2

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
02/19/85	13:20	NA	49.556	0.00	0.000	Moist muck. First entry.
03/07/85	09:30	00.29	65.396	0.29	0.017	Lots of muck, some oil.
03/12/85	11:30	00.62	70.479	0.91	0.122	Brine and muck.
03/20/85	13:04	00.52	78.544	1.43	0.064	
03/26/85	11:02	00.38	84.460	1.81	0.064	
04/02/85	11:58	00.36	91.499	2.17	0.051	
04/10/85	11:53	00.36	99.495	2.53	0.045	Some muck included.
04/17/85	11:10	00.27	106.465	2.80	0.039	
04/23/85	10:30	00.24	112.438	3.04	0.040	
04/30/85	13:50	00.29	119.576	3.33	0.041	
05/07/85	08:45	00.25	126.365	3.58	0.037	
05/14/85	09:40	00.24	133.403	3.82	0.034	
05/21/85	12:08	00.24	140.506	4.06	0.034	
05/29/85	09:00	00.26	148.375	4.32	0.033	
06/04/85	09:35	00.20	154.399	4.52	0.033	
06/11/85	09:15	00.23	161.385	4.75	0.033	
06/18/85	09:15	00.23	168.385	4.98	0.033	
06/25/85	09:15	00.23	175.385	5.21	0.033	
07/02/85	11:00	00.23	182.458	5.44	0.033	
07/09/85	09:29	00.22	189.395	5.66	0.032	
07/16/85	10:30	00.23	196.438	5.89	0.033	Effervesces.
07/24/85	09:39	00.24	204.402	6.13	0.030	
07/30/85	08:55	00.19	210.372	6.32	0.032	
08/06/85	09:21	00.21	217.390	6.53	0.030	
08/14/85	09:05	00.25	225.378	6.78	0.031	
08/20/85	09:50	00.19	231.410	6.97	0.031	
08/28/85	08:45	00.21	239.365	7.18	0.026	Valved leaked, some brine drained back down hole.
09/04/85	09:21	00.25	246.390	7.43	0.036	
09/10/85	09:09	00.18	252.381	7.61	0.030	
09/17/85	08:50	00.21	259.368	7.82	0.030	
09/24/85	08:48	00.21	266.367	8.03	0.030	
10/01/85	09:12	00.21	273.383	8.24	0.030	
10/08/85	12:57	00.21	280.540	8.45	0.029	Room A2 heaters turned on 10/02/85.
10/15/85	09:20	00.20	287.389	8.65	0.029	
10/23/85	09:32	00.22	295.397	8.87	0.027	
10/29/85	11:20	00.15	301.472	9.02	0.025	
11/05/85	08:28	00.21	308.353	9.23	0.031	
11/13/85	09:00	00.23	316.375	9.46	0.029	
11/21/85	10:15	00.23	324.427	9.69	0.029	
11/26/85	09:40	00.14	329.403	9.83	0.028	
12/04/85	13:45	00.20	337.573	10.03	0.024	
12/10/85	10:56	00.16	343.456	10.19	0.027	
12/17/85	13:39	00.21	350.569	10.40	0.030	
01/03/86	09:30	00.47	367.396	10.87	0.028	
01/08/86	09:50	00.15	372.410	11.02	0.030	
01/16/86	09:20	00.22	380.389	11.24	0.028	
01/23/86	09:40	00.19	387.403	11.43	0.027	
01/31/86	10:45	00.25	395.448	11.68	0.031	
02/12/86	09:40	00.34	407.403	12.02	0.028	
02/19/86	14:20	00.12	414.597	12.14	0.017	Suction soil probe was used, some fluid was left in hole.
02/28/86	14:30	00.20	423.604	12.34	0.022	Soil suction probe was used, some fluid left in hole.
03/04/86	09:00	00.15	427.375	12.49	0.040	

TABLE E.3
Inflow Data for Hole A2X01 in Room A2

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
03/06/86	09:30	00.07	429.396	12.71	0.035	Two days accumulation.
03/13/86	09:00	00.15	436.375	12.86	0.021	Soil water probe.
03/26/86	09:05	00.15	449.378	13.01	0.011	Partial evacuation, brine left in hole.
04/02/86	08:40	00.32	456.361	13.33	0.046	
04/08/86	08:50	00.19	462.368	13.52	0.032	
04/16/86	10:45	00.15	470.448	13.67	0.019	
04/24/86	09:20	00.24	478.389	13.91	0.030	Removed suction probe.
04/30/86	09:55	00.20	484.413	14.11	0.033	Resumed sampling with bailer.
05/06/86	09:25	00.13	490.392	14.24	0.022	
05/13/86	09:10	00.20	497.382	14.44	0.029	
05/20/86	09:45	00.20	504.406	14.64	0.028	
05/27/86	14:45	00.20	511.615	14.84	0.028	
06/03/86	09:10	00.19	518.382	15.03	0.028	
06/10/86	10:34	00.19	525.440	15.22	0.027	
06/17/86	09:38	00.19	532.401	15.41	0.027	
06/24/86	09:55	00.18	539.413	15.59	0.026	
07/01/86	12:17	00.19	546.512	15.78	0.027	
07/08/86	09:37	00.19	553.401	16.97	0.028	
07/16/86	09:37	00.18	561.401	16.15	0.022	
07/22/86	09:10	00.18	567.382	16.33	0.030	
07/29/86	09:50	00.18	574.410	16.51	0.026	
08/05/86	10:03	00.13	581.419	16.64	0.019	
08/12/86	09:40	00.18	588.403	16.82	0.026	
08/19/86	10:20	00.18	595.431	17.00	0.026	

TABLE E.4
Inflow Data for Hole A2X02 in Room A2

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
02/19/85	13:20	NA	49.556	0.00	0.000	Installed collecting device. First entry.
03/07/85	09:30	00.34	65.396	0.34	0.020	Moist area 1.5 ft. around the collar.
03/12/85	11:30	00.21	70.479	0.55	0.041	Back wet, 5 ft diameter.
03/20/85	13:04	00.31	78.544	0.86	0.038	
03/26/85	11:02	00.14	84.460	1.00	0.024	
04/02/85	11:58	00.12	91.499	1.12	0.017	Significant salt buildup. 4' dia. wet spot on back.
04/10/85	11:53	00.11	99.495	1.23	0.014	Reset collecting device.
04/23/85	10:30	00.01	112.438	1.24	0.001	
05/07/85	08:41	NA	126.362	0.00	0.000	Some drips missing funnel.
05/14/85	09:40	NA	133.403	0.00	0.000	Some drips missing funnel.
07/09/85	09:25	00.05	189.392	1.29	0.001	
07/16/85	10:23	00.06	196.433	1.35	0.009	
07/24/85	09:33	00.02	204.398	1.37	0.003	
08/06/85	09:22	00.01	217.390	1.38	0.001	
08/28/85	08:35	00.01	239.358	1.39	0.000	Some drips missing funnel.
09/04/85	09:18	00.08	246.387	1.47	0.011	
09/10/85	09:04	00.02	252.378	1.49	0.003	
09/17/85	08:55	00.02	259.372	1.51	0.003	
10/15/85	09:17	00.02	287.387	1.53	0.001	Room A2 heaters turned on 10/02/85.
01/31/86	10:40	00.05	395.444	1.58	0.000	
02/12/86	09:40	00.02	407.403	1.60	0.002	
03/13/86	09:00	00.01	436.375	1.61	0.000	
03/26/86	09:05	00.07	449.378	1.68	0.005	
04/02/86	08:40	00.10	456.361	1.78	0.014	High reading probably due to unplugging temporary blockage in collecting tube on 3/26/86.
04/16/86	10:45	00.09	470.448	1.87	0.006	
04/24/86	09:20	00.02	478.389	1.89	0.003	
04/30/86	09:55	00.02	484.413	1.91	0.003	
05/06/86	09:25	00.02	490.392	1.93	0.003	
05/13/86	09:10	NA	497.382	1.93	0.000	Trace collected.
05/20/86	09:45	NA	504.406	1.93	0.001	Trace collected.
06/03/86	09:10	NA	518.382	1.93	0.000	Trace.
06/10/86	10:34	NA	525.440	1.93	0.000	Trace.
06/17/86	09:38	00.01	532.401	1.94	0.000	
06/24/86	09:50	00.35	539.410	2.29	0.050	Very humid air. High reading probably due to unplugging temporary blockage in collecting tube on 6/17/86.
07/01/86	12:15	00.28	546.510	2.57	0.039	
07/08/86	09:27	00.17	553.394	2.74	0.025	
07/16/86	09:33	00.14	561.398	2.88	0.017	
07/22/86	09:09	00.05	567.381	2.93	0.008	
07/29/86	09:50	00.12	574.410	3.05	0.017	
08/05/86	09:59	00.07	581.416	3.12	0.010	
08/12/86	09:40	00.12	588.403	3.24	0.017	
08/19/86	10:20	00.11	595.431	3.35	0.016	

TABLE E.5
Inflow Data for Hole A3X01 in Room A3

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
02/05/85	11:10	NA	35.465	0.00	0.000	Moist muck at the bottom.
02/19/85	13:40	00.30	49.569	0.30	0.020	Some oil. First time bailed.
02/26/85	13:20	00.23	56.556	0.53	0.033	Brine and oil.
03/07/85	09:45	00.26	65.406	0.79	0.029	
03/12/85	11:45	00.17	70.490	0.96	0.033	
03/20/85	13:14	00.19	78.551	1.15	0.024	Valve leaked. Some brine drained back down hole.
03/26/85	11:12	00.22	84.467	1.37	0.037	
04/02/85	12:00	00.21	91.500	1.58	0.030	
04/10/85	12:00	00.23	99.500	1.81	0.029	
04/17/85	11:20	00.20	106.472	2.01	0.029	
04/23/85	10:41	00.16	112.445	2.17	0.027	
04/30/85	13:35	00.20	119.566	2.37	0.028	
05/07/85	08:55	00.20	126.372	2.57	0.029	
05/14/85	09:56	00.17	133.414	2.74	0.024	
05/21/85	12:00	00.20	140.500	2.94	0.028	
05/29/85	09:25	00.21	148.392	3.15	0.027	
06/04/85	09:55	00.16	154.413	3.31	0.027	
06/11/85	09:25	00.18	161.392	3.49	0.026	
06/18/85	09:27	00.18	168.394	3.67	0.026	
06/25/85	09:30	00.19	175.396	3.86	0.027	
07/02/85	11:00	00.19	182.458	4.05	0.027	
07/09/85	09:50	00.17	189.410	4.22	0.024	
07/16/85	10:50	00.18	196.451	4.40	0.026	Effervesces.
07/24/85	09:47	00.21	204.408	4.61	0.026	
07/30/85	09:30	00.15	210.396	4.76	0.025	
08/06/85	09:30	00.17	217.396	4.93	0.024	
08/14/85	09:21	00.20	225.390	5.13	0.025	
08/20/85	10:08	00.16	231.422	5.29	0.027	
08/28/85	09:05	00.21	239.378	5.50	0.026	
09/04/85	09:29	00.17	246.395	5.67	0.024	
09/10/85	09:20	00.15	252.389	5.82	0.025	
09/17/85	09:06	00.16	259.379	5.98	0.023	
09/24/85	09:03	00.17	266.377	6.15	0.024	
10/01/85	09:18	00.18	273.387	6.33	0.026	
10/08/85	12:35	00.18	280.524	6.51	0.025	Room A3 heaters turned on 10/02/85.
10/15/85	09:35	00.16	287.399	6.67	0.023	
10/23/85	09:40	00.19	295.403	6.86	0.024	
10/29/85	11:11	00.14	301.466	7.00	0.023	
11/05/85	08:42	00.16	308.362	7.16	0.023	
11/13/85	09:30	00.19	316.396	7.35	0.024	
11/21/85	10:30	00.19	324.438	7.54	0.024	
11/26/85	09:55	00.10	329.413	7.64	0.020	
12/04/85	14:03	00.18	337.585	7.82	0.022	
12/10/85	10:46	00.14	343.449	7.96	0.024	
12/17/85	13:55	00.14	350.580	8.10	0.020	
01/03/86	10:00	00.39	367.417	8.49	0.023	
01/08/86	10:10	00.11	372.424	8.60	0.022	
01/16/86	09:35	00.18	380.399	8.78	0.023	
01/23/86	10:00	00.15	387.417	8.93	0.021	
01/31/86	10:55	00.18	395.455	9.11	0.022	
02/12/86	10:00	00.27	407.417	9.38	0.023	
02/19/86	10:40	00.15	414.444	9.53	0.021	
02/28/86	14:20	00.22	423.597	9.75	0.024	
03/06/86	09:50	00.14	429.410	9.89	0.024	

TABLE E.5
Inflow Data for Hole A3X01 in Room A3

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
03/13/86	09:20	00.15	436.389	10.04	0.021	
03/26/86	09:15	00.30	449.385	10.34	0.023	
04/02/86	08:50	00.16	456.368	10.50	0.023	
04/08/86	09:05	00.14	462.378	10.64	0.023	
04/16/86	11:25	00.18	470.476	10.82	0.022	
04/24/86	09:30	00.18	478.396	11.00	0.023	
04/30/86	10:00	00.14	484.417	11.14	0.023	
05/06/86	09:35	00.14	490.399	11.28	0.023	
05/13/86	09:20	00.15	497.389	11.43	0.021	
05/20/86	10:10	00.15	504.424	11.58	0.021	
05/27/86	15:00	00.16	511.625	11.74	0.022	
06/03/86	09:20	00.15	518.389	11.89	0.022	
06/10/86	10:42	00.16	525.446	12.05	0.023	
06/17/86	09:51	00.12	532.410	12.17	0.017	
06/24/86	10:05	00.16	539.420	12.33	0.023	
07/01/86	12:35	00.16	546.524	12.49	0.023	
07/08/86	09:57	00.15	553.415	12.64	0.022	
07/16/86	09:47	00.19	561.408	12.83	0.024	
07/22/86	09:23	00.14	567.391	12.97	0.023	
07/29/86	10:00	00.14	574.417	13.11	0.020	
08/05/86	10:15	00.18	581.427	13.29	0.026	
08/12/86	09:50	00.16	588.410	13.45	0.023	
08/19/86	10:35	00.16	595.441	13.61	0.023	

TABLE E.6
Inflow Data for Hole A3X02 in Room A3

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
02/05/85	11:10	NA	35.465	0.00	0.000	No drips noticed.
02/19/85	13:40	00.11	49.569	0.11	0.007	First time collected.
02/26/85	13:20	00.11	56.556	0.22	0.016	Wet spot within 1.5 ft. radius.
03/07/85	09:45	00.21	65.406	0.43	0.024	Moist area on back, approximately 1 ft radius.
03/12/85	11:45	00.11	70.490	0.54	0.022	Wet spot on back 3 ft diameter.
03/20/85	13:14	00.01	78.551	0.55	0.001	
03/26/85	11:12	00.28	84.467	0.83	0.047	Tube found plugged. Brine in tubing.
04/02/85	12:00	00.08	91.500	0.91	0.011	
04/10/85	12:02	00.05	99.501	0.96	0.006	Tube plugged.
04/17/85	11:20	00.11	106.472	1.07	0.016	
04/23/85	10:40	00.09	112.444	1.16	0.015	
04/30/85	13:29	00.12	119.562	1.28	0.017	
05/07/85	08:50	00.13	126.368	1.41	0.019	
05/14/85	09:53	00.13	133.412	1.54	0.018	
05/21/85	11:55	00.13	140.497	1.67	0.018	
05/29/85	09:20	00.14	148.389	1.81	0.018	
06/04/85	09:50	00.10	154.410	1.91	0.017	
06/11/85	09:20	00.13	161.389	2.04	0.019	
06/18/85	09:25	00.12	168.392	2.16	0.017	
06/25/85	09:25	00.13	175.392	2.29	0.019	
07/02/85	11:00	00.10	182.458	2.39	0.014	
07/09/85	09:44	00.02	189.406	2.41	0.003	
07/16/85	10:46	00.02	196.449	2.43	0.003	
07/24/85	09:45	00.19	204.406	2.62	0.024	High reading probably due to unplugging temporary blockage in collecting tube on 7/16/85.
07/30/85	09:25	00.08	210.392	2.70	0.013	
08/06/85	09:28	00.08	217.394	2.78	0.011	
08/14/85	09:10	00.10	225.382	2.88	0.013	
08/20/85	10:00	00.08	231.417	2.96	0.013	
08/28/85	08:58	00.09	239.374	3.05	0.011	
09/04/85	09:26	00.09	246.393	3.14	0.013	
09/10/85	09:14	00.08	252.385	3.22	0.013	
09/17/85	09:05	00.09	259.378	3.31	0.013	
09/24/85	09:03	00.08	266.377	3.39	0.011	
10/01/85	09:15	00.07	273.385	3.46	0.010	
10/08/85	12:33	00.09	280.523	3.55	0.013	
10/15/85	09:31	00.06	287.397	3.61	0.009	
10/23/85	09:37	00.07	295.401	3.68	0.009	
10/29/85	11:09	00.08	301.465	3.76	0.013	
11/05/85	08:39	00.04	308.360	3.80	0.006	
11/13/85	09:28	00.08	316.394	3.88	0.010	
11/21/85	10:25	00.05	324.434	3.93	0.006	
12/04/85	13:56	00.10	337.581	4.03	0.008	
12/10/85	10:42	00.05	343.446	4.08	0.009	
12/17/85	13:50	00.03	350.576	4.11	0.004	
01/03/86	10:00	00.13	367.417	4.24	0.008	
01/08/86	10:10	00.03	372.424	4.27	0.006	
01/16/86	09:35	00.05	380.399	4.32	0.006	
01/31/86	10:55	00.01	395.455	4.33	0.001	Trace <00.01
04/24/86	09:30	00.01	478.396	4.34	0.000	
05/06/86	09:35	00.02	490.399	4.36	0.002	

TABLE E.6
Inflow Data for Hole A3X02 in Room A3

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
05/27/86	15:00	NA	511.625	4.36	0.000	Trace.
06/03/86	09:20	00.03	518.389	4.39	0.001	
06/10/86	10:42	NA	525.446	4.39	0.000	Trace.
06/17/86	09:51	NA	532.410	4.39	0.000	Trace.
07/01/86	12:32	00.03	546.522	4.42	0.001	
07/08/86	09:57	00.01	553.415	4.43	0.001	
07/29/86	10:00	NA	574.417	4.43	0.000	Trace.
08/12/86	09:50	NA	588.410	4.43	0.000	Dry.
08/19/86	10:33	NA	595.440	4.43	0.000	Dry.

TABLE E.7
Inflow Data for Hole BX01 in Room B

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
01/26/85	10:00	NA	25.417	0.00	0.000	Hole drilled. Wet core and brine encountered at 35 to 36.5 feet.
02/05/85	11:00	00.39	35.458	0.39	0.035	First time bailed.
02/11/85	12:00	00.72	41.500	1.11	0.119	
02/19/85	13:00	00.70	49.542	1.81	0.087	
02/26/85	12:45	00.61	56.531	2.42	0.087	
03/07/85	09:15	00.70	65.385	3.12	0.079	
03/12/85	11:45	00.41	70.490	3.53	0.080	
03/20/85	12:50	00.61	78.535	4.14	0.076	
03/26/85	10:45	00.45	84.448	4.59	0.076	
04/02/85	11:44	00.51	91.489	5.10	0.072	
04/10/85	11:38	00.55	99.485	5.65	0.069	
04/17/85	11:00	00.45	106.458	6.10	0.065	
04/23/85	10:05	00.38	112.420	6.48	0.064	Room B heaters turned on 4/23/85.
05/01/85	11:40	00.46	120.486	6.94	0.057	
06/04/85	09:30	02.00	154.396	8.94	0.059	First check in several weeks.
07/16/85	10:15	02.34	196.427	11.28	0.056	Effervesces.
08/26/85	13:56	02.38	237.581	13.66	0.058	Room temp. 98 degrees F. at collar, 103 F. in center of room.
10/08/85	12:00	02.27	280.500	15.93	0.053	
11/21/85	10:05	02.42	324.420	18.35	0.055	
12/04/85	13:35	00.69	337.566	19.04	0.052	
01/31/86	10:25	02.95	395.434	21.99	0.051	
02/12/86	09:30	00.80	407.396	22.79	0.067	
04/16/86	11:00	03.45	470.458	26.24	0.055	
04/30/86	09:45	00.73	484.406	26.97	0.052	
05/06/86	09:18	00.30	490.387	27.27	0.050	
06/10/86	10:20	01.85	525.431	29.12	0.053	
08/19/86	10:50	03.21	595.451	32.33	0.046	

TABLE E.8
Inflow Data for Hole BX02 in Room B

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
02/05/85	11:00	NA	35.458	0.00	0.000	No drips noticed. Finished drilling 2/01/85.
02/19/85	13:00	NA	49.542	0.00	0.000	Tubing plugged.
03/12/85	11:45	NA	70.490	0.00	0.000	Trace, few drops in jug.
03/20/85	12:50	00.10	78.535	0.10	0.002	
03/26/85	10:45	00.12	84.448	0.22	0.020	
04/02/85	11:44	00.10	91.489	0.32	0.014	
04/10/85	11:38	00.21	99.485	0.53	0.026	
04/17/85	11:00	00.13	106.458	0.66	0.019	
04/23/85	10:05	00.01	112.420	0.67	0.002	Room B heaters turned on 4/23/85. Low reading probably due to partial blockage of collecting tube.
05/01/85	11:31	00.12	120.480	0.79	0.015	
06/04/85	09:25	00.50	154.392	1.29	0.015	First check in several weeks.
07/16/85	10:00	00.16	196.417	1.45	0.004	Changed funnel.
10/08/85	12:00	00.04	280.500	1.49	0.000	
01/17/86	09:00	00.26	381.375	1.75	0.003	Changed funnel.
01/31/86	10:15	NA	395.427	1.75	0.000	
04/16/86	11:00	NA	470.458	1.75	0.000	Trace in plastic tube, salt build up in tube and container.
08/19/86	10:50	NA	595.451	1.75	0.000	Dry.
10/01/86	11:05	00.00	638.462	1.75	0.000	Dry.

TABLE E.9
Inflow Data for Hole DH35 in Room G

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
02/05/85	11:15	NA	35.469	0.00	0.000	Started to drip.
03/05/85	10:00	00.19	63.417	0.19	0.007	Salt crystals in container. First time collected.
03/12/85	10:00	00.17	70.417	0.36	0.024	Salt crystals in container.
03/20/85	10:26	00.19	78.435	0.55	0.024	
03/26/85	09:45	00.13	84.406	0.68	0.022	
04/02/85	10:15	00.15	91.427	0.83	0.021	Salt crystals in container.
04/10/85	10:14	00.19	99.426	1.02	0.024	
04/23/85	11:46	00.12	112.490	1.14	0.009	
04/30/85	11:09	00.16	119.465	1.30	0.023	Clay in container.
05/07/85	09:53	00.14	126.412	1.44	0.020	
05/14/85	10:48	00.16	133.450	1.60	0.023	
05/21/85	10:42	00.15	140.446	1.75	0.021	
05/29/85	10:00	00.15	148.417	1.90	0.019	
06/11/85	10:10	00.02	161.424	1.92	0.002	
07/09/85	11:10	00.06	189.465	1.98	0.002	
07/16/85	11:48	00.13	196.492	2.11	0.019	
07/24/85	10:37	00.12	204.442	2.23	0.015	
07/30/85	10:17	00.08	210.428	2.31	0.013	Clay in container.
08/06/85	10:37	00.08	217.442	2.39	0.011	Clay chunks in container.
08/14/85	10:53	00.11	225.453	2.50	0.014	
08/20/85	11:05	00.09	231.462	2.59	0.015	
08/28/85	10:00	00.14	239.417	2.73	0.018	
09/04/85	10:30	00.11	246.438	2.84	0.016	
09/10/85	10:38	00.11	252.443	2.95	0.018	
09/17/85	09:40	00.12	259.403	3.07	0.017	
09/24/85	09:48	00.07	266.408	3.14	0.010	
10/08/85	10:44	00.08	280.447	3.22	0.006	
10/15/85	10:17	00.06	287.428	3.28	0.009	
10/29/85	09:42	00.06	301.404	3.34	0.004	
11/05/85	09:24	00.08	308.392	3.42	0.011	
11/13/85	10:06	00.11	316.421	3.53	0.014	
11/21/85	11:32	00.07	324.481	3.60	0.009	
11/26/85	11:25	00.05	329.476	3.65	0.010	Changed collecting container.
01/23/86	10:40	00.06	387.444	3.71	0.001	Clay in container. Entry has been restricted due mining activities since 12/10/85.
01/31/86	12:16	00.06	395.511	3.77	0.007	
02/12/86	10:55	00.09	407.455	3.86	0.008	
02/19/86	11:45	00.07	414.490	3.93	0.010	
02/28/86	13:20	00.06	423.556	3.99	0.007	
03/06/86	10:45	00.03	429.448	4.02	0.005	
03/13/86	10:10	00.07	436.424	4.09	0.010	
03/26/86	10:20	NA	449.431	4.09	0.000	Funnel broken, 5 inch stalactite formed from collar.
04/02/86	09:40	NA	456.403	4.09	0.000	Installed new funnel.
05/27/86	15:45	NA	511.656	4.09	0.000	Trace.
06/03/86	10:08	00.01	518.422	4.10	0.000	
06/10/86	11:35	00.02	525.483	4.12	0.003	
06/17/86	10:58	00.01	532.457	4.13	0.001	
06/24/86	10:57	00.02	539.456	4.15	0.003	
07/01/86	14:03	00.02	546.585	4.17	0.003	
07/08/86	10:37	00.02	553.442	4.19	0.003	
07/16/86	10:36	00.03	561.442	4.22	0.004	
07/22/86	10:05	NA	567.420	4.22	0.000	Trace of brine, cleaned soft clay out of funnel.

TABLE E.9
Inflow Data for Hole DH35 in Room G

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
07/29/86	10:35	00.01	574.441	4.23	0.001	
08/05/86	11:13	00.03	581.467	4.26	0.004	
08/12/86	10:35	00.03	588.441	4.29	0.004	
08/19/86	11:35	00.01	595.483	4.30	0.001	

TABLE E.10
Inflow Data for Hole DH36 in Room G

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
01/28/85	09:00	NA	27.375	0.00	0.000	Moist muck at the bottom.
02/05/85	11:15	02.50	35.469	2.50	0.275	About 1 ft. muck, brine and hydraulic fluid. First time bailed.
02/11/85	11:00	01.51	41.458	4.01	0.252	Brine, muck, hydraulic fluid.
02/19/85	12:10	01.78	49.507	5.79	0.221	Some muck.
02/26/85	10:45	01.48	56.448	7.27	0.213	Brine and muck.
03/05/85	10:00	01.76	63.417	9.03	0.253	
03/12/85	10:00	01.55	70.417	10.58	0.221	
03/20/85	10:26	01.59	78.435	12.17	0.198	
03/26/85	09:45	01.35	84.406	13.52	0.226	
04/02/85	10:15	01.58	91.427	15.10	0.225	
04/10/85	10:25	01.71	99.434	16.81	0.214	
04/17/85	13:30	01.49	106.562	18.30	0.209	
04/23/85	11:46	01.45	112.490	19.75	0.245	
04/30/85	11:21	01.49	119.473	21.24	0.213	
05/07/85	09:58	01.55	126.415	22.79	0.223	
05/14/85	10:54	01.77	133.454	24.56	0.251	
05/21/85	10:45	01.61	140.448	26.17	0.230	
05/29/85	10:00	01.50	148.417	27.67	0.188	
06/04/85	11:33	01.40	154.481	29.07	0.231	
06/11/85	11:15	01.55	161.469	30.62	0.222	
06/18/85	10:17	01.58	168.428	32.20	0.227	
06/25/85	10:40	01.43	175.444	33.63	0.204	
07/02/85	11:00	01.59	182.458	35.22	0.227	
07/09/85	11:15	01.54	189.469	36.76	0.220	
07/16/85	11:50	01.58	196.493	38.34	0.225	Effervesces.
07/24/85	10:46	01.78	204.449	40.12	0.224	
07/30/85	10:20	01.39	210.431	41.51	0.232	
08/06/85	10:43	01.70	217.447	43.21	0.242	
08/14/85	11:02	01.58	225.460	44.79	0.197	Valve leaked, some brine drained back down hole.
08/20/85	11:11	01.42	231.466	46.21	0.236	
08/28/85	10:00	01.94	239.417	48.15	0.244	
09/04/85	10:32	01.69	246.439	49.84	0.241	
09/10/85	10:35	01.41	252.441	51.25	0.235	
09/17/85	09:42	01.53	259.404	52.78	0.220	
09/24/85	09:50	01.53	266.410	54.31	0.218	
10/01/85	09:55	01.58	273.413	55.89	0.226	
10/08/85	10:52	01.63	280.453	57.52	0.232	
10/15/85	10:30	01.58	287.438	59.10	0.226	
10/23/85	10:23	01.82	295.433	60.92	0.228	
10/29/85	09:51	01.36	301.410	62.28	0.228	
11/05/85	09:27	01.63	308.394	63.91	0.233	
11/13/85	10:14	01.79	316.426	65.70	0.223	
11/21/85	11:36	01.91	324.483	67.61	0.237	
11/26/85	11:30	01.01	329.479	68.62	0.202	
12/03/85	13:35	01.50	336.566	70.12	0.212	
12/10/85	12:15	01.52	343.510	71.64	0.219	
01/23/86	11:00	09.30	387.458	80.94	0.212	Entry restricted since 12/10/85 due to mining activities.
01/31/86	12:20	01.38	395.514	82.32	0.171	
02/12/86	11:00	03.02	407.458	85.34	0.253	
02/19/86	11:45	01.55	414.490	86.89	0.220	
02/28/86	13:20	01.85	423.556	88.74	0.204	

TABLE E.10
Inflow Data for Hole DH36 in Room G

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
03/06/86	10:45	01.30	429.448	90.04	0.221	Volume was estimated.
03/13/86	10:10	01.50	436.424	91.54	0.215	
03/26/86	10:20	02.56	449.431	94.10	0.197	
04/02/86	09:40	01.75	456.403	95.85	0.251	
04/08/86	09:45	00.97	462.406	96.82	0.162	
04/16/86	12:25	01.65	470.517	98.47	0.203	
04/24/86	10:20	02.00	478.431	100.47	0.253	
04/30/86	10:55	01.21	484.455	101.68	0.201	
05/06/86	10:14	01.20	490.426	102.88	0.201	
05/13/86	11:13	01.42	497.467	104.30	0.202	
05/20/86	11:10	01.50	504.465	105.80	0.214	
05/27/86	15:45	01.40	511.656	107.20	0.195	
06/03/86	10:10	01.38	518.424	108.58	0.204	
06/10/86	11:35	01.24	525.483	109.82	0.176	Valve leaked, some brine drained back down hole.
06/17/86	11:00	01.65	532.458	111.47	0.237	
06/24/86	11:00	01.45	539.458	112.92	0.207	
07/01/86	14:05	01.55	546.587	114.47	0.217	
07/08/86	10:45	01.40	553.448	115.87	0.204	
07/16/86	10:45	01.76	561.448	117.63	0.220	
07/22/86	10:07	01.29	567.422	118.92	0.216	
07/29/86	10:40	01.45	574.444	120.37	0.206	
08/05/86	11:20	01.46	581.472	121.83	0.208	
08/12/86	10:37	01.50	588.442	123.33	0.215	
08/19/86	11:35	01.38	595.483	124.71	0.196	

TABLE E.11
Inflow Data for Hole DH37 in Room G

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
02/05/85	11:15	NA	35.469	0.00	0.000	Started to drip.
03/05/85	10:10	00.06	63.424	0.06	0.002	Stalactite.
03/12/85	10:00	00.06	70.417	0.12	0.009	Salt crystals.
03/26/85	09:50	NA	84.410	0.12	0.000	Trace, none collected.
04/17/85	13:30	00.06	106.562	0.18	0.002	
04/23/85	11:41	00.04	112.487	0.22	0.007	
04/30/85	10:50	00.03	119.451	0.25	0.004	
05/07/85	09:45	00.06	126.406	0.31	0.009	
05/14/85	10:37	00.07	133.442	0.38	0.010	
05/21/85	10:31	00.06	140.438	0.44	0.009	
05/29/85	10:00	00.06	148.417	0.50	0.008	
06/04/85	11:22	00.05	154.474	0.55	0.008	
06/11/85	10:32	00.05	161.439	0.60	0.007	
06/18/85	10:05	00.08	168.420	0.68	0.011	Stalactites formed at collar.
06/25/85	10:44	00.05	175.447	0.73	0.007	
07/02/85	11:00	00.04	182.458	0.77	0.006	
07/09/85	11:00	00.03	189.458	0.80	0.004	
07/16/85	11:40	00.06	196.486	0.86	0.009	
07/24/85	10:33	00.06	204.440	0.92	0.008	
07/30/85	10:11	00.02	210.424	0.94	0.003	
08/06/85	10:32	00.01	217.439	0.95	0.001	
08/14/85	10:49	00.02	225.451	0.97	0.002	
08/20/85	10:56	00.03	231.456	1.00	0.005	
08/28/85	09:55	00.04	239.413	1.04	0.005	
09/04/85	10:21	00.02	246.431	1.06	0.003	
09/10/85	10:14	00.03	252.426	1.09	0.005	
09/17/85	09:35	00.02	259.399	1.11	0.003	
09/24/85	09:45	00.02	266.406	1.13	0.003	
10/01/85	09:50	00.01	273.410	1.14	0.001	
10/15/85	10:10	00.01	287.424	1.15	0.001	
10/23/85	10:17	00.02	295.428	1.17	0.002	
10/29/85	09:35	00.02	301.399	1.19	0.003	
07/01/86	14:00	00.02	546.583	1.21	0.000	

TABLE E.12
Inflow Data for Hole DH38 in Room G

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
01/28/85	09:00	NA	27.375	0.00	0.000	Dry.
02/05/85	11:15	NA	35.469	0.00	0.000	Wet at bottom.
02/19/85	12:10	00.80	49.507	0.80	0.035	Brine and fine muck.
02/26/85	10:45	01.26	56.448	2.06	0.182	Brine and fine muck.
03/05/85	10:00	00.45	63.417	2.51	0.065	
03/12/85	10:00	00.39	70.417	2.90	0.056	
03/20/85	10:37	00.45	78.442	3.35	0.056	
03/26/85	09:50	00.36	84.410	3.71	0.060	
04/02/85	10:25	00.41	91.434	4.12	0.058	Some muck.
04/10/85	10:31	00.44	99.438	4.56	0.055	
04/17/85	13:30	00.41	106.562	4.97	0.058	
04/23/85	11:41	00.34	112.487	5.31	0.057	
04/30/85	11:05	00.39	119.462	5.70	0.056	
05/07/85	09:50	00.42	126.410	6.12	0.060	
05/14/85	10:45	00.41	133.448	6.53	0.058	
05/21/85	10:35	00.41	140.441	6.94	0.059	
05/29/85	11:35	00.47	148.483	7.41	0.058	
06/04/85	11:25	00.35	154.476	7.76	0.058	
06/11/85	10:35	00.40	161.441	8.16	0.057	
06/18/85	10:09	00.39	168.423	8.55	0.056	
06/25/85	10:50	00.42	175.451	8.97	0.060	
07/02/85	11:00	00.44	182.458	9.41	0.063	
07/09/85	11:05	00.43	189.462	9.84	0.061	
07/16/85	11:45	00.43	196.490	10.27	0.061	Effervesces.
07/24/85	10:35	00.49	204.441	10.76	0.062	
07/30/85	10:14	00.38	210.426	11.14	0.063	
08/06/85	10:34	00.42	217.440	11.56	0.060	
08/14/85	10:51	00.49	225.452	12.05	0.061	
08/20/85	11:02	00.37	231.460	12.42	0.062	
08/28/85	10:00	00.51	239.417	12.93	0.064	
09/04/85	10:23	00.44	246.433	13.37	0.063	
09/10/85	10:19	00.39	252.430	13.76	0.065	
09/17/85	09:37	00.44	259.401	14.20	0.063	
09/24/85	09:45	00.44	266.406	14.64	0.063	
10/01/85	09:53	00.44	273.412	15.08	0.063	
10/08/85	10:38	00.46	280.443	15.54	0.065	
10/15/85	10:15	00.44	287.427	15.98	0.063	
10/23/85	10:20	00.49	295.431	16.47	0.061	
10/29/85	09:40	00.39	301.403	16.86	0.065	
11/05/85	09:14	00.43	308.385	17.29	0.062	
11/13/85	10:00	00.52	316.417	17.81	0.065	
11/21/85	11:29	00.47	324.478	18.28	0.058	
11/26/85	11:20	00.33	329.472	18.61	0.066	
12/03/85	13:30	00.42	336.562	19.03	0.059	
12/10/85	12:30	00.41	343.521	19.44	0.059	
01/23/86	11:20	02.70	387.472	22.14	0.061	Entry restricted since 12/10/85 due to mining activities.
01/31/86	12:10	00.53	395.507	22.67	0.066	
02/12/86	10:50	00.75	407.451	23.42	0.063	
02/19/86	11:40	00.43	414.486	23.85	0.061	
02/28/86	13:15	00.17	423.552	24.02	0.019	Lost substantial volume due to brake in suction line. Brine flowed back down into hole.
03/06/86	10:35	00.65	429.441	24.67	0.110	
03/13/86	10:05	00.43	436.420	25.10	0.062	

TABLE E.12
Inflow Data for Hole DH38 in Room G

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
03/26/86	10:10	00.59	449.424	25.69	0.045	
04/02/86	09:35	00.58	456.399	26.27	0.083	
04/08/86	09:40	00.35	462.403	26.62	0.058	
04/16/86	12:10	00.50	470.507	27.12	0.062	
04/24/86	10:12	00.47	478.425	27.59	0.059	
04/30/86	10:50	00.35	484.451	27.94	0.058	
05/06/86	10:14	00.31	490.426	28.25	0.052	
05/13/86	11:05	00.41	497.462	28.66	0.058	
05/20/86	11:05	00.40	504.462	29.06	0.057	
05/27/86	15:40	00.38	511.653	29.44	0.053	
06/03/86	10:05	00.44	518.420	29.88	0.065	
06/10/86	11:22	00.43	525.474	30.31	0.061	
06/17/86	10:50	00.37	532.451	30.68	0.053	
06/24/86	10:52	00.50	539.453	31.18	0.071	
07/01/86	14:01	00.40	546.584	31.58	0.056	
07/08/86	10:30	00.38	553.438	31.96	0.055	
07/16/86	10:34	00.43	561.440	32.39	0.054	
07/22/86	09:58	00.35	567.415	32.74	0.059	
07/29/86	10:40	00.38	574.444	33.12	0.054	
08/05/86	11:10	00.39	581.465	33.51	0.056	
08/12/86	10:30	00.40	588.438	33.91	0.057	
08/19/86	11:30	00.41	595.479	34.32	0.058	

TABLE E.13
Inflow Data for Hole DH40 in Room G

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
01/28/85	09:00	NA	27.375	0.00	0.000	Dry.
02/05/85	11:15	NA	35.469	0.00	0.000	Moist at bottom.
03/12/85	10:10	NA	70.424	0.00	0.000	Moist muck.
03/26/85	09:55	NA	84.413	0.00	0.000	Moist muck.
04/17/85	13:30	00.98	106.562	0.98	0.012	Brine,muck and oil.
04/23/85	11:33	00.26	112.481	1.24	0.044	Brine and muck.
04/30/85	10:49	00.11	119.451	1.35	0.016	Feel something spongy in bottom of hole.
05/07/85	09:42	00.10	126.404	1.45	0.014	
05/14/85	10:40	00.09	133.444	1.54	0.013	
05/21/85	10:26	00.07	140.435	1.61	0.010	
05/29/85	11:30	00.08	148.479	1.69	0.010	
06/04/85	11:15	00.10	154.469	1.79	0.017	Contained a lot of salt muck.
06/11/85	10:30	00.05	161.438	1.84	0.007	
06/18/85	10:01	00.09	168.417	1.93	0.013	
06/25/85	11:00	00.08	175.458	2.01	0.011	
07/02/85	11:00	00.09	182.458	2.10	0.013	
07/09/85	10:45	00.12	189.448	2.22	0.017	
07/16/85	11:38	00.09	196.485	2.31	0.013	
07/24/85	10:31	00.07	204.438	2.38	0.009	
07/30/85	10:08	00.07	210.422	2.45	0.012	
08/06/85	10:20	00.06	217.431	2.51	0.009	
08/14/85	10:43	00.07	225.447	2.58	0.009	
08/20/85	10:50	00.05	231.451	2.63	0.008	
08/28/85	09:53	00.08	239.412	2.71	0.010	
09/04/85	10:18	00.03	246.429	2.74	0.004	
09/10/85	10:11	00.04	252.424	2.78	0.007	
09/17/85	09:31	00.03	259.397	2.81	0.004	
09/24/85	09:40	00.06	266.403	2.87	0.009	
10/01/85	09:47	00.06	273.408	2.93	0.009	
10/08/85	10:32	00.04	280.439	2.97	0.006	
10/15/85	10:05	00.09	287.420	3.06	0.013	
10/23/85	10:13	00.04	295.426	3.10	0.005	
10/29/85	09:32	00.07	301.397	3.17	0.012	
11/05/85	09:10	00.04	308.382	3.21	0.006	
11/13/85	09:55	00.07	316.413	3.28	0.009	
11/21/85	11:24	00.02	324.475	3.30	0.002	
12/03/85	13:20	00.08	336.556	3.38	0.007	
12/10/85	12:40	00.04	343.528	3.42	0.006	
01/23/86	11:25	00.24	387.476	3.66	0.005	Entry restricted since 12/10/85 due to mining.
01/31/86	12:10	00.02	395.507	3.68	0.002	
02/19/86	11:20	00.14	414.472	3.82	0.007	
02/28/86	13:10	00.05	423.549	3.87	0.006	
03/13/86	10:00	00.02	436.417	3.89	0.002	
04/24/86	10:05	00.13	478.420	4.02	0.003	
05/20/86	11:05	00.10	504.462	4.12	0.004	
06/03/86	09:58	00.20	518.415	4.32	0.014	

TABLE E.14
Inflow Data for Hole DH42 in ROOM G

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
01/28/85	09:00	NA	27.375	0.00	0.000	Moist muck at the bottom.
02/05/85	11:15	00.27	35.469	0.27	0.030	First time collected.
02/11/85	11:00	00.30	41.458	0.57	0.050	
02/19/85	13:10	00.33	49.549	0.90	0.041	
02/26/85	10:45	00.26	56.448	1.16	0.038	
03/05/85	10:00	00.28	63.417	1.44	0.040	
03/12/85	10:20	00.25	70.431	1.69	0.036	
03/20/85	10:54	00.25	78.454	1.94	0.031	Valve leaked, some brine drained back down hole.
03/26/85	10:06	00.28	84.421	2.22	0.047	
04/02/85	10:45	00.26	91.448	2.48	0.037	
04/10/85	10:45	00.29	99.448	2.77	0.036	
04/17/85	13:30	00.24	106.562	3.01	0.034	
04/23/85	13:23	00.04	112.558	3.05	0.007	Significant volume of brine lost back down hole.
04/30/85	10:31	00.38	119.438	3.43	0.055	
05/07/85	09:25	00.33	126.392	3.76	0.047	
05/14/85	10:30	00.25	133.438	4.01	0.035	
05/21/85	10:17	00.26	140.428	4.27	0.037	
05/29/85	10:10	00.30	148.424	4.57	0.038	
06/04/85	10:45	00.22	154.448	4.79	0.037	
06/11/85	10:10	00.25	161.424	5.04	0.036	
06/18/85	09:53	00.25	168.412	5.29	0.036	
06/25/85	11:15	00.25	175.469	5.54	0.035	
07/02/85	11:00	00.24	182.458	5.78	0.034	
07/09/85	10:30	00.25	189.438	6.03	0.036	
07/16/85	11:08	00.25	196.464	6.28	0.036	Effervesces.
07/24/85	10:19	00.28	204.430	6.56	0.035	
07/30/85	09:57	00.22	210.415	6.78	0.037	
08/06/85	10:13	00.26	217.426	7.04	0.037	
08/14/85	10:59	00.27	225.458	7.31	0.034	
08/20/85	10:45	00.21	231.448	7.52	0.035	
08/28/85	09:45	00.29	239.406	7.81	0.036	
09/04/85	10:12	00.25	246.425	8.06	0.036	
09/10/85	09:56	00.21	252.414	8.27	0.035	
09/17/85	09:26	00.28	259.393	8.55	0.040	
09/24/85	09:37	00.24	266.401	8.79	0.034	
10/01/85	09:44	00.24	273.406	9.03	0.034	
10/08/85	10:25	00.23	280.434	9.26	0.033	
10/15/85	10:00	00.23	287.417	9.49	0.033	
10/23/85	10:07	00.26	295.422	9.75	0.032	
10/29/85	09:16	00.24	301.386	9.99	0.040	
11/05/85	09:05	00.22	308.378	10.21	0.031	
11/13/85	09:46	00.26	316.407	10.47	0.032	
11/21/85	10:53	00.26	324.453	10.73	0.032	
11/26/85	10:59	00.16	329.458	10.89	0.032	
12/03/85	13:10	00.20	336.549	11.09	0.028	
12/10/85	12:50	00.22	343.535	11.31	0.031	
01/23/86	11:30	01.32	387.479	12.63	0.030	Entry restricted since 12/10/85 due to mining.
01/31/86	12:05	00.30	395.503	12.93	0.037	
02/12/86	10:35	00.38	407.441	13.31	0.032	
02/19/86	11:10	00.22	414.465	13.53	0.031	
02/28/86	13:00	00.31	423.542	13.84	0.034	
03/06/86	10:30	00.17	429.438	14.01	0.029	
03/13/86	09:53	00.21	436.412	14.22	0.030	

TABLE E.14
Inflow Data for Hole DH42 in ROOM G

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
03/26/86	10:00	00.39	449.417	14.61	0.030	
04/02/86	09:25	00.20	456.392	14.81	0.029	
04/08/86	09:30	00.20	462.396	15.01	0.033	
04/16/86	11:55	00.24	470.497	15.25	0.030	
04/24/86	09:55	00.21	478.413	15.46	0.027	
04/30/86	10:41	00.17	484.445	15.63	0.028	
05/06/86	10:10	00.19	490.424	15.82	0.032	
05/13/86	10:00	00.20	497.417	16.02	0.029	
05/20/86	11:00	00.20	504.458	16.22	0.028	
05/27/86	15:35	00.20	511.649	16.42	0.028	
06/03/86	09:50	00.20	518.410	16.62	0.030	
06/10/86	11:13	00.17	525.467	16.79	0.024	
06/17/86	10:40	00.20	532.444	16.99	0.029	
06/24/86	10:40	00.18	539.444	17.17	0.026	
07/01/86	13:45	00.20	546.573	17.37	0.028	
07/08/86	10:22	00.20	553.432	17.57	0.029	
07/16/86	10:15	00.30	561.427	17.87	0.038	
07/22/86	09:50	00.16	567.410	18.03	0.027	
07/29/86	10:25	00.20	574.434	18.23	0.028	
08/05/86	11:00	00.22	581.458	18.45	0.031	
08/12/86	10:20	00.20	588.431	18.65	0.029	
08/19/86	11:20	00.18	595.472	18.83	0.026	

TABLE E.15
Inflow Data for Hole DH42A in Room G

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
01/28/85	09:00	NA	27.375	0.00	0.000	Brine in hole. This hole is a redrill of DH42 to obtain better core.
02/05/85	11:15	00.85	35.469	0.85	0.093	First time collected.
02/11/85	11:00	00.99	41.458	1.84	0.165	
02/19/85	12:10	01.45	49.507	3.29	0.180	
02/26/85	10:45	01.18	56.448	4.47	0.170	
03/05/85	10:00	01.24	63.417	5.71	0.178	
03/12/85	10:20	01.29	70.431	7.00	0.184	
03/20/85	11:00	01.45	78.458	8.45	0.181	
03/26/85	10:10	01.07	84.424	9.52	0.179	
04/02/85	10:45	01.15	91.448	10.67	0.164	
04/10/85	10:45	01.45	99.448	12.12	0.181	
04/17/85	13:30	01.32	106.562	13.44	0.186	
04/23/85	13:23	01.07	112.558	14.51	0.178	
04/30/85	10:23	01.35	119.433	15.86	0.196	
05/07/85	09:23	01.39	126.391	17.25	0.200	
05/14/85	10:25	01.34	133.434	18.59	0.190	
05/21/85	10:14	01.29	140.426	19.88	0.184	
05/29/85	10:30	01.28	148.438	21.16	0.160	
06/04/85	10:50	01.03	154.451	22.19	0.171	
06/11/85	10:15	01.19	161.427	23.38	0.171	
06/18/85	09:51	01.18	168.410	24.56	0.169	
06/25/85	11:05	01.16	175.462	25.72	0.164	
07/02/85	11:00	01.12	182.458	26.84	0.160	
07/09/85	10:25	01.12	189.434	27.96	0.161	Gas effervescing from sample.
07/16/85	11:10	01.11	196.465	29.07	0.158	Effervesces.
07/24/85	10:25	01.23	204.434	30.30	0.154	
07/30/85	09:54	00.94	210.412	31.24	0.157	
08/06/85	10:10	01.05	217.424	32.29	0.150	
08/14/85	10:33	01.11	225.440	33.40	0.138	
08/20/85	10:14	00.92	231.426	34.32	0.154	
08/28/85	09:40	01.17	239.403	35.49	0.147	
09/04/85	10:10	00.99	246.424	36.48	0.141	
09/10/85	09:55	00.83	252.413	37.31	0.139	
09/17/85	09:25	00.92	259.392	38.23	0.132	
09/24/85	09:25	00.94	266.392	39.17	0.134	
10/01/85	09:40	00.93	273.403	40.10	0.133	
10/08/85	10:24	00.96	280.433	41.06	0.137	
10/15/85	10:15	00.81	287.427	41.87	0.116	
10/23/85	10:10	01.02	295.424	42.89	0.128	
10/29/85	09:20	00.75	301.389	43.64	0.126	
11/05/85	09:00	00.86	308.375	44.50	0.123	
11/13/85	09:44	01.03	316.406	45.53	0.128	
11/21/85	10:50	00.94	324.451	46.47	0.117	
11/26/85	10:55	00.61	329.455	47.08	0.122	
12/03/85	13:05	00.78	336.545	47.86	0.110	
12/10/85	12:50	00.86	343.535	48.72	0.123	
01/23/86	11:40	05.13	387.486	53.85	0.117	Entry restricted since 12/10/85 due to mining.
01/31/86	12:00	00.92	395.500	54.77	0.115	
02/12/86	10:40	01.36	407.444	56.13	0.114	
02/19/86	11:15	00.80	414.469	56.93	0.114	
02/28/86	12:55	00.90	423.538	57.83	0.099	
03/06/86	10:25	00.70	429.434	58.53	0.119	
03/13/86	09:48	00.73	436.408	59.26	0.105	

TABLE E.15
Inflow Data for Hole DH42A in Room G

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
03/26/86	09:40	01.39	449.403	60.65	0.107	
04/02/86	09:20	00.80	456.389	61.45	0.115	
04/08/86	09:28	00.63	462.394	62.08	0.105	
04/16/86	11:50	00.89	470.493	62.97	0.110	
04/24/86	09:50	00.67	478.410	63.64	0.085	
04/30/86	10:36	00.76	484.442	64.40	0.126	
05/06/86	10:00	00.55	490.417	64.95	0.092	
05/13/86	10:00	00.73	497.417	65.68	0.104	
05/20/86	11:00	00.70	504.458	66.38	0.099	
05/27/86	15:35	00.65	511.649	67.03	0.090	
06/03/86	09:50	00.66	518.410	67.69	0.098	
06/10/86	11:15	00.54	525.469	68.23	0.076	
06/17/86	10:31	00.65	532.438	68.88	0.093	
06/24/86	10:45	00.63	539.448	69.51	0.090	
07/01/86	13:50	00.71	546.576	70.22	0.100	
07/08/86	10:25	00.63	553.434	70.85	0.092	
07/16/86	10:00	00.66	561.417	71.51	0.083	
07/22/86	09:48	00.61	567.408	72.12	0.102	
07/29/86	10:25	00.71	574.434	72.83	0.101	
08/05/86	10:55	00.66	581.455	73.49	0.094	
08/12/86	10:23	00.63	588.433	74.12	0.090	
08/19/86	11:22	00.68	595.474	74.80	0.097	

TABLE E.16
Inflow Data for Hole DH215 at S1950-E140

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
04/20/84	NA	NA	0.000	0.00	0.000	Experimental collecting device installed.
01/15/85	11:00	00.05	14.458	0.05	0.050	First data entry in BTP Phase I collection program.
01/22/85	12:00	00.08	21.500	0.13	0.011	
01/29/85	12:00	00.08	28.500	0.21	0.011	
02/05/85	12:00	00.04	35.500	0.25	0.006	
02/11/85	13:00	00.06	41.542	0.31	0.010	
02/14/85	11:00	00.03	44.458	0.34	0.010	Replace collecting device.
02/19/85	10:35	00.07	49.441	0.41	0.014	
02/26/85	12:10	00.09	56.507	0.50	0.013	
03/07/85	10:30	00.12	65.438	0.62	0.013	
03/12/85	12:30	00.10	70.521	0.72	0.020	
03/20/85	14:00	00.11	78.583	0.83	0.014	
03/26/85	11:30	00.05	84.479	0.88	0.008	
04/02/85	13:00	00.05	91.542	0.93	0.007	
04/10/85	13:00	00.09	99.542	1.02	0.011	
04/17/85	14:00	00.03	106.583	1.05	0.004	Drip missing funnel.
04/23/85	14:30	00.10	112.604	1.15	0.017	
04/30/85	09:09	00.08	119.381	1.23	0.012	
05/07/85	10:50	00.09	126.451	1.32	0.013	Salt crystals in container.
05/14/85	13:06	00.11	133.546	1.43	0.016	
05/21/85	12:15	00.08	140.510	1.51	0.011	
05/29/85	11:00	00.09	148.458	1.60	0.011	
06/04/85	13:15	00.09	154.552	1.69	0.015	Salt crystals in container.
06/11/85	13:10	00.13	161.549	1.82	0.019	
06/18/85	11:22	00.13	168.474	1.95	0.019	
06/25/85	12:55	00.12	175.538	2.07	0.017	
07/02/85	11:00	00.10	182.458	2.17	0.014	
07/09/85	12:39	00.09	189.527	2.26	0.013	
07/16/85	12:37	00.11	196.526	2.37	0.016	Salt crystals in container.
07/24/85	12:39	00.14	204.527	2.51	0.017	
07/30/85	11:09	00.10	210.465	2.61	0.017	
08/06/85	11:20	00.11	217.472	2.72	0.016	
08/14/85	13:17	00.17	225.553	2.89	0.021	
08/20/85	12:57	00.10	231.540	2.99	0.017	
08/26/85	14:36	00.12	237.608	3.11	0.020	
09/04/85	11:35	00.14	246.483	3.25	0.016	
09/10/85	12:05	00.09	252.503	3.34	0.015	
09/17/85	10:00	00.12	259.417	3.46	0.017	
09/24/85	11:11	00.13	266.466	3.59	0.018	
10/01/85	10:55	00.12	273.455	3.71	0.017	Salt crystals in container.
10/08/85	12:00	00.10	280.500	3.81	0.014	
10/15/85	11:31	00.20	287.480	4.01	0.029	
10/23/85	11:54	00.33	295.496	4.34	0.041	
10/29/85	11:54	00.12	301.496	4.46	0.020	
11/13/85	11:18	00.18	316.471	4.64	0.012	Floor being lowered in E140 north of this location.
12/04/85	15:00	00.35	337.625	4.99	0.017	Floor lowered at this location 11/19/85, downhole DH216 destroyed. Cross-drift excavation initiated toward east on 11/20/85.
12/10/85	13:05	00.11	343.545	5.10	0.019	
12/17/85	14:20	00.40	350.597	5.50	0.057	
01/03/86	11:00	01.00	367.458	6.50	0.059	Brine overflowing container, unknown amount not collected.

TABLE E.16
Inflow Data for Hole DH215 at S1950-E140

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
01/08/86	11:25	00.36	372.476	6.86	0.072	
01/16/86	11:00	00.70	380.458	7.56	0.088	
01/23/86	12:00	00.63	387.500	8.19	0.089	
01/31/86	13:50	00.45	395.576	8.64	0.056	Cross-drift extended toward west starting 1/29/86.
02/12/86	12:25	00.27	407.517	8.91	0.023	Stalactites removed from container.
02/19/86	13:15	00.26	414.552	9.17	0.037	
03/06/86	12:20	00.96	429.514	10.13	0.064	Floor lowered in E140 south of this location starting 2/28/86.
03/13/86	11:30	00.40	436.479	10.53	0.057	
03/26/86	11:15	00.72	449.469	11.25	0.055	
04/02/86	10:30	00.30	456.438	11.55	0.043	
04/08/86	11:00	00.15	462.458	11.70	0.025	
04/16/86	13:00	00.40	470.542	12.10	0.049	
04/24/86	11:00	00.26	478.458	12.36	0.033	
04/30/86	11:35	00.16	484.483	12.52	0.027	
05/06/86	11:05	00.21	490.462	12.73	0.035	
05/13/86	10:10	00.29	497.424	13.02	0.042	
05/20/86	11:45	00.20	504.490	13.22	0.028	
05/27/86	16:00	00.20	511.667	13.42	0.028	
06/03/86	11:05	00.27	518.462	13.69	0.040	
06/10/86	12:10	00.33	525.507	14.02	0.047	
06/17/86	11:47	00.23	532.491	14.25	0.033	
06/24/86	11:50	00.10	539.493	14.35	0.014	
07/01/86	14:32	00.15	546.606	14.50	0.021	
07/08/86	11:30	00.14	553.479	14.64	0.020	About 1 lb. of salt encrustation was removed from funnel on 7/07/86.
07/16/86	11:45	00.10	561.490	14.74	0.012	
07/22/86	10:31	00.06	567.438	14.80	0.010	
07/29/86	11:27	00.13	574.477	14.93	0.018	
08/05/86	11:59	00.14	581.499	15.07	0.020	
08/12/86	11:40	00.13	588.486	15.20	0.019	
08/19/86	12:00	00.04	595.500	15.24	0.006	

TABLE E.17
Inflow Data for Hole IG201 in ROOM 2

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
11/30/84	12:00	63.10	-31.500	63.10	0.000	Hole was evacuated dry first time, 63.10 litres had been removed. First time bailed.
01/08/85	12:00	01.52	7.500	64.62	0.000	Partialy evacuated.
01/09/85	10:00	02.48	8.417	67.10	2.704	Some fluid was lost. Should add 1.52 liters from partial evacuation day before to this volume for liters/day calculation
01/15/85	09:10	00.33	14.382	67.43	0.055	
01/22/85	10:10	00.38	21.424	67.81	0.054	
01/29/85	10:44	00.25	28.447	68.06	0.036	
02/05/85	09:20	00.30	35.389	68.36	0.043	
02/11/85	09:45	00.24	41.406	68.60	0.040	
02/19/85	11:15	00.32	49.469	68.92	0.040	
02/26/85	09:45	00.26	56.406	69.18	0.037	
03/05/85	09:22	00.25	63.390	69.43	0.036	
03/12/85	09:00	00.25	70.375	69.68	0.036	
03/20/85	09:38	00.17	78.401	69.85	0.021	
03/26/85	09:10	00.27	84.382	70.12	0.045	
04/02/85	09:30	00.24	91.396	70.36	0.034	
04/10/85	09:30	00.26	99.396	70.62	0.033	
04/17/85	13:40	00.26	106.569	70.88	0.036	
04/23/85	12:00	00.23	112.500	71.11	0.039	
04/30/85	11:41	00.21	119.487	71.32	0.030	
05/07/85	10:30	00.23	126.438	71.55	0.033	
05/14/85	11:00	00.24	133.458	71.79	0.034	
05/21/85	11:09	00.23	140.465	72.02	0.033	
05/29/85	10:00	00.30	148.417	72.32	0.038	
06/04/85	11:45	00.16	154.490	72.48	0.026	
06/11/85	11:20	00.22	161.472	72.70	0.032	
06/18/85	10:42	00.21	168.446	72.91	0.030	
06/25/85	09:55	00.22	175.413	73.13	0.032	
07/02/85	11:00	00.23	182.458	73.36	0.033	
07/09/85	11:33	00.24	189.481	73.60	0.034	Effervesces.
07/16/85	12:00	00.27	196.500	73.87	0.038	Effervesces.
07/24/85	11:02	00.31	204.460	74.18	0.039	
07/30/85	10:40	00.24	210.444	74.42	0.040	
08/06/85	10:49	00.24	217.451	74.66	0.034	
08/14/85	12:04	00.28	225.503	74.94	0.035	
08/20/85	11:24	00.26	231.475	75.20	0.044	
08/28/85	10:00	00.21	239.417	75.41	0.026	
09/04/85	10:52	00.16	246.453	75.57	0.023	
09/10/85	11:16	00.12	252.469	75.69	0.020	
09/17/85	10:11	00.15	259.424	75.84	0.022	
09/24/85	10:08	00.16	266.422	76.00	0.023	
10/01/85	10:20	00.13	273.431	76.13	0.019	
10/08/85	11:09	00.18	280.465	76.31	0.026	
10/15/85	10:45	00.17	287.448	76.48	0.024	
10/23/85	10:52	00.19	295.453	76.67	0.024	
10/29/85	10:37	00.14	301.442	76.81	0.023	
11/05/85	09:38	00.19	308.401	77.00	0.027	
11/13/85	10:40	00.24	316.444	77.24	0.030	
11/21/85	11:48	00.25	324.492	77.49	0.031	
11/26/85	10:35	00.15	329.441	77.64	0.030	
12/10/85	11:10	00.35	343.465	77.99	0.025	

TABLE E.17
Inflow Data for Hole IG201 in ROOM 2

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
12/17/85	14:10	00.23	350.590	78.22	0.032	
01/03/86	10:20	00.42	367.431	78.64	0.025	
01/08/86	10:30	00.20	372.438	78.84	0.040	
01/16/86	10:10	00.16	380.424	79.00	0.020	
01/23/86	10:20	00.15	387.431	79.15	0.021	
01/31/86	12:38	00.17	395.526	79.32	0.021	
02/12/86	11:30	00.25	407.479	79.57	0.021	
02/19/86	12:00	00.17	414.500	79.74	0.024	
02/28/86	13:45	00.30	423.573	80.04	0.033	
03/06/86	11:00	00.19	429.458	80.23	0.032	
03/13/86	10:27	00.20	436.435	80.43	0.029	
03/26/86	10:25	00.31	449.434	80.74	0.024	
04/02/86	10:05	00.16	456.420	80.90	0.023	
04/08/86	10:15	00.13	462.427	81.03	0.022	
04/16/86	12:30	00.15	470.521	81.18	0.019	
04/24/86	10:35	00.13	478.441	81.31	0.016	
04/30/86	11:14	00.10	484.468	81.41	0.017	Last time sampled. Guide tube became too distorted by shear and would not allow sampler to pass.

TABLE E.18
Inflow Data for Hole IG202 in Room 1

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
11/30/84	12:00	52.00	-31.500	52.00	0.000	Hole was evacuated dry. First time sampled.
01/08/85	12:00	12.58	7.500	64.58	0.323	
01/15/85	09:25	00.59	14.392	65.17	0.086	
01/22/85	12:00	00.34	21.500	65.51	0.048	
01/29/85	12:00	00.33	28.500	65.84	0.047	
02/05/85	10:17	00.41	35.428	66.25	0.059	
02/11/85	09:30	00.27	41.396	66.52	0.045	
02/19/85	12:00	00.32	49.500	66.84	0.039	
02/26/85	12:00	00.25	56.500	67.09	0.036	
03/05/85	09:03	00.20	63.377	67.29	0.029	
03/12/85	08:58	00.23	70.374	67.52	0.033	
03/20/85	09:16	00.25	78.386	67.77	0.031	
03/26/85	09:00	00.18	84.375	67.95	0.030	
04/02/85	09:10	00.19	91.382	68.14	0.027	
04/10/85	09:19	00.21	99.388	68.35	0.026	
04/17/85	13:56	00.18	106.581	68.53	0.025	
04/23/85	12:12	00.14	112.508	68.67	0.024	
04/30/85	13:00	00.15	119.542	68.82	0.021	
05/07/85	10:40	00.14	126.444	68.96	0.020	
05/14/85	11:16	00.14	133.469	69.10	0.020	
05/21/85	11:30	00.14	140.479	69.24	0.020	
05/29/85	10:00	00.15	148.417	69.39	0.019	
06/04/85	12:10	00.11	154.507	69.50	0.018	
06/11/85	11:40	00.12	161.486	69.62	0.017	Hole entry becoming tight due to shear closure of guide tube.
06/18/85	10:55	00.12	168.455	69.74	0.017	
06/25/85	09:50	00.11	175.410	69.85	0.016	
07/02/85	11:30	00.11	182.479	69.96	0.016	
07/09/85	11:15	00.09	189.469	70.05	0.013	Effervesces.
07/16/85	12:19	00.07	196.513	70.12	0.010	Effervesces.
07/24/85	11:15	00.11	204.469	70.23	0.014	
08/06/85	11:08	00.18	217.464	70.41	0.014	
08/14/85	12:17	00.09	225.512	70.50	0.011	
08/20/85	11:00	00.06	231.458	70.56	0.010	
08/28/85	10:00	00.13	239.417	70.69	0.016	
09/04/85	10:00	00.09	246.417	70.78	0.013	
09/10/85	11:35	00.09	252.483	70.87	0.015	
09/17/85	10:00	00.13	259.417	71.00	0.019	
09/24/85	10:00	00.10	266.417	71.10	0.014	
10/01/85	10:35	00.08	273.441	71.18	0.011	
10/08/85	11:15	00.10	280.469	71.28	0.014	Last time sampled. Guide tube too distorded due to shear closure to allow sampler to pass.

TABLE E.19
Inflow Data for Hole L1X00 in ROOM L1

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
05/14/85	11:24	11.46	133.475	11.46	0.000	First time collected. Brine & muck.
05/21/85	12:33	00.31	140.523	11.77	0.044	
05/29/85	10:00	00.23	148.417	12.00	0.029	About 1 lb. of salt removed with brine during bailing.
06/04/85	09:25	00.17	154.392	12.17	0.028	
06/11/85	09:00	00.23	161.375	12.40	0.033	About 2 lbs. of salt removed with brine during bailing.
06/18/85	09:05	00.23	168.378	12.63	0.033	
06/25/85	08:55	00.21	175.372	12.84	0.030	
07/02/85	11:00	00.23	182.458	13.07	0.032	
07/09/85	09:10	00.21	189.382	13.28	0.030	
07/16/85	09:12	00.21	196.383	13.49	0.030	
07/24/85	09:29	00.22	204.395	13.71	0.027	
07/30/85	08:42	00.18	210.363	13.89	0.030	
08/06/85	09:07	00.18	217.380	14.07	0.026	
08/14/85	08:53	00.23	225.370	14.30	0.029	
08/20/85	08:58	00.16	231.374	14.46	0.027	
08/28/85	08:25	00.23	239.351	14.69	0.029	
09/04/85	09:09	00.19	246.381	14.88	0.027	
09/10/85	08:53	00.16	252.370	15.04	0.027	
09/17/85	08:25	00.21	259.351	15.25	0.030	
09/24/85	08:40	00.21	266.361	15.46	0.030	
10/01/85	08:52	00.17	273.369	15.63	0.024	
10/08/85	09:55	00.19	280.413	15.82	0.027	
10/15/85	08:45	00.16	287.365	15.98	0.023	
10/23/85	09:09	00.20	295.381	16.18	0.025	
10/29/85	11:30	00.18	301.479	16.36	0.030	
11/05/85	08:17	00.16	308.345	16.52	0.023	
11/13/85	08:47	00.18	316.366	16.70	0.022	
11/21/85	10:00	00.17	324.417	16.87	0.021	
11/26/85	09:25	00.12	329.392	16.99	0.024	
12/03/85	14:35	00.14	336.608	17.13	0.019	
12/10/85	12:55	00.14	343.538	17.27	0.020	
12/17/85	13:02	00.15	350.543	17.42	0.021	
01/03/86	09:05	00.38	367.378	17.80	0.023	
01/08/86	09:25	00.11	372.392	17.91	0.022	
01/16/86	09:00	00.18	380.375	18.09	0.023	
01/23/86	09:15	00.14	387.385	18.23	0.020	
01/31/86	09:45	00.18	395.406	18.41	0.022	
02/12/86	08:50	00.30	407.368	18.71	0.025	
02/19/86	09:40	00.16	414.403	18.87	0.023	
02/28/86	11:20	00.24	423.472	19.11	0.026	
03/06/86	09:10	00.12	429.382	19.23	0.020	
03/13/86	08:30	00.16	436.354	19.39	0.023	
03/26/86	08:35	00.29	449.358	19.68	0.022	
04/02/86	08:15	00.17	456.344	19.85	0.024	
04/08/86	08:26	00.15	462.351	20.00	0.025	
04/16/86	10:20	00.19	470.431	20.19	0.024	
04/24/86	08:50	00.16	478.368	20.35	0.020	
04/30/86	09:20	00.16	484.389	20.51	0.027	
05/06/86	08:50	00.15	490.368	20.66	0.025	
05/13/86	08:48	00.18	497.367	20.84	0.026	
05/20/86	09:20	00.18	504.389	21.02	0.026	
05/27/86	14:20	00.17	511.597	21.19	0.024	
06/03/86	08:43	00.15	518.363	21.34	0.022	

TABLE E.19
Inflow Data for Hole L1X00 in ROOM L1

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
06/10/86	09:20	00.21	525.389	21.55	0.030	
06/17/86	09:12	00.14	532.383	21.69	0.020	
06/24/86	09:15	00.22	539.385	21.91	0.031	
07/01/86	11:53	00.22	546.495	22.13	0.031	
07/08/86	09:10	00.22	553.382	22.35	0.032	
07/16/86	09:00	00.21	561.375	22.56	0.026	
07/22/86	08:45	00.17	567.365	22.73	0.028	
07/29/86	09:08	00.18	574.381	22.91	0.026	
08/05/86	09:33	00.20	581.398	23.11	0.029	
08/12/86	09:05	00.20	588.378	23.31	0.029	
08/19/86	09:49	00.20	595.409	23.51	0.028	

TABLE E.20
Short-Term Inflow Data for NG 252 in Room 2

DATE	TIME	ELAPSED TIME REF. 0	RISE IN STATIC LEVEL(FT)	EQUIVALENT VOLUME (LITERS)
01/08/85	09:43	0.00	0.00	0.00
01/08/85	10:45	1.03	0.32	0.11
01/08/85	11:37	1.90	0.41	0.14
01/08/85	12:45	3.03	0.57	0.20
01/08/85	13:45	4.03	0.65	0.23
01/08/85	15:05	5.37	0.75	0.26
01/08/85	16:30	6.78	0.86	0.30
01/09/85	04:02	18.32	1.51	0.52
01/09/85	08:38	22.92	1.69	0.59
01/09/85	12:45	27.03	1.83	0.64
01/09/85	14:10	28.45	1.87	0.65
01/09/85	16:50	31.12	1.91	0.66
01/09/85	21:00	35.28	1.99	0.69
01/10/85	08:26	46.72	2.16	0.75
01/10/85	17:00	55.28	2.35	0.82
01/11/85	01:25	63.70	2.54	0.88
01/11/85	09:42	71.98	2.61	0.91
01/11/85	16:15	78.53	2.71	0.94
01/12/85	01:14	87.52	2.88	1.00
01/12/85	09:35	95.87	3.04	1.06
01/12/85	17:23	103.67	3.21	1.12
01/13/85	04:38	114.92	3.50	1.22
01/13/85	10:17	120.57	3.58	1.24
01/13/85	17:24	127.68	3.77	1.31
01/14/85	01:31	135.80	4.00	1.39
01/14/85	09:15	143.53	4.19	1.46
01/14/85	17:14	151.52	4.38	1.52
01/15/85	01:19	159.60	4.58	1.59
01/15/85	09:00	167.28	4.83	1.68
01/15/85	12:45	171.03	4.93	1.71
01/15/85	17:17	175.57	5.05	1.75
01/16/85	00:30	182.78	5.12	2.04
01/16/85	08:57	191.23	5.16	2.26
01/16/85	18:02	200.32	5.17	2.32
01/17/85	00:20	206.69	5.18	2.37
01/17/85	09:40	215.95	5.26	2.82
01/17/85	11:40	217.95	5.29	2.98
01/17/85	16:55	223.20	5.30	3.04
01/18/85	01:25	231.70	5.35	3.32
01/18/85	09:18	239.58	5.36	3.37
01/18/85	17:45	248.03	5.40	3.59
01/19/85	00:32	254.82	5.45	3.87
01/19/85	09:50	264.12	5.47	3.98
01/19/85	17:00	271.28	5.50	4.15
01/20/85	00:45	279.03	5.53	4.32
01/20/85	09:33	287.83	5.55	4.43
01/20/85	16:40	294.95	5.58	4.60
01/21/85	01:00	303.28	5.60	4.71
01/21/85	09:16	311.55	5.61	4.76
01/21/85	16:45	319.03	5.65	4.98
01/22/85	01:00	327.28	5.67	5.10
01/22/85	17:50	343.37	5.72	5.37
01/23/85	09:24	359.68	5.73	5.43
01/23/85	17:50	368.12	5.77	5.65
01/24/85	02:19	376.60	5.79	5.76
01/24/85	09:12	383.48	5.80	5.82
01/24/85	17:44	392.02	5.82	5.93
01/25/85	01:11	399.47	5.83	5.99
01/27/85	08:37	454.90	5.90	6.37
01/27/85	20:30	466.78	5.94	6.60
01/28/85	11:20	481.62	5.96	6.71
01/28/85	17:51	488.13	5.99	6.88
01/29/85	08:43	503.00	6.03	7.10
01/29/85	11:01	505.30	6.03	7.10

TABLE E.20
Short-Term Inflow Data for NG 252 in Room 2

DATE	TIME	ELAPSED TIME REF. 0	RISE IN STATIC LEVEL(FT)	EQUIVALENT VOLUME (LITERS)
01/30/85	00:50	519.12	6.06	7.26
01/30/85	12:00	530.28	6.09	7.43
01/30/85	18:15	536.53	6.09	7.43
01/31/85	12:37	554.90	6.08	7.38
01/31/85	18:23	560.67	6.09	7.43
02/01/85	17:08	583.42	6.08	7.38
02/02/85	00:40	590.95	6.08	7.38
02/02/85	08:56	599.22	6.09	7.43
02/02/85	17:05	607.37	6.08	7.38
02/03/85	00:55	615.20	6.08	7.38
02/03/85	09:05	623.37	6.09	7.43
02/03/85	17:07	631.40	6.10	7.49
02/04/85	00:47	639.07	6.10	7.49
02/04/85	08:30	646.78	6.10	7.49
02/04/85	16:18	654.58	6.10	7.49
02/05/85	01:23	663.67	6.10	7.49
02/05/85	09:00	671.28	6.10	7.49

TABLE E.21
Inflow Data for Hole NG252 in ROOM 2

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
12/19/84	12:00	04.60	-12.500	4.60	0.000	Partial removal. First time collected.
12/20/84	09:00	04.35	-11.625	8.95	0.000	Pumped dry. Inflow rate about 2 cc/hr.
01/08/85	09:43	08.19	7.405	17.14	0.430	Pumped dry.
02/05/85	09:30	08.48	35.396	25.62	0.303	Gas bubbles.
02/14/85	10:33	04.14	44.440	29.76	0.458	
02/19/85	10:18	03.92	49.429	33.68	0.786	
03/07/85	10:57	03.83	65.456	37.51	0.239	
03/12/85	09:10	03.41	70.382	40.92	0.692	
03/20/85	10:00	03.71	78.417	44.63	0.462	
03/26/85	09:30	03.24	84.396	47.87	0.542	
04/02/85	10:00	03.38	91.417	51.25	0.481	
04/10/85	10:02	03.29	99.418	54.54	0.411	
04/17/85	13:50	03.57	106.576	58.11	0.499	
04/23/85	12:00	02.58	112.500	60.69	0.436	
04/30/85	11:39	03.28	119.485	63.97	0.470	
05/07/85	10:25	02.96	126.434	66.93	0.426	
05/14/85	11:05	02.83	133.462	69.76	0.403	
05/21/85	11:12	03.01	140.467	72.77	0.430	Brine degassing from jar.
05/29/85	10:00	03.45	148.417	76.22	0.434	
06/04/85	11:50	02.90	154.493	79.12	0.477	
06/11/85	11:35	03.06	161.483	82.18	0.438	
06/18/85	10:47	02.82	168.449	85.00	0.405	
06/25/85	10:00	03.34	175.417	88.34	0.479	
07/02/85	11:00	03.50	182.458	91.84	0.497	
07/09/85	11:30	03.46	189.479	95.30	0.493	Effervesces.
07/16/85	12:09	03.43	196.506	98.73	0.488	Effervesces.
07/24/85	11:10	03.83	204.465	102.56	0.481	
07/30/85	10:45	02.79	210.448	105.35	0.466	
08/06/85	10:58	03.05	217.457	108.40	0.435	
08/14/85	12:10	03.48	225.507	111.88	0.432	
08/20/85	11:31	03.15	231.480	115.03	0.527	
08/28/85	10:00	03.11	239.417	118.14	0.392	
09/04/85	10:58	03.17	246.457	121.31	0.450	
09/10/85	11:23	03.04	252.474	124.35	0.505	
09/17/85	10:16	02.68	259.428	127.03	0.385	
09/24/85	10:20	02.98	266.431	130.01	0.426	
10/01/85	10:25	03.19	273.434	133.20	0.456	
10/08/85	11:05	03.36	280.462	136.56	0.478	
10/15/85	10:46	02.64	287.449	139.20	0.378	
10/23/85	10:58	02.93	295.457	142.13	0.366	
10/29/85	10:45	02.64	301.448	144.77	0.441	
11/05/85	09:40	02.16	308.403	146.93	0.311	10 days after brine was removed from 36" hole in Room 3.
11/13/85	10:45	02.72	316.448	149.65	0.338	
11/21/85	11:50	02.88	324.493	152.53	0.358	
11/26/85	10:40	02.28	329.444	154.81	0.461	
12/03/85	14:15	02.45	336.594	157.26	0.343	
12/10/85	13:41	02.34	343.570	159.60	0.335	
12/17/85	14:15	02.73	350.594	162.33	0.389	
01/03/86	10:30	04.03	367.438	166.36	0.239	Partial removal only.
01/08/86	10:40	03.00	372.444	169.36	0.599	High amount due to only partial removal on 1/03/86.
01/16/86	10:10	03.90	380.424	173.26	0.489	

TABLE E.21
Inflow Data for Hole NG252 in ROOM 2

Date	Time	Liters Removed	Days Since 1/01/85	Cumulative Liters Collected	Liters per Day	Remarks
01/23/86	10:20	02.84	387.431	176.10	0.405	
01/31/86	12:45	02.94	395.531	179.04	0.363	
02/12/86	11:30	02.87	407.479	181.91	0.240	
02/19/86	12:13	02.85	414.509	184.76	0.405	
03/06/86	11:00	04.10	429.458	188.86	0.274	
03/13/86	10:30	02.78	436.438	191.64	0.398	
03/26/86	10:25	03.50	449.434	195.14	0.269	
04/02/86	10:10	02.67	456.424	197.81	0.382	
04/08/86	10:15	02.00	462.427	199.81	0.333	
04/16/86	12:30	02.52	470.521	202.33	0.311	
04/24/86	10:40	01.93	478.444	204.26	0.244	
04/30/86	11:20	02.10	484.472	206.36	0.348	
05/06/86	10:45	01.80	490.448	208.16	0.301	
05/13/86	11:35	01.33	497.483	209.49	0.189	
05/20/86	11:25	01.22	504.476	210.71	0.174	
05/27/86	16:10	01.60	511.674	212.31	0.222	
06/03/86	10:45	01.49	518.448	213.80	0.220	
06/10/86	11:45	02.18	525.490	215.98	0.310	
06/17/86	11:21	02.65	532.473	218.63	0.379	
06/24/86	11:15	01.77	539.469	220.40	0.253	
07/01/86	14:20	01.80	546.597	222.20	0.253	
07/08/86	10:55	01.50	553.455	223.70	0.219	
07/16/86	11:00	01.88	561.458	225.58	0.235	
07/22/86	10:22	01.94	567.432	227.52	0.325	
07/29/86	10:55	02.16	574.455	229.68	0.308	
08/05/86	11:33	01.92	581.481	231.60	0.273	
08/12/86	10:50	01.90	588.451	233.50	0.273	
08/19/86	11:45	01.82	595.490	235.32	0.259	

From: Farnsworth, Jill - WTS
Sent: Wednesday, August 24, 2011 1:41 PM
To: 'johnbcase@cs.com'
Cc: DAmico, Eric - WRES; Carrasco, Rey - WTS
Subject: FW: Bulkhead Resistance

John,

To answer the questions you posed to me in the attached document:

1) The bulkheads used for the panel closure would have a smaller resistance value because the pressure drop is very small and the air flow is very small. The smaller range values are more apt to apply in the case of a panel closure bulkhead.
2) I am assuming that you are referencing the pressure drops in our E300 drift when you spoke of compiling the pressure drop for the "air exhaust entries adjacent to the panel entries for closed or inactive panels." E300 is our main exhaust drift. The high pressure drops that you saw were related to overcasts that were in place when the various test and balances of the vent system were performed. All overcasts have been removed, so you won't see the "high" values of 300-400 milli. In. in E300. In addition the floor has been trimmed, increasing the area of the drift which will help to reduce the pressure drop. For now I would expect to see pressure drops in the range of 100-150 milli. In. Over time as the entry area decreases with the salt convergence, the pressure drop will increase. I would think that 500 milli. In. would be very conservative for bounding purposes.
3) Our vent expert (sub-contractor) has told me that there is virtually no pressure drop in the closed panel. Air movement in and out of existing interim panel closure bulkheads is due to changes in barometric pressure. In reality, I have notice air movement when the pressure changes due to people opening and closing other bulkhead doors in the vicinity of the closed panels.
4) Yes, ventilation modeling of 9A and 10A has been performed with 9A as an active disposal panel and 10A under "construction" (mining). I don't have the model. I could ask our sub-contractor for the pressure drop info associated with the model if you would like to have it. Please let me know.

Jill Farnsworth
Sr. Eng.
Washington TRU Solutions LLC
P.O. Box 2078
Carlsbad, NM 88221-2078
Contractor for the U.S. Department of Energy

From: John B. Case [mailto:johnbcase@cs.com]
Sent: Wednesday, August 24, 2011 9:01 AM
To: Farnsworth, Jill - WTS
Subject: RE: Bulkhead Resistance

Thanks for your timely response in providing ventilation data. I have had the opportunity to compile and review the information. I have several questions in the attached file. Please feel free to contact me either by Email or by phone (Office 702 839-1612 or Cell 702 480-1652).

From: Farnsworth, Jill - WTS [mailto:Jill.Farnsworth@wipp.ws]
Sent: Monday, August 22, 2011 1:24 PM
To: DAmico, Eric - WRES; johnbcase@cs.com
Cc: Carrasco, Rey - WTS
Subject: Bulkhead Resistance

Gentlemen:

I have attached a file with data about bulkhead resistance. We haven't spent time measuring resistance with and without bulkheads in drifts in the UG. The best that I could do was compare similar sized drifts with and without bulkheads in the model. I also used models from 2 different years to show the resistance of the same drift with and without a bulkhead. I'm not sure how you plan to use the bulkhead resistance number. If it is for a closed panel I would assume it is on the small side as there is neither a large flow nor a significant pressure drop across a closed panel. Let me know if there is anything more that I can do.

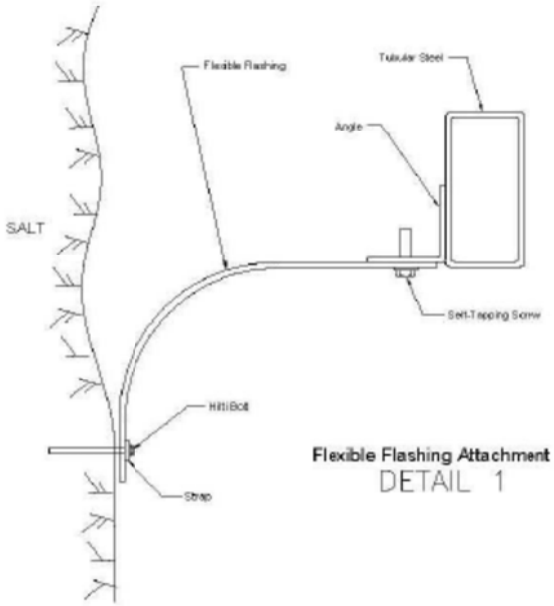
Jill Farnsworth
Sr. Eng.
Washington TRU Solutions LLC
P.O. Box 2078
Carlsbad, NM 88221-2078
Contractor for the U.S. Department of Energy

Ventilation Data

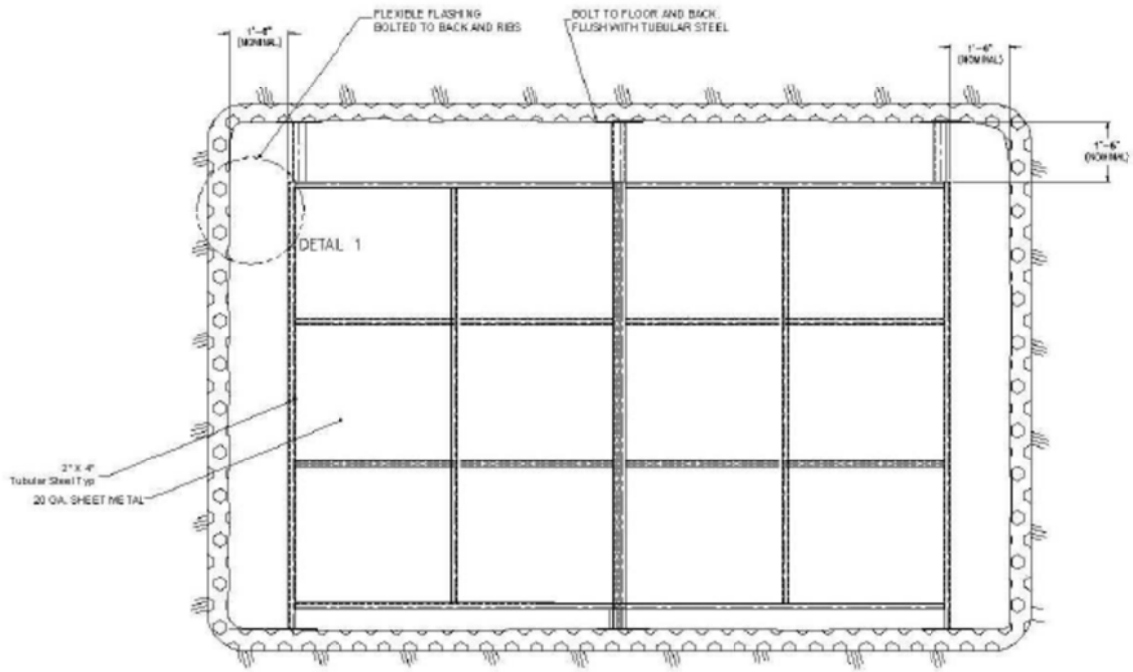
Thanks for the timely response in providing me with ventilation information. I have had the opportunity to compile and review the information. I have several questions.

Figure 1 shows a typical bulkhead comprised of sheet metal with a flexible flashing attachment to accommodate panel entry creep closure. This is the bulkhead that would be used in the Panel Closure Design emplaced in the intake and exhaust panel entries (Intake Entry: 20 ft. wide by 13 ft. high and Exhaust Entry: 14 ft. wide by 12 ft. high). You state that the resistance of large entry bulkheads is from 30 to 200 Practical Units (milli. In. w.g./kcfm^2). Smaller drifts have a higher air flow resistance. Some smaller drifts with bulkheads near the exhaust shaft have resistances as high as 2200 PU. Would the value of 2200 PU apply to a bulkhead comprised of reinforced sheet metal with flexible flashing installed in the intake and exhaust panel entries adjacent to closed or inactive panels?

I compiled the information concerning pressure drop (milli inches of water gage) for the air exhaust entries adjacent to the panel entries for closed or inactive panels. I obtain a range from 11 to 350 milli inches of water gage for the normal mode, and 25 to 460 milli inches of water gage for the full flow operating mode. The results reflect a broad range of pressure drops associated with changes in ventilation to the active room. I am currently thinking of using a value of 500 milli inches of water gage to conservatively bound the pressure drop for calculating the VOCs emissions rate. What do you think of this pressure drop for purposes of calculating air flow rates through closed or inactive panels? Would the value apply to future underground development? For example, if Panel 10 were being excavated, and Panel 9 were receiving waste, would the maximum value for pressure drop in the exhaust entries adjacent to closed/inactive panels be 500 milli inches of water gage? Have ventilation modeling studies been performed for the repository when Panel 10 is in development, and Panel 9 is receiving waste?



Flexible Flashing Attachment
DETAIL 1



Not to Scale. All dimensions are nominal.

Golder Associates Inc.

44 Union Boulevard Suite 300
Lakewood CO USA 80228
Telephone (303) 980-0540
Fax (303) 985-2080

November 30, 2006

Our Ref: 063-2213

Washington TRU Solutions LLC
P.O. Box 2078
4021 National Parks Highway
Carlsbad, NM 88221

Attention: Mr. Rick Chavez

RE: EARLY TIME GENERATION OF METHANE AND HYDROGEN IN FILLED PANELS AT THE WIPP

Dear Mr.Chavez:

This letter addresses expected maximum generation rates for methane and hydrogen in filled panels at the WIPP in response to some stakeholder concerns conveyed by the New Mexico Environment Department (NMED) during the November 22, 2006 conference call. Specifically it addresses the expected maximum concentrations of these gases five years after waste disposal in a panel is complete and ventilation to the panel is stopped. The generation rates and concentrations discussed here are taken from the existing application, supplemented as appropriate by additional publically available information.

Methane Concentrations

Analyses included in Appendix I1 of the WIPP Resource Conservation and Recovery Act Part B Permit Application, and in Appendix PCS of the 1996 Compliance Certification Application, show the potential build up of methane in the closed panels for gas generation rates of 0.01 and 0.1 moles per drum per year, assuming that 70% of the gas generated by microbial degradation is methane. Based on these calculations the concentration of methane for the 0.1 mole per drum per year generation rate will only reach 1% after 5 years, or 20% of the lower explosion limit (LEL) for methane in an atmospheric oxygen environment.

The 0.1 mole per drum per year rate is based on expected gas generation rates under inundated conditions where the rooms are filled with brine. It is not anticipated that these inundated conditions will exist in the first five years after shutting off ventilation to the panel, as evidenced by the lack of significant moisture in open rooms, or in rooms which have been shut-off from ventilation during panel filling. Expected generation rates under humid conditions are about one order of magnitude slower[1].

[1] US Department of Energy, Carlsbad Field Office, "Compliance Recertification Application, Appendix PA, Attachment PAR," March 2004

Gas generated by microbial action is expected to contain at least as much inflammable CO_2 as methane. A series of gas generation experiments under simulated WIPP conditions have been carried out at Brookhaven National Laboratory. These experiments subjected simulated waste materials to microbial degradation under simulated WIPP conditions. Early time data showed that after 853 days the major gas generated was CO_2, and no methane was detected[2]. Later results showed that after 1228 days methane had still not been produced. Minor amounts of methane were detected in some samples after 2718 days[3].

Based on this experimental evidence, and the use of a high generation rate in the calculations included in Attachment I1 of the permit application, it is apparent that the calculated value of 1% methane concentration after 5 years is extremely conservative.

Hydrogen Concentrations

Recently WTS has evaluated the potential for hydrogen generation by radiolysis, based on an analysis of the Panel 3 inventory, and generation rates obtained from head-space hydrogen data from actual containers prior to shipping[4]. These lead to a conservative estimate for the potential rate of hydrogen generation by radiolysis, and by extension to the maximum potential hydrogen concentrations in an unventilated panel. Using these rates, which equate to about 0.397 litres of hydrogen per drum per year, leads to a maximum potential hydrogen concentration from radiolysis of about 0.75% after 3 years, or 1.2% after 5 years. This is about 25% of the LEL for hydrogen in an atmospheric oxygen concentration. Hydrogen can also be generated by anoxic corrosion of steel in the wastes and the drums. However it is anticipated that anoxic conditions will take some time to develop and hydrogen is not generated by oxic corrosion. It should also be noted that rapid corrosion requires inundated conditions which, as discussed above, are also not expected to occur within the first five years...

Data on hydrogen concentrations for actual WIPP waste have been obtained by a series of gas generation experiments conducted at Argonne National Laboratories – West[5]. These experiments were run under inundated conditions, and under anoxic conditions established by pressurizing the containers with nitrogen. After about 5 ½ years the hydrogen concentrations in the containers were, less than 1% with the exception of one container which did show a value of 4.2%. It should be emphasized that these experiments were run under both anoxic and inundated conditions, which are not expected in the first five years after shutting off the ventilation to a panel.

It therefore has been determined that even under the most conservative assumptions of generation rates, and neglecting any affects of diffusion, the hydrogen concentrations after 5 years will be less than 1%, or 25 % of the LEL.

---

[2] Francis, A.J., J.B. Gillow and M.R. Giles, "Microbial Gas Generation Under Expected WIPP Repository Conditions," SAND96-2582, March 1997.

[3] Gillow, J. and A. J. Francis, "Microbial Gas Generation under Expected WIPP Repository Conditions, Final Report, Rev 0", Draft Report, Brookhaven national Laboratory, October 6, 2003

[4] Washington TRU Solutions LLC, "Estimation of Hydrogen Generation rates from Radiolysis in WIPP Panels", letter report from M. Devarakonda (WTS) to Daryl Mercer (CBFO), July 26, 2006

[5] Felicione, F. S., K. P. Carney, C. C. Dwight, D. G. Cummings, and L. E. Foulkrod, "Gas-Generation Experiments For Long-Term Storage of TRU Wastes at WIPP," Waste Management '03 Conference, February 23-27, 2003, Tucson, AZ

Conclusions

Existing calculational data and actual experimental results indicate that even under the most conservative assumptions methane and hydrogen concentrations in a filled and unventilated panel will not exceed between 1% and 1.2% for methane and hydrogen, respectively, in more than five years. These values represent 20% and 30% of the individual LELs, respectively, and 50% of the combined LEL.

Sincerely,

GOLDER ASSOCIATES INC.

T. William Thompson, Ph.D.
Principal

cc: Steve Kouba, WRES

JAN 22 1998

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Crushed-Salt Constitutive Model Update

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F. D. Hansen, G. D. Callahan, M. C. Loken, K. D. Mellegard

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Crushed-Salt Constitutive Model Update

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RE/SPEC Inc.
Rapid City, SD 57709-0725

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ABSTRACT

Modifications to the constitutive model used to describe the deformation of crushed salt are presented in this report. Two mechanisms—dislocation creep and grain boundary diffusional pressure solutioning—defined previously but used separately are combined to form the basis for the constitutive model governing the deformation of crushed salt. The constitutive model is generalized to represent three-dimensional states of stress. New creep consolidation tests are combined with an existing database that includes hydrostatic consolidation and shear consolidation tests conducted on Waste Isolation Pilot Plant and southeastern New Mexico salt to determine material parameters for the constitutive model. Nonlinear least-squares model fitting to data from the shear consolidation tests and a combination of the shear and hydrostatic consolidation tests produced two sets of material parameter values for the model. The change in material parameter values from test group to test group indicates the empirical nature of the model but demonstrates improvement over earlier work with the previous models. Key improvements are the ability to capture lateral strain reversal and better resolve parameter values. To demonstrate the predictive capability of the model, each parameter value set was used to predict each of the tests in the database. Based on the fitting statistics and the ability of the model to predict the test data, the model appears to capture the creep consolidation behavior of crushed salt quite well.

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1.0 INTRODUCTION

1.1 Background

Construction of the Waste Isolation Pilot Plant (WIPP) was initiated by the U. S. Department of Energy (DOE) in 1981 to develop the technology for the safe management, storage, and disposal of transuranic (TRU) radioactive wastes generated by DOE defense programs. The WIPP, located in southeastern New Mexico at a depth of approximately 655 meters in bedded halites, consists of a series of underground shafts, drifts, panels, and disposal rooms. The WIPP may eventually become a repository for TRU wastes, provided the facility is demonstrated to be in compliance with the Environmental Protection Agency's requirements. If the compliance requirements are satisfied, each disposal room will be filled with containers holding TRU wastes of various forms. Ultimately a seal system designed to prevent water from entering the repository and to prevent gases and brines from migrating out of the repository must be in place.

Crushed salt has been proposed as a viable material for permanent sealing of WIPP underground openings. Crushed salt's desirable characteristics include chemical compatibility, eventual mechanical similarity with the host salt formation, and availability from the site excavation. Laboratory tests have shown that crushed salt achieves desirable permeability characteristics as consolidation increases the material density. In addition, voids and fractures close and heal in salt in response to applied loads. Reconsolidated crushed salt becomes a long-term seal component. Thus an understanding of the consolidation processes in crushed salt is fundamental to the design and analysis of a credible seal system that will provide confidence and establish regulatory compliance.

To gain an understanding of the crushed-salt consolidation processes, knowledge of the overall repository isolation system is required along with the interactions of key components such as host geology, brine, waste forms, generated gases, and seal elements. Representative and defensible material, flow, and chemical models are needed that describe the behavior of these components in the isolation system. The objective of this report is to update the mechanical material model appropriate for describing crushed-salt deformation. The WIPP crushed-salt material model or constitutive model, which relates stress and strain, predicts deformations and stresses in the underground sealing system. The magnitude of the stresses and strains throughout the isolation system determines the location and extent of the disturbed rock zone and serviceability of the seal components. Because crushed salt is an important seal material, its constitutive model must satisfy the needs of performance assessment and regulatory compliance.

1.2 Earlier Work

Crushed salt has received international attention over the past 20 years, primarily within a repository setting. An earlier study (Callahan et al., 1995) searched the literature for constitutive models developed for crushed salt. Ten models, based to varying degrees on phenomenology, micromechanics, or empiricism, were found. Three of these models were selected for detailed examination. The three models are those attributable to Sjaardema-Krieg (1987), Zeuch and Holcomb (Zeuch, 1990), and Spiers and coworkers (Spiers and Brzesowsky, 1993). These constitutive models were developed to reproduce hydrostatic (isostatic) consolidation laboratory tests and include only the volumetric strain component. The Sjaardema and Krieg model is empirical and was retained for comparative purposes because it was used in the past for calculation of crushed-salt problems at the WIPP. The Zeuch and Holcomb model was constructed for nominally dry crushed salt and is based on the isostatic hot-pressing models combined with dislocation creep. The Spiers and coworkers model was formulated for wet crushed-salt aggregates and is based on grain boundary diffusional pressure solution processes. These three models were modified to include effects thought to be important for WIPP salt. A flow potential and associated three-dimensional generalization were developed for the models so that they could operate over a wide range of stress triaxialities (ratio of mean stress to effective or deviatoric stress) and be applicable to arbitrary states of stress. A database of applicable crushed-salt laboratory tests was constructed comprising 40 hydrostatic consolidation tests and 10 shear consolidation tests. The experimental data were fit to determine values for the material parameters associated with each of the models. The hydrostatic and shear consolidation tests and their combination were fit separately so that three different parameter value sets were obtained. If a constitutive model was representative and the data were unbiased, the change in parameter values among fits should have been minimal. However, in the earlier study, the change in the parameter values was significant. These three models performed about equally well, with the modified Spiers model exhibiting moderate superiority.

Following completion of the earlier study for the evaluation of potential constitutive models for crushed salt (Callahan et al., 1995), the constitutive model formulation was found to be inadequate at high fractional densities. In addition, because of the heavy bias in the database toward hydrostatic consolidation tests, along with the fact that none of the shear consolidation tests reached high enough fractional densities to exhibit positive lateral strains, the constants associated with the flow potential made it impossible for the simulated crushed salt to move toward a volume-preserving flow (as is exhibited by intact salt) as the fractional density approached one. Most of the test data in the crushed-salt laboratory database exhibit a positive lateral-to-axial strain rate ratio, whereas the lateral-to-axial strain rate ratio is negative for a triaxial test conducted on intact salt. However, as the crushed salt consolidates, at some density

level the lateral deformation must change direction (i.e., cease to move inward and begin to move outward as is observed for the intact salt tests). In addition to being a function of the density, this change in lateral strain direction is also, undoubtedly, a function of the state of stress. Having identified these shortcomings in the crushed-salt model, two additional shear consolidation tests were conducted to expand the database at higher fractional densities near 0.8 (RE/SPEC Inc., 1996). The functional form of the flow potential for the models was modified, and the models were refit to the database. This study, discussed in RE/SPEC Inc. (1996) and Callahan et al. (1996), resulted in satisfactory model predictions over a wide range of fractional densities and stress triaxialities. However, the governing deformation mechanisms for crushed salt with varying degrees of added moisture were contained independently in two separate models.

Thus a goal of the present study was to incorporate the governing mechanisms into a single model. In addition, four new laboratory shear consolidation experiments were conducted with fractional densities near the initial fractional density expected in the dynamically compacted crushed-salt seal (approximately 0.9). These tests allow the database to be expanded into fractional density ranges previously untested and provide information on the crushed-salt flow behavior as its density increases. These tests were added to the experimental database, which was fit to obtain material parameter values for the updated crushed-salt constitutive model. The sign convention used throughout this report is tension positive.

1.3 Report Organization

This report focuses on the mechanical constitutive behavior of crushed salt. Chapter 2 describes the constitutive model, provides the three-dimensional generalization of the model, and reduces the general model form to specific types of laboratory tests. Chapter 3 summarizes the crushed-salt experimental database along with recently completed tests used to fit the constitutive model and determine its material constants. Chapter 4 describes the nonlinear least-squares fitting procedure used to fit the constitutive model to the experimental database and presents the resulting parameter values. Chapter 5 compares the crushed model to other models for porous materials available in the literature. Chapter 6 discusses modifications to the moisture function and flow potential, which were subsequently not used in the final form of the crushed-salt model. The report is concluded with a summary and recommendations in Chapter 7, followed by a list of referenced material, a bibliography, and three appendices.

2.0 CRUSHED-SALT CONSTITUTIVE MODEL

This chapter presents the crushed-salt deformation mechanisms, the general form for the crushed-salt constitutive model, development of the three-dimensional generalization for the creep consolidation model, and reduction of the constitutive model to the form necessary to fit the laboratory data and evaluate the material model parameters.

2.1 Crushed-Salt Deformation Mechanisms

Multiple deformation mechanisms control the densification of crushed salt for the seal emplacement processes and range of conditions expected at the WIPP, where crushed salt is planned as a major sealing component in the shafts. During emplacement in the shafts, crushed salt will be dynamically compacted with small amounts of added moisture (less than 2 percent by weight) to a fractional density of about 0.9. During dynamic compaction, the densification of the crushed salt will occur through particle rearrangement, cataclasis, and plastic yield. These *instantaneous* processes provide a dense, locked-up aggregate. Further densification occurs over time through compactional loading on the crushed-salt column caused by creep of the host salt formation and inward movement of the shaft walls. As crushed salt is loaded, the principal densification mechanisms include dislocation creep and fluid-phase diffusional creep (grain boundary diffusional pressure solutioning). Without the added moisture during construction of the crushed-salt seal component, the importance of the diffusional creep mechanism would diminish. The model that defines the dislocation creep of intact salt is defined in terms of three dislocation mechanisms involving dislocation climb, an undefined (but experimentally and empirically well established) mechanism, and dislocation glide (Munson et al., 1989). The presence of the liquid phase leads to the additional deformational processes characterized by stress-induced dissolution, diffusion, and precipitation. The diffusional creep rate is controlled by the slowest of these serial processes. The grain boundary diffusional pressure solution mechanism dramatically enhances the densification rate in crushed salt (Spiers and Schutjens, 1990).

The idea of pressure solutioning as a deformation mechanism has been around for over 100 years but has only been studied in detail for application to geologic systems during the last 25 years. The fundamental process is characterized by a liquid phase occurring perhaps as a thin liquid film at grain interfaces. The diffusive mass transfer process has been called fluid-phase diffusional creep, solution-precipitation creep, pressure solution, and grain boundary diffusional pressure solution. The mechanism is analogous to diffusional creep (Coble creep) where matter is transported distances on the order of the grain size and controlled by diffusion of atoms

through the grain interfaces. In the solution-precipitation creep process, matter transport is characterized by diffusion through the fluid at the grain interfaces. A significant difference between the two creep processes is that solution-precipitation creep occurs at much lower temperatures than the classical diffusional creep.

The constitutive model developed for crushed salt discussed in the following sections incorporates the dislocation creep and pressure solutioning mechanisms.

2.2 General Form for the Crushed-Salt Constitutive Model

The total strain rate for the crushed-salt constitutive model is assumed to consist of two components. The components include nonlinear elastic $\left(\dot{\epsilon}_{ij}^{e} \right)$ and creep consolidation $\left(\dot{\epsilon}_{ij}^{c} \right)$ contributions, and the total strain rate is written as:

$$\dot{\epsilon}_{ij} = \dot{\epsilon}_{ij}^{e} + \dot{\epsilon}_{ij}^{c} \tag{2-1}$$

When the strains become finite, the expressions for strain rate should be interpreted as the rate of deformation. Both the nonlinear elastic and creep consolidation portions of the model describe the material behavior in bulk (volumetric) and in shear (deviatoric). However, as shown later, when the fractional density approaches unity, the creep consolidation portion of the model only describes deviatoric material behavior and is, in fact, the creep deformation model used for intact salt. The nonlinear elastic portion of the model presented by Callahan et al. (1995) has not changed and will not be presented again. The creep consolidation portion of the model is presented along with its evolution to the intact salt model.

2.3 Creep Consolidation Model

The creep consolidation model is of primary concern in this study, and thus this section is divided into subsections that address important issues regarding the creep consolidation portion of the crushed-salt consolidation model. Typically equations proposed to describe the behavior of a particular material are written in one-dimensional form or as scalar relationships. To be useful in numerical analyses and applicable to a variety of laboratory experiments with different load paths, any constitutive model must be generalized to include three-dimensional states of stress. The first subsection presents the generalization of the creep consolidation model. The next subsection collapses or reduces the generalized form of the creep consolidation equation to specific laboratory test conditions, which yields simplified forms that can be used in fitting the model to the experimental database. The third subsection presents the effective strain rate model

forms that represent the two mechanisms associated with the crushed-salt creep consolidation component of the constitutive model.

2.3.1 Creep Consolidation Model Generalization

To develop the creep consolidation constitutive equation for crushed salt, two operative deformation mechanisms are assumed: dislocation creep and grain boundary diffusional pressure solutioning. Dislocation creep is the governing mechanism for deformation of intact salt (e.g., Munson et al., 1989). The stress-induced dissolution and precipitation process or simply pressure solutioning is an operative mechanism when small quantities of water (brine) are contained in the aggregate (e.g., Spiers and Brzesowsky, 1993). As discussed by Stocker and Ashby (1973) and Helle et al. (1985), the creep and diffusional mechanisms are independent and additive. From the application of thermodynamic concepts, the three-dimensional generalization of kinetic equations is given by Fossum et al. (1988). Following this approach, the generalized average kinetic equation for the creep consolidation inelastic flow of crushed salt can be written as:

$$\dot{\epsilon}^{c}_{ij} = \left[\dot{\epsilon}^{d}_{eq}\left(\sigma^{f}_{eq}\right) + \dot{\epsilon}^{w}_{eq}\left(\sigma^{f}_{eq}\right) \right] \frac{\partial \sigma_{eq}}{\partial \sigma_{ij}} \tag{2-2}$$

where $\dot{\epsilon}^{c}_{ij}$ is the inelastic strain rate tensor and σ^{f}_{eq} is an equivalent stress measure. The equivalent inelastic strain rate measures for dislocation creep $\left(\dot{\epsilon}^{d}_{eq}\right)$ and pressure solutioning $\left(\dot{\epsilon}^{w}_{eq}\right)$ are written as functions of the equivalent stress measure. For use in the flow potential, another equivalent stress measure, σ_{eq}, is used to provide a nonassociative type of formulation that provides flexibility in governing the magnitude of the volumetric behavior.

Motivation for selection of the equivalent stress measures comes from laboratory experiments reported in previous work (Callahan et al., 1995; 1996). Tests on crushed-salt specimens exhibit a strong dependence on the pressure (mean stress) applied to the specimens. Shear consolidation experiments also exhibit differing behavior depending on the magnitude of applied stress difference. Thus the appropriate stress measure should include both mean and deviatoric stress dependencies. Laboratory tests on intact salt specimens show little dependence on moderate mean stress levels (< –2 MPa), and typically the deformation of intact salt is described as a volume-preserving process. Therefore one would expect the mean stress influence to decrease as the crushed salt approaches full consolidation. Perhaps most importantly, in a typical triaxial test, the effective stress measure describing the potential surface must provide a reversal in lateral strain rate as the fractional density approaches one. This condition is a natural consequence at low stress triaxialities (ratio of mean to deviatoric stress) because porous crushed salt decreases in volume but intact salt inelastic deformation is isochoric (volume preserving) unless damage is occurring.

Sofronis and McMeeking (1992) discuss the ratio of mean stress to deviatoric stress or stress triaxiality as considered by a number of researchers. They discuss investigations of stress triaxiality over ranges of fractional density, which are pertinent to the crushed-salt investigations. Crushed salt emplaced in the underground workings and shafts at the WIPP will experience moderate levels of stress triaxiality. Models for hot isostatic pressing (HIPing) of powders presented by Helle et al. (1985), which also provide the basis for Zeuch's (1990) crushed-salt model, have an infinite ratio of mean stress to shear stress. Therefore, Callahan et al. (1995) and RE/SPEC Inc. (1996) modified Zeuch's model for applicability in the moderate stress triaxiality ranges. Duva and Hutchinson (1984) developed a constitutive model for power-law creep of an incompressible matrix material containing a dilute concentration of spherical voids. Their model is thought to be valid for moderate stress triaxialities with fractional densities greater than 0.9. However, when the triaxiality is high, the model is only valid for porosities less than 1 percent. Duva (1986) modified the original model of Duva and Hutchinson (1984) so that the accuracy was improved at higher porosities for moderate triaxialities, but the model is still unsatisfactory for high triaxial stress states except when the porosity is low. Cocks (1989) states that the surface of constant energy dissipation rate (i.e., the creep potential surface) for a creeping solid is a function of stress and void volume fraction only, and independent of material parameters apart from a weak dependence on the creep stress exponent. Cocks' conclusion is based on a lower bound analysis for an isolated spherical void. Cocks' constitutive law for power-law creeping materials is not accurate for low porosities when the stress is predominantly hydrostatic, but performs better at higher void volume fractions. In contrast to the constitutive laws that contain a range of stress triaxialities, the models of Wilkinson and Ashby (1975), Arzt et al. (1983), and Helle et al. (1985) are valid only for states of pure hydrostatic stress; however, the models are probably more accurate over a larger range of fractional densities for these stress conditions. Sofronis and McMeeking (1992) developed a creep potential for power-law materials based on finite element calculations of spherical unit cells with a central spherical hole to represent the voids. They found that the dominant component, whether dilational or deviatoric, is always well represented. Comparisons with uniaxial compression experimental data from other sources showed that the ratio of the lateral-to-axial strain rates was predicted fairly accurately, although the strain rate magnitudes were not.

Crushed salt emplaced at the WIPP will experience broad ranges of fractional density and stress triaxiality over the life of the repository. As discussed for the earlier studies, little success has been achieved in a single constitutive model's ability to cover all these required conditions. Fortunately the crushed salt emplaced in the shaft will be dynamically compacted to an initial fractional density of about 0.9. This limits the accuracy required in the crushed-salt constitutive model to fractional densities between 0.9 and 1.0. However, much of the existing crushed-salt laboratory data have been generated for fractional densities less than 0.9. In our first study (Callahan et al., 1995), the most promising existing models for crushed salt were identified and generalized for arbitrary states of stress. However, the large number of hydrostatic consolidation test results in the database used to evaluate material parameters resulted in a model that was invalid at low stress triaxialities. The second study (RE/SPEC Inc., 1996; Callahan et al., 1996) corrected this problem by designing and adding two tests that expanded the experimental results

into a previously unrepresented region of material behavior, modifying the functional form of the flow potential, and independently fitting the flow potential to the strain rates to determine the parameter values. In the present study, the two identified operative mechanisms are combined in the constitutive model to characterize the consolidation of crushed salt.

With these considerations, the equivalent stress measures are homogeneous of degree one in terms of stress and are given by:

$$\sigma_{eq}^{f} = \left[\eta_0 \Omega_f^{\eta_1} \sigma_m^2 + \eta_2 \left(\frac{2 - D}{D} \right)^{\frac{2n_f}{n_f + 1}} (\sigma_1 - \sigma_3)^2 \right]^{1/2}$$

$$\sigma_{eq} = \left[\kappa_0 \Omega^{\kappa_1} \sigma_m^2 + \kappa_2 \left(\frac{2 - D}{D} \right)^{\frac{2n}{n + 1}} (\sigma_1 - \sigma_3)^2 \right]^{1/2} \qquad (2\text{-}3)$$

where:

$$\Omega_f = \left[\frac{(1 - D)\, n_f}{\left[1 - (1 - D)^{1/n_f} \right]^{n_f}} \right]^{\frac{2}{n_f + 1}} \qquad (2\text{-}4)$$

$$\Omega = \left[\frac{\left(1 - D_v\right) n}{\left[1 - \left(1 - D_v\right)^{1/n} \right]^{n}} \right]^{\frac{2}{n + 1}} \qquad (2\text{-}5)$$

$$D_v = \begin{cases} D_t & D \le D_t \\ D & D > D_t \end{cases} \qquad (2\text{-}6)$$

D = current fractional density

σ_m = mean stress = $\frac{\sigma_{kk}}{3}$

σ_3 = minimum principal stress

σ_1 = maximum principal stress

η_0, η_1, η_2, κ_0, κ_1, κ_2, n_f, n, and D_t = material parameters.

The fractional density relationships given in Equations 2-4 and 2-5 are similar to the densification relationship derived by Wilkinson and Ashby (1975) for an isolated spherical void

in a power-law creeping material when the fractional density is greater than 0.9. Their analytical solution to this problem showed that the macroscopic densification rate was proportional to the fractional density relationship written as:

$$\frac{\dot{D}}{D} \alpha \frac{(1 - D)}{\left[1 - (1 - D)^{1/n}\right]^n} \tag{2-7}$$

where n is the stress exponent for the power-law material. The functional form for the fractional density relationship is carried through in the models presented by Arzt et al. (1983), Helle et al. (1985), and Zeuch (1990). Sofronis and McMeeking (1992) adopted a similar form for their elliptic form of the potential function for power-law creep of a material containing spherical voids. Kwon and Kim (1996a; 1996b) used the potential functions derived by Kuhn and McMeeking (1992) and Sofronis and McMeeking (1992) to develop models for densification of alumina powder.

As crushed salt approaches full consolidation (i.e., D → 1), Ω_f and Ω approach zero and the dependence on mean stress diminishes, which is required for an incompressible material matrix. The fractional density functions multiplying the deviatoric terms in Equation 2-3 are taken from Sofronis and McMeeking (1992). They state that, under purely deviatoric situations, this term exceeds the lower bound developed by Ponte Casteneda and Willis (1988) for large fractional densities but provides a good approximation to the results of Duva and Hutchinson (1984). Thus, letting $D = 1$, Equation 2-3 becomes:

$$\begin{aligned} \sigma_{eq}^{f} &= \sqrt{\eta_2}\left(\sigma_1 - \sigma_3\right) \\ \sigma_{eq} &= \sqrt{\kappa_2}\left(\sigma_1 - \sigma_3\right) \end{aligned} \tag{2-8}$$

Twice the maximum shear stress or Tresca equivalent stress is used in the equivalent stress measures to describe the shear behavior, as is common for intact salt, and is given by:

$$\sigma_1 - \sigma_3 = 2\cos\psi\sqrt{J_2} \tag{2-9}$$

with the second and third invariants of the deviator stress (J_2 and J_3) defined by:

$$\begin{aligned} J_2 &= \frac{1}{2} s_{ij} s_{ji} \\ J_3 &= \frac{1}{3} s_{ij} s_{jk} s_{ki} \end{aligned} \tag{2-10}$$

where the Lode angle (ψ), which is a convenient alternative invariant to J_3, is given by:

$$\psi = \frac{1}{3}\sin^{-1}\left(\frac{-3\sqrt{3}J_3}{2J_2^{3/2}}\right), \left(-\frac{\pi}{6} \le \psi \le \frac{\pi}{6}\right) \tag{2-11}$$

The partial derivative given in Equation 2-2 may be determined using the chain rule as:

$$\frac{\partial \sigma_{eq}}{\partial \sigma_{ij}} = \frac{\partial \sigma_{eq}}{\partial \sigma_m}\frac{\partial \sigma_m}{\partial \sigma_{ij}} + \frac{\partial \sigma_{eq}}{\partial J_2}\frac{\partial J_2}{\partial \sigma_{ij}} + \frac{\partial \sigma_{eq}}{\partial \psi}\frac{\partial \psi}{\partial J_3}\frac{\partial J_3}{\partial \sigma_{ij}} \tag{2-12}$$

The derivatives of the invariants in Equation 2-12 are the same regardless of the invariant stress and strain measures selected. These derivatives are:

$$\begin{aligned}
\frac{\partial \sigma_m}{\partial \sigma_{ij}} &= \frac{\delta_{ij}}{3} \\
\frac{\partial J_2}{\partial \sigma_{ij}} &= s_{ij} \\
\frac{\partial \psi}{\partial J_3}\frac{\partial J_3}{\partial \sigma_{ij}} &= -\frac{\sqrt{3}}{2J_2^{3/2}\cos 3\psi}\, t_{ij}
\end{aligned} \tag{2-13}$$

where:

δ_{ij} = Kronecker delta

$$t_{ij} = s_{ip}s_{pj} - \frac{2}{3}J_2\delta_{ij}$$

Equation 2-12, defining the flow potential, also requires the partial derivatives of the equivalent stress measure (Equation 2-3) with respect to stress. Performing the required differentiation yields:

$$\frac{\partial \sigma_{eq}}{\partial \sigma_m} = \frac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{\sigma_{eq}}$$

$$\frac{\partial \sigma_{eq}}{\partial J_2} = \frac{4 \kappa_2}{\sigma_{eq}} \left(\frac{2 - D}{D} \right)^{\frac{2n}{n+1}} \frac{\cos\psi \cos 2\psi}{\cos 3\psi} \tag{2-14}$$

$$\frac{\partial \sigma_{eq}}{\partial \psi} = -\frac{4 \kappa_2}{\sigma_{eq}} \left(\frac{2 - D}{D} \right)^{\frac{2n}{n+1}} \cos\psi \sin\psi J_2$$

Substituting Equations 2-12, 2-13, and 2-14 into Equation 2-2 provides the tensorial strain rate components for the creep consolidation portion of the crushed-salt model, which is given by:

$$\dot{\epsilon}_{ij}^{c} = \frac{\dot{\epsilon}_{eq}^{d} + \dot{\epsilon}_{eq}^{w}}{\sigma_{eq}} \left\{ \frac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{3} \delta_{ij} + \kappa_2 \left(\frac{2 - D}{D} \right)^{\frac{2n}{n+1}} 2\sqrt{J_2} \cos\psi \right.$$

$$\left. \left(\left[\frac{\cos 2\psi}{\cos 3\psi} \right] \frac{s_{ij}}{\sqrt{J_2}} + \left[\frac{\sqrt{3} \sin\psi}{J_2 \cos 3\psi} \right] t_{ij} \right) \right\} \tag{2-15}$$

Equation 2-15 is seen to be undefined as the Lode angle approaches $\pm\pi/6$. In other words, the flow potential forms corners at $\psi = \pm\pi/6$, and the direction of straining is not unique. To eliminate this problem computationally, the flow potentials on either side of the corner are averaged, which produces an indeterminant form that is examined in the limit as $\psi \rightarrow \pm\pi/6$. Performing this limiting operation, Equation 2-15 becomes:

$$\dot{\epsilon}_{ij}^{c} = \frac{\dot{\epsilon}_{eq}^{d} + \dot{\epsilon}_{eq}^{w}}{\sigma_{eq}} \left\{ \frac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{3} \delta_{ij} + \kappa_2 \left(\frac{2 - D}{D} \right)^{\frac{2n}{n+1}} \sqrt{3 J_2} \right.$$

$$\left. \left(\frac{s_{ij}}{\sqrt{3 J_2}} \mp \frac{t_{ij}}{2 J_2} \right) \right\} \tag{2-16}$$

The flow potential contains five material parameters (κ_0, κ_1, κ_2, D_i, and n) that need to be determined from laboratory experiments. To complete the crushed-salt creep consolidation

description, the kinetic equations describing dislocation creep and pressure solutioning in crushed salt need to be defined. In general, these kinetic equations could be a form of any specific model that captures the desired characteristics of the material deformation. Discussion of these specific forms is included in Sections 2.3.3 and 2.3.4 following presentation of other general considerations for the crushed-salt consolidation model.

2.3.2 Evaluation of Laboratory Test Equation Forms

To compare the crushed-salt constitutive equations to laboratory experiments, one needs to reduce the equations to the applicable test conditions. In particular, tests of interest are the hydrostatic compression, triaxial compression, and extension tests. To derive these forms, one simply needs to substitute the applicable test conditions into the constitutive equations and reduce them to their simplest forms. The hydrostatic compression test conditions can be easily obtained from the triaxial compression test conditions by letting the stress difference ($\Delta\sigma = \sqrt{3J_2}$) equal zero. The directions $\{zz, yy, xx\}$ are taken as $\{33, 22, 11\}$, and the $\{zz\}$ direction is taken to be the axial direction. For simplicity, the following variables are defined:

$$\alpha = \frac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{3}$$
$$\beta = \kappa_2 \left[\frac{2 - D}{D}\right]^{\frac{2n}{n+1}} \sqrt{3 J_2} \qquad (2\text{-}17)$$

Fitting of the constitutive model can be conveniently separated into two separate stages. The first step includes fitting the ratio of the lateral strain rate to the axial strain rate defined as **R** and written as:

$$\mathbf{R} = \frac{\dot{\epsilon}_l^c}{\dot{\epsilon}_a^c} \qquad (2\text{-}18)$$

Fitting the strain rate ratio allows the parameter values associated with the flow potential (i.e., α and β in Equation 2-17) to be determined independently of the other material parameter values. Obviously the test data must contain experiments where the stress triaxiality conditions lie between zero and infinity for the fitting to be successful. This can be accomplished with the shear consolidation tests.

Reduction to Triaxial Compression Creep Test ($\psi = \pi/6$)

The triaxial compression creep test is prescribed by controlling a constant stress state defined by $\sigma_{zz} < \sigma_{xx} = \sigma_{yy}$. Under these stress conditions, the stress measures included in Equation 2-16 reduce to:

$$\sqrt{3J_2} = \Delta\sigma = \sigma_1 - \sigma_3$$

$$J_2 = \frac{\Delta\sigma^2}{3}$$

$$s_{zz} = \sigma_{zz} - \sigma_m = -\frac{2}{3}\Delta\sigma$$

$$s_{xx} = s_{yy} = \sigma_{xx} - \sigma_m = \frac{\Delta\sigma}{3} \qquad (2\text{-}19)$$

$$t_{zz} = s_{zz}^2 + s_{zx}^2 + s_{zy}^2 - \frac{2}{3}J_2 = \frac{2\Delta\sigma^2}{9}$$

$$t_{xx} = t_{yy} = s_{xx}^2 + s_{xy}^2 + s_{xz}^2 - \frac{2}{3}J_2 = -\frac{\Delta\sigma^2}{9}$$

$$\left(\frac{s_{zz}}{\sqrt{3J_2}} - \frac{t_{zz}}{2J_2}\right) = -1$$

$$\left(\frac{s_{xx}}{\sqrt{3J_2}} - \frac{t_{xx}}{2J_2}\right) = \frac{1}{2}$$

Therefore the axial (*a*), lateral (*l*), and volumetric (*v*) strain components and strain rate ratio for the creep consolidation portion of the model may be determined from Equations 2-16, 2-17, 2-18, and 2-19 as:

$$\dot{\epsilon}_a^c = [\alpha - \beta]\frac{\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w}{\sigma_{eq}}$$

$$\dot{\epsilon}_l^c = \left[\alpha + \frac{\beta}{2}\right]\frac{\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w}{\sigma_{eq}} \qquad (2\text{-}20)$$

$$\dot{\epsilon}_v^c = 3\,\alpha\,\frac{\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w}{\sigma_{eq}}$$

$$\mathbf{R} = \frac{\alpha + \frac{\beta}{2}}{\alpha - \beta}$$

Reduction to Triaxial Extension Test ($\psi = -\pi/6$)

The triaxial extension creep test is prescribed by controlling a constant stress state defined by $\sigma_{zz} > \sigma_{xx} = \sigma_{yy}$. Under these stress conditions, the stress measures in Equation 2-16 reduce to:

$$\sqrt{3J_2} = \Delta\sigma = \sigma_1 - \sigma_3$$

$$J_2 = \frac{\Delta\sigma^2}{3}$$

$$s_{zz} = \sigma_{zz} - \sigma_m = \frac{2}{3}\Delta\sigma \qquad (2\text{-}21)$$

$$s_{xx} = s_{yy} = \sigma_{xx} - \sigma_m = -\frac{\Delta\sigma}{3}$$

$$t_{zz} = s_{zz}^2 + s_{zx}^2 + s_{zy}^2 - \frac{2}{3}J_2 = \frac{2\Delta\sigma^2}{9}$$

$$t_{xx} = t_{yy} = s_{xx}^2 + s_{xy}^2 + s_{xz}^2 - \frac{2}{3}J_2 = -\frac{\Delta\sigma^2}{9}$$

$$\left(\frac{s_{zz}}{\sqrt{3J_2}} + \frac{t_{zz}}{2J_2}\right) = 1$$

$$\left(\frac{s_{xx}}{\sqrt{3J_2}} + \frac{t_{xx}}{2J_2}\right) = -\frac{1}{2}$$

Therefore the axial (a), lateral (l), and volumetric (v) strain components and strain rate ratio for the creep consolidation portion of the model may be determined from Equations 2-16, 2-17, 2-18, and 2-21 as:

$$\dot{\epsilon}_a^c = [\alpha + \beta] \frac{\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w}{\sigma_{eq}}$$

$$\dot{\epsilon}_l^c = \left[\alpha - \frac{\beta}{2}\right] \frac{\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w}{\sigma_{eq}} \qquad (2\text{-}22)$$

$$\dot{\epsilon}_v^c = 3\,\alpha \frac{\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w}{\sigma_{eq}}$$

$$\mathbf{R} = \frac{\alpha - \frac{\beta}{2}}{\alpha + \beta}$$

2.3.3 Equivalent Inelastic Strain Rate Form for Dislocation Creep

Dislocation creep of intact salt has been characterized by the Multimechanism Deformation (M-D) model (Munson, 1979; Munson and Dawson, 1979; Munson et al., 1989). Thus the equivalent inelastic strain rate measure for the dislocation creep portion of the crushed-salt model is taken to be the M-D material model. The model is written as:

$$\dot{\epsilon}_{eq}^d = F\,\dot{\epsilon}_s \qquad (2\text{-}23)$$

where $\dot{\epsilon}_{eq}^d$ is the kinetic equation and $\dot{\epsilon}_s$ is the steady-state strain rate. The transient function F consists of three branches — a work-hardening branch, an equilibrium branch, and a recovery branch — and is written in that order as:

$$F = \begin{cases} \exp\left[\Delta\left(1 - \dfrac{\zeta}{\epsilon_t^f}\right)^2\right] & \zeta < \epsilon_t^f \\ 1 & \zeta = \epsilon_t^f \\ \exp\left[-\delta\left(1 - \dfrac{\zeta}{\epsilon_t^f}\right)^2\right] & \zeta > \epsilon_t^f \end{cases} \qquad (2\text{-}24)$$

Δ and δ are the work-hardening and recovery parameters, respectively, and ϵ_t^f is the transient strain rate limit. The internal variable ζ is governed by the evolution equation:

$$\dot{\zeta} = (F - 1)\,\dot{\epsilon}_s \tag{2-27}$$

and the transient strain limit is given by:

$$\epsilon_t^f = K_0 e^{cT}\left(\frac{\sigma_{eq}^f}{\mu}\right)^m \tag{2-28}$$

where:

T = temperature

μ = shear modulus

K_0, c, and m = material parameters.

The work-hardening parameter is defined as a function of stress:

$$\Delta = \alpha + \beta \log\left(\frac{\sigma_{eq}^f}{\mu}\right) \tag{2-28}$$

where α and β are material parameters. Because of insufficient data, the recovery parameter (δ) is taken to be a constant. However, functional forms similar to Equation 2-27 are sometimes used for recovery, viz:

$$\delta = \alpha_r + \beta_r \log\left(\frac{\sigma_{eq}^f}{\mu}\right) \tag{2-28}$$

where α_r and β_r are material parameters.

The steady-state strain rate is the sum of the three individual strain rate mechanisms acting together:

$$\dot{\epsilon}_s = \sum_{i=1}^{3} \dot{\epsilon}_{s_i} \tag{2-29}$$

The three contributing mechanisms — dislocation climb, an undefined mechanism, and slip — are written respectively as:

$$\dot{\epsilon}_{s_1} = A_1 \left(\frac{\sigma_{eq}^f}{\mu} \right)^{n_1} \exp\left(-\frac{Q_1}{RT} \right) \tag{2-30}$$

$$\dot{\epsilon}_{s_2} = A_2 \left(\frac{\sigma_{eq}^f}{\mu} \right)^{n_2} \exp\left(-\frac{Q_2}{RT} \right) \tag{2-31}$$

$$\dot{\epsilon}_{s_3} = \left(B_1 e^{-Q_1/RT} + B_2 e^{-Q_2/RT} \right) \sinh\left[q \left(\frac{\sigma_{eq}^f - \sigma_0}{\mu} \right) \right] H\left(\sigma_{eq}^f - \sigma_0 \right) \tag{2-32}$$

where:

μ = shear modulus

q = activation volume

A_1, A_2, B_1, B_2, n_1, n_2, Q_1, Q_2, and σ_0 = experimental constants

R = universal gas constant

$H(.)$ = Heaviside step function.

2.3.4 Equivalent Inelastic Strain Rate Form for Pressure Solutioning

Spiers and Brzesowsky (1993) presented a grain boundary diffusional pressure solution model for wet crushed salt as:

$$\dot{\epsilon}_v^c = A V_m \frac{\exp\left(-\frac{Q_s}{RT}\right)}{T} \left(\frac{\sigma_m - P}{d^p}\right) \left(\frac{\left(1 + \epsilon_v\right)^{r_3}}{\left|\epsilon_v\right|^{r_4}}\right) \Gamma \tag{2-33}$$

where A, V_m, Q_s, r_3, and r_4 are material constants; T is absolute temperature; R is the universal gas constant; d is the grain size; and P is the pore pressure. The model consists of two functional forms, one for small strain and one for large strain, which are invoked depending on the prescribed value for Γ given as:

$$\Gamma = \begin{cases} 1 & \text{small strain } \left(\epsilon_v > -15\%\right) \\ \left[\frac{\epsilon_v + \phi_0}{\phi_0\left(\epsilon_v + 1\right)}\right]^{n_s} & \text{large strain } \left(\epsilon_v < -15\%\right) \end{cases} \tag{2-34}$$

where ϕ_0 is the initial porosity and n_s is a material parameter. Spiers and Brzesowsky (1993) developed the function Γ to account for increasing surface contact (increasing area and decreasing stress) as the strains become large. This geometrically interpreted variable serves to decrease the magnitude of the driving force.

The Spiers and Brzesowsky model is used to represent the equivalent inelastic strain rate form for pressure solutioning with modifications. The functional form given in Equation 2-33 is modified by changing the stress-dependent term (using the equivalent stress measure defined in Equation 2-3) and adding the effect of moisture (w is the moisture fraction by weight). The moisture function (simply w raised to a power, a) eliminates any strain rate contribution to the crushed-salt consolidation model when moisture content is zero. In addition, the pore pressure dependency (parameter P in Equation 2-33) has been dropped from the model because insufficient test data are available to include pore pressure as a state variable. With these modifications, the modified Spiers model used to define the kinetic equation becomes:

$$\dot{\epsilon}_{eq}^w = \frac{r_1 w^a}{d^p} \frac{e^{-\frac{Q_s}{RT}}}{T} \left(\frac{\left(1 + \epsilon_v\right)^{r_3}}{\left|\epsilon_v\right|^{r_4}}\right) \Gamma \sigma_{eq}^f \tag{2-35}$$

Notice that material constants A and V_m appearing in Equation 2-33 have been combined into one parameter, r_1, in Equation 2-35 and defined as:

$$r_1 = AV_m = \text{material constant} \left[\frac{\text{m}^p \cdot K}{\text{MPa} \cdot \text{s}}\right] \tag{2-36}$$

A problem is evident in the Spiers model at time zero. Equation 2-35 can be indeterminate because when $\sigma_{eq}^f = 0$ the initial volumetric strain is zero. To eliminate this problem during computations, some initial value must be assumed for the volumetric strain. Typically this initial strain value will be computed based on an original fractional density of 0.64 (random dense packing of spherical particles) and the fractional density at the beginning of creep consolidation. The modified Spiers model has seven material constants – a, p, Q_s, r_1, r_3, r_4, and n_s, excluding those that appear in the effective stress measure.

2.4 Summary of the Crushed-Salt Consolidation Model

The equation describing the combined crushed-salt constitutive model, which includes dislocation creep and pressure solutioning, is summarized in this section. The final equation for the total creep consolidation strain rate constitutive model for crushed salt is obtained by substituting Equations 2-23 and 2-35 into Equation 2-15:

$$\dot{\epsilon}_{ij}^c = \frac{1}{\sigma_{eq}} \left\{ \frac{r_1 w^a}{d^p} \frac{e^{-\frac{Q_s}{RT}}}{T} \left(\frac{\left(1 + \epsilon_v\right)^{r_3}}{\left|\epsilon_v\right|^{r_4}} \right) \Gamma \sigma_{eq}^f + F \dot{\epsilon}_s \right\} \times$$

$$\left\{ \frac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{3} \delta_{ij} + \kappa_2 \left(\frac{2-D}{D} \right)^{\frac{2n}{n+1}} \left(2 \cos\psi \sqrt{J_2}\right) \left(\left[\frac{\cos 2\psi}{\cos 3\psi}\right] \frac{s_{ij}}{\sqrt{J_2}} + \left[\frac{\sqrt{3}\sin\psi}{J_2 \cos 3\psi}\right] t_{ij} \right) \right\} \tag{2-37}$$

As the material approaches full consolidation, the fractional density approaches 1 and the M-D model creep component becomes the same as that for intact salt. Simultaneously the pressure solutioning portion of the model diminishes as the material approaches full consolidation. This decrease is implemented through the geometric Γ function, which becomes zero at full consolidation. Thus, at complete consolidation (i.e., $D = 1$), Equation 2-37 may be written as:

$$\dot{\epsilon}_{ij}^{c} = \sqrt{\kappa_2}\, F\, \dot{\epsilon}_s \left(\left[\frac{\cos 2\psi}{\cos 3\psi} \right] \frac{s_{ij}}{\sqrt{J_2}} + \left[\frac{\sqrt{3}\sin\psi}{J_2 \cos 3\psi} \right] t_{ij} \right) \tag{2-38}$$

which is identical to the M-D model for intact salt, provided $\kappa_2 = 1$. This condition is easily met by modifying κ_0 appropriately. Substitution of α and β given in Equation 2-17 into Equation 2-20 gives:

$$\mathbf{R} = \frac{\dfrac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{3} + \dfrac{\kappa_2}{2} \left[\dfrac{2 - D}{D} \right]^{\frac{2n}{n+1}} \sqrt{3 J_2}}{\dfrac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{3} - \kappa_2 \left[\dfrac{2 - D}{D} \right]^{\frac{2n}{n+1}} \sqrt{3 J_2}} \tag{2-39}$$

Dividing the numerator and denominator in Equation 2-39 by κ_2 gives:

$$\mathbf{R} = \frac{\dfrac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{\kappa_2 3} + \dfrac{1}{2} \left[\dfrac{2 - D}{D} \right]^{\frac{2n}{n+1}} \sqrt{3 J_2}}{\dfrac{\kappa_0 \Omega^{\kappa_1} \sigma_m}{\kappa_2 3} - \left[\dfrac{2 - D}{D} \right]^{\frac{2n}{n+1}} \sqrt{3 J_2}} \tag{2-40}$$

Thus, if κ_0 is scaled by κ_2 and κ_2 is set equal to one, the appropriate strain rate ratio is maintained and the M-D model is produced exactly when $D = 1$. Therefore the described model provides a smooth transition from crushed salt to intact salt behavior.

3.0 EXPERIMENTAL DATABASE

A database of crushed-salt consolidation laboratory test results was assembled, analyzed, and reported in previous work (Callahan et al., 1995; 1996). This previous work started the process of formulating the functional form of a constitutive model for crushed salt and assembled existing test data into a database to obtain quantitative estimates for the material parameters appearing in the model. The assembled database consists of a collection of tests conducted for a variety of reasons. Thus the database contains biases and shortcomings when viewed strictly from the standpoint of developing constitutive models. The crushed-salt constitutive model has deviatoric and mean stress components that drive the strain response, and the database has shear and hydrostatic consolidation test results used for evaluating the parameters within those respective stress components. When circumstances allow, additional tests are conducted to fill gaps in the database. Two additional shear consolidation tests (RE/SPEC Inc. [1996] and Callahan et al. [1996]) were conducted and added to the database during our most recent work. These two tests represent the first tests with high initial fractional densities (near 0.8) that emulate intact salt behavior accompanied by volumetric consolidation. Associated with the current study, additional laboratory work was conducted to add test data to the shear consolidation portion of the extant database because that portion of the database was relatively sparse, particularly in the higher initial fractional density range expected at the WIPP. The remainder of this chapter is divided into two sections: the first summarizes the status of the database, and the second presents details on the four shear consolidation tests that were performed as part of the current effort.

3.1 Summary of Existing Test Data

The creation of the database being used for parameter estimation began with an extensive library search and compilation of potentially useful test results (Pfeifle, 1995). That compilation was reviewed to document those tests deemed inappropriate for parameter estimation, and the surviving tests formed the database for parameter estimation work (Callahan et al., 1995). Two subsequent shear consolidation tests were added to the database for recent parameter estimation work (Callahan et al., 1996). That database was constructed from two types of tests: hydrostatic consolidation and shear consolidation. The two parts of the database are shown separately here in Tables 3-1 and 3-2, which summarize the tests for the hydrostatic and shear consolidation groupings, respectively.

Table 3-1. Summary of Hydrostatic Test Conditions

Test I.D.	Test Type	Seq. No.	T (K)	σ_1 (MPa)	σ_3 (MPa)	Mean Grain Size (mm)	Added Water (%)	Test Duration (days)	ρ_0 (kg/m^3)	ρ_1 (kg/m^3)	ρ_f (kg/m^3)
CS1	1	1	298	-1.72	-172	2.30	0	4.0	1,430	1,490	1,548
CS2	1	2	298	-1.72	-1.72	1.36	0	4.3	1,480	1,570	1,720
CS3	1	3	298	-1.72	-1.72	0.77	0	4.0	1,410	1,480	1,552
CS4	1	4	298	-1.72	-1.72	0.42	0	4.0	1,290	1,400	1,485
CS5	1	5	298	-1.72	-1.72	2.30	4.44	3.8	1,360	1,440	1,697
CS6	1	6	298	-1.72	-1.72	1.36	4.28	4.0	1,440	1,500	1,775
CS7	1	7	298	-1.72	-1.72	0.77	4.57	4.3	1,420	1,470	1,572
CS8	1	8	298	-1.72	-1.72	0.42	4.61	4.0	1,400	1,430	1,822
CS9	1	9	298	-1.72	-1.72	2.30	0	37.0	1,480	1,530	1,759
CS10	1	10	298	-3.45	-3.45	2.30	0	34.2	1,470	1,570	1,648
HC1A	1	11	298	-1.72	-1.72	1.56	Sat	28.8	1,462	1,539	1,921
HC2A	1	12	298	-1.72	-1.72	1.56	Sat	98.7	1,388	1,574	2,026
HC3A	1	13	298	-3.45	-3.45	1.56	Sat	49.9	1,448	1,550	2,042
HC4A	1	14	298	-3.45	-3.45	1.56	Sat	110.8	1,409	1,610	2,065
HC5A	1	15	298	-6.90	-6.90	1.56	Sat	53.0	1,496	1,741	2,124
HC6A	1	16	298	-6.90	-6.90	1.56	Sat	77.9	1,395	1,721	2,125
27JUL82	1	1	294	-1.72	-1.72	2.5	0	2.7	1,273	1,390	1,440
04MAY82	1	2	313	-1.72	-1.72	2.5	0	2.8	1,396	1,563	1,621
30APR82	1	3	333	-1.72	-1.72	2.5	0	3.0	1,448	1,605	1,677
07MAY82	1	4	353	-1.72	-1.72	2.5	0	2.9	1,240	1,415	1,492
12MAY82	1	5	373	-1.72	-1.72	2.5	0	4.8	1,371	1,621	1,738
05FEB82	1	6	294	-3.44	-3.44	2.5	0	3.4	1,263	1,432	1,466
09APR82	1	7	313	-3.44	-3.44	2.5	0	3.0	1,330	1,495	1,561
26MAR82	1	8	333	-3.44	-3.44	2.5	0	3.9	1,242	1,393	1,451
02APR82	1	9	353	-3.44	-3.44	2.5	0	2.7	1,249	1,428	1,501
13APR82	1	10	373	-3.44	-3.44	2.5	0	2.8	1,240	1,424	1,522
29JAN82	1	11	294	-6.70	-6.70	2.5	0	3.2	1,279	1,506	1,557
26FEB82	1	12	294	-10.1	-10.1	2.5	0	3.1	1,256	1,538	1,601
27JU61	1	1	293	-0 69	-0.69	1.75	2.5	31.8	1,440	1,493	1,732
23JL51	1	2	293	-1.72	-1.72	1.75	0.5	19.7	1,498	1,593	1,827
14NV51	1	3	293	-1.72	-1.72	1.75	1.5	24.1	1,477	1,571	1,860
25FE61	1	4	293	-1.72	-1.72	1.75	2.0	36.6	1,455	1,548	1,853
10MY51	1	5	293	-1.72	-1.72	1.75	2.4	28.9	1,412	1,601	1,890
20AU51	1	6	293	-1.72	-1.72	1.75	3.0	20.0	1,348	1,516	1,821
16 JL51	1	7	293	-3.44	-3.44	1.75	0.5	20.6	1,391	1,608	1,920
18JU51	1	8	293	-3.44	-3.44	1.75	1.0	21.6	1,455	1,668	1,930
30OC51	1	9	293	-3.44	-3.44	1.75	1.5	13.8	1,477	1,648	1,930
16JA61	1	10	293	-3.44	-3.44	1.75	2.0	27.9	1,489	1,640	1,950
19DC44	1	11	293	-3.44	-3.44	1.75	2.4	52.1	1,434	1,566	1,899
13AU51	1	12	293	-3.44	-3.44	1.75	3.0	21.7	1,370	1,586	1,899

Table 3-2. Summary of Shear Consolidation Test Conditions

Test I.D.	Test Type	Seq. No.	T (K)	σ_1 (MPa)	σ_3 (MPa)	Mean Grain Size (mm)	Added Water (%)	Test Duration (days)	ρ_0 (kg/m^3)	ρ_1 (kg/m^3)	ρ_f (kg/m^3)
SC1B	2	1	298	-3.45	-4.14	1.56	2.34	62.9	1,449	1,574	2,009
SC2A	2	2	298	-3.45	-4.83	1.56	2.25	61.9	1,479	1,608	2,014
SC3A	2	3	298	-3.45	-5.52	1.56	2.21	61.7	1,448	1,575	2,005
SC4A	2	4	298	-6.90	-7.59	1.56	2.27	60.9	1,428	1,607	2,007
SC5A	2	5	298	-6.90	-8.97	1.56	2.52	61.4	1,522	1,764	2,135
SC6A	2	6	298	-6.90	-10.34	1.56	2.19	67.9	1,375	1,701	2,053
SC7A	2	7	298	-5.17	-6.55	1.56	2.33	66.0	1,455	1,665	2,091
SC8A	2	8	298	-5.17	-7.93	1.56	2.29	60.8	1,423	1,611	2,000
SC9B	2	9	298	-5.17	-9.31	1.56	2.33	60.9	1,415	1,683	2,080
SC10	2	10	298	-1.00	-6.00	1.56	0	28.1	1,531	1,808	1,819
SC11	2	11	298	-1.00	-6.00	1.56	0	17.0	1,483	1,688	1,724
120C891	2	1	293	-3.26	-3.70	2.00	2.40	33.8	1,284	1,516	1,805
RS/DCCS/1	2	1	298	-1.00	-5.00	0.5[a]	1.66	6.2	1,953	2,000	2,035
RS/DCCS/3	2	2	298	-2.00	-6.00	0.5[a]	1.63	37.1	1,954	1,964	2,087
RS/DCCS/4	2	3	298	-3.00	-7.00	0.5[a]	1.59	57.0	1,953	2,011	2,139
RS/DCCS/5	2	4	298	-4.00	-8.00	0.5[a]	1.55	59.1	1,939	1,953	2,093

(a) Grain size was assumed to be 0.5 because dynamic compacted reduces grain sizes.

Table 3-1 lists the 40 tests contained in the hydrostatic consolidation portion of the database. All the testing was performed in a drained condition; i.e., the pore pressure was zero. The database discussed by Callahan et al. (1995) contained 45 tests. Five of the hydrostatic consolidation tests were eliminated from the database as recommended by Callahan et al. (1995). These tests were performed under saturated conditions and were not very well drained, which resulted in the generation of pore pressures with reduced deformation. The maximum and minimum principal stresses are listed under the columns titled σ_1 and σ_3. The principal stresses are equal for the hydrostatic case, but the formatting of the table has been maintained for both types of tests. The initial dry density of the specimens, the density at the beginning of the consolidation stage, and the final density at the end of the test are given under the respective column headings titled ρ_o, ρ_i, and ρ_f.

Table 3-2 lists the shear consolidation tests in the database and is formatted like Table 3-1. The table contains the twelve tests that were used in previous work and another four tests that are part of the current work, which is reported in the next section. As with the hydrostatic consolidation tests, all the shear consolidation tests were performed in a drained condition.

The tests listed in Tables 3-1 and 3-2 comprise the entire database used for parameter estimation in Chapter 4. The original data files often contained thousands of data points and were of impractical size for regression analysis. Each data file was reduced in size to create representative data sets containing only 100 data points, with the first and last data points always being retained and the remaining data points uniformly sampled. This sampling technique is the same as was used in previous work.

3.2 Description of Recent Shear Consolidation Tests

Four shear consolidation creep tests were performed on dynamically compacted crushed-salt specimens that were fabricated with a laboratory scale device following a procedure similar to that used for dynamic compaction of large-scale samples (Hansen and Ahrens, 1996). This device served as a simulant of the compaction technique envisioned for the shaft sealing design. The laboratory scale device used two Proctor split compaction molds to receive the disaggregated salt. After compaction, the molds were removed and the ends of the cylindrical samples were machined to produce testable specimens with nominal dimensions of 100 millimeters in diameter and 200 millimeters in length. The starting material was wetted with a brine, so the specimen moisture content was nominally 1.6 percent by weight. The dry density of the specimens was about 1,985 kg/m^3, which is a fractional density of approximately 0.9 (assuming intact salt density of 2,160 kg/m^3). The energy input to create this density was approximately 2.6 times the modified Proctor energy. The specimens fabricated with the laboratory scale device were identified with the unique labels, RS/DCCS/*n*, where *n* took on values of 1, 2, 3, etc. to designate individual specimens.

The four shear consolidation tests were effectively standard triaxial compression creep tests ($\psi = \pi/6$), and typical test procedures have been described previously (Callahan et al., 1995; Brodsky, 1994). The specimens were initially loaded hydrostatically to the level of specified confining pressure (radial stress) and allowed to stabilize. The specified confining pressure levels for the four tests were –1, –2, –3, and –4 MPa, respectively. Data were collected during the hydrostatic loading phase. Following stabilization, the axial compressive stress for each test was increased by 4 MPa while holding the confining pressure constant so that each of the four specimens was subjected to a stress difference of $\Delta\sigma = 4$ MPa; only the confining pressure was different among tests. Data were also acquired when the axial stress difference was applied. After the axial stress difference was imposed, it was held constant at $\Delta\sigma = 4$ MPa while data were acquired during the shear consolidation creep phase. The test matrix for the shear consolidation creep tests is shown in Table 3-3, where the first column contains the specimen identification and the following three columns give the axial stress, lateral stress, and

temperature, respectively. All four tests were performed in a drained condition; i.e., the pore pressure was zero.

Table 3-3. Shear Consolidated Creep Test Matrix

Specimen Identification	Test Conditions		
	Axial Stress (MPa)	Lateral Stress (MPa)	Temperature (°C)
RS/DCCS/1	-5	-1	25
RS/DCCS/3	-6	-2	25
RS/DCCS/4	-7	-3	25
RS/DCCS/5	-8	-4	25

Analyses based on the constitutive model predicted that a stress state existed wherein the lateral strain rate would initially be negative (compaction) and then reverse direction and become positive as the specimen density increased. As seen in Table 3-3, the scheme for finding this stress state was to change the mean stress by testing at different confining pressures while holding the axial stress difference constant. The creep strain results from the four tests are compared in Figure 3-1, which plots axial and lateral creep strains as a function of time. A significant observation apparent in Figure 3-1 is the trend appearing in the lateral strain response; that is, the magnitude of the lateral strain rate decreases as the confining pressure (mean stress) increases. A very significant phenomenon was observed in the test performed at a confining pressure of –4 MPa. The lateral strain rate in that test was initially negative (specimen diameter decreasing); after some densification of the specimen, the lateral strain rate decreased and ultimately changed sign and became positive (specimen diameter increasing). This observation is important to the work presented in Chapter 4, where the parameters of the crushed-salt constitutive model are determined.

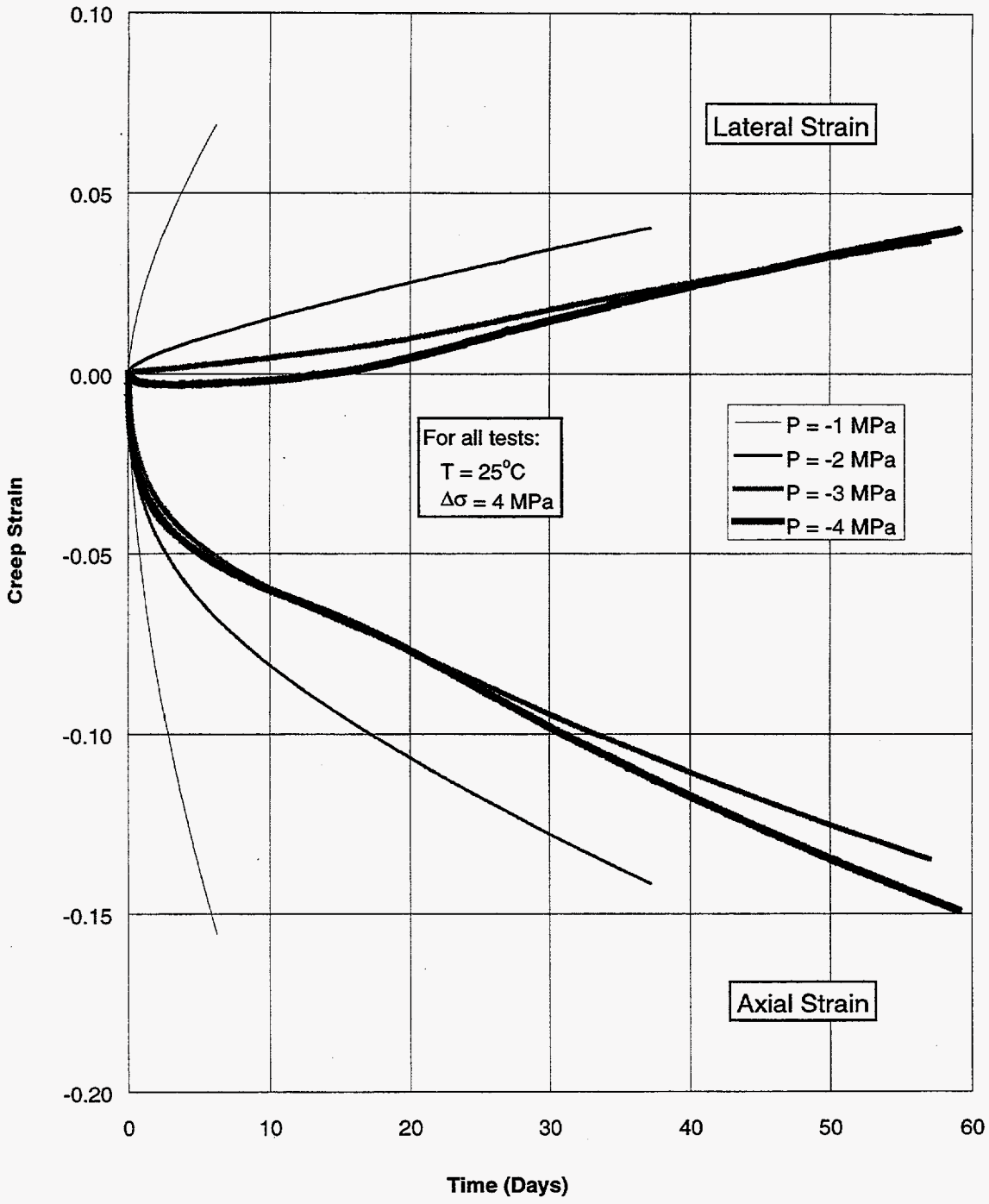

Figure 3-1. Axial and lateral strain as a function of time for four shear consolidation creep tests on dynamically compacted crushed salt.

4.0 MODEL FITTING

4.1 Introduction

The crushed-salt (C-S) constitutive model given in Equation 2-37 contains 33 material parameters. Seventeen of these parameters are contained in the dislocation creep (M-D) portion of the model. The M-D model parameters were fixed at the values provided by Munson et al. (1989) for clean salt. The remaining 16 material parameters consist of 5 flow potential material parameters and 11 creep consolidation parameters. These parameters were determined by fitting the equations that define the C-S constitutive model to the laboratory data such that the weighted squared difference between the measured and calculated response was minimized. First, the flow potential parameters (κ_0, κ_1, κ_2, n, and D_t) were determined by fitting Equation 2-20 (which defines the lateral-to-axial strain rate ratio) to the data measured in the 16 shear consolidation tests. Second, these flow rate parameters were fixed and the 11 creep consolidation parameters (η_0, η_1, η_2, n_f, a, p, n_s, r_1, r_3, r_4, and Q_s/R) were determined by fitting the rate equations that define the axial and lateral strains to the data measured in the 16 shear consolidation and 40 hydrostatic consolidation tests. These nonlinear regressions were performed using the personal-computer platform BioMedical Data Processing (BMDP, Version 7.01) statistical software package (Frane et al., 1985).

4.2 Modeling Procedure

The *object function* is the mathematical function that is to be minimized in the least-squares sense. For example, when performing a least-squares fit of some data to a straight line, the object function is the squared difference between the measured response (the data) and the predicted response from the equation for the straight line. The equation for the straight line when performing linear regression is called the *response model.*

The object function is evaluated at discrete points; these are the points where data have been taken or are available. Some of the measurements may be more important than others and should hold more importance or "weight" than other data points. Mathematically, the relative importance of the level of fit to each data point is accommodated through a *weighting function.*

Application of least squares results in an estimation of the parameters of the response model. In the example cited above, application of least squares will result in the estimation of the two parameters necessary to specify a straight line under the implicit assumption that the measurements will be distributed in the response model for fixed values of the (hopefully)

independent parameters. For complex nonlinear models, the independence of the parameters is not always obvious before fitting. The parameters from the least squares fit to a nonlinear model may not be appropriate if the parameters are highly correlated.

The response model will almost never reproduce all the measurements exactly. The difference between the measured data points and the predicted model response is termed the *residual*. When a weighting function is used in the model fitting, the weighted residual is also of interest. The weighted residual is the usual residual multiplied by the weighting function value for the specific observation or data point.

The object function reflects the relative importance attributed to individual data points and was developed under the following assumptions:

1. Within a given test, there are an equal number of measurement points (100). Each data point was assumed to have equal weight.
2. Within each test, the data are not uniformly distributed with respect to time; the data are denser early in time when the strain rates are highest. Thus the weight function that was used in the model fitting reflects the time step size relative to each data point in each test, such that higher weights are assigned to data points at the end of the test than are assigned to early-time data points.
3. Tests of longer duration were assumed to be more important than tests of shorter duration.
4. Residuals were normalized. They are represented as percent deviations from the measured data. Thus a 10 percent deviation from a very small strain results in the same error in the object function as a 10 percent deviation from a very large strain.

4.2.1 Response Functions

In the shear consolidation tests, there are two independent measurements (superscript m is used to indicate measurements): the volumetric strain $\left(\epsilon_v^m\right)$ and the axial strain $\left(\epsilon_a^m\right)$. The lateral strain $\left(\epsilon_l^m\right)$ was calculated as:

$$\epsilon_l^m = \frac{\epsilon_v^m - \epsilon_a^m}{2} \tag{4-1}$$

The axial strain rate $\left(\dot{\epsilon}_a^m\right)$ was calculated from the measurement of axial strain and elapsed time as follows. At every data point in the original test data file (some contained thousands of

data points), the axial strain rate was calculated as the linear least-square fit to a small interval of data (window) centered on the point in time. The window was then shifted by one data point to the next point in time and the linear fit was repeated. This process was repeated until a point was reached where the width of the window reached the end of the data file for each test. A 50-point window was used in this process. The lateral strain rate $\left(\dot{\epsilon}_l^m\right)$ was calculated in a similar fashion. The measured lateral-to-axial strain rate ratio ($\mathbf{R}^m$) is defined as:

$$\mathbf{R}^m = \frac{\dot{\epsilon}_l^m}{\dot{\epsilon}_a^m} \tag{4-2}$$

Following the development in Chapter 2, the response function used to determine the flow potential parameters is:

$$\mathbf{R}^p = \frac{\alpha + \frac{\beta}{2}}{\alpha - \beta} \tag{4-3}$$

where:

$\mathbf{R}^p$ = predicted lateral-to-axial strain rate ratio

$$\alpha = \frac{\kappa_0 \, \Omega^{\kappa_1} \, \sigma_m}{3}$$

$$\beta = \kappa_2 \left(\frac{2 - D}{D} \right)^{\frac{2n}{n+1}} \left(\sigma_1 - \sigma_3\right)$$

$$\Omega = \left\{ \frac{\left(1 - D_v\right)n}{\left[1 - \left(1 - D_v\right)^{1/n}\right]^n} \right\}^{\frac{2}{n+1}}$$

$$D_v = \begin{cases} D_t & D \le D_t \\ D & D > D_t \end{cases}$$

D = current fractional density

σ_m = mean stress = $(\sigma_3 + 2\sigma_1)/3$

σ_3 = minimum principal stress

σ_1 = maximum principal stress

κ_0, κ_1, κ_2, n, and D_t = flow potential parameters.

Examination of Equation 4-3 reveals that two of the flow potential parameters (κ_0 and κ_2) are not independent of one another (cf., Equation 2-40). Therefore the parameter κ_2 was fixed at a value of 1.0 and the remaining four flow rate parameters were determined in the fit.

The response function (ρ) used to determine the creep consolidation parameters is:

$$\rho = 1 - \left\{\left[\left(1 - R_1\right)^2 + \left(1 - R_2\right)^2\right] wt\right\}^{1/2} \tag{4-4}$$

where:

$R_1 = \epsilon_a^p / \epsilon_a^m$

$R_2 = \epsilon_l^p / \epsilon_l^m$

$wt = \Delta t / \bar{t}$ = weighting function

Δt = time step size

$\bar{t}$ = normalizing time = 10^6(s)

ϵ_l^p = predicted lateral strain = $\int_0^t \dot{\epsilon}_l^p \, dt$

ϵ_a^p = predicted axial strain = $\int_0^t \dot{\epsilon}_a^p \, dt$

$\dot{\epsilon}_l^p$ = predicted lateral strain rate = $\left(\alpha + \beta/2\right) \dfrac{\dot{\epsilon}_{eq}}{\sigma_{eq}}$

$\dot{\epsilon}_a^p$ = predicted axial strain rate = $\left(\alpha - \beta\right) \dfrac{\dot{\epsilon}_{eq}}{\sigma_{eq}}$

$\dot{\epsilon}_{eq}$ = equivalent inelastic strain rate = $\dot{\epsilon}_{eq}^d + \dot{\epsilon}_{eq}^w$

σ_{eq} = equivalent stress measure = $\left[\kappa_0 \, \Omega^{\kappa_1} \, \sigma_m^2 + \kappa_2 \left(\dfrac{2 - D}{D}\right)^{\frac{2n}{n+1}} \left(\sigma_1 - \sigma_3\right)^2\right]^{1/2}$

$\dot{\epsilon}_{eq}^d$ = Munson-Dawson dislocation creep strain-rate model given in Equations 2-23 to 2-32

$\dot{\epsilon}_{eq}^w$ = Spiers pressure-solutioning inelastic strain-rate model given in Equations 2-34 and 2-35

η_0, η_1, η_2, n_f, a, p, n_s,
r_1, r_3, r_4, and Q_s/R = creep consolidation parameters.

The Munson-Dawson dislocation creep model has 17 parameters, which are given in Table 4-1 for clean WIPP salt.

Table 4-1. Munson-Dawson Model Parameter Values for Clean Salt (after Munson et al., 1989)

Parameter	Units	Clean Salt
A_1	yr^{-1} s^{-1}	2.645E+30 8.386E+22
A_2	yr^{-1} s^{-1}	3.050E+20 9.672E+12
Q_1/R Q_1	K cal/mol	12,581 25,000
Q_2/R Q_2	K cal/mol	5,033 10,000
n_1	—	5.5
n_2	—	5.0
B_1	yr^{-1} s^{-1}	1.919E+14 6.0856E+06
B_2	yr^{-1} s^{-1}	9.568E+05 3.034E-02
q	—	5,335
σ_0	MPa	20.57
m	—	3.0
K_0	—	6.275E+05
c	K^{-1}	9.198E-03
α	—	-17.37
β	—	-7.738
δ	—	0.58

4.2.2 Object Function

The object function is the sum-of-squared errors (SS_E). In determining the flow rate parameters, the sum-of-squared error is defined as:

$$SS_E = \sum_{i=1}^{N} \left(R_i^P - R_i^m\right)^2 \tag{4-5}$$

where:

R_i^P = predicted lateral to axial strain rate for the ith data point (Equation 4-3)

R_i^m = measured lateral to axial strain rate for the ith data point (Equation 4-2)

N = number of data points in test database.

In determining the creep consolidation parameters, the sum-of-squared error is defined as:

$$SS_E = \sum_{i=1}^{N} \left(1 - \rho_i\right)^2 \tag{4-6}$$

where:

ρ_i = response function defined in Equation 4-4 for the ith data point.

4.3 Statistical Measures

One key aspect of the model-fitting effort is deciding if the model fit to one database is better than the fit to the other database. In this section, the statistical measures for evaluating and comparing fits to the candidate constitutive model are discussed.

4.3.1 Weighted Residual

In all types of regression, the residual squared times a weighting function is the function that is minimized, where the residual is defined as the difference between the observed and predicted functional values. The sum-of-squared error term defined in Equation 4-6 was used in evaluating the model fits to the two databases.

The specific weighting function associated with the sum-of-squared error is equal to the reciprocal of the measured axial strain squared $\left(\epsilon_a^m\right)^2$, the reciprocal of the measured lateral strain

squared $\left(\epsilon_l^m\right)^2$, the time increment (Δt), and the reciprocal of a normalizing time (10^6 *s*). Thus, if the response model (Equation 4-4) predicts zero axial strain and zero lateral strain over the duration of all tests in the database, the term SS_E in Equation 4-6 will have a value of twice the number of million seconds in the database. This is termed here the maximum value of the sum-of-squared error $\left(SS_E^{max}\right)$. The 40 hydrostatic consolidation tests constitute a total of 76.0(10^6) *s*. The 16 shear consolidation tests total 69.35(10^6) *s*. Therefore SS_E^{max} = 138.7 in the fit to the shear tests, and SS_E^{max} = 290.7 in the fit to the combined test database.

In a similar fashion, if the response model is a perfect predictor for all the tests in the database, the sum-of-squared error will be exactly zero. This is the minimum value of the sum-of-squared error.

For each model fit, the sum-of-squared error was normalized as follows:

$$0 \leq \overline{SS}_E \leq 1 \tag{4-7}$$

where:

$$\overline{SS}_E = SS_E / SS_E^{max}$$

The normalized sum-of-squared error was used in comparing the two model fits.

4.3.2 Parameter Multicollinearity

When fitting a mathematical relation to a set of laboratory-measured data, it is desirable to have enough information in the measured database to ensure that each of the parameters can be uniquely determined. Two possibilities can occur that will not allow for a unique determination of each parameter in a mathematical relation. First, the mathematical relation may inherently include parameters that are dependent on one another. For example, in the relation:

$$F = A + B \tag{4-8}$$

the parameters *A* and *B* cannot be determined uniquely.

Second, there may not be sufficient data in the database to uniquely determine the magnitude of certain model parameters. For example, there are minimal variations in grain size (*d*), moisture content (*w*), and temperature (*T*) in the shear consolidation tests ($\Delta\sigma \neq 0$). Thus, in fitting the candidate models to these tests, the parameters *p*, *a*, and Q_s/R in the term

$$\xi(d,w,T) = \frac{w^{a}}{d^{p}T} \exp\left(-Q_s/RT\right) \tag{4-9}$$

cannot be uniquely determined.

When either of the two aforementioned conditions exist, a condition of multicollinearity is said to exist (Montgomery and Peck, 1982). An examination of the parameter covariance matrix will determine the degree to which the material parameters are correlated to each other. The higher the parameter covariance, the higher the parameter collinearity. When a multicollinearity situation exists, one must (1) expand the database of measurements or (2) modify the functional form of the model.

The elements of the correlation matrix (C_{ij}) can be expressed as:

$$C_{ij} = \frac{q_{ij}}{\sqrt{q_{ii}\, q_{jj}}} \tag{4-10}$$

where:

$q_{ij} = \left[z_{ip}\, z_{pj}\right]^{-1}$

$z_{ij} = \dfrac{\partial\, \epsilon^{m}\left(x_j, \bar{p}\right)}{\partial p_i}$

$\bar{p}$ = set of parameters taken at their mean values

p_i = i^{th} parameter

x_j = j^{th} model variable

ϵ^{m} = measured response.

If the parameters are uncorrelated, then $C_{ij} = 0$. Conversely, the correlation coefficient is one if the parameters are totally correlated. The parameters are highly correlated if $C_{ij} \geq 0.90$, and a state of parameter multicollinearity may exist.

A scalar quantity, termed the parameter correlation measure (pcm), was used in this study as a global measure of the parameter correlations associated with each model's fit to each database. This measure is defined as:

$$\text{pcm} = \frac{\sum_{i=1}^{p-1} \sum_{j=p}^{i+1} C_{ij}^2}{\sum_{i=1}^{p-1} i} = \frac{2 \sum_{i=1}^{p-1} \sum_{j=p}^{i+1} C_{ij}^2}{p^2 - p} \tag{4-11}$$

where p is the number of parameters in the model and $0 \leq \text{pcm} \leq 1$. The numerator in Equation 4-11 is the sum of the squares of the lower triangular components of the parameter correlation matrix (Equation 4-10), and the denominator simply normalizes the result by the number of components in the sum. Obviously, lower parameter correlations will reduce the magnitude of the parameter correlation measure. Finally, an average parameter correlation $(\bar{c})$ can be quantified as:

$$\bar{c} = \sqrt{\text{pcm}} \tag{4-12}$$

4.3.3 Parameter Variation Among Fits

The C-S constitutive model was fit to two databases: (1) the shear consolidation tests only and (2) the combination of shear and hydrostatic consolidation tests. If a specific model is truly a constitutive law in representing the consolidation of crushed salt, the material parameters in each of the different fits should be the same or nearly the same. To evaluate the parameter variation in each of the models, comparisons of the parameter values determined in the fits to the shear consolidation tests were made to the parameter values determined in the fit to the combined database. The ratio of the number of parameters that changed by more than one order of magnitude to the total number of model parameters was calculated for each of the fits to the hydrostatic and shear consolidation tests.

4.3.4 Predictive Capability

The aptness of each of the candidate models (predictive capability) can be demonstrated using the parameter values determined by fitting to the individual test databases. The material parameters determined in the fit to the shear consolidation tests were used to predict each of the hydrostatic consolidation tests. A quantitative measure of the predictive capability is simply the

sum-of-squared error (Equations 4-5 and 4-6). This measure was calculated using the BMDP Program AR (Section 4.4) by fixing the parameter values at those determined in the fit to the shear consolidation tests and fitting (predicting) the hydrostatic consolidation tests.

4.4 BMDP Statistical Software

This section describes in detail the BMDP nonlinear regression Programs 3R and AR used in the model fitting. BMDP is a statistical software package developed at the University of California at Berkeley, supported by grants from the Biotechnology Resources Branch of the National Institutes of Health and the National Science Foundation.

BMDP Program AR is a nonlinear regression program that estimates the parameters of a nonlinear function by least squares using a pseudo Gauss-Newton algorithm. The response model can be specified as a system of coupled rate equations. The response model derivatives are evaluated numerically based on the initial parameter estimates and are not updated during the regression. In addition to calculating the weighted sum-of-squared error (SS_E), the program calculates the coefficient of multiple determination (R_p^2), the residual mean-squared error (MS_E), and the coefficients of the parameter correlation matrix (C_{ij}). The various program features and supporting documentation of AR are provided in various BMDP technical reports, including Frane et al. (1985). Program AR was used in determining the creep consolidation parameters.

BMDP Program 3R is identical to AR with the following exceptions: (1) the model function cannot be expressed as a system of coupled rate equations and (2) the response model derivatives are updated continuously during the regression. Program 3R was used in determining the flow potential parameters.

The input files required to execute an AR or 3R analysis are described in detail by Dixon et al. (1985) and in the BMDP Users' Digest (Hill, 1984). Basically the input files can be thought of as a series of paragraphs that are further subdivided into sentences using keywords. Each paragraph is activated by a slash (/) followed immediately by a keyword. Each of these sentences are activated by keywords and ended with periods. All comment cards are noted using the pound symbol (#). The BMDP input files for the model fits are given in Appendix A.

The BMDP input files are composed of 12 paragraphs. The first paragraph (/INPUT) contains the title card, the database file name, the format to be used in reading the data, and the number of variables in the database. The second paragraph (/VARIABLES) names each of the 18 variables contained in the database file. The third paragraph (/TRANS) identifies the defined

variables (or functions of variables) that are specific to the response model. Specifically, MS and DS are the mean stress and stress difference, respectively. Similarly, D0 and DI are the emplaced and initial fractional density, respectively. The variable USE identifies which test database is to be used in the fit, and the variable WT is the weight function. The fourth paragraph (/REGRESS) identifies the dependent variable (DEPEND), the number of parameters in the model, the weight function variable (WEIGHT), the integration variable (ITIME) in the rate equations, the number of differential equations (NEQN), the number of iterations (ITER), the number of interval halvings for each iteration (HALVINGS), and the maximum number of integration steps (MAXC). The fifth paragraph (/PARAMETER) identifies the parameter names and the initial estimates, as well as the maximum and minimum values for each of the parameters. The sixth paragraph (/DIFIN) identifies the initial values for each of the dependent variables in the rate equations (Z(i),i=1,NEQN). The seventh paragraph (/DIFEQ) specifies the functional form of the rate equations (DZ(i), i=1,NEQN). The eighth paragraph (/FUN) identifies the dependent variable (response) function (F). The ninth through eleventh paragraphs (/SAVE, /PRINT, and /PLOT) specify output options for the program. The last paragraph (/END) identifies the end of the input file.

4.5 Results

In this section the results of the model fits are presented and discussed in terms of the model parameters and the statistical measures defined in Section 4.3.

The C-S constitutive model contains a total of 16 parameters. Five of these parameters are termed the flow potential parameters (κ_0, κ_1, κ_2, n, and D_t). These parameters were determined by fitting the C-S constitutive model to the lateral-to-axial strain rate ratios measured in the 16 shear consolidation tests. The remaining 11 parameters in the C-S constitutive model are termed the creep consolidation parameters (η_0, η_1, η_2, n_f, a_1, p, n_s, r_1, r_3, r_4, and Q_s/R). Two sets of creep consolidation parameters were determined: one set each resulting from fits to a database composed of 16 shear consolidation tests and to a combined database composed of the 16 shear and 40 hydrostatic consolidation tests. The parameters were determined by fitting the C-S constitutive model to the axial and lateral strains measured in each of the tests. The parameters η_0, η_1, η_2, and n_f define the stress measure σ_{eq}^{f}. Moisture dependence, grain-size dependence, and temperature dependence are defined by the parameters a, p, and Q_s/R, respectively. The remaining parameters (r_1, r_3, and r_4) are for the Spiers pressure-solutioning model (Equation 2-35). In both fits, the parameter η_2 was fixed at unity, ensuring that the C-S constitutive model smoothly transitions into the M-D dislocation creep model at a fractional density of 1.0, according to Equation 2-8.

4.5.1 Flow Potential Parameters

The flow potential parameters are given in Table 4-2. Plots of the predicted and measured lateral-to-axial strain rate ratios as a function of density for each of the 16 shear consolidation tests are given in Appendix B.

Table 4-2. Flow Potential Parameters

Parameter	Magnitude	Units
K_0	0.095	—
K_1	1.412	—
K_2	1.000	—
n	7.578	—
D_t	0.891	—

4.5.2 Creep Consolidation Parameters

The creep consolidation parameters for each of the two model fits are given in Table 4-3. Plots of the predicted and measured lateral and axial strains for each of the 16 shear consolidation tests and 40 hydrostatic consolidation tests are given in Appendix C.

4.6 Statistical Measures

4.6.1 Sum-of-Squared Error

The sum-of-squared error (SS_E) was calculated using Equation 4-5 for each of the model fits to the shear test database and the combined test database. Using these results and Equation 4-7, the normalized sum-of-squared error $\left(\overline{SS}_E\right)$ was calculated for each of the model fits. The results are given in Table 4-4.

Table 4-3. Creep Consolidation Parameters

Parameter	Units	Shear Tests	Combined Tests
η_0	—	0.1319	$2.581(10^{-2})$
η_1	—	3.9387	2.587
η_2	—	1.000	1.00
n_f	—	3.5122	4.792
a	—	0.3179	0.0230
p	—	1.6366	1.099
n_s	—	0.1209	0.0
r_1	m^p•k(MPa•s)	$3.58(10^{-4})$	$5.53(10^{-4})$
r_3	—	6.7325	11.12
r_4	—	0.0	0.6003
Q_s/R	K	1074.5	811.28

Table 4-4. Sum-of-Squared Error, SS_E

Test Database	SS_E	$\overline{SS}_E$
Shear	10.41	0.075
Combined	37.9	0.130

These results indicate that the model fit to the shear test database is qualitatively better than the fit to the combined tests (i.e., 7 percent relative error in comparison to 13 percent relative error).

4.6.2 Parameter Multicollinearity

The parameter correlation coefficient matrices for each of the two model fits are given in Tables 4-5 and 4-6. High parameter correlations (>0.90) are indicative of possible parameter multicollinearity. As noted in Section 4.3.2, high parameter correlations are indicative of either (1) deficiencies in the functional form of the C-S constitutive model or (2) deficiencies (or gaps) in the test database.

Table 4-5. Parameter Correlation Coefficient Matrix—Model Fit to Shear Consolidation Tests

	n_t	η_0	η_1	a	p	n_s	r_1	r_s	r_4	Q_s/R
n_t	1.0									
η_0	0	1.0								
η_1	-1.0	0	1.0							
a	0	0.1161	0	1.0						
p	0	0.2081	0	0.8733	1.0					
n_s	0	-0.0359	0	-0.3507	-0.3923	1.0				
r_1	0	-0.1910	0	-0.9088	-0.9716	0.3375	1.0			
r_3	0	-0.0165	0	0.1381	0.3908	-0.6131	-0.3347	1.0		
r_4	0	-0.1392	0	-0.9858	-0.8583	0.4379	0.8655	-0.1531	1.0	
Q_s/R	0	0.0143	0	-0.1111	-0.3849	0.5813	0.3144	0.9955	0.1276	1.0

Table 4-6. Parameter Correlation Coefficient Matrix—Model Fit to Combined Test Database

	n_t	η_0	η_1	a	p	n_s	r_1	r_s	r_4	Q_s/R
n_t	1.0									
η_0	-0.6128	1.0								
η_1	-0.9603	0.4052	1.0							
a	0.1552	-0.2347	-0.1098	1.0						
p	0.1547	0.0350	-0.1722	0.0654	1.0					
n_s	-0.0363	0.1291	0.0016	0.5740	0.4327	1.0				
r_1	-0.2663	0.1258	0.2754	0.1462	-0.3891	0.0097	1.0			
r_3	0.2624	-0.1480	-0.2551	-0.0825	0.4067	0.0097	0.0881	1.0		
r_4	0.0305	0.0281	-0.0443	-0.2723	0.1707	-0.0894	-0.9394	-0.2828	1.0	
Q_s/R	-0.2654	0.1436	0.2590	0.0747	-0.4851	-0.0878	-0.1369	-0.9816	0.3348	1.0

In general, most of the parameter correlations are low (<0.90) for both fits. However, four sets of parameters in the fit to the shear test database ($n_f - \eta_1$, $a_1 - r_4$, $p - r_1$, and $r_3 - Q_s/R$) and three sets of parameters in the fit to the combined test database ($n_f - \eta_1$, $r_1 - r_4$, and $r_3 - Q_s/R$) have correlation coefficients greater than 0.90.

The parameter correlation measure (pcm) and the average correlation coefficient $(\bar{c})$ were evaluated using Equations 4-11 and 4-12, respectively. The results are given in Table 4-7 for each of the model fits.

Table 4-7. Parameter Correlation Measure

Test Database	pcm	$\bar{c}$
Shear	0.200	0.447
Combined	0.120	0.346

The results in Table 4-7 indicate that the parameters are slightly less correlated in the fit to the combined test database. However, the average correlation coefficient is less than 0.5 in both fits, which indicates that the possibility of parameter multicollinearity is low.

4.6.3 Parameter Variation Among Fits

A quantitative measure of the parameter variation between the C-S constitutive model fits to the two databases was defined in Section 4.3.5. The measure simply indicates the percentage change in each of the parameter values in the fit to the combined test database as compared to the parameter value determined in the model fit to the shear consolidation tests. The variation in parameter values in the fit to the combined test database is given in Table 4-8. As can be seen in this table, no parameters varied by more than one order of magnitude (i.e., parameter variation >10). Qualitatively the parameters did not change appreciably overall in the two model fits.

4.6.4 Predictive Capability

The predictive capability of the C-S constitutive model is measured qualitatively by how successfully the model fits to the shear consolidation tests predict the hydrostatic consolidation tests. Figures showing the C-S constitutive model fits to the hydrostatic consolidation tests are given in Appendix C, specifically Figures C-1 through C-40. The sum-of-squared error in predicting the hydrostatic consolidation tests was calculated using Equation 4-6. These results are given in Table 4-9.

Visual examination of Figures C-17 to C-28 reveals that the model fit to the shear test database does not predict the hydrostatic tests that are dry ($w = 0$), particularly as the mean stress increases. Therefore the shear database model parameters were used to predict the wet hydrostatic consolidation tests. As seen in Table 4-9, the sum-of-squared error in predicting these tests (22.84) is nearly identical to that determined in the model fit to the combined tests (22.00).

Table 4-8. Parameter Variation

Parameter	Variation (%)
η_0	19
η_1	66
n_f	136
a_1	7
p	67
n_s	0
r_1	149
r_3	165
r_4	0
Q_s/R	75

Table 4-9. Sum-of-Squared Error in Hydrostatic Consolidation Tests

Database Fit	Database Predicted	
	Hydrostatic	Wet Hydrostatic
Shear	$>10^{22}$	22.84
Combined	23.61	22.00

These results suggest that the crushed-salt constitutive model (with parameter values determined from the shear consolidation tests) has excellent predictive quality. As shown in Table 4-9, this form of the model *predicts* the wet hydrostatic tests nearly as well as the model *fits* to the same tests. As further evidenced in the figures in Appendix C, visual comparison of the two fits shows qualitative sameness, even though the parameter values themselves might appear to be quite different (Table 4-3). For some tests (e.g., CS3 and CS9) the shear-determined parameters predict the laboratory data even better than the fit. Furthermore the model contains both a volumetric (hydrostatic) component and a deviatoric (shear) component, both of which are

captured in the shear consolidation tests. This provides a good sense of compatibility between theory (the model) and reality (the data). Thus the model not only characterizes (fits) the shear data well; it can also reproduce (predict) simpler conditions nearly as well. This provides strong evidence that the model has the potential for predicting the consolidation of crushed salt in other, more complex conditions, including the behavior of the shaft seal.

5.0 MODEL COMPARISONS

Over the past 20 years the behavior of particles has received growing interest in an effort to optimize manufacturing processes for forming parts from metallic powders and ceramics. On the surface, the task of predicting the behavior of a well-characterized material changed only by the introduction of voids would seem to be a straightforward process. However, the task is much more formidable because of the idealized, continually changing geometry and potential changes in the micromechanisms themselves over a wide range of porosity. Much of the research conducted to date is derived from cell models (i.e., a single void surrounded by the matrix material) analyzed to develop microscopic models that are homogenized to produce a macroscopic model of a void-filled material. Naturally the single cell models do not behave exactly like aggregates with random void distributions, nor do they account for interaction of the voids. Thus bounding solutions are typically derived that provide estimates for the random aggregate assemblage. Cell model analysis methods have mainly included analytical solutions and finite element analyses. Analytical solutions are usually derived for the simpler void geometries, which are typically spherical or cylindrical with preferred orientations. Then macroscopic solutions are derived that bound the microscopic cell solutions. Finite element analyses have been applied to problems similar to the analytical solution cell geometries, but they also provide flexibility in void shape and orientation. Hypothesized macroscopic constitutive models are matched to the cell behavior resulting from the finite element analyses. In this chapter, the effective stress measure for the crushed-salt flow potential is compared to each of these model types. The analytical model was developed by Gurson (1977) and later modified by Tvergaard (1981), and the finite element unit cell calculation-assisted model was developed by Sofronis and McMeeking (1992). Gurson's and Tvergaard's models are classic models for voided material that are cited by numerous researchers. Thus the crushed-salt model is compared with their models to enhance our understanding of the crushed-salt model predictive ability over a wide range of fractional densities and stress triaxialities. The Sofronis and McMeeking model forms the basis for the crushed-salt model. Comparison with this model shows the effect of modifications aimed at making the model more representative of crushed salt. Comparisons to these models are discussed separately in the remainder of this chapter.

5.1 Gurson and Tvergaard Models Comparison

Gurson (1977) developed approximate yield criteria and flow rules for porous ductile materials. Previous plastic models relied on the deviatoric response of the material matrix predicting incompressibility and could not predict the dilational aspects evident in porous inelastic materials. Gurson used simple cell models to develop upper bound yield loci to provide an approximate picture of the role of the hydrostatic stress in the yield and flow of porous, ductile

materials. Gurson considered long, circular, cylindrical voids and spherical voids as the void geometries. Later, Tvergaard (1981) recommended a modification to Gurson's model based on his numerical calculations to account for void interaction.

Comparison of the crushed-salt flow potential function (described in Chapter 2) to Gurson's and Tvergaard's models may help bring a physical basis to the crushed-salt model. However, at the outset we must recognize a significant difference between these earlier plastic models and the crushed-salt model. The plastic models are concerned with void nucleation and growth causing bulk dilatancy, which commonly accompanies large plastic flow. Thus the plastic models attempt to capture the increase in volume, whereas the crushed-salt model attempts to capture the decrease in volume. However, for the most part, consistency of the dilatancy terms is accomplished by the accompanying change in sign of the mean stress from tension to compression.

The yield or plastic potential function (F) developed by Gurson and modified by Tvergaard can be written as:

$$F = \left(\frac{\sigma_e}{\sigma_0}\right)^2 + 2q_1(1 - D)\cosh\left(\frac{3\alpha q_2 \hat{\sigma}}{2\sigma_0}\right) - \left[1 + q_3(1 - D)^2\right] \tag{5-1}$$

where:

$$\sigma_e = \left(\frac{3}{2}s_{ij}s_{ij}\right)^{1/2} = \sqrt{3J_2}, \text{ von Mises effective stress}$$

$$s_{ij} = \sigma_{ij} - \sigma_m\delta_{ij}, \text{ deviatoric stress}$$

$$\hat{\sigma} = \begin{cases} \sigma_p, \text{ in-plane mean stress (cylindrical voids)} \\ \sigma_m = \dfrac{\sigma_{kk}}{3}, \text{ mean stress (spherical voids)} \end{cases}$$

$$\alpha = \begin{cases} \sqrt{3}, & \text{cylindrical voids} \\ 1, & \text{spherical voids} \end{cases}$$

$$q_1, q_2, q_3 = \begin{cases} q_1 = q_2 = q_3 = 1, & \text{Gurson model} \\ q_1 = 1.5,\ q_2 = 1,\ q_3 = q_1^2, & \text{Tvergaard model} \end{cases}$$

D = fractional density

σ_0 = material equivalent yield stress.

The variable σ_p is the partial trace of the stress tensor in the plane orthogonal to the axis of the void for the cylindrical void model and the mean stress for the spherical void model. Equation 5-1 describes the level or magnitude of stress required to yield a porous, plastic material as described by Gurson and Tvergaard. The direction of flow is described by the normal to the yield surface and defined as the derivative of the yield function with respect to stress for associative flow. For comparative purposes, the effective stress measure used to describe the crushed-salt flow potential is used, which is given in Equation 2-3 and repeated here for convenience.

$$\sigma_{eq} = \left[\kappa_0 \Omega^{\kappa_1} \sigma_m^2 + \kappa_2 \left(\frac{2 - D}{D} \right)^{\frac{2n}{n+1}} (\sigma_1 - \sigma_3)^2 \right]^{\frac{1}{2}} \tag{5-2}$$

To aid in comparing the crushed-salt equivalent stress with Gurson's and Tvergaard's models, Equation 5-2 is rewritten as a similar type of yield function (F_{cs}) as:

$$F_{cs} = \left[\kappa_0 \Omega^{\kappa_1} \sigma_m^2 + \kappa_2 \left(\frac{2 - D}{D} \right)^{\frac{2n}{n+1}} (\sigma_1 - \sigma_3)^2 \right]^{\frac{1}{2}} - \left[1 + (1 - D)^2 \right]^{\frac{1}{2}} \tag{5-3}$$

The added term in Equation 5-3 makes the magnitudes of the effective stress similar to the magnitudes predicted by Gurson's and Tvergaard's yield functions. However, the flow direction is unaffected by the additional term because the derivative of Equation 5-3 with respect to stress remains the same as that for Equation 5-2. In this comparison, the shapes of the resulting curves are most important because Equation 5-2 governs the direction of flow for the crushed-salt model.

To aid in a numerical comparison of the models, consider a triaxial compression test where:

$$\begin{aligned} &\sigma_3 < \sigma_1 = \sigma_2 \\ &\sigma_e = \sqrt{3 J_2} = \sigma_1 - \sigma_3 = \Delta\sigma \end{aligned} \tag{5-4}$$

Substituting Equation 5-4 into Equations 5-1 and 5-3 and solving for $\Delta\sigma$ at yield ($F = F_{cs} = 0$) gives:

$$\Delta\sigma = \left[-2q_1(1 - D)\sigma_0^2 \cosh\left(\frac{3\alpha q_2 \sigma_m}{2\sigma_0} \right) + \left(1 + q_3[1 - D]^2\right)\sigma_0^2 \right]^{1/2} \tag{5-5}$$

for Gurson's and Tvergaard's model and

$$\Delta\sigma_{cs} = \left[\frac{1}{\kappa_2} \left(\frac{2 - D}{D} \right)^{\frac{-2n}{n+1}} \left(-\kappa_0 \Omega^{\kappa_1} \sigma_m^2 + 1 + [1 - D]^2 \right) \right]^{1/2} \tag{5-6}$$

for the crushed-salt model. Substitution of mean stress values produces effective stress (stress difference) values that form data pairs for plotting in stress space.

To compare Equations 5-5 and 5-6, fractional density values of 0.9, 0.8, and 0.7 or porosity values ($\phi = 1 - D$) of 0.1, 0.2, and 0.3 are assumed. The crushed-salt model parameter values given in Chapter 4 (Table 4-2) are used in the comparison. For Gurson's and Tvergaard's models, σ_0 is taken to equal one. Figures 5-1 and 5-2 are compressive stress space plots that compare the crushed-salt model to Gurson's and Tvergaard's models for spherical voids and long, circular, cylindrical voids, respectively. As shown in Figure 5-1, the crushed-salt model shape is most similar to Gurson's and Tvergaard's model shapes at the lowest fractional density. In addition, the crushed-salt model appears to be less sensitive to changes in fractional density. Comparison to the cylindrical void form of Gurson's and Tvergaard's models given in Figure 5-2 is academic because the cylindrical void model includes the partial trace of the stress tensor normal to the axis of the void, whereas the crushed-salt model includes the mean stress. Thus the abscissa is different for the models as labeled in Figure 5-2. However, it is still interesting that the crushed-salt model appears to compare most closely with Gurson's and Tvergaard's cylindrical void model at the higher fractional densities, which is the opposite of what was observed in Figure 5-1 for the spherical void model.

5.2 Sofronis and McMeeking Model Comparison

Sofronis and McMeeking (1992) conducted finite element calculations for a unit spherical cell containing a concentric spherical hole to characterize a power-law creep material containing voids. Calculations were carried out for isostatic and nonisostatic cases. Based on the results of

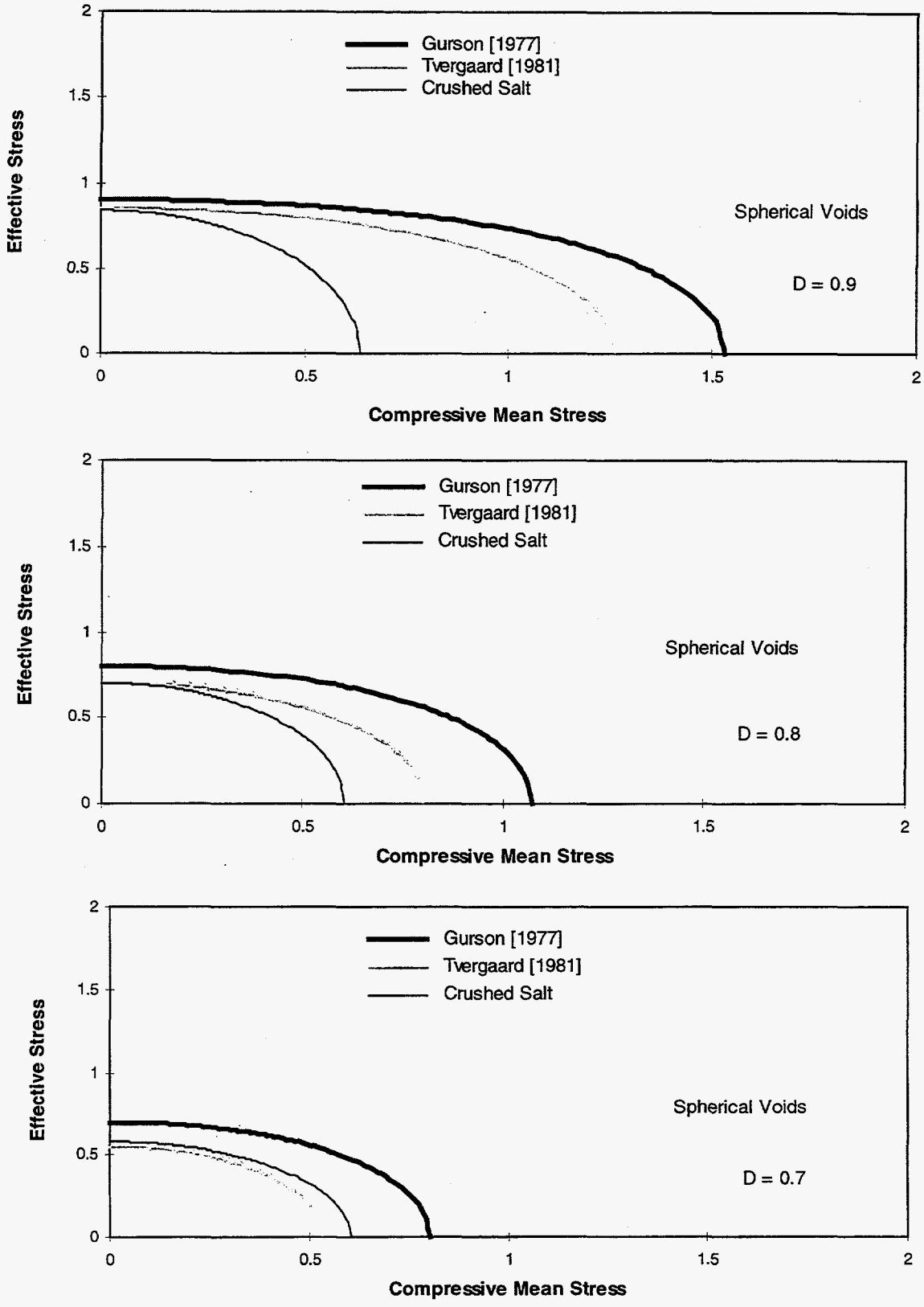

Figure 5-1. Comparison of the crushed-salt model to Gurson's and Tvergaard's models, assuming spherical voids.

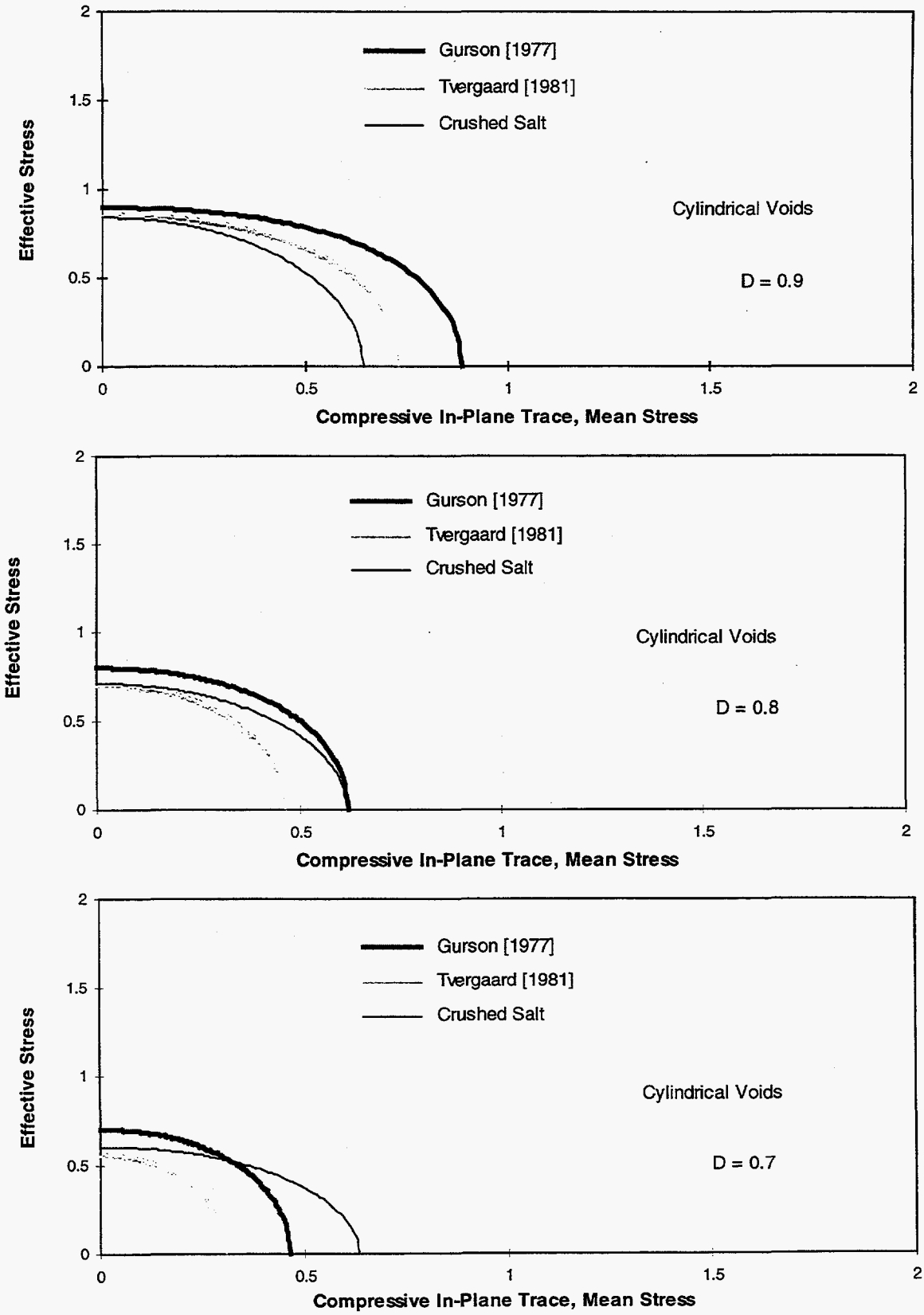

Figure 5-2. Comparison of the crushed-salt model to Gurson's and Tvergaard's models, assuming long, circular, cylindrical voids.

the calculations and equation forms suggested by others, they formulated an elliptic potential function to describe the porous material, which may be written as:

$$F_{sm} = \left[\left(\frac{(1 - D)m}{\left(1 - (1 - D)^{1/m}\right)^m} \right)^{\frac{2}{m+1}} \left(\frac{3\sigma_m}{2m} \right)^2 + \left(\frac{2 - D}{D} \right)^{\frac{2m}{m+1}} \left(3J_2\right) \right]^{1/2} \tag{5-7}$$

where m is the effective stress exponent for the creep power law. To compare Equations 5-2 and 5-7, contours are computed where the potential functions are equal to one. As for the comparison to the Gurson and Tvergaard models, a triaxial compression test is assumed and the stress differences are computed for values of mean stress. Thus Equations 5-2 and 5-7 are rewritten as:

$$\Delta\sigma_{cs} = \left[\frac{1}{\kappa_2} \left(\frac{2 - D}{D} \right)^{\frac{-2n}{n+1}} \left(-\kappa_0 \, \Omega^{\kappa_1} \sigma_m^2 + 1 \right) \right]^{1/2}$$

$$\Delta\sigma_{sm} = \left\{ \left(\frac{2 - D}{D} \right)^{\frac{-2m}{m+1}} \left[- \left(\frac{(1 - D)m}{\left[1 - (1 - D)^{1/m}\right]^m} \right)^{\frac{2}{m+1}} \left(\frac{3\sigma_m}{2m} \right)^2 + 1 \right] \right\}^{1/2} \tag{5-8}$$

The crushed-salt model parameters given in Chapter 4 are used for the crushed-salt model, and the exponent m in Sofronis and McMeeking's model was assumed to be equal to n. Figure 5-3 contains compressive stress space plots that compare the crushed-salt potential to the one presented by Sofronis and McMeeking (1992). Despite the subtle differences between the crushed salt and Sofronis and McMeeking potential functions, Figure 5-3 shows significant differences in their contours. Comparison of Figure 5-3 to Figure 5-1 shows that Sofronis and McMeeking's model compares closely with Gurson's spherical void model.

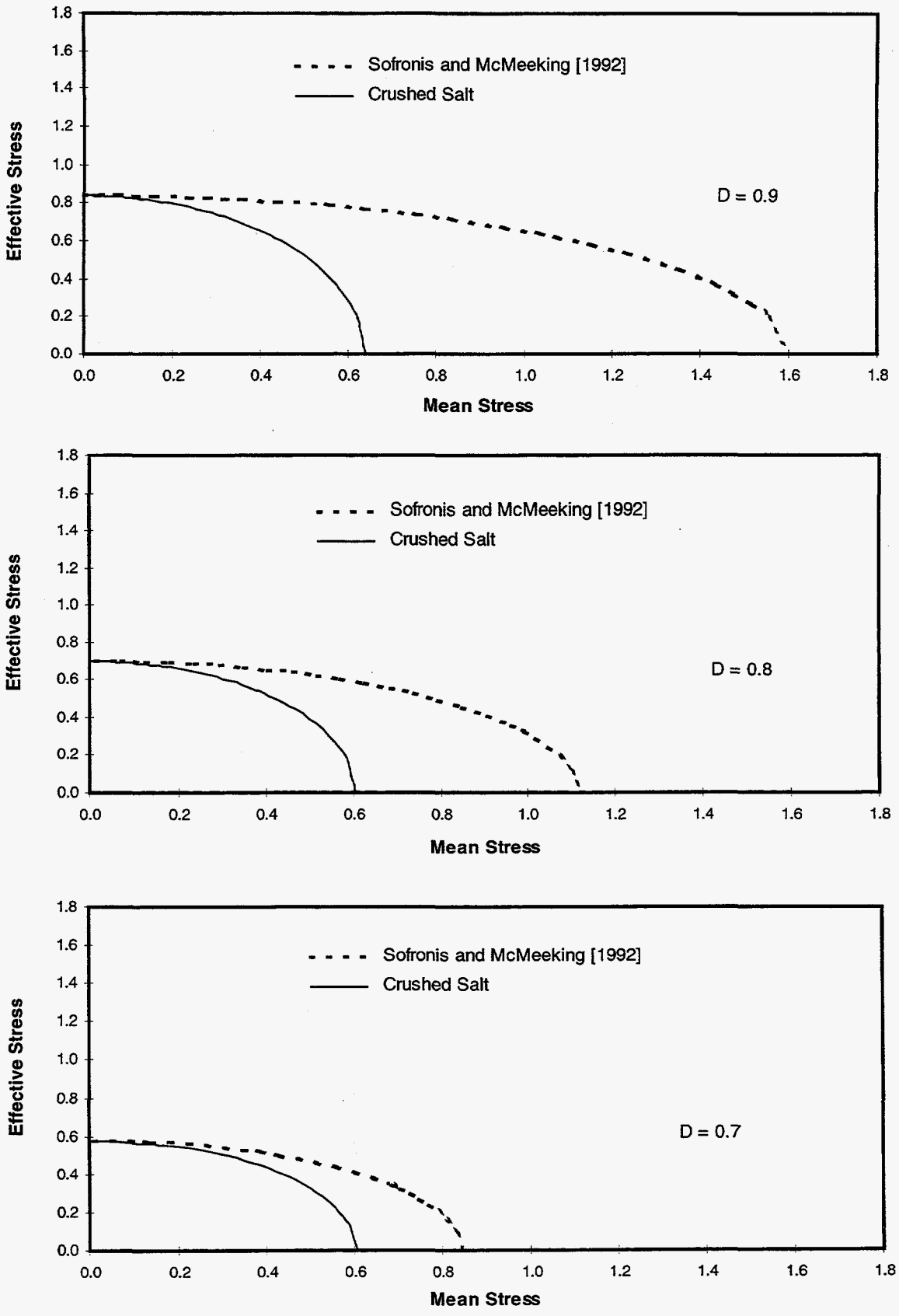

Figure 5-3. Comparison of the crushed-salt model to Sofronis and McMeeking's model.

6.0 OTHER MODEL CONSIDERATIONS

During the course of this study, various functional forms addressing specific parts of the constitutive model were developed in an effort to improve the constitutive model. Model improvement was judged by fitting the experimental database and observing changes in the goodness of fit. These investigations mainly involved the moisture function and the flow potential, which are discussed in the remainder of this chapter.

6.1 Moisture Function

Many researchers (e.g., Pfeifle and Senseny [1985], Holcomb and Shields [1987], Yost and Aronson [1987], Fordham [1988], Spiers et al. [1989], Zeuch and Holcomb [1991], Zeuch et al. [1991], and Wang et al. [1992]) have found that the addition of a small amount of moisture significantly increases the consolidation rate of crushed salt. In addition, there appears to be a quantity of moisture above which further increases in the consolidation rate are not noticeable. However, the amount of moisture producing the largest consolidation rate may vary depending on temperature and pressure. When a significant amount of moisture is available, a retardation in the consolidation rate could occur if the interconnected porosity disappears and the moisture is trapped, leading to the generation of pore pressures. In Chapter 2, the Spiers and Brzesowsky (1993) grain boundary diffusional pressure solutioning model was adapted to represent the increased creep consolidation caused by added moisture. However, during their model development, Spiers and Brzesowsky assumed that the aggregate was flooded with brine. Since an essentially unlimited supply of saturated solution phase was assumed, moisture or brine content does not appear explicitly in their model as a state variable. Therefore, moisture functions were assumed as direct multipliers of the Spiers and Brzesowsky model's predicted effective strain rate to account for varying moisture content. The first functional relationship for moisture effects (M) was taken from Callahan et al. (1995) and is written as:

$$M = 1 - e^{-aw} \tag{6-1}$$

where:

w = moisture fraction by weight

a = material parameter.

Equation 6-1 has a value of zero when the moisture content is zero and asymptotically approaches a value of one as the moisture content increases without bound. The rate at which M approaches the asymptote is governed by parameter a. Equation 6-1 served as a direct multiplier on the equivalent consolidation strain rate contributed by the pressure solutioning portion of the crushed-salt constitutive model. Thus, when the moisture content was zero, only the dislocation creep mechanism contributed to the strain rate, and when the moisture content was nonzero, both the dislocation creep and pressure solutioning mechanisms contributed to the strain rate. When the creep consolidation model was fit to the experimental data, the fitting algorithm produced a large value for parameter a. Thus the function included in Equation 6-1 acted like a Heaviside function, turning the pressure solutioning portion of the model on and off, depending on whether or not a particular specimen was wet or dry. No improvement in the goodness of fit could be achieved by accounting for the moisture variation once moisture was present. In other words, the significant difference between wet and dry specimen deformation is accounted for by the binary nature of the function, but once moisture is present the variation for different moisture contents is not significant. Four potential explanations exist to help understand this behavior:

1. The specimen-to-specimen variability is as great as changes caused by moisture content differences.

2. Moisture content effects are correlated to other test conditions or combinations of test conditions that mask the moisture effects.

3. The test conditions (i.e., the database) are inadequate.

4. The effect of moisture is nearly constant for our range of grain sizes.

The tests included in the database with added moisture are shown in Table 6-1. Thirty-six of the 56 tests in the database were conducted with added moisture. Review of the figures presented in Appendix C shows that specimen-to-specimen variability can be significant. For example, test conditions for Tests CS7 and CS8 (Figures C-7 and C-8) are nearly the same, yet their strain rates and deformation are quite different.

Table 3-2 showed the mean grain size for each of the tests in the database. As noted in the table footnote, the grain size was estimated for four tests. For the remaining tests, the grain size was measured using standard sieve analysis. Also of significance is the fact that six of the tests were performed on dynamically compacted crushed-salt specimens. Tests SC10 and SC11 were performed on field samples from the large-scale dynamic compaction tests. Tests RS/DCCS/1, RS/DCCS/3, RS/DCCS/4, and RS/DCCS/5 were performed on laboratory samples from the small-scale dynamic compaction tests. The remaining tests were performed on mine-run salt, with the loads applied quasi-statically.

Table 6-1. Hydrostatic and Shear Consolidation Tests Conducted with Added Moisture

Test ID	% Moisture by Weight	Average Grain Size (mm)	Mean Stress (MPa)	Stress Difference (MPa)
27JU61	2.50	1.75	–0.69	0.0
23JL51	0.50	1.75	–1.72	0.0
14NV51	1.50	1.75	–1.72	0.0
25FE61	2.00	1.75	–1.72	0.0
10MY51	2.40	1.75	–1.72	0.0
20AU51	3.00	1.75	–1.72	0.0
CS6	4.28	1.36	–1.72	0.0
CS5	4.44	2.30	–1.72	0.0
CS7	4.57	0.77	–1.72	0.0
CS8	4.61	0.42	–1.72	0.0
HC2A[(a)]	15.19	1.56	–1.72	0.0
HC1A[(a)]	16.47	1.56	–1.72	0.0
16JL51	0.50	1.75	–3.44	0.0
18JU51	1.00	1.75	–3.44	0.0
30OC51	1.50	1.75	–3.44	0.0
16JA61	2.00	1.75	–3.44	0.0
19DC44	2.40	1.75	–3.44	0.0
13AU51	3.00	1.75	–3.44	0.0
HC4A[(a)]	13.96	1.56	–3.45	0.0
HC3A[(a)]	16.08	1.56	–3.45	0.0
HC5A[(a)]	9.84	1.56	–6.90	0.0
HC6A[(a)]	10.41	1.56	–6.90	0.0
DCCS/1[(b)]	1.66	0.50	–2.33	4.00
DCCS/3[(b)]	1.63	0.50	–3.33	4.00
12OC891	2.40	2.00	–3.41	0.44
SC1B	2.34	1.56	–3.68	0.69
SC2A	2.25	1.56	–3.91	1.38
SC3A	2.21	1.56	–4.14	2.07
DCCS/4[(b)]	1.59	0.50	–4.33	4.00
DCCS/5[(b)]	1.55	0.50	–5.33	4.00
SC7A	2.33	1.56	–5.63	1.38
SC8A	2.29	1.56	–6.09	2.76
SC9B	2.33	1.56	–6.55	4.14
SC4A	2.27	1.56	–7.13	0.69
SC5A	2.52	1.56	–7.59	2.07
SC6A	2.19	1.56	–8.05	3.44

(a) Saturated tests moisture content computed from initial void ratio.

(b) Grain size for the dynamically compacted specimens is an estimate.

In the model fitting performed in this study, the consolidation rate was not assumed to be dependent on the type of loading used to preconsolidate the crushed salt. However, recent microscopic analysis has suggested that the consolidation rate is greatly enhanced in the dynamic compaction process. Furthermore this analysis has revealed that the deformation is localized to zones where the grain size is much smaller in comparison to the mean grain size reported: i.e., approximately 2–5 microns for the large-scale compaction test and 20 microns for the small-scale compaction tests. These zones are located along the "lift planes" where the material has been pulverized because of the localized dynamic effort used to compact the crushed salt. The conclusion of this microscopy is that the global functional form that defines the grain-size dependence used in the current model fit may not be appropriate because the deformation is localized. However, this information was not available at the time this study was initiated.

Figures 6-1, 6-2, and 6-3 plot moisture content versus average grain size, compressive mean stress, and stress difference. The saturated tests were not plotted on these figures so that the individual tests could be seen in the range up to 5 percent moisture by weight. These figures illustrate holes in the database but also illustrate that moisture content is not directly correlated to these other variables.

Spiers and Brzesowsky (1993) present data that illustrate the effect of grain size on strain rate in wet aggregates. However, their experiments were conducted on grain sizes about an order of magnitude smaller (0.098 to 0.41 millimeter) than those in the database discussed in Chapter 3. Information presented by Callahan et al. (1995) shows that the strain rates in these larger grain-size tests are quite similar despite the different moisture contents (e.g., see Callahan et al. [1995], Figure 4-9). Based on this information, it appears that moisture content variation in these larger grain sizes is not as important as the smaller grain sizes. However, insufficient data are available to judge where the transition occurs.

Because information could not be collected using Equation 6-1, a different functional form for moisture content was adopted. This form is written as:

$$M = w^{a} \tag{6-2}$$

As in Equation 6-1, Equation 6-2 has a value of zero when the moisture content is zero, but grows as the moisture content increases. The rate at which M increases is governed by parameter a. Equation 6-2 served as a direct multiplier on the equivalent consolidation strain rate contributed by the pressure solutioning portion of the crushed-salt constitutive model. Thus when the moisture content was zero only the dislocation creep mechanism contributed to the strain rate, and when the moisture content was nonzero both the dislocation creep and pressure solutioning mechanisms contributed to the strain rate. Equation 6-2 is the form used in the constitutive model presented in Chapter 2.

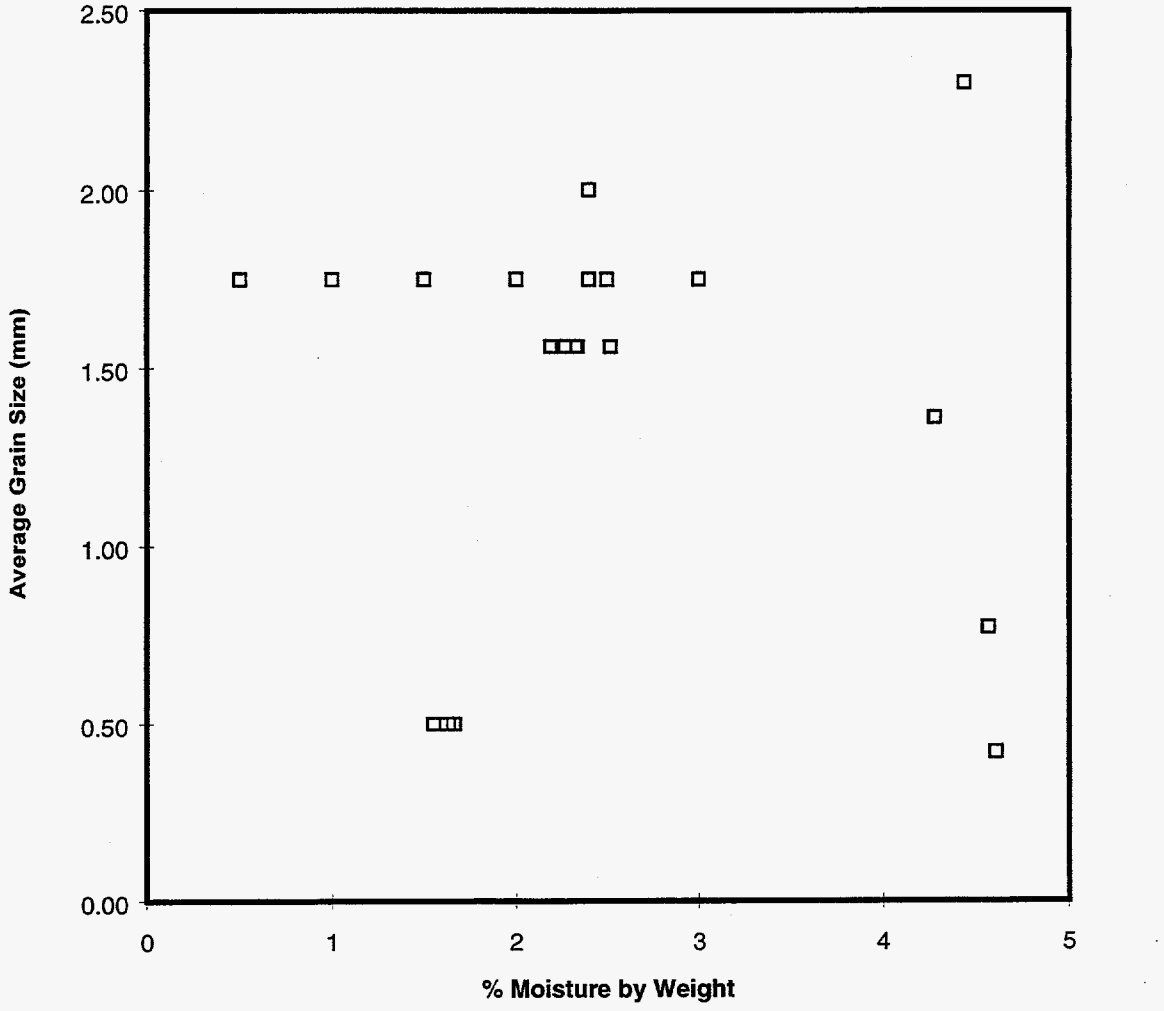

Figure 6-1. Plot of shear and hydrostatic consolidation tests as a function of moisture content and grain size.

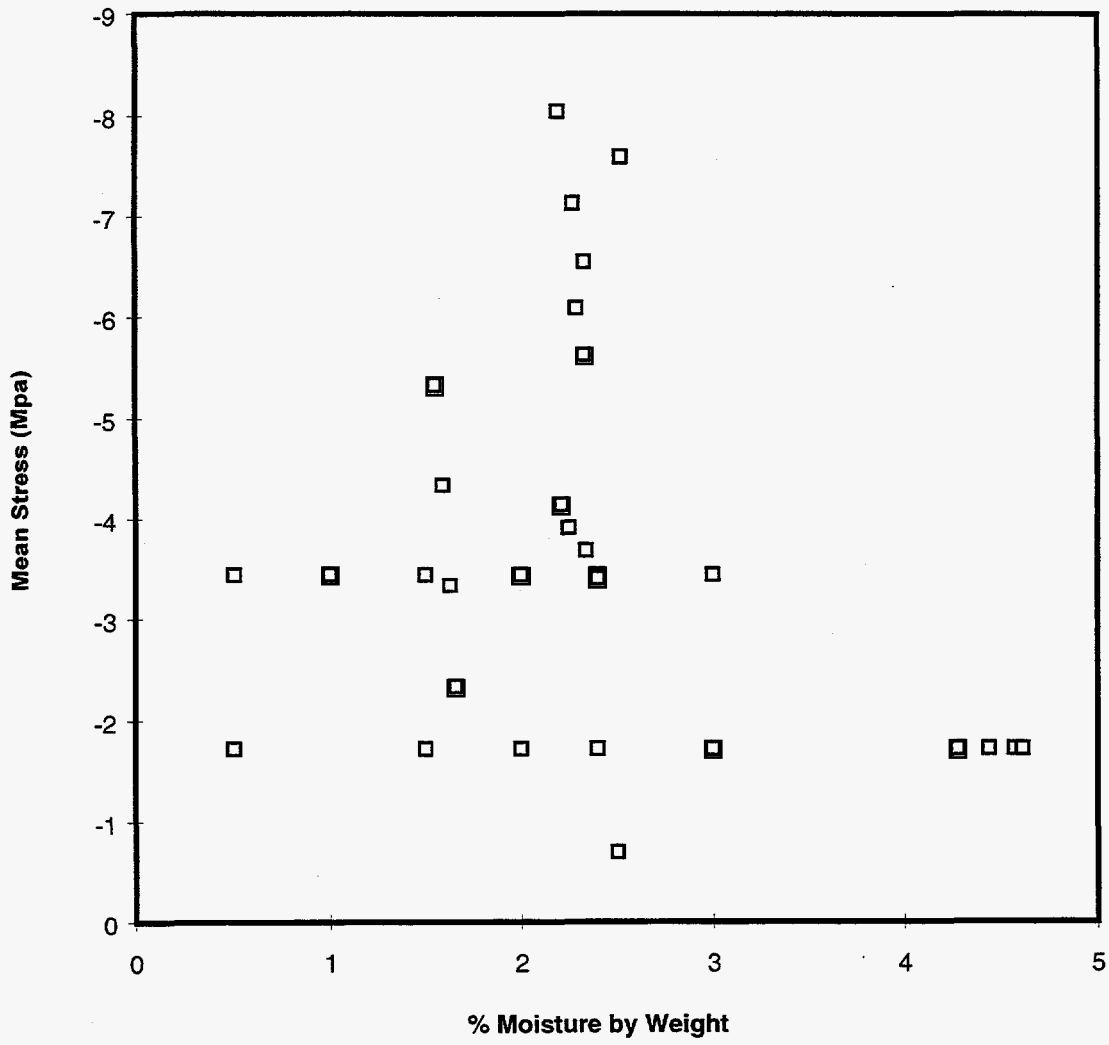

Figure 6-2. Plot of shear and hydrostatic consolidation tests as a function of moisture content and mean stress.

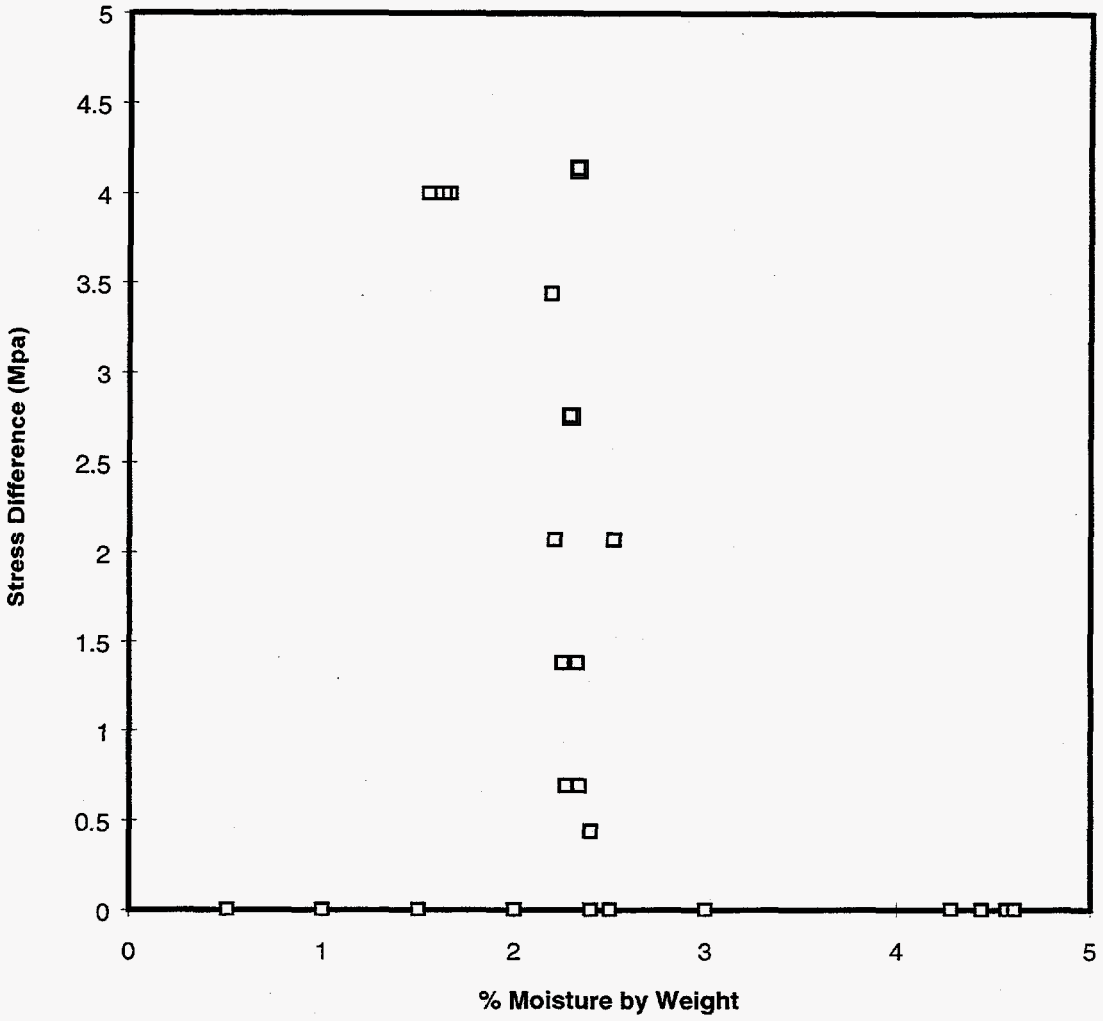

Figure 6-3. Plot of shear and hydrostatic consolidation tests as a function of moisture content and stress difference.

6.2 Flow Potential

Two different attempts were made to improve the goodness of fit for the flow potential. The first attempt involved a change in Ω given in Equation 2-5, which was successful. The second attempt consisted of the consideration of different stages in the densification process, which was not successful. These two modifications to the flow potential are described in the remainder of this section.

The fractional density function, Ω, was originally written as:

$$\Omega = \left[\frac{(1 - D)\, n}{\left[1 - (1 - D)^{1/n}\right]^n} \right]^{\frac{2}{n+1}} \tag{6-3}$$

Comparing Equation 6-3 to Equation 2-5 shows that Equation 2-5 incorporates a transition defined by parameter D_v, whereas Equation 6-3 does not. For fractional density values less than D_v, Equation 2-5 produces a constant value for Ω. The goodness of fit to the lateral-to-axial strain rate ratios (Appendix B) was improved when Equation 2-5 was used; thus this functional form was adopted.

Many researchers consider different stages in the densification process (e.g., Helle et al. [1985]). Usually a fractional density (D) of 0.9 is assumed to be a demarcation between an initial stage and a final stage in the process. The initial stage ($D < 0.9$) is characterized by distinguishable particles densifying by neck growth at the increasing number of contact points. The final stage ($0.9 < D < 1$) is characterized by an array of spherical holes that decrease in size as densification progresses. With these distinctive regions identified and apparently used successfully by others, an attempt was made to improve the flow potential by considering multiple stages in the consolidation process. This was accomplished by considering an initial stage, a transitional stage, and a final stage defined as follows:

$$\begin{aligned} \text{Initial Stage} &= D_0 \le D \le D_s \\ \text{Transitional Stage} &= D_s \le D \le D_t \\ \text{Final Stage} &= D_t \le D \le 1 \end{aligned} \tag{6-4}$$

D_s and D_t are assumed to be parameter values. The transitional zone is included so that a smooth transition occurs between the discontinuous initial and final stages. The effective stress measure for the final stage is assumed to be the same as the effective stress measure given in Equation 2-3. The effective stress measure for the initial stage is assumed to be:

$$\sigma_{eq_1} = \zeta_0 \frac{\sigma_0}{m+1}\left[\Omega_1\left(\frac{|\sigma_m|}{\sigma_0}\right)^{\frac{m+1}{m}} + \left(\frac{2-D}{D}\right)^{\frac{2m}{m+1}}\left(\frac{\sigma_1-\sigma_3}{\sigma_0}\right)^{\frac{m+1}{m}}\right]^m \tag{6-5}$$

where:

$$\Omega_1 = \left(\frac{D_0}{D}\right)^{1/3}\left(\frac{D-D_0}{1-D_0}\right)^{1/2}\left(\frac{1-D}{D^2(D-D_0)}\right)^m \tag{6-6}$$

D_0 = initial fractional density (0.64)

D = current fractional density

σ_m = mean stress = $\frac{\sigma_{kk}}{3}$

σ_3 = minimum principal stress

σ_1 = maximum principal stress

ζ_0, σ_0, and m = material parameters.

Motivation for use of the functional form described by Equation 6-6 comes from Helle et al. (1985). This is the geometrical relationship they used for initial stage densification. This form was also used by Zeuch (1990) for WIPP salt, since he adopted the hot isostatic pressing equations of Helle et al.

In the transition region, the effective stress is:

$$\sigma_{eq}^t = \frac{D_t - D}{D_t - D_s}\sigma_{eq_1} + \frac{D - D_s}{D_t - D_s}\sigma_{eq} \tag{6-7}$$

The flow potential is described by the derivative of the effective stress measure. The derivative in the initial stage is:

$$\frac{\partial \sigma_{eq_1}}{\partial \sigma_{ij}} = \zeta\left\{\alpha_1 \delta_{ij} + \beta_1\left(\left[\frac{\cos 2\psi}{\cos 3\psi}\right]\frac{s_{ij}}{\sqrt{J_2}} + \left[\frac{\sqrt{3}\sin\psi}{J_2\cos 3\psi}\right] t_{ij}\right)\right\} \tag{6-8}$$

where:

$$\zeta = (\zeta_0)^{1/m}\left(\frac{\sigma_0}{m+1}\right)^{\frac{1-m}{m}}\left(\sigma_{eq_1}\right)^{\frac{m-1}{m}}$$

$$\alpha_1 = \frac{\Omega_1 \operatorname{sgn}(\sigma_m)}{3}\left|\frac{\sigma_m}{\sigma_0}\right|^{1/m} \tag{6-9}$$

$$\beta_1 = \left[\frac{2-D}{D}\right]^{\frac{2m}{m+1}}\left(\frac{2\sqrt{J_2}\cos\psi}{\sigma_0}\right)^{1/m}$$

Equation 6-8 is seen to be undefined as the Lode angle approaches $\pm\pi/6$. In other words, the flow potential forms corners at $\psi = \pm\pi/6$, and the direction of straining is not unique. To eliminate this problem computationally, the flow potentials on either side of the corner are averaged, which produces an indeterminant form that is examined in the limit as $\psi \rightarrow \pm\pi/6$. Performing this limiting operation, Equation 6-8 becomes:

$$\frac{\partial \sigma_{eq_1}}{\partial \sigma_{ij}} = \zeta\left\{\alpha_1 \delta_{ij} + \beta_1\left(\frac{s_{ij}}{\sqrt{3J_2}} \mp \frac{t_{ij}}{2J_2}\right)\right\} \tag{6-10}$$

Following the procedure used to compute the lateral-to-axial strain rate ratio outlined in Chapter 2, Equation 6-10 may be used to express the initial stage strain rate ratio for a triaxial compression test as:

$$\mathbf{R}_1 = \frac{\alpha_1 + \frac{\beta_1}{2}}{\alpha_1 - \beta_1} \tag{6-11}$$

In the transition zone, the flow potential is written as:

$$\frac{\partial \sigma^t_{eq_1}}{\partial \sigma_{ij}} = \frac{(D_t - D)}{(D_t - D_s)}\frac{\partial \sigma_{eq_1}}{\partial \sigma_{ij}} + \frac{(D - D_s)}{(D_t - D_s)}\frac{\partial \sigma_{eq}}{\partial \sigma_{ij}} \tag{6-12}$$

Substitution of Equations 6-5 and 2-5 into Equation 6-12 yields:

$$\frac{\partial \sigma^{t}_{eq_1}}{\partial \sigma_{ij}} = \frac{(D_t - D)}{(D_t - D_s)} \zeta \left\{ \alpha_1 \delta_{ij} + \beta_1 \left(\left[\frac{\cos 2\psi}{\cos 3\psi} \right] \frac{s_{ij}}{\sqrt{J_2}} + \left[\frac{\sqrt{3} \sin \psi}{J_2 \cos 3\psi} \right] t_{ij} \right) \right\}$$
$$+ \frac{(D - D_s)}{(D_t - D_s)} \frac{1}{\sigma_{eq}} \left\{ \alpha \delta_{ij} + \beta \left(\left[\frac{\cos 2\psi}{\cos 3\psi} \right] \frac{s_{ij}}{\sqrt{J_2}} + \left[\frac{\sqrt{3} \sin \psi}{J_2 \cos 3\psi} \right] t_{ij} \right) \right\} \tag{6-13}$$

Then, as was done for Equation 6-8 to create Equation 6-10 at the corners, Equation 6-13 becomes:

$$\frac{\partial \sigma^{t}_{eq_1}}{\partial \sigma_{ij}} = \frac{(D_t - D)}{(D_t - D_s)} \zeta \left[\alpha_1 \delta_{ij} + \beta_1 \left(\frac{s_{ij}}{\sqrt{3J_2}} \mp \frac{t_{ij}}{2J_2} \right) \right]$$
$$+ \frac{(D - D_s)}{(D_t - D_s)} \frac{1}{\sigma_{eq}} \left[\alpha \delta_{ij} + \beta \left(\frac{s_{ij}}{\sqrt{3J_2}} \mp \frac{t_{ij}}{2J_2} \right) \right] \tag{6-14}$$

Again, following the procedure used to compute the lateral-to-axial strain rate ratio outlined in Chapter 2, Equation 6-14 may be used to express the transitional stage strain rate ratio for a triaxial compression test as:

$$\mathbf{R}_t = \frac{(D_t - D)\zeta \left(\alpha_1 + \frac{\beta_1}{2} \right) + (D - D_s) \frac{1}{\sigma_{eq}} \left(\alpha + \frac{\beta}{2} \right)}{(D_t - D)\zeta (\alpha_1 - \beta_1) + (D - D_s) \frac{1}{\sigma_{eq}} (\alpha - \beta)} \tag{6-15}$$

Thus Equations 2-20, 6-11, and 6-15 form the equations fitted to the laboratory test data for densification stages described in Equation 6-4. Use of the densification stages did not improve the goodness of fit for the flow potential. Thus the equations as stated in Chapter 2 were retained.

7.0 SUMMARY AND CONCLUSIONS

Crushed salt is planned to be a major long-term component of the shaft seal system at the WIPP. The crushed-salt seal gradually becomes effective as it consolidates over time because of the creep of the surrounding intact salt, which produces shaft closure and loading of the crushed salt. The ability to predict creep consolidation of crushed salt is important to the design and compliance evaluation of WIPP seals. The work reported here represents a continuation of earlier studies devoted to constitutive models for crushed-salt reconsolidation. Understanding the creep consolidation of WIPP crushed salt and our ability to predict its mechanical behavior have been greatly improved as a result of these studies. Crushed-salt consolidation is important in two specific areas:

1. Crushed salt consolidates with time as the intact salt surrounding the shaft creeps inward. This consolidation process resists movement of the surrounding intact salt and produces a load on the shaft surface, which promotes healing of the disturbed rock zone (DRZ) in the salt immediately surrounding the shaft. This healing greatly reduces the DRZ's flow characteristics and helps eliminate this potential pathway.

2. The consolidation of crushed salt reduces the permeability and porosity of the crushed salt itself, greatly enhancing the crushed salt as an effective seal material.

The present study is a continuation of two earlier studies (Callahan et al. [1995], RE/SPEC Inc. [1996], Callahan et al. [1996]). The objectives of the current study were to incorporate the governing deformation mechanisms into a single model and to enhance the database with shear consolidation tests applicable to the operating conditions expected for the dynamically compacted crushed-salt seal material. Before these studies were initiated, the only model used to characterize creep consolidation of WIPP crushed salt was the model proposed by Sjaardema and Krieg (1987).

The first study (Callahan et al. [1995]) identified ten models developed to characterize the deformation of crushed salt. Three of these models were selected for further evaluation. The models were modified to include effects of potentially important parameters such as deviatoric stress, temperature, moisture content, and particle size. The models were generalized to be applicable to three-dimensional states of stress and fit to an assembled database of hydrostatic and shear consolidation tests applicable to the WIPP. The study identified two primary operative mechanisms that contribute to crushed-salt deformation: dislocation creep and grain boundary diffusional pressure solutioning. The first mechanism dominates in dry granular aggregates, whereas the second mechanism is only operative in wet granular aggregates. These mechanisms are included separately in two of the constitutive models evaluated in the first study.

The second study (RE/SPEC Inc. [1996], Callahan et al. [1996]) was conducted to correct deficiencies discovered in the three models. Basically the models were unable to predict a

reversal in the lateral strain rate in a triaxial test. The ability to predict this behavior is a necessary condition for the transition to intact salt behavior as the crushed-salt fractional density approaches one. Unfortunately all tests in the crushed-salt laboratory database assembled in the first study exhibit primarily a positive lateral-to-axial strain rate ratio. Thus the database was biased toward conditions unrepresentative of the anticipated dynamically compacted crushed salt with initial fractional densities near 0.9. Therefore two additional shear consolidation tests with initial fractional densities near 0.8 were conducted and added to the database. The functional form of the flow potential was modified, and the shear consolidation tests were fit to determine material constants for the three crushed-salt consolidation models. The refined model characterizations were found to provide appropriate behavior under uniaxial states of stress, enable a sign reversal of the lateral strain rate, and provide a natural transition to intact salt at complete consolidation. However, predictions of the hydrostatic tests with the models were found to be quite poor.

In this study the creep consolidation model for crushed salt was updated to combine dislocation creep and grain boundary diffusional pressure solutioning into a single constitutive model. The dislocation creep model was adapted from the multimechanism deformation constitutive model (Munson et al. [1989]) used to describe creep deformation of intact salt. The pressure solutioning model was adapted from the densification model for wet salt aggregates presented by Spiers and Brzesowsky (1993). The strain rates from the two contributing mechanisms are additive, with the contribution from the pressure solutioning portion of the model disappearing as the moisture content goes to zero. When the fractional density of the crushed salt reaches one, the model produces intact salt behavior predicted by the multi-mechanism deformation model. Four new laboratory shear consolidation experiments were conducted with fractional densities near the initial fractional density expected in the dynamically compacted crushed-salt seal (approximately 0.9). These tests expand the database into fractional density ranges previously untested and provide information on the crushed-salt flow behavior as its density increases. One test clearly demonstrates the reversal in lateral deformation as the density increases. These tests were added to the experimental database, which was fit to obtain material parameter values for the updated crushed-salt constitutive model. The results of the model fitting produced material parameter values representative of the entire database. Two separate fits were performed. The first fit used only the shear consolidation tests in the database, and the second fit used both the shear and hydrostatic consolidation tests. In our previous studies, dramatic changes in the parameter values were observed when the different tests were fit. In the present study, these separate fits produced similar parameter values, which indicates that the constitutive model is more representative of the physics of the creep consolidation of crushed salt than were the previous models.

As a result of this study, a constitutive model for crushed salt is available that contains the observed mechanisms for crushed-salt consolidation. When consolidation is complete, the model predicts intact salt behavior. The model characterizes the experimental data quite well over a wide range of porosities and stress triaxialities.

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APPENDIX A

Input Files to BMDP, Nonlinear Regression Programs 3R and AR

This appendix contains three input files. The first file (FLOW.INP) was the input file to the Program 3R and was used to determine the flow rate parameters. The second and third files (MDSP2.INP and MDSP3.INP) were the input files to the Program AR. The files were used to determine two sets of the creep consolidation parameters fit to the shear consolidation database (MDSP2.INP) and the combined shear and hydrostatic consolidation database (MDSP3.INP).

```
#    file = e:\325\md\flow.inp
#
#           fit to shear consolidation tests only (itype = 2)
#
# ================================================================
#
#    This code uses the BMDP routine AR to fit the differential
#    equations that describe the axial and lateral strain rates
#    as functions of the following test conditions:
#       1.  mean stress                                  (MS)
#       2.  stress difference                            (DS)
#       3.  emplaced fractional density                  (D0)
#       4.  initial fractional density                   (DI)
#       5.  grain size                                   (DD)
#       6.  absolute temperature                         (T)
#       7.  moisture content                             (W)
#
# ================================================================
#
# ------  INPUT PARAGRAPH
#
/INPUT
    TITLE = 'SPIERS MODEL FIT TO SHEAR CONSOLIDATION TESTS -- sp.INP'.
    FILE = 'E:\325\MD\flow.dat'.                    # Data file name
    FORMAT = '(2I3,3F10.0,F6.1,2F9.4,4F9.5,F9.3,F9.6,
               2F9.3,F5.2,F7.2,3e10.3)'.
    VARIABLES = 21.
#
# ------  VARIABLES PARAGRAPH  ------
#
/VARIABLE
  NAMES=ICASE,ITEST,TIME,DT,TF,TEMP,AS,LS,EVT,EVC,EAT,EAC,RHO,D,
        RHO0,RHOI,DD,W,EVR,EAR,ELR.
#
# ------  TRANSFORMATION PARAGRAPH ------
#
/TRANS
     MS = (2.0*LS+AS)/3.0.      # mean stress, as=axial stress, ls=conf. pres.
     DS = LS - AS.              # stress difference
    ELC = (EVC - EAC)/2.        # lateral strain, evt=vol. strain, eat=ax.strain
     D0 = 1382.4/2160.          # emplaced fractional density
     DI = RHOI/2160.            # initial fractional density
    RAT = ELR/EAR.              # regression function

#    FLOW PARAMETERS

     KAP0 = .0952.
      KAP1 = 1.412.
      KAP2 = 1.001.
       DDT = .89098.
        NK = 7.578.

    USE = TIME NE 0.          # use shear consolidation tests
     WT = 1.           # uniform weight function
#
# ------  REGRESS PARAGRAPH  ------
#
/REGRESS
      DEPEND = RAT.             # Dependent variable
      PARAMETERS=1.            # Number of regression parameters
      WEIGHT = WT.              # WEIGHT VARIABLE
      ITER = 1.                 # NUMBER OF ITERATIONS
      HALVINGS = 2.             # NUMBER OF INTERVAL HALVINGS
#
# ------  PARAMETERS PARAGRAPH  ------
#
#    Specify the names, initial estimates, and the range of the sixteen
# regression parameters, where R1 is the over all leading parameter; R3, R4,
# and N are strain dependent parameters; KAPPA0, KAPPA1, KAPPA2, M2 determine
# the equivalent stress measure for the flow-rule; ETA0, ETA1, ETA2, and M1
# determine the equivalent stress measure in strain rate measure; A1 and A2
# are water-content dependent parameters; P defines grain size dependence;
# and QCR defines temperature effect.
#
/PARAMETER
     NAMES =     DUM.

   INITIAL =   1.0.
```

```
MINIMUM =       0.0.
MAXIMUM =       50.0.
#
# ------  SPECIFY FUNCTION  ------
#
/FUN
     IF(D LE DDT) THEN VAR = DDT.
     IF(D GT DDT) THEN VAR = D.
     NUM = (1 - VAR)*NK.
     DEN = (1 -(1-VAR)**(1/NK) ) ** NK.
     OMEGAK = (NUM/DEN) ** (2/(NK+1)).
     KAP = KAP0 * OMEGAK**KAP1.
    TERMK = ( (2-D)/D )**( 2*NK/(NK+1) ).

  ALPHA2 = KAP * MS/3.
   BETA2 = KAP2 * TERMK * DS.

     F2A = (ALPHA2 -     BETA2).
     F2L = (ALPHA2 + 0.5*BETA2).
       F = F2L/F2A.
#
# ------  SPECIFY VARIOUS PRINTING AND PLOTTING OPTIONS  ------
#
/SAVE
      FILE = 'E:\325\MD\flow.SAV'.
      NEW.
      KEEP = rho,RAT.
      FORMAT = '(f10.3,5E12.3)'.
/PRINT
          FORMAT = E.
/PLOT
          RESIDUAL.
/END
```

```
#    file = e:\dynamic\MDsp2.inp
#
#          fit to shear consolidation tests only (itype = 2)
#
# ================================================================
#
#    This code uses the BMDP routine AR to fit the differential
#    equations that describe the axial and lateral strain rates
#    as functions of the following test conditions:
#       1.  mean stress                                  (MS)
#       2.  stress difference                            (DS)
#       3.  emplaced fractional density                  (D0)
#       4.  initial fractional density                   (DI)
#       5.  grain size                                   (DD)
#       6.  absolute temperature                         (T)
#       7.  moisture content                             (W)
#
# ================================================================
#
# ------  INPUT PARAGRAPH
#
/INPUT
    TITLE = 'MD-SPIERS MODEL FIT TO shear CONSOLIDATION TESTS -- MDsp2.INP'.
    FILE = 'e:\325\md\ALL.CSV'.                    # Data file name
    FORMAT = '(2I3,3F10.0,F6.1,2F9.4,4F9.5,F9.3,F9.6,2F9.3,F5.2,F7.2)'.
    VARIABLES = 18.
#
# ------  VARIABLES PARAGRAPH  ------
#
/VARIABLE
  NAMES=ICASE,ITEST,TIME,DT,TF,TEMP,AS,LS,EVT,EVC,EAT,EAC,RHO,D,RHO0,RHOI,DD,W.
#
# ------  TRANSFORMATION PARAGRAPH ------
#
/TRANS
     MS = (2.0*LS+AS)/3.0.       # mean stress, as=axial stress, ls=conf. pres.
     DS = LS - AS.              # stress difference
    ELC = (EVC - EAC)/2.        # lateral strain, evt=vol. strain, eat=ax.strain
#    ELT = (EVT - EAT)/2.
#     DIFL = ELT-ELC.
#     DIFA = EAT-EAC.
     D0 = 1382.4/2160.          # emplaced fractional density
#     D02 = RHO0/2160.
     DI = RHOI/2160.            # initial fractional density
    ONE = 1.0.                  # regression function

#   17 MUNSON-DAWSON CREEP PARAMETERS FOR CLEAN SALT (FIXED)

     A1 = 8.386E+22.
     A2 = 9.672E+12.
    Q1R = 12581.
    Q2R = 5033.
     N1 = 5.5.
     N2 = 5.0.
     B1 = 6.0856E+6.
     B2 = 3.034E-2.
      Q = 5335.
     S0 = 20.57.
      M = 3.
     K0 = 6.275E+5.
      C = 9.198E-3.
  ALPHA = -17.37.
   BETA = -7.738.
  DELTA = 0.58.
     MU = 12400.                # SHEAR MODULUS

#    USE SHEAR CONSOLIDATION TESTS

   USE = ICASE EQ 2.

#    ELIMINATE SNL SATURATED HYDROSTATIC TESTS

     IF(KASE GE 4001 AND KASE LE 4500) THEN USE = 0.

#    WEIGHT FUNCTIONS

     WT1 = DT/1.E+6.
     WT = 1.0.                  # uniform weight function
```

```
#    ESTIMATE GRAIN SIZE FOR DCCS TESTS

     DC = DD.
     IF(KASE GT 5700) THEN DC = 0.5.
#
# ------  REGRESS PARAGRAPH  ------
#
/REGRESS
      DEPEND = ONE.              # Dependent variable
      PARAMETERS=17.             # Number of regression parameters
      WEIGHT = WT.               # WEIGHT VARIABLE
      ITIME = 3.                 # INTEGRATION VARIABLE NUMBER
      NEQN = 3.                  # Number of differential equations
      ITER = 1.                 # NUMBER OF ITERATIONS
      HALVINGS = 3.              # NUMBER OF INTERVAL HALVINGS
      MAXC = 300000.             # MAXIMUM NUMBER OF TIMES 'DIFEQ' IS USED
#
# ------  PARAMETERS PARAGRAPH  ------
#
#    Specify the names, initial estimates, and the range of the sixteen
# regression parameters, where R1 is the over all leading parameter; R3, R4,
# and N are strain dependent parameters; KAPPA0, KAPPA1, KAPPA2, M2 determine
# the equivalent stress measure for the flow-rule; ETA0, ETA1, ETA2, and M1
# determine the equivalent stress measure in strain rate measure; A1 and A2
# are water-content dependent parameters; P defines grain size dependence;
# and QCR defines temperature effect.
#
/PARAMETER
     NAMES =     KAP0,          KAP1,      KAP2, DUM,
                   NK,           DDT,        NA,

                 ETA0,          ETA1,      ETA2,
                  AA1,            PP,       NSP,
                   R1,            R3,        R4, QSR.

   INITIAL =  0.0952,        1.41202,    1.001, 1.00,
               7.5776,       0.89098,    3.735,

              .1424,       3.254,     3.424,
                0.2269,          1.1248,     .1038,
              2.68e-4,          7.26,      .1440,  1028.5.

MINIMUM =       16 * -10.0.
MAXIMUM =       16 * 5000.0.
#DELTA   =       6*.1,
#               6*.05,
#               1E-3,       1, .05.
  FIXED = KAP0, KAP1, KAP2,
            NK,  DDT,  na,
          eta0, eta1, eta2,
           aa1,   pp,  nsp,
            r1,   r3,   r4,     qsr.

# ------  INITIAL VALUES FOR DIFERENTIAL EQUATIONS  ------
#
/DIFIN
      Z1 = EAC.
      Z2 = ELC.
      Z3 = 0.
#
# ------  SPECIFY THE DIFFERENTIAL EQUATION  ------
#
/DIFEQ
     IF(TIME NE 0) THEN (

     VOL = Z1 + 2*Z2.
     VOLT = VOL + LN(0.64/DI).
     DEN = DI / EXP(VOL).

  IF(DEN GE 1.0) THEN (
        MD = 0.
        SP = 0. ).

  IF(DEN LT 1.0) THEN (

     IF(DEN LE DDT) THEN VAR = DDT.
     IF(DEN GT DDT) THEN VAR = DEN.
```

```
     OMEGAA = ((1.-DEN)*NA / (1-(1-DEN)**(1/NA))**NA)**(2/(NA+1)).
     OMEGAK = ((1.-VAR)*NK / (1-(1-VAR)**(1/NK))**NK)**(2/(NK+1)).
     ETA = ETA0 * OMEGAA**ETA1.
     KAP = KAP0 * OMEGAK**KAP1.
    TERMA = ((2-DEN)/DEN)**(2*NA/(NA+1)).
    TERMK = ((2-DEN)/DEN)**(2*NK/(NK+1)).
    SEQF = SQRT(ETA * MS**2 + ETA2 * TERMA * DS**2).
    SEQ  = SQRT(KAP * MS**2 + KAP2 * TERMK * DS**2).

  ALPHA2 = KAP * MS/3.
   BETA2 = KAP2 * TERMK * DS.

     F2A = (ALPHA2 -     BETA2) / SEQ.
     F2L = (ALPHA2 + 0.5*BETA2) / SEQ.

      ES1 = A1*(SEQF/MU)**N1 * EXP (-Q1R / TEMP).
      ES2 = A2*(SEQF/MU)**N2 * EXP (-Q2R / TEMP).
      ES3 = 0.

      IF(SEQF GT S0) THEN (
        ARG = Q * (SEQF-S0)/MU.
        ES3 = 0.5*( B1*EXP(-Q1R/TEMP) + B2*EXP(-Q2R/TEMP) )
            * ( EXP(ARG) - EXP(-ARG) ) .).

      ESS = ES1 + ES2 + ES3.

      EFT = K0*EXP(C*TEMP)*(SEQF/MU)**M.
      BIGD = ALPHA + BETA * LOG(SEQF/MU).

      IF(Z3 LT EFT) THEN F = EXP(  BIGD*(1-Z3/EFT)**2).
      IF(Z3 EQ EFT) THEN F = 1.
      IF(Z3 GT EFT) THEN F = EXP(-DELTA*(1-Z3/EFT)**2).

      MD = F * ESS.

      CR = ABS(EXP(VOLT)-1).

      IF(CR LE 0.15) THEN GAMMA = 1.0.
      IF(CR GT 0.15) THEN
         GAMMA = (ABS((D0-EXP(VOLT))/((1-D0)*EXP(VOLT))))**NSP.

      X3 = EXP((R3-1)*VOLT)/(ABS(1-EXP(VOLT)))**R4.

      IF(W EQ 0) THEN M2 = 0.
      IF(W GT 0) THEN M2 = W**AA1.
      G2 = 1/DC**PP.
      T2 = EXP(-QSR/TEMP)/TEMP.

      SP = R1*M2*G2*T2*X3*GAMMA*SEQF.).

     DZ1 = (MD + SP) * F2A.
     DZ2 = (MD + SP) * F2L.
     DZ3 = (F-1) * ESS.    ).

     IF(TIME EQ 0) THEN (

     DZ1 = 0.
     DZ2 = 0.
     DZ3 = 0.    ).
#
#  ------  SPECIFY THE DEPENDENT VARIABLE FUNCTION
#
/FUN
  IF(TIME NE 0.) THEN (
      AA = Z1/EAC.
      BB = Z2/ELC.
       F = 1.0 - SQRT(((1.0-AA)**2 + (1.0-BB)**2)*WT1).  ).
  IF(TIME EQ 0.) THEN (
     NEW = 0.
      Z1 = EAC.
      Z2 = ELC.
      Z3 = 0.
       F = 1.0 ).
#
# ------  SPECIFY VARIOUS PRINTING AND PLOTTING OPTIONS  ------
#
/SAVE
      FILE = 'e:\325\md\MDSP2.SAV'.
```

```
#    file = e:\dynamic\MDsp3.inp
#
#          fit to hydrostatic and shear consolidation tests only (itype = 1 and 2)
#
# ================================================================================
#
#    This code uses the BMDP routine AR to fit the differential
#    equations that describe the axial and lateral strain rates
#    as functions of the following test conditions:
#       1.  mean stress                                  (MS)
#       2.  stress difference                            (DS)
#       3.  emplaced fractional density                  (D0)
#       4.  initial fractional density                   (DI)
#       5.  grain size                                   (DD)
#       6.  absolute temperature                         (T)
#       7.  moisture content                             (W)
#
# ================================================================================
#
# ------   INPUT PARAGRAPH
#
/INPUT
    TITLE = 'MD-SPIERS MODEL FIT TO ALL CONSOLIDATION TESTS -- MDsp3.INP'.
    FILE = 'e:\325\md\ALL.CSV'.                    # Data file name
    FORMAT = '(2I3,3F10.0,F6.1,2F9.4,4F9.5,F9.3,F9.6,2F9.3,F5.2,F7.2)'.
    VARIABLES = 18.
#
# ------   VARIABLES PARAGRAPH  ------
#
/VARIABLE
  NAMES=ICASE,ITEST,TIME,DT,TF,TEMP,AS,LS,EVT,EVC,EAT,EAC,RHO,D,RHO0,RHOI,DD,W.
#
# ------   TRANSFORMATION PARAGRAPH ------
#
/TRANS
     MS = (2.0*LS+AS)/3.0.       # mean stress, as=axial stress, ls=conf. pres.
     DS = LS - AS.               # stress difference
    ELC = (EVC - EAC)/2.         # lateral strain, evt=vol. strain, eat=ax.strain
#    ELT = (EVT - EAT)/2.
#     DIFL = ELT-ELC.
#     DIFA = EAT-EAC.
     D0 = 1382.4/2160.           # emplaced fractional density
#     D02 = RHO0/2160.
     DI = RHOI/2160.             # initial fractional density
    ONE = 1.0.                   # regression function

#   17 MUNSON-DAWSON CREEP PARAMETERS FOR CLEAN SALT (FIXED)

     A1 = 8.386E+22.
     A2 = 9.672E+12.
    Q1R = 12581.
    Q2R = 5033.
     N1 = 5.5.
     N2 = 5.0.
     B1 = 6.0856E+6.
     B2 = 3.034E-2.
      Q = 5335.
     S0 = 20.57.
      M = 3.
     K0 = 6.275E+5.
      C = 9.198E-3.
  ALPHA = -17.37.
   BETA = -7.738.
  DELTA = 0.58.
     MU = 12400.                 # SHEAR MODULUS

#    USE SHEAR CONSOLIDATION TESTS

#    USE = ICASE EQ 2.

#    ELIMINATE SNL SATURATED HYDROSTATIC TESTS

     IF(KASE GE 4001 AND KASE LE 4500) THEN USE = 0.

#    WEIGHT FUNCTIONS

     WT1 = DT/1.E+6.
     WT = 1.0.                   # uniform weight function
```

```
#    ESTIMATE GRAIN SIZE FOR DCCS TESTS

     DC = DD.
     IF(KASE GT 5700) THEN DC = 0.5.
#
# ------  REGRESS PARAGRAPH  ------
#
/REGRESS
      DEPEND = ONE.              # Dependent variable
      PARAMETERS=17.             # Number of regression parameters
      WEIGHT = WT.               # WEIGHT VARIABLE
      ITIME = 3.                 # INTEGRATION VARIABLE NUMBER
      NEQN = 3.                  # Number of differential equations
      ITER = 1.                 # NUMBER OF ITERATIONS
      HALVINGS = 3.              # NUMBER OF INTERVAL HALVINGS
      MAXC = 300000.             # MAXIMUM NUMBER OF TIMES 'DIFEQ' IS USED
#
# ------  PARAMETERS PARAGRAPH  ------
#
#    Specify the names, initial estimates, and the range of the sixteen
# regression parameters, where R1 is the over all leading parameter; R3, R4,
# and N are strain dependent parameters; KAPPA0, KAPPA1, KAPPA2, M2 determine
# the equivalent stress measure for the flow-rule; ETA0, ETA1, ETA2, and M1
# determine the equivalent stress measure in strain rate measure; A1 and A2
# are water-content dependent parameters; P defines grain size dependence;
# and QCR defines temperature effect.
#
/PARAMETER
     NAMES =     KAP0,          KAP1,      KAP2, DUM,
                   NK,           DDT,        NA,

                 ETA0,          ETA1,      ETA2,
                  AA1,            PP,       NSP,
                   R1,            R3,        R4, QSR.

   INITIAL =  0.0952,         1.41202,    1.001, 1.00,
               7.5776,        0.89098,    4.792,

              2.736e-2,        2.587,     4.21,
               0.0230,          .649,    -2.277e-2,
             3.834e-4,          11.12,     .6003,  811.28.

MINIMUM =       16 * -10.0.
MAXIMUM =       16 * 5000.0.
#DELTA   =       6*.1,
#               6*.05,
#               1E-3,       1, .05.
  FIXED = KAP0, KAP1, KAP2,
            NK,  DDT,   na,
          eta0, eta1, eta2,
           aa1,   pp,  nsp,
            r1,   r3,   r4,   qsr.

# ------  INITIAL VALUES FOR DIFERENTIAL EQUATIONS  ------
#
/DIFIN
      Z1 = EAC.
      Z2 = ELC.
      Z3 = 0.
#
# ------  SPECIFY THE DIFFERENTIAL EQUATION  ------
#
/DIFEQ
     IF(TIME NE 0) THEN (

     VOL = Z1 + 2*Z2.
     VOLT = VOL + LN(0.64/DI).
     DEN = DI / EXP(VOL).

 IF(DEN GE 1.0) THEN (
       MD = 0.
       SP = 0. ).

 IF(DEN LT 1.0) THEN (

     IF(DEN LE DDT) THEN VAR = DDT.
     IF(DEN GT DDT) THEN VAR = DEN.
```

```
      OMEGAA = ((1.-DEN)*NA / (1-(1-DEN)**(1/NA))**NA)**(2/(NA+1)).
      OMEGAK = ((1.-VAR)*NK / (1-(1-VAR)**(1/NK))**NK)**(2/(NK+1)).
       ETA = ETA0 * OMEGAA**ETA1.
       KAP = KAP0 * OMEGAK**KAP1.
      TERMA = ((2-DEN)/DEN)**(2*NA/(NA+1)).
      TERMK = ((2-DEN)/DEN)**(2*NK/(NK+1)).
      SEQF = SQRT(ETA * MS**2 + ETA2 * TERMA * DS**2).
      SEQ  = SQRT(KAP * MS**2 + KAP2 * TERMK * DS**2).

   ALPHA2 = KAP * MS/3.
    BETA2 = KAP2 * TERMK * DS.

      F2A = (ALPHA2 -     BETA2) / SEQ.
      F2L = (ALPHA2 + 0.5*BETA2) / SEQ.

       ES1 = A1*(SEQF/MU)**N1 * EXP (-Q1R / TEMP).
       ES2 = A2*(SEQF/MU)**N2 * EXP (-Q2R / TEMP).
       ES3 = 0.

       IF(SEQF GT S0) THEN (
         ARG = Q * (SEQF-S0)/MU.
         ES3 = 0.5*( B1*EXP(-Q1R/TEMP) + B2*EXP(-Q2R/TEMP) )
             * ( EXP(ARG) - EXP(-ARG) ) .).

       ESS = ES1 + ES2 + ES3.

       EFT = K0*EXP(C*TEMP)*(SEQF/MU)**M.
       BIGD = ALPHA + BETA * LOG(SEQF/MU).

       IF(Z3 LT EFT) THEN F = EXP(  BIGD*(1-Z3/EFT)**2).
       IF(Z3 EQ EFT) THEN F = 1.
       IF(Z3 GT EFT) THEN F = EXP(-DELTA*(1-Z3/EFT)**2).

       MD = F * ESS.

       CR = ABS(EXP(VOLT)-1).

       IF(CR LE 0.15) THEN GAMMA = 1.0.
       IF(CR GT 0.15) THEN
          GAMMA = (ABS((D0-EXP(VOLT))/((1-D0)*EXP(VOLT))))**NSP.

       X3 = EXP((R3-1)*VOLT)/(ABS(1-EXP(VOLT)))**R4.

       IF(W EQ 0) THEN M2 = 0.
       IF(W GT 0) THEN M2 = W**AA1.
       G2 = 1/DC**PP.
       T2 = EXP(-QSR/TEMP)/TEMP.

       SP = R1*M2*G2*T2*X3*GAMMA*SEQF.).

      DZ1 = (MD + SP) * F2A.
      DZ2 = (MD + SP) * F2L.
      DZ3 = (F-1) * ESS.     ).

      IF(TIME EQ 0) THEN (

      DZ1 = 0.
      DZ2 = 0.
      DZ3 = 0.     ).
#
#  ------  SPECIFY THE DEPENDENT VARIABLE FUNCTION
#
/FUN
   IF(TIME NE 0.) THEN (
       AA = Z1/EAC.
       BB = Z2/ELC.
        F = 1.0 - SQRT(((1.0-AA)**2 + (1.0-BB)**2)*WT1).  ).
   IF(TIME EQ 0.) THEN (
      NEW = 0.
       Z1 = EAC.
       Z2 = ELC.
       Z3 = 0.
        F = 1.0 ).
#
# ------  SPECIFY VARIOUS PRINTING AND PLOTTING OPTIONS  ------
#
/SAVE
       FILE = 'e:\325\md\MDSP3.SAV'.
```

```
      NEW.
      KEEP = TIME,EAC,ELC.
      FORMAT = '(5E12.3)'.
/PRINT
         FORMAT = E.
/PLOT
         RESIDUAL.
/END
```

APPENDIX B

Lateral-to-Axial Strain Rate Ratio Model Fits to the Shear Consolidation Tests

This appendix contains the plots of the model fits to the 16 shear consolidation tests used in determining the flow potential parameters. Each plot shows the measured and predicted lateral-to-axial strain rates ratios as a function of density for each of the 16 tests.

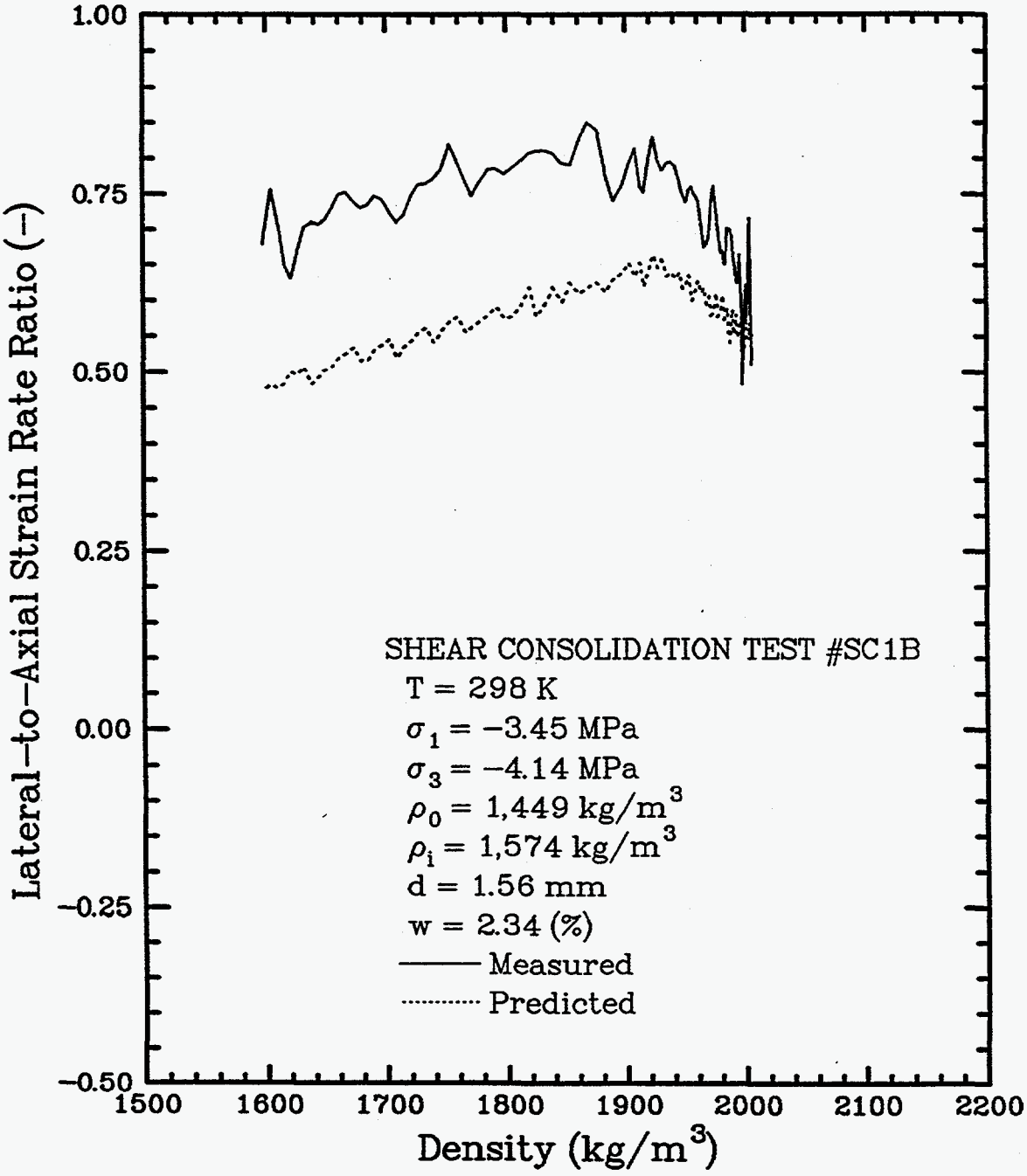


Figure B-1. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test SC1B.

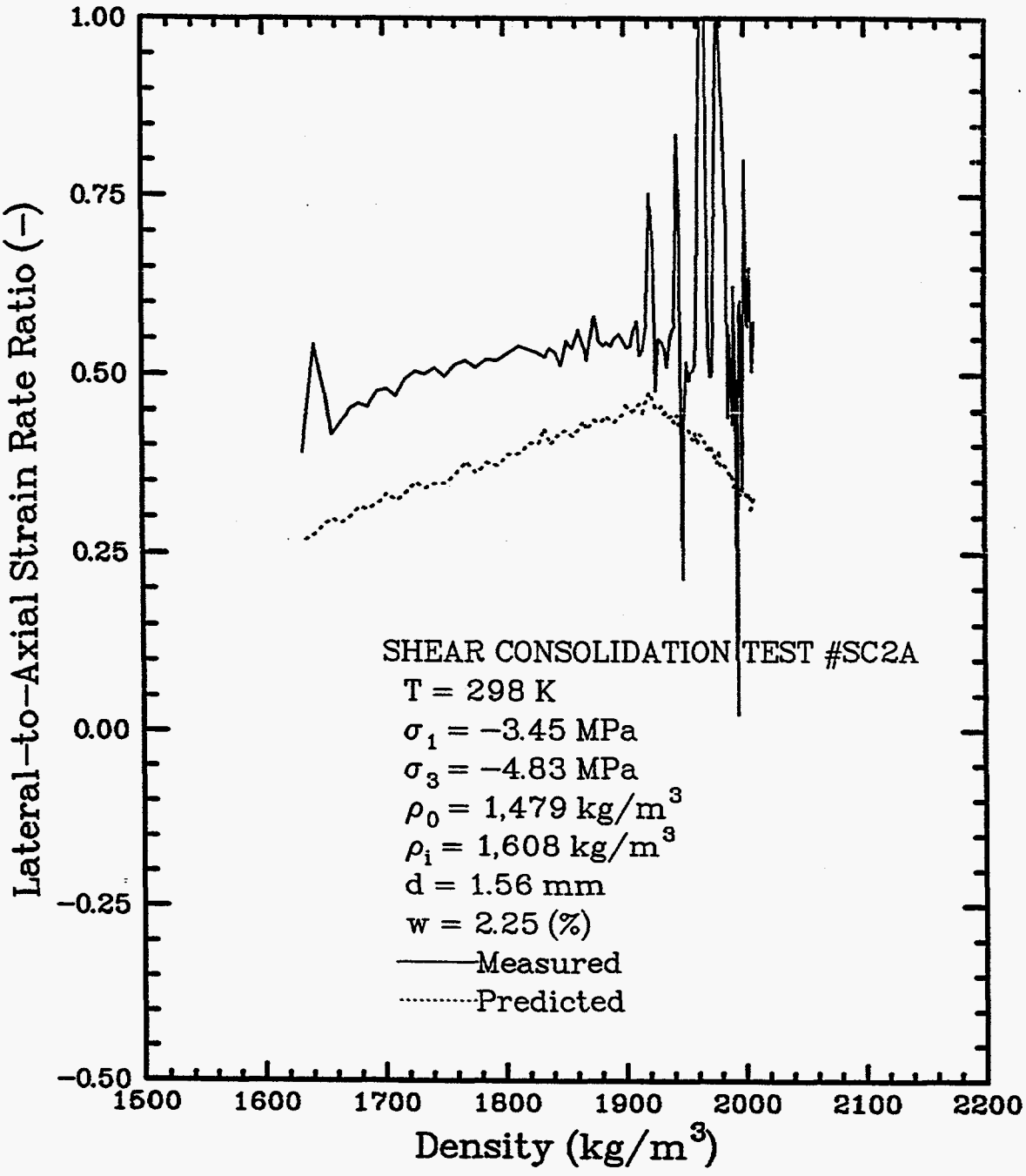


Figure B-2. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test SC2A.

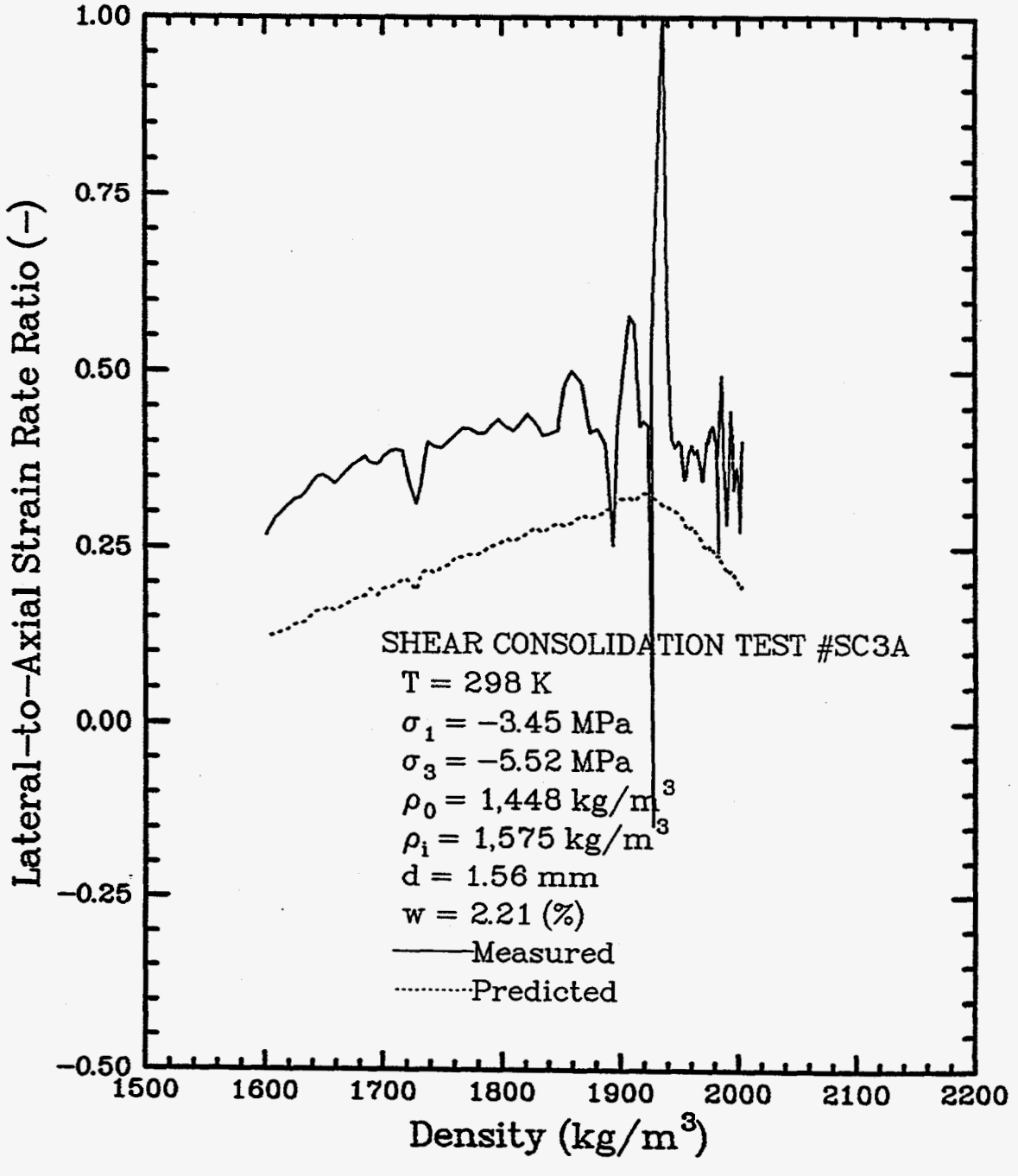


Figure B-3. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test SC3A.

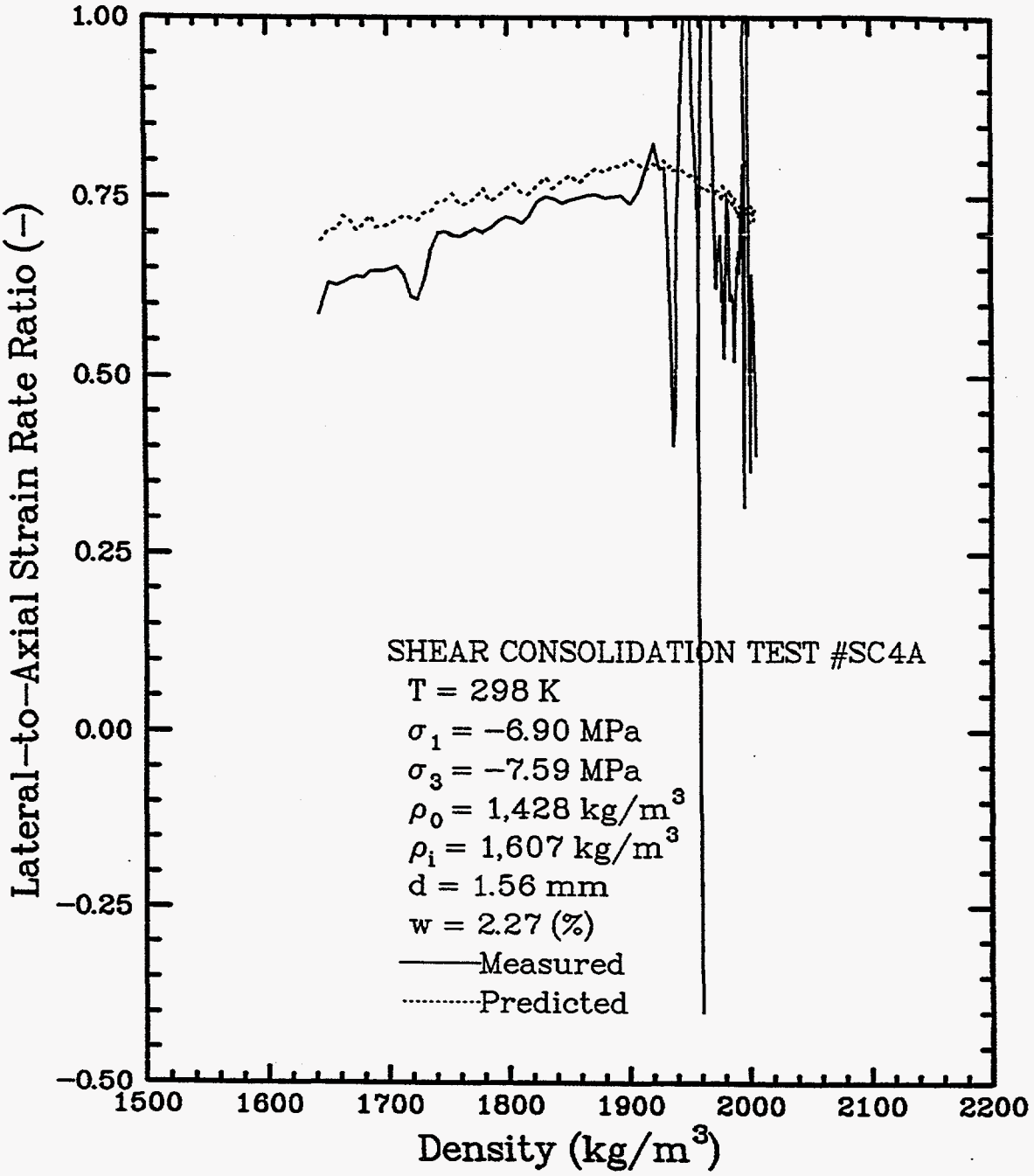


Figure B-4. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test SC4A.

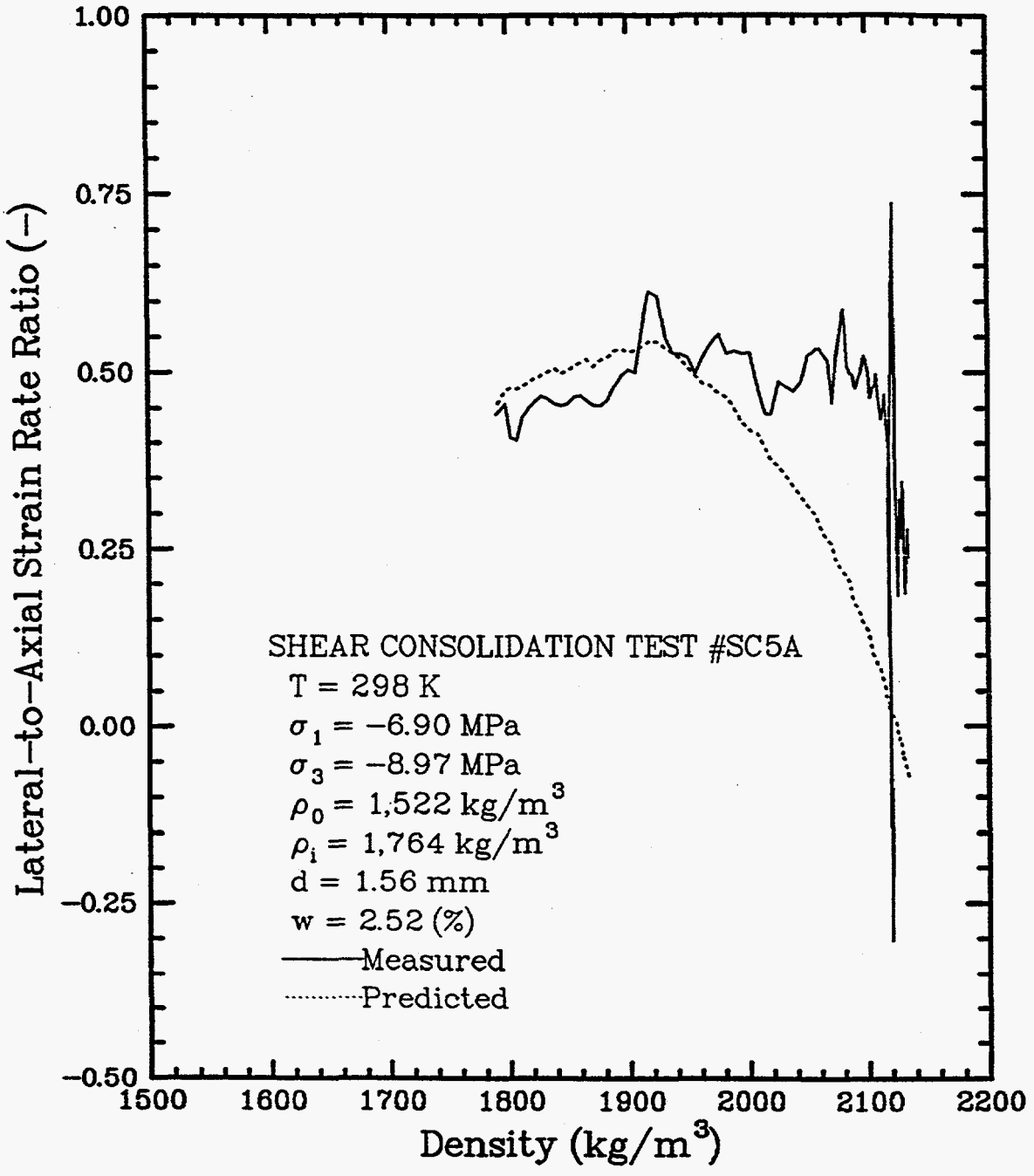


Figure B-5. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test SC5A.

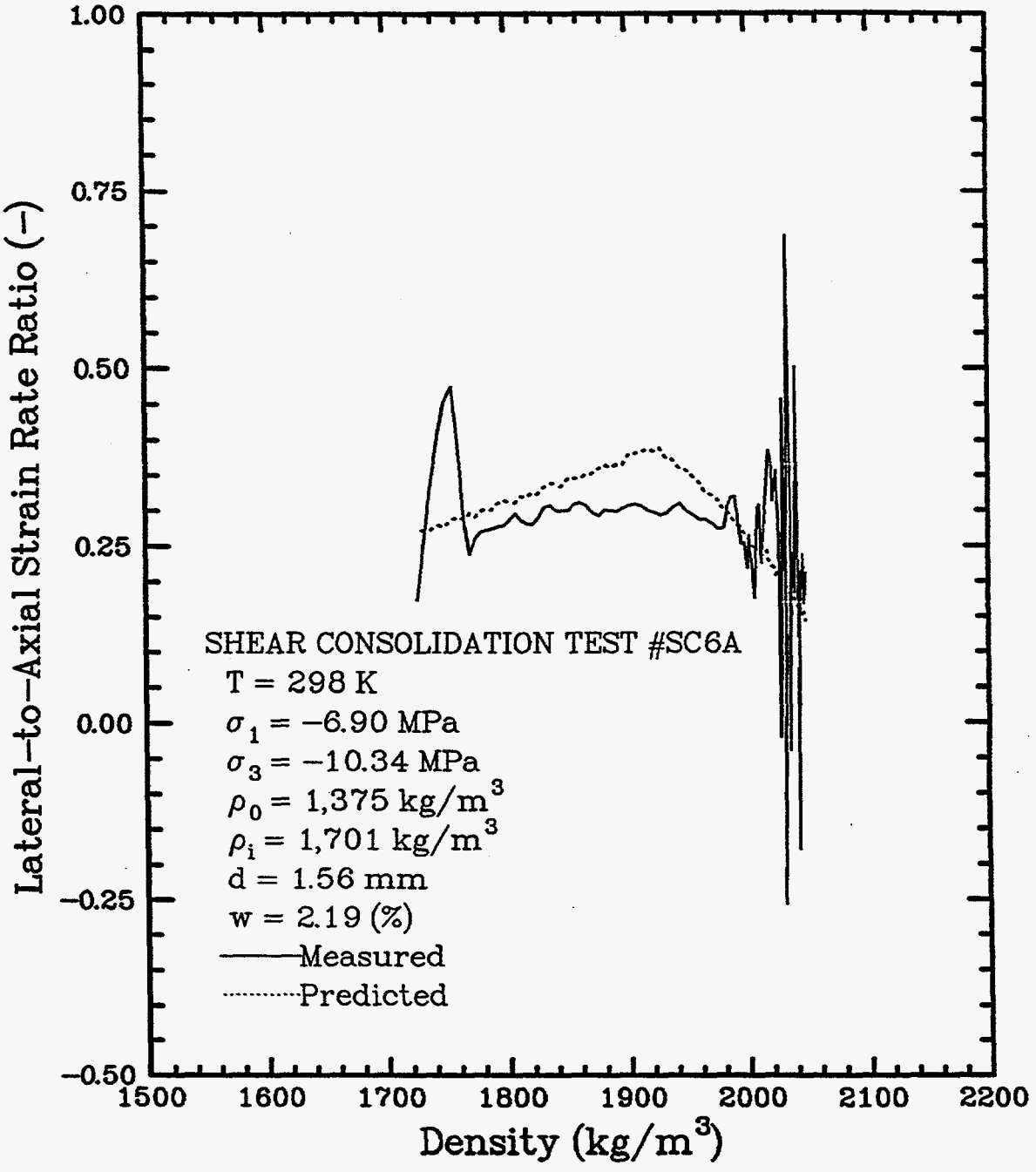


Figure B-6. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test SC6A.

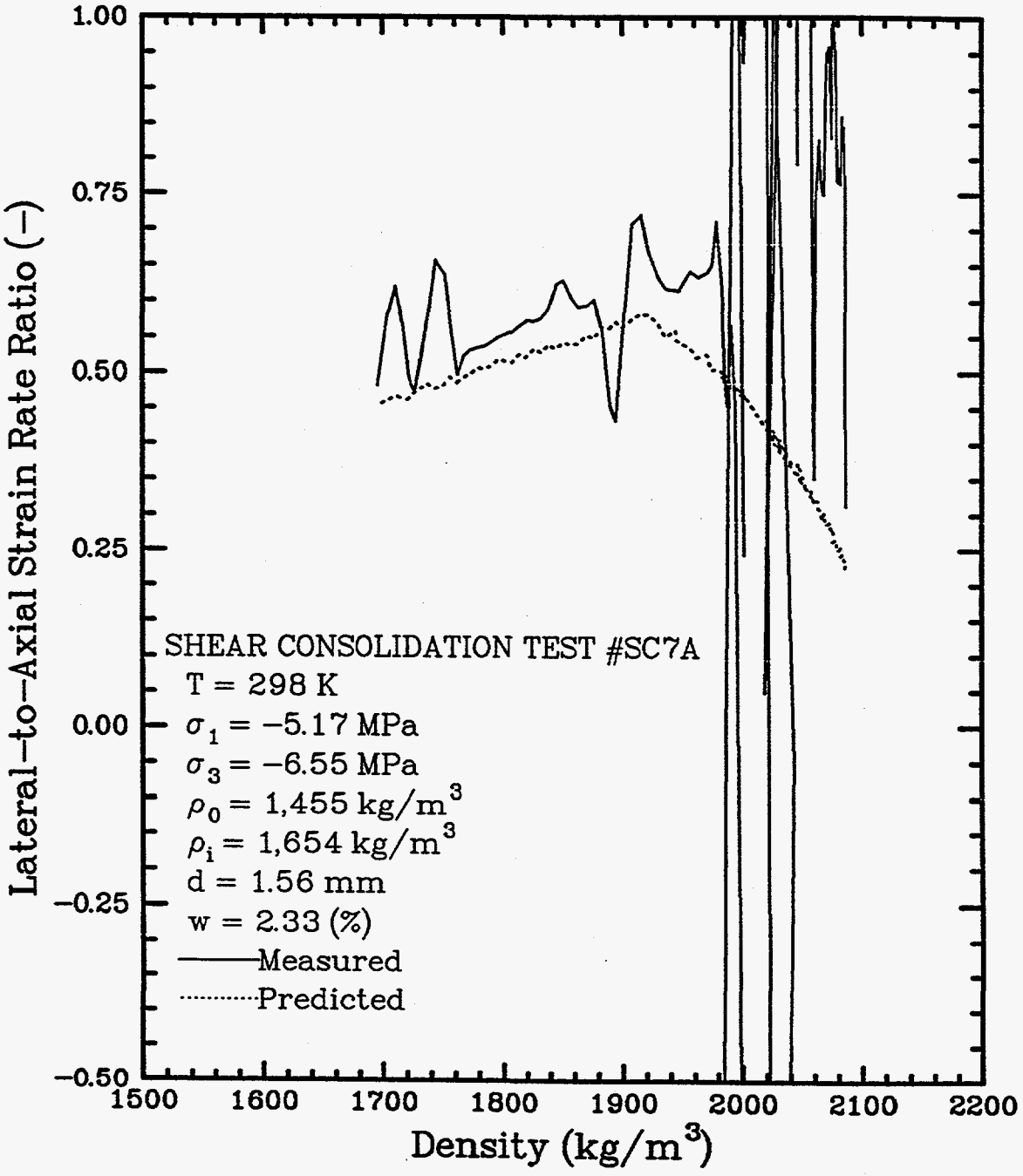


Figure B-7. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test SC7A.

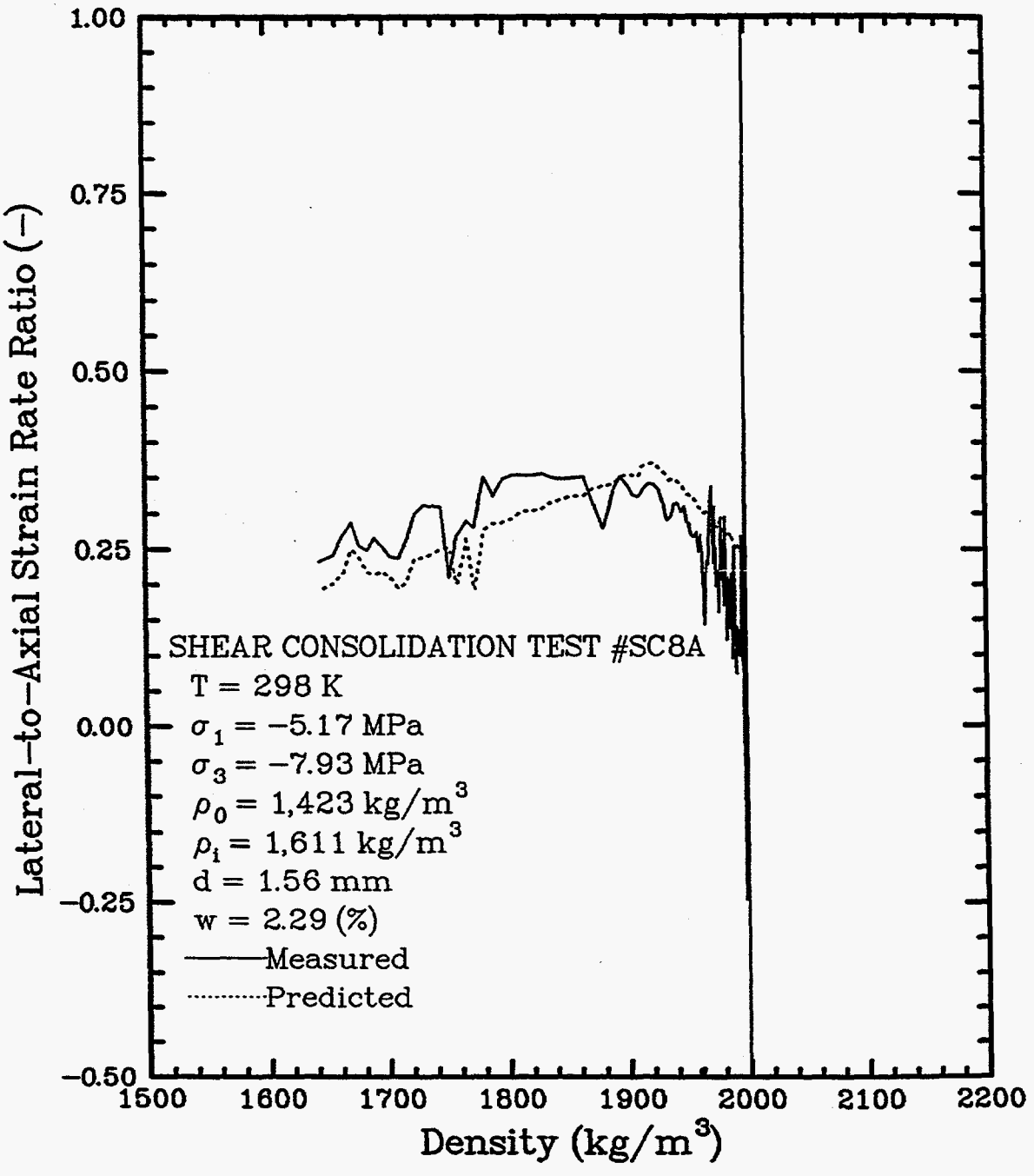


Figure B-8. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test SC8A.

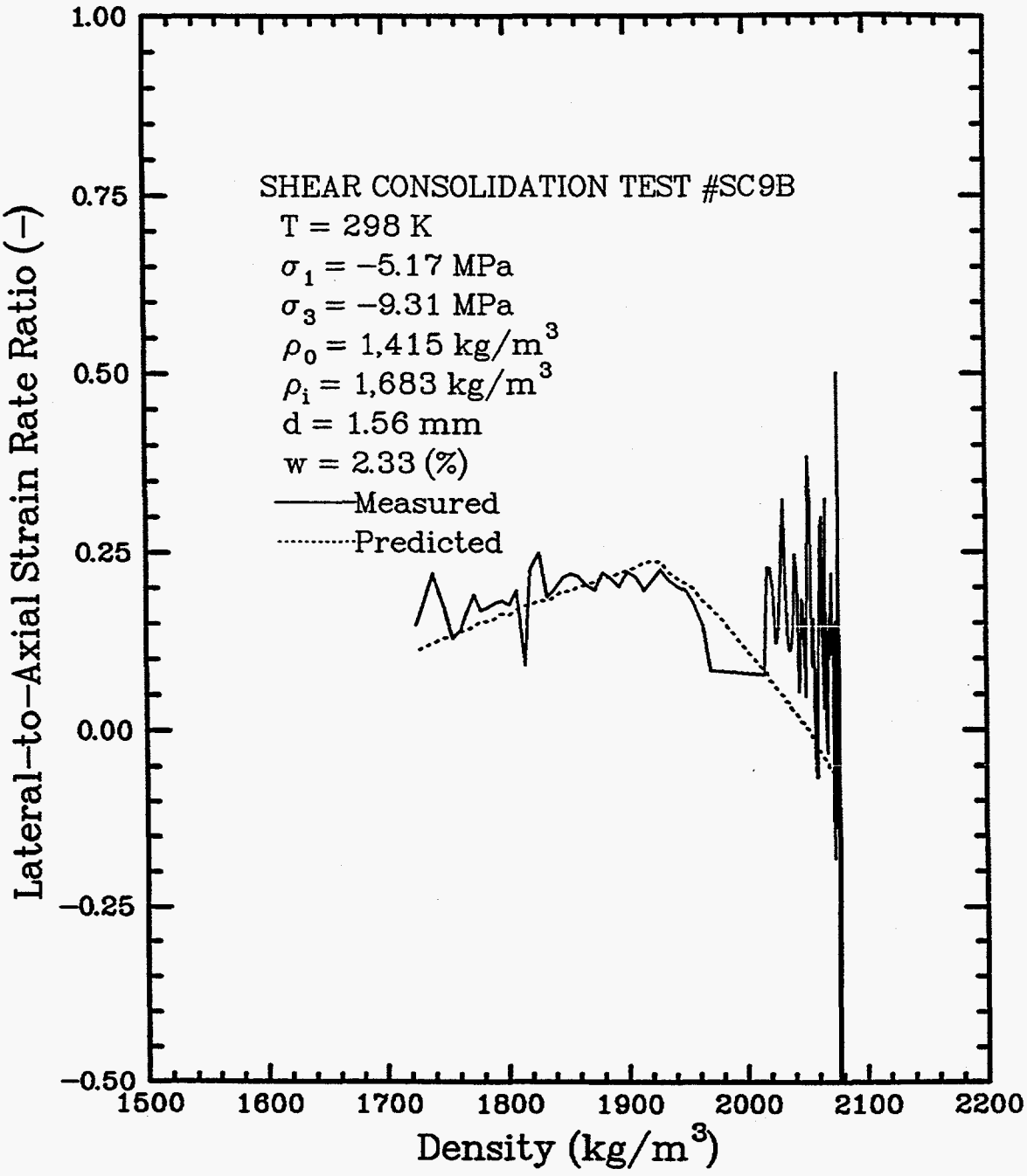


Figure B-9. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test SC9B.

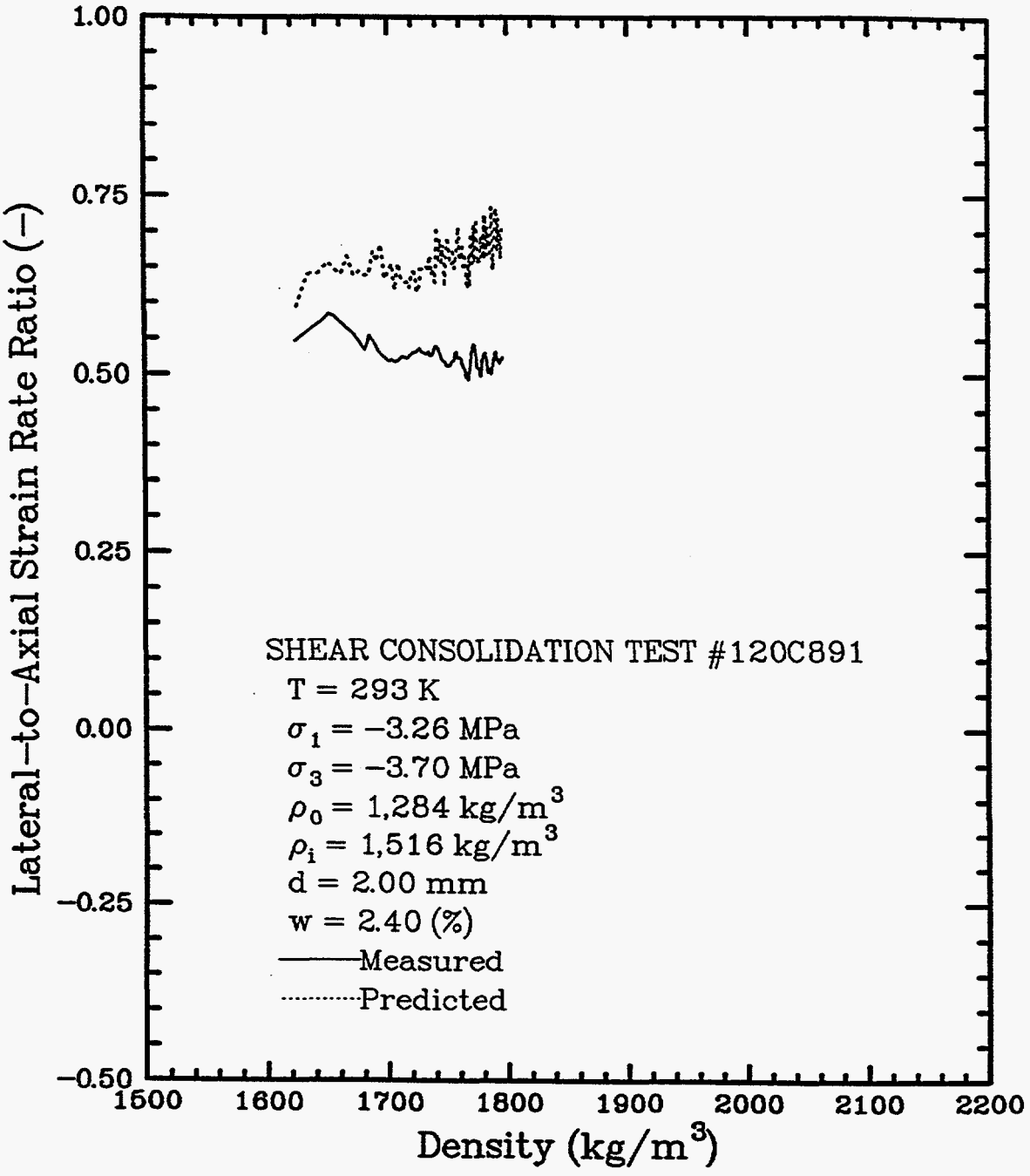


Figure B-10. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test 120C891.

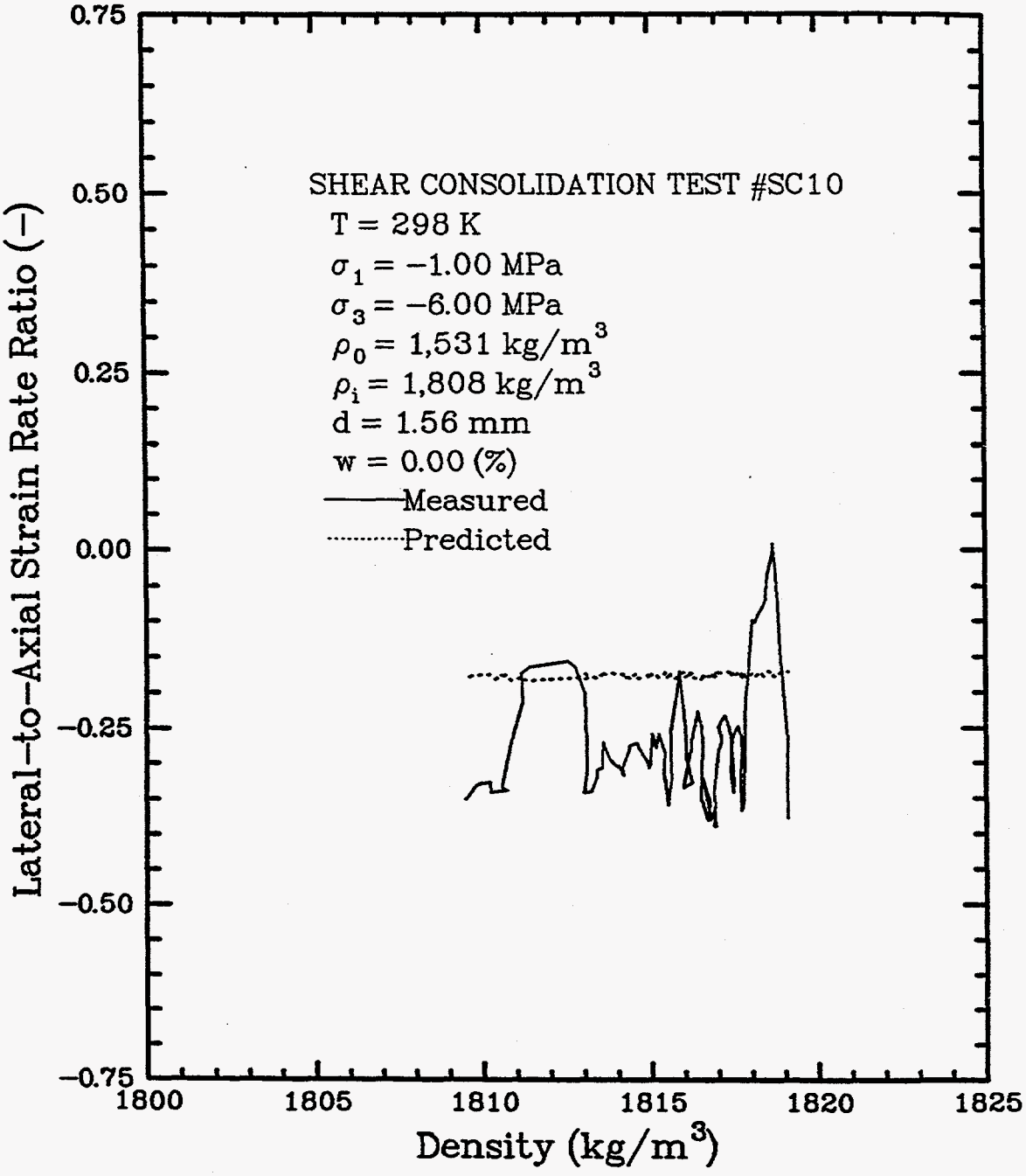


Figure B-11. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test SC10.

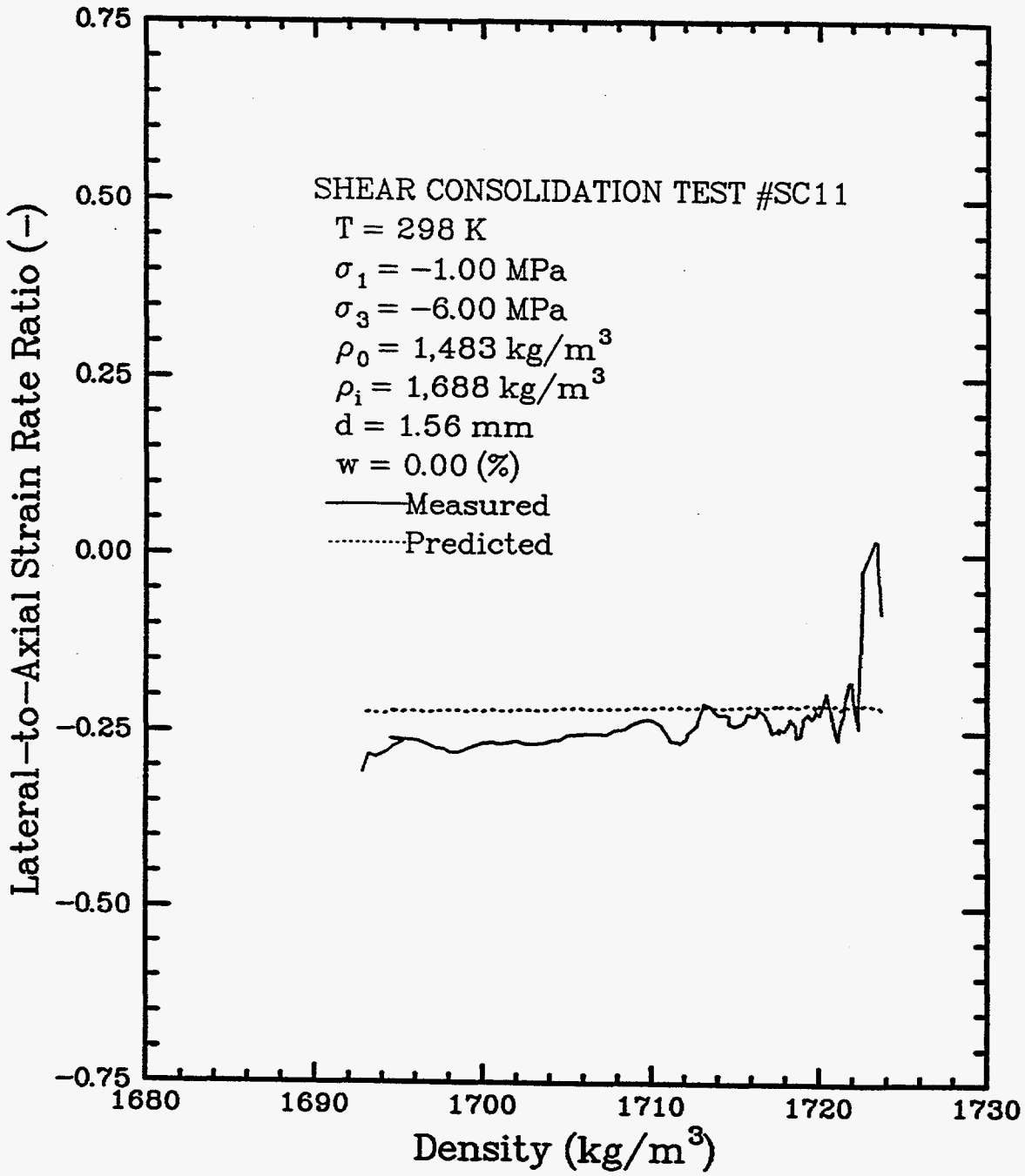


Figure B-12. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test SC11.

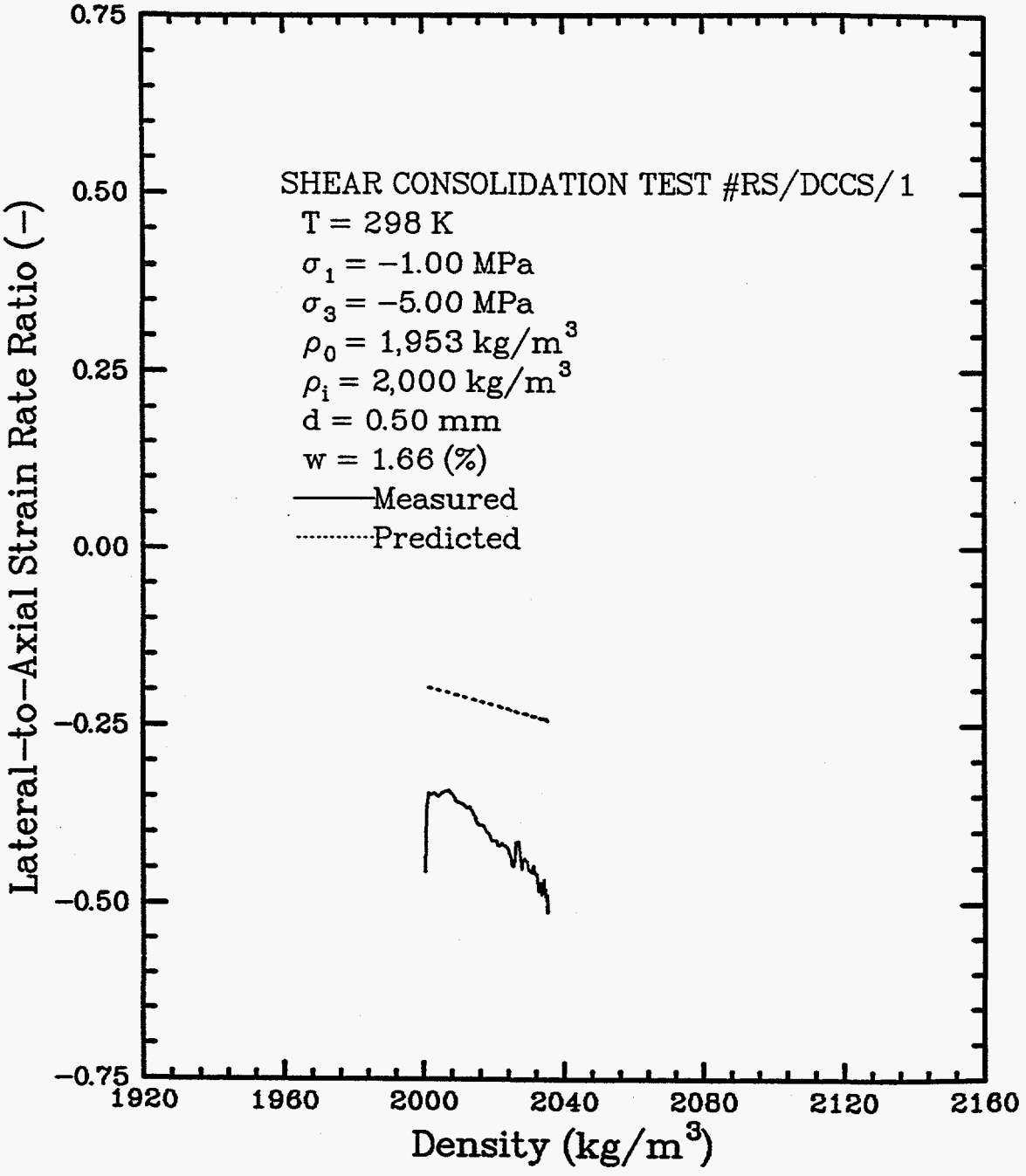


Figure B-13. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test RS/DCCS/1.

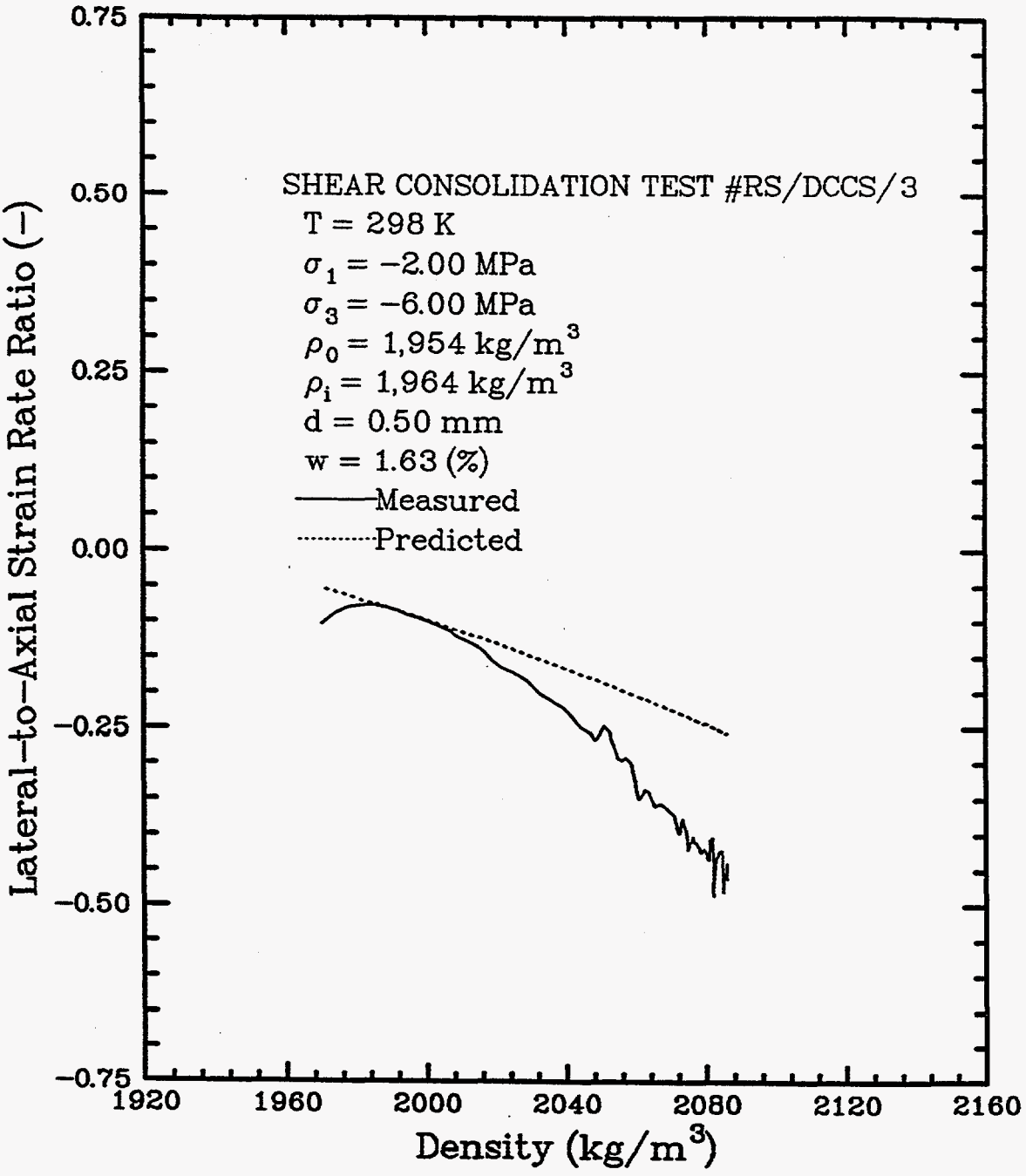


Figure B-14. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test RS/DCCS/3.

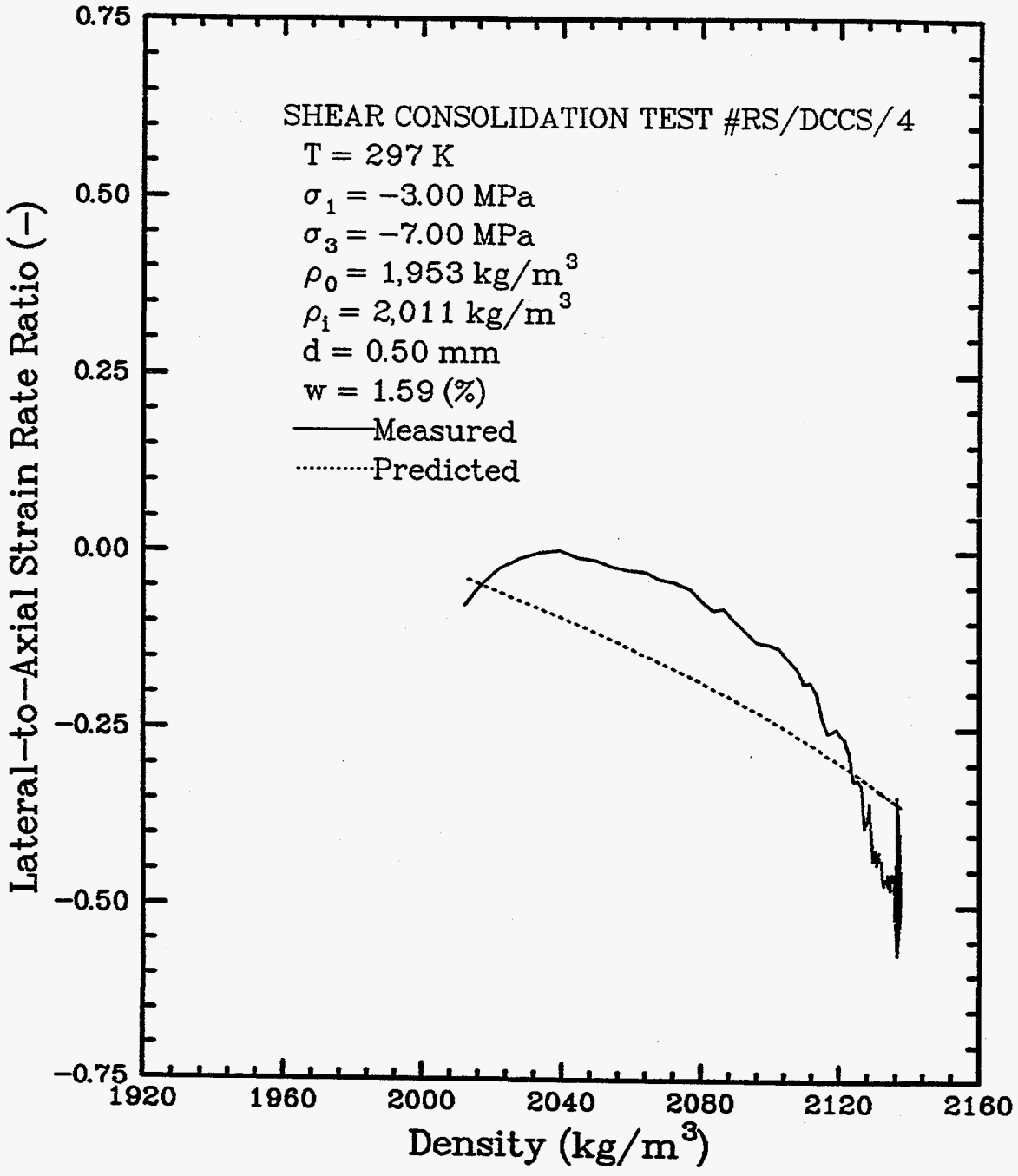


Figure B-15. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test RS/DCCS/4.

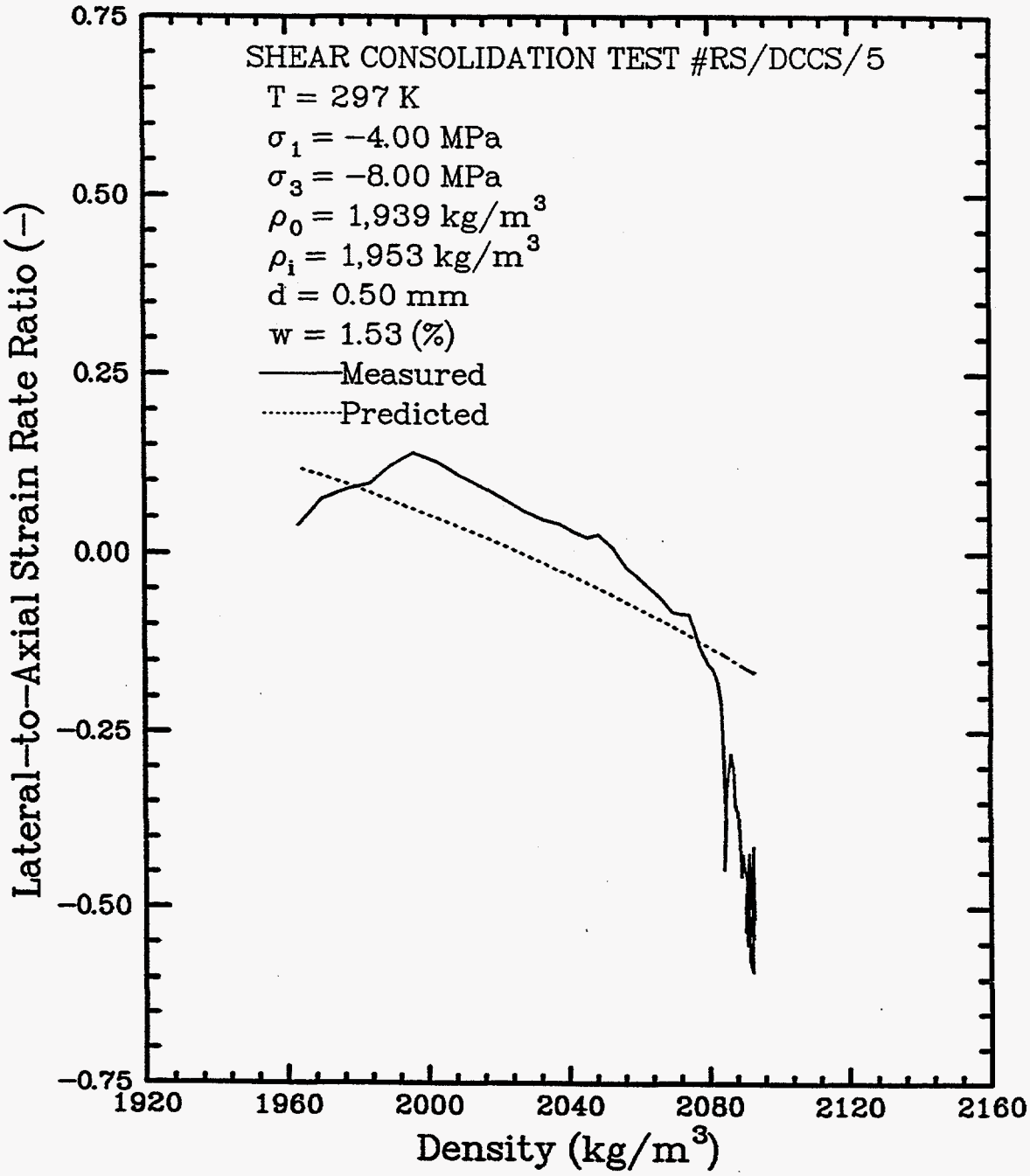


Figure B-16. Lateral-to-Axial Strain Rate Ratio as a Function of Density for Shear Consolidation Test RS/DCCS/5.

APPENDIX C

C-S Constitutive Model Fits to the Hydrostatic and Shear Consolidation Tests

This appendix contains the plots of the C-S constitutive model fits to the 40 hydrostatic consolidation tests and the 16 shear consolidation tests. The two C-S constitutive model fits are fits to two test databases; namely, (1) a database containing the 16 shear consolidation tests only and (2) a database containing the combined 56 shear and hydrostatic consolidation tests.

The appendix contains 56 figures. Each figure shows the two model fits to each particular laboratory test; either a hydrostatic consolidation test (Figure C-1 through C-40) or a shear consolidation test (Figures C-41 through C-56). The plots labeled "Shear Database" represent the C-S constitutive model fit to the shear test database, and the plots labeled "Combined Database" represent the C-S constitutive model fit to the combined test database.

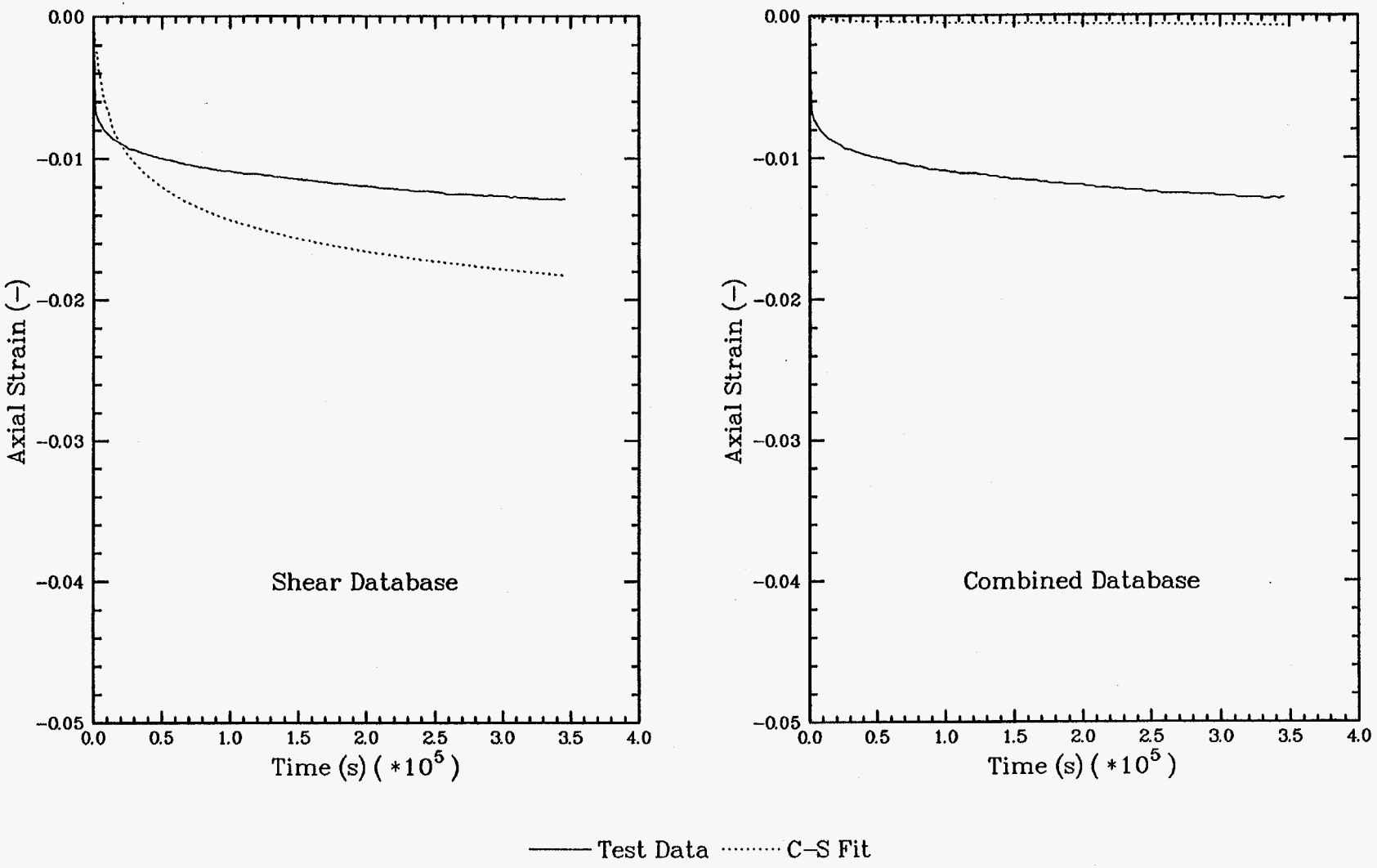


Figure C-1. Hydrostatic Consolidation Test CS1

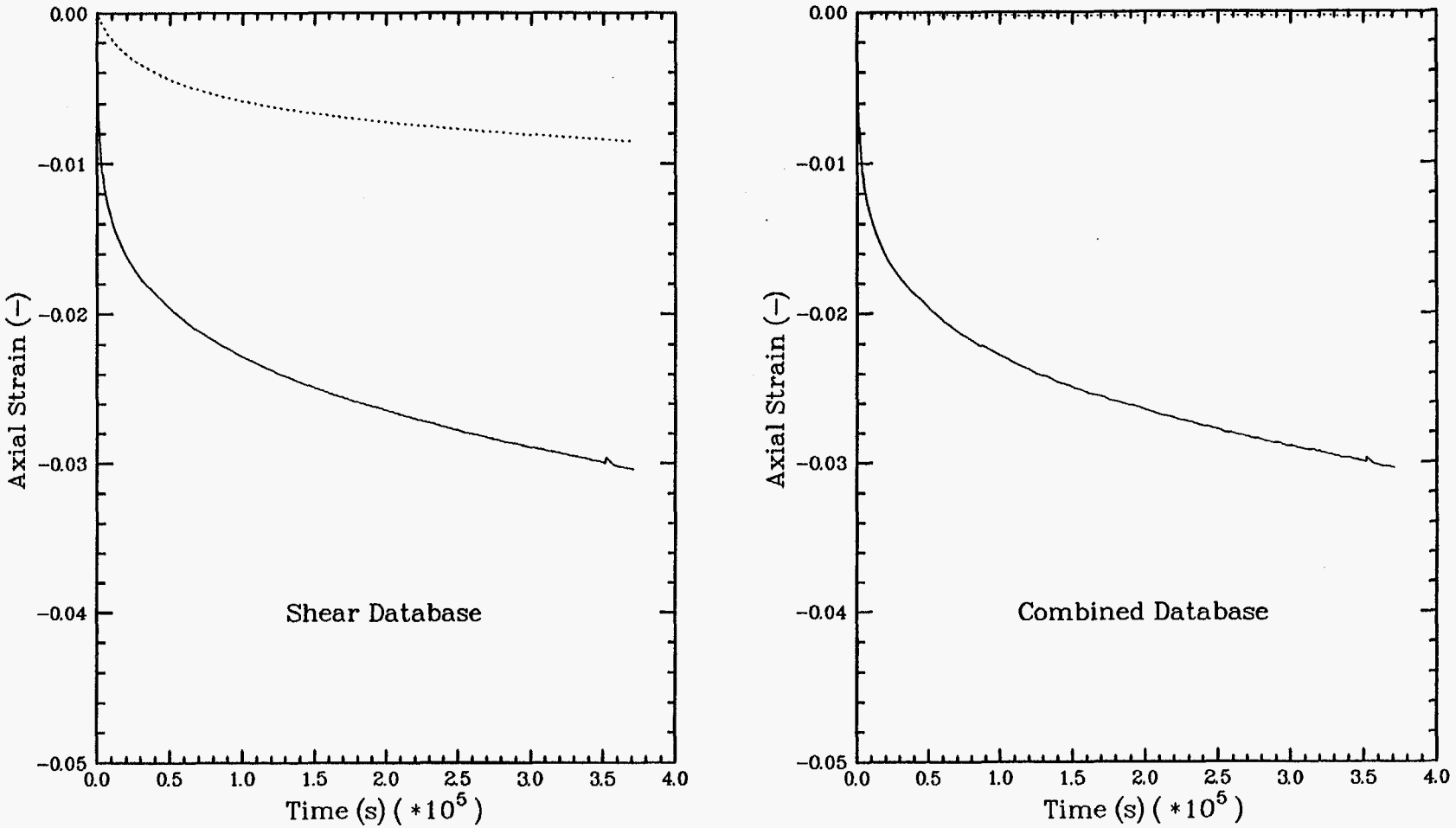


Figure C–2. Hydrostatic Consolidation Test CS2

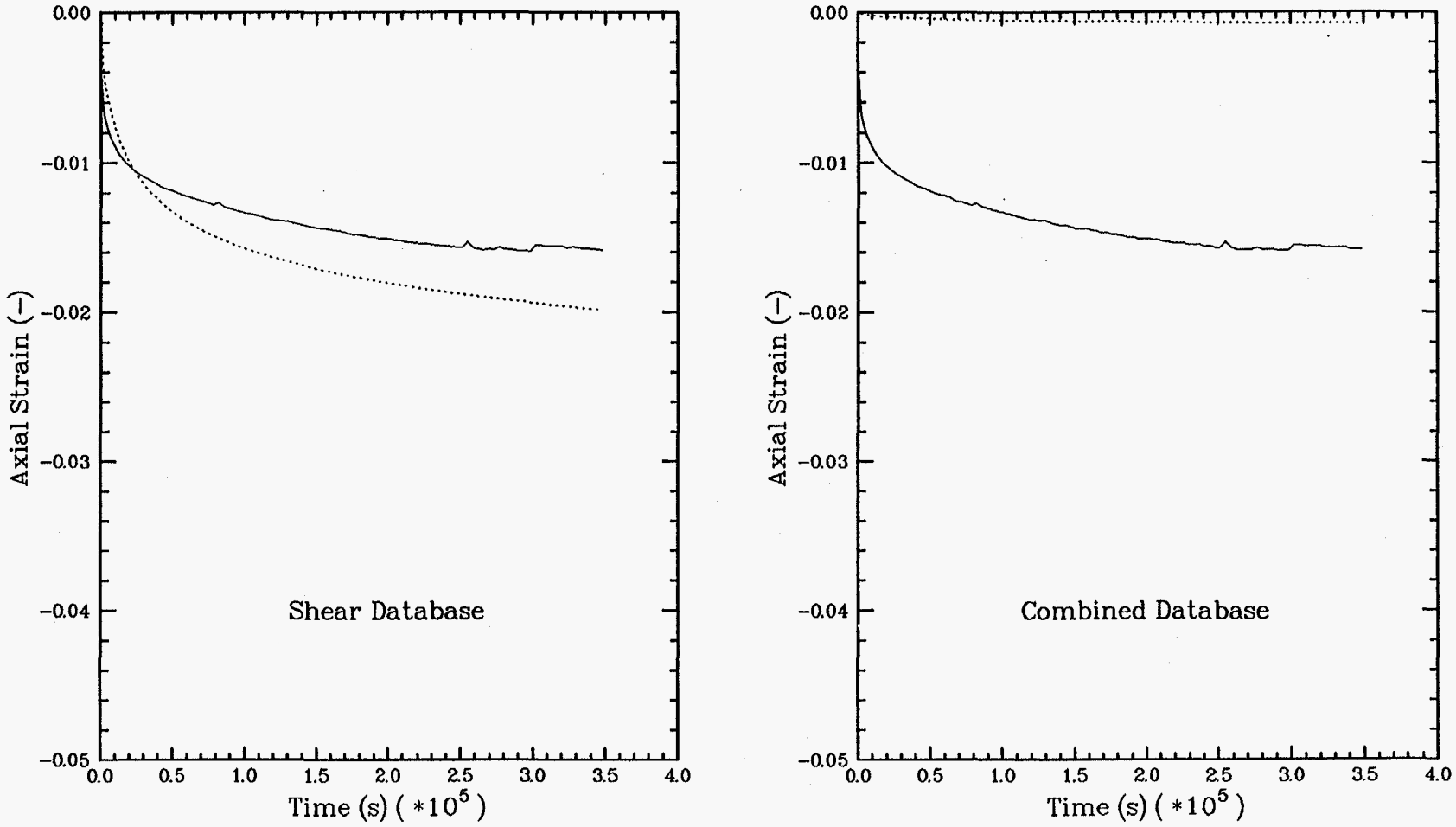


Figure C-3. Hydrostatic Consolidation Test CS3

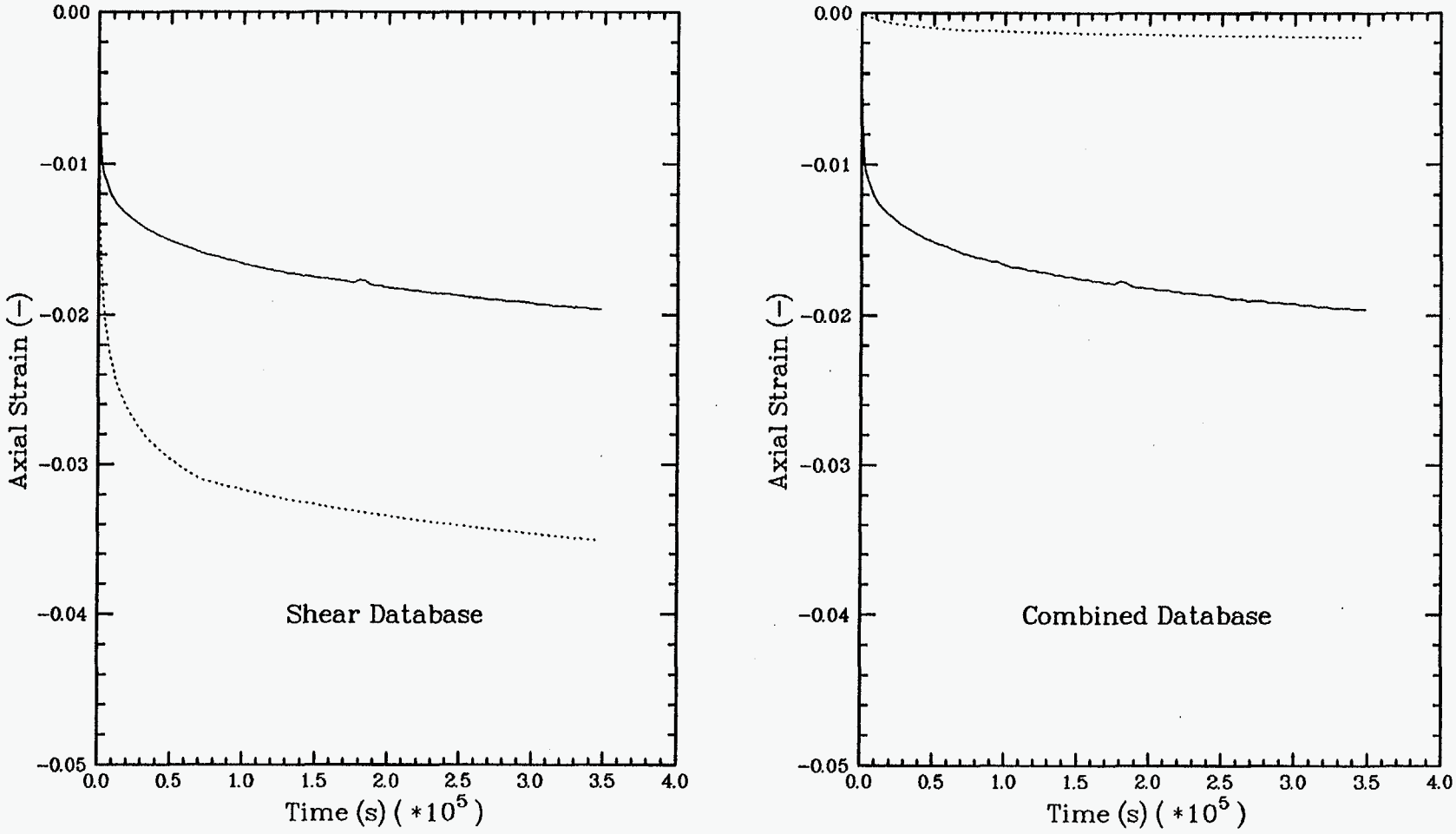


Figure C–4. Hydrostatic Consolidation Test CS4

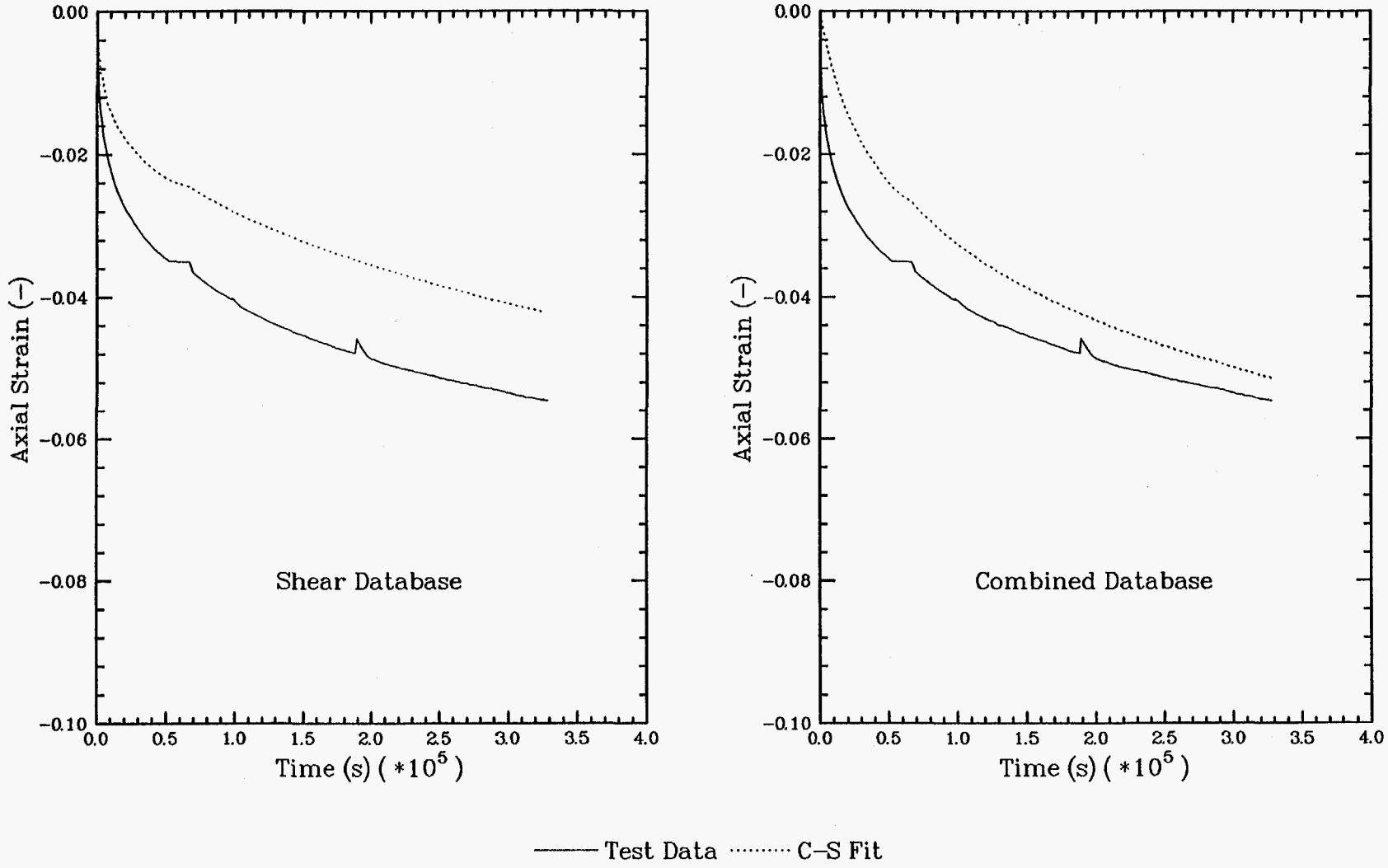


Figure C-5. Hydrostatic Consolidation Test CS5

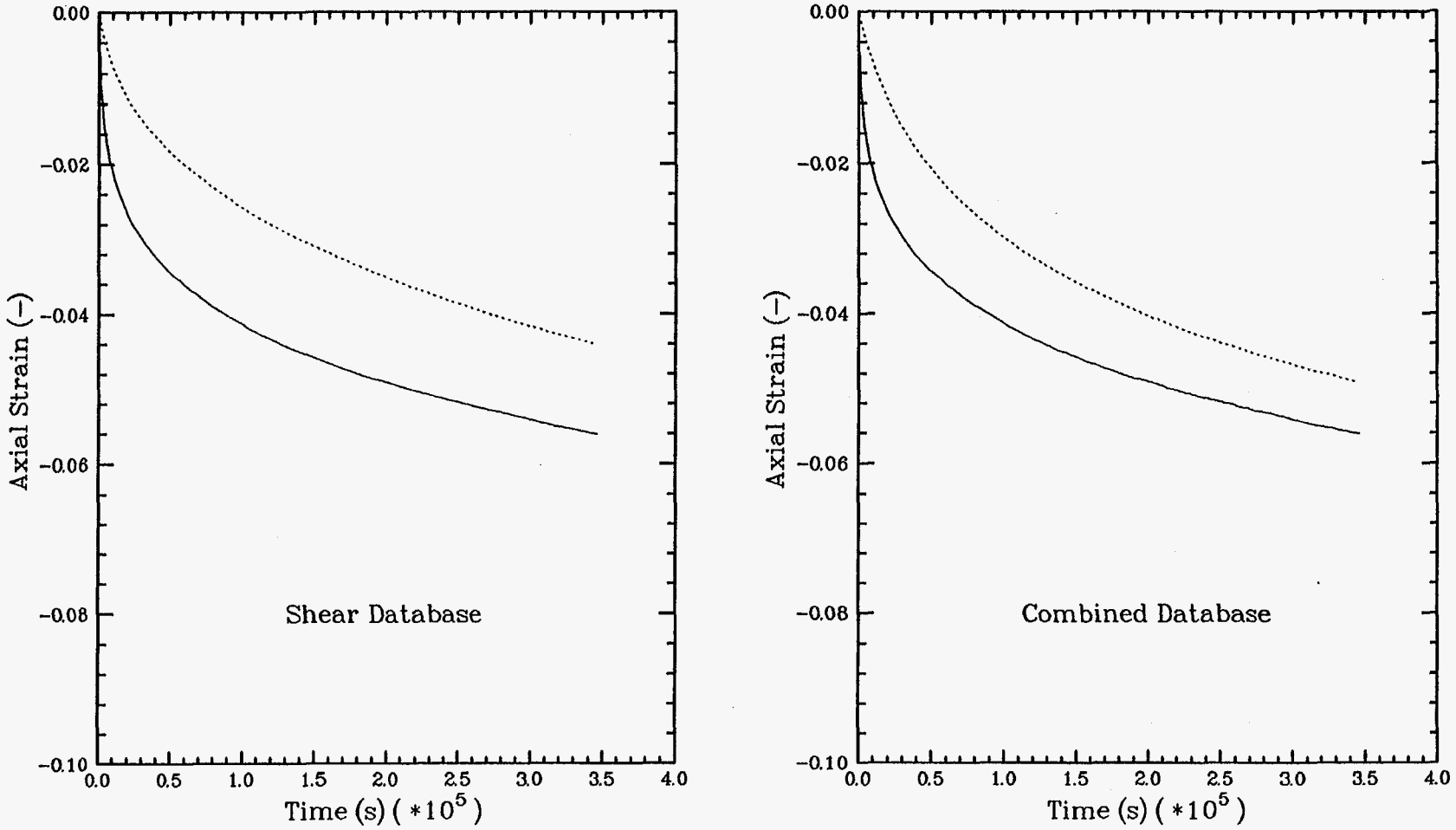


Figure C-6. Hydrostatic Consolidation Test CS6

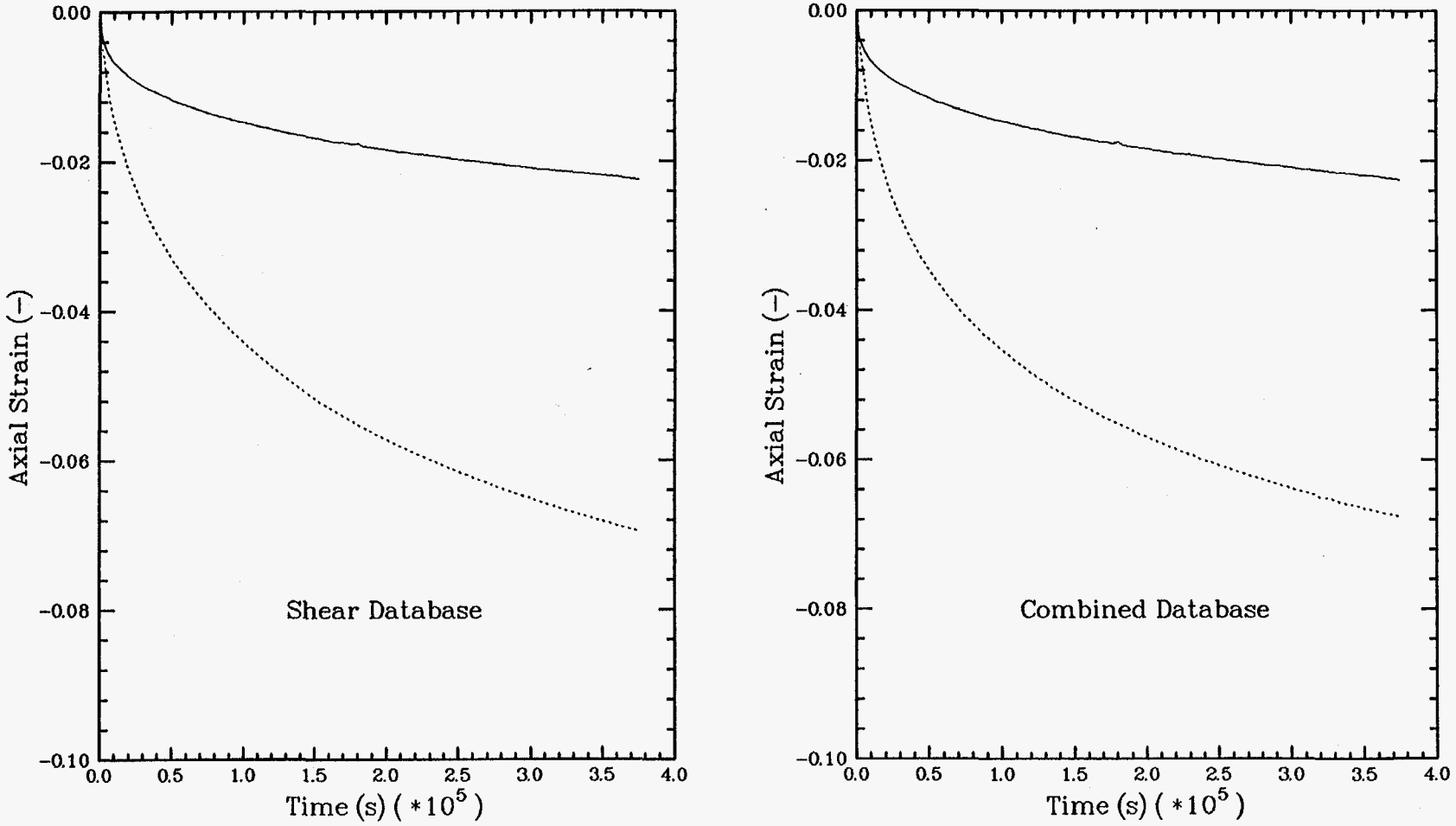


Figure C-7. Hydrostatic Consolidation Test CS7

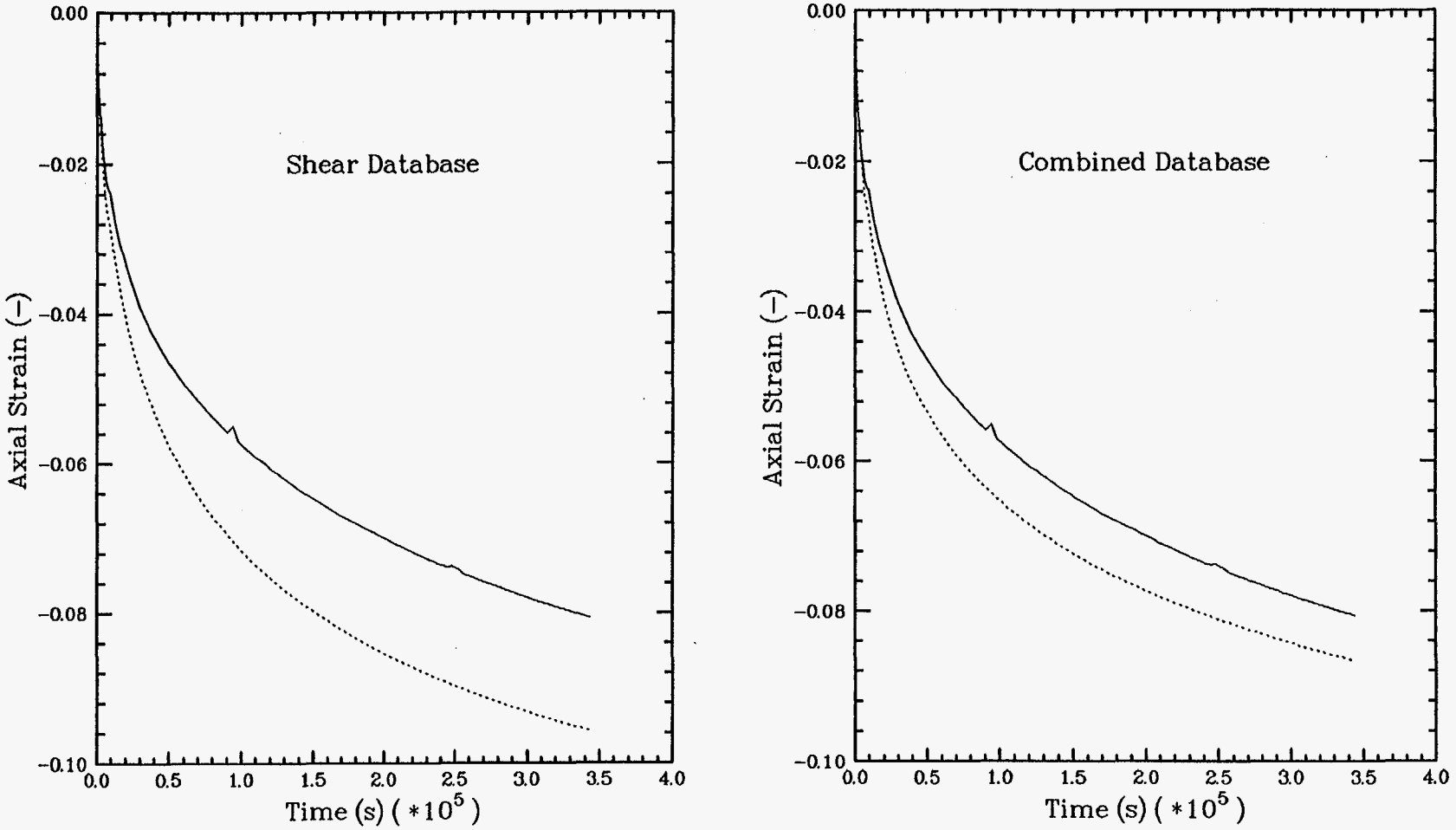


Figure C–8. Hydrostatic Consolidation Test CS8

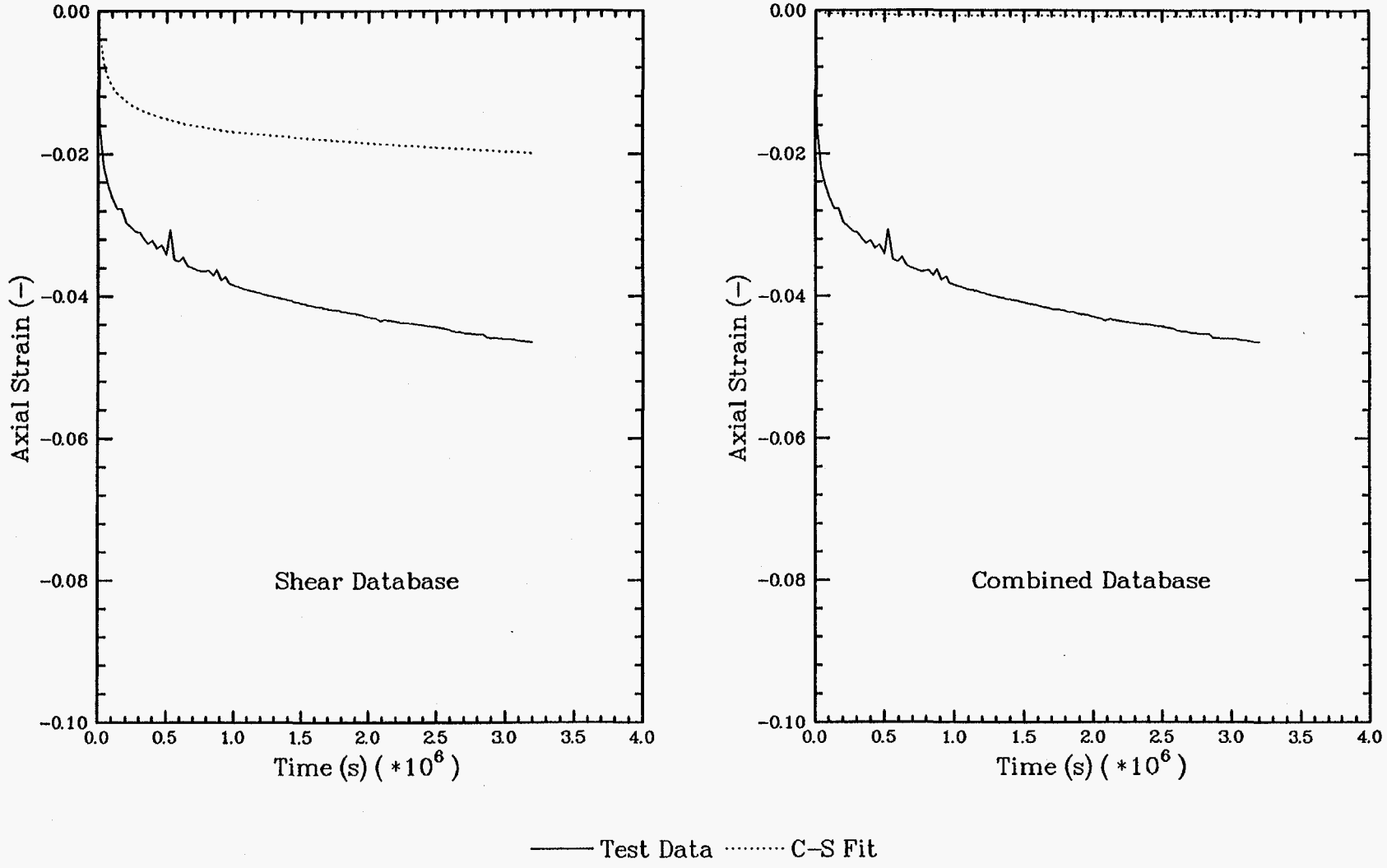


Figure C-9. Hydrostatic Consolidation Test CS9

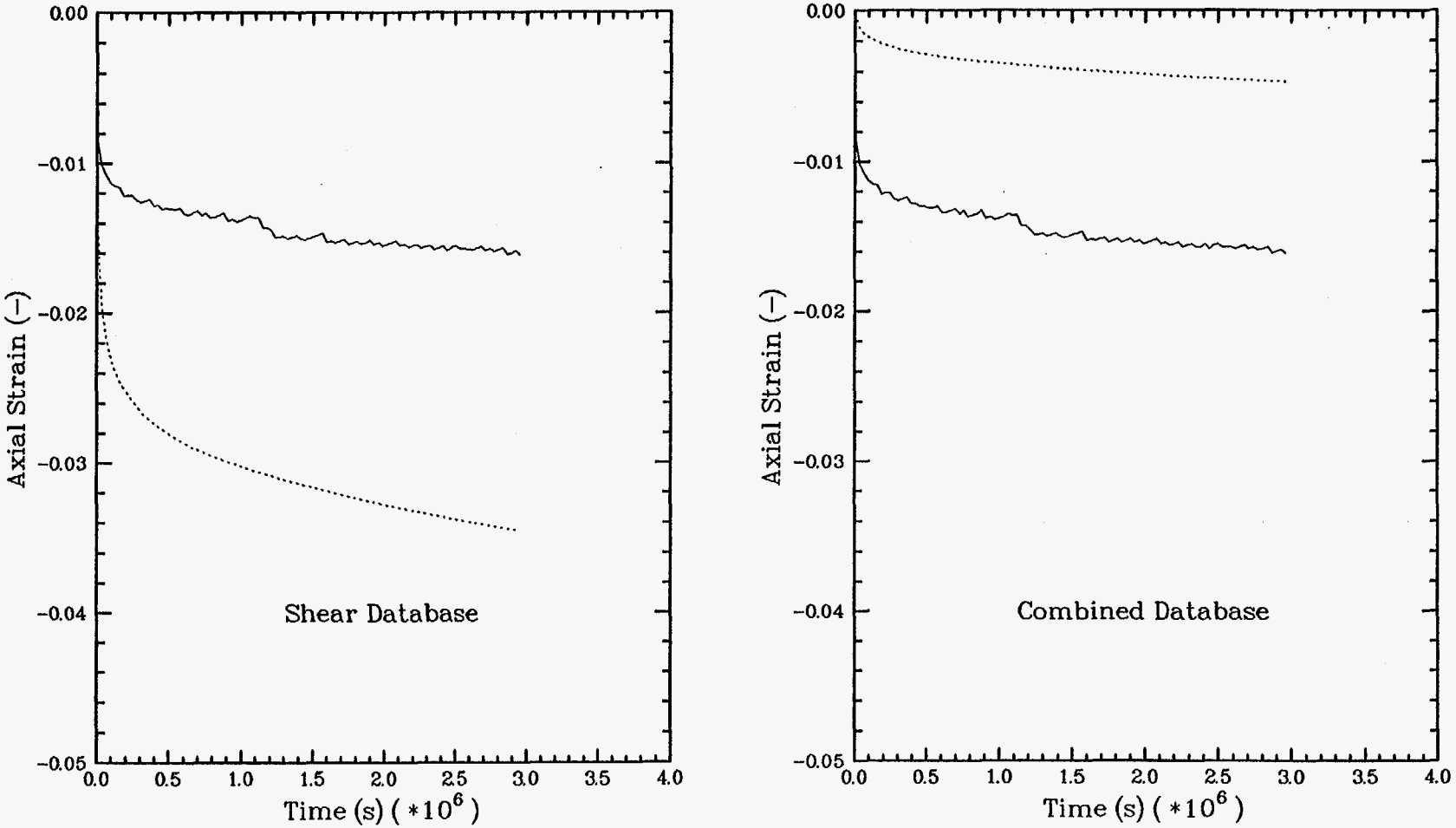


Figure C-10. Hydrostatic Consolidation Test CS10

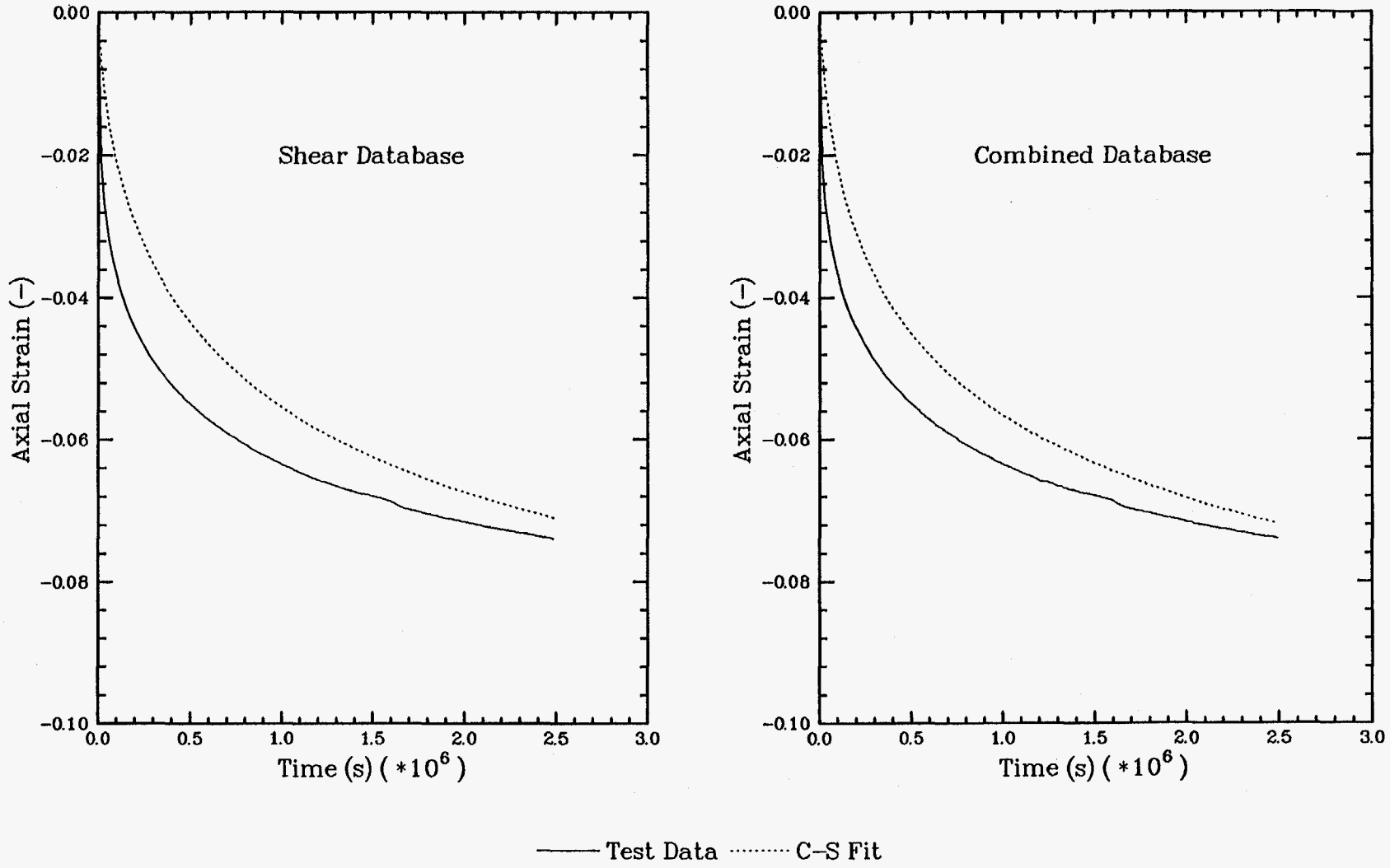


Figure C-11. Hydrostatic Consolidation Test HC1A

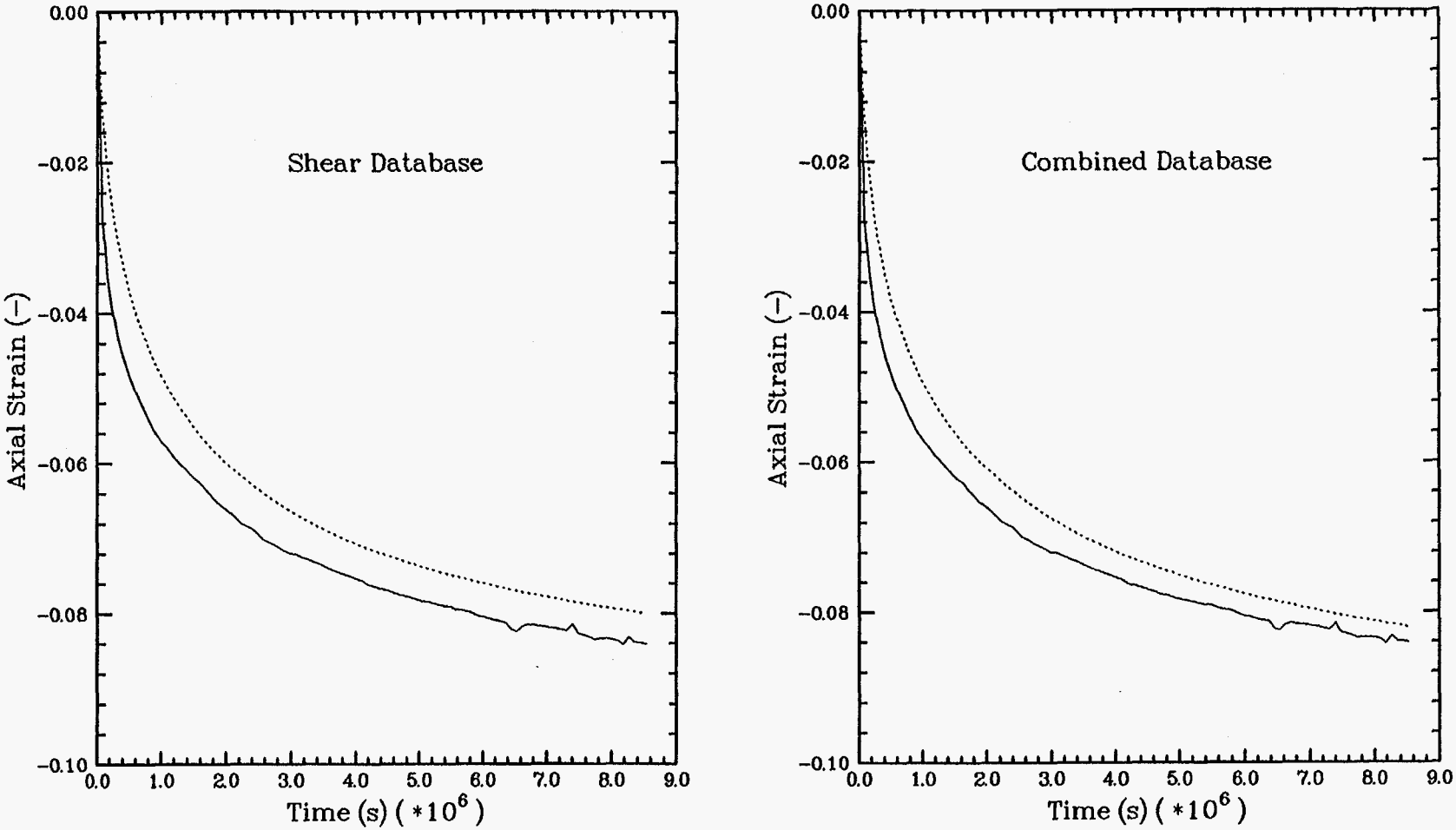


Figure C-12. Hydrostatic Consolidation Test HC2A

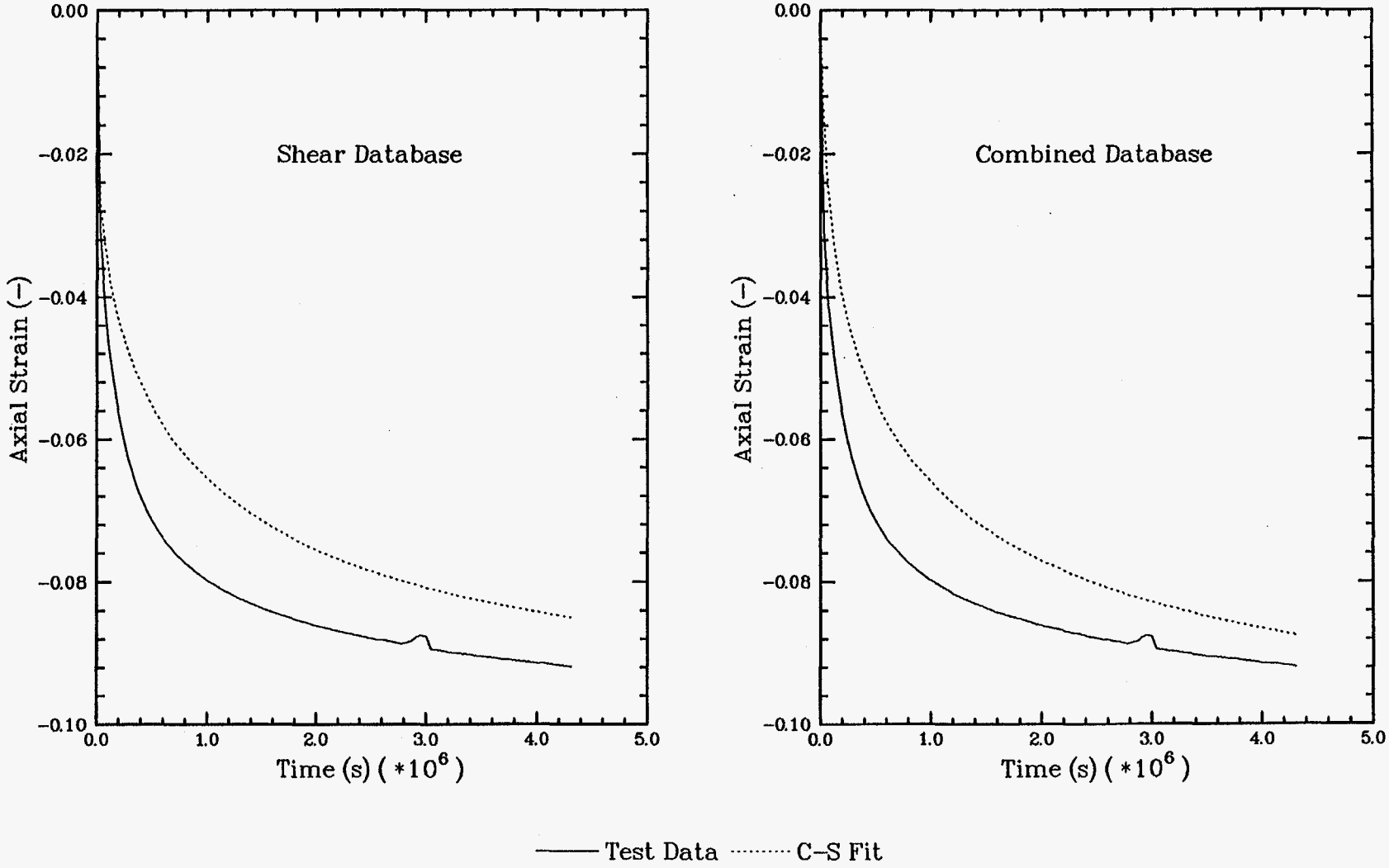


Figure C-13. Hydrostatic Consolidation Test HC3A

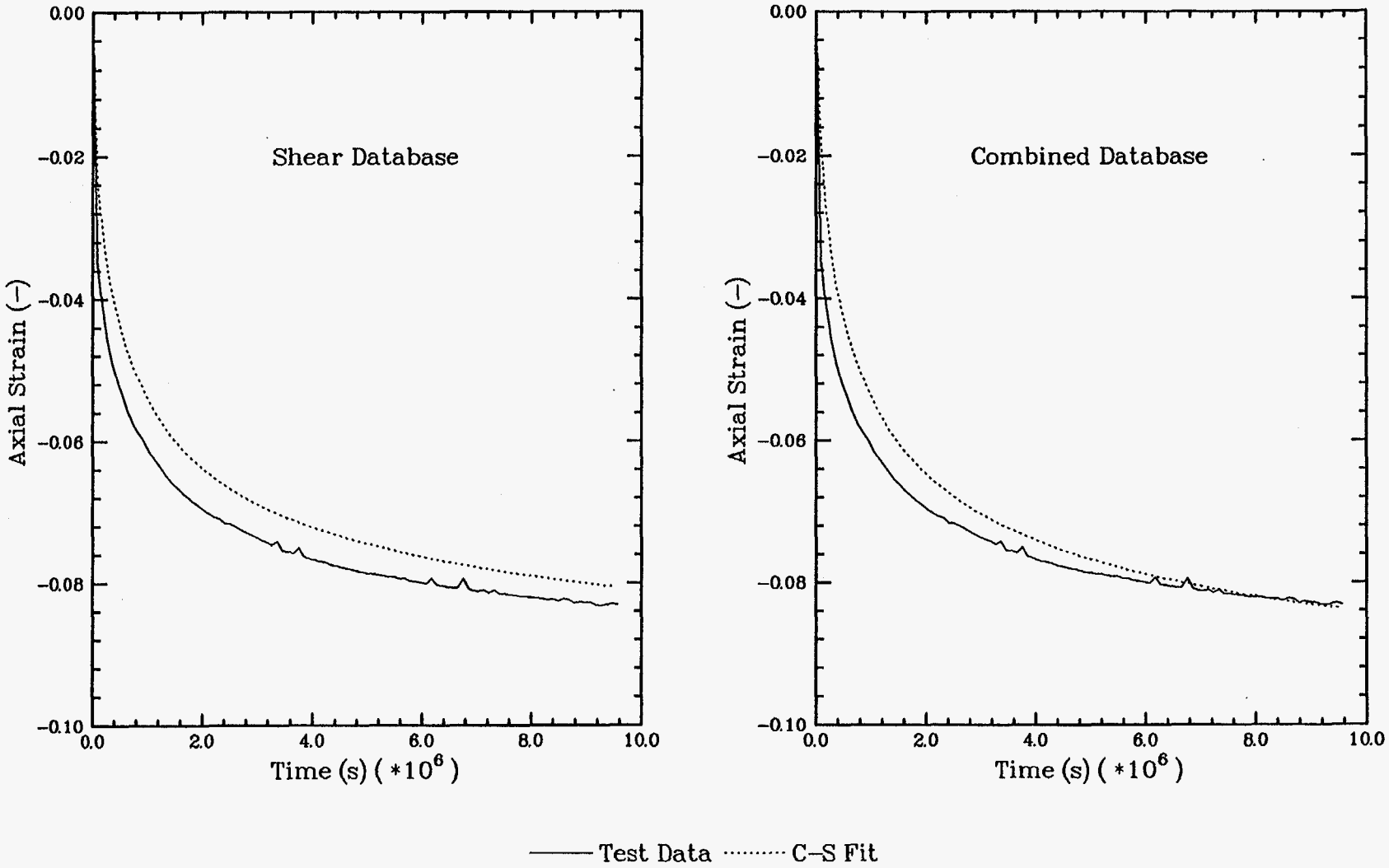


Figure C-14. Hydrostatic Consolidation Test HC4A

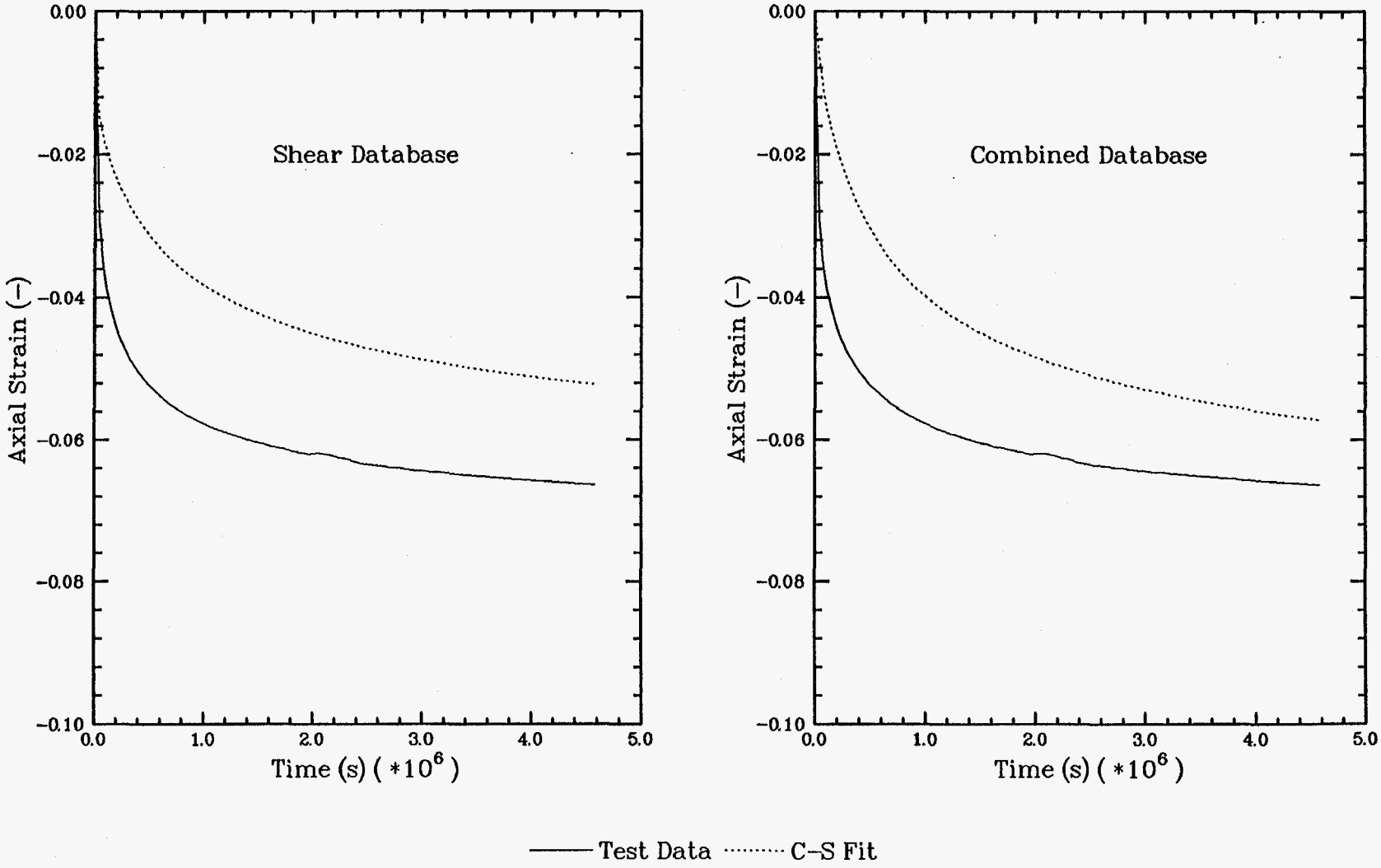


Figure C-15. Hydrostatic Consolidation Test HC5A

—— Test Data ····· C-S Fit

Figure C-16. Hydrostatic Consolidation Test HC6A

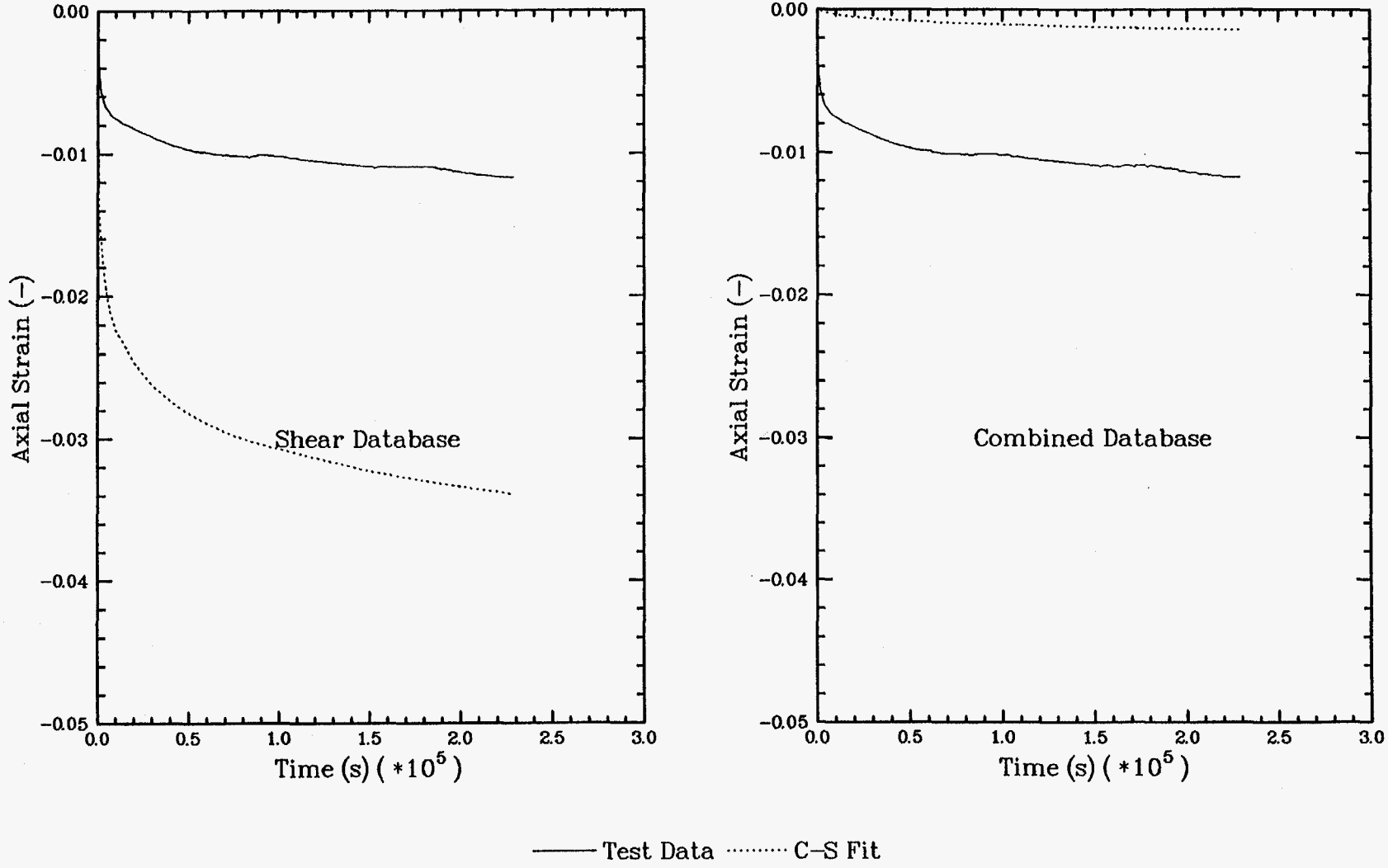


Figure C-17. Hydrostatic Consolidation Test 27JUL82

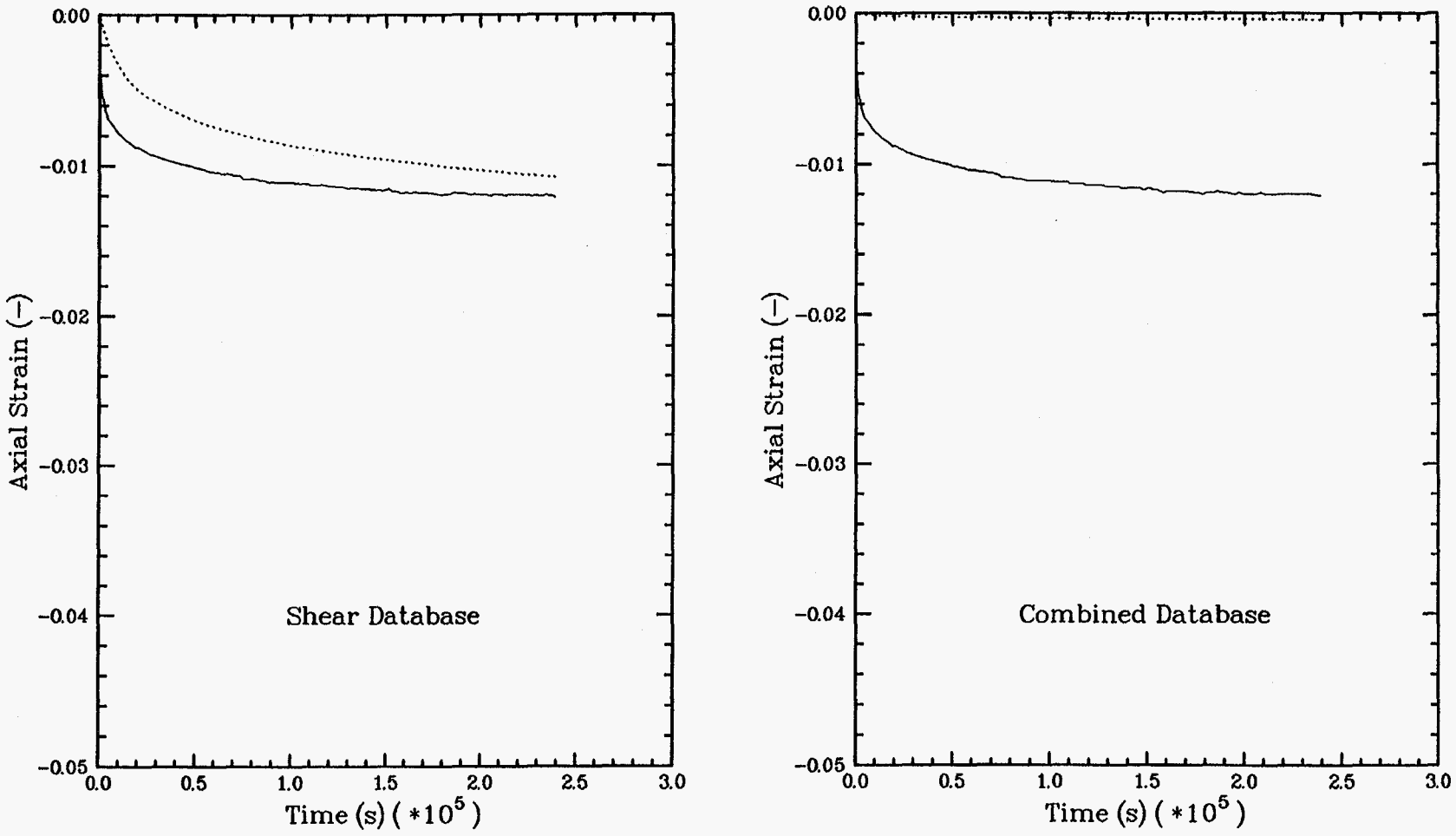


Figure C-18. Hydrostatic Consolidation Test 04MAY82

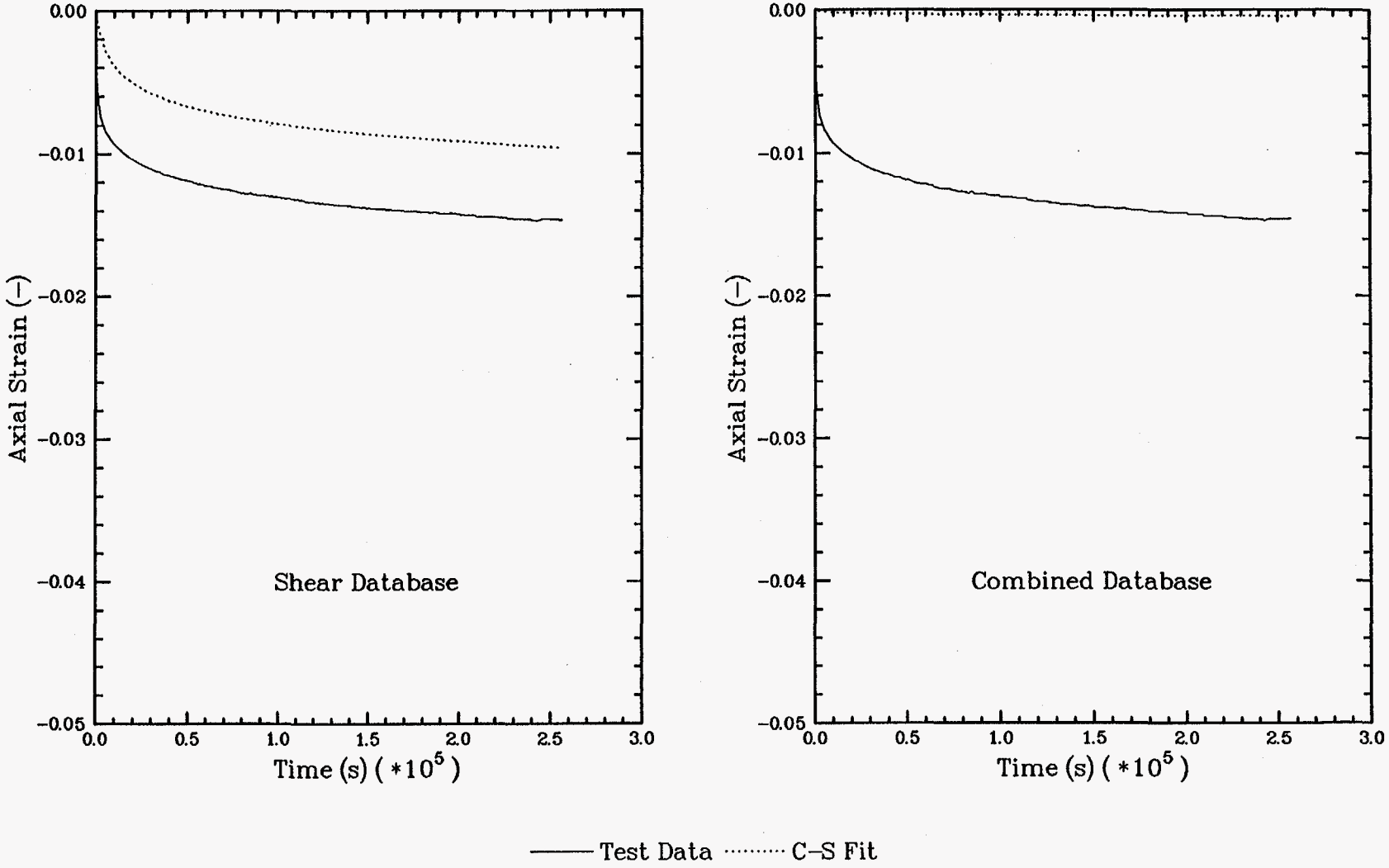


Figure C-19. Hydrostatic Consolidation Test 30APR82

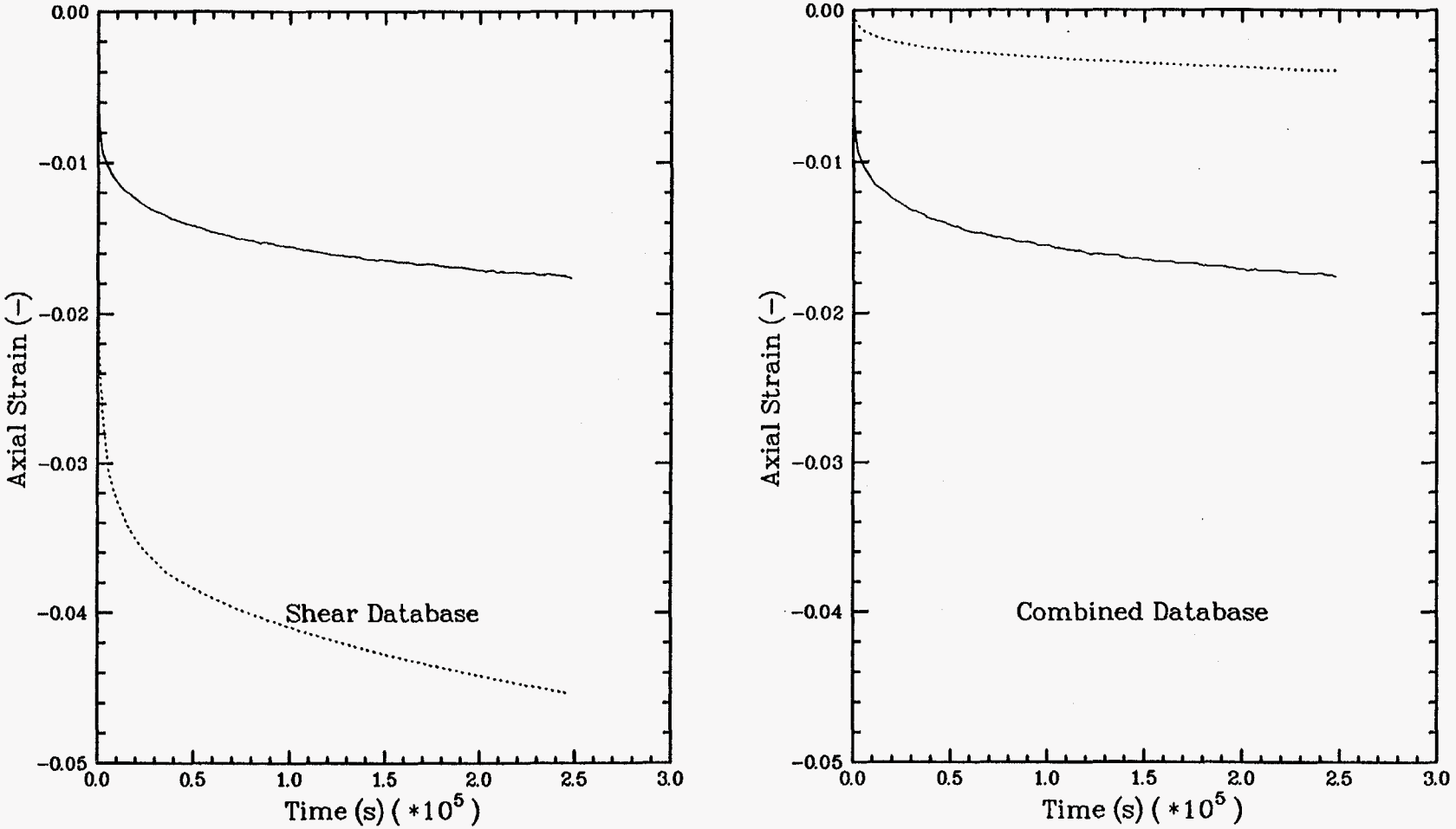


Figure C-20. Hydrostatic Consolidation Test 07MAY82

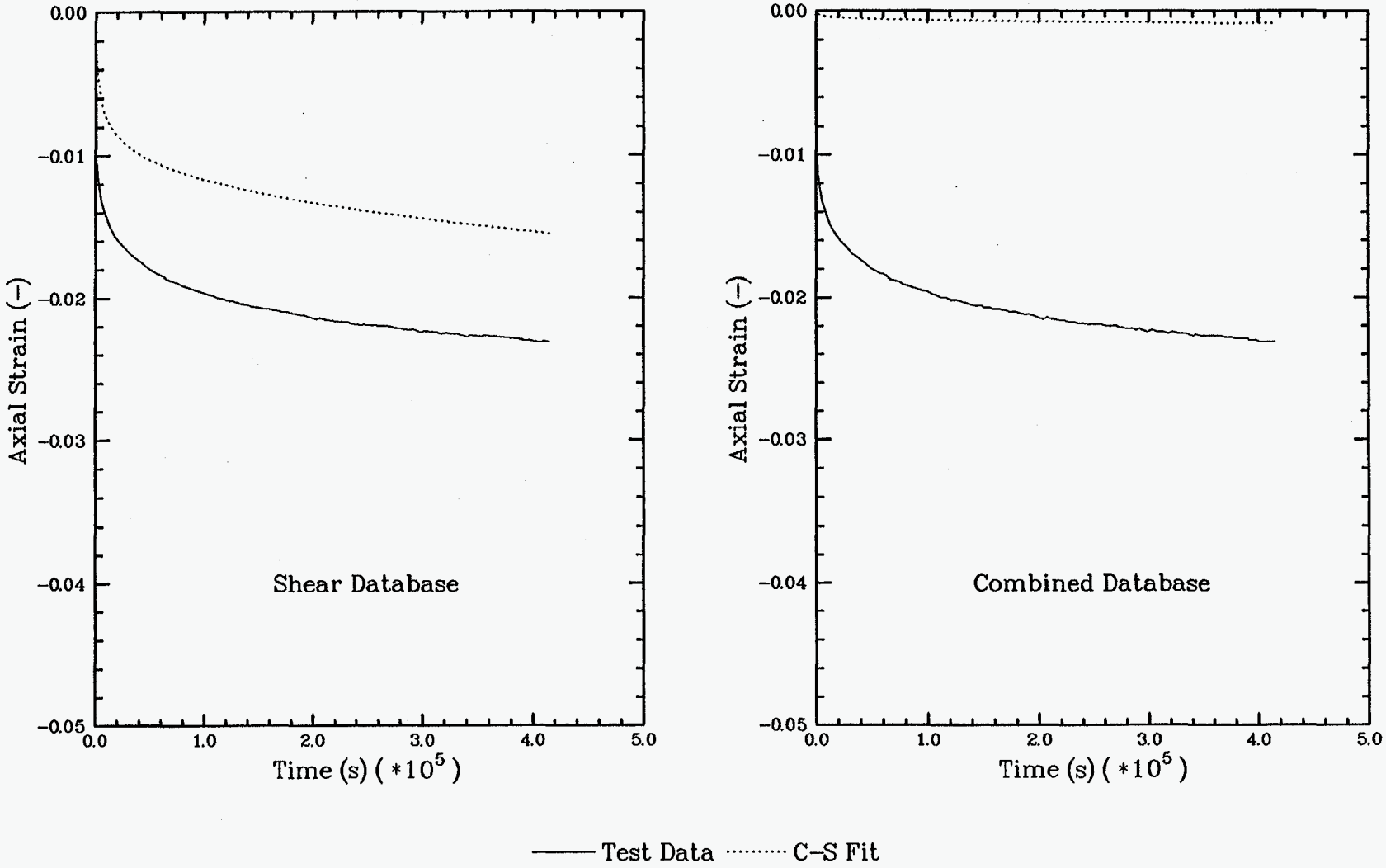


Figure C-21. Hydrostatic Consolidation Test 12MAY82

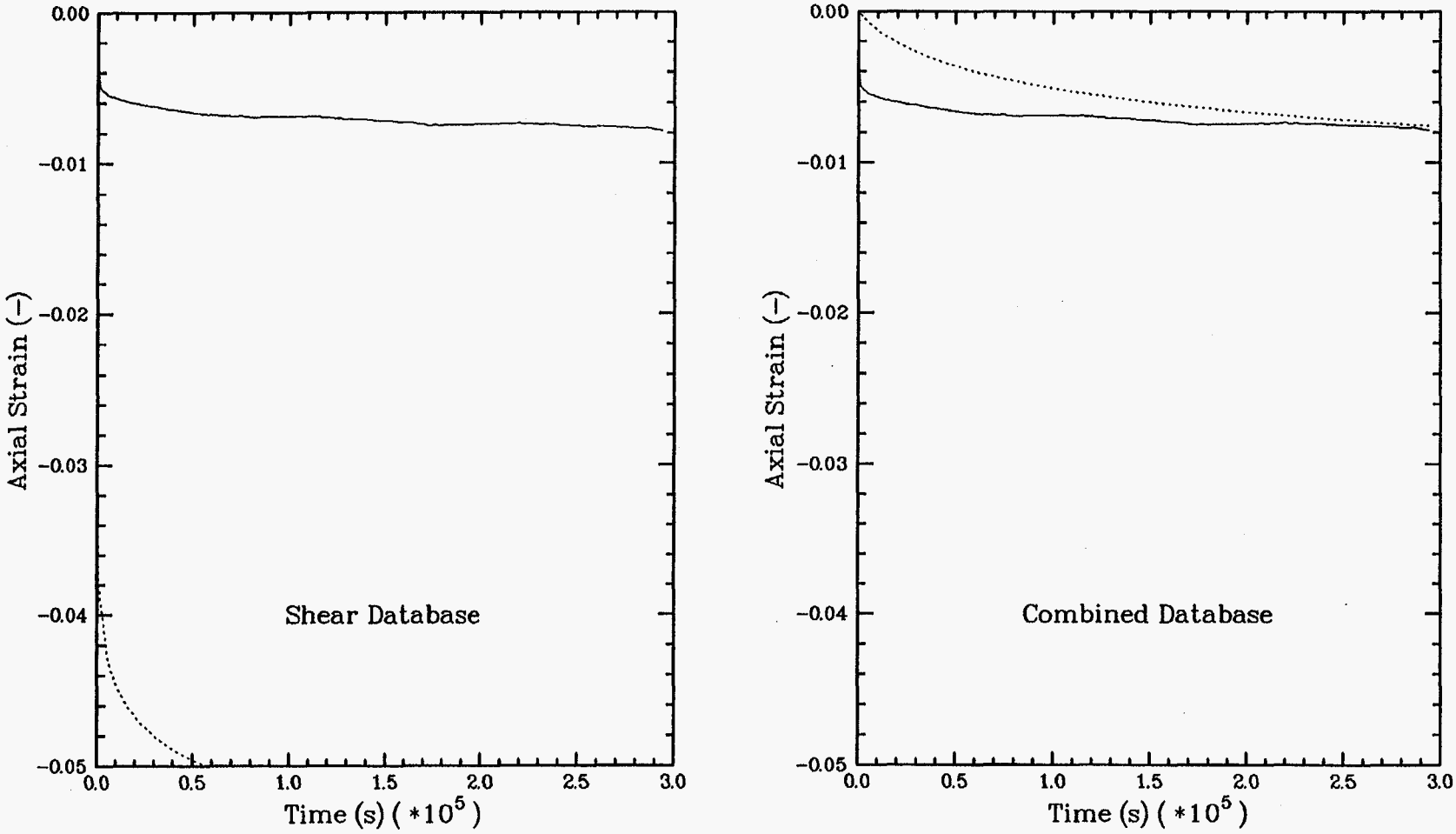


Figure C-22. Hydrostatic Consolidation Test 05FEB82

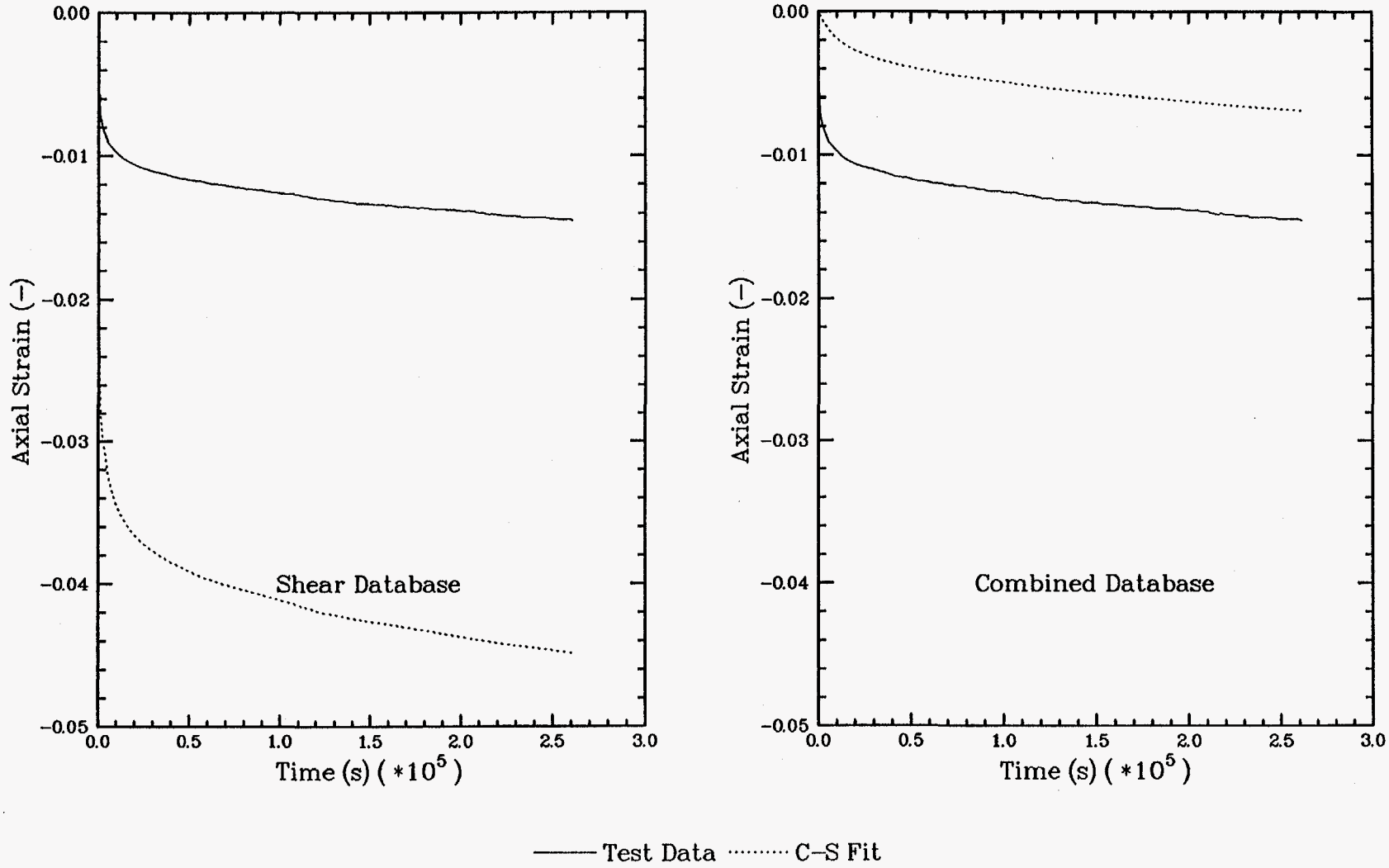


Figure C-23. Hydrostatic Consolidation Test 09APR82

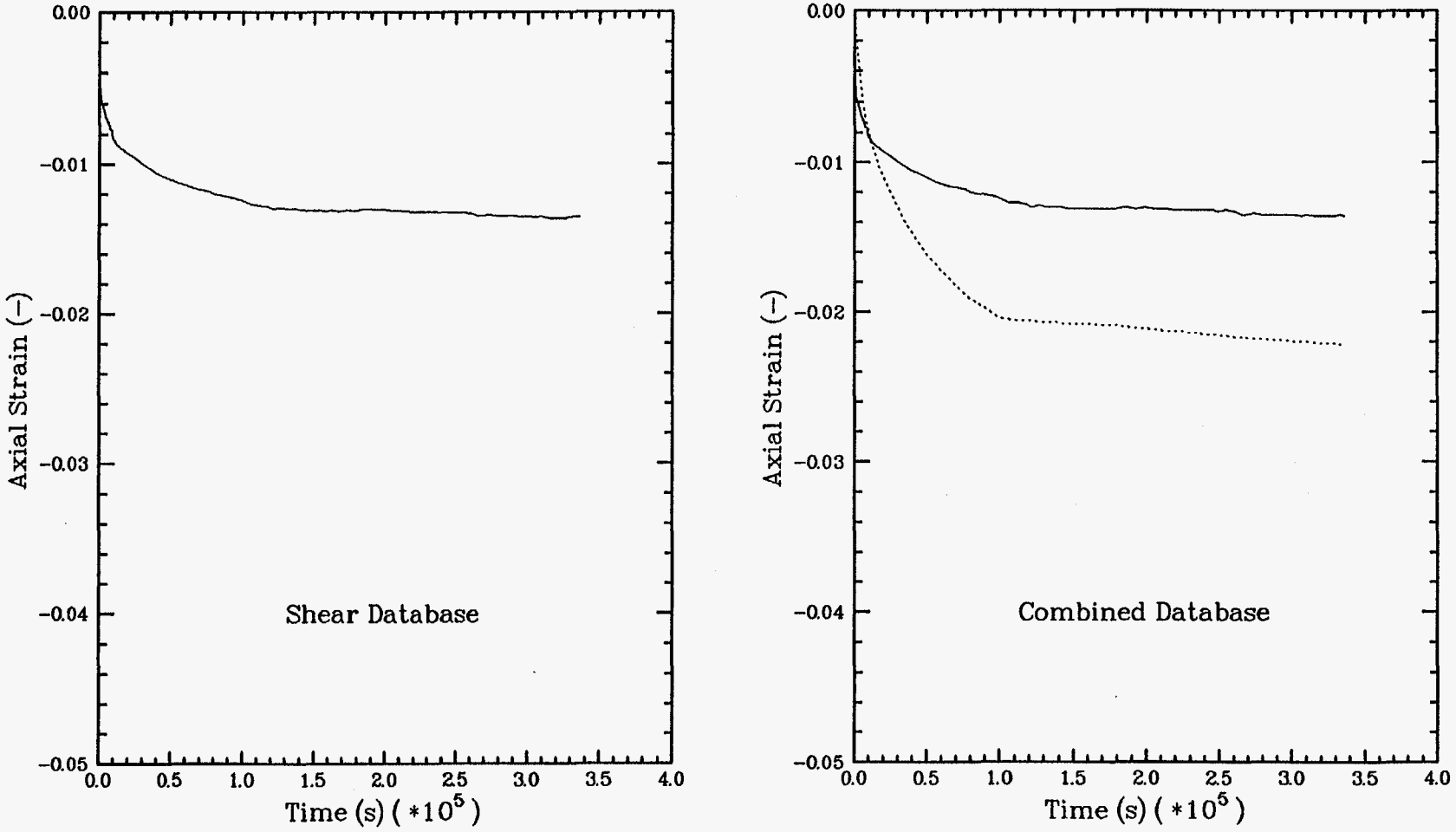
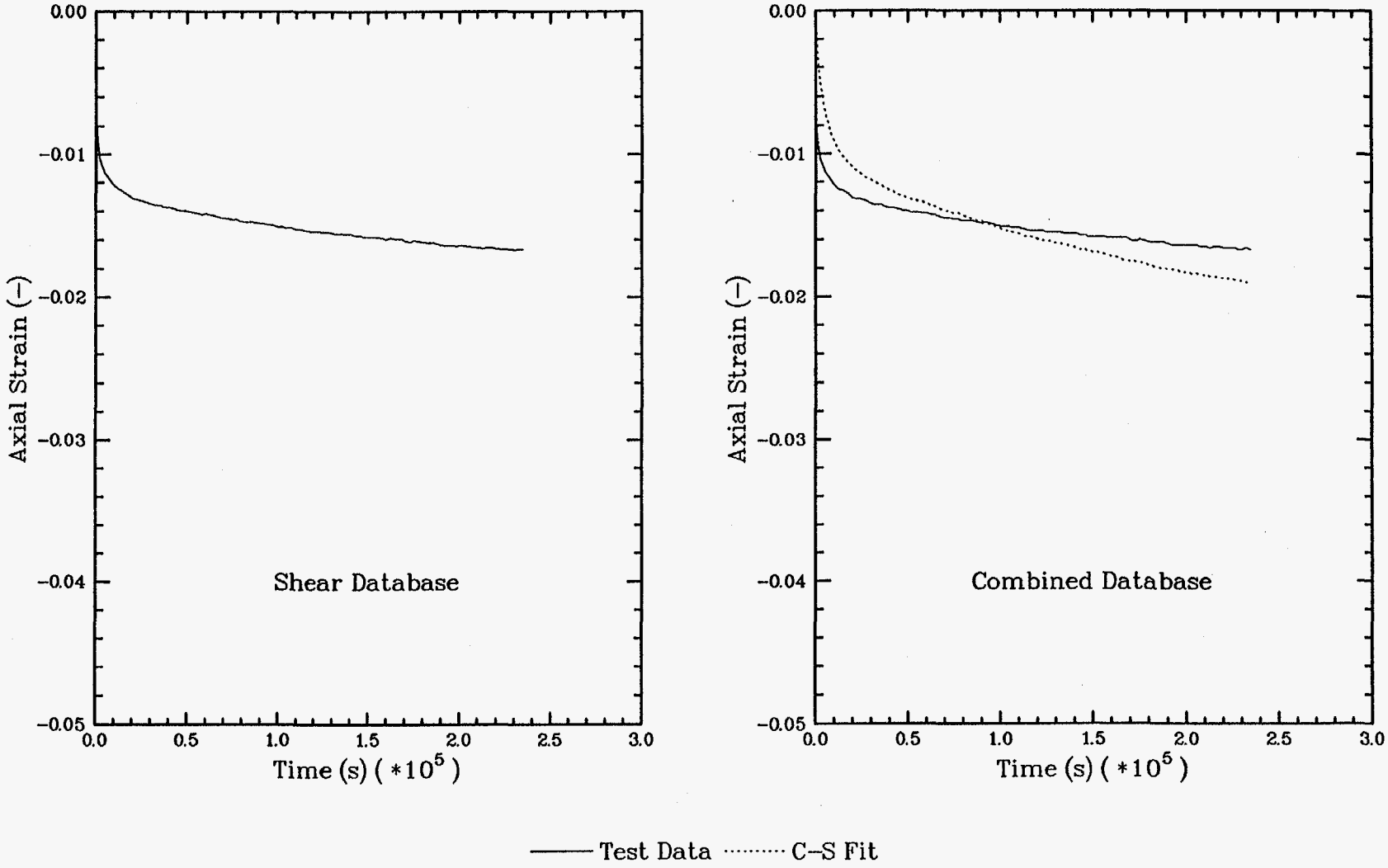


Figure C-24. Hydrostatic Consolidation Test 26MAR82



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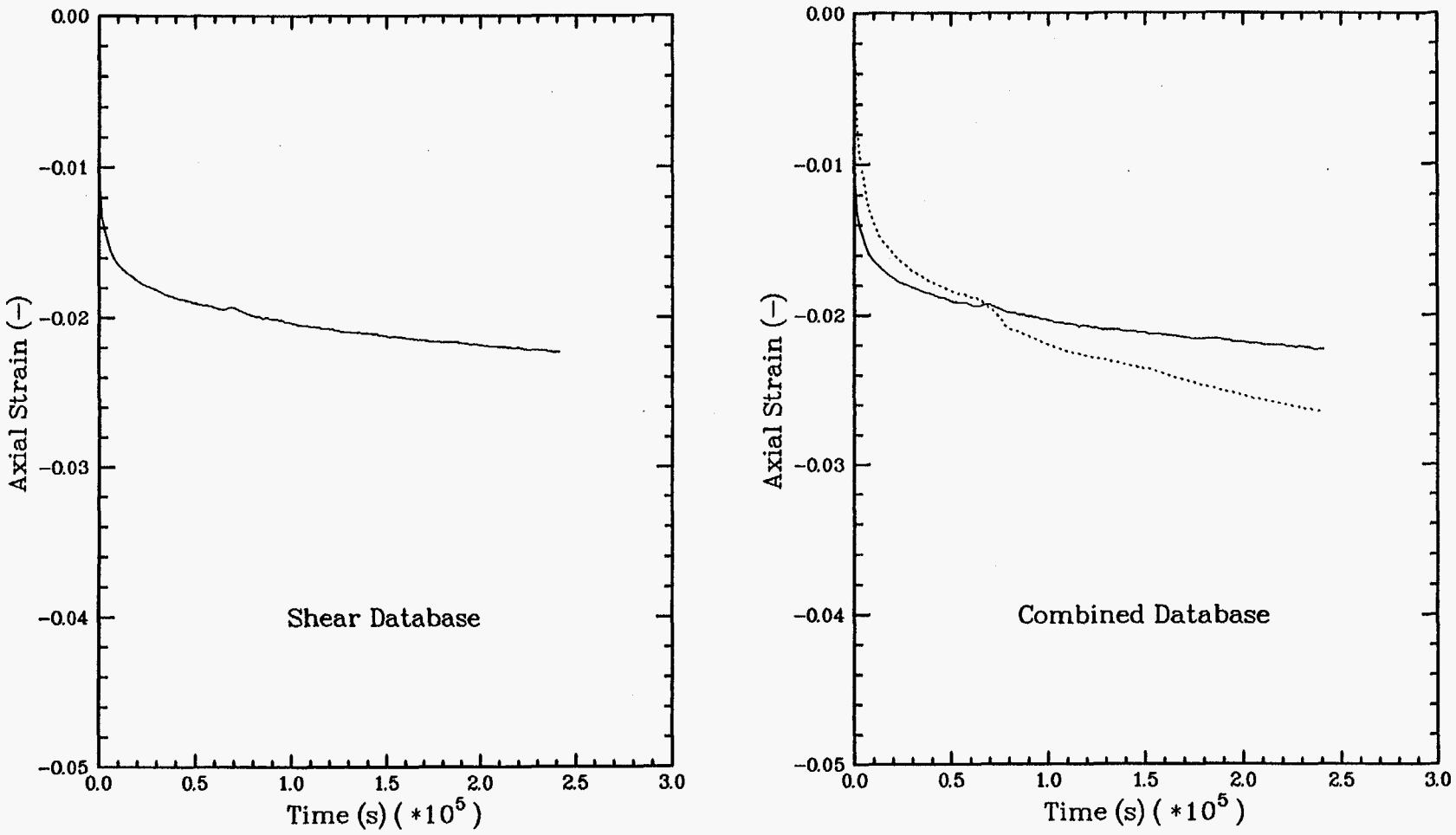
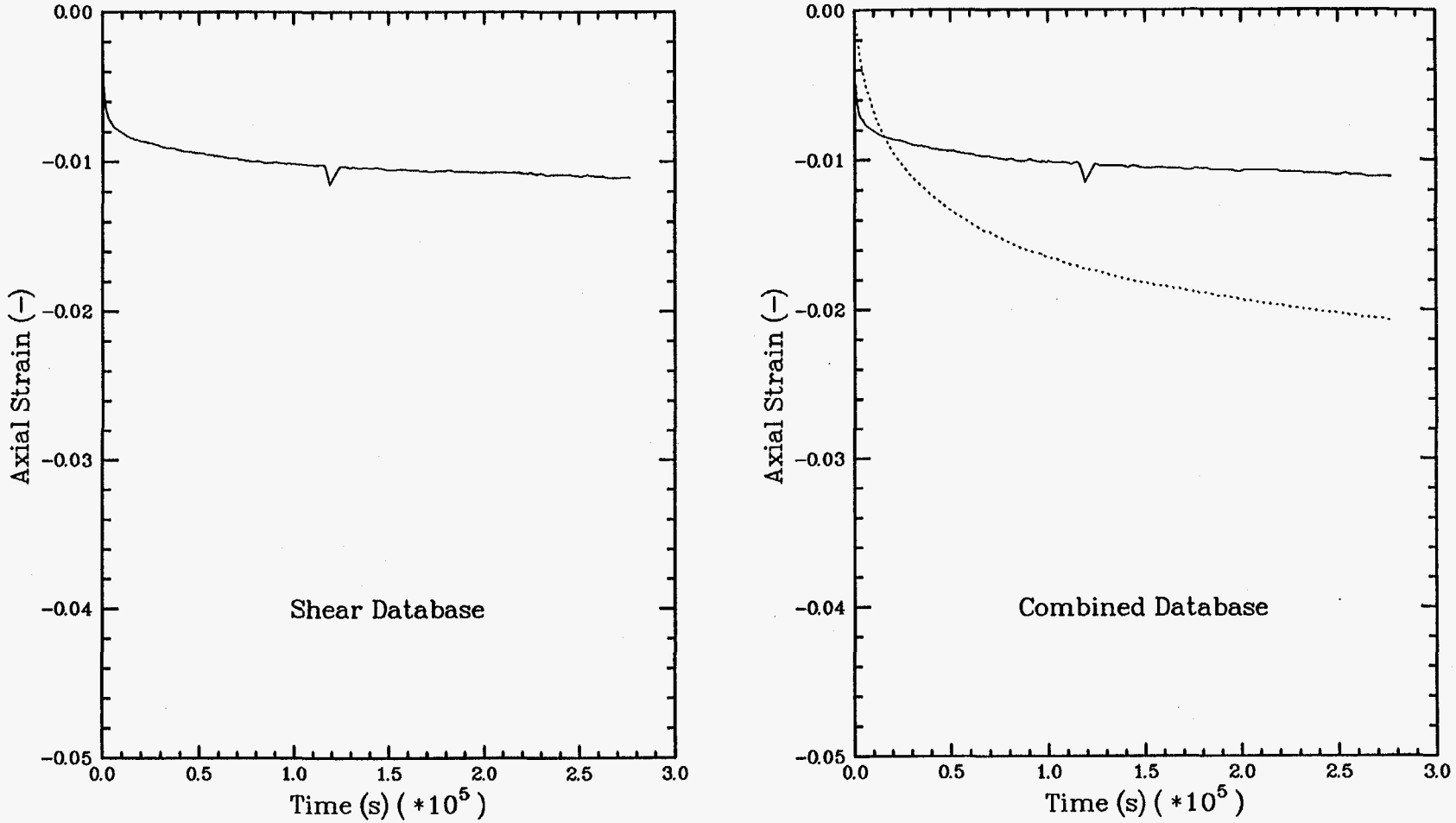


Figure C-26. Hydrostatic Consolidation Test 13APR82



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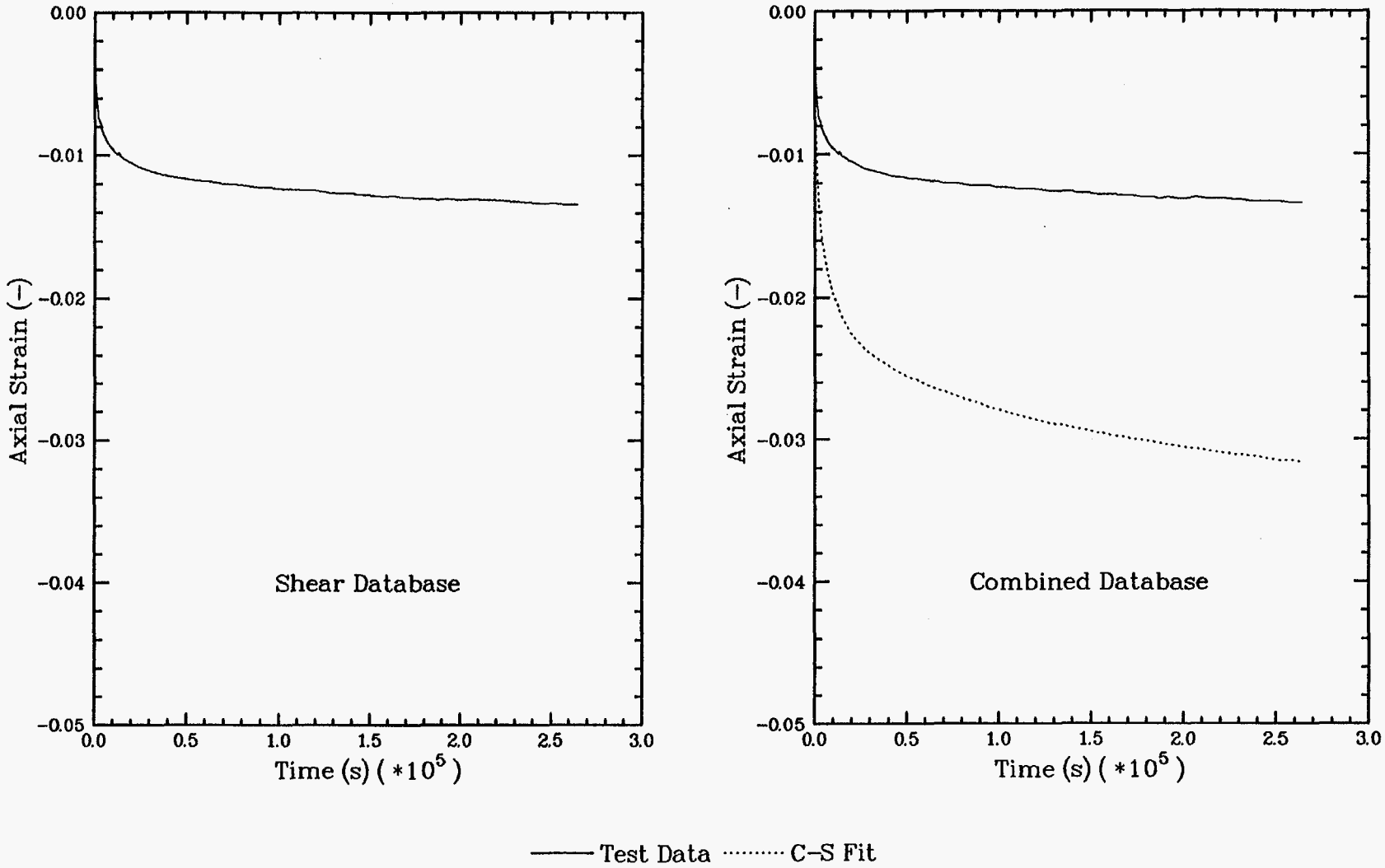

Figure C-28. Hydrostatic Consolidation Test 26FEB82

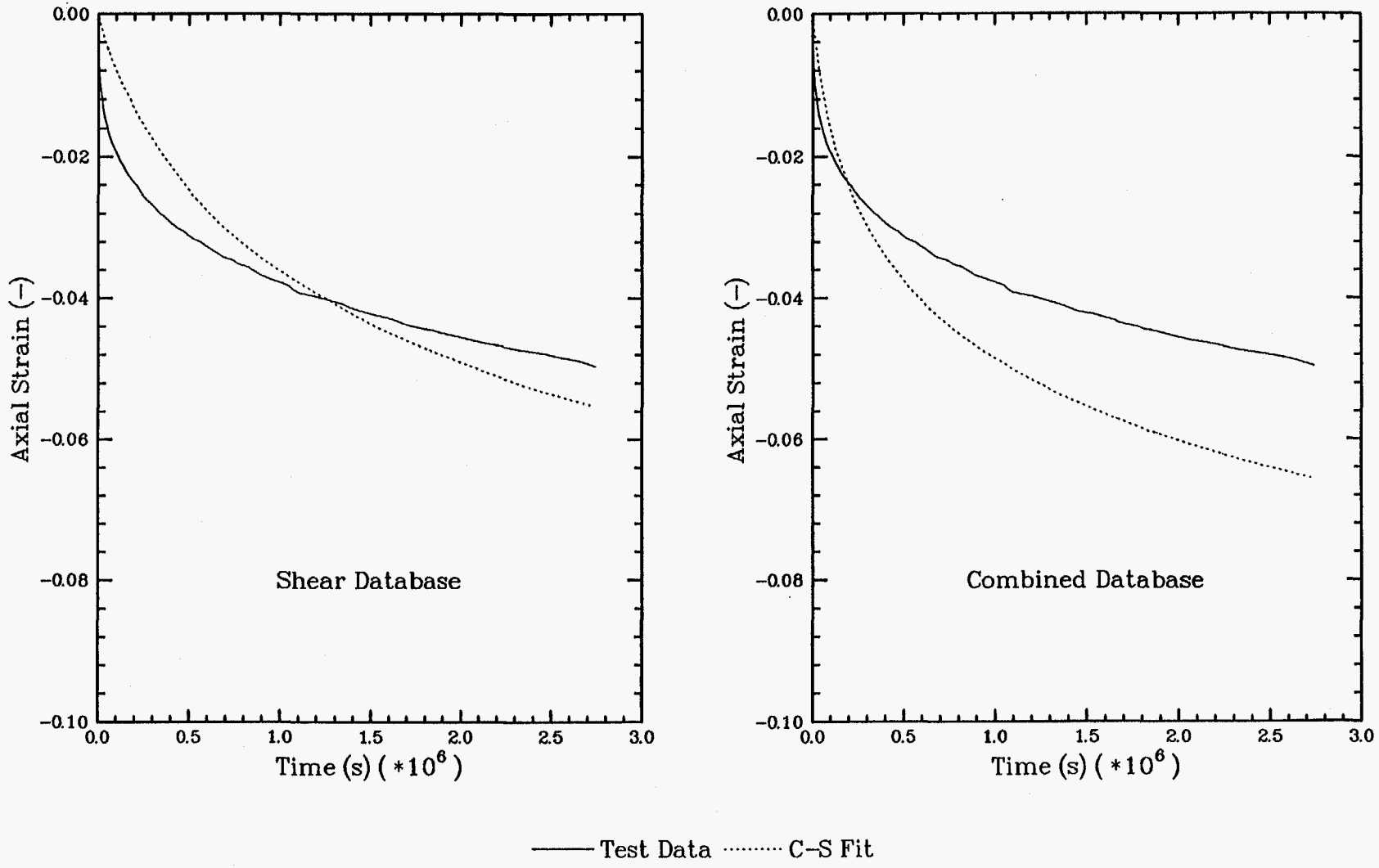

Figure C-29. Hydrostatic Consolidation Test 27JU61

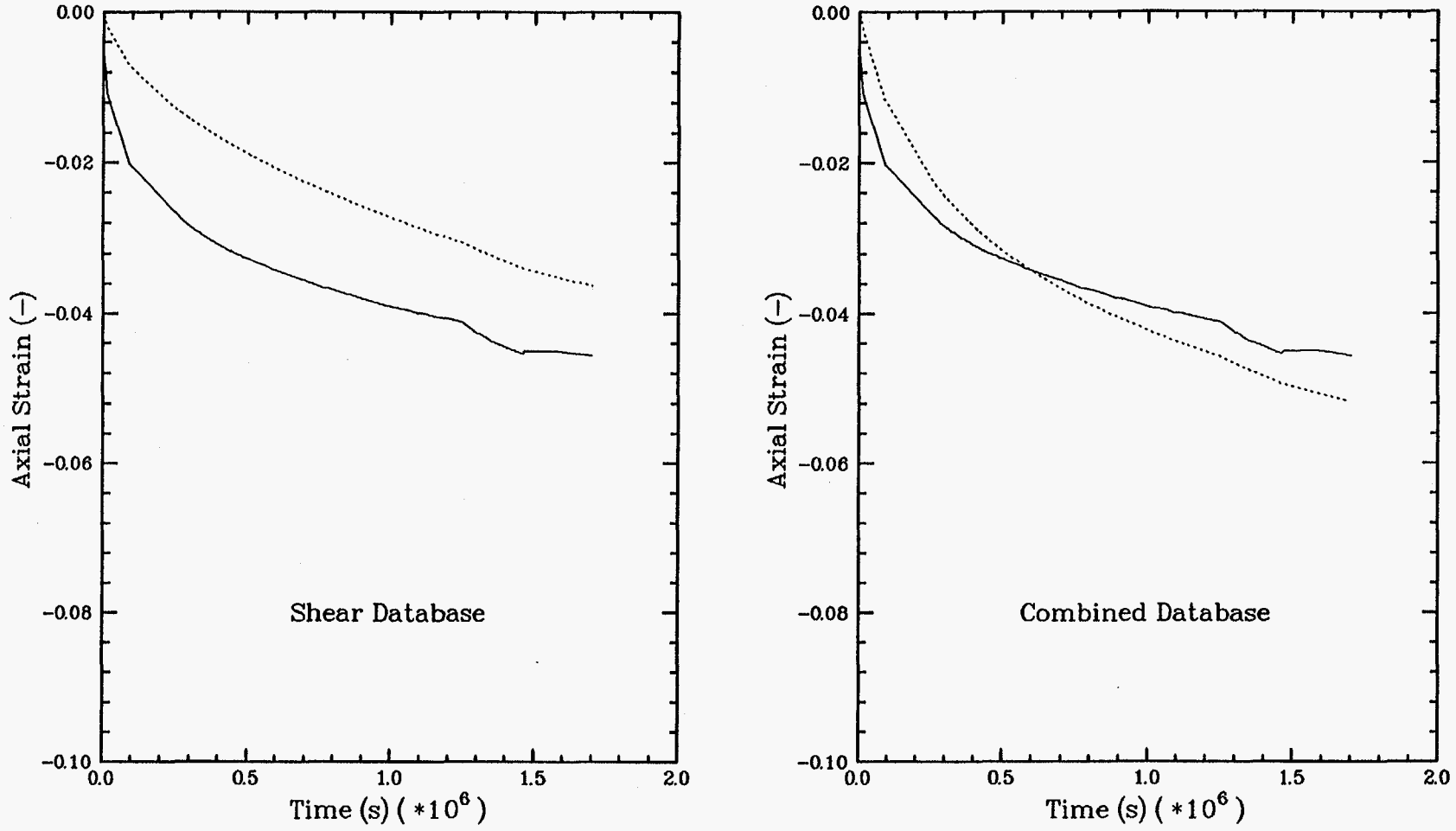

Figure C-30. Hydrostatic Consolidation Test 23JL51

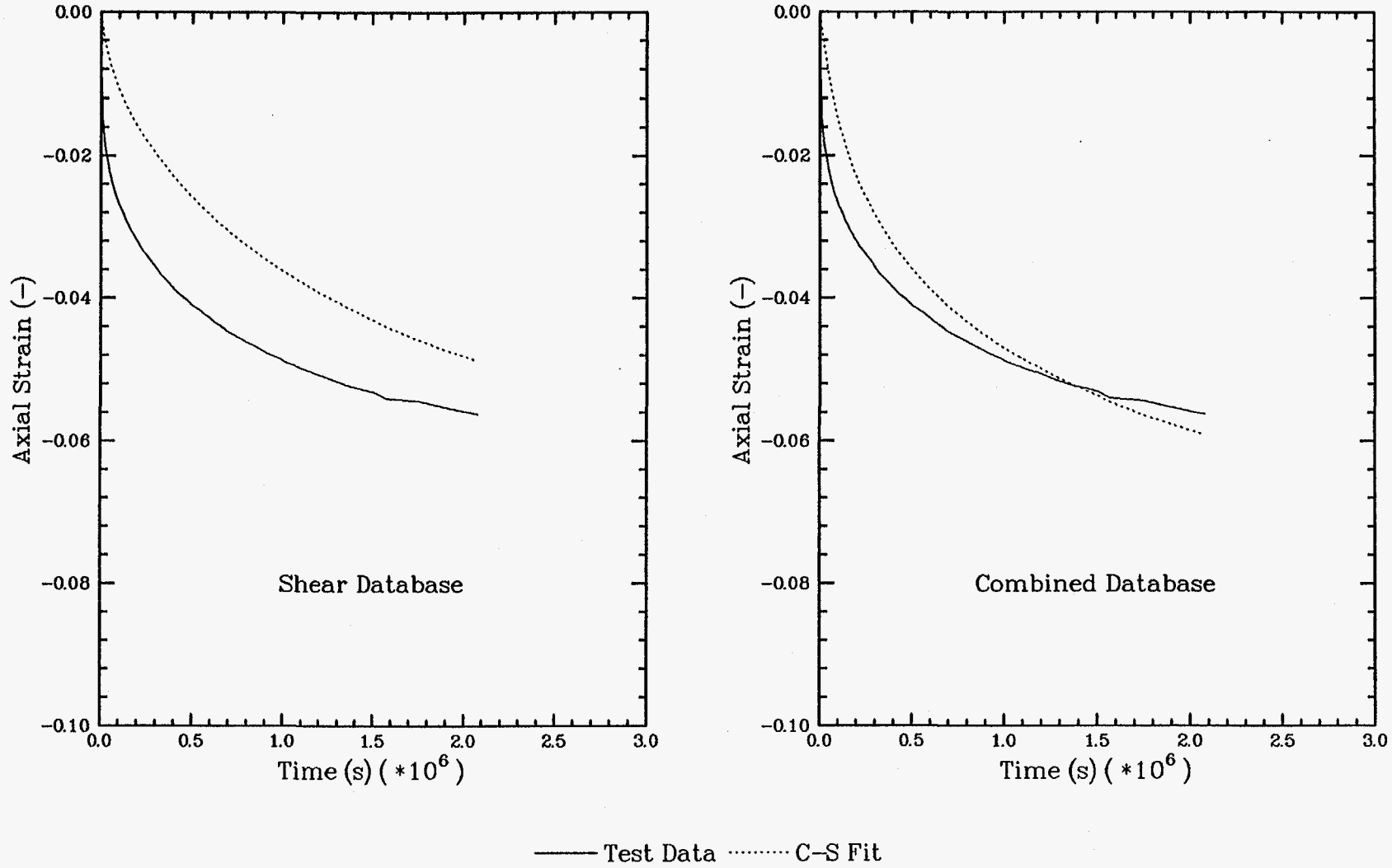

Figure C-31. Hydrostatic Consolidation Test 14NV51

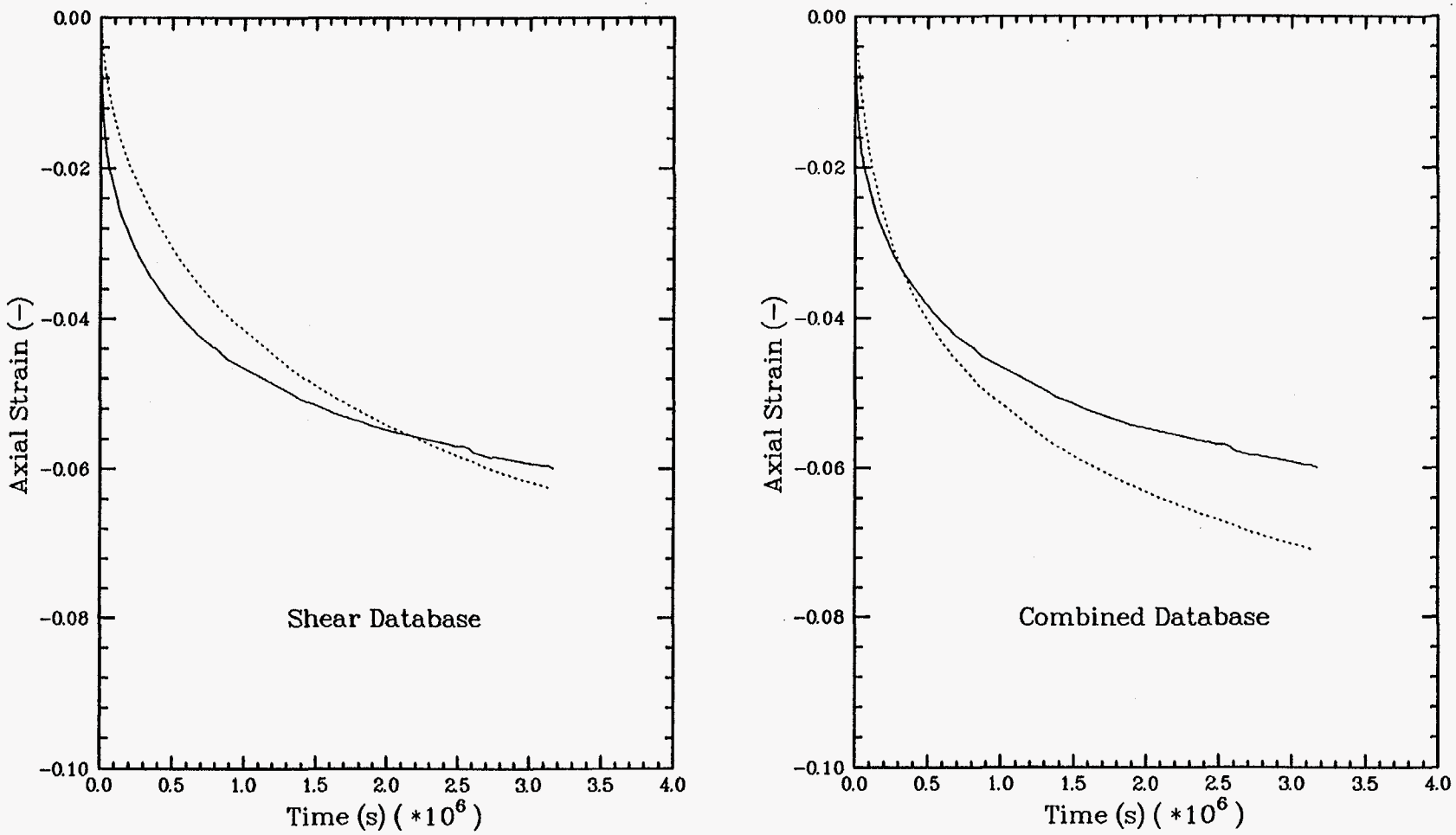

Figure C-32. Hydrostatic Consolidation Test 25FEB61

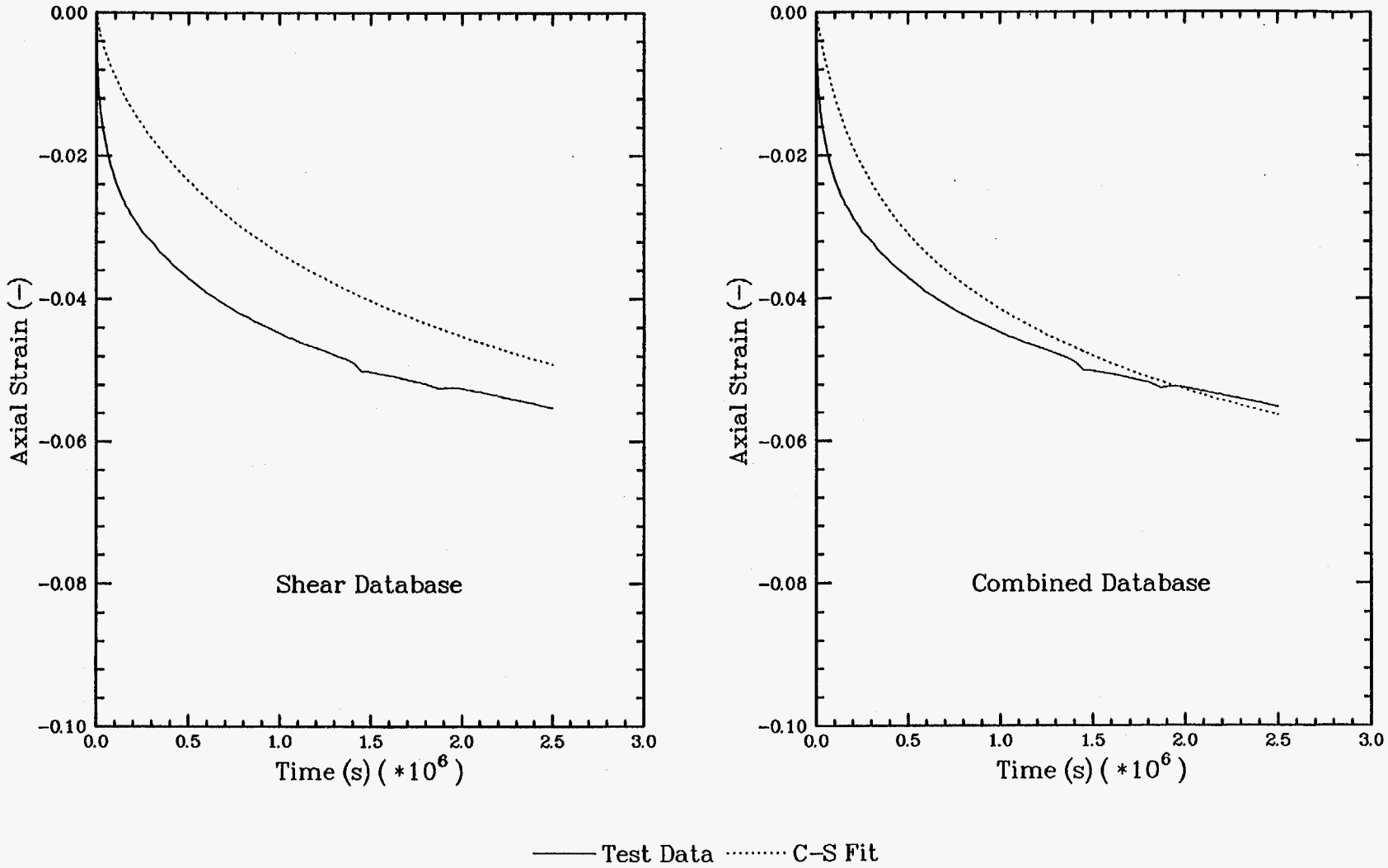

Figure C-33. Hydrostatic Consolidation Test 10MY51

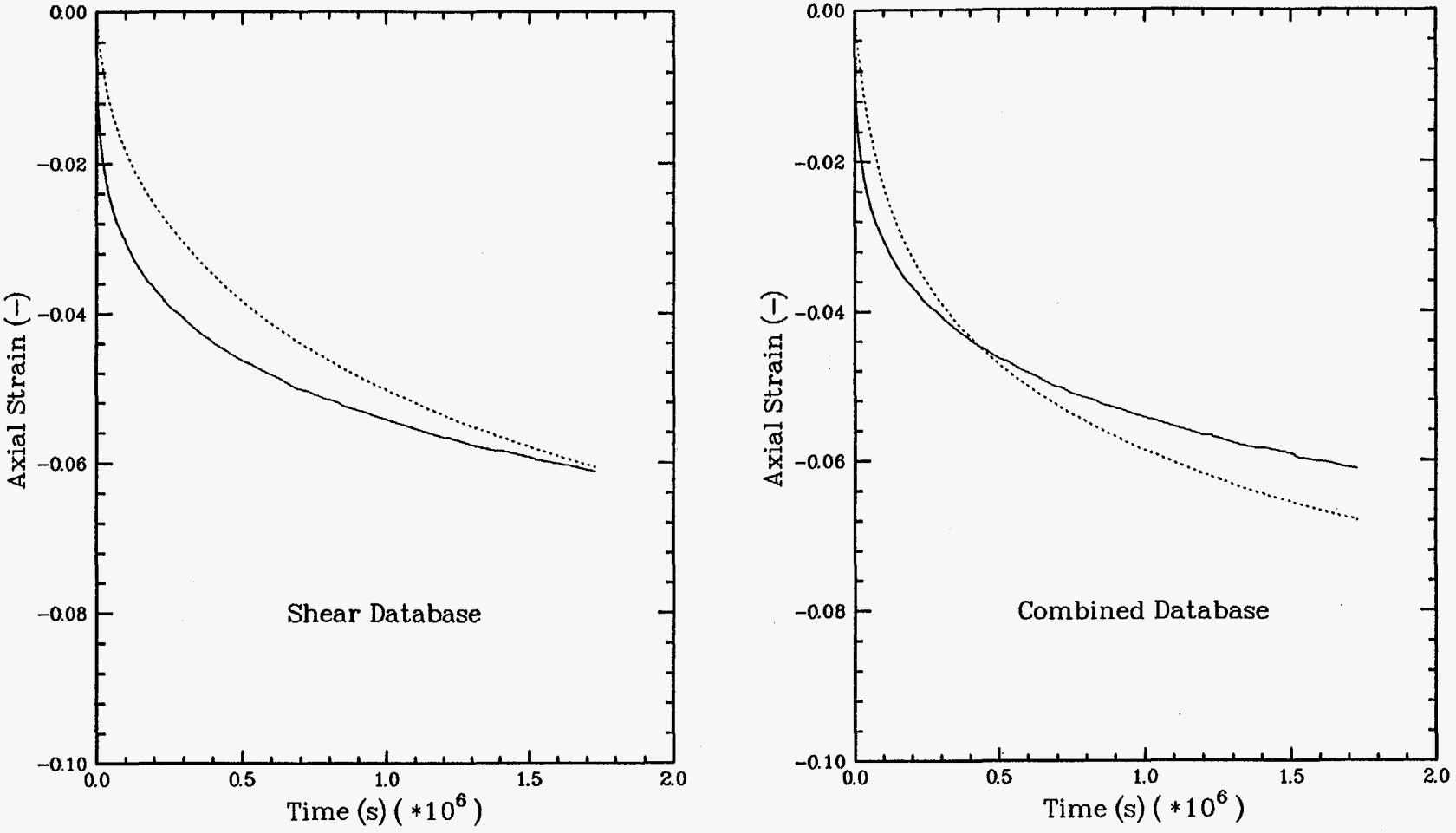

Figure C-34. Hydrostatic Consolidation Test 20AU51

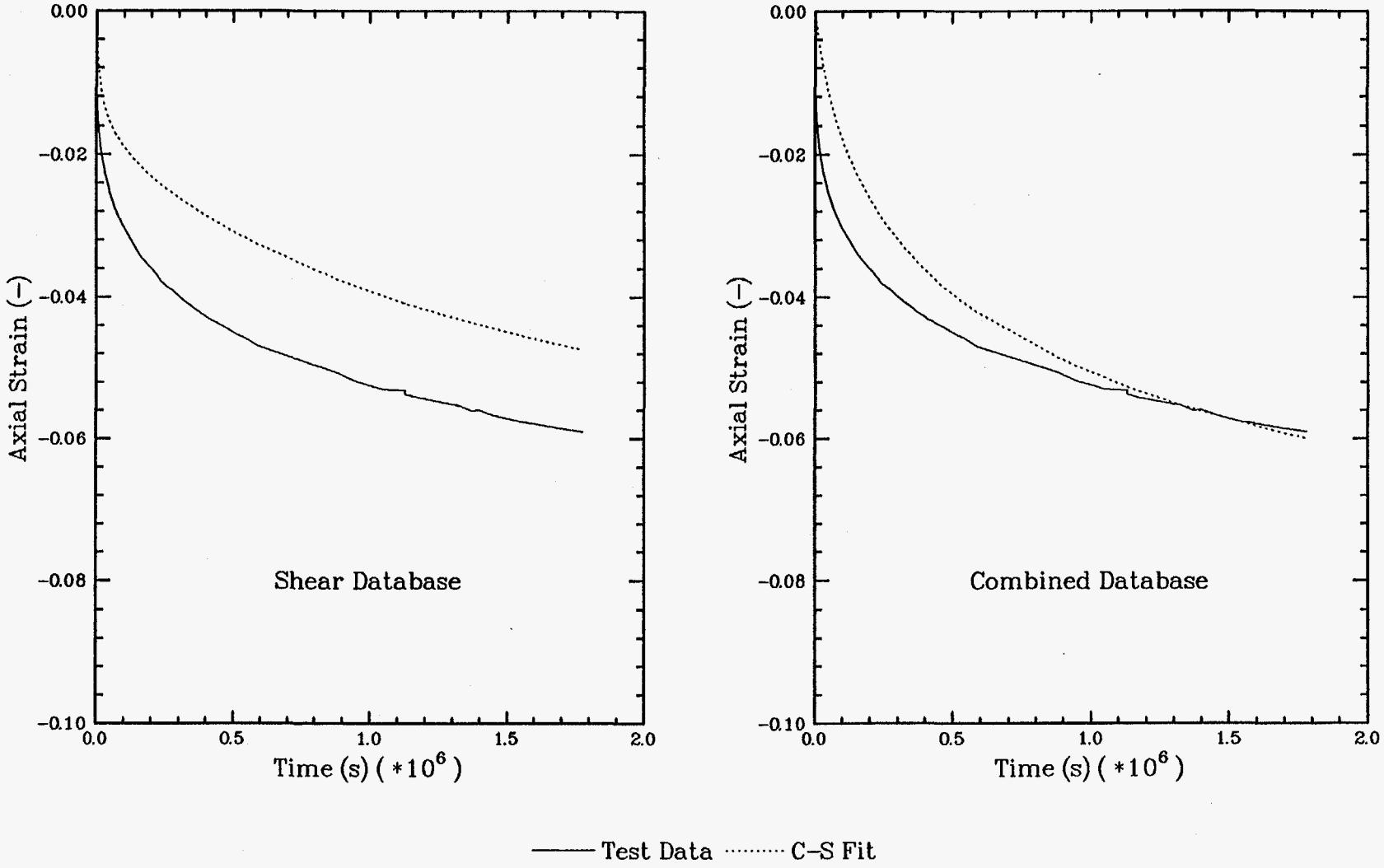

Figure C-35. Hydrostatic Consolidation Test 16JL51

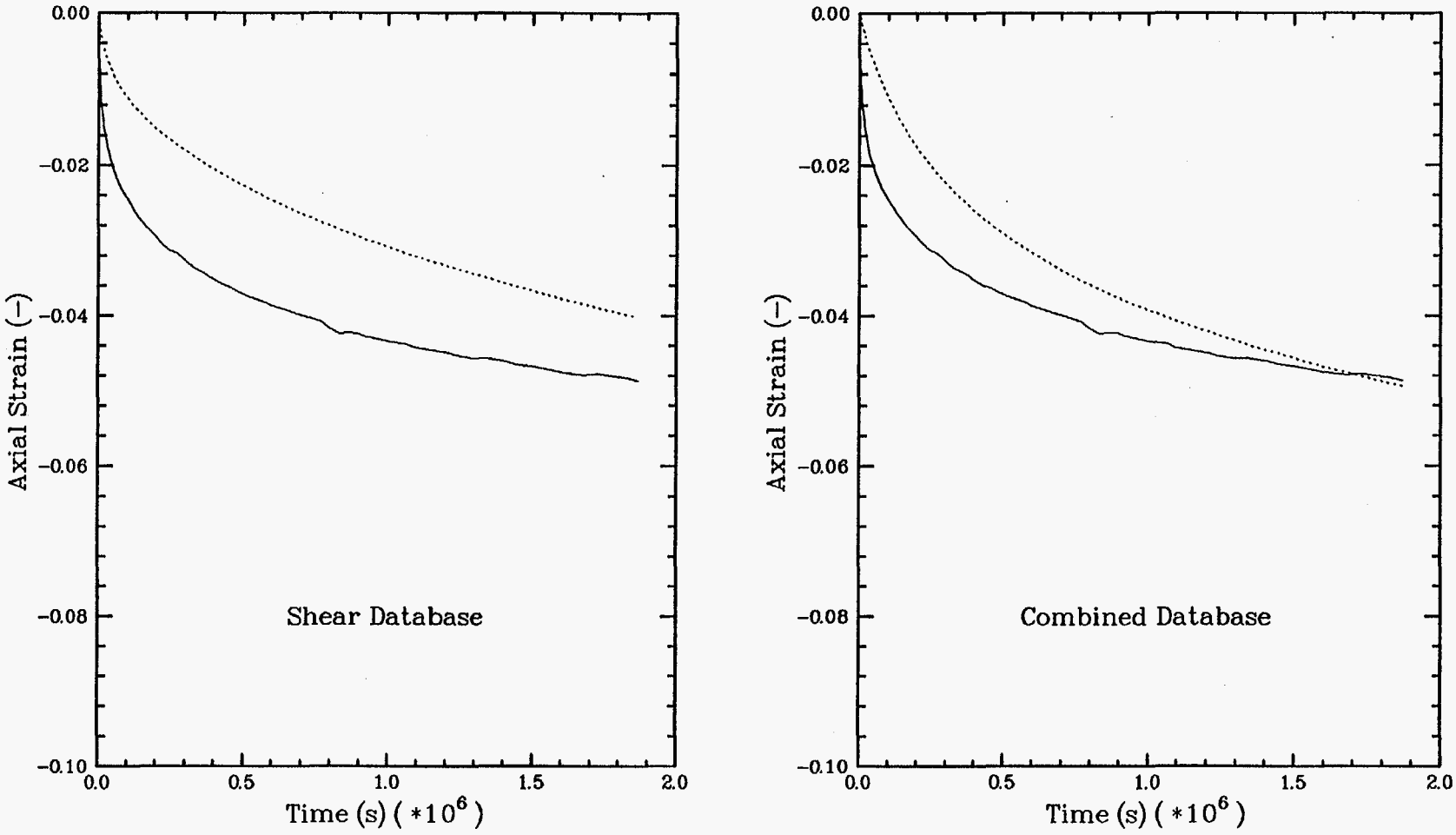

Figure C-36. Hydrostatic Consolidation Test 18JU51

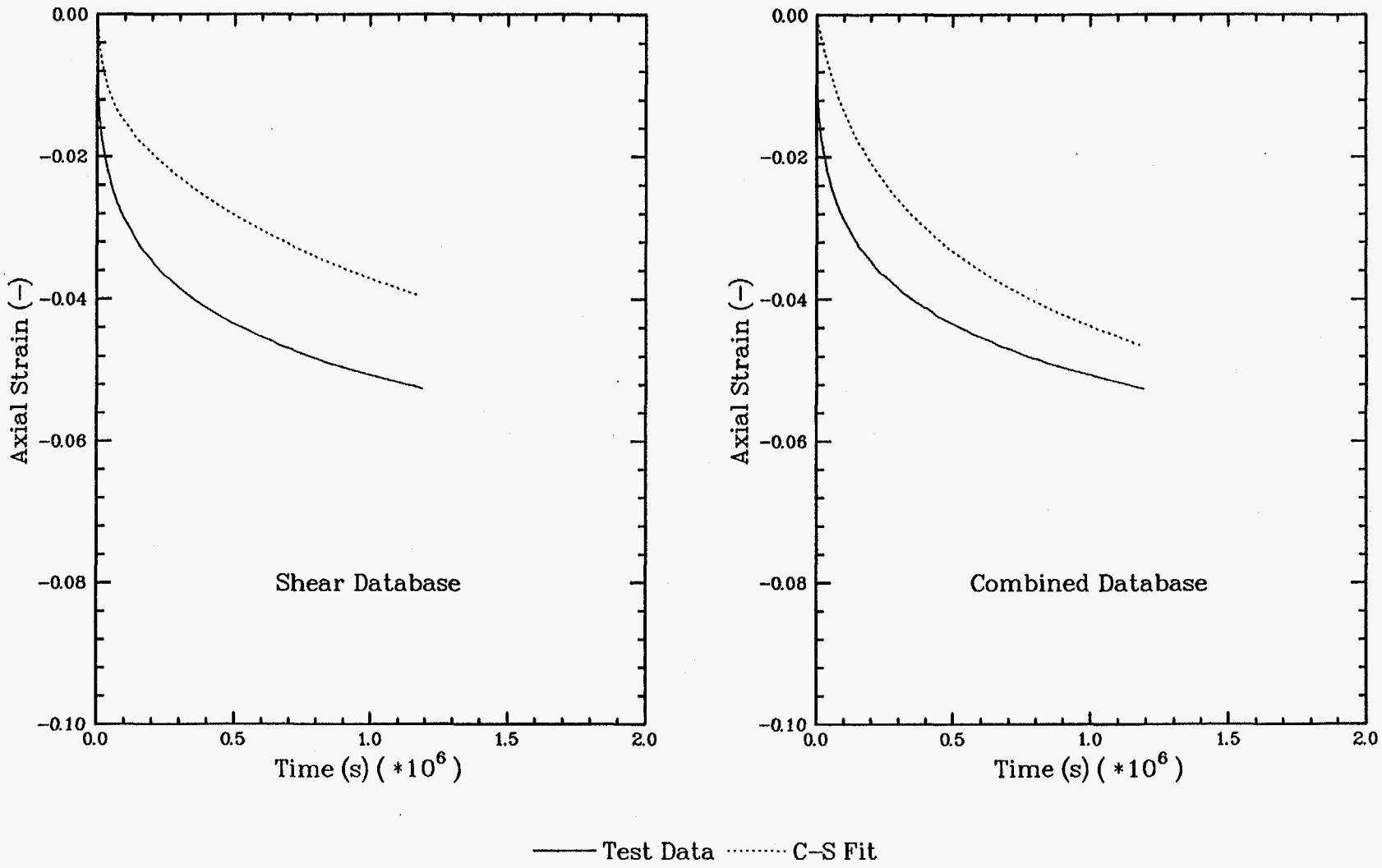

Figure C-37. Hydrostatic Consolidation Test 300C51

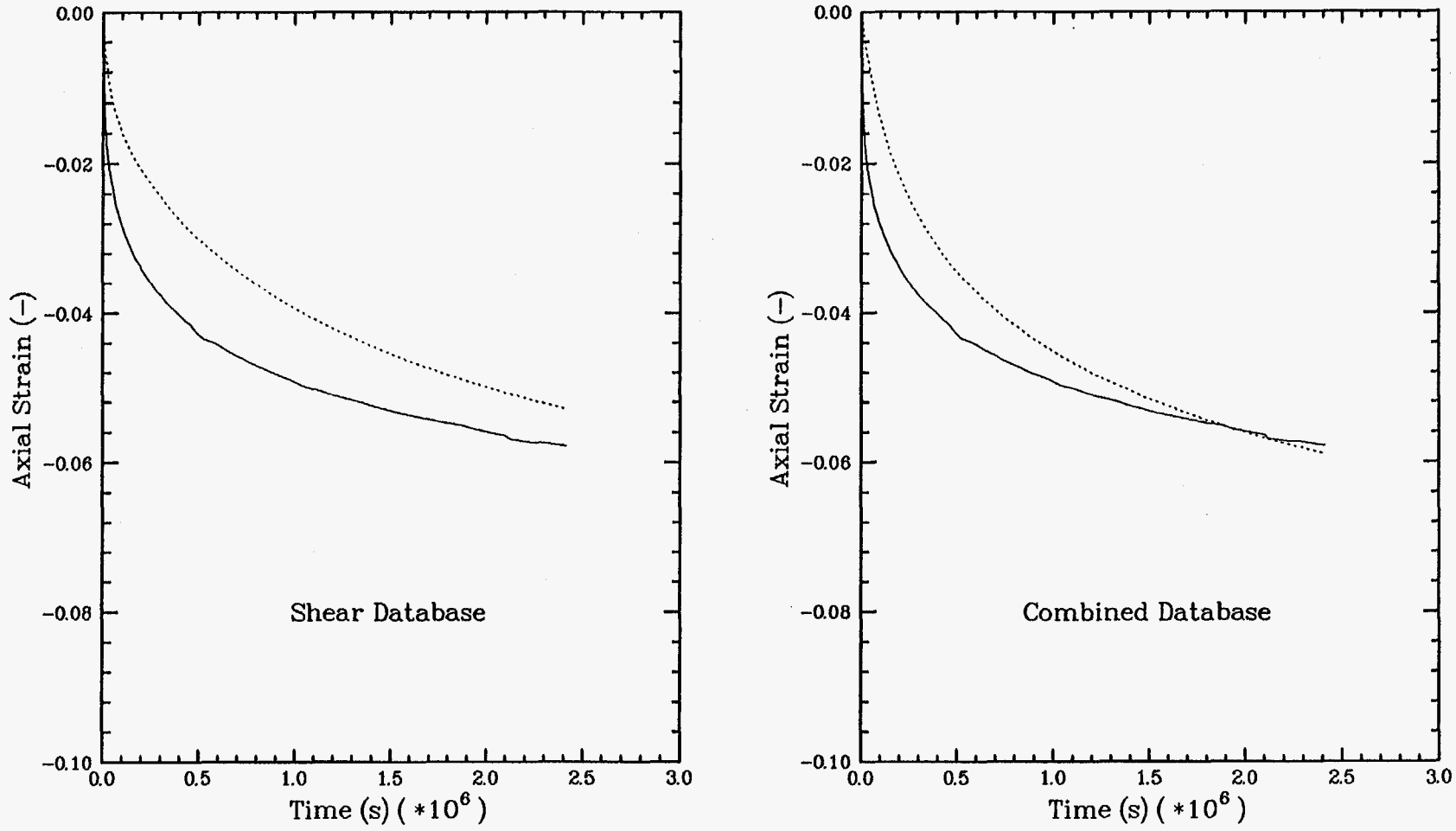

Figure C-38. Hydrostatic Consolidation Test 16JA61

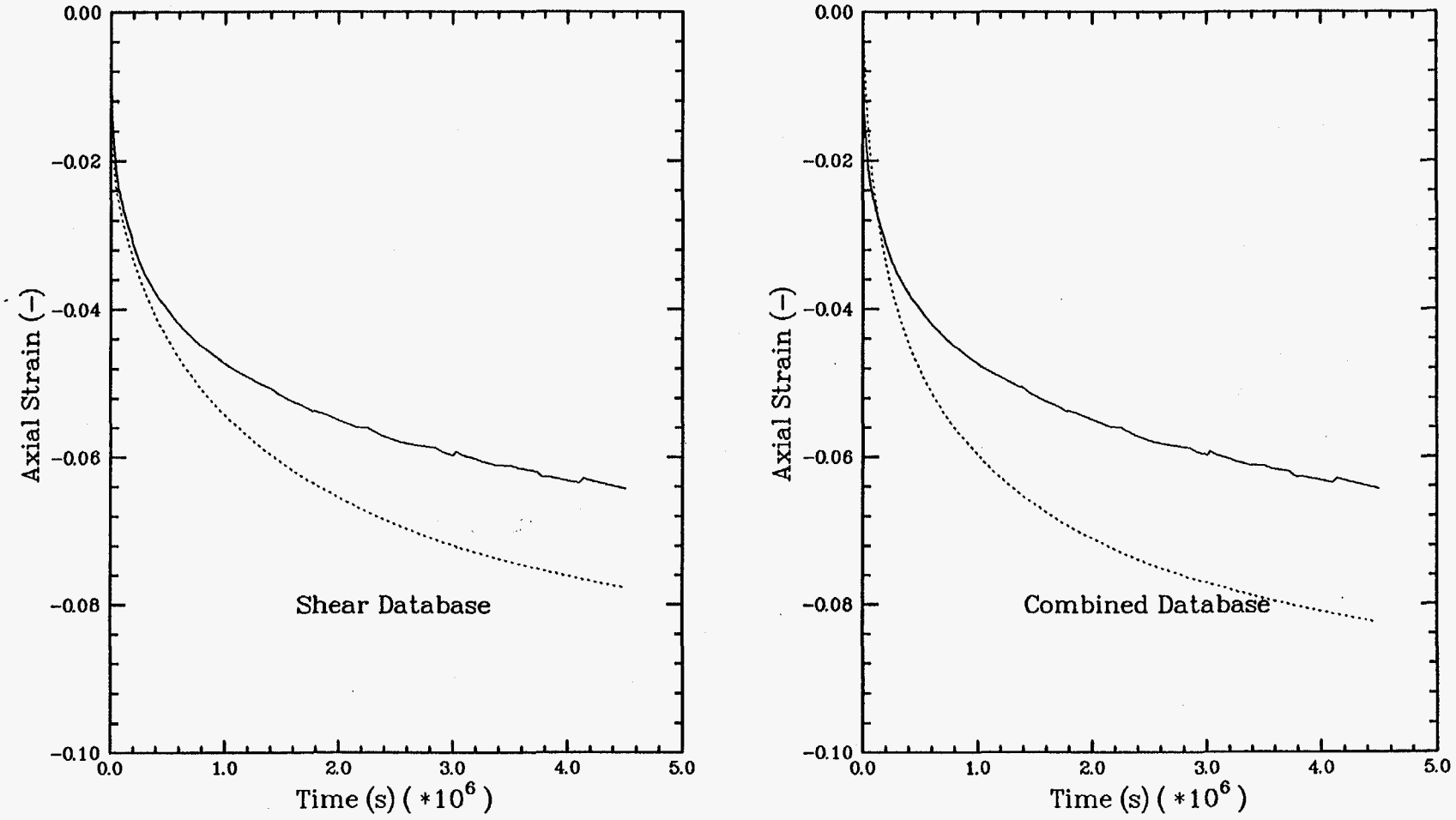

Figure C-39. Hydrostatic Consolidation Test 19DC44

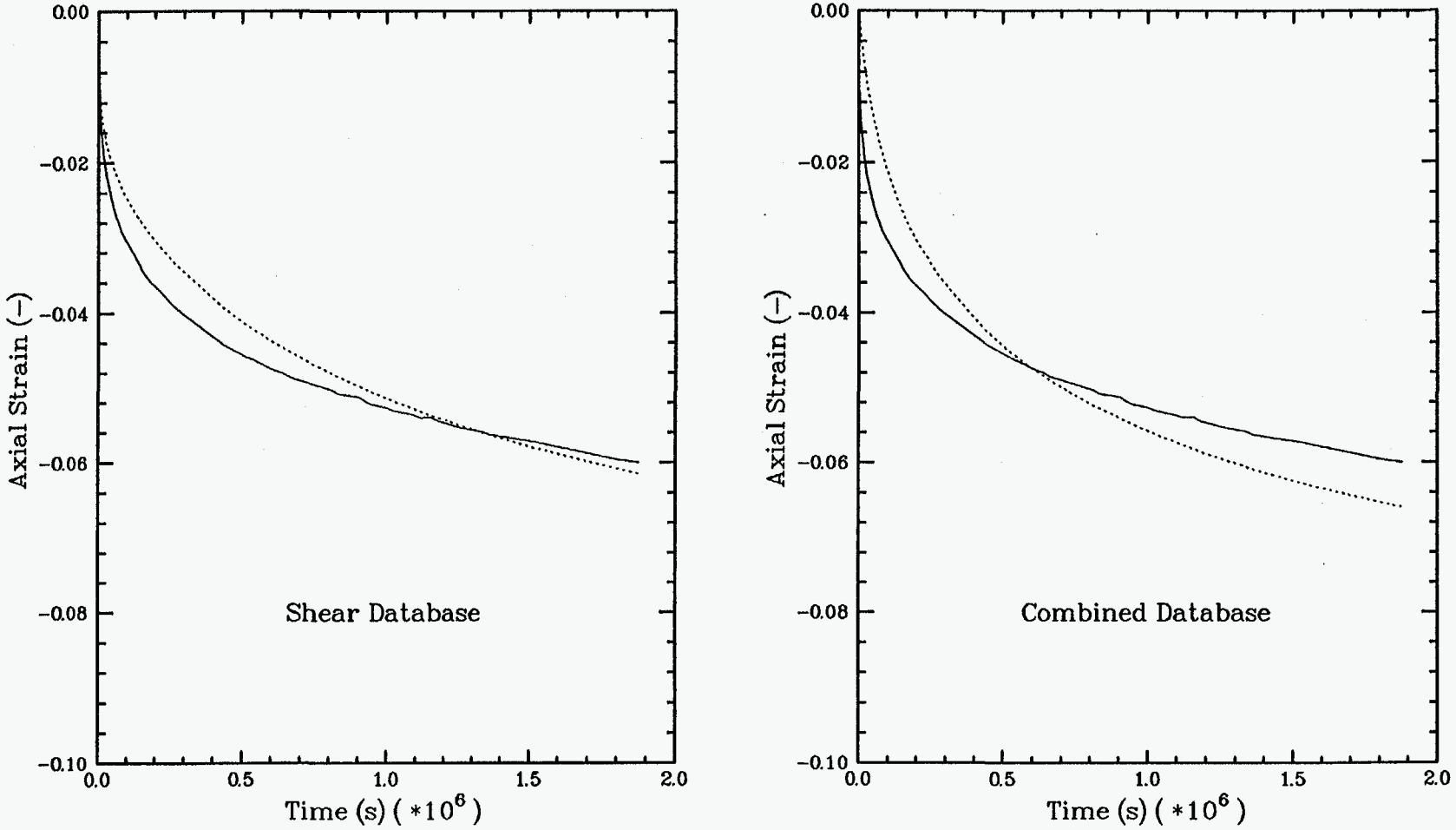

Figure C-40. Hydrostatic Consolidation Test 13AU51

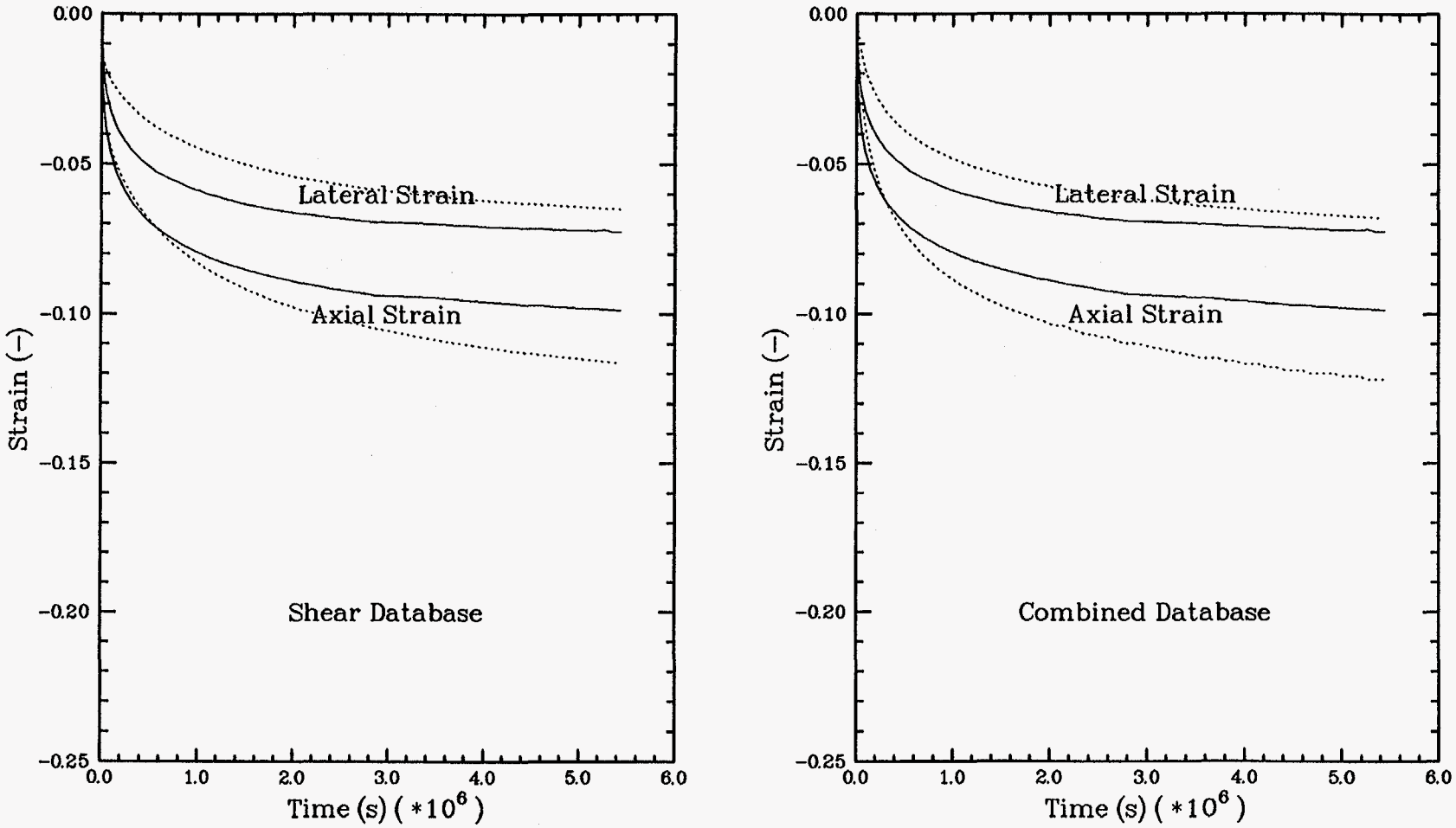

Figure C-41. Shear Consolidation Test SC1B

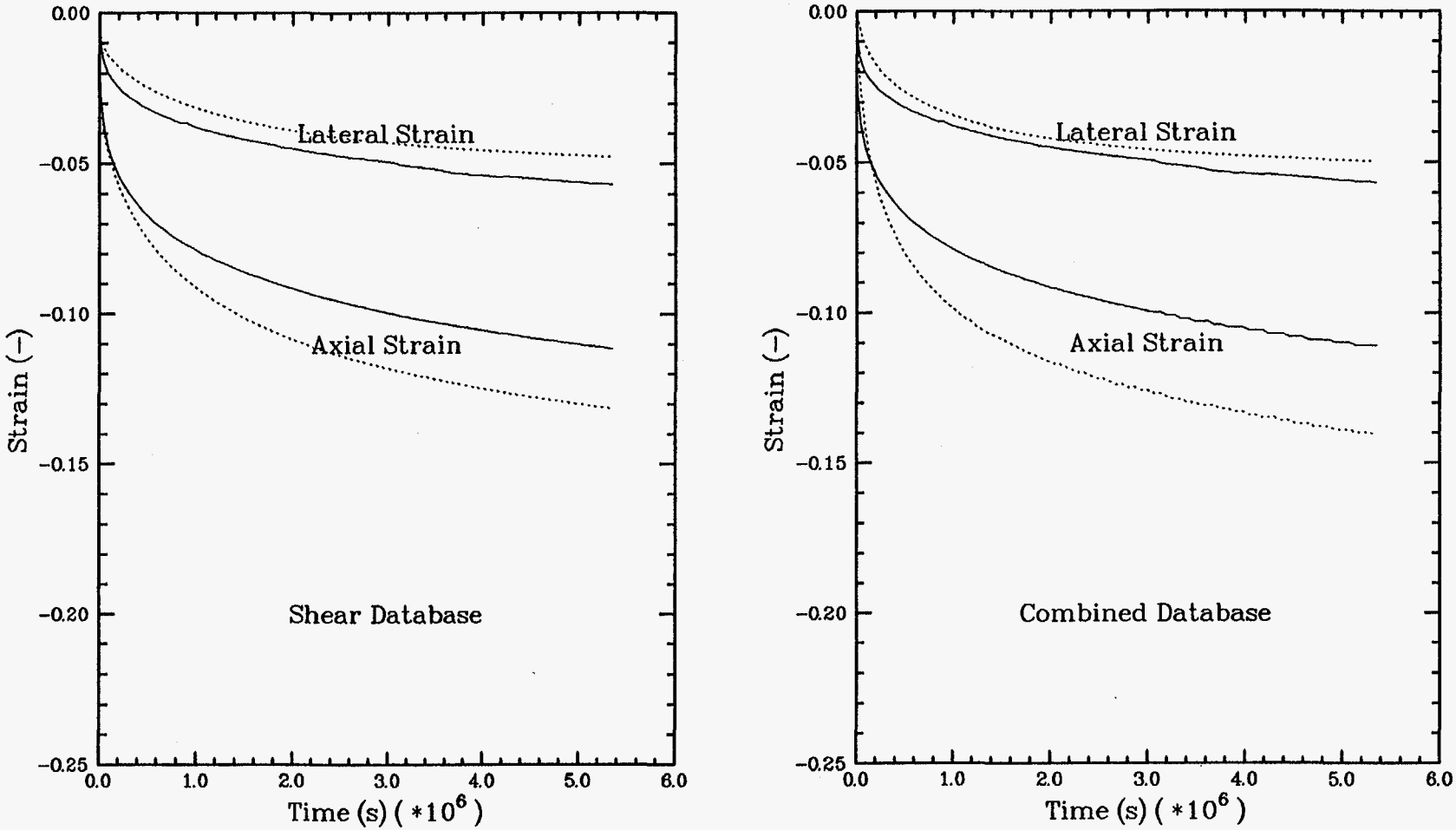

Figure C-42. Shear Consolidation Test SC2A

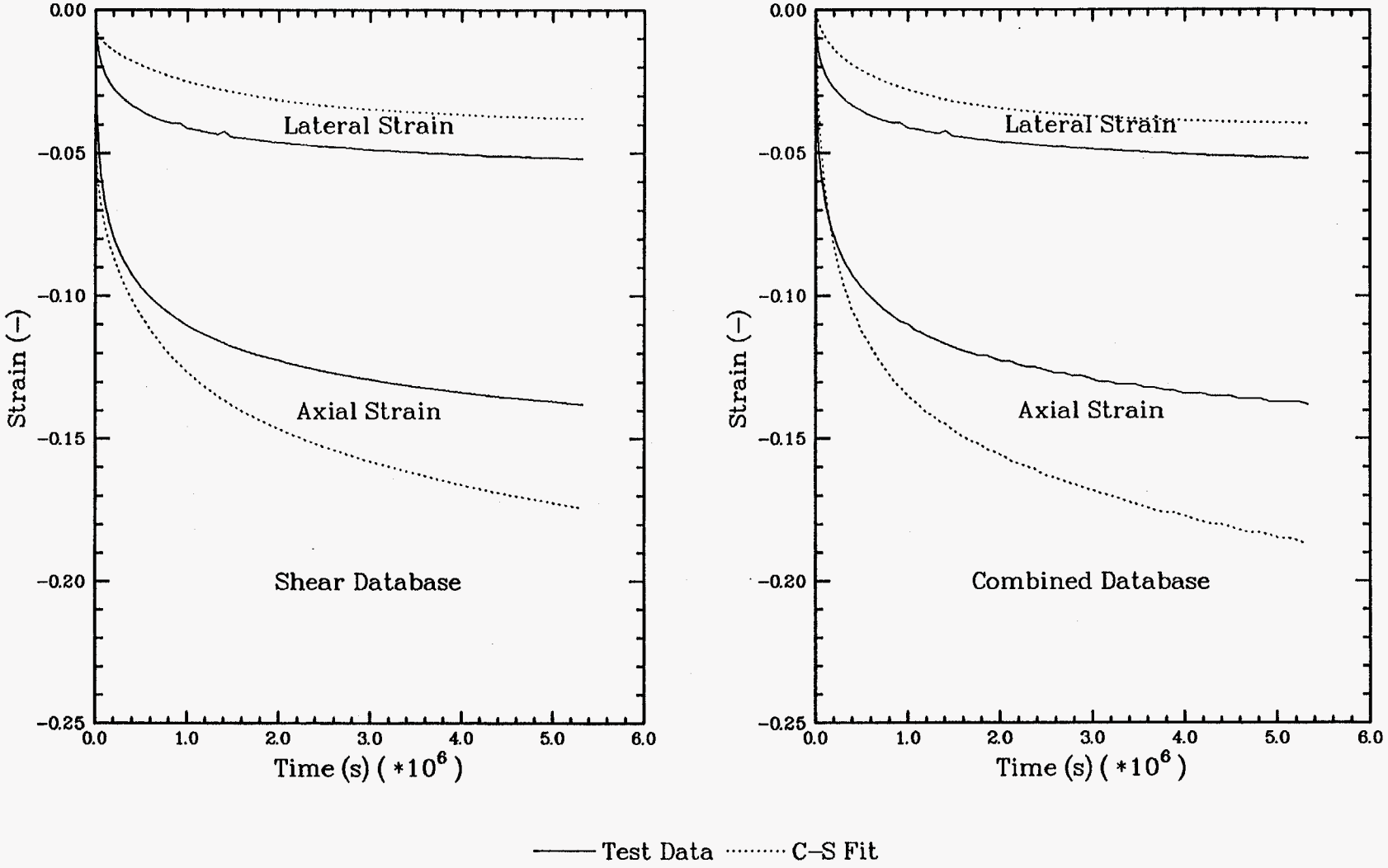

Figure C-43. Shear Consolidation Test SC3A

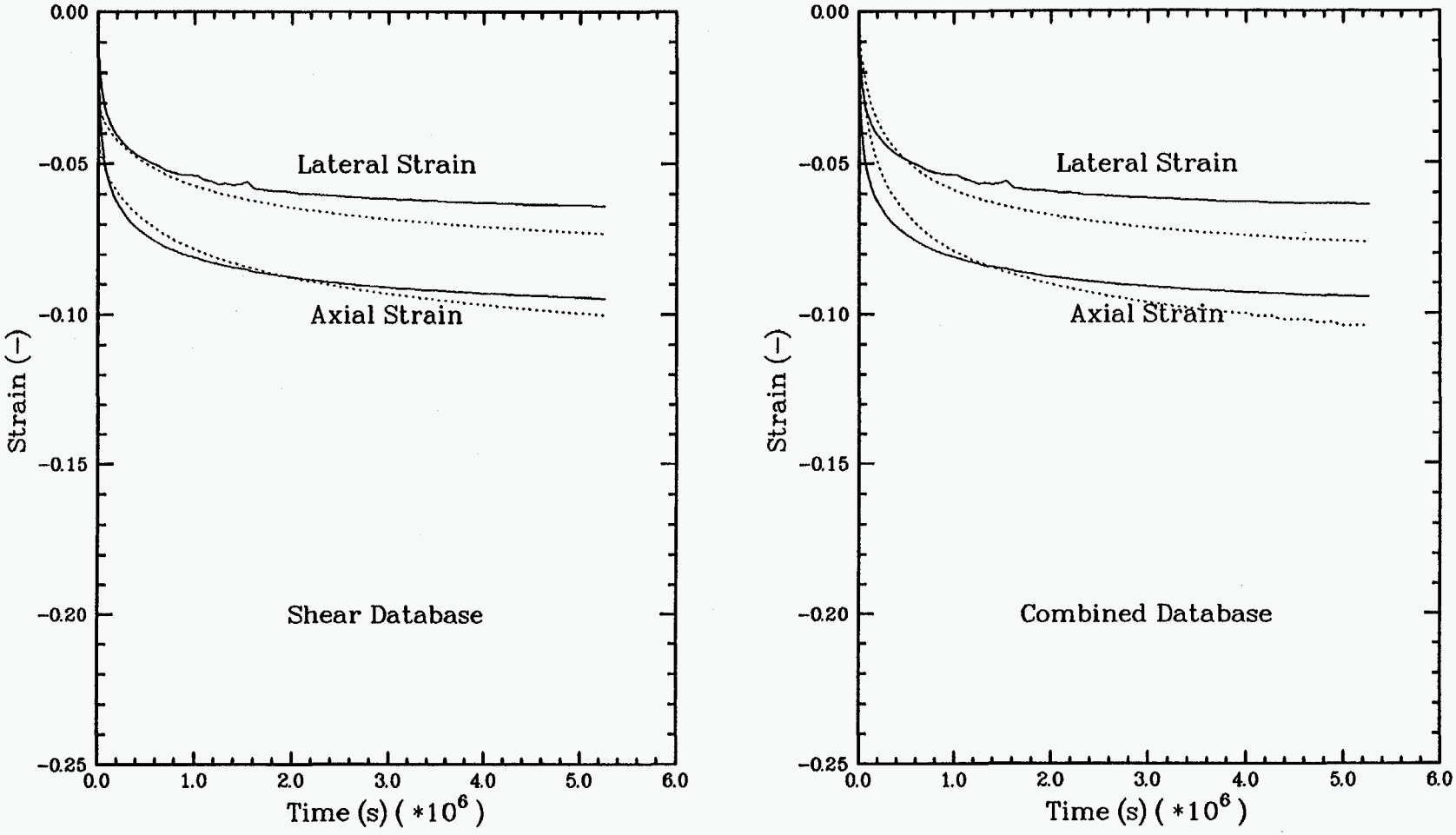

Figure C-44. Shear Consolidation Test SC4A

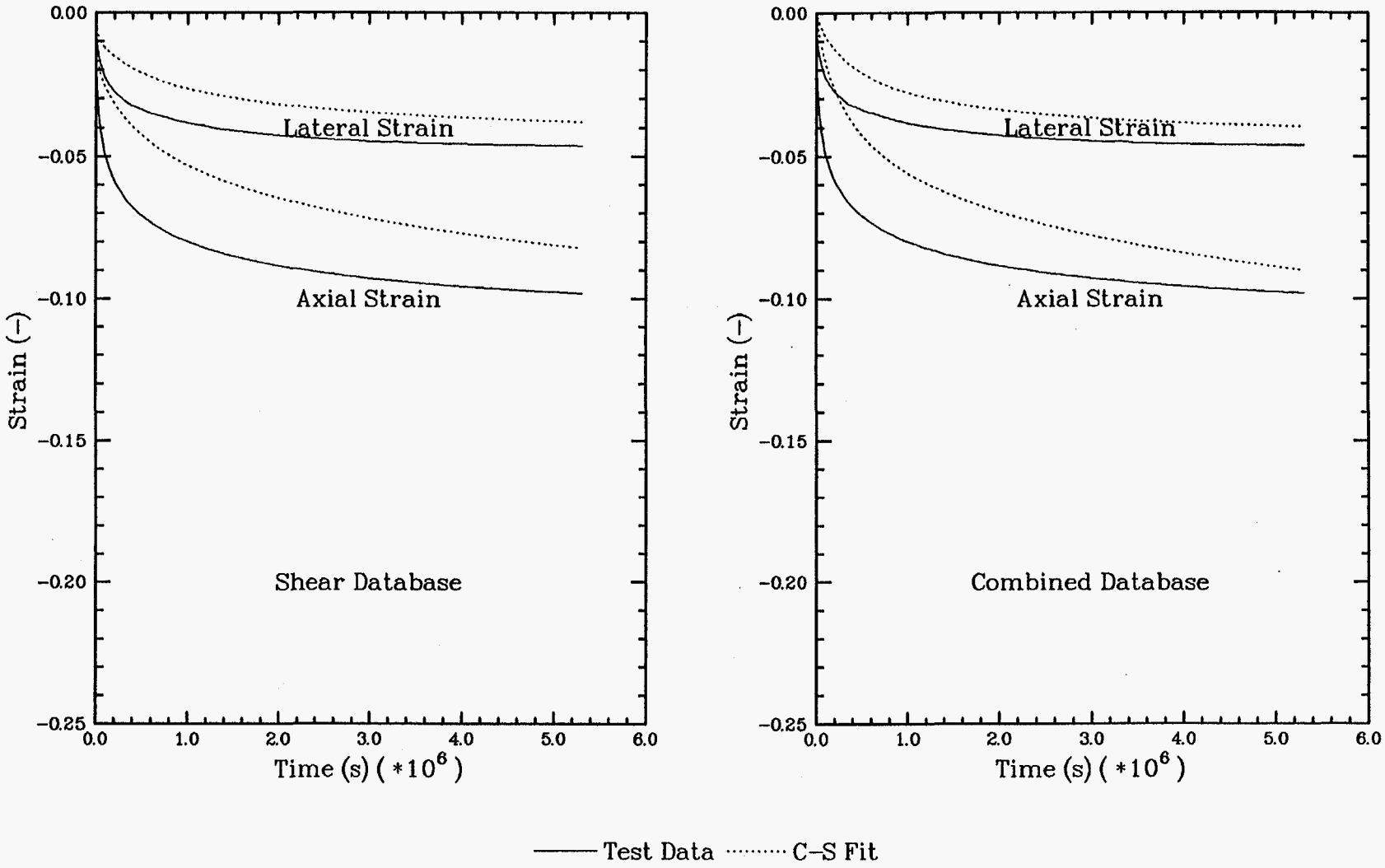

Figure C-45. Shear Consolidation Test SC5A

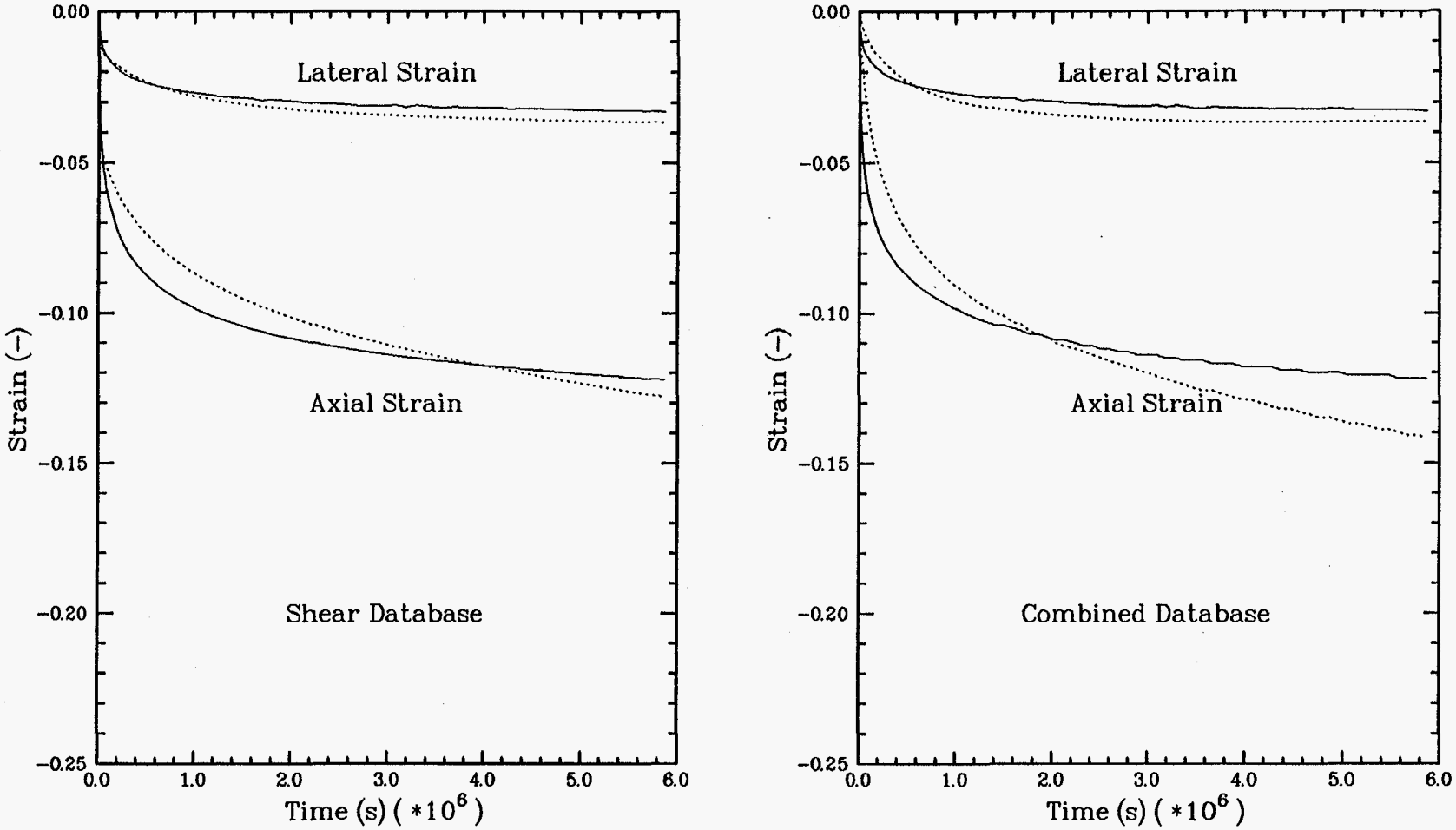

Figure C–46. Shear Consolidation Test SC6A

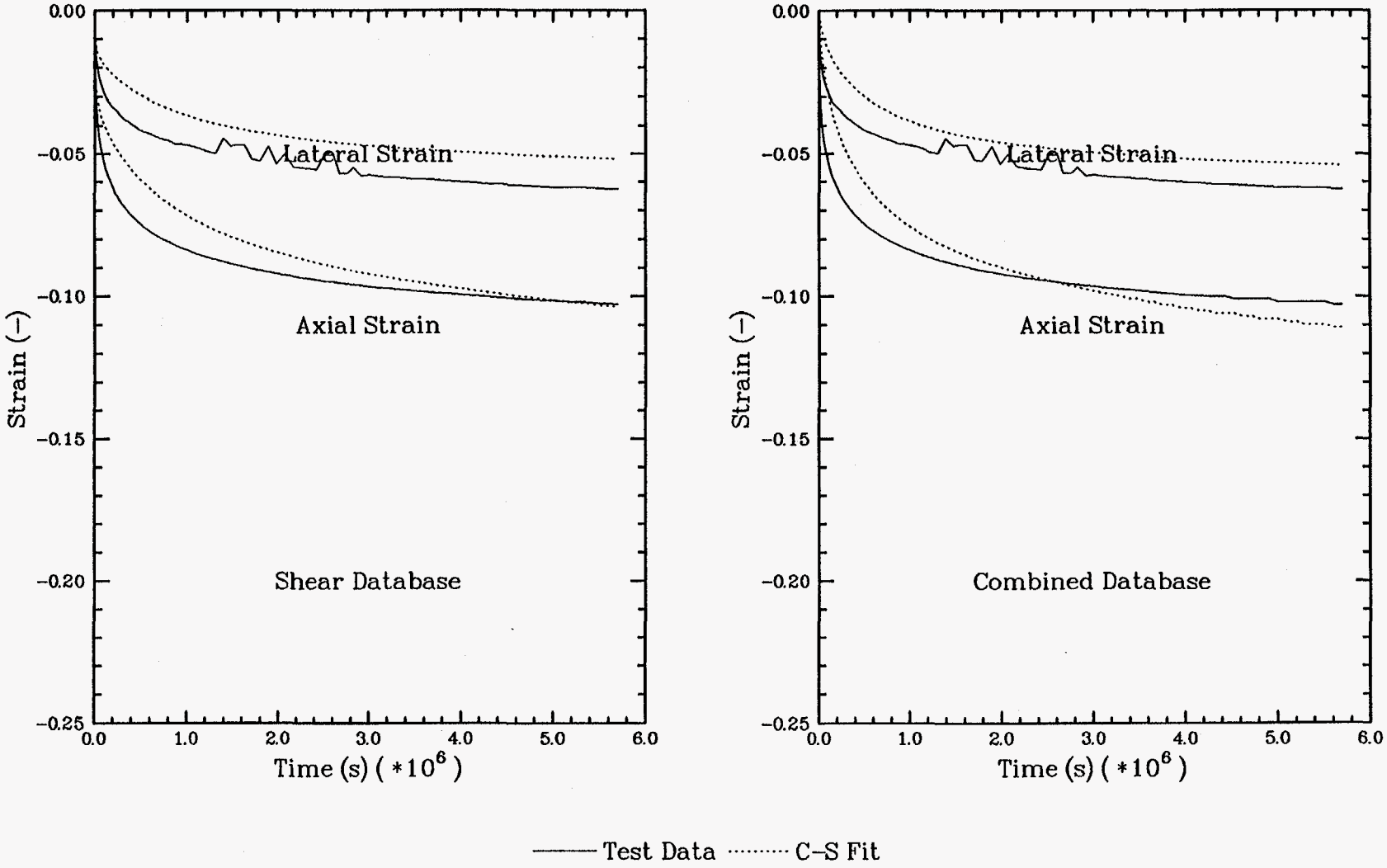

Figure C-47. Shear Consolidation Test SC7A

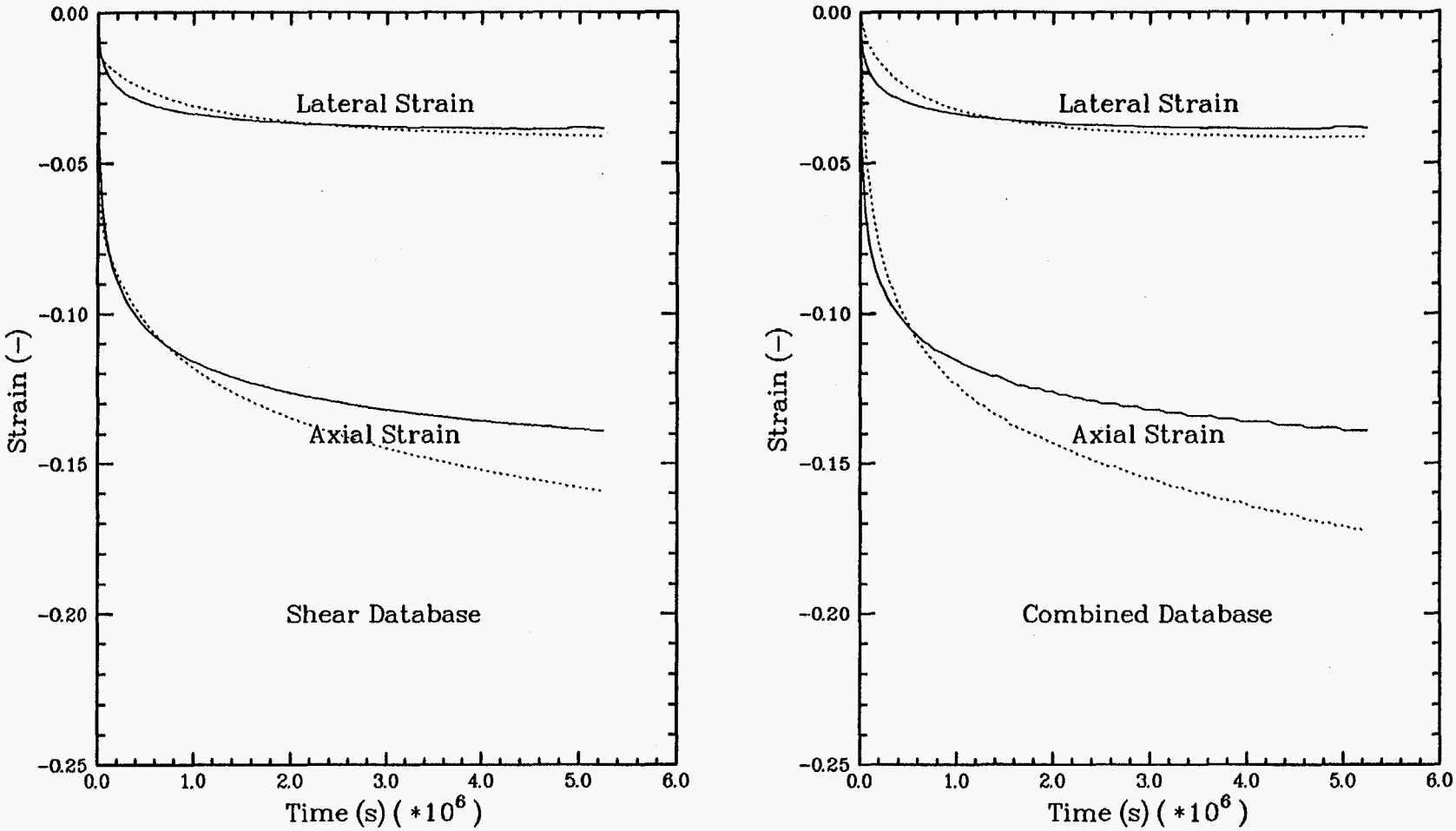

Figure C–48. Shear Consolidation Test SC8A

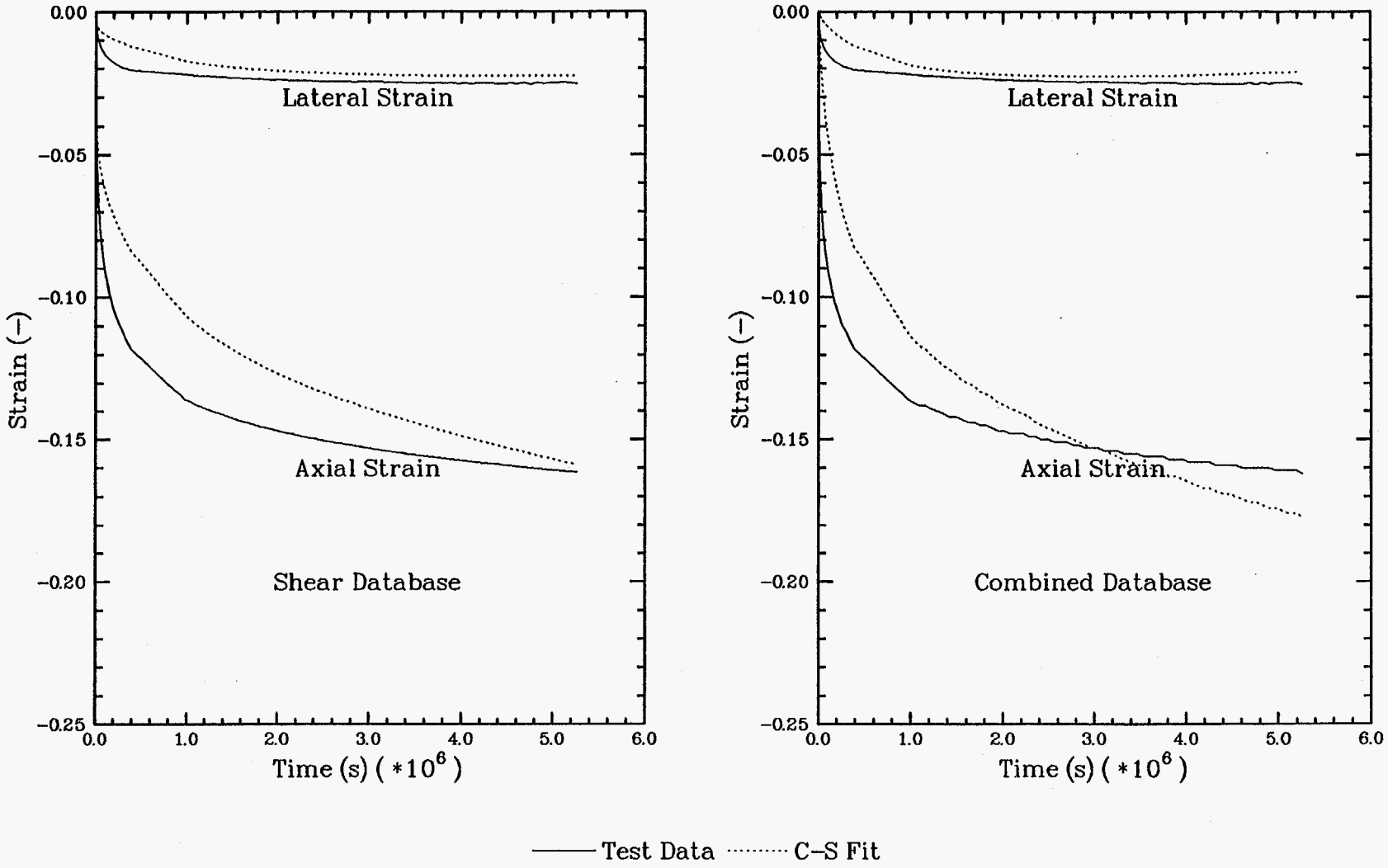

Figure C-49. Shear Consolidation Test SC9B

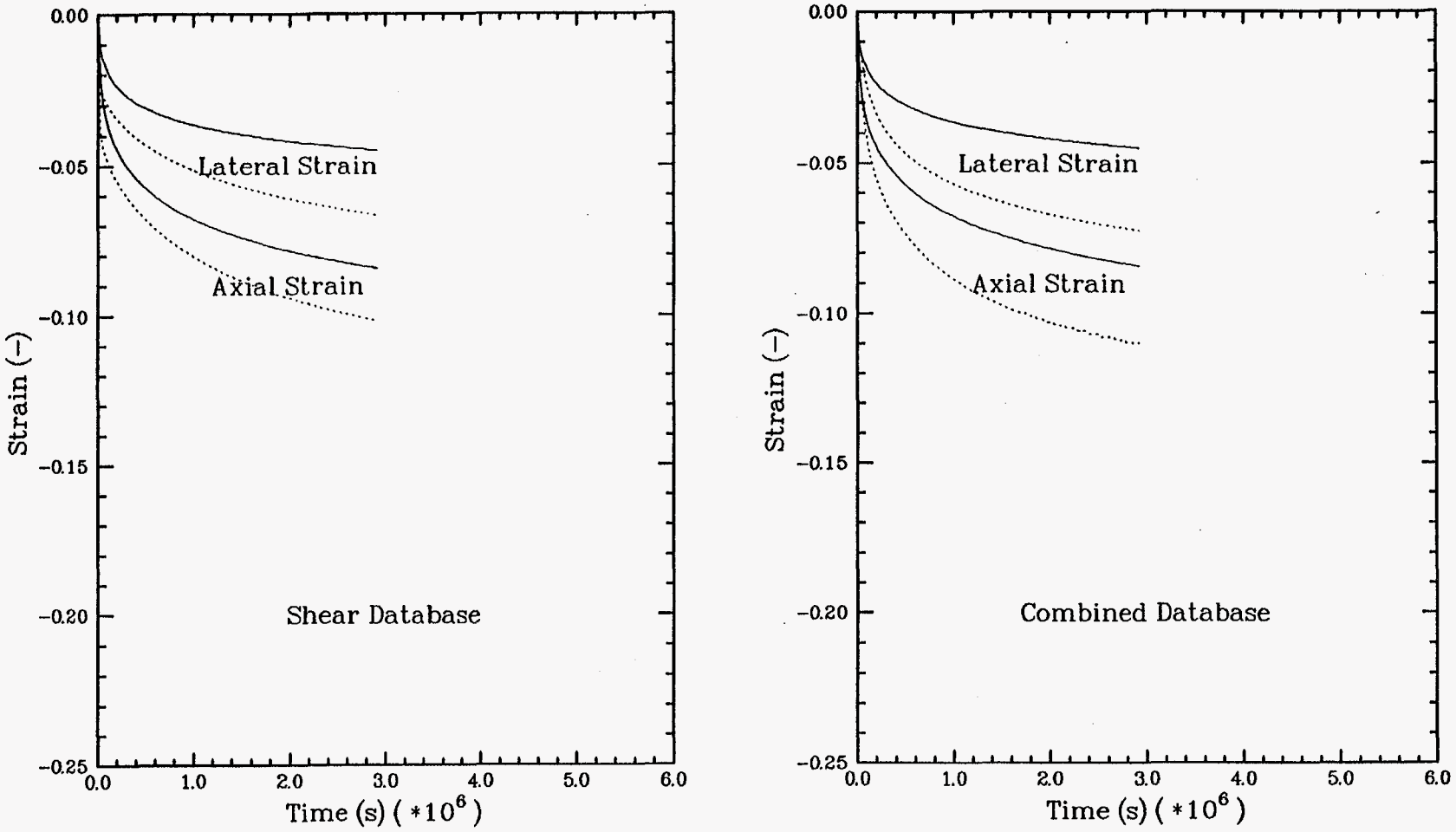

Figure C-50. Shear Consolidation Test 120C891

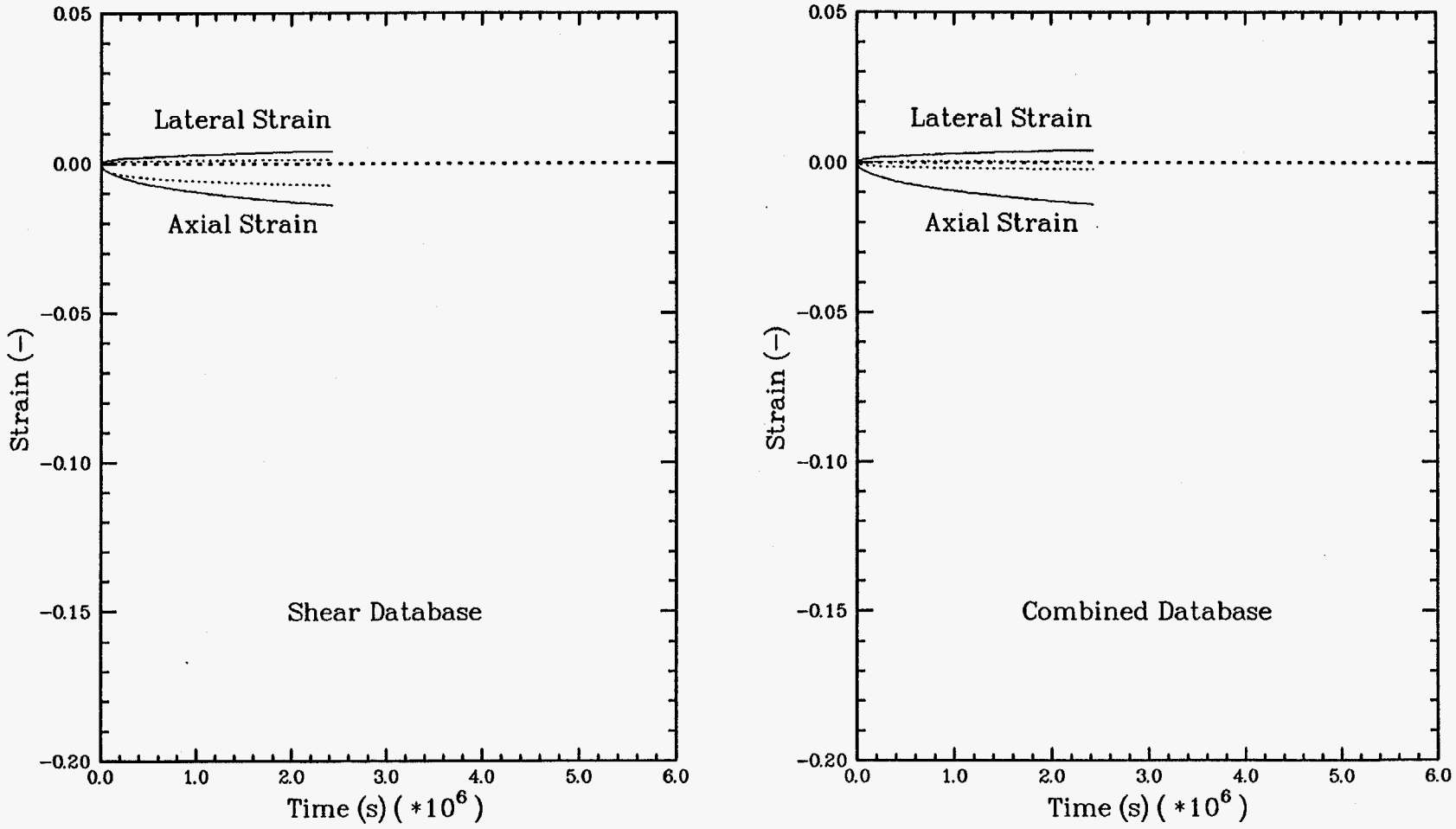

Figure C–51. Shear Consolidation Test SC10

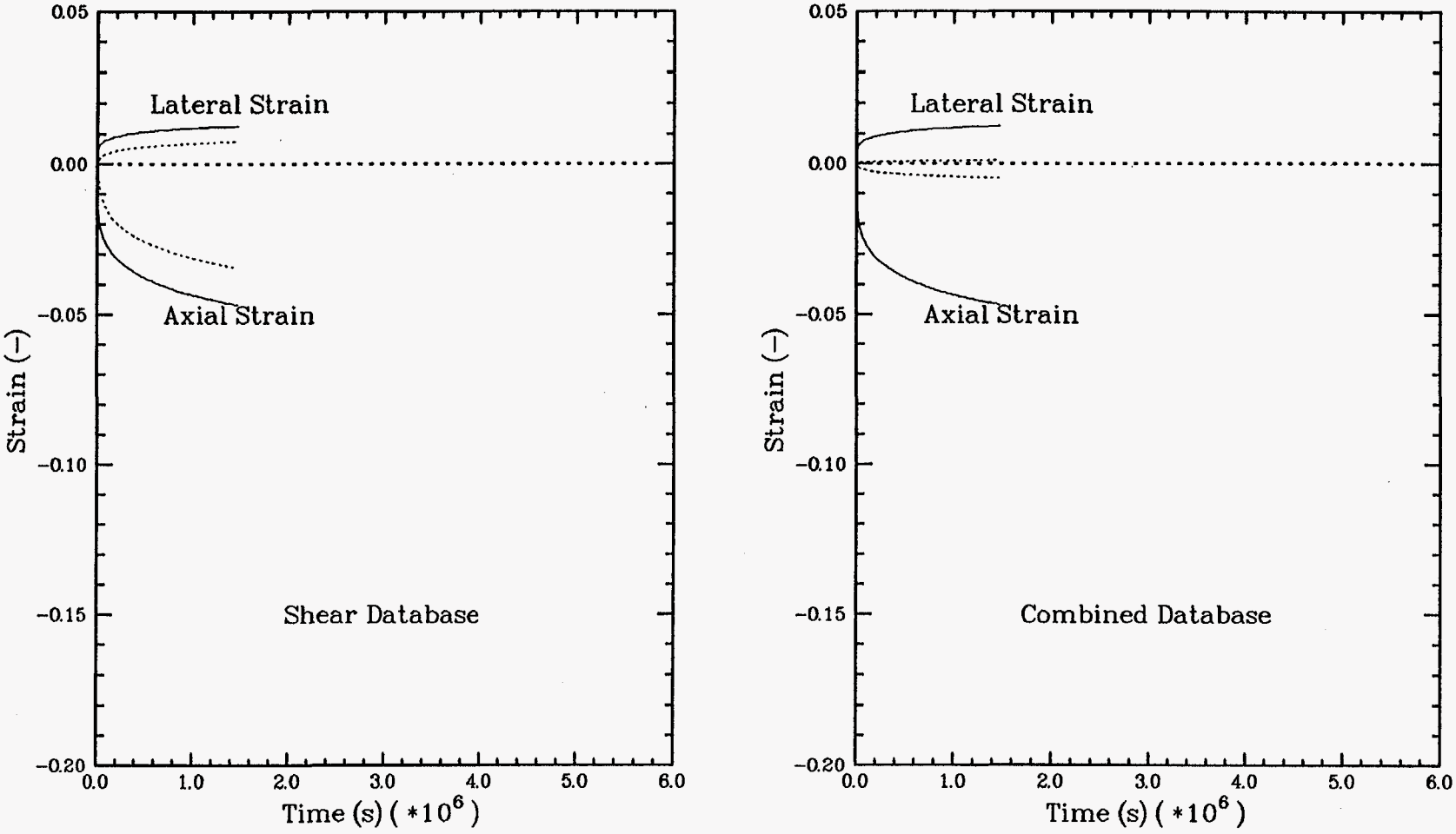

Figure C–52. Shear Consolidation Test SC11

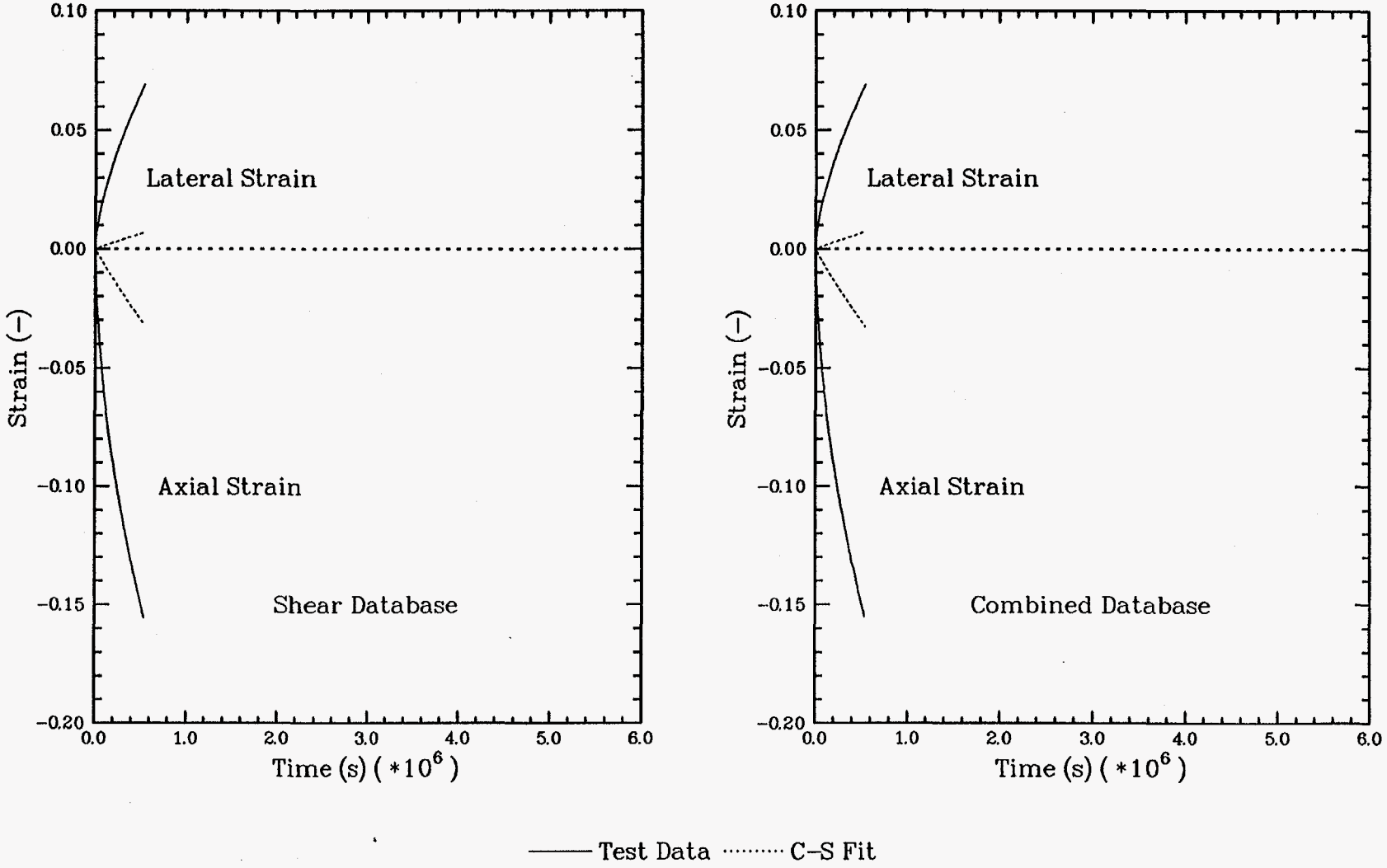

Figure C-53. Shear Consolidation Test RS/DCCS/1

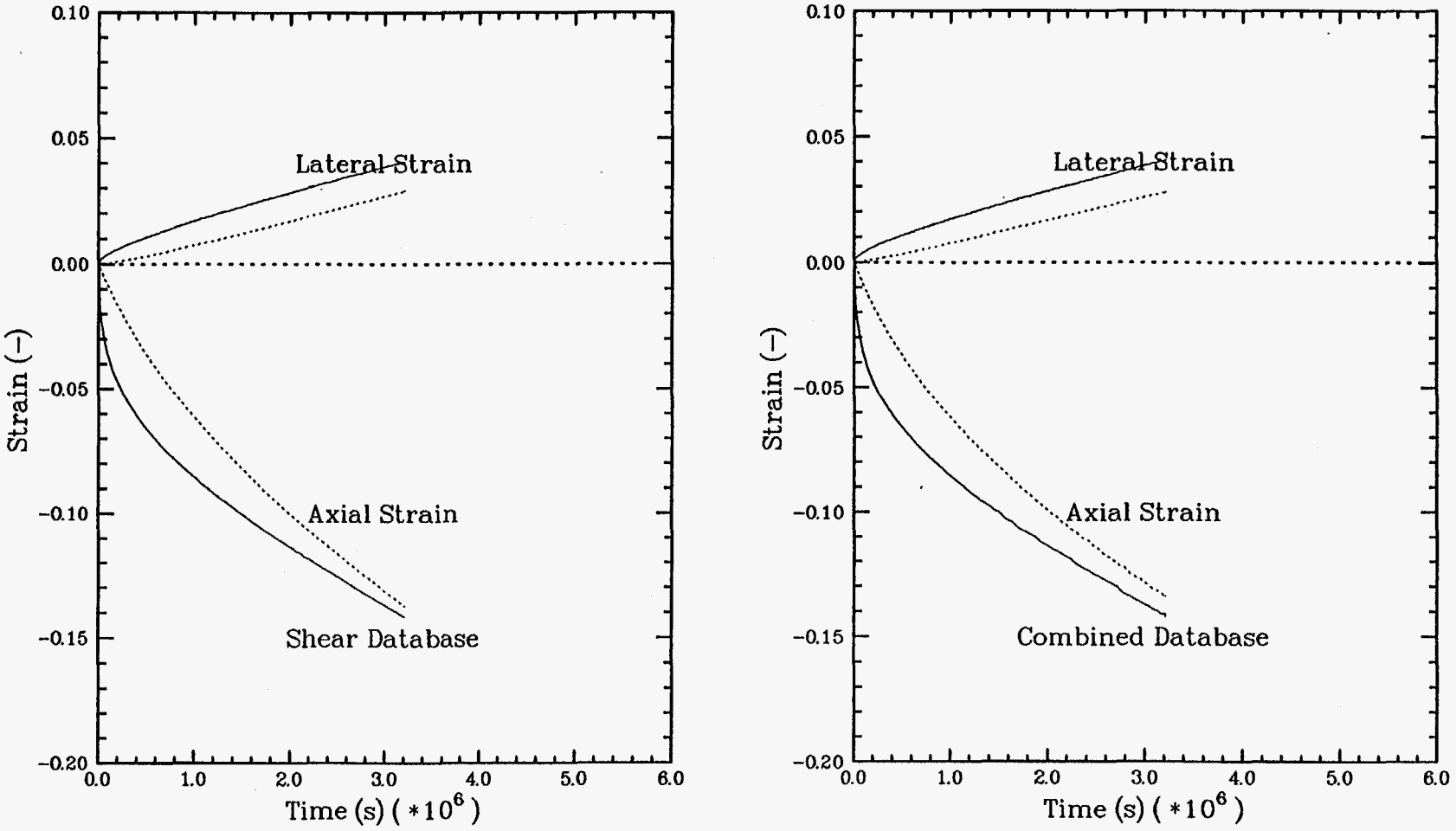

Figure C-54. Shear Consolidation Test RS/DCCS/3

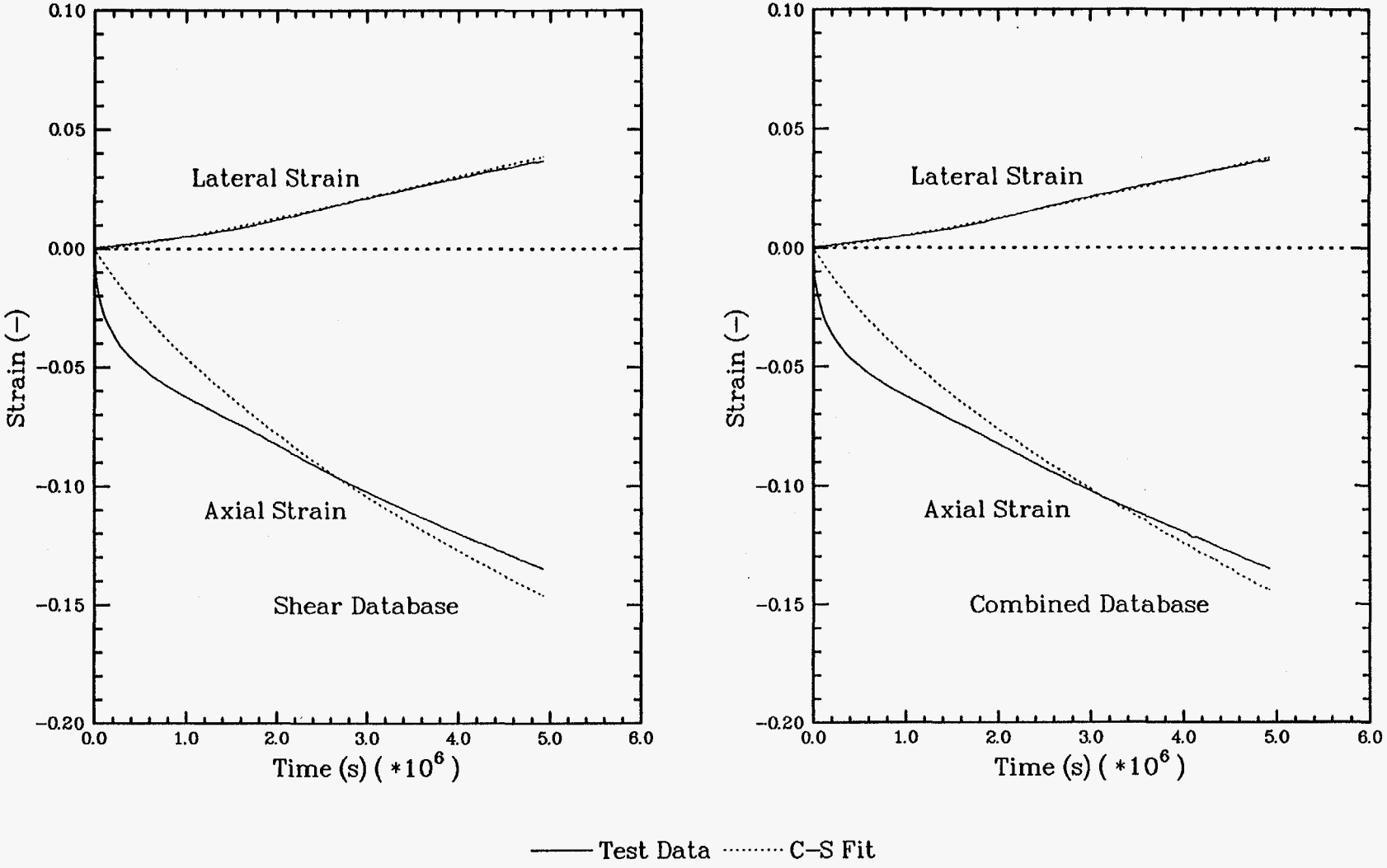

Figure C–55. Shear Consolidation Test RS/DCCS/4

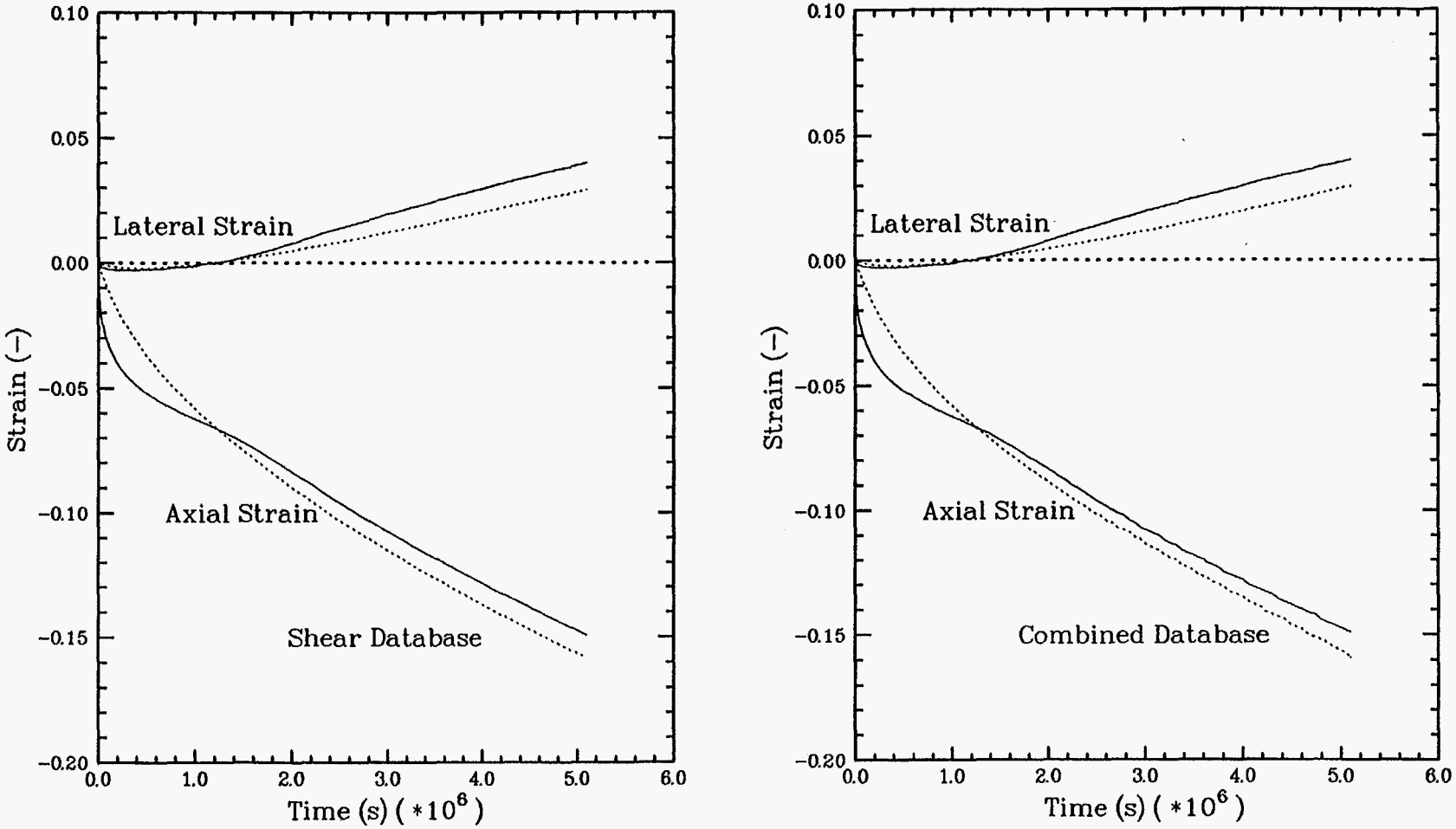

Figure C–56. Shear Consolidation Test RS/DCCS/5

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NM Bureau of Mines & Mineral Resources
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Hydrogen Data-Panel 3

All samples were sampled at sub-atmospheric pressure and pressurized by the lab as required for analysis; dilution factors included in data set. The MDL (method detection limit) is the sample quantitation limit determined in accordance with 40 CFR Part 136; actual and dilution corrected MDLs included in data set.

8/21/07-7/24/08 MDL = 10.79 ppmv
7/25/08-6/16/09 MDL = 14.93 ppmv
6/17/09-6/8/10 MDL = 15.17 ppmv
6/9/10-12/28/10 MDL = 7.00 ppmv
12/29/10-11/30/11 MDL = 14.03 ppmv
12/1/11-10/21/12 MDL = 14.40 ppmv
10/22/12-? MDL = 17.29 ppmv ← MDL end date not yet determined

Some values in column "Results" are less than dilution corrected MDLs. These values are not included in the statistical evaluation. When results are N.D. (not-detected) or less than dilution corrected MDLs, the values used for the statistical evaluation are 1/2 the corrected MDL.

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 7e	3176	4/24/2008	4/30/2008	59.74	2	10.79	21.58	59.74
Panel 3 Room 7e	3213	5/15/2008	5/23/2008	86.52	2	10.79	21.58	86.52
Panel 3 Room 7e	3281	6/19/2008	6/25/2008	103.78	2	10.79	21.58	103.78
Panel 3 Room 7e	3340	7/16/2008	7/22/2008	178.92	2	10.79	21.58	178.92
Panel 3 Room 7e	3405	8/19/2008	8/22/2008	353.02	2	14.93	29.86	353.02
Panel 3 Room 7e	3453	9/10/2008	9/12/2008	209.46	2	14.93	29.86	209.46
Panel 3 Room 7e	3509	10/8/2008	10/10/2008	352.68	2	14.93	29.86	352.68
Panel 3 Room 7e	3582	11/13/2008	11/18/2008	146.54	2	14.93	29.86	146.54
Panel 3 Room 7e	3621	12/3/2008	12/6/2008	89.50	2	14.93	29.86	89.50
Panel 3 Room 7e	3720	1/13/2009	1/21/2009	83.18	2	14.93	29.86	83.18
Panel 3 Room 7e	3777	2/10/2009	2/13/2009	53.76	2	14.93	29.86	53.76
Panel 3 Room 7e	3844	3/11/2009	3/27/2009	53.88	2	14.93	29.86	53.88
Panel 3 Room 7e	3919	4/14/2009	4/22/2009	51.82	2	14.93	29.86	51.82
Panel 3 Room 7e	3990	5/12/2009	5/15/2009	88.94	2	14.93	29.86	88.94
Panel 3 Room 7e	4048	6/2/2009	6/8/2009	68.52	2	14.93	29.86	68.52
Panel 3 Room 7e	4106	7/7/2009	7/10/2009	123.32	2	15.17	30.34	123.32
Panel 3 Room 7e	4165	8/5/2009	8/13/2009	84.52	2	15.17	30.34	84.52
Panel 3 Room 7e	4236	9/1/2009	9/4/2009	130.44	2	15.17	30.34	130.44
Panel 3 Room 7e	4333	10/12/2009	10/15/2009	95.60	2	15.17	30.34	95.60
Panel 3 Room 7e	4375	11/2/2009	11/12/2009	90.80	2	15.17	30.34	90.80
Panel 3 Room 7e	4465	12/8/2009	12/15/2009	23.62	2	15.17	30.34	15.17
Panel 3 Room 7e	4626	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 7e	4724	2/17/2010	2/23/2010	84.12	2	15.17	30.34	84.12
Panel 3 Room 7e	4790	3/9/2010	3/12/2010	64.72	2	15.17	30.34	64.72
Panel 3 Room 7e	4958	4/20/2010	4/28/2010	57.18	2	15.17	30.34	57.18
Panel 3 Room 7e	5082	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 7e	5117	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 7e	5255	7/13/2010	7/19/2010	127.94	2	7.00	14.00	127.94
Panel 3 Room 7i	3175	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 7i	3222	5/19/2008	5/23/2008	10.40	2	10.79	21.58	10.79
Panel 3 Room 6e	3178	4/24/2008	4/30/2008	27.34	2	10.79	21.58	27.34
Panel 3 Room 6e	3212	5/14/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 6e	3280	6/19/2008	6/25/2008	69.22	2	10.79	21.58	69.22
Panel 3 Room 6e	3339	7/16/2008	7/22/2008	145.62	2	10.79	21.58	145.62
Panel 3 Room 6e	3426	8/20/2008	8/22/2008	228.66	2	14.93	29.86	228.66
Panel 3 Room 6e	3452	9/10/2008	9/12/2008	136.30	2	14.93	29.86	136.30
Panel 3 Room 6e	3508	10/8/2008	10/10/2008	12.42	2	14.93	29.86	14.93
Panel 3 Room 6e	3581	11/13/2008	11/18/2008	35.30	2	14.93	29.86	35.30
Panel 3 Room 6e	3620	12/3/2008	12/6/2008	76.10	2	14.93	29.86	76.10
Panel 3 Room 6e	3719	1/13/2009	1/21/2009	64.12	2	14.93	29.86	64.12
Panel 3 Room 6e	3776	2/10/2009	2/13/2009	43.60	2	14.93	29.86	43.60
Panel 3 Room 6e	3843	3/10/2009	3/27/2009	67.46	2	14.93	29.86	67.46
Panel 3 Room 6e	3918	4/14/2009	4/22/2009	53.12	2	14.93	29.86	53.12
Panel 3 Room 6e	3989	5/12/2009	5/15/2009	76.46	2	14.93	29.86	76.46
Panel 3 Room 6e	4047	6/2/2009	6/8/2009	39.94	2	14.93	29.86	39.94
Panel 3 Room 6e	4107	7/7/2009	7/10/2009	110.02	2	15.17	30.34	110.02
Panel 3 Room 6e	4166	8/5/2009	8/13/2009	79.50	2	15.17	30.34	79.50
Panel 3 Room 6e	4237	9/1/2009	9/4/2009	106.26	2	15.17	30.34	106.26
Panel 3 Room 6e	4334	10/12/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 6e	4376	11/2/2009	11/12/2009	51.54	2	15.17	30.34	51.54
Panel 3 Room 6e	4466	12/8/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 6e	4627	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 6e	4725	2/17/2010	2/23/2010	49.20	2	15.17	30.34	49.20
Panel 3 Room 6e	4791	3/9/2010	3/12/2010	77.26	2	15.17	30.34	77.26
Panel 3 Room 6e	4959	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 6e	5083	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 6e	5118	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 6e	5256	7/13/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 6e	5349	8/9/2010	8/17/2010	97.04	2	7.00	14.00	97.04
Panel 3 Room 6e	5475	9/21/2010	9/27/2010	114.26	2	7.00	14.00	114.26
Panel 3 Room 6e	5534	10/11/2010	10/18/2010	98.94	2	7.00	14.00	98.94
Panel 3 Room 6e	5627	11/8/2010	11/15/2010	93.20	2	7.00	14.00	93.20
Panel 3 Room 6e	5746	12/14/2010	12/20/2010	92.60	2	7.00	14.00	92.60
Panel 3 Room 6e	5844	1/18/2011	1/24/2011	140.32	2	14.03	28.06	140.32
Panel 3 Room 6e	5930	2/15/2011	2/21/2011	62.32	2	14.03	28.06	62.32
Panel 3 Room 6e	6018	3/8/2011	3/11/2011	87.88	2	14.03	28.06	87.88
Panel 3 Room 6e	6131	4/19/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 6e	6213	5/9/2011	5/13/2011	48.58	2	14.03	28.06	48.58
Panel 3 Room 6e	6313	6/14/2011	6/21/2011	53.46	2	14.03	28.06	53.46
Panel 3 Room 6e	6427	7/18/2011	7/28/2011	36.06	2	14.03	28.06	36.06
Panel 3 Room 6e	6495	8/15/2011	8/22/2011	76.68	2	14.03	28.06	76.68
Panel 3 Room 6e	6573	9/19/2011	9/27/2011	46.88	2	14.03	28.06	46.88
Panel 3 Room 6e	6646	10/17/2011	10/25/2011	38.82	2	14.03	28.06	38.82
Panel 3 Room 6e	6718	11/7/2011	11/11/2011	32.08	2	14.03	28.06	32.08
Panel 3 Room 6e	6773	12/5/2011	12/9/2011	27.48	2	14.40	28.80	14.40
Panel 3 Room 6e	6858	1/9/2012	1/13/2012	52.82	2	14.40	28.80	52.82
Panel 3 Room 6e	6961	2/16/2012	2/22/2012	34.02	2	14.40	28.80	34.02
Panel 3 Room 6e	7011	3/6/2012	3/9/2012	45.38	2	14.40	28.80	45.38
Panel 3 Room 6e	7084	4/2/2012	4/9/2012	29	2	14.40	28.80	29.00
Panel 3 Room 6e	7162	5/1/2012	5/4/2012	32.72	2	14.40	28.80	32.72
Panel 3 Room 6e	7235	6/4/2012	6/8/2012	34.3	2	14.40	28.80	34.30
Panel 3 Room 6e	7362	7/16/2012	7/23/2012	37.86	2	14.40	28.80	37.86
Panel 3 Room 6e	7420	8/6/2012	8/10/2012	29.3	2	14.40	28.80	29.30
Panel 3 Room 6e	7505	9/4/2012	9/7/2012	31.18	2	14.40	28.80	31.18
Panel 3 Room 6i	3166	4/24/2008	4/30/2008	21.80	2	10.79	21.58	21.80
Panel 3 Room 6i	3221	5/15/2008	5/23/2008	23.28	2	10.79	21.58	23.28
Panel 3 Room 6i	3289	6/19/2008	6/25/2008	78.90	2	10.79	21.58	78.90
Panel 3 Room 6i	3348	7/16/2008	7/22/2008	126.18	2	10.79	21.58	126.18
Panel 3 Room 6i	3412	8/20/2008	8/22/2008	185.26	2	14.93	29.86	185.26
Panel 3 Room 6i	3460	9/10/2008	9/12/2008	311.62	2	14.93	29.86	311.62
Panel 3 Room 6i	3516	10/8/2008	10/10/2008	19.46	2	14.93	29.86	14.93
Panel 3 Room 6i	3589	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 6i	3628	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 6i	3723	1/14/2009	1/21/2009	25.66	2	14.93	29.86	14.93
Panel 3 Room 6i	3784	2/11/2009	2/13/2009	22.22	2	14.93	29.86	14.93
Panel 3 Room 6i	3847	3/11/2009	3/27/2009	27.96	2	14.93	29.86	14.93
Panel 3 Room 6i	3922	4/14/2009	4/22/2009	32.58	2	14.93	29.86	32.58
Panel 3 Room 6i	3986	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 6i	4055	6/2/2009	6/8/2009	28.90	2	14.93	29.86	14.93
Panel 3 Room 6i	4114	7/8/2009	7/10/2009	71.36	2	15.17	30.34	71.36
Panel 3 Room 6i	4171	8/5/2009	8/13/2009	44.14	2	15.17	30.34	44.14
Panel 3 Room 6i	4244	9/2/2009	9/4/2009	60.60	2	15.17	30.34	60.60
Panel 3 Room 6i	4341	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 6i	4383	11/3/2009	11/12/2009	36.66	2	15.17	30.34	36.66
Panel 3 Room 6i	4473	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 6i	4634	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 6i	4732	2/18/2010	2/23/2010	31.48	2	15.17	30.34	31.48
Panel 3 Room 6i	4800	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 6i	4966	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 6i	5090	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 6i	5125	6/2/2010	6/7/2010	50.92	2	15.17	30.34	50.92
Panel 3 Room 6i	5263	7/14/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 6i	5356	8/10/2010	8/17/2010	96.30	2	7.00	14.00	96.30
Panel 3 Room 5e	3179	4/24/2008	4/30/2008	45.70	2	10.79	21.58	45.70
Panel 3 Room 5e	3211	5/14/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 5e	3279	6/17/2008	6/25/2008	91.62	2	10.79	21.58	91.62
Panel 3 Room 5e	3338	7/16/2008	7/22/2008	156.04	2	10.79	21.58	156.04
Panel 3 Room 5e	3403	8/19/2008	8/22/2008	221.24	2	14.93	29.86	221.24
Panel 3 Room 5e	3451	9/10/2008	9/12/2008	207.98	2	14.93	29.86	207.98
Panel 3 Room 5e	3507	10/8/2008	10/10/2008	187.98	2	14.93	29.86	187.98
Panel 3 Room 5e	3580	11/13/2008	11/18/2008	101.64	2	14.93	29.86	101.64
Panel 3 Room 5e	3619	12/3/2008	12/6/2008	66.24	2	14.93	29.86	66.24
Panel 3 Room 5e	3718	1/13/2009	1/21/2009	61.18	2	14.93	29.86	61.18
Panel 3 Room 5e	3775	2/10/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 5e	3842	3/10/2009	3/27/2009	63.18	2	14.93	29.86	63.18
Panel 3 Room 5e	3917	4/14/2009	4/22/2009	51.28	2	14.93	29.86	51.28
Panel 3 Room 5e	3988	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 5e	4046	6/1/2009	6/8/2009	42.80	2	14.93	29.86	42.80
Panel 3 Room 5e	4108	7/7/2009	7/10/2009	102.20	2	15.17	30.34	102.20
Panel 3 Room 5e	4167	8/5/2009	8/13/2009	57.74	2	15.17	30.34	57.74
Panel 3 Room 5e	4238	9/1/2009	9/4/2009	59.18	2	15.17	30.34	59.18
Panel 3 Room 5e	4335	10/12/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5e	4377	11/2/2009	11/12/2009	65.18	2	15.17	30.34	65.18
Panel 3 Room 5e	4467	12/8/2009	12/15/2009	12.40	2	15.17	30.34	15.17

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 5e	4628	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5e	4726	2/17/2010	2/23/2010	76.68	2	15.17	30.34	76.68
Panel 3 Room 5e	4792	3/9/2010	3/12/2010	61.28	2	15.17	30.34	61.28
Panel 3 Room 5e	4960	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5e	5084	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5e	5119	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5e	5257	7/13/2010	7/19/2010	49.72	2	7.00	14.00	49.72
Panel 3 Room 5e	5350	8/9/2010	8/17/2010	101.44	2	7.00	14.00	101.44
Panel 3 Room 5e	5476	9/21/2010	9/27/2010	100.80	2	7.00	14.00	100.80
Panel 3 Room 5e	5535	10/11/2010	10/18/2010	80.42	2	7.00	14.00	80.42
Panel 3 Room 5e	5628	11/8/2010	11/15/2010	50.66	2	7.00	14.00	50.66
Panel 3 Room 5e	5747	12/14/2010	12/20/2010	89.50	2	7.00	14.00	89.50
Panel 3 Room 5e	5845	1/18/2011	1/24/2011	125.50	2	14.03	28.06	125.50
Panel 3 Room 5e	5931	2/15/2011	2/21/2011	69.84	2	14.03	28.06	69.84
Panel 3 Room 5e	6019	3/8/2011	3/11/2011	88.68	2	14.03	28.06	88.68
Panel 3 Room 5e	6132	4/19/2011	4/26/2011	47.86	2	14.03	28.06	47.86
Panel 3 Room 5e	6214	5/9/2011	5/13/2011	51.18	2	14.03	28.06	51.18
Panel 3 Room 5e	6314	6/14/2011	6/21/2011	56.52	2	14.03	28.06	56.52
Panel 3 Room 5e	6428	7/18/2011	7/22/2011	50.44	2	14.03	28.06	50.44
Panel 3 Room 5e	6496	8/15/2011	8/22/2011	59.04	2	14.03	28.06	59.04
Panel 3 Room 5e	6574	9/19/2011	9/27/2011	41.84	2	14.03	28.06	41.84
Panel 3 Room 5e	6647	10/17/2011	10/25/2011	25.74	2	14.03	28.06	14.03
Panel 3 Room 5e	6719	11/7/2011	11/11/2011	32.00	2	14.03	28.06	32.00
Panel 3 Room 5e	6774	12/5/2011	12/9/2011	44.44	2	14.40	28.80	44.44
Panel 3 Room 5e	6859	1/9/2012	1/13/2012	51.44	2	14.40	28.80	51.44
Panel 3 Room 5e	6962	2/16/2012	2/22/2012	22.48	2	14.40	28.80	14.40
Panel 3 Room 5e	7012	3/6/2012	3/9/2012	52.86	2	14.40	28.80	52.86
Panel 3 Room 5e	7085	4/2/2012	4/9/2012	43.68	2	14.40	28.80	43.68
Panel 3 Room 5e	7163	5/1/2012	5/4/2012	48.28	2	14.40	28.80	48.28
Panel 3 Room 5e	7236	6/4/2012	6/8/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 5e	7363	7/16/2012	7/23/2012	29.78	2	14.40	28.80	29.78
Panel 3 Room 5e	7421	8/6/2012	8/10/2012	44.24	2	14.40	28.80	44.24
Panel 3 Room 5e	7506	9/4/2012	9/7/2012	37.76	2	14.40	28.80	37.76
Panel 3 Room 5e	7617	10/8/2012	10/16/2012	32.84	2	14.40	28.80	32.84
Panel 3 Room 5e	7687	11/5/2012	11/9/2012	37.16	2	17.29	34.58	37.16
Panel 3 Room 5e	7773	12/3/2012	12/7/2012	42.52	2	17.29	34.58	42.52
Panel 3 Room 5i	3177	4/24/2008	4/30/2008	24.18	2	10.79	21.58	24.18
Panel 3 Room 5i	3220	5/15/2008	5/23/2008	17.68	2	10.79	21.58	10.79
Panel 3 Room 5i	3288	6/19/2008	6/25/2008	60.62	2	10.79	21.58	60.62
Panel 3 Room 5i	3347	7/16/2008	7/22/2008	166.08	2	10.79	21.58	166.08
Panel 3 Room 5i	3411	8/19/2008	8/22/2008	247.14	2	14.93	29.86	247.14
Panel 3 Room 5i	3459	9/10/2008	9/12/2008	220.32	2	14.93	29.86	220.32
Panel 3 Room 5i	3515	10/8/2008	10/10/2008	57.40	2	14.93	29.86	57.40
Panel 3 Room 5i	3588	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 5i	3627	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 5i	3722	1/13/2009	1/21/2009	26.62	2	14.93	29.86	14.93
Panel 3 Room 5i	3783	2/11/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 5i	3846	3/11/2009	3/27/2009	16.56	2	14.93	29.86	14.93
Panel 3 Room 5i	3921	4/14/2009	4/22/2009	18.66	2	14.93	29.86	14.93
Panel 3 Room 5i	3985	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 5i	4054	6/2/2009	6/8/2009	32.80	2	14.93	29.86	32.80
Panel 3 Room 5i	4115	7/8/2009	7/10/2009	99.70	2	15.17	30.34	99.70
Panel 3 Room 5i	4176	8/6/2009	8/13/2009	81.66	2	15.17	30.34	81.66
Panel 3 Room 5i	4245	9/2/2009	9/4/2009	62.66	2	15.17	30.34	62.66
Panel 3 Room 5i	4342	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5i	4384	11/3/2009	11/12/2009	32.30	2	15.17	30.34	32.30
Panel 3 Room 5i	4474	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5i	4635	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5i	4733	2/18/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5i	4801	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5i	4967	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5i	5091	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5i	5126	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 5i	5264	7/14/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 5i	5357	8/10/2010	8/17/2010	93.94	2	7.00	14.00	93.94
Panel 3 Room 5i	5483	9/22/2010	9/27/2010	96.22	2	7.00	14.00	96.22
Panel 3 Room 5i	5541	10/12/2010	10/18/2010	46.98	2	7.00	14.00	46.98
Panel 3 Room 5i	5634	11/9/2010	11/15/2010	54.98	2	7.00	14.00	54.98
Panel 3 Room 5i	5753	12/15/2010	12/20/2010	76.98	2	7.00	14.00	76.98
Panel 3 Room 5i	5851	1/19/2011	1/24/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 5i	5937	2/15/2011	2/21/2011	31.10	2	14.03	28.06	31.10
Panel 3 Room 5i	6025	3/9/2011	3/11/2011	39.10	2	14.03	28.06	39.10
Panel 3 Room 5i	6138	4/19/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 5i	6220	5/10/2011	5/13/2011	30.62	2	14.03	28.06	30.62
Panel 3 Room 5i	6320	6/15/2011	6/21/2011	18.64	2	14.03	28.06	14.03
Panel 3 Room 5i	6436	7/19/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 5i	6502	8/16/2011	8/22/2011	49.46	2	14.03	28.06	49.46

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 5i	6580	9/20/2011	9/27/2011	27.16	2	14.03	28.06	14.03
Panel 3 Room 5i	6651	10/17/2011	10/25/2011	15.38	2	14.03	28.06	14.03
Panel 3 Room 5i	6725	11/7/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 5i	6780	12/5/2011	12/9/2011	N.D.	2	14.40	28.80	14.40
Panel 3 Room 5i	6865	1/10/2012	1/13/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 5i	6968	2/16/2012	2/22/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 5i	7018	3/6/2012	3/9/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 5i	7091	4/3/2012	4/9/2012	12.68	2	14.40	28.80	14.40
Panel 3 Room 5i	7169	5/1/2012	5/4/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 5i	7242	6/5/2012	6/8/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 5i	7369	7/17/2012	7/23/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 5i	7427	8/6/2012	8/10/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 5i	7512	9/4/2012	9/7/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 5i	7623	10/9/2012	10/16/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 5i	7693	11/6/2012	11/9/2012	N.D.	2	17.29	34.58	17.29
Panel 3 Room 5i	7779	12/4/2012	12/7/2012	29.86	2	17.29	34.58	17.29
Panel 3 Room 4e	3174	4/24/2008	4/30/2008	56.32	2	10.79	21.58	56.32
Panel 3 Room 4e	3210	5/14/2008	5/23/2008	48.84	2	10.79	21.58	48.84
Panel 3 Room 4e	3278	6/17/2008	6/25/2008	20.00	2	10.79	21.58	10.79
Panel 3 Room 4e	3337	7/16/2008	7/22/2008	54.12	2	10.79	21.58	54.12
Panel 3 Room 4e	3402	8/19/2008	8/22/2008	120.12	2	14.93	29.86	120.12
Panel 3 Room 4e	3450	9/10/2008	9/12/2008	136.06	2	14.93	29.86	136.06
Panel 3 Room 4e	3506	10/8/2008	10/10/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 4e	3579	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 4e	3618	12/3/2008	12/6/2008	49.22	2	14.93	29.86	49.22
Panel 3 Room 4e	3717	1/13/2009	1/21/2009	55.40	2	14.93	29.86	55.40
Panel 3 Room 4e	3774	2/10/2009	2/13/2009	35.76	2	14.93	29.86	35.76
Panel 3 Room 4e	3841	3/10/2009	3/27/2009	47.92	2	14.93	29.86	47.92
Panel 3 Room 4e	3916	4/14/2009	4/22/2009	35.76	2	14.93	29.86	35.76
Panel 3 Room 4e	3987	5/12/2009	5/15/2009	15.26	2	14.93	29.86	14.93
Panel 3 Room 4e	4045	6/1/2009	6/8/2009	41.08	2	14.93	29.86	41.08
Panel 3 Room 4e	4109	7/7/2009	7/10/2009	91.98	2	15.17	30.34	91.98
Panel 3 Room 4e	4168	8/5/2009	8/13/2009	52.92	2	15.17	30.34	52.92
Panel 3 Room 4e	4239	9/1/2009	9/4/2009	45.46	2	15.17	30.34	45.46
Panel 3 Room 4e	4336	10/12/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4e	4378	11/2/2009	11/12/2009	54.43	2.1	15.17	31.86	54.43
Panel 3 Room 4e	4468	12/8/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4e	4629	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4e	4727	2/17/2010	2/23/2010	63.46	2	15.17	30.34	63.46
Panel 3 Room 4e	4793	3/9/2010	3/12/2010	43.46	2	15.17	30.34	43.46
Panel 3 Room 4e	4961	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4e	5085	5/25/2010	5/28/2010	58.64	2	15.17	30.34	58.64
Panel 3 Room 4e	5120	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4e	5258	7/13/2010	7/19/2010	39.14	2	7.00	14.00	39.14
Panel 3 Room 4e	5351	8/9/2010	8/17/2010	99.22	2	7.00	14.00	99.22
Panel 3 Room 4e	5477	9/21/2010	9/27/2010	90.04	2	7.00	14.00	90.04
Panel 3 Room 4e	5536	10/11/2010	10/18/2010	85.22	2	7.00	14.00	85.22
Panel 3 Room 4e	5629	11/8/2010	11/15/2010	68.10	2	7.00	14.00	68.10
Panel 3 Room 4e	5748	12/14/2010	12/20/2010	89.98	2	7.00	14.00	89.98
Panel 3 Room 4e	5846	1/18/2011	1/24/2011	132.24	2	14.03	28.06	132.24
Panel 3 Room 4e	5932	2/15/2011	2/21/2011	66.56	2	14.03	28.06	66.56
Panel 3 Room 4e	6020	3/8/2011	3/11/2011	58.04	2	14.03	28.06	58.04
Panel 3 Room 4e	6133	4/19/2011	4/26/2011	43.64	2	14.03	28.06	43.64
Panel 3 Room 4e	6215	5/9/2011	5/13/2011	55.34	2	14.03	28.06	55.34
Panel 3 Room 4e	6315	6/14/2011	6/21/2011	43.96	2	14.03	28.06	43.96
Panel 3 Room 4e	6429	7/18/2011	7/22/2011	55.78	2	14.03	28.06	55.78
Panel 3 Room 4e	6497	8/15/2011	8/22/2011	66.62	2	14.03	28.06	66.62
Panel 3 Room 4e	6575	9/19/2011	9/27/2011	51.62	2	14.03	28.06	51.62
Panel 3 Room 4e	6648	10/17/2011	10/25/2011	34.04	2	14.03	28.06	34.04
Panel 3 Room 4e	6720	11/7/2011	11/11/2011	30.00	2	14.03	28.06	30.00
Panel 3 Room 4e	6775	12/5/2011	12/9/2011	29.26	2	14.40	28.80	29.26
Panel 3 Room 4e	6860	1/9/2012	1/13/2012	58.28	2	14.40	28.80	58.28
Panel 3 Room 4e	6963	2/16/2012	2/22/2012	14.74	2	14.40	28.80	14.40
Panel 3 Room 4e	7013	3/6/2012	3/9/2012	42.2	2	14.40	28.80	42.20
Panel 3 Room 4e	7086	4/2/2012	4/9/2012	33.4	2	14.40	28.80	33.40
Panel 3 Room 4e	7164	5/1/2012	5/4/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 4e	7237	6/4/2012	6/8/2012	41.1	2	14.40	28.80	41.10
Panel 3 Room 4e	7364	7/16/2012	7/23/2012	49.44	2	14.40	28.80	49.44
Panel 3 Room 4e	7422	8/6/2012	8/10/2012	27.22	2	14.40	28.80	14.40
Panel 3 Room 4e	7507	9/4/2012	9/7/2012	37.36	2	14.40	28.80	37.36
Panel 3 Room 4e	7618	10/9/2012	10/16/2012	38.28	2	14.40	28.80	38.28
Panel 3 Room 4e	7688	11/5/2012	11/9/2012	23.1	2	17.29	34.58	17.29
Panel 3 Room 4e	7774	12/3/2012	12/7/2012	34.96	2	17.29	34.58	34.96
Panel 3 Room 4i	3170	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 4i	3219	5/15/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 4i	3287	6/19/2008	6/25/2008	43.70	2	10.79	21.58	43.70
Panel 3 Room 4i	3346	7/16/2008	7/22/2008	94.38	2	10.79	21.58	94.38

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 4i	3410	8/19/2008	8/22/2008	122.86	2	14.93	29.86	122.86
Panel 3 Room 4i	3458	9/10/2008	9/12/2008	55.78	2	14.93	29.86	55.78
Panel 3 Room 4i	3514	10/8/2008	10/10/2008	14.80	2	14.93	29.86	14.93
Panel 3 Room 4i	3587	11/13/2008	11/18/2008	21.26	2	14.93	29.86	14.93
Panel 3 Room 4i	3626	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 4i	3721	1/13/2009	1/21/2009	14.98	2	14.93	29.86	14.93
Panel 3 Room 4i	3782	2/10/2009	2/13/2009	19.84	2	14.93	29.86	14.93
Panel 3 Room 4i	3845	3/11/2009	3/27/2009	5.50	2	14.93	29.86	14.93
Panel 3 Room 4i	3920	4/14/2009	4/22/2009	18.42	2	14.93	29.86	14.93
Panel 3 Room 4i	3984	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 4i	4053	6/2/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 4i	4116	7/8/2009	7/10/2009	70.10	2	15.17	30.34	70.10
Panel 3 Room 4i	4177	8/6/2009	8/13/2009	69.88	2	15.17	30.34	69.88
Panel 3 Room 4i	4246	9/2/2009	9/4/2009	19.66	2	15.17	30.34	15.17
Panel 3 Room 4i	4343	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4i	4385	11/3/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4i	4475	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4i	4636	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4i	4734	2/18/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4i	4802	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4i	4968	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4i	5092	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4i	5127	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 4i	5265	7/14/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 4i	5358	8/10/2010	8/17/2010	78.80	2	7.00	14.00	78.80
Panel 3 Room 4i	5484	9/22/2010	9/27/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 4i	5542	10/12/2010	10/18/2010	49.60	2	7.00	14.00	49.60
Panel 3 Room 4i	5635	11/9/2010	11/15/2010	30.22	2	7.00	14.00	30.22
Panel 3 Room 4i	5754	12/15/2010	12/20/2010	85.24	2	7.00	14.00	85.24
Panel 3 Room 4i	5852	1/19/2011	1/24/2011	58.84	2	14.03	28.06	58.84
Panel 3 Room 4i	5938	2/15/2011	2/21/2011	28.12	2	14.03	28.06	28.12
Panel 3 Room 4i	6026	3/9/2011	3/11/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 4i	6139	4/19/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 4i	6221	5/10/2011	5/13/2011	24.72	2	14.03	28.06	14.03
Panel 3 Room 4i	6321	6/15/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 4i	6437	7/19/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 4i	6503	8/16/2011	8/22/2011	42.26	2	14.03	28.06	42.26
Panel 3 Room 4i	6581	9/20/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 4i	6656	10/18/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 4i	6726	11/7/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 4i	6781	12/6/2011	12/9/2011	N.D.	2	14.40	28.80	14.40
Panel 3 Room 4i	6866	1/10/2012	1/13/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 4i	6969	2/16/2012	2/22/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 4i	7019	3/6/2012	3/9/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 4i	7092	4/3/2012	4/9/2012	15.68	2	14.40	28.80	14.40
Panel 3 Room 4i	7170	5/1/2012	5/4/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 4i	7243	6/5/2012	6/8/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 4i	7370	7/17/2012	7/23/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 4i	7428	8/6/2012	8/10/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 4i	7513	9/4/2012	9/7/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 4i	7624	10/9/2012	10/16/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 4i	7694	11/6/2012	11/9/2012	N.D.	2	17.29	34.58	17.29
Panel 3 Room 4i	7780	12/4/2012	12/7/2012	N.D.	2	17.29	34.58	17.29
Panel 3 Room 3e	3172	4/24/2008	4/30/2008	38.24	2	10.79	21.58	38.24
Panel 3 Room 3e	3209	5/14/2008	5/23/2008	45.78	2	10.79	21.58	45.78
Panel 3 Room 3e	3277	6/17/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 3e	3336	7/15/2008	7/22/2008	49.56	2	10.79	21.58	49.56
Panel 3 Room 3e	3401	8/20/2008	8/22/2008	46.38	2	14.93	29.86	46.38
Panel 3 Room 3e	3449	9/8/2008	9/12/2008	76.02	2	14.93	29.86	76.02
Panel 3 Room 3e	3505	10/6/2008	10/10/2008	91.54	2	14.93	29.86	91.54
Panel 3 Room 3e	3578	11/10/2008	11/18/2008	76.38	2	14.93	29.86	76.38
Panel 3 Room 3e	3617	12/3/2008	12/6/2008	51.44	2	14.93	29.86	51.44
Panel 3 Room 3e	3712	1/12/2009	1/21/2009	46.52	2	14.93	29.86	46.52
Panel 3 Room 3e	3773	2/9/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 3e	3834	3/12/2009	3/27/2009	49.78	2	14.93	29.86	49.78
Panel 3 Room 3e	3911	4/13/2009	4/22/2009	36.44	2	14.93	29.86	36.44
Panel 3 Room 3e	3979	5/12/2009	5/15/2009	40.06	2	14.93	29.86	40.06
Panel 3 Room 3e	4044	6/1/2009	6/8/2009	44.98	2	14.93	29.86	44.98
Panel 3 Room 3e	4110	7/7/2009	7/10/2009	88.52	2	15.17	30.34	88.52
Panel 3 Room 3e	4169	8/5/2009	8/13/2009	62.82	2	15.17	30.34	62.82
Panel 3 Room 3e	4240	9/1/2009	9/4/2009	54.22	2	15.17	30.34	54.22
Panel 3 Room 3e	4337	10/12/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3e	4379	11/3/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3e	4469	12/8/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3e	4630	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3e	4728	2/17/2010	2/23/2010	55.36	2	15.17	30.34	55.36
Panel 3 Room 3e	4796	3/10/2010	3/12/2010	41.42	2	15.17	30.34	41.42

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 3e	4962	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3e	5086	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3e	5121	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3e	5259	7/13/2010	7/19/2010	88.48	2	7.00	14.00	88.48
Panel 3 Room 3e	5352	8/9/2010	8/17/2010	105.14	2	7.00	14.00	105.14
Panel 3 Room 3e	5478	9/21/2010	9/27/2010	58.68	2	7.00	14.00	58.68
Panel 3 Room 3e	5537	10/11/2010	10/18/2010	59.18	2	7.00	14.00	59.18
Panel 3 Room 3e	5630	11/8/2010	11/15/2010	66.94	2	7.00	14.00	66.94
Panel 3 Room 3e	5749	12/14/2010	12/20/2010	80.20	2	7.00	14.00	80.20
Panel 3 Room 3e	5847	1/18/2011	1/24/2011	136.16	2	14.03	28.06	136.16
Panel 3 Room 3e	5933	2/15/2011	2/21/2011	53.02	2	14.03	28.06	53.02
Panel 3 Room 3e	6021	3/8/2011	3/11/2011	84.28	2	14.03	28.06	84.28
Panel 3 Room 3e	6134	4/19/2011	4/26/2011	47.04	2	14.03	28.06	47.04
Panel 3 Room 3e	6216	5/9/2011	5/13/2011	39.22	2	14.03	28.06	39.22
Panel 3 Room 3e	6316	6/14/2011	6/21/2011	34.02	2	14.03	28.06	34.02
Panel 3 Room 3e	6430	7/18/2011	7/22/2011	53.20	2	14.03	28.06	53.20
Panel 3 Room 3e	6498	8/15/2011	8/22/2011	50.46	2	14.03	28.06	50.46
Panel 3 Room 3e	6576	9/19/2011	9/27/2011	38.60	2	14.03	28.06	38.60
Panel 3 Room 3e	6649	10/17/2011	10/25/2011	28.86	2	14.03	28.06	28.86
Panel 3 Room 3e	6721	11/7/2011	11/11/2011	26.00	2	14.03	28.06	14.03
Panel 3 Room 3e	6776	12/5/2011	12/9/2011	38.26	2	14.40	28.80	38.26
Panel 3 Room 3e	6861	1/9/2012	1/13/2012	53.6	2	14.40	28.80	53.60
Panel 3 Room 3e	6964	2/16/2012	2/22/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 3e	7014	3/6/2012	3/9/2012	32.26	2	14.40	28.80	32.26
Panel 3 Room 3e	7087	4/2/2012	4/9/2012	23	2	14.40	28.80	14.40
Panel 3 Room 3e	7165	5/1/2012	5/4/2012	27.48	2	14.40	28.80	14.40
Panel 3 Room 3e	7238	6/4/2012	6/8/2012	19.22	2	14.40	28.80	14.40
Panel 3 Room 3e	7365	7/16/2012	7/23/2012	34.56	2	14.40	28.80	34.56
Panel 3 Room 3e	7423	8/6/2012	8/10/2012	43.44	2	14.40	28.80	43.44
Panel 3 Room 3e	7508	9/4/2012	9/7/2012	30.22	2	14.40	28.80	30.22
Panel 3 Room 3e	7619	10/9/2012	10/16/2012	30.9	2	14.40	28.80	30.90
Panel 3 Room 3e	7689	11/5/2012	11/9/2012	39.38	2	17.29	34.58	39.38
Panel 3 Room 3e	7775	12/3/2012	12/7/2012	31.02	2	17.29	34.58	17.29
Panel 3 Room 3i	3171	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 3i	3218	5/14/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 3i	3286	6/17/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 3i	3345	7/15/2008	7/22/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 3i	3409	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 3i	3457	9/8/2008	9/12/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 3i	3513	10/6/2008	10/10/2008	48.84	2	14.93	29.86	48.84
Panel 3 Room 3i	3586	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 3i	3625	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 3i	3714	1/12/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 3i	3781	2/10/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 3i	3836	3/12/2009	3/27/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 3i	3913	4/13/2009	4/22/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 3i	3981	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 3i	4052	6/2/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 3i	4117	7/8/2009	7/10/2009	36.74	2	15.17	30.34	36.74
Panel 3 Room 3i	4178	8/6/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3i	4247	9/2/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3i	4344	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3i	4386	11/3/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3i	4476	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3i	4637	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3i	4735	2/18/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3i	4803	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3i	4969	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3i	5093	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3i	5128	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 3i	5266	7/14/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 3i	5359	8/10/2010	8/17/2010	69.66	2	7.00	14.00	69.66
Panel 3 Room 3i	5485	9/22/2010	9/27/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 3i	5543	10/12/2010	10/18/2010	34.78	2	7.00	14.00	34.78
Panel 3 Room 3i	5636	11/9/2010	11/15/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 3i	5755	12/15/2010	12/20/2010	70.66	2	7.00	14.00	70.66
Panel 3 Room 3i	5853	1/19/2011	1/24/2011	79.18	2	14.03	28.06	79.18
Panel 3 Room 3i	5939	2/15/2011	2/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 3i	6027	3/9/2011	3/11/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 3i	6140	4/19/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 3i	6222	5/10/2011	5/13/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 3i	6322	6/15/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 3i	6438	7/19/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 3i	6504	8/16/2011	8/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 3i	6582	9/20/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 3i	6657	10/18/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 3i	6727	11/8/2011	11/11/2011	N.D.	2	14.03	28.06	14.03

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 3i	6782	12/6/2011	12/9/2011	N.D.	2	14.40	28.80	14.40
Panel 3 Room 3i	6867	1/10/2012	1/13/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 3i	6970	2/16/2012	2/22/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 3i	7020	3/6/2012	3/9/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 3i	7093	4/3/2012	4/9/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 3i	7171	5/1/2012	5/4/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 3i	7244	6/5/2012	6/8/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 3i	7371	7/17/2012	7/23/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 3i	7429	8/6/2012	8/10/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 3i	7514	9/4/2012	9/7/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 3i	7625	10/9/2012	10/16/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 3i	7695	11/6/2012	11/9/2012	N.D.	2	17.29	34.58	17.29
Panel 3 Room 3i	7781	12/4/2012	12/7/2012	N.D.	2	17.29	34.58	17.29
Panel 3 Room 2e	3164	4/24/2008	4/30/2008	32.02	2	10.79	21.58	32.02
Panel 3 Room 2e	3208	5/14/2008	5/23/2008	31.20	2	10.79	21.58	31.20
Panel 3 Room 2e	3276	6/17/2008	6/25/2008	22.78	2	10.79	21.58	22.78
Panel 3 Room 2e	3335	7/15/2008	7/22/2008	32.36	2	10.79	21.58	32.36
Panel 3 Room 2e	3400	8/20/2008	8/22/2008	37.30	2	14.93	29.86	37.30
Panel 3 Room 2e	3448	9/8/2008	9/12/2008	35.04	2	14.93	29.86	35.04
Panel 3 Room 2e	3504	10/6/2008	10/10/2008	36.14	2	14.93	29.86	36.14
Panel 3 Room 2e	3577	11/10/2008	11/18/2008	36.90	2	14.93	29.86	36.90
Panel 3 Room 2e	3616	12/3/2008	12/6/2008	33.86	2	14.93	29.86	33.86
Panel 3 Room 2e	3711	1/12/2009	1/21/2009	36.68	2	14.93	29.86	36.68
Panel 3 Room 2e	3772	2/9/2009	2/13/2009	24.04	2	14.93	29.86	14.93
Panel 3 Room 2e	3833	3/12/2009	3/27/2009	16.42	2	14.93	29.86	14.93
Panel 3 Room 2e	3910	4/13/2009	4/22/2009	23.94	2	14.93	29.86	14.93
Panel 3 Room 2e	3978	5/12/2009	5/15/2009	35.24	2	14.93	29.86	35.24
Panel 3 Room 2e	4043	6/1/2009	6/8/2009	14.40	2	14.93	29.86	14.93
Panel 3 Room 2e	4111	7/7/2009	7/10/2009	37.48	2	15.17	30.34	37.48
Panel 3 Room 2e	4170	8/5/2009	8/13/2009	18.32	2	15.17	30.34	15.17
Panel 3 Room 2e	4241	9/1/2009	9/4/2009	21.32	2	15.17	30.34	15.17
Panel 3 Room 2e	4338	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2e	4380	11/3/2009	11/12/2009	22.38	2	15.17	30.34	15.17
Panel 3 Room 2e	4470	12/8/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2e	4631	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2e	4729	2/17/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2e	4797	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2e	4963	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2e	5087	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2e	5122	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2e	5260	7/13/2010	7/19/2010	105.46	2	7.00	14.00	105.46
Panel 3 Room 2e	5353	8/9/2010	8/17/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 2e	5479	9/21/2010	9/27/2010	52.60	2	7.00	14.00	52.60
Panel 3 Room 2e	5538	10/12/2010	10/18/2010	66.54	2	7.00	14.00	66.54
Panel 3 Room 2e	5631	11/8/2010	11/15/2010	50.14	2	7.00	14.00	50.14
Panel 3 Room 2e	5750	12/14/2010	12/20/2010	75.48	2	7.00	14.00	75.48
Panel 3 Room 2e	5848	1/18/2011	1/24/2011	123.08	2	14.03	28.06	123.08
Panel 3 Room 2e	5934	2/15/2011	2/21/2011	48.58	2	14.03	28.06	48.58
Panel 3 Room 2e	6022	3/8/2011	3/11/2011	54.10	2	14.03	28.06	54.10
Panel 3 Room 2e	6135	4/19/2011	4/26/2011	49.12	2	14.03	28.06	49.12
Panel 3 Room 2e	6217	5/10/2011	5/13/2011	42.72	2	14.03	28.06	42.72
Panel 3 Room 2e	6317	6/14/2011	6/21/2011	31.62	2	14.03	28.06	31.62
Panel 3 Room 2e	6431	7/18/2011	7/22/2011	37.94	2	14.03	28.06	37.94
Panel 3 Room 2e	6499	8/15/2011	8/22/2011	55.18	2	14.03	28.06	55.18
Panel 3 Room 2e	6577	9/19/2011	9/27/2011	33.10	2	14.03	28.06	33.10
Panel 3 Room 2e	6650	10/17/2011	10/25/2011	22.14	2	14.03	28.06	14.03
Panel 3 Room 2e	6722	11/7/2011	11/11/2011	20.36	2	14.03	28.06	14.03
Panel 3 Room 2e	6777	12/5/2011	12/9/2011	31.18	2	14.40	28.80	31.18
Panel 3 Room 2e	6862	1/9/2012	1/13/2012	60.96	2	14.40	28.80	60.96
Panel 3 Room 2e	6965	2/16/2012	2/22/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 2e	7015	3/6/2012	3/9/2012	40.78	2	14.40	28.80	40.78
Panel 3 Room 2e	7088	4/2/2012	4/9/2012	35.32	2	14.40	28.80	35.32
Panel 3 Room 2e	7166	5/1/2012	5/4/2012	25.76	2	14.40	28.80	14.40
Panel 3 Room 2e	7239	6/4/2012	6/8/2012	36.96	2	14.40	28.80	36.96
Panel 3 Room 2e	7366	7/16/2012	7/23/2012	28.5	2	14.40	28.80	14.40
Panel 3 Room 2e	7424	8/6/2012	8/10/2012	34.66	2	14.40	28.80	34.66
Panel 3 Room 2e	7509	9/4/2012	9/7/2012	46.42	2	14.40	28.80	46.42
Panel 3 Room 2e	7620	10/9/2012	10/16/2012	37.68	2	14.40	28.80	37.68
Panel 3 Room 2e	7690	11/6/2012	11/9/2012	26.16	2	17.29	34.58	17.29
Panel 3 Room 2e	7776	12/3/2012	12/7/2012	46.82	2	17.29	34.58	46.82
Panel 3 Room 2i	3162	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 2i	3217	5/14/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 2i	3285	6/17/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 2i	3344	7/15/2008	7/22/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 2i	3408	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 2i	3456	9/8/2008	9/12/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 2i	3512	10/6/2008	10/10/2008	13.24	2	14.93	29.86	14.93

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 2i	3585	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 2i	3624	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 2i	3713	1/12/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 2i	3780	2/10/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 2i	3835	3/12/2009	3/27/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 2i	3912	4/13/2009	4/22/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 2i	3980	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 2i	4051	6/2/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 2i	4118	7/8/2009	7/10/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2i	4179	8/6/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2i	4248	9/2/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2i	4345	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2i	4387	11/3/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2i	4477	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2i	4638	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2i	4736	2/18/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2i	4804	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2i	4970	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2i	5094	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2i	5129	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 2i	5267	7/14/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 2i	5360	8/10/2010	8/17/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 2i	5486	9/22/2010	9/27/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 2i	5544	10/12/2010	10/18/2010	19.24	2	7.00	14.00	19.24
Panel 3 Room 2i	5637	11/9/2010	11/15/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room 2i	5756	12/15/2010	12/20/2010	68.86	2	7.00	14.00	68.86
Panel 3 Room 2i	5854	1/19/2011	1/24/2011	55.84	2	14.03	28.06	55.84
Panel 3 Room 2i	5940	2/15/2011	2/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 2i	6028	3/9/2011	3/11/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 2i	6141	4/19/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 2i	6223	5/10/2011	5/13/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 2i	6323	6/15/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 2i	6439	7/19/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 2i	6505	8/16/2011	8/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 2i	6583	9/20/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 2i	6658	10/18/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 2i	6728	11/8/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 2i	6783	12/6/2011	12/9/2011	N.D.	2	14.40	28.80	14.40
Panel 3 Room 2i	6868	1/10/2012	1/13/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 2i	6971	2/16/2012	2/22/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 2i	7021	3/6/2012	3/9/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 2i	7094	4/3/2012	4/9/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 2i	7172	5/1/2012	5/4/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 2i	7245	6/5/2012	6/8/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 2i	7372	7/17/2012	7/23/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 2i	7430	8/6/2012	8/10/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 2i	7515	9/4/2012	9/7/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 2i	7626	10/9/2012	10/16/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 2i	7696	11/6/2012	11/9/2012	N.D.	2	17.29	34.58	17.29
Panel 3 Room 2i	7782	12/4/2012	12/7/2012	N.D.	2	17.29	34.58	17.29
Panel 3 Room 1e	3163	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 1e	3207	5/14/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 1e	3293	6/17/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 1e	3334	7/15/2008	7/22/2008	58.36	2	10.79	21.58	58.36
Panel 3 Room 1e	3399	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room 1e	3447	9/8/2008	9/12/2008	19.46	2	14.93	29.86	14.93
Panel 3 Room 1e	3503	10/6/2008	10/10/2008	21.18	2	14.93	29.86	14.93
Panel 3 Room 1e	3575	11/10/2008	11/18/2008	14.10	2	14.93	29.86	14.93
Panel 3 Room 1e	3614	12/3/2008	12/6/2008	23.54	2	14.93	29.86	14.93
Panel 3 Room 1e	3709	1/12/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 1e	3770	2/9/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 1e	3831	3/11/2009	3/27/2009	8.86	2	14.93	29.86	14.93
Panel 3 Room 1e	3908	4/13/2009	4/22/2009	8.00	2	14.93	29.86	14.93
Panel 3 Room 1e	3976	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 1e	4041	6/1/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room 1e	4112	7/7/2009	7/10/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 1e	4172	8/6/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 1e	4242	9/1/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 1e	4339	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 1e	4381	11/3/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 1e	4471	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room 1e	4632	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 1e	4730	2/17/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 1e	4798	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 1e	4964	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 1e	5088	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room 1e	5123	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 1e	5261	7/13/2010	7/19/2010	54.82	2	7.00	14.00	54.82
Panel 3 Room 1e	5354	8/10/2010	8/17/2010	43.64	2	7.00	14.00	43.64
Panel 3 Room 1e	5480	9/21/2010	9/27/2010	34.86	2	7.00	14.00	34.86
Panel 3 Room 1e	5539	10/12/2010	10/18/2010	58.30	2	7.00	14.00	58.30
Panel 3 Room 1e	5632	11/9/2010	11/15/2010	26.00	2	7.00	14.00	26.00
Panel 3 Room 1e	5751	12/15/2010	12/20/2010	75.32	2	7.00	14.00	75.32
Panel 3 Room 1e	5849	1/18/2011	1/24/2011	84.54	2	14.03	28.06	84.54
Panel 3 Room 1e	5935	2/15/2011	2/21/2011	58.96	2	14.03	28.06	58.96
Panel 3 Room 1e	6023	3/9/2011	3/11/2011	67.98	2	14.03	28.06	67.98
Panel 3 Room 1e	6136	4/19/2011	4/26/2011	32.52	2	14.03	28.06	32.52
Panel 3 Room 1e	6218	5/10/2011	5/13/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 1e	6318	6/15/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 1e	6433	7/19/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 1e	6506	8/16/2011	8/22/2011	34.00	2	14.03	28.06	34.00
Panel 3 Room 1e	6584	9/20/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 1e	6659	10/18/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 1e	6729	11/8/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room 1e	6784	12/6/2011	12/9/2011	N.D.	2	14.40	28.80	14.40
Panel 3 Room 1e	6869	1/10/2012	1/13/2012	50.88	2	14.40	28.80	50.88
Panel 3 Room 1e	6972	2/16/2012	2/22/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 1e	7022	3/6/2012	3/9/2012	32.8	2	14.40	28.80	32.80
Panel 3 Room 1e	7095	4/3/2012	4/9/2012	16.56	2	14.40	28.80	14.40
Panel 3 Room 1e	7173	5/1/2012	5/4/2012	31.26	2	14.40	28.80	31.26
Panel 3 Room 1e	7246	6/5/2012	6/8/2012	16.54	2	14.40	28.80	14.40
Panel 3 Room 1e	7373	7/17/2012	7/23/2012	33.04	2	14.40	28.80	33.04
Panel 3 Room 1e	7431	8/6/2012	8/10/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 1e	7516	9/4/2012	9/7/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room 1e	7627	10/9/2012	10/16/2012	32.06	2	14.40	28.80	32.06
Panel 3 Room 1e	7697	11/6/2012	11/9/2012	21.14	2	17.29	34.58	17.29
Panel 3 Room 1e	7783	12/4/2012	12/7/2012	32.9	2	17.29	34.58	17.29
Panel 3 Room 1i	3169	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 1i	3216	5/19/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room 1i	3284	6/19/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room EBW	3165	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room EBW	3215	5/15/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room EBW	3283	6/17/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room EBW	3342	7/15/2008	7/22/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room EBW	3407	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBW	3455	9/8/2008	9/12/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBW	3511	10/6/2008	10/10/2008	32.88	2	14.93	29.86	32.88
Panel 3 Room EBW	3584	11/10/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBW	3623	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBW	3716	1/12/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBW	3779	2/9/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBW	3838	3/12/2009	3/27/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBW	3915	4/13/2009	4/22/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBW	3983	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBW	4049	6/2/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBW	4105	7/7/2009	7/10/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBW	4164	8/5/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBW	4235	9/1/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBW	4332	10/12/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBW	4374	11/2/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBW	4464	12/8/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBW	4625	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBW	4723	2/17/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBW	4789	3/9/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBW	4957	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBW	5081	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBW	5116	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBW	5254	7/13/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room EBW	5347	8/9/2010	8/17/2010	47.32	2	7.00	14.00	47.32
Panel 3 Room EBW	5474	9/21/2010	9/27/2010	35.28	2	7.00	14.00	35.28
Panel 3 Room EBW	5533	10/11/2010	10/18/2010	60.22	2	7.00	14.00	60.22
Panel 3 Room EBW	5626	11/8/2010	11/15/2010	36.90	2	7.00	14.00	36.90
Panel 3 Room EBW	5745	12/14/2010	12/20/2010	71.48	2	7.00	14.00	71.48
Panel 3 Room EBW	5843	1/18/2011	1/24/2011	95.56	2	14.03	28.06	95.56
Panel 3 Room EBW	5929	2/15/2011	2/21/2011	53.14	2	14.03	28.06	53.14
Panel 3 Room EBW	6017	3/8/2011	3/11/2011	73.22	2	14.03	28.06	73.22
Panel 3 Room EBW	6130	4/18/2011	4/26/2011	31.08	2	14.03	28.06	31.08
Panel 3 Room EBW	6212	5/9/2011	5/13/2011	40.20	2	14.03	28.06	40.20
Panel 3 Room EBW	6312	6/14/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBW	6432	7/18/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBW	6500	8/15/2011	8/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBW	6578	9/19/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBW	6652	10/17/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBW	6723	11/7/2011	11/11/2011	N.D.	2	14.03	28.06	14.03

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room EBW	6778	12/5/2011	12/9/2011	29.60	2	14.40	28.80	29.60
Panel 3 Room EBW	6863	1/9/2012	1/13/2012	51.46	2	14.40	28.80	51.46
Panel 3 Room EBW	6966	2/16/2012	2/22/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBW	7016	3/6/2012	3/9/2012	23.1	2	14.40	28.80	14.40
Panel 3 Room EBW	7089	4/2/2012	4/9/2012	27.82	2	14.40	28.80	14.40
Panel 3 Room EBW	7167	5/1/2012	5/4/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBW	7240	6/4/2012	6/8/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBW	7367	7/16/2012	7/23/2012	31.38	2	14.40	28.80	31.38
Panel 3 Room EBW	7425	8/6/2012	8/10/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBW	7510	9/4/2012	9/7/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBW	7621	10/9/2012	10/16/2012	26.92	2	14.40	28.80	14.40
Panel 3 Room EBW	7691	11/6/2012	11/9/2012	28.84	2	17.29	34.58	17.29
Panel 3 Room EBW	7777	12/4/2012	12/7/2012	22.64	2	17.29	34.58	17.29
Panel 3 Room EBA	3167	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room EBA	3214	5/15/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room EBA	3282	6/19/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room EBA	3341	7/15/2008	7/22/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room EBA	3406	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBA	3454	9/8/2008	9/12/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBA	3510	10/6/2008	10/10/2008	15.14	2	14.93	29.86	14.93
Panel 3 Room EBA	3583	11/10/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBA	3622	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBA	3715	1/12/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBA	3778	2/9/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBA	3837	3/12/2009	3/27/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBA	3914	4/13/2009	4/22/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBA	3982	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBA	4050	6/2/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room EBA	4104	7/7/2009	7/10/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBA	4163	8/5/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBA	4234	9/1/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBA	4331	10/12/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBA	4373	11/2/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBA	4463	12/8/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBA	4624	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBA	4722	2/17/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBA	4788	3/9/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBA	4956	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBA	5080	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBA	5115	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room EBA	5253	7/13/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room EBA	5346	8/9/2010	8/17/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room EBA	5473	9/21/2010	9/27/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room EBA	5532	10/11/2010	10/18/2010	41.80	2	7.00	14.00	41.80
Panel 3 Room EBA	5625	11/8/2010	11/15/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room EBA	5744	12/14/2010	12/20/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room EBA	5842	1/18/2011	1/24/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBA	5928	2/15/2011	2/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBA	6016	3/8/2011	3/11/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBA	6129	4/18/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBA	6211	5/9/2011	5/13/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBA	6311	6/14/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBA	6435	7/19/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBA	6501	8/16/2011	8/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBA	6579	9/20/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBA	6653	10/17/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBA	6724	11/7/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room EBA	6779	12/5/2011	12/9/2011	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBA	6864	1/10/2012	1/13/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBA	6967	2/16/2012	2/22/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBA	7017	3/6/2012	3/9/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBA	7090	4/3/2012	4/9/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBA	7168	5/1/2012	5/4/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBA	7241	6/5/2012	6/8/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBA	7368	7/16/2012	7/23/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBA	7426	8/6/2012	8/10/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBA	7511	9/4/2012	9/7/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBA	7622	10/9/2012	10/16/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room EBA	7692	11/6/2012	11/9/2012	N.D.	2	17.29	34.58	17.29
Panel 3 Room EBA	7778	12/4/2012	12/7/2012	N.D.	2	17.29	34.58	17.29
Panel 3 Room IBW	3173	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room IBW	3224	5/15/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room IBW	3292	6/19/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room IBW	3350	7/16/2008	7/22/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room IBW	3414	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBW	3462	9/10/2008	9/12/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBW	3518	10/8/2008	10/10/2008	N.D.	2	14.93	29.86	14.93

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room IBW	3591	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBW	3630	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBW	3725	1/14/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBW	3786	2/11/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBW	3840	3/10/2009	3/27/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBW	3924	4/15/2009	4/22/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBW	3992	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBW	4040	6/1/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBW	4103	7/7/2009	7/10/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBW	4181	8/6/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBW	4250	9/2/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBW	4347	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBW	4372	11/2/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBW	4479	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBW	4640	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBW	4738	2/18/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBW	4795	3/9/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBW	5078	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBW	5130	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBW	5252	7/13/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room IBW	5362	8/10/2010	8/17/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room IBW	5487	9/22/2010	9/27/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room IBW	5531	10/11/2010	10/18/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room IBW	5624	11/8/2010	11/15/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room IBW	5743	12/14/2010	12/20/2010	51.16	2	7.00	14.00	51.16
Panel 3 Room IBW	5841	1/18/2011	1/24/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBW	5927	2/15/2011	2/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBW	6015	3/8/2011	3/11/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBW	6128	4/18/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBW	6210	5/9/2011	5/13/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBW	6309	6/14/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBW	6426	7/18/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBW	6494	8/15/2011	8/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBW	6571	9/19/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBW	6654	10/18/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBW	6716	11/7/2011	11/11/2011	38.82	2	14.03	28.06	38.82
Panel 3 Room IBW	6771	12/5/2011	12/9/2011	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBW	6857	1/9/2012	1/13/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBW	6959	2/16/2012	2/22/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBW	7009	3/6/2012	3/9/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBW	7083	4/2/2012	4/9/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBW	7161	5/1/2012	5/4/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBW	7234	6/4/2012	6/8/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBW	7361	7/16/2012	7/23/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBW	7419	8/6/2012	8/10/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBW	7504	9/4/2012	9/7/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBW	7615	10/8/2012	10/16/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBW	7686	11/5/2012	11/9/2012	N.D.	2	17.29	34.58	17.29
Panel 3 Room IBW	7772	12/3/2012	12/7/2012	N.D.	2	17.29	34.58	17.29
Panel 3 Room IBA	3168	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room IBA	3223	5/15/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room IBA	3291	6/19/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room IBA	3349	7/16/2008	7/22/2008	N.D.	2	10.79	21.58	10.79
Panel 3 Room IBA	3413	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBA	3461	9/10/2008	9/12/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBA	3517	10/8/2008	10/10/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBA	3590	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBA	3629	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBA	3724	1/14/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBA	3785	2/11/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBA	3839	3/10/2009	3/27/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBA	3923	4/15/2009	4/22/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBA	3991	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBA	4039	6/1/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
Panel 3 Room IBA	4102	7/7/2009	7/10/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBA	4180	8/6/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBA	4249	9/2/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBA	4346	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBA	4371	11/2/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBA	4478	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBA	4639	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBA	4737	2/18/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBA	4794	3/9/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBA	4954	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBA	5079	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBA	5131	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
Panel 3 Room IBA	5251	7/13/2010	7/19/2010	N.D.	2	7.00	14.00	7.00

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room IBA	5361	8/10/2010	8/17/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room IBA	5488	9/22/2010	9/27/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room IBA	5530	10/11/2010	10/18/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room IBA	5623	11/8/2010	11/15/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room IBA	5742	12/14/2010	12/20/2010	N.D.	2	7.00	14.00	7.00
Panel 3 Room IBA	5840	1/18/2011	1/24/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBA	5926	2/15/2011	2/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBA	6014	3/8/2011	3/11/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBA	6127	4/18/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBA	6209	5/9/2011	5/13/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBA	6310	6/14/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBA	6425	7/18/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBA	6493	8/15/2011	8/22/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBA	6572	9/19/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBA	6655	10/18/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBA	6717	11/7/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
Panel 3 Room IBA	6772	12/5/2011	12/9/2011	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBA	6856	1/9/2012	1/13/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBA	6960	2/16/2012	2/22/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBA	7010	3/6/2012	3/9/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBA	7082	4/2/2012	4/9/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBA	7160	5/1/2012	5/4/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBA	7233	6/4/2012	6/8/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBA	7360	7/16/2012	7/23/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBA	7418	8/6/2012	8/10/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBA	7503	9/4/2012	9/7/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBA	7614	10/8/2012	10/16/2012	N.D.	2	14.40	28.80	14.40
Panel 3 Room IBA	7685	11/5/2012	11/9/2012	N.D.	2	17.29	34.58	17.29
Panel 3 Room IBA	7771	12/3/2012	12/7/2012	N.D.	2	17.29	34.58	17.29

Methane Data-Panel 3

All samples were sampled at sub-atmospheric pressure and pressurized by the lab as required for analysis; dilution factors included in data set. The MDL (method detection limit) is the sample quantitation limit determined in accordance with 40 CFR Part 136; actual and dilution corrected MDLs included in data set.

8/21/07-7/24/08 MDL = 17.99 ppmv
7/25/08-6/16/09 MDL = 23.74 ppmv
6/17/09-6/8/10 MDL = 22.21 ppmv
6/9/10-12/28/10 MDL = 21.39 ppmv
12/29/10-11/30/11 MDL = 23.97 ppmv
12/1/11-10/21/12 MDL = 17.45 ppmv
10/22/12-? MDL = 15.71 ppmv ← MDL end date not yet determined

Some values in column "Results" are less than dilution corrected MDLs. These values are not included in the statistical evaluation. When results are N.D. (not-detected) or less than dilution corrected MDLs, the values used for the statistical evaluation are 1/2 the corrected MDL.

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 7e	3176	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 7e	3213	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 7e	3281	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 7e	3340	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 7e	3405	8/19/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 7e	3453	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 7e	3509	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 7e	3582	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 7e	3621	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 7e	3720	1/13/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 7e	3777	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 7e	3844	3/11/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 7e	3919	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 7e	3990	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 7e	4048	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 7e	4106	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 7e	4165	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 7e	4236	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 7e	4333	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 7e	4375	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 7e	4465	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 7e	4626	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 7e	4724	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 7e	4790	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 7e	4958	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 7e	5082	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 7e	5117	6/1/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 7e	5255	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 7i	3175	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 7i	3222	5/19/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 6e	3178	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 6e	3212	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 6e	3280	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 6e	3339	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 6e	3426	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6e	3452	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6e	3508	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6e	3581	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6e	3620	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6e	3719	1/13/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6e	3776	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6e	3843	3/10/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6e	3918	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6e	3989	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6e	4047	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6e	4107	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6e	4166	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6e	4237	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6e	4334	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6e	4376	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6e	4466	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6e	4627	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6e	4725	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6e	4791	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6e	4959	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6e	5083	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6e	5118	6/1/2010	6/7/2010	N.D.	2	22.21	44.42	22.21

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 6e	5256	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 6e	5349	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 6e	5475	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 6e	5534	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 6e	5627	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 6e	5746	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 6e	5844	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 6e	5930	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 6e	6018	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 6e	6131	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 6e	6213	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 6e	6313	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 6e	6427	7/18/2011	7/28/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 6e	6495	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 6e	6573	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 6e	6646	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 6e	6718	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 6e	6773	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room 6e	6858	1/9/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 6e	6961	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 6e	7011	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 6e	7084	4/2/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 6e	7162	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 6e	7235	6/4/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 6e	7362	7/16/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 6e	7420	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 6e	7505	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 6i	3166	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 6i	3221	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 6i	3289	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 6i	3348	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 6i	3412	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6i	3460	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6i	3516	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6i	3589	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6i	3628	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6i	3723	1/14/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6i	3784	2/11/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6i	3847	3/11/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6i	3922	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6i	3986	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6i	4055	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 6i	4114	7/8/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6i	4171	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6i	4244	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6i	4341	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6i	4383	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6i	4473	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6i	4634	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6i	4732	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6i	4800	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6i	4966	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6i	5090	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6i	5125	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 6i	5263	7/14/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 6i	5356	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5e	3179	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 5e	3211	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 5e	3279	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 5e	3338	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 5e	3403	8/19/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5e	3451	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5e	3507	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5e	3580	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5e	3619	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5e	3718	1/13/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5e	3775	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5e	3842	3/10/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5e	3917	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5e	3988	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5e	4046	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5e	4108	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5e	4167	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5e	4238	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5e	4335	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5e	4377	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5e	4467	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 5e	4628	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5e	4726	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5e	4792	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5e	4960	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5e	5084	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5e	5119	6/1/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5e	5257	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5e	5350	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5e	5476	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5e	5535	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5e	5628	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5e	5747	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5e	5845	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5e	5931	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5e	6019	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5e	6132	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5e	6214	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5e	6314	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5e	6428	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5e	6496	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5e	6574	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5e	6647	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5e	6719	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5e	6774	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5e	6859	1/9/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5e	6962	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5e	7012	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5e	7085	4/2/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5e	7163	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5e	7236	6/4/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5e	7363	7/16/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5e	7421	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5e	7506	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5e	7617	10/8/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5e	7687	11/5/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 5e	7773	12/3/2012	12/7/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 5i	3177	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 5i	3220	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 5i	3288	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 5i	3347	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 5i	3411	8/19/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5i	3459	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5i	3515	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5i	3588	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5i	3627	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5i	3722	1/13/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5i	3783	2/11/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5i	3846	3/11/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5i	3921	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5i	3985	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5i	4054	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 5i	4115	7/8/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5i	4176	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5i	4245	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5i	4342	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5i	4384	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5i	4474	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5i	4635	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5i	4733	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5i	4801	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5i	4967	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5i	5091	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5i	5126	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 5i	5264	7/14/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5i	5357	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5i	5483	9/22/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5i	5541	10/12/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5i	5634	11/9/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5i	5753	12/15/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 5i	5851	1/19/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5i	5937	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5i	6025	3/9/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5i	6138	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5i	6220	5/10/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5i	6320	6/15/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5i	6436	7/19/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5i	6502	8/16/2011	8/22/2011	N.D.	2	23.97	47.94	23.97

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 5i	6580	9/20/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5i	6651	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5i	6725	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 5i	6780	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5i	6865	1/10/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5i	6968	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5i	7018	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5i	7091	4/3/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5i	7169	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5i	7242	6/5/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5i	7369	7/17/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5i	7427	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5i	7512	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5i	7623	10/9/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 5i	7693	11/6/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 5i	7779	12/4/2012	12/7/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 4e	3174	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 4e	3210	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 4e	3278	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 4e	3337	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 4e	3402	8/19/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4e	3450	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4e	3506	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4e	3579	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4e	3618	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4e	3717	1/13/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4e	3774	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4e	3841	3/10/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4e	3916	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4e	3987	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4e	4045	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4e	4109	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4e	4168	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4e	4239	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4e	4336	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4e	4378	11/2/2009	11/12/2009	N.D.	2.1	22.21	46.64	23.32
Panel 3 Room 4e	4468	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4e	4629	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4e	4727	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4e	4793	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4e	4961	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4e	5085	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4e	5120	6/1/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4e	5258	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 4e	5351	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 4e	5477	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 4e	5536	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 4e	5629	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 4e	5748	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 4e	5846	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4e	5932	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4e	6020	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4e	6133	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4e	6215	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4e	6315	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4e	6429	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4e	6497	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4e	6575	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4e	6648	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4e	6720	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4e	6775	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4e	6860	1/9/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4e	6963	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4e	7013	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4e	7086	4/2/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4e	7164	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4e	7237	6/4/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4e	7364	7/16/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4e	7422	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4e	7507	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4e	7618	10/9/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4e	7688	11/5/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 4e	7774	12/3/2012	12/7/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 4i	3170	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 4i	3219	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 4i	3287	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 4i	3346	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 4i	3410	8/19/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4i	3458	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4i	3514	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4i	3587	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4i	3626	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4i	3721	1/13/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4i	3782	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4i	3845	3/11/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4i	3920	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4i	3984	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4i	4053	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 4i	4116	7/8/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4i	4177	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4i	4246	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4i	4343	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4i	4385	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4i	4475	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4i	4636	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4i	4734	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4i	4802	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4i	4968	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4i	5092	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4i	5127	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 4i	5265	7/14/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 4i	5358	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 4i	5484	9/22/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 4i	5542	10/12/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 4i	5635	11/9/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 4i	5754	12/15/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 4i	5852	1/19/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4i	5938	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4i	6026	3/9/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4i	6139	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4i	6221	5/10/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4i	6321	6/15/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4i	6437	7/19/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4i	6503	8/16/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4i	6581	9/20/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4i	6656	10/18/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4i	6726	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 4i	6781	12/6/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4i	6866	1/10/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4i	6969	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4i	7019	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4i	7092	4/3/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4i	7170	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4i	7243	6/5/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4i	7370	7/17/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4i	7428	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4i	7513	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4i	7624	10/9/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 4i	7694	11/6/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 4i	7780	12/4/2012	12/7/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 3e	3172	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 3e	3209	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 3e	3277	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 3e	3336	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 3e	3401	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3e	3449	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3e	3505	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3e	3578	11/10/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3e	3617	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3e	3712	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3e	3773	2/9/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3e	3834	3/12/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3e	3911	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3e	3979	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3e	4044	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3e	4110	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3e	4169	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3e	4240	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3e	4337	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3e	4379	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3e	4469	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3e	4630	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3e	4728	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3e	4796	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 3e	4962	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3e	5086	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3e	5121	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3e	5259	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 3e	5352	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 3e	5478	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 3e	5537	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 3e	5630	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 3e	5749	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 3e	5847	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3e	5933	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3e	6021	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3e	6134	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3e	6216	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3e	6316	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3e	6430	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3e	6498	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3e	6576	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3e	6649	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3e	6721	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3e	6776	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3e	6861	1/9/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3e	6964	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3e	7014	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3e	7087	4/2/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3e	7165	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3e	7238	6/4/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3e	7365	7/16/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3e	7423	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3e	7508	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3e	7619	10/9/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3e	7689	11/5/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 3e	7775	12/3/2012	12/7/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 3i	3171	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 3i	3218	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 3i	3286	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 3i	3345	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 3i	3409	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3i	3457	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3i	3513	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3i	3586	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3i	3625	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3i	3714	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3i	3781	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3i	3836	3/12/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3i	3913	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3i	3981	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3i	4052	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 3i	4117	7/8/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3i	4178	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3i	4247	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3i	4344	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3i	4386	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3i	4476	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3i	4637	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3i	4735	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3i	4803	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3i	4969	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3i	5093	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3i	5128	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 3i	5266	7/14/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 3i	5359	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 3i	5485	9/22/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 3i	5543	10/12/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 3i	5636	11/9/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 3i	5755	12/15/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 3i	5853	1/19/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3i	5939	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3i	6027	3/9/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3i	6140	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3i	6222	5/10/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3i	6322	6/15/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3i	6438	7/19/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3i	6504	8/16/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3i	6582	9/20/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3i	6657	10/18/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 3i	6727	11/8/2011	11/11/2011	N.D.	2	23.97	47.94	23.97

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 3i	6782	12/6/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3i	6867	1/10/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3i	6970	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3i	7020	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3i	7093	4/3/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3i	7171	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3i	7244	6/5/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3i	7371	7/17/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3i	7429	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3i	7514	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3i	7625	10/9/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 3i	7695	11/6/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 3i	7781	12/4/2012	12/7/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 2e	3164	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 2e	3208	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 2e	3276	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 2e	3335	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 2e	3400	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2e	3448	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2e	3504	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2e	3577	11/10/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2e	3616	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2e	3711	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2e	3772	2/9/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2e	3833	3/12/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2e	3910	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2e	3978	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2e	4043	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2e	4111	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2e	4170	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2e	4241	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2e	4338	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2e	4380	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2e	4470	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2e	4631	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2e	4729	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2e	4797	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2e	4963	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2e	5087	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2e	5122	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2e	5260	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 2e	5353	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 2e	5479	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 2e	5538	10/12/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 2e	5631	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 2e	5750	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 2e	5848	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2e	5934	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2e	6022	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2e	6135	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2e	6217	5/10/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2e	6317	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2e	6431	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2e	6499	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2e	6577	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2e	6650	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2e	6722	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2e	6777	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2e	6862	1/9/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2e	6965	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2e	7015	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2e	7088	4/2/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2e	7166	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2e	7239	6/4/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2e	7366	7/16/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2e	7424	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2e	7509	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2e	7620	10/9/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2e	7690	11/6/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 2e	7776	12/3/2012	12/7/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 2i	3162	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 2i	3217	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 2i	3285	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 2i	3344	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 2i	3408	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2i	3456	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2i	3512	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 2i	3585	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2i	3624	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2i	3713	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2i	3780	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2i	3835	3/12/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2i	3912	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2i	3980	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2i	4051	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 2i	4118	7/8/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2i	4179	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2i	4248	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2i	4345	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2i	4387	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2i	4477	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2i	4638	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2i	4736	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2i	4804	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2i	4970	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2i	5094	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2i	5129	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 2i	5267	7/14/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 2i	5360	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 2i	5486	9/22/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 2i	5544	10/12/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 2i	5637	11/9/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 2i	5756	12/15/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 2i	5854	1/19/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2i	5940	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2i	6028	3/9/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2i	6141	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2i	6223	5/10/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2i	6323	6/15/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2i	6439	7/19/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2i	6505	8/16/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2i	6583	9/20/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2i	6658	10/18/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2i	6728	11/8/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 2i	6783	12/6/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2i	6868	1/10/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2i	6971	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2i	7021	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2i	7094	4/3/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2i	7172	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2i	7245	6/5/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2i	7372	7/17/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2i	7430	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2i	7515	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2i	7626	10/9/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 2i	7696	11/6/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 2i	7782	12/4/2012	12/7/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 1e	3163	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 1e	3207	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 1e	3293	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 1e	3334	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 1e	3399	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 1e	3447	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 1e	3503	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 1e	3575	11/10/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 1e	3614	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room 1e	3709	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 1e	3770	2/9/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 1e	3831	3/11/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 1e	3908	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 1e	3976	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 1e	4041	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room 1e	4112	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 1e	4172	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 1e	4242	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 1e	4339	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 1e	4381	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 1e	4471	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room 1e	4632	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 1e	4730	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 1e	4798	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 1e	4964	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 1e	5088	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room 1e	5123	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room 1e	5261	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 1e	5354	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 1e	5480	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 1e	5539	10/12/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 1e	5632	11/9/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 1e	5751	12/15/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room 1e	5849	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 1e	5935	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 1e	6023	3/9/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 1e	6136	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 1e	6218	5/10/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 1e	6318	6/15/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 1e	6433	7/19/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 1e	6506	8/16/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 1e	6584	9/20/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 1e	6659	10/18/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 1e	6729	11/8/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room 1e	6784	12/6/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room 1e	6869	1/10/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 1e	6972	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 1e	7022	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 1e	7095	4/3/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 1e	7173	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 1e	7246	6/5/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 1e	7373	7/17/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 1e	7431	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 1e	7516	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 1e	7627	10/9/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room 1e	7697	11/6/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 1e	7783	12/4/2012	12/7/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room 1i	3169	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 1i	3216	5/19/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room 1i	3284	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room EBW	3165	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room EBW	3215	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room EBW	3283	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room EBW	3342	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room EBW	3407	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBW	3455	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBW	3511	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBW	3584	11/10/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBW	3623	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBW	3716	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBW	3779	2/9/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBW	3838	3/12/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBW	3915	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBW	3983	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBW	4049	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBW	4105	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBW	4164	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBW	4235	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBW	4332	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBW	4374	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBW	4464	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBW	4625	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBW	4723	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBW	4789	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBW	4957	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBW	5081	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBW	5116	6/1/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBW	5254	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room EBW	5347	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room EBW	5474	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room EBW	5533	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room EBW	5626	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room EBW	5745	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room EBW	5843	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBW	5929	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBW	6017	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBW	6130	4/18/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBW	6212	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBW	6312	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBW	6432	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBW	6500	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBW	6578	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBW	6652	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBW	6723	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room EBW	6778	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBW	6863	1/9/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBW	6966	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBW	7016	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBW	7089	4/2/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBW	7167	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBW	7240	6/4/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBW	7367	7/16/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBW	7425	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBW	7510	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBW	7621	10/9/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBW	7691	11/6/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room EBW	7777	12/4/2012	12/7/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room EBA	3167	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room EBA	3214	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room EBA	3282	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room EBA	3341	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room EBA	3406	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBA	3454	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBA	3510	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBA	3583	11/10/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBA	3622	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBA	3715	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBA	3778	2/9/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBA	3837	3/12/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBA	3914	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBA	3982	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBA	4050	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room EBA	4104	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBA	4163	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBA	4234	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBA	4331	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBA	4373	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBA	4463	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBA	4624	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBA	4722	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBA	4788	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBA	4956	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBA	5080	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBA	5115	6/1/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room EBA	5253	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room EBA	5346	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room EBA	5473	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room EBA	5532	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room EBA	5625	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room EBA	5744	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room EBA	5842	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBA	5928	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBA	6016	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBA	6129	4/18/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBA	6211	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBA	6311	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBA	6435	7/19/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBA	6501	8/16/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBA	6579	9/20/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBA	6653	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBA	6724	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room EBA	6779	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBA	6864	1/10/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBA	6967	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBA	7017	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBA	7090	4/3/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBA	7168	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBA	7241	6/5/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBA	7368	7/16/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBA	7426	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBA	7511	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBA	7622	10/9/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room EBA	7692	11/6/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room EBA	7778	12/4/2012	12/7/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room IBW	3173	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room IBW	3224	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room IBW	3292	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room IBW	3350	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room IBW	3414	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBW	3462	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBW	3518	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room IBW	3591	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBW	3630	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBW	3725	1/14/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBW	3786	2/11/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBW	3840	3/10/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBW	3924	4/15/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBW	3992	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBW	4040	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBW	4103	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBW	4181	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBW	4250	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBW	4347	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBW	4372	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBW	4479	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBW	4640	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBW	4738	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBW	4795	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBW	5078	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBW	5130	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBW	5252	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room IBW	5362	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room IBW	5487	9/22/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room IBW	5531	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room IBW	5624	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room IBW	5743	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room IBW	5841	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBW	5927	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBW	6015	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBW	6128	4/18/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBW	6210	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBW	6309	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBW	6426	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBW	6494	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBW	6571	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBW	6654	10/18/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBW	6716	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBW	6771	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBW	6857	1/9/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBW	6959	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBW	7009	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBW	7083	4/2/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBW	7161	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBW	7234	6/4/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBW	7361	7/16/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBW	7419	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBW	7504	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBW	7615	10/8/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBW	7686	11/5/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room IBW	7772	12/3/2012	12/7/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room IBA	3168	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room IBA	3223	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room IBA	3291	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room IBA	3349	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
Panel 3 Room IBA	3413	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBA	3461	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBA	3517	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBA	3590	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBA	3629	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBA	3724	1/14/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBA	3785	2/11/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBA	3839	3/10/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBA	3923	4/15/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBA	3991	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBA	4039	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
Panel 3 Room IBA	4102	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBA	4180	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBA	4249	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBA	4346	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBA	4371	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBA	4478	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBA	4639	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBA	4737	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBA	4794	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBA	4954	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBA	5079	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBA	5131	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
Panel 3 Room IBA	5251	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 3 Room IBA	5361	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room IBA	5488	9/22/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room IBA	5530	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room IBA	5623	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room IBA	5742	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
Panel 3 Room IBA	5840	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBA	5926	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBA	6014	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBA	6127	4/18/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBA	6209	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBA	6310	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBA	6425	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBA	6493	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBA	6572	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBA	6655	10/18/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBA	6717	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
Panel 3 Room IBA	6772	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBA	6856	1/9/2012	1/13/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBA	6960	2/16/2012	2/22/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBA	7010	3/6/2012	3/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBA	7082	4/2/2012	4/9/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBA	7160	5/1/2012	5/4/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBA	7233	6/4/2012	6/8/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBA	7360	7/16/2012	7/23/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBA	7418	8/6/2012	8/10/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBA	7503	9/4/2012	9/7/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBA	7614	10/8/2012	10/16/2012	N.D.	2	17.45	34.9	17.45
Panel 3 Room IBA	7685	11/5/2012	11/9/2012	N.D.	2	15.71	31.42	15.71
Panel 3 Room IBA	7771	12/3/2012	12/7/2012	N.D.	2	15.71	31.42	15.71

Hydrogen Data-Panel 4

All samples were sampled at sub-atmospheric pressure and pressurized by the lab as required for analysis; dilution factors included in data set. The MDL (method detection limit) is the sample quantitation limit determined in accordance with 40 CFR Part 136; actual and dilution corrected MDLs included in data set.

7/25/08-6/16/09 MDL = 14.93 ppmv
6/17/09-6/8/10 MDL = 15.17 ppmv
6/9/10-12/28/10 MDL = 7.00 ppmv
12/29/10-11/30/11 MDL = 14.03 ppmv
12/1/11-10/21/12 MDL = 14.40 ppmv
10/22/12-? MDL = 17.29 ppmv ← MDL end date not yet determined

Some values in column "Results" are less than dilution corrected MDLs. These values are not included in the statistical evaluation. When results are N.D. (not-detected) or less than dilution corrected MDLs, the values used for the statistical evaluation are 1/2 the corrected MDL.

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 7e	4032	5/27/2009	5/29/2009	214.50	2	14.93	29.86	214.50
Panel 4 Room 7e	4069	6/9/2009	6/12/2009	81.40	2	14.93	29.86	81.40
Panel 4 Room 7e	4139	7/21/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room 7e	4200	8/11/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room 7e	4274	9/15/2009	9/18/2009	52.08	2	15.17	30.34	52.08
Panel 4 Room 7e	4315	10/5/2009	10/12/2009	29.58	2	15.17	30.34	15.17
Panel 4 Room 7e	4404	11/9/2009	11/16/2009	376.32	2	15.17	30.34	376.32
Panel 4 Room 7e	4531	12/30/2009	1/12/2010	732.38	2	15.17	30.34	732.38
Panel 4 Room 7e	4595	1/20/2010	1/22/2010	230.68	2	15.17	30.34	230.68
Panel 4 Room 7e	4680	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room 7e	4833	3/17/2010	3/29/2010	538.04	2	15.17	30.34	538.04
Panel 4 Room 7e	4915	4/13/2010	4/20/2010	470.54	2	15.17	30.34	470.54
Panel 4 Room 7e	5050	5/17/2010	5/24/2010	432.10	2	15.17	30.34	432.10
Panel 4 Room 7e	5175	6/15/2010	6/21/2010	923.52	2	7.00	14.00	923.52
Panel 4 Room 7e	5310	7/26/2010	8/2/2010	291.14	2	7.00	14.00	291.14
Panel 4 Room 7e	5396	8/24/2010	8/30/2010	257.50	2	7.00	14.00	257.50
Panel 4 Room 7e	5450	9/13/2010	9/20/2010	867.36	2	7.00	14.00	867.36
Panel 4 Room 7e	5569	10/20/2010	10/25/2010	873.20	2	7.00	14.00	873.20
Panel 4 Room 7e	5661	11/16/2010	11/22/2010	868.52	2	7.00	14.00	868.52
Panel 4 Room 7e	5718	12/7/2010	12/13/2010	983.72	2	7.00	14.00	983.72
Panel 4 Room 7e	5816	1/11/2011	1/18/2011	938.74	2	14.03	28.06	938.74
Panel 4 Room 7e	5892	2/7/2011	2/10/2011	785.90	2	14.03	28.06	785.90
Panel 4 Room 7e	5980	3/1/2011	3/4/2011	841.20	2	14.03	28.06	841.20
Panel 4 Room 7e	6083	4/5/2011	4/20/2011	739.96	2	14.03	28.06	739.96
Panel 4 Room 7e	6182	5/3/2011	5/6/2011	920.04	2	14.03	28.06	920.04
Panel 4 Room 7e	6333	6/16/2011	6/24/2011	854.28	2	14.03	28.06	854.28
Panel 4 Room 7e	6409	7/12/2011	7/15/2011	775.72	2	14.03	28.06	775.72
Panel 4 Room 7e	6477	8/9/2011	8/19/2011	837.04	2	14.03	28.06	837.04
Panel 4 Room 7e	6553	9/14/2011	9/16/2011	823.62	2	14.03	28.06	823.62
Panel 4 Room 7e	6627	10/11/2011	10/14/2011	856.32	2	14.03	28.06	856.32
Panel 4 Room 7e	6700	11/1/2011	11/4/2011	793.36	2	14.03	28.06	793.36
Panel 4 Room 7e	6804	12/12/2011	12/16/2011	737.98	2	14.40	28.80	737.98
Panel 4 Room 7e	6890	1/17/2012	1/23/2012	759.7	2	14.40	28.80	759.70
Panel 4 Room 7e	6942	2/7/2012	2/10/2012	735.92	2	14.40	28.80	735.92
Panel 4 Room 7e	7043	3/13/2012	3/16/2012	669.68	2	14.40	28.80	669.68
Panel 4 Room 7e	7113	4/10/2012	4/13/2012	635.18	2	14.40	28.80	635.18
Panel 4 Room 7e	7191	5/9/2012	5/15/2012	530.68	2	14.40	28.80	530.68
Panel 4 Room 7e	7270	6/11/2012	6/18/2012	466.46	2	14.40	28.80	466.46
Panel 4 Room 7e	7341	7/10/2012	7/13/2012	409.74	2	14.40	28.80	409.74
Panel 4 Room 7e	7457	8/13/2012	8/17/2012	288.84	2	14.40	28.80	288.84
Panel 4 Room 7e	7535	9/10/2012	9/14/2012	344.36	2	14.40	28.80	344.36
Panel 4 Room 7e	7581	10/2/2012	10/5/2012	399.12	2	14.40	28.80	399.12
Panel 4 Room 7e	7721	11/13/2012	11/16/2012	389.44	2	17.29	34.58	389.44
Panel 4 Room 7e	7809	12/11/2012	12/14/2012	421.08	2	17.29	34.58	421.08
Panel 4 Room 7i	4028	5/27/2009	5/29/2009	77.78	2	14.93	29.86	77.78
Panel 4 Room 7i	4073	6/9/2009	6/12/2009	100.20	2	14.93	29.86	100.20
Panel 4 Room 7i	4130	7/20/2009	7/24/2009	226.46	2	15.17	30.34	226.46
Panel 4 Room 7i	4191	8/11/2009	8/17/2009	235.94	2	15.17	30.34	235.94
Panel 4 Room 7i	4265	9/14/2009	9/18/2009	242.14	2	15.17	30.34	242.14
Panel 4 Room 7i	4306	10/5/2009	10/12/2009	48.62	2	15.17	30.34	48.62
Panel 4 Room 7i	4413	11/11/2009	11/16/2009	179.38	2	15.17	30.34	179.38
Panel 4 Room 7i	4522	12/30/2009	1/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room 7i	4586	1/19/2010	1/22/2010	242.94	2	15.17	30.34	242.94
Panel 4 Room 7i	4671	2/9/2010	2/12/2010	341.44	2	15.17	30.34	341.44
Panel 4 Room 7i	4824	3/16/2010	3/29/2010	652.14	2	15.17	30.34	652.14
Panel 4 Room 7i	4925	4/14/2010	4/20/2010	453.88	2	15.17	30.34	453.88
Panel 4 Room 7i	5041	5/17/2010	5/24/2010	879.08	2	15.17	30.34	879.08

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 7i	5166	6/14/2010	6/21/2010	823.70	2	7.00	14.00	823.70
Panel 4 Room 7i	5301	7/26/2010	8/2/2010	45.56	2	7.00	14.00	45.56
Panel 4 Room 7i	5387	8/24/2010	8/30/2010	686.82	2	7.00	14.00	686.82
Panel 4 Room 7i	5441	9/13/2010	9/20/2010	758.66	2	7.00	14.00	758.66
Panel 4 Room 7i	5560	10/19/2010	10/25/2010	761.02	2	7.00	14.00	761.02
Panel 4 Room 7i	5652	11/15/2010	11/22/2010	849.62	2	7.00	14.00	849.62
Panel 4 Room 7i	5709	12/7/2010	12/13/2010	828.18	2	7.00	14.00	828.18
Panel 4 Room 7i	5807	1/11/2011	1/18/2011	708.12	2	14.03	28.06	708.12
Panel 4 Room 7i	5881	2/1/2011	2/10/2011	707.46	2	14.03	28.06	707.46
Panel 4 Room 7i	5971	3/1/2011	3/4/2011	902.20	2	14.03	28.06	902.20
Panel 4 Room 7i	6074	4/5/2011	4/20/2011	831.04	2	14.03	28.06	831.04
Panel 4 Room 7i	6173	5/2/2011	5/6/2011	729.88	2	14.03	28.06	729.88
Panel 4 Room 7i	6324	6/15/2011	6/24/2011	687.94	2	14.03	28.06	687.94
Panel 4 Room 7i	6400	7/11/2011	7/15/2011	674.94	2	14.03	28.06	674.94
Panel 4 Room 7i	6461	8/9/2011	8/19/2011	507.68	2	14.03	28.06	507.68
Panel 4 Room 7i	6544	9/13/2011	9/16/2011	500.24	2	14.03	28.06	500.24
Panel 4 Room 7i	6618	10/10/2011	10/14/2011	388.58	2	14.03	28.06	388.58
Panel 4 Room 7i	6691	11/1/2011	11/4/2011	425.88	2	14.03	28.06	425.88
Panel 4 Room 7i	6795	12/12/2011	12/16/2011	557.70	2	14.40	28.80	557.70
Panel 4 Room 7i	6881	1/17/2012	1/23/2012	529.76	2	14.40	28.80	529.76
Panel 4 Room 7i	6933	2/7/2012	2/10/2012	435.94	2	14.40	28.80	435.94
Panel 4 Room 7i	7034	3/13/2012	3/16/2012	378.74	2	14.40	28.80	378.74
Panel 4 Room 7i	7104	4/10/2012	4/13/2012	168.24	2	14.40	28.80	168.24
Panel 4 Room 7i	7182	5/8/2012	5/15/2012	217.16	2	14.40	28.80	217.16
Panel 4 Room 7i	7261	6/11/2012	6/18/2012	141.74	2	14.40	28.80	141.74
Panel 4 Room 7i	7332	7/10/2012	7/13/2012	135.1	2	14.40	28.80	135.10
Panel 4 Room 7i	7448	8/13/2012	8/17/2012	102.58	2	14.40	28.80	102.58
Panel 4 Room 7i	7526	9/10/2012	9/14/2012	358.82	2	14.40	28.80	358.82
Panel 4 Room 7i	7572	10/1/2012	10/5/2012	357.82	2	14.40	28.80	357.82
Panel 4 Room 7i	7712	11/12/2012	11/16/2012	323.84	2	17.29	34.58	323.84
Panel 4 Room 7i	7800	12/10/2012	12/14/2012	348.26	2	17.29	34.58	348.26
Panel 4 Room 6e	4031	5/27/2009	5/29/2009	190.82	2	14.93	29.86	190.82
Panel 4 Room 6e	4068	6/8/2009	6/12/2009	114.46	2	14.93	29.86	114.46
Panel 4 Room 6e	4140	7/21/2009	7/24/2009	177.58	2	15.17	30.34	177.58
Panel 4 Room 6e	4201	8/11/2009	8/17/2009	247.88	2	15.17	30.34	247.88
Panel 4 Room 6e	4275	9/15/2009	9/18/2009	159.46	2	15.17	30.34	159.46
Panel 4 Room 6e	4316	10/5/2009	10/12/2009	117.88	2	15.17	30.34	117.88
Panel 4 Room 6e	4403	11/9/2009	11/16/2009	341.80	2	15.17	30.34	341.80
Panel 4 Room 6e	4532	12/30/2009	1/12/2010	466.88	2	15.17	30.34	466.88
Panel 4 Room 6e	4596	1/20/2010	1/22/2010	576.72	2	15.17	30.34	576.72
Panel 4 Room 6e	4681	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room 6e	4834	3/17/2010	3/29/2010	599.50	2	15.17	30.34	599.50
Panel 4 Room 6e	4916	4/13/2010	4/20/2010	741.36	2	15.17	30.34	741.36
Panel 4 Room 6e	5051	5/17/2010	5/24/2010	234.98	2	15.17	30.34	234.98
Panel 4 Room 6e	5176	6/15/2010	6/21/2010	207.18	2	7.00	14.00	207.18
Panel 4 Room 6e	5311	7/27/2010	8/2/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room 6e	5397	8/25/2010	8/30/2010	880.34	2	7.00	14.00	880.34
Panel 4 Room 6e	5451	9/14/2010	9/20/2010	902.54	2	7.00	14.00	902.54
Panel 4 Room 6e	5570	10/20/2010	10/25/2010	1012.68	2	7.00	14.00	1012.68
Panel 4 Room 6e	5662	11/16/2010	11/22/2010	991.58	2	7.00	14.00	991.58
Panel 4 Room 6e	5719	12/8/2010	12/13/2010	768.08	2	7.00	14.00	768.08
Panel 4 Room 6e	5817	1/12/2011	1/18/2011	619.40	2	14.03	28.06	619.40
Panel 4 Room 6e	5893	2/7/2011	2/10/2011	911.52	2	14.03	28.06	911.52
Panel 4 Room 6e	5981	3/2/2011	3/4/2011	946.96	2	14.03	28.06	946.96
Panel 4 Room 6e	6084	4/5/2011	4/20/2011	616.24	2	14.03	28.06	616.24
Panel 4 Room 6e	6183	5/3/2011	5/6/2011	720.54	2	14.03	28.06	720.54
Panel 4 Room 6e	6334	6/16/2011	6/24/2011	543.56	2	14.03	28.06	543.56
Panel 4 Room 6e	6410	7/12/2011	7/15/2011	648.56	2	14.03	28.06	648.56
Panel 4 Room 6e	6478	8/9/2011	8/19/2011	692.68	2	14.03	28.06	692.68
Panel 4 Room 6e	6554	9/14/2011	9/16/2011	656.56	2	14.03	28.06	656.56
Panel 4 Room 6e	6628	10/11/2011	10/14/2011	679.30	2	14.03	28.06	679.30
Panel 4 Room 6e	6701	11/1/2011	11/4/2011	661.62	2	14.03	28.06	661.62
Panel 4 Room 6i	4027	5/27/2009	5/29/2009	67.96	2	14.93	29.86	67.96
Panel 4 Room 6i	4072	6/9/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room 6i	4131	7/20/2009	7/24/2009	247.58	2	15.17	30.34	247.58
Panel 4 Room 6i	4192	8/11/2009	8/17/2009	230.00	2	15.17	30.34	230.00
Panel 4 Room 6i	4266	9/14/2009	9/18/2009	247.62	2	15.17	30.34	247.62
Panel 4 Room 6i	4307	10/5/2009	10/12/2009	324.08	2	15.17	30.34	324.08
Panel 4 Room 6i	4412	11/11/2009	11/16/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room 6i	4523	12/30/2009	1/12/2010	419.66	2	15.17	30.34	419.66
Panel 4 Room 6i	4587	1/19/2010	1/22/2010	199.04	2	15.17	30.34	199.04
Panel 4 Room 6i	4672	2/9/2010	2/12/2010	85.18	2	15.17	30.34	85.18
Panel 4 Room 6i	4825	3/16/2010	3/29/2010	647.86	2	15.17	30.34	647.86
Panel 4 Room 6i	4926	4/14/2010	4/20/2010	528.88	2	15.17	30.34	528.88
Panel 4 Room 6i	5042	5/17/2010	5/24/2010	613.98	2	15.17	30.34	613.98
Panel 4 Room 6i	5167	6/14/2010	6/21/2010	613.10	2	7.00	14.00	613.10
Panel 4 Room 6i	5302	7/26/2010	8/2/2010	555.22	2	7.00	14.00	555.22

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 6i	5388	8/24/2010	8/30/2010	750.22	2	7.00	14.00	750.22
Panel 4 Room 6i	5442	9/13/2010	9/20/2010	713.28	2	7.00	14.00	713.28
Panel 4 Room 6i	5561	10/19/2010	10/25/2010	902.74	2	7.00	14.00	902.74
Panel 4 Room 6i	5653	11/15/2010	11/22/2010	760.56	2	7.00	14.00	760.56
Panel 4 Room 6i	5710	12/7/2010	12/13/2010	740.56	2	7.00	14.00	740.56
Panel 4 Room 6i	5808	1/11/2011	1/18/2011	740.30	2	14.03	28.06	740.30
Panel 4 Room 6i	5882	2/1/2011	2/10/2011	704.76	2	14.03	28.06	704.76
Panel 4 Room 6i	5972	3/1/2011	3/4/2011	736.38	2	14.03	28.06	736.38
Panel 4 Room 6i	6075	4/5/2011	4/20/2011	648.88	2	14.03	28.06	648.88
Panel 4 Room 6i	6174	5/2/2011	5/6/2011	512.20	2	14.03	28.06	512.20
Panel 4 Room 6i	6325	6/15/2011	6/24/2011	531.00	2	14.03	28.06	531.00
Panel 4 Room 6i	6401	7/11/2011	7/15/2011	494.48	2	14.03	28.06	494.48
Panel 4 Room 6i	6469	8/9/2011	8/19/2011	397.04	2	14.03	28.06	397.04
Panel 4 Room 6i	6545	9/13/2011	9/16/2011	461.88	2	14.03	28.06	461.88
Panel 4 Room 6i	6619	10/10/2011	10/14/2011	323.52	2	14.03	28.06	323.52
Panel 4 Room 6i	6692	11/1/2011	11/4/2011	370.18	2	14.03	28.06	370.18
Panel 4 Room 6i	6796	12/12/2011	12/16/2011	459.02	2	14.40	28.80	459.02
Panel 4 Room 6i	6882	1/17/2012	1/23/2012	496.08	2	14.40	28.80	496.08
Panel 4 Room 6i	6934	2/7/2012	2/10/2012	382.54	2	14.40	28.80	382.54
Panel 4 Room 6i	7035	3/13/2012	3/16/2012	376.9	2	14.40	28.80	376.90
Panel 4 Room 6i	7105	4/10/2012	4/13/2012	143.8	2	14.40	28.80	143.80
Panel 4 Room 6i	7183	5/8/2012	5/15/2012	239.76	2	14.40	28.80	239.76
Panel 4 Room 6i	7262	6/11/2012	6/18/2012	131.74	2	14.40	28.80	131.74
Panel 4 Room 6i	7333	7/10/2012	7/13/2012	125.18	2	14.40	28.80	125.18
Panel 4 Room 6i	7449	8/13/2012	8/17/2012	103.14	2	14.40	28.80	103.14
Panel 4 Room 6i	7527	9/10/2012	9/14/2012	337.64	2	14.40	28.80	337.64
Panel 4 Room 6i	7573	10/1/2012	10/5/2012	358.46	2	14.40	28.80	358.46
Panel 4 Room 6i	7713	11/12/2012	11/16/2012	318.78	2	17.29	34.58	318.78
Panel 4 Room 6i	7801	12/10/2012	12/14/2012	352.86	2	17.29	34.58	352.86
Panel 4 Room 5e	4030	5/27/2009	5/29/2009	143.28	2	14.93	29.86	143.28
Panel 4 Room 5e	4067	6/8/2009	6/12/2009	65.66	2	14.93	29.86	65.66
Panel 4 Room 5e	4141	7/21/2009	7/24/2009	175.06	2	15.17	30.34	175.06
Panel 4 Room 5e	4202	8/11/2009	8/17/2009	33.02	2	15.17	30.34	33.02
Panel 4 Room 5e	4276	9/15/2009	9/18/2009	172.86	2	15.17	30.34	172.86
Panel 4 Room 5e	4317	10/5/2009	10/12/2009	129.82	2	15.17	30.34	129.82
Panel 4 Room 5e	4402	11/9/2009	11/16/2009	406.36	2	15.17	30.34	406.36
Panel 4 Room 5e	4533	12/30/2009	1/12/2010	468.60	2	15.17	30.34	468.60
Panel 4 Room 5e	4597	1/20/2010	1/22/2010	408.40	2	15.17	30.34	408.40
Panel 4 Room 5e	4682	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room 5e	4835	3/17/2010	3/29/2010	575.58	2	15.17	30.34	575.58
Panel 4 Room 5e	4917	4/13/2010	4/20/2010	510.30	2	15.17	30.34	510.30
Panel 4 Room 5e	5052	5/17/2010	5/24/2010	747.14	2	15.17	30.34	747.14
Panel 4 Room 5e	5177	6/15/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room 5e	5312	7/27/2010	8/2/2010	601.06	2	7.00	14.00	601.06
Panel 4 Room 5e	5398	8/25/2010	8/30/2010	688.94	2	7.00	14.00	688.94
Panel 4 Room 5e	5452	9/14/2010	9/20/2010	792.94	2	7.00	14.00	792.94
Panel 4 Room 5e	5571	10/20/2010	10/25/2010	655.86	2	7.00	14.00	655.86
Panel 4 Room 5e	5663	11/16/2010	11/22/2010	756.48	2	7.00	14.00	756.48
Panel 4 Room 5e	5720	12/8/2010	12/13/2010	583.38	2	7.00	14.00	583.38
Panel 4 Room 5e	5818	1/12/2011	1/18/2011	709.40	2	14.03	28.06	709.40
Panel 4 Room 5e	5894	2/7/2011	2/10/2011	677.24	2	14.03	28.06	677.24
Panel 4 Room 5e	5982	3/2/2011	3/4/2011	683.92	2	14.03	28.06	683.92
Panel 4 Room 5e	6085	4/5/2011	4/20/2011	608.70	2	14.03	28.06	608.70
Panel 4 Room 5e	6184	5/3/2011	5/6/2011	731.70	2	14.03	28.06	731.70
Panel 4 Room 5e	6335	6/16/2011	6/24/2011	689.48	2	14.03	28.06	689.48
Panel 4 Room 5e	6411	7/12/2011	7/15/2011	640.36	2	14.03	28.06	640.36
Panel 4 Room 5e	6479	8/9/2011	8/19/2011	646.18	2	14.03	28.06	646.18
Panel 4 Room 5e	6557	9/14/2011	9/16/2011	671.18	2	14.03	28.06	671.18
Panel 4 Room 5e	6629	10/11/2011	10/14/2011	673.00	2	14.03	28.06	673.00
Panel 4 Room 5e	6702	11/1/2011	11/4/2011	604.10	2	14.03	28.06	604.10
Panel 4 Room 5e	6806	12/13/2011	12/16/2011	558.76	2	14.40	28.80	558.76
Panel 4 Room 5e	6892	1/17/2012	1/23/2012	648.78	2	14.40	28.80	648.78
Panel 4 Room 5e	6943	2/7/2012	2/10/2012	606.14	2	14.40	28.80	606.14
Panel 4 Room 5e	7044	3/13/2012	3/16/2012	533.38	2	14.40	28.80	533.38
Panel 4 Room 5e	7114	4/10/2012	4/13/2012	484.22	2	14.40	28.80	484.22
Panel 4 Room 5e	7192	5/9/2012	5/15/2012	425.66	2	14.40	28.80	425.66
Panel 4 Room 5e	7271	6/11/2012	6/18/2012	337.64	2	14.40	28.80	337.64
Panel 4 Room 5e	7342	7/10/2012	7/13/2012	381.12	2	14.40	28.80	381.12
Panel 4 Room 5i	4026	5/27/2009	5/29/2009	68.62	2	14.93	29.86	68.62
Panel 4 Room 5i	4071	6/9/2009	6/12/2009	95.90	2	14.93	29.86	95.90
Panel 4 Room 5i	4132	7/20/2009	7/24/2009	198.24	2	15.17	30.34	198.24
Panel 4 Room 5i	4193	8/11/2009	8/17/2009	250.44	2	15.17	30.34	250.44
Panel 4 Room 5i	4267	9/14/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room 5i	4308	10/5/2009	10/12/2009	371.50	2	15.17	30.34	371.50
Panel 4 Room 5i	4411	11/11/2009	11/16/2009	429.94	2	15.17	30.34	429.94
Panel 4 Room 5i	4524	12/30/2009	1/12/2010	576.48	2	15.17	30.34	576.48
Panel 4 Room 5i	4588	1/19/2010	1/22/2010	312.66	2	15.17	30.34	312.66

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 5i	4673	2/9/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room 5i	4826	3/16/2010	3/29/2010	649.22	2	15.17	30.34	649.22
Panel 4 Room 5i	4927	4/14/2010	4/20/2010	480.98	2	15.17	30.34	480.98
Panel 4 Room 5i	5043	5/17/2010	5/24/2010	386.14	2	15.17	30.34	386.14
Panel 4 Room 5i	5168	6/14/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room 5i	5303	7/26/2010	8/2/2010	593.42	2	7.00	14.00	593.42
Panel 4 Room 5i	5389	8/24/2010	8/30/2010	606.30	2	7.00	14.00	606.30
Panel 4 Room 5i	5443	9/13/2010	9/20/2010	790.44	2	7.00	14.00	790.44
Panel 4 Room 5i	5562	10/19/2010	10/25/2010	764.12	2	7.00	14.00	764.12
Panel 4 Room 5i	5654	11/15/2010	11/22/2010	686.16	2	7.00	14.00	686.16
Panel 4 Room 5i	5711	12/7/2010	12/13/2010	636.06	2	7.00	14.00	636.06
Panel 4 Room 5i	5809	1/11/2011	1/18/2011	647.44	2	14.03	28.06	647.44
Panel 4 Room 5i	5883	2/1/2011	2/10/2011	580.90	2	14.03	28.06	580.90
Panel 4 Room 5i	5973	3/1/2011	3/4/2011	636.12	2	14.03	28.06	636.12
Panel 4 Room 5i	6076	4/5/2011	4/20/2011	698.90	2	14.03	28.06	698.90
Panel 4 Room 5i	6175	5/2/2011	5/6/2011	695.86	2	14.03	28.06	695.86
Panel 4 Room 5i	6326	6/15/2011	6/24/2011	608.70	2	14.03	28.06	608.70
Panel 4 Room 5i	6402	7/11/2011	7/15/2011	715.64	2	14.03	28.06	715.64
Panel 4 Room 5i	6470	8/9/2011	8/19/2011	631.96	2	14.03	28.06	631.96
Panel 4 Room 5i	6546	9/13/2011	9/16/2011	564.12	2	14.03	28.06	564.12
Panel 4 Room 5i	6620	10/10/2011	10/14/2011	449.38	2	14.03	28.06	449.38
Panel 4 Room 5i	6693	11/1/2011	11/4/2011	421.78	2	14.03	28.06	421.78
Panel 4 Room 5i	6797	12/12/2011	12/16/2011	502.48	2	14.40	28.80	502.48
Panel 4 Room 5i	6883	1/17/2012	1/23/2012	517	2	14.40	28.80	517.00
Panel 4 Room 5i	6935	2/7/2012	2/10/2012	442.04	2	14.40	28.80	442.04
Panel 4 Room 5i	7036	3/13/2012	3/16/2012	421.6	2	14.40	28.80	421.60
Panel 4 Room 5i	7106	4/10/2012	4/13/2012	312.3	2	14.40	28.80	312.30
Panel 4 Room 5i	7184	5/8/2012	5/15/2012	279.52	2	14.40	28.80	279.52
Panel 4 Room 5i	7263	6/11/2012	6/18/2012	258.1	2	14.40	28.80	258.10
Panel 4 Room 5i	7334	7/10/2012	7/13/2012	325.82	2	14.40	28.80	325.82
Panel 4 Room 5i	7450	8/13/2012	8/17/2012	223.98	2	14.40	28.80	223.98
Panel 4 Room 5i	7528	9/10/2012	9/14/2012	364.56	2	14.40	28.80	364.56
Panel 4 Room 5i	7574	10/1/2012	10/5/2012	387.78	2	14.40	28.80	387.78
Panel 4 Room 5i	7714	11/12/2012	11/16/2012	354.74	2	17.29	34.58	354.74
Panel 4 Room 5i	7802	12/10/2012	12/14/2012	362.94	2	17.29	34.58	362.94
Panel 4 Room 4e	4029	5/27/2009	5/29/2009	52.26	2	14.93	29.86	52.26
Panel 4 Room 4e	4066	6/8/2009	6/12/2009	29.26	2	14.93	29.86	14.93
Panel 4 Room 4e	4142	7/21/2009	7/24/2009	145.02	2	15.17	30.34	145.02
Panel 4 Room 4e	4203	8/13/2009	8/17/2009	256.40	2	15.17	30.34	256.40
Panel 4 Room 4e	4277	9/15/2009	9/18/2009	239.74	2	15.17	30.34	239.74
Panel 4 Room 4e	4318	10/5/2009	10/12/2009	107.02	2	15.17	30.34	107.02
Panel 4 Room 4e	4401	11/9/2009	11/16/2009	293.96	2	15.17	30.34	293.96
Panel 4 Room 4e	4534	12/30/2009	1/12/2010	525.70	2	15.17	30.34	525.70
Panel 4 Room 4e	4598	1/20/2010	1/22/2010	298.72	2	15.17	30.34	298.72
Panel 4 Room 4e	4683	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room 4e	4836	3/17/2010	3/29/2010	512.92	2	15.17	30.34	512.92
Panel 4 Room 4e	4918	4/13/2010	4/20/2010	516.80	2	15.17	30.34	516.80
Panel 4 Room 4e	5053	5/17/2010	5/24/2010	479.40	2	15.17	30.34	479.40
Panel 4 Room 4e	5178	6/15/2010	6/21/2010	144.16	2	7.00	14.00	144.16
Panel 4 Room 4e	5313	7/27/2010	8/2/2010	597.18	2	7.00	14.00	597.18
Panel 4 Room 4e	5399	8/25/2010	8/30/2010	779.30	2	7.00	14.00	779.30
Panel 4 Room 4e	5453	9/14/2010	9/20/2010	561.66	2	7.00	14.00	561.66
Panel 4 Room 4e	5572	10/20/2010	10/25/2010	643.42	2	7.00	14.00	643.42
Panel 4 Room 4e	5664	11/16/2010	11/22/2010	640.36	2	7.00	14.00	640.36
Panel 4 Room 4e	5721	12/8/2010	12/13/2010	570.10	2	7.00	14.00	570.10
Panel 4 Room 4e	5819	1/12/2011	1/18/2011	656.70	2	14.03	28.06	656.70
Panel 4 Room 4e	5895	2/7/2011	2/10/2011	479.42	2	14.03	28.06	479.42
Panel 4 Room 4e	5983	3/2/2011	3/4/2011	561.46	2	14.03	28.06	561.46
Panel 4 Room 4i	4025	5/27/2009	5/29/2009	46.62	2	14.93	29.86	46.62
Panel 4 Room 4i	4070	6/9/2009	6/12/2009	66.00	2	14.93	29.86	66.00
Panel 4 Room 4i	4133	7/20/2009	7/24/2009	162.30	2	15.17	30.34	162.30
Panel 4 Room 4i	4194	8/11/2009	8/17/2009	184.72	2	15.17	30.34	184.72
Panel 4 Room 4i	4268	9/14/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room 4i	4309	10/5/2009	10/12/2009	167.38	2	15.17	30.34	167.38
Panel 4 Room 4i	4410	11/11/2009	11/16/2009	390.88	2	15.17	30.34	390.88
Panel 4 Room 4i	4525	12/30/2009	1/12/2010	476.76	2	15.17	30.34	476.76
Panel 4 Room 4i	4589	1/19/2010	1/22/2010	302.16	2	15.17	30.34	302.16
Panel 4 Room 4i	4674	2/9/2010	2/12/2010	73.90	2	15.17	30.34	73.90
Panel 4 Room 4i	4827	3/16/2010	3/29/2010	532.06	2	15.17	30.34	532.06
Panel 4 Room 4i	4928	4/14/2010	4/20/2010	91.48	2	15.17	30.34	91.48
Panel 4 Room 4i	5044	5/17/2010	5/24/2010	537.96	2	15.17	30.34	537.96
Panel 4 Room 4i	5169	6/14/2010	6/21/2010	111.78	2	7.00	14.00	111.78
Panel 4 Room 4i	5304	7/26/2010	8/2/2010	275.10	2	7.00	14.00	275.10
Panel 4 Room 4i	5390	8/24/2010	8/30/2010	709.50	2	7.00	14.00	709.50
Panel 4 Room 4i	5444	9/13/2010	9/20/2010	728.04	2	7.00	14.00	728.04
Panel 4 Room 4i	5563	10/19/2010	10/25/2010	670.12	2	7.00	14.00	670.12
Panel 4 Room 4i	5655	11/15/2010	11/22/2010	672.26	2	7.00	14.00	672.26

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 4i	5712	12/7/2010	12/13/2010	610.84	2	7.00	14.00	610.84
Panel 4 Room 4i	5810	1/11/2011	1/18/2011	597.58	2	14.03	28.06	597.58
Panel 4 Room 4i	5884	2/1/2011	2/10/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room 4i	5974	3/1/2011	3/4/2011	622.32	2	14.03	28.06	622.32
Panel 4 Room 4i	6077	4/5/2011	4/20/2011	734.34	2	14.03	28.06	734.34
Panel 4 Room 4i	6176	5/2/2011	5/6/2011	663.88	2	14.03	28.06	663.88
Panel 4 Room 4i	6327	6/15/2011	6/24/2011	583.40	2	14.03	28.06	583.40
Panel 4 Room 4i	6403	7/11/2011	7/15/2011	629.18	2	14.03	28.06	629.18
Panel 4 Room 4i	6471	8/9/2011	8/19/2011	445.40	2	14.03	28.06	445.40
Panel 4 Room 4i	6547	9/13/2011	9/16/2011	428.76	2	14.03	28.06	428.76
Panel 4 Room 4i	6621	10/10/2011	10/14/2011	357.76	2	14.03	28.06	357.76
Panel 4 Room 4i	6694	11/1/2011	11/4/2011	381.34	2	14.03	28.06	381.34
Panel 4 Room 4i	6798	12/12/2011	12/16/2011	552.18	2	14.40	28.80	552.18
Panel 4 Room 4i	6884	1/17/2012	1/23/2012	550.82	2	14.40	28.80	550.82
Panel 4 Room 4i	6936	2/7/2012	2/10/2012	457.42	2	14.40	28.80	457.42
Panel 4 Room 4i	7037	3/13/2012	3/16/2012	389.74	2	14.40	28.80	389.74
Panel 4 Room 4i	7107	4/10/2012	4/13/2012	312.08	2	14.40	28.80	312.08
Panel 4 Room 4i	7185	5/8/2012	5/15/2012	290.96	2	14.40	28.80	290.96
Panel 4 Room 4i	7264	6/11/2012	6/18/2012	282.7	2	14.40	28.80	282.70
Panel 4 Room 4i	7335	7/10/2012	7/13/2012	327.42	2	14.40	28.80	327.42
Panel 4 Room 4i	7451	8/13/2012	8/17/2012	266.4	2	14.40	28.80	266.40
Panel 4 Room 4i	7529	9/10/2012	9/14/2012	370.9	2	14.40	28.80	370.90
Panel 4 Room 4i	7575	10/1/2012	10/5/2012	398.82	2	14.40	28.80	398.82
Panel 4 Room 4i	7715	11/12/2012	11/16/2012	371.26	2	17.29	34.58	371.26
Panel 4 Room 4i	7803	12/10/2012	12/14/2012	383.66	2	17.29	34.58	383.66
Panel 4 Room 3e	4019	5/26/2009	5/29/2009	135.72	2	14.93	29.86	135.72
Panel 4 Room 3e	4077	6/10/2009	6/12/2009	46.60	2	14.93	29.86	46.60
Panel 4 Room 3e	4143	7/21/2009	7/24/2009	137.72	2	15.17	30.34	137.72
Panel 4 Room 3e	4204	8/13/2009	8/17/2009	160.64	2	15.17	30.34	160.64
Panel 4 Room 3e	4278	9/15/2009	9/18/2009	166.84	2	15.17	30.34	166.84
Panel 4 Room 3e	4319	10/5/2009	10/12/2009	33.06	2	15.17	30.34	33.06
Panel 4 Room 3e	4400	11/9/2009	11/16/2009	391.36	2	15.17	30.34	391.36
Panel 4 Room 3e	4535	12/30/2009	1/12/2010	538.14	2	15.17	30.34	538.14
Panel 4 Room 3e	4599	1/20/2010	1/22/2010	407.96	2	15.17	30.34	407.96
Panel 4 Room 3e	4684	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room 3e	4837	3/17/2010	3/29/2010	554.86	2	15.17	30.34	554.86
Panel 4 Room 3e	4919	4/13/2010	4/20/2010	458.06	2	15.17	30.34	458.06
Panel 4 Room 3e	5054	5/17/2010	5/24/2010	377.58	2	15.17	30.34	377.58
Panel 4 Room 3e	5179	6/15/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room 3e	5314	7/27/2010	8/2/2010	647.24	2	7.00	14.00	647.24
Panel 4 Room 3e	5400	8/25/2010	8/30/2010	241.08	2	7.00	14.00	241.08
Panel 4 Room 3e	5454	9/14/2010	9/20/2010	622.18	2	7.00	14.00	622.18
Panel 4 Room 3e	5573	10/20/2010	10/25/2010	533.98	2	7.00	14.00	533.98
Panel 4 Room 3e	5665	11/16/2010	11/22/2010	691.12	2	7.00	14.00	691.12
Panel 4 Room 3e	5722	12/8/2010	12/13/2010	620.50	2	7.00	14.00	620.50
Panel 4 Room 3e	5820	1/12/2011	1/18/2011	656.18	2	14.03	28.06	656.18
Panel 4 Room 3e	5896	2/7/2011	2/10/2011	661.56	2	14.03	28.06	661.56
Panel 4 Room 3e	5984	3/2/2011	3/4/2011	573.94	2	14.03	28.06	573.94
Panel 4 Room 3e	6087	4/6/2011	4/20/2011	676.52	2	14.03	28.06	676.52
Panel 4 Room 3e	6185	5/3/2011	5/6/2011	662.62	2	14.03	28.06	662.62
Panel 4 Room 3e	6336	6/16/2011	6/24/2011	674.22	2	14.03	28.06	674.22
Panel 4 Room 3e	6412	7/12/2011	7/15/2011	635.28	2	14.03	28.06	635.28
Panel 4 Room 3e	6480	8/9/2011	8/19/2011	663.40	2	14.03	28.06	663.40
Panel 4 Room 3e	6558	9/14/2011	9/16/2011	626.82	2	14.03	28.06	626.82
Panel 4 Room 3e	6630	10/11/2011	10/14/2011	628.78	2	14.03	28.06	628.78
Panel 4 Room 3e	6703	11/1/2011	11/4/2011	605.58	2	14.03	28.06	605.58
Panel 4 Room 3e	6807	12/13/2011	12/16/2011	552.70	2	14.40	28.80	552.70
Panel 4 Room 3e	6893	1/17/2012	1/23/2012	590.8	2	14.40	28.80	590.80
Panel 4 Room 3e	6944	2/7/2012	2/10/2012	533.58	2	14.40	28.80	533.58
Panel 4 Room 3e	7045	3/13/2012	3/16/2012	524.88	2	14.40	28.80	524.88
Panel 4 Room 3e	7115	4/10/2012	4/13/2012	407.36	2	14.40	28.80	407.36
Panel 4 Room 3e	7193	5/9/2012	5/15/2012	353.58	2	14.40	28.80	353.58
Panel 4 Room 3e	7272	6/11/2012	6/18/2012	322.22	2	14.40	28.80	322.22
Panel 4 Room 3e	7343	7/10/2012	7/13/2012	298.32	2	14.40	28.80	298.32
Panel 4 Room 3e	7459	8/13/2012	8/17/2012	188.78	2	14.40	28.80	188.78
Panel 4 Room 3e	7536	9/10/2012	9/14/2012	351.6	2	14.40	28.80	351.60
Panel 4 Room 3e	7582	10/2/2012	10/5/2012	408.14	2	14.40	28.80	408.14
Panel 4 Room 3e	7722	11/13/2012	11/16/2012	395.1	2	17.29	34.58	395.10
Panel 4 Room 3e	7810	12/11/2012	12/14/2012	415.32	2	17.29	34.58	415.32
Panel 4 Room 3i	4024	5/27/2009	5/29/2009	15.48	2	14.93	29.86	14.93
Panel 4 Room 3i	4079	6/10/2009	6/12/2009	40.10	2	14.93	29.86	40.10
Panel 4 Room 3i	4134	7/20/2009	7/24/2009	65.92	2	15.17	30.34	65.92
Panel 4 Room 3i	4195	8/11/2009	8/17/2009	120.62	2	15.17	30.34	120.62
Panel 4 Room 3i	4269	9/14/2009	9/18/2009	130.34	2	15.17	30.34	130.34
Panel 4 Room 3i	4310	10/5/2009	10/12/2009	23.22	2	15.17	30.34	15.17
Panel 4 Room 3i	4409	11/11/2009	11/16/2009	317.70	2	15.17	30.34	317.70
Panel 4 Room 3i	4526	12/30/2009	1/12/2010	410.20	2	15.17	30.34	410.20

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 3i	4590	1/19/2010	1/22/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room 3i	4675	2/9/2010	2/12/2010	92.42	2	15.17	30.34	92.42
Panel 4 Room 3i	4828	3/16/2010	3/29/2010	484.76	2	15.17	30.34	484.76
Panel 4 Room 3i	4929	4/14/2010	4/20/2010	331.22	2	15.17	30.34	331.22
Panel 4 Room 3i	5045	5/17/2010	5/24/2010	408.70	2	15.17	30.34	408.70
Panel 4 Room 3i	5170	6/15/2010	6/21/2010	491.76	2	7.00	14.00	491.76
Panel 4 Room 3i	5305	7/26/2010	8/2/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room 3i	5391	8/24/2010	8/30/2010	824.28	2	7.00	14.00	824.28
Panel 4 Room 3i	5445	9/13/2010	9/20/2010	177.42	2	7.00	14.00	177.42
Panel 4 Room 3i	5564	10/19/2010	10/25/2010	658.14	2	7.00	14.00	658.14
Panel 4 Room 3i	5656	11/15/2010	11/22/2010	693.76	2	7.00	14.00	693.76
Panel 4 Room 3i	5713	12/7/2010	12/13/2010	653.24	2	7.00	14.00	653.24
Panel 4 Room 3i	5811	1/11/2011	1/18/2011	539.18	2	14.03	28.06	539.18
Panel 4 Room 3i	5885	2/1/2011	2/10/2011	610.30	2	14.03	28.06	610.30
Panel 4 Room 3i	5975	3/1/2011	3/4/2011	567.88	2	14.03	28.06	567.88
Panel 4 Room 3i	6078	4/5/2011	4/20/2011	647.26	2	14.03	28.06	647.26
Panel 4 Room 3i	6177	5/2/2011	5/6/2011	579.32	2	14.03	28.06	579.32
Panel 4 Room 3i	6328	6/16/2011	6/24/2011	604.84	2	14.03	28.06	604.84
Panel 4 Room 3i	6404	7/11/2011	7/15/2011	592.78	2	14.03	28.06	592.78
Panel 4 Room 3i	6472	8/9/2011	8/19/2011	589.06	2	14.03	28.06	589.06
Panel 4 Room 3i	6548	9/13/2011	9/16/2011	586.56	2	14.03	28.06	586.56
Panel 4 Room 3i	6622	10/10/2011	10/14/2011	543.54	2	14.03	28.06	543.54
Panel 4 Room 3i	6695	11/1/2011	11/4/2011	476.68	2	14.03	28.06	476.68
Panel 4 Room 3i	6799	12/12/2011	12/16/2011	538.20	2	14.40	28.80	538.20
Panel 4 Room 3i	6885	1/17/2012	1/23/2012	557.32	2	14.40	28.80	557.32
Panel 4 Room 3i	6937	2/7/2012	2/10/2012	489.38	2	14.40	28.80	489.38
Panel 4 Room 3i	7038	3/13/2012	3/16/2012	446.26	2	14.40	28.80	446.26
Panel 4 Room 3i	7108	4/10/2012	4/13/2012	403.18	2	14.40	28.80	403.18
Panel 4 Room 3i	7186	5/8/2012	5/15/2012	322.48	2	14.40	28.80	322.48
Panel 4 Room 3i	7265	6/11/2012	6/18/2012	251.78	2	14.40	28.80	251.78
Panel 4 Room 3i	7336	7/10/2012	7/13/2012	195.46	2	14.40	28.80	195.46
Panel 4 Room 3i	7452	8/13/2012	8/17/2012	141.14	2	14.40	28.80	141.14
Panel 4 Room 3i	7530	9/10/2012	9/14/2012	324.08	2	14.40	28.80	324.08
Panel 4 Room 3i	7576	10/1/2012	10/5/2012	344.38	2	14.40	28.80	344.38
Panel 4 Room 3i	7716	11/12/2012	11/16/2012	351.76	2	17.29	34.58	351.76
Panel 4 Room 3i	7804	12/10/2012	12/14/2012	381.98	2	17.29	34.58	381.98
Panel 4 Room 2e	4018	5/26/2009	5/29/2009	119.42	2	14.93	29.86	119.42
Panel 4 Room 2e	4076	6/10/2009	6/12/2009	40.70	2	14.93	29.86	40.70
Panel 4 Room 2e	4144	7/22/2009	7/24/2009	21.58	2	15.17	30.34	15.17
Panel 4 Room 2e	4205	8/13/2009	8/17/2009	41.80	2	15.17	30.34	41.80
Panel 4 Room 2e	4279	9/15/2009	9/18/2009	33.74	2	15.17	30.34	33.74
Panel 4 Room 2e	4320	10/6/2009	10/12/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room 2e	4399	11/9/2009	11/16/2009	360.32	2	15.17	30.34	360.32
Panel 4 Room 2e	4536	12/30/2009	1/12/2010	447.06	2	15.17	30.34	447.06
Panel 4 Room 2e	4600	1/20/2010	1/22/2010	412.04	2	15.17	30.34	412.04
Panel 4 Room 2e	4685	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room 2e	4838	3/17/2010	3/29/2010	401.50	2	15.17	30.34	401.50
Panel 4 Room 2e	4920	4/13/2010	4/20/2010	384.86	2	15.17	30.34	384.86
Panel 4 Room 2e	5055	5/17/2010	5/24/2010	450.50	2	15.17	30.34	450.50
Panel 4 Room 2e	5180	6/16/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room 2e	5315	7/27/2010	8/2/2010	252.22	2	7.00	14.00	252.22
Panel 4 Room 2e	5401	8/25/2010	8/30/2010	453.70	2	7.00	14.00	453.70
Panel 4 Room 2e	5455	9/14/2010	9/20/2010	505.30	2	7.00	14.00	505.30
Panel 4 Room 2e	5574	10/20/2010	10/25/2010	164.70	2	7.00	14.00	164.70
Panel 4 Room 2e	5666	11/16/2010	11/22/2010	478.96	2	7.00	14.00	478.96
Panel 4 Room 2e	5723	12/8/2010	12/13/2010	477.24	2	7.00	14.00	477.24
Panel 4 Room 2e	5821	1/12/2011	1/18/2011	530.64	2	14.03	28.06	530.64
Panel 4 Room 2e	5897	2/7/2011	2/10/2011	498.90	2	14.03	28.06	498.90
Panel 4 Room 2e	5985	3/2/2011	3/4/2011	456.92	2	14.03	28.06	456.92
Panel 4 Room 2e	6088	4/6/2011	4/20/2011	573.66	2	14.03	28.06	573.66
Panel 4 Room 2e	6186	5/3/2011	5/6/2011	435.26	2	14.03	28.06	435.26
Panel 4 Room 2e	6337	6/16/2011	6/24/2011	549.10	2	14.03	28.06	549.10
Panel 4 Room 2e	6413	7/12/2011	7/15/2011	472.86	2	14.03	28.06	472.86
Panel 4 Room 2e	6481	8/9/2011	8/19/2011	416.32	2	14.03	28.06	416.32
Panel 4 Room 2e	6559	9/14/2011	9/16/2011	465.28	2	14.03	28.06	465.28
Panel 4 Room 2e	6631	10/11/2011	10/14/2011	327.84	2	14.03	28.06	327.84
Panel 4 Room 2e	6704	11/1/2011	11/4/2011	426.68	2	14.03	28.06	426.68
Panel 4 Room 2e	6808	12/13/2011	12/16/2011	506.18	2	14.40	28.80	506.18
Panel 4 Room 2e	6894	1/17/2012	1/23/2012	552.66	2	14.40	28.80	552.66
Panel 4 Room 2e	6945	2/7/2012	2/10/2012	432.98	2	14.40	28.80	432.98
Panel 4 Room 2e	7046	3/13/2012	3/16/2012	424.6	2	14.40	28.80	424.60
Panel 4 Room 2e	7116	4/10/2012	4/13/2012	348.22	2	14.40	28.80	348.22
Panel 4 Room 2e	7194	5/9/2012	5/15/2012	259.1	2	14.40	28.80	259.10
Panel 4 Room 2e	7273	6/11/2012	6/18/2012	249.62	2	14.40	28.80	249.62
Panel 4 Room 2e	7344	7/10/2012	7/13/2012	269.48	2	14.40	28.80	269.48
Panel 4 Room 2e	7460	8/13/2012	8/17/2012	274.92	2	14.40	28.80	274.92
Panel 4 Room 2e	7537	9/10/2012	9/14/2012	319.26	2	14.40	28.80	319.26

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 2e	7583	10/2/2012	10/5/2012	382.74	2	14.40	28.80	382.74
Panel 4 Room 2e	7723	11/13/2012	11/16/2012	363.98	2	17.29	34.58	363.98
Panel 4 Room 2e	7811	12/11/2012	12/14/2012	386.38	2	17.29	34.58	386.38
Panel 4 Room 2i	4023	5/27/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room 2i	4078	6/10/2009	6/12/2009	9.74	2	14.93	29.86	14.93
Panel 4 Room 2i	4135	7/20/2009	7/24/2009	18.58	2	15.17	30.34	15.17
Panel 4 Room 2i	4196	8/11/2009	8/17/2009	39.14	2	15.17	30.34	39.14
Panel 4 Room 2i	4270	9/14/2009	9/18/2009	27.80	2	15.17	30.34	15.17
Panel 4 Room 2i	4311	10/5/2009	10/12/2009	123.80	2	15.17	30.34	123.80
Panel 4 Room 2i	4408	11/11/2009	11/16/2009	360.98	2	15.17	30.34	360.98
Panel 4 Room 2i	4527	12/30/2009	1/12/2010	345.20	2	15.17	30.34	345.20
Panel 4 Room 2i	4591	1/19/2010	1/22/2010	212.78	2	15.17	30.34	212.78
Panel 4 Room 2i	4676	2/9/2010	2/12/2010	100.50	2	15.17	30.34	100.50
Panel 4 Room 2i	4829	3/16/2010	3/29/2010	315.38	2	15.17	30.34	315.38
Panel 4 Room 2i	4930	4/14/2010	4/20/2010	465.72	2	15.17	30.34	465.72
Panel 4 Room 2i	5046	5/17/2010	5/24/2010	359.90	2	15.17	30.34	359.90
Panel 4 Room 2i	5171	6/15/2010	6/21/2010	297.24	2	7.00	14.00	297.24
Panel 4 Room 2i	5306	7/26/2010	8/2/2010	106.64	2	7.00	14.00	106.64
Panel 4 Room 2i	5392	8/24/2010	8/30/2010	484.80	2	7.00	14.00	484.80
Panel 4 Room 2i	5446	9/13/2010	9/20/2010	525.82	2	7.00	14.00	525.82
Panel 4 Room 2i	5565	10/19/2010	10/25/2010	466.74	2	7.00	14.00	466.74
Panel 4 Room 2i	5657	11/15/2010	11/22/2010	516.38	2	7.00	14.00	516.38
Panel 4 Room 2i	5714	12/7/2010	12/13/2010	479.42	2	7.00	14.00	479.42
Panel 4 Room 2i	5812	1/11/2011	1/18/2011	445.86	2	14.03	28.06	445.86
Panel 4 Room 2i	5886	2/1/2011	2/10/2011	479.84	2	14.03	28.06	479.84
Panel 4 Room 2i	5976	3/1/2011	3/4/2011	417.06	2	14.03	28.06	417.06
Panel 4 Room 2i	6079	4/5/2011	4/20/2011	501.76	2	14.03	28.06	501.76
Panel 4 Room 2i	6178	5/2/2011	5/6/2011	373.08	2	14.03	28.06	373.08
Panel 4 Room 2i	6329	6/16/2011	6/24/2011	505.80	2	14.03	28.06	505.80
Panel 4 Room 2i	6405	7/11/2011	7/15/2011	460.76	2	14.03	28.06	460.76
Panel 4 Room 2i	6473	8/9/2011	8/19/2011	353.70	2	14.03	28.06	353.70
Panel 4 Room 2i	6549	9/13/2011	9/16/2011	468.10	2	14.03	28.06	468.10
Panel 4 Room 2i	6623	10/10/2011	10/14/2011	332.94	2	14.03	28.06	332.94
Panel 4 Room 2i	6696	11/1/2011	11/4/2011	399.78	2	14.03	28.06	399.78
Panel 4 Room 2i	6800	12/12/2011	12/16/2011	494.62	2	14.40	28.80	494.62
Panel 4 Room 2i	6886	1/17/2012	1/23/2012	486.72	2	14.40	28.80	486.72
Panel 4 Room 2i	6938	2/7/2012	2/10/2012	375.26	2	14.40	28.80	375.26
Panel 4 Room 2i	7039	3/13/2012	3/16/2012	344.34	2	14.40	28.80	344.34
Panel 4 Room 2i	7109	4/10/2012	4/13/2012	209.4	2	14.40	28.80	209.40
Panel 4 Room 2i	7187	5/8/2012	5/15/2012	217.4	2	14.40	28.80	217.40
Panel 4 Room 2i	7266	6/11/2012	6/18/2012	146.8	2	14.40	28.80	146.80
Panel 4 Room 2i	7337	7/10/2012	7/13/2012	142.92	2	14.40	28.80	142.92
Panel 4 Room 2i	7453	8/13/2012	8/17/2012	114.18	2	14.40	28.80	114.18
Panel 4 Room 2i	7531	9/10/2012	9/14/2012	357.32	2	14.40	28.80	357.32
Panel 4 Room 2i	7577	10/1/2012	10/5/2012	384.32	2	14.40	28.80	384.32
Panel 4 Room 2i	7717	11/12/2012	11/16/2012	317.22	2	17.29	34.58	317.22
Panel 4 Room 2i	7805	12/10/2012	12/14/2012	356.8	2	17.29	34.58	356.80
Panel 4 Room 1e	4016	5/26/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room 1e	4074	6/9/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room 1e	4145	7/22/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room 1e	4206	8/13/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room 1e	4280	9/15/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room 1e	4321	10/6/2009	10/12/2009	239.96	2	15.17	30.34	239.96
Panel 4 Room 1e	4397	11/9/2009	11/16/2009	350.24	2	15.17	30.34	350.24
Panel 4 Room 1e	4537	12/30/2009	1/12/2010	390.52	2	15.17	30.34	390.52
Panel 4 Room 1e	4601	1/20/2010	1/22/2010	267.72	2	15.17	30.34	267.72
Panel 4 Room 1e	4686	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room 1e	4839	3/17/2010	3/29/2010	319.58	2	15.17	30.34	319.58
Panel 4 Room 1e	4923	4/14/2010	4/20/2010	384.86	2	15.17	30.34	384.86
Panel 4 Room 1e	5056	5/18/2010	5/24/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room 1e	5181	6/16/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room 1e	5316	7/27/2010	8/2/2010	307.08	2	7.00	14.00	307.08
Panel 4 Room 1e	5402	8/25/2010	8/30/2010	223.64	2	7.00	14.00	223.64
Panel 4 Room 1e	5456	9/14/2010	9/20/2010	270.82	2	7.00	14.00	270.82
Panel 4 Room 1e	5575	10/20/2010	10/25/2010	355.54	2	7.00	14.00	355.54
Panel 4 Room 1e	5667	11/16/2010	11/22/2010	451.70	2	7.00	14.00	451.70
Panel 4 Room 1e	5724	12/8/2010	12/13/2010	347.96	2	7.00	14.00	347.96
Panel 4 Room 1e	5822	1/12/2011	1/18/2011	460.36	2	14.03	28.06	460.36
Panel 4 Room 1e	5890	2/1/2011	2/10/2011	371.40	2	14.03	28.06	371.40
Panel 4 Room 1e	5986	3/2/2011	3/4/2011	391.48	2	14.03	28.06	391.48
Panel 4 Room 1e	6089	4/6/2011	4/20/2011	480.62	2	14.03	28.06	480.62
Panel 4 Room 1e	6187	5/4/2011	5/6/2011	345.60	2	14.03	28.06	345.60
Panel 4 Room 1e	6338	6/16/2011	6/24/2011	488.10	2	14.03	28.06	488.10
Panel 4 Room 1e	6414	7/12/2011	7/15/2011	283.24	2	14.03	28.06	283.24
Panel 4 Room 1e	6482	8/9/2011	8/19/2011	143.48	2	14.03	28.06	143.48
Panel 4 Room 1e	6560	9/14/2011	9/16/2011	410.04	2	14.03	28.06	410.04
Panel 4 Room 1e	6634	10/11/2011	10/14/2011	305.92	2	14.03	28.06	305.92

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 1e	6707	11/1/2011	11/4/2011	388.88	2	14.03	28.06	388.88
Panel 4 Room 1e	6811	12/13/2011	12/16/2011	494.32	2	14.40	28.80	494.32
Panel 4 Room 1e	6897	1/17/2012	1/23/2012	501.8	2	14.40	28.80	501.80
Panel 4 Room 1e	6948	2/7/2012	2/10/2012	414.88	2	14.40	28.80	414.88
Panel 4 Room 1e	7049	3/13/2012	3/16/2012	376.52	2	14.40	28.80	376.52
Panel 4 Room 1e	7119	4/10/2012	4/13/2012	322.28	2	14.40	28.80	322.28
Panel 4 Room 1e	7197	5/9/2012	5/15/2012	278.46	2	14.40	28.80	278.46
Panel 4 Room 1e	7276	6/11/2012	6/18/2012	219.08	2	14.40	28.80	219.08
Panel 4 Room 1e	7347	7/10/2012	7/13/2012	79.5	2	14.40	28.80	79.50
Panel 4 Room 1e	7463	8/14/2012	8/17/2012	203.66	2	14.40	28.80	203.66
Panel 4 Room 1e	7540	9/10/2012	9/14/2012	281.34	2	14.40	28.80	281.34
Panel 4 Room 1e	7586	10/2/2012	10/5/2012	329.02	2	14.40	28.80	329.02
Panel 4 Room 1e	7726	11/13/2012	11/16/2012	356.44	2	17.29	34.58	356.44
Panel 4 Room 1e	7814	12/11/2012	12/14/2012	424.38	2	17.29	34.58	424.38
Panel 4 Room 1i	4020	5/27/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room 1i	4061	6/8/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room 1i	4136	7/20/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room 1i	4197	8/11/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room 1i	4271	9/14/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room 1i	4312	10/5/2009	10/12/2009	197.06	2	15.17	30.34	197.06
Panel 4 Room 1i	4407	11/11/2009	11/16/2009	173.66	2	15.17	30.34	173.66
Panel 4 Room 1i	4528	12/30/2009	1/12/2010	340.76	2	15.17	30.34	340.76
Panel 4 Room 1i	4592	1/19/2010	1/22/2010	231.74	2	15.17	30.34	231.74
Panel 4 Room 1i	4677	2/9/2010	2/12/2010	93.12	2	15.17	30.34	93.12
Panel 4 Room 1i	4830	3/16/2010	3/29/2010	163.52	2	15.17	30.34	163.52
Panel 4 Room 1i	4931	4/14/2010	4/20/2010	408.26	2	15.17	30.34	408.26
Panel 4 Room 1i	5047	5/17/2010	5/24/2010	342.24	2	15.17	30.34	342.24
Panel 4 Room 1i	5172	6/15/2010	6/21/2010	218.42	2	7.00	14.00	218.42
Panel 4 Room 1i	5307	7/26/2010	8/2/2010	125.26	2	7.00	14.00	125.26
Panel 4 Room 1i	5393	8/24/2010	8/30/2010	333.46	2	7.00	14.00	333.46
Panel 4 Room 1i	5447	9/13/2010	9/20/2010	328.02	2	7.00	14.00	328.02
Panel 4 Room 1i	5566	10/19/2010	10/25/2010	427.46	2	7.00	14.00	427.46
Panel 4 Room 1i	5658	11/15/2010	11/22/2010	443.82	2	7.00	14.00	443.82
Panel 4 Room 1i	5715	12/7/2010	12/13/2010	455.58	2	7.00	14.00	455.58
Panel 4 Room 1i	5813	1/11/2011	1/18/2011	362.94	2	14.03	28.06	362.94
Panel 4 Room 1i	5887	2/1/2011	2/10/2011	353.66	2	14.03	28.06	353.66
Panel 4 Room 1i	5977	3/1/2011	3/4/2011	370.72	2	14.03	28.06	370.72
Panel 4 Room 1i	6080	4/5/2011	4/20/2011	414.54	2	14.03	28.06	414.54
Panel 4 Room 1i	6179	5/2/2011	5/6/2011	252.54	2	14.03	28.06	252.54
Panel 4 Room 1i	6330	6/16/2011	6/24/2011	519.66	2	14.03	28.06	519.66
Panel 4 Room 1i	6406	7/11/2011	7/15/2011	411.26	2	14.03	28.06	411.26
Panel 4 Room 1i	6474	8/9/2011	8/19/2011	300.02	2	14.03	28.06	300.02
Panel 4 Room 1i	6550	9/13/2011	9/16/2011	429.54	2	14.03	28.06	429.54
Panel 4 Room 1i	6624	10/10/2011	10/14/2011	294.66	2	14.03	28.06	294.66
Panel 4 Room 1i	6697	11/1/2011	11/4/2011	365.72	2	14.03	28.06	365.72
Panel 4 Room 1i	6801	12/12/2011	12/16/2011	483.68	2	14.40	28.80	483.68
Panel 4 Room 1i	6887	1/17/2012	1/23/2012	505.6	2	14.40	28.80	505.60
Panel 4 Room 1i	6939	2/7/2012	2/10/2012	412.76	2	14.40	28.80	412.76
Panel 4 Room 1i	7040	3/13/2012	3/16/2012	362.8	2	14.40	28.80	362.80
Panel 4 Room 1i	7110	4/10/2012	4/13/2012	192.06	2	14.40	28.80	192.06
Panel 4 Room 1i	7188	5/8/2012	5/15/2012	191.24	2	14.40	28.80	191.24
Panel 4 Room 1i	7267	6/11/2012	6/18/2012	134.02	2	14.40	28.80	134.02
Panel 4 Room 1i	7338	7/10/2012	7/13/2012	151.34	2	14.40	28.80	151.34
Panel 4 Room 1i	7454	8/13/2012	8/17/2012	114.52	2	14.40	28.80	114.52
Panel 4 Room 1i	7532	9/10/2012	9/14/2012	334.94	2	14.40	28.80	334.94
Panel 4 Room 1i	7578	10/1/2012	10/5/2012	332.66	2	14.40	28.80	332.66
Panel 4 Room 1i	7718	11/13/2012	11/16/2012	364.88	2	17.29	34.58	364.88
Panel 4 Room 1i	7806	12/10/2012	12/14/2012	376.58	2	17.29	34.58	376.58
Panel 4 Room EBW	4015	5/26/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room EBW	4065	6/8/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room EBW	4147	7/22/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBW	4208	8/13/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBW	4282	9/15/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBW	4323	10/6/2009	10/12/2009	105.10	2	15.17	30.34	105.10
Panel 4 Room EBW	4396	11/9/2009	11/16/2009	141.00	2	15.17	30.34	141.00
Panel 4 Room EBW	4539	12/30/2009	1/12/2010	235.40	2	15.17	30.34	235.40
Panel 4 Room EBW	4603	1/20/2010	1/22/2010	270.16	2	15.17	30.34	270.16
Panel 4 Room EBW	4688	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBW	4841	3/17/2010	3/29/2010	324.28	2	15.17	30.34	324.28
Panel 4 Room EBW	4921	4/13/2010	4/20/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBW	5058	5/18/2010	5/24/2010	64.70	2	15.17	30.34	64.70
Panel 4 Room EBW	5183	6/16/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room EBW	5318	7/27/2010	8/2/2010	137.54	2	7.00	14.00	137.54
Panel 4 Room EBW	5404	8/25/2010	8/30/2010	60.18	2	7.00	14.00	60.18
Panel 4 Room EBW	5458	9/14/2010	9/20/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room EBW	5577	10/20/2010	10/25/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room EBW	5669	11/16/2010	11/22/2010	N.D.	2	7.00	14.00	7.00

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room EBW	5726	12/8/2010	12/13/2010	149.84	2	7.00	14.00	149.84
Panel 4 Room EBW	5824	1/12/2011	1/18/2011	268.54	2	14.03	28.06	268.54
Panel 4 Room EBW	5898	2/7/2011	2/10/2011	316.50	2	14.03	28.06	316.50
Panel 4 Room EBW	5988	3/2/2011	3/4/2011	281.32	2	14.03	28.06	281.32
Panel 4 Room EBW	6091	4/6/2011	4/20/2011	182.90	2	14.03	28.06	182.90
Panel 4 Room EBW	6189	5/4/2011	5/6/2011	42.48	2	14.03	28.06	42.48
Panel 4 Room EBW	6340	6/16/2011	6/24/2011	206.20	2	14.03	28.06	206.20
Panel 4 Room EBW	6416	7/12/2011	7/15/2011	68.52	2	14.03	28.06	68.52
Panel 4 Room EBW	6484	8/9/2011	8/19/2011	45.78	2	14.03	28.06	45.78
Panel 4 Room EBW	6562	9/14/2011	9/16/2011	109.38	2	14.03	28.06	109.38
Panel 4 Room EBW	6632	10/11/2011	10/14/2011	51.88	2	14.03	28.06	51.88
Panel 4 Room EBW	6705	11/1/2011	11/4/2011	183.10	2	14.03	28.06	183.10
Panel 4 Room EBW	6809	12/13/2011	12/16/2011	214.68	2	14.40	28.80	214.68
Panel 4 Room EBW	6895	1/17/2012	1/23/2012	152.46	2	14.40	28.80	152.46
Panel 4 Room EBW	6946	2/7/2012	2/10/2012	126.92	2	14.40	28.80	126.92
Panel 4 Room EBW	7047	3/13/2012	3/16/2012	169.86	2	14.40	28.80	169.86
Panel 4 Room EBW	7117	4/10/2012	4/13/2012	158.14	2	14.40	28.80	158.14
Panel 4 Room EBW	7195	5/9/2012	5/15/2012	274.44	2	14.40	28.80	274.44
Panel 4 Room EBW	7274	6/11/2012	6/18/2012	181.18	2	14.40	28.80	181.18
Panel 4 Room EBW	7345	7/10/2012	7/13/2012	93.14	2	14.40	28.80	93.14
Panel 4 Room EBW	7461	8/13/2012	8/17/2012	274.6	2	14.40	28.80	274.60
Panel 4 Room EBW	7538	9/10/2012	9/14/2012	105.1	2	14.40	28.80	105.10
Panel 4 Room EBW	7584	10/2/2012	10/5/2012	110.02	2	14.40	28.80	110.02
Panel 4 Room EBW	7724	11/13/2012	11/16/2012	157.24	2	17.29	34.58	157.24
Panel 4 Room EBW	7812	12/11/2012	12/14/2012	312.46	2	17.29	34.58	312.46
Panel 4 Room EBA	4014	5/26/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room EBA	4064	6/8/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room EBA	4148	7/22/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBA	4209	8/13/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBA	4283	9/15/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBA	4324	10/6/2009	10/12/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBA	4395	11/9/2009	11/16/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBA	4540	12/30/2009	1/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBA	4604	1/20/2010	1/22/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBA	4689	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBA	4842	3/17/2010	3/29/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBA	4922	4/13/2010	4/20/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBA	5059	5/18/2010	5/24/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room EBA	5184	6/16/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room EBA	5319	7/27/2010	8/2/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room EBA	5405	8/25/2010	8/30/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room EBA	5459	9/14/2010	9/20/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room EBA	5578	10/20/2010	10/25/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room EBA	5670	11/16/2010	11/22/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room EBA	5727	12/8/2010	12/13/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room EBA	5825	1/12/2011	1/18/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room EBA	5899	2/7/2011	2/10/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room EBA	5989	3/2/2011	3/4/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room EBA	6092	4/6/2011	4/20/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room EBA	6190	5/4/2011	5/6/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room EBA	6341	6/16/2011	6/24/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room EBA	6417	7/12/2011	7/15/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room EBA	6485	8/9/2011	8/19/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room EBA	6563	9/14/2011	9/16/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room EBA	6633	10/11/2011	10/14/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room EBA	6706	11/1/2011	11/4/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room EBA	6810	12/13/2011	12/16/2011	N.D.	2	14.40	28.80	14.40
Panel 4 Room EBA	6896	1/17/2012	1/23/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room EBA	6947	2/7/2012	2/10/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room EBA	7048	3/13/2012	3/16/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room EBA	7118	4/10/2012	4/13/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room EBA	7196	5/9/2012	5/15/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room EBA	7275	6/11/2012	6/18/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room EBA	7346	7/10/2012	7/13/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room EBA	7462	8/13/2012	8/17/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room EBA	7539	9/10/2012	9/14/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room EBA	7585	10/2/2012	10/5/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room EBA	7725	11/13/2012	11/16/2012	N.D.	2	17.29	34.58	17.29
Panel 4 Room EBA	7813	12/11/2012	12/14/2012	31.6	2	17.29	34.58	17.29
Panel 4 Room IBW	4022	5/27/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room IBW	4063	6/8/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room IBW	4137	7/20/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBW	4198	8/11/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBW	4272	9/14/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBW	4313	10/5/2009	10/12/2009	12.56	2	15.17	30.34	15.17
Panel 4 Room IBW	4406	11/11/2009	11/16/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBW	4529	12/30/2009	1/12/2010	166.08	2	15.17	30.34	166.08

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room IBW	4593	1/19/2010	1/22/2010	129.08	2	15.17	30.34	129.08
Panel 4 Room IBW	4678	2/9/2010	2/12/2010	50.74	2	15.17	30.34	50.74
Panel 4 Room IBW	4831	3/16/2010	3/29/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBW	4932	4/14/2010	4/20/2010	236.70	2	15.17	30.34	236.70
Panel 4 Room IBW	5048	5/17/2010	5/24/2010	230.88	2	15.17	30.34	230.88
Panel 4 Room IBW	5173	6/15/2010	6/21/2010	252.06	2	7.00	14.00	252.06
Panel 4 Room IBW	5308	7/26/2010	8/2/2010	283.86	2	7.00	14.00	283.86
Panel 4 Room IBW	5394	8/24/2010	8/30/2010	114.94	2	7.00	14.00	114.94
Panel 4 Room IBW	5448	9/13/2010	9/20/2010	70.54	2	7.00	14.00	70.54
Panel 4 Room IBW	5567	10/19/2010	10/25/2010	398.20	2	7.00	14.00	398.20
Panel 4 Room IBW	5659	11/15/2010	11/22/2010	329.56	2	7.00	14.00	329.56
Panel 4 Room IBW	5716	12/7/2010	12/13/2010	357.10	2	7.00	14.00	357.10
Panel 4 Room IBW	5814	1/11/2011	1/18/2011	302.90	2	14.03	28.06	302.90
Panel 4 Room IBW	5888	2/1/2011	2/10/2011	298.64	2	14.03	28.06	298.64
Panel 4 Room IBW	5978	3/1/2011	3/4/2011	317.72	2	14.03	28.06	317.72
Panel 4 Room IBW	6081	4/5/2011	4/20/2011	329.26	2	14.03	28.06	329.26
Panel 4 Room IBW	6180	5/3/2011	5/6/2011	334.28	2	14.03	28.06	334.28
Panel 4 Room IBW	6331	6/16/2011	6/24/2011	319.28	2	14.03	28.06	319.28
Panel 4 Room IBW	6407	7/11/2011	7/15/2011	263.72	2	14.03	28.06	263.72
Panel 4 Room IBW	6475	8/9/2011	8/19/2011	264.52	2	14.03	28.06	264.52
Panel 4 Room IBW	6551	9/13/2011	9/16/2011	289.72	2	14.03	28.06	289.72
Panel 4 Room IBW	6625	10/10/2011	10/14/2011	229.52	2	14.03	28.06	229.52
Panel 4 Room IBW	6698	11/1/2011	11/4/2011	249.70	2	14.03	28.06	249.70
Panel 4 Room IBW	6802	12/12/2011	12/16/2011	356.14	2	14.40	28.80	356.14
Panel 4 Room IBW	6888	1/17/2012	1/23/2012	310.84	2	14.40	28.80	310.84
Panel 4 Room IBW	6940	2/7/2012	2/10/2012	318.06	2	14.40	28.80	318.06
Panel 4 Room IBW	7041	3/13/2012	3/16/2012	226.6	2	14.40	28.80	226.60
Panel 4 Room IBW	7111	4/10/2012	4/13/2012	51.64	2	14.40	28.80	51.64
Panel 4 Room IBW	7189	5/8/2012	5/15/2012	95.04	2	14.40	28.80	95.04
Panel 4 Room IBW	7268	6/11/2012	6/18/2012	77.72	2	14.40	28.80	77.72
Panel 4 Room IBW	7339	7/10/2012	7/13/2012	16.24	2	14.40	28.80	14.40
Panel 4 Room IBW	7455	8/13/2012	8/17/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room IBW	7533	9/10/2012	9/14/2012	230.78	2	14.40	28.80	230.78
Panel 4 Room IBW	7579	10/2/2012	10/5/2012	227.7	2	14.40	28.80	227.70
Panel 4 Room IBW	7719	11/13/2012	11/16/2012	220.86	2	17.29	34.58	220.86
Panel 4 Room IBW	7807	12/10/2012	12/14/2012	296.5	2	17.29	34.58	296.50
Panel 4 Room IBA	4021	5/27/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room IBA	4062	6/8/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
Panel 4 Room IBA	4138	7/20/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBA	4199	8/11/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBA	4273	9/14/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBA	4314	10/5/2009	10/12/2009	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBA	4405	11/11/2009	11/16/2009	130.72	2	15.17	30.34	130.72
Panel 4 Room IBA	4530	12/30/2009	1/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBA	4594	1/19/2010	1/22/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBA	4679	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBA	4832	3/16/2010	3/29/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBA	4933	4/14/2010	4/20/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBA	5049	5/17/2010	5/24/2010	N.D.	2	15.17	30.34	15.17
Panel 4 Room IBA	5174	6/15/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room IBA	5309	7/26/2010	8/2/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room IBA	5395	8/24/2010	8/30/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room IBA	5449	9/13/2010	9/20/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room IBA	5568	10/19/2010	10/25/2010	N.D.	2	7.00	14.00	7.00
Panel 4 Room IBA	5660	11/15/2010	11/22/2010	42.12	2	7.00	14.00	42.12
Panel 4 Room IBA	5717	12/7/2010	12/13/2010	63.50	2	7.00	14.00	63.50
Panel 4 Room IBA	5815	1/11/2011	1/18/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room IBA	5889	2/1/2011	2/10/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room IBA	5979	3/1/2011	3/4/2011	45.52	2	14.03	28.06	45.52
Panel 4 Room IBA	6082	4/5/2011	4/20/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room IBA	6181	5/3/2011	5/6/2011	67.86	2	14.03	28.06	67.86
Panel 4 Room IBA	6332	6/16/2011	6/24/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room IBA	6408	7/12/2011	7/15/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room IBA	6476	8/9/2011	8/19/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room IBA	6552	9/14/2011	9/16/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room IBA	6626	10/10/2011	10/14/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room IBA	6699	11/1/2011	11/4/2011	N.D.	2	14.03	28.06	14.03
Panel 4 Room IBA	6803	12/12/2011	12/16/2011	N.D.	2	14.40	28.80	14.40
Panel 4 Room IBA	6889	1/17/2012	1/23/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room IBA	6941	2/7/2012	2/10/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room IBA	7042	3/13/2012	3/16/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room IBA	7112	4/10/2012	4/13/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room IBA	7190	5/8/2012	5/15/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room IBA	7269	6/11/2012	6/18/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room IBA	7340	7/10/2012	7/13/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room IBA	7456	8/13/2012	8/17/2012	N.D.	2	14.40	28.80	14.40
Panel 4 Room IBA	7534	9/10/2012	9/14/2012	N.D.	2	14.40	28.80	14.40

Hydrogen (H_2) **CAS# 1333-74-0**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room IBA	7580	10/2/2012	10/5/2012	20.8	2	14.40	28.80	14.40
Panel 4 Room IBA	7720	11/13/2012	11/16/2012	N.D.	2	17.29	34.58	17.29
Panel 4 Room IBA	7808	12/11/2012	12/14/2012	N.D.	2	17.29	34.58	17.29

Methane Data-Panel 4

All samples were sampled at sub-atmospheric pressure and pressurized by the lab as required for analysis; dilution factors included in data set. The MDL (method detection limit) is the sample quantitation limit determined in accordance with 40 CFR Part 136; actual and dilution corrected MDLs included in data set.

7/25/08-6/16/09 MDL = 23.74 ppmv
6/17/09-6/8/10 MDL = 22.21 ppmv
6/9/10-12/28/10 MDL = 21.39 ppmv
12/29/10-11/30/11 MDL = 23.97 ppmv
12/1/11-10/21/12 MDL = 17.45 ppmv
10/22/12-? MDL = 15.71 ppmv ← MDL end date not yet determined

Some values in column "Results" are less than dilution corrected MDLs. These values are not included in the statistical evaluation. When results are N.D. (not-detected) or less than dilution corrected MDLs, the values used for the statistical evaluation are 1/2 the corrected MDL.

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 7e	4032	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 7e	4069	6/9/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 7e	4139	7/21/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7e	4200	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7e	4274	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7e	4315	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7e	4404	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7e	4531	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7e	4595	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7e	4680	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7e	4833	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7e	4915	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7e	5050	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7e	5175	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7e	5310	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7e	5396	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7e	5450	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7e	5569	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7e	5661	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7e	5718	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7e	5816	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7e	5892	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7e	5980	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7e	6083	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7e	6182	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7e	6333	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7e	6409	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7e	6477	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7e	6553	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7e	6627	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7e	6700	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7e	6804	12/12/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7e	6890	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7e	6942	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7e	7043	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7e	7113	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7e	7191	5/9/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7e	7270	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7e	7341	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7e	7457	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7e	7535	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7e	7581	10/2/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7e	7721	11/13/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 7e	7809	12/11/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 7i	4028	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 7i	4073	6/9/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 7i	4130	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7i	4191	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7i	4265	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7i	4306	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7i	4413	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7i	4522	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7i	4586	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7i	4671	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7i	4824	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7i	4925	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 7i	5041	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 7i	5166	6/14/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7i	5301	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7i	5387	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7i	5441	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7i	5560	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7i	5652	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7i	5709	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 7i	5807	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7i	5881	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7i	5971	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7i	6074	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7i	6173	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7i	6324	6/15/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7i	6400	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7i	6461	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7i	6544	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7i	6618	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7i	6691	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 7i	6795	12/12/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7i	6881	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7i	6933	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7i	7034	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7i	7104	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7i	7182	5/8/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7i	7261	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7i	7332	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7i	7448	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7i	7526	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7i	7572	10/1/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 7i	7712	11/12/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 7i	7800	12/10/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 6e	4031	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 6e	4068	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 6e	4140	7/21/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6e	4201	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6e	4275	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6e	4316	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6e	4403	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6e	4532	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6e	4596	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6e	4681	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6e	4834	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6e	4916	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6e	5051	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6e	5176	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6e	5311	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6e	5397	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6e	5451	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6e	5570	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6e	5662	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6e	5719	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6e	5817	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6e	5893	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6e	5981	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6e	6084	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6e	6183	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6e	6334	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6e	6410	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6e	6478	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6e	6554	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6e	6628	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6e	6701	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6i	4027	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 6i	4072	6/9/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 6i	4131	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6i	4192	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6i	4266	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6i	4307	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6i	4412	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6i	4523	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6i	4587	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6i	4672	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6i	4825	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6i	4926	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6i	5042	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 6i	5167	6/14/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6i	5302	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 6i	5388	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6i	5442	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6i	5561	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6i	5653	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6i	5710	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 6i	5808	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6i	5882	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6i	5972	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6i	6075	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6i	6174	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6i	6325	6/15/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6i	6401	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6i	6469	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6i	6545	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6i	6619	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6i	6692	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 6i	6796	12/12/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room 6i	6882	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 6i	6934	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 6i	7035	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 6i	7105	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 6i	7183	5/8/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 6i	7262	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 6i	7333	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 6i	7449	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 6i	7527	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 6i	7573	10/1/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 6i	7713	11/12/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 6i	7801	12/10/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 5e	4030	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 5e	4067	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 5e	4141	7/21/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5e	4202	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5e	4276	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5e	4317	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5e	4402	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5e	4533	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5e	4597	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5e	4682	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5e	4835	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5e	4917	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5e	5052	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5e	5177	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5e	5312	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5e	5398	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5e	5452	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5e	5571	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5e	5663	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5e	5720	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5e	5818	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5e	5894	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5e	5982	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5e	6085	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5e	6184	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5e	6335	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5e	6411	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5e	6479	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5e	6557	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5e	6629	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5e	6702	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5e	6806	12/13/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5e	6892	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5e	6943	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5e	7044	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5e	7114	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5e	7192	5/9/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5e	7271	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5e	7342	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5i	4026	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 5i	4071	6/9/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 5i	4132	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5i	4193	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5i	4267	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5i	4308	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5i	4411	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5i	4524	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5i	4588	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 5i	4673	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5i	4826	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5i	4927	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5i	5043	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 5i	5168	6/14/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5i	5303	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5i	5389	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5i	5443	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5i	5562	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5i	5654	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5i	5711	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 5i	5809	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5i	5883	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5i	5973	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5i	6076	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5i	6175	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5i	6326	6/15/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5i	6402	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5i	6470	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5i	6546	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5i	6620	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5i	6693	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 5i	6797	12/12/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5i	6883	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5i	6935	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5i	7036	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5i	7106	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5i	7184	5/8/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5i	7263	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5i	7334	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5i	7450	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5i	7528	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5i	7574	10/1/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 5i	7714	11/12/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 5i	7802	12/10/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 4e	4029	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 4e	4066	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 4e	4142	7/21/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4e	4203	8/13/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4e	4277	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4e	4318	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4e	4401	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4e	4534	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4e	4598	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4e	4683	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4e	4836	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4e	4918	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4e	5053	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4e	5178	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4e	5313	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4e	5399	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4e	5453	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4e	5572	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4e	5664	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4e	5721	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4e	5819	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4e	5895	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4e	5983	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4i	4025	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 4i	4070	6/9/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 4i	4133	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4i	4194	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4i	4268	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4i	4309	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4i	4410	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4i	4525	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4i	4589	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4i	4674	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4i	4827	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4i	4928	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4i	5044	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 4i	5169	6/14/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4i	5304	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4i	5390	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4i	5444	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4i	5563	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4i	5655	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 4i	5712	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 4i	5810	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4i	5884	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4i	5974	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4i	6077	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4i	6176	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4i	6327	6/15/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4i	6403	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4i	6471	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4i	6547	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4i	6621	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4i	6694	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 4i	6798	12/12/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room 4i	6884	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 4i	6936	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 4i	7037	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 4i	7107	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 4i	7185	5/8/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 4i	7264	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 4i	7335	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 4i	7451	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 4i	7529	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 4i	7575	10/1/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 4i	7715	11/12/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 4i	7803	12/10/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 3e	4019	5/26/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 3e	4077	6/10/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 3e	4143	7/21/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3e	4204	8/13/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3e	4278	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3e	4319	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3e	4400	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3e	4535	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3e	4599	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3e	4684	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3e	4837	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3e	4919	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3e	5054	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3e	5179	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3e	5314	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3e	5400	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3e	5454	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3e	5573	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3e	5665	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3e	5722	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3e	5820	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3e	5896	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3e	5984	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3e	6087	4/6/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3e	6185	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3e	6336	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3e	6412	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3e	6480	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3e	6558	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3e	6630	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3e	6703	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3e	6807	12/13/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3e	6893	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3e	6944	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3e	7045	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3e	7115	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3e	7193	5/9/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3e	7272	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3e	7343	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3e	7459	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3e	7536	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3e	7582	10/2/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3e	7722	11/13/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 3e	7810	12/11/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 3i	4024	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 3i	4079	6/10/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 3i	4134	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3i	4195	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3i	4269	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3i	4310	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3i	4409	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3i	4526	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 3i	4590	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3i	4675	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3i	4828	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3i	4929	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3i	5045	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 3i	5170	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3i	5305	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3i	5391	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3i	5445	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3i	5564	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3i	5656	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3i	5713	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 3i	5811	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3i	5885	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3i	5975	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3i	6078	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3i	6177	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3i	6328	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3i	6404	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3i	6472	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3i	6548	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3i	6622	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3i	6695	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 3i	6799	12/12/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3i	6885	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3i	6937	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3i	7038	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3i	7108	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3i	7186	5/8/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3i	7265	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3i	7336	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3i	7452	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3i	7530	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3i	7576	10/1/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 3i	7716	11/12/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 3i	7804	12/10/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 2e	4018	5/26/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 2e	4076	6/10/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 2e	4144	7/22/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2e	4205	8/13/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2e	4279	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2e	4320	10/6/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2e	4399	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2e	4536	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2e	4600	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2e	4685	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2e	4838	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2e	4920	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2e	5055	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2e	5180	6/16/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2e	5315	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2e	5401	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2e	5455	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2e	5574	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2e	5666	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2e	5723	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2e	5821	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2e	5897	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2e	5985	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2e	6088	4/6/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2e	6186	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2e	6337	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2e	6413	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2e	6481	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2e	6559	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2e	6631	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2e	6704	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2e	6808	12/13/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2e	6894	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2e	6945	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2e	7046	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2e	7116	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2e	7194	5/9/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2e	7273	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2e	7344	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2e	7460	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2e	7537	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 2e	7583	10/2/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2e	7723	11/13/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 2e	7811	12/11/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 2i	4023	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 2i	4078	6/10/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 2i	4135	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2i	4196	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2i	4270	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2i	4311	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2i	4408	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2i	4527	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2i	4591	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2i	4676	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2i	4829	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2i	4930	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2i	5046	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 2i	5171	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2i	5306	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2i	5392	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2i	5446	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2i	5565	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2i	5657	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2i	5714	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 2i	5812	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2i	5886	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2i	5976	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2i	6079	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2i	6178	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2i	6329	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2i	6405	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2i	6473	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2i	6549	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2i	6623	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2i	6696	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 2i	6800	12/12/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2i	6886	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2i	6938	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2i	7039	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2i	7109	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2i	7187	5/8/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2i	7266	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2i	7337	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2i	7453	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2i	7531	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2i	7577	10/1/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 2i	7717	11/12/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 2i	7805	12/10/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 1e	4016	5/26/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 1e	4074	6/9/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 1e	4145	7/22/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1e	4206	8/13/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1e	4280	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1e	4321	10/6/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1e	4397	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1e	4537	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1e	4601	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1e	4686	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1e	4839	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1e	4923	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1e	5056	5/18/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1e	5181	6/16/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1e	5316	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1e	5402	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1e	5456	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1e	5575	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1e	5667	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1e	5724	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1e	5822	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1e	5890	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1e	5986	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1e	6089	4/6/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1e	6187	5/4/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1e	6338	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1e	6414	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1e	6482	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1e	6560	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1e	6634	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room 1e	6707	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1e	6811	12/13/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1e	6897	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1e	6948	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1e	7049	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1e	7119	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1e	7197	5/9/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1e	7276	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1e	7347	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1e	7463	8/14/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1e	7540	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1e	7586	10/2/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1e	7726	11/13/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 1e	7814	12/11/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 1i	4020	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 1i	4061	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room 1i	4136	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1i	4197	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1i	4271	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1i	4312	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1i	4407	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1i	4528	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1i	4592	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1i	4677	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1i	4830	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1i	4931	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1i	5047	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room 1i	5172	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1i	5307	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1i	5393	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1i	5447	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1i	5566	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1i	5658	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1i	5715	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room 1i	5813	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1i	5887	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1i	5977	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1i	6080	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1i	6179	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1i	6330	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1i	6406	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1i	6474	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1i	6550	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1i	6624	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1i	6697	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room 1i	6801	12/12/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1i	6887	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1i	6939	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1i	7040	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1i	7110	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1i	7188	5/8/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1i	7267	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1i	7338	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1i	7454	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1i	7532	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1i	7578	10/1/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room 1i	7718	11/13/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room 1i	7806	12/10/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room EBW	4015	5/26/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room EBW	4065	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room EBW	4147	7/22/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBW	4208	8/13/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBW	4282	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBW	4323	10/6/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBW	4396	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBW	4539	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBW	4603	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBW	4688	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBW	4841	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBW	4921	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBW	5058	5/18/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBW	5183	6/16/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBW	5318	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBW	5404	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBW	5458	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBW	5577	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBW	5669	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room EBW	5726	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBW	5824	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBW	5898	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBW	5988	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBW	6091	4/6/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBW	6189	5/4/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBW	6340	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBW	6416	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBW	6484	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBW	6562	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBW	6632	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBW	6705	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBW	6809	12/13/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBW	6895	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBW	6946	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBW	7047	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBW	7117	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBW	7195	5/9/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBW	7274	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBW	7345	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBW	7461	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBW	7538	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBW	7584	10/2/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBW	7724	11/13/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room EBW	7812	12/11/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room EBA	4014	5/26/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room EBA	4064	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room EBA	4148	7/22/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBA	4209	8/13/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBA	4283	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBA	4324	10/6/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBA	4395	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBA	4540	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBA	4604	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBA	4689	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBA	4842	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBA	4922	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBA	5059	5/18/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room EBA	5184	6/16/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBA	5319	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBA	5405	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBA	5459	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBA	5578	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBA	5670	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBA	5727	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room EBA	5825	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBA	5899	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBA	5989	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBA	6092	4/6/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBA	6190	5/4/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBA	6341	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBA	6417	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBA	6485	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBA	6563	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBA	6633	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBA	6706	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room EBA	6810	12/13/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBA	6896	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBA	6947	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBA	7048	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBA	7118	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBA	7196	5/9/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBA	7275	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBA	7346	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBA	7462	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBA	7539	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBA	7585	10/2/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room EBA	7725	11/13/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room EBA	7813	12/11/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room IBW	4022	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room IBW	4063	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room IBW	4137	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBW	4198	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBW	4272	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBW	4313	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBW	4406	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBW	4529	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21

Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room IBW	4593	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBW	4678	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBW	4831	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBW	4932	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBW	5048	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBW	5173	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBW	5308	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBW	5394	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBW	5448	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBW	5567	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBW	5659	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBW	5716	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBW	5814	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBW	5888	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBW	5978	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBW	6081	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBW	6180	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBW	6331	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBW	6407	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBW	6475	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBW	6551	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBW	6625	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBW	6698	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBW	6802	12/12/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBW	6888	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBW	6940	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBW	7041	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBW	7111	4/10/2012	4/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBW	7189	5/8/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBW	7268	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBW	7339	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBW	7455	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBW	7533	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBW	7579	10/2/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBW	7719	11/13/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room IBW	7807	12/10/2012	12/14/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room IBA	4021	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room IBA	4062	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
Panel 4 Room IBA	4138	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBA	4199	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBA	4273	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBA	4314	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBA	4405	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBA	4530	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBA	4594	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBA	4679	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBA	4832	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBA	4933	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBA	5049	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
Panel 4 Room IBA	5174	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBA	5309	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBA	5395	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBA	5449	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBA	5568	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBA	5660	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBA	5717	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
Panel 4 Room IBA	5815	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBA	5889	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBA	5979	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBA	6082	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBA	6181	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBA	6332	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBA	6408	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBA	6476	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBA	6552	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBA	6626	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBA	6699	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
Panel 4 Room IBA	6803	12/12/2011	12/16/2011	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBA	6889	1/17/2012	1/23/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBA	6941	2/7/2012	2/10/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBA	7042	3/13/2012	3/16/2012	N.D.	2	17.45	34.9	17.45
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Panel 4 Room IBA	7190	5/8/2012	5/15/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBA	7269	6/11/2012	6/18/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBA	7340	7/10/2012	7/13/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBA	7456	8/13/2012	8/17/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBA	7534	9/10/2012	9/14/2012	N.D.	2	17.45	34.9	17.45

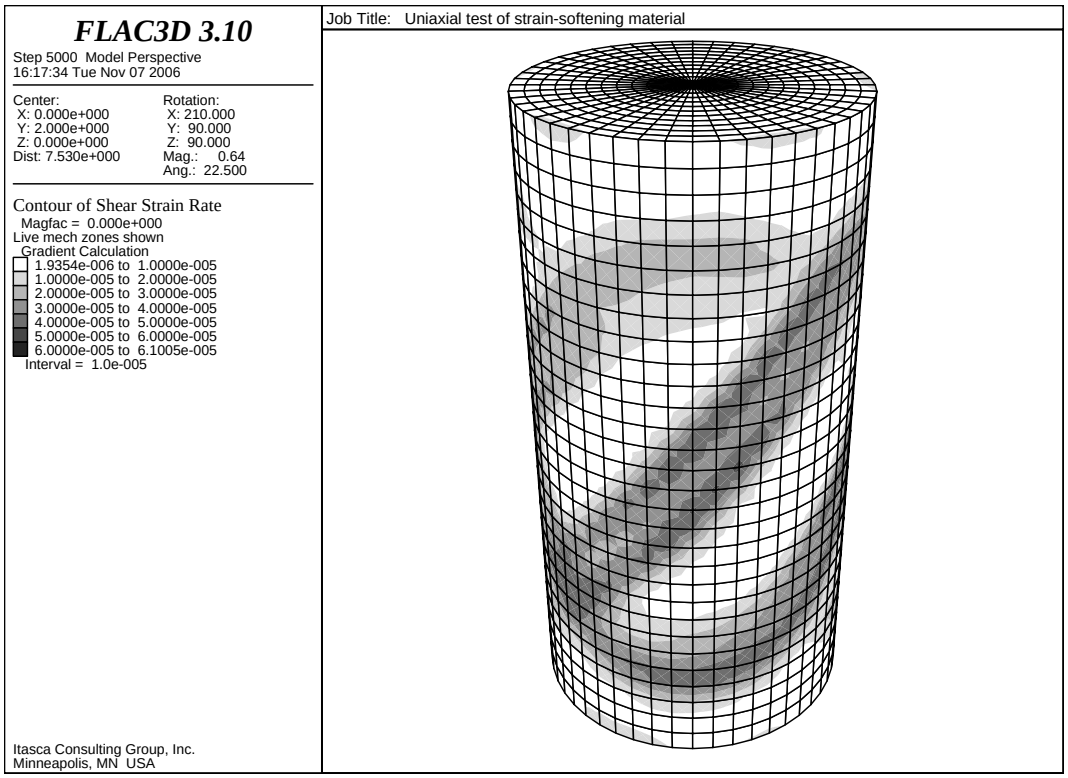
Methane (CH_4) **CAS# 74-82-8**

Location	Sample ID	Sample Date	Analysis Date	Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for statistical evaluation (ppmv)
Panel 4 Room IBA	7580	10/2/2012	10/5/2012	N.D.	2	17.45	34.9	17.45
Panel 4 Room IBA	7720	11/13/2012	11/16/2012	N.D.	2	15.71	31.42	15.71
Panel 4 Room IBA	7808	12/11/2012	12/14/2012	N.D.	2	15.71	31.42	15.71

FLAC3D

Fast Lagrangian Analysis of Continua in 3 Dimensions

User's Guide



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PRECIS

This volume is the user's guide to *FLAC3D*. This guide contains general information on the operation of *FLAC3D* for engineering mechanics computation.

Section 1 gives an introduction to the capabilities and applications of *FLAC3D*. An overview of the new features in the latest version of *FLAC3D* is also provided.

The first-time user should consult Section 2 for an introduction to the operation of *FLAC3D*. The installation and operation procedures are given along with a simple tutorial to guide the new user through a *FLAC3D* analysis.

Section 3 provides general guidance in the use of *FLAC3D* in problem solving for static mechanical analysis for geotechnical engineering.

An introduction to the built-in programming language, *FISH*, is given in Section 4. This includes a tutorial on the use of the *FISH* language. Note that no programming experience is assumed.

Various items of interest to *FLAC3D* users are contained in Section 5, including a *FLAC3D* run-time benchmark on several different types of computers and procedures for reporting errors and requesting technical assistance.

Section 6 contains a bibliography of published papers describing some applications of *FLAC3D* in different fields of engineering.

The *FLAC3D* Manual consists of ten documents. The following list of volumes, which comprise the *FLAC3D* Manual, are available. (The titles in parentheses below are the names used to refer to the volumes in the text.)

USER'S GUIDE — (User's Guide) — an introduction to *FLAC3D* and its capabilities

COMMAND REFERENCE — (Command Reference) — descriptions of all *FLAC3D* commands

FISH in FLAC3D — (FISH volume) — a complete guide to *FISH* as applied in *FLAC3D*

THEORY AND BACKGROUND — (Theory and Background) — thorough discussions of the built-in features in *FLAC3D*

FLUID-MECHANICAL INTERACTION — (Fluid-Mechanical Interaction) — discussion of the formulation and examples of the groundwater flow model

STRUCTURAL ELEMENTS — (Structural Elements) — descriptions for the six types of structural elements in *FLAC3D*: beams, cables, piles, shells, liners and geogrids

OPTIONAL FEATURES — (Optional Features) — detailed descriptions of the optional features: thermal analysis, creep models, dynamic analysis and C++ user-defined models.

HEXAHEDRAL-MESHING PREPROCESSOR — 3DShop — (3DShop) — a user's guide for *3DShop*, a hexahedral-meshing preprocessor for *FLAC3D*.

VERIFICATION PROBLEMS — (Verifications volume) — a collection of verification problems

EXAMPLE APPLICATIONS — (Examples volume) — a collection of example applications

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1 INTRODUCTION

1.1 Overview

FLAC3D is a three-dimensional explicit finite-difference program for engineering mechanics computation. The basis for this program is the well-established numerical formulation used by our two-dimensional program, *FLAC*.* *FLAC3D* extends the analysis capability of *FLAC* into three dimensions, simulating the behavior of three-dimensional structures built of soil, rock or other materials that undergo plastic flow when their yield limits are reached. Materials are represented by polyhedral elements within a three-dimensional grid that is adjusted by the user to fit the shape of the object to be modeled. Each element behaves according to a prescribed linear or nonlinear stress/strain law in response to applied forces or boundary restraints. The material can yield and flow, and the grid can deform (in large-strain mode) and move with the material that is represented. The explicit, Lagrangian calculation scheme and the mixed-discretization zoning technique used in *FLAC3D* ensure that plastic collapse and flow are modeled very accurately. Because no matrices are formed, large three-dimensional calculations can be made without excessive memory requirements. The drawbacks of the explicit formulation (i.e., small timestep limitation and the question of required damping) are overcome by automatic inertia scaling and automatic damping that does not influence the mode of failure. *FLAC3D* offers an ideal analysis tool for solution of three-dimensional problems in geotechnical engineering.

FLAC3D is designed specifically to operate on Microsoft Windows systems, and is currently supported on Windows 2000 and Windows XP (including XP64). Itanium-based systems are not supported. Calculations on realistically sized three-dimensional models in geo-engineering can be made in a reasonable time period. For example, a model containing 125,000 zones of a Mohr-Coulomb material can be generated within 350 MB RAM. The runtime to perform 5000 calculation steps for a 10,000 zone model of Mohr-Coulomb material is roughly 12 minutes on a 2.8 GHz Pentium IV microcomputer.† The number of calculation steps required to reach a solution state with the explicit-calculation scheme can vary, but a solution typically can be reached within 3000 to 5000 steps for models containing up to 10,000 elements, regardless of material type. (The explicit-solution scheme is explained in Section 1 in **Theory and Background**.) With the advancements in floating-point operation speed, and the ability to install additional RAM at low cost, it should be possible to solve increasingly larger three-dimensional problems with *FLAC3D*.

FLAC3D can be operated from either a command-driven mode or a graphics menu-driven mode. The default command-driven mode is very similar to that used by other Itasca software products. You will find that most of the commands are the same as, or three-dimensional extensions of, those in *FLAC*. A menu-driven, graphical user interface is also available in *FLAC3D* for performing plotting, printing and file access.

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* Itasca Consulting Group, Inc. ***FLAC (Fast Lagrangian Analysis of Continua.)***, Version 5.0, 2005.

† See Section 5 for a comparison of *FLAC3D* runtimes on various computer systems.

With the graphics facilities* built into *FLAC3D*, high-resolution, color-rendered plots are generated quite rapidly. We have developed a graphics screen-plotting facility that allows you to instantly view the model during creation from either command-mode or graphics menu-mode. The model can be translated, rotated and magnified on the screen for better viewing. Color-rendered plots of surfaces showing vectors or contours can be made in 3D, and a two-dimensional plane can be located at any orientation and location in the model for the purpose of viewing vector or contour output on the plane. All output can be directed to a black-and-white or color hardcopy device, to the Windows clipboard, or to a file.

You will find that *FLAC3D* offers a facility for problem solving similar to the one in *FLAC*. A comparison of *FLAC3D* to other numerical methods, a description of general features and updates in *FLAC3D* Version 3.1, and a discussion of fields of application are provided in the following sections. If you wish to try *FLAC3D* right away, the program installation instructions and a simple tutorial are provided in Section 2.

* The graphics facilities in *FLAC3D* utilize the Windows GDI.

1.2 Comparison with Other Methods

How does *FLAC3D* compare to the more common method of using finite elements for numerical modeling? Both methods translate a set of differential equations into matrix equations for each element, relating forces at nodes to displacements at nodes. Although *FLAC3D*'s equations are derived by the finite difference method, the resulting element matrices for an elastic material are identical to those of the finite element method (for constant-strain tetrahedra). However, *FLAC3D* differs in the following respects:

1. The "mixed discretization" scheme (Marti and Cundall, 1982) is used for accurate modeling of plastic collapse loads and plastic flow. This scheme is believed to be physically more justifiable than the "reduced integration" scheme commonly used with finite elements.

2. The full dynamic equations of motion are used, even when modeling systems are essentially static. This enables *FLAC3D* to follow physically unstable processes without numerical distress. The approach to provide a time-static solution is discussed in the definition for "Static Solution" given in Section 2.3.

3. An "explicit" solution scheme is used (in contrast to the more usual implicit methods). Explicit schemes can follow arbitrary nonlinearity in stress/strain laws in almost the same computer time as linear laws, whereas implicit solutions can take significantly longer to solve nonlinear problems. Furthermore, it is not necessary to store any matrices, which means: (a) a large number of elements may be modeled with a modest memory requirement; and (b) a large-strain simulation is hardly more time-consuming than a small-strain run, because there is no stiffness matrix to be updated.

4. *FLAC3D* is robust in the sense that it can handle any constitutive model with no adjustment to the solution algorithm; many finite element codes need different solution techniques for different constitutive models.

These differences are mainly in *FLAC3D*'s favor, but there are two disadvantages:

1. Linear simulations run more slowly with *FLAC3D* than with equivalent finite element programs. *FLAC3D* is most effective when applied to nonlinear or large-strain problems, or to situations in which physical instability may occur.

2. The solution time with *FLAC3D* is determined by the ratio of the longest natural period to the shortest natural period in the system being modeled. This point is discussed in more detail in Section 1 in **Theory and Background**, but certain problems are very inefficient to model (e.g., beams, represented by solid elements rather than structural elements, or problems that contain large disparities in elastic moduli or element sizes).

1.3 General Features

1.3.1 Basic Features

FLAC3D offers a wide range of capabilities to solve complex problems in mechanics, and especially in geomechanics. Like *FLAC*, *FLAC3D* embodies special numerical representations for the mechanical response of geologic materials. The program has twelve basic built-in material models: the "null" model; three elasticity models (isotropic, transversely isotropic and orthotropic elasticity); and eight plasticity models (Drucker-Prager, Mohr-Coulomb, strain-hardening/softening, ubiquitous-joint, bilinear strain-hardening/softening ubiquitous-joint, double-yield, modified Cam-clay and Hoek-Brown). These models are described in detail in Section 2 in **Theory and Background**. Each zone in a *FLAC3D* grid may have a different material model or property, and a continuous gradient or statistical distribution of any property may be specified.

Additionally, an interface, or slip-plane, model is available to represent distinct interfaces between two or more portions of the grid. The interfaces are planes upon which slip and/or separation are allowed, thereby simulating the presence of faults, joints or frictional boundaries. The interface model is described in Section 3 in **Theory and Background**.

FLAC3D contains an automatic 3D grid generator in which grids are created by manipulating and connecting pre-defined shapes.* The generator permits the creation of intersecting internal regions (e.g., intersecting tunnels). The 3D grid is defined by a global x,y,z-coordinate system (rather than in a row-and-column fashion as in *FLAC*). This provides more flexibility in model creation and definition of parameters in a three-dimensional space. Grid generation procedures are described in Section 1 in the **Command Reference** under the **GENERATE** command.

Boundary conditions and initial conditions are specified in much the same way as in *FLAC*. Either velocity (and displacement) boundary conditions, or stress (and force) boundary conditions, may be specified at any boundary orientation. Initial stress conditions, including gravitational loading, may also be given, and a water table may be defined for effective stress calculations. All conditions may be specified with gradients. Boundary conditions are primarily assigned via the **APPLY** command, and initial conditions via the **INITIAL** command, as described in Section 1 in the **Command Reference**.

FLAC3D incorporates the facility to model groundwater flow and pore-pressure dissipation, and the full coupling between a deformable porous solid and a viscous fluid flowing within the pore space. (The coupled interaction is described further in Section 1.3.3.) The fluid is assumed to obey either the isotropic or anisotropic form of Darcy's law. Both the fluid and the grains within the porous solid are deformable. Non-steady flow is modeled, with steady flow treated as an asymptotic case. Fixed pore pressure and constant-flow boundary conditions may be used, and sources and sinks (wells) may be modeled. The flow model can also be run independent of the mechanical calculation, and both confined and unconfined flow can be simulated, with automatic calculation of the phreatic surface. The fluid-flow model is described in Section 1 in **Fluid-Mechanical Interaction**.

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* An optional meshing preprocessor is also available – see Section 1.3.2.

Structures such as tunnel liners, piles, sheet piles, cables, rock bolts or geotextiles, that interact with the surrounding rock or soil, may be modeled with the structural element logic in *FLAC3D*. It is possible to either examine the stabilizing effects of supported excavations, or to study the effects of soil or rock instability on surface structures. The different types of structural elements are described in Section 1 in **Structural Elements**.

A factor of safety can be calculated automatically for any *FLAC3D* model composed of Mohr-Coulomb material. The calculation is based on a "strength reduction technique" that performs a series of simulations while changing the strength properties to determine the condition at which an unstable state exists. A factor of safety which corresponds to the point of instability is found, and the critical failure surface is located in the model. The factor-of-safety algorithm is described in Section 3.8.

FLAC3D also contains a powerful built-in programming language, *FISH*, that enables the user to define new variables and functions. *FISH* offers a unique capability to users who wish to tailor analyses to suit their specific needs. For example, *FISH* permits:

- user-prescribed property variations in the grid (e.g., nonlinear increase in modulus with depth);
- plotting and printing of user-defined variables (i.e., custom-designed plots);
- implementation of special grid generators;
- servo-control of numerical tests;
- specification of unusual boundary conditions; variations in time and space; and
- automation of parameter studies.

An introduction to *FISH* is given in Section 4. See Section 2 in the ***FISH* volume** for a detailed reference to the *FISH* language.

FLAC3D contains extensive graphics facilities for generating plots of virtually any problem variable. Three-dimensional graphics rendering is provided in high-resolution video modes. Plotting features include hidden surface plots, surface contour plots and vector plots. Plotted variables can be viewed in front of, behind, or on an arbitrary cross-section plane through, the model. This version of *FLAC3D* has been compiled as a native Windows executable using the WIN32 API to support execution under Windows 98 and later operating systems. The program has the look and feel of a typical Windows program; however, most modeling operations are performed in the command-driven mode, while the graphical user interface supports file-handling, model and response visualization (plotting), and printing (using standard Windows file-handling and printing facilities). Plotting operations are described in Section 1 in the **Command Reference** under the **PLOT** command.

1.3.2 Optional Features

Four optional features (for dynamic analysis, thermal analysis, modeling creep-material behavior, and writing user-defined constitutive models) are available as separate modules that can be included in *FLAC3D* at an additional cost per module. Also, a fifth optional feature, a hexahedral-meshing preprocessor (*3DShop*), is available as a separate program, at an additional cost.*

Dynamic analysis can be performed with *FLAC3D*, using the optional dynamic-calculation module. User-specified acceleration, velocity or stress waves can be input directly to the model, as either an exterior boundary condition or an interior excitation to the model. *FLAC3D* contains absorbing and free-field boundary conditions to simulate the effect of an infinite elastic medium surrounding the model. The dynamic calculation can be coupled to the groundwater flow model; the level of coupling, including dynamic pore-pressure generation (liquefaction), is discussed in Section 1.3.3. The dynamic analysis capability is described in Section 3 in **Optional Features**.

There is a thermal analysis option available as a special module in *FLAC3D*. This model simulates the transient flux of heat in materials, and the subsequent development of thermally induced stresses. The thermal model can be run independently, or coupled to the mechanical-stress calculation or pore-pressure calculation, either static or dynamic. (The coupling interactions are described in Section 1.3.3.) The thermal analysis capability is described in Section 1 in **Optional Features**.

There are eight optional material models available that simulate time-dependent (creep) material behavior (All creep models are described in Section 2 in **Optional Features**.):

(1) the classical viscoelastic (Maxwell) model;

(2) a Burger's substance viscoelastic model;

(3) a two-component power law;

(4) a reference creep formulation (the WIPP model) implemented for nuclear waste isolation studies;

(5) a Burger-creep viscoplastic model combining the Burger's model with the Mohr-Coulomb model;

(6) a power-law viscoplastic model combining the two-component power law and the Mohr-Coulomb model;

(7) a WIPP-creep viscoplastic model combining the reference creep formulation with the Drucker-Prager plasticity model; and

(8) a "crushed-salt" model that simulates both volumetric and deviatoric creep compaction.

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* The hexahedral-meshing preprocessor *3DShop*, enables the creation of complex meshes for *FLAC3D*. *3DShop* can substantially reduce model creation time. See Section 1 in the **Hexahedral-Meshing Preprocessor — *3DShop* volume** for more information and a tutorial on *3DShop*.

With this optional feature, user-defined constitutive models can be written in C++ and compiled as DLL (dynamic link library) files that can be loaded whenever needed. Microsoft Visual C++ Version 8.0 (Microsoft Visual Studio 2005) is used to compile the DLL files. The procedure to write new constitutive models and create DLLs is described in Section 4 in **Optional Features**.

1.3.3 Modeling Physical Processes and Interactions

The default calculation mode in *FLAC3D* is for static mechanical analysis. Alternatively, a groundwater flow analysis or a heat-transfer analysis can be performed, independent of the mechanical calculation. Both the groundwater flow and thermal models may be coupled to the mechanical stress model and to each other. Because the full equations of motion are used in *FLAC3D*, the coupling mechanisms operate in dynamic analyses as well as static analyses.

The coupling mechanisms are divided into three types of interaction: mechanical and groundwater flow; mechanical and thermal; and thermal and groundwater flow. The level of interaction modeled in *FLAC3D* for each type is described below.

Mechanical-Groundwater Flow Coupling — Several types of fluid/solid interaction can be specified in *FLAC3D*. One type of interaction is consolidation, in which the slow dissipation of pore pressure causes displacements to occur in the solid (e.g., soil). Two mechanical effects are at work in this case: (1) the fluid in a zone reacts to mechanical volume changes by a change in the pore pressure; and (2) the pore-pressure change causes changes in the effective stress that affect the response of the solid (e.g., a reduction in effective stress may induce plastic yield). Coupling between fluid and solid due to deformable grains can also be specified.

FLAC3D can calculate pore-pressure effects, with or without pore-pressure dissipation, simply by setting the flow calculation on or off. Also, dynamic pore-pressure generation (e.g., related to liquefaction) can be modeled by accounting for irreversible volume strain in the constitutive model. This is done with two different built-in constitutive models: the “Finn” model, and the “Byrne” model. Both models are provided with the dynamic option.

By default, porosity and permeability are assumed constant. However, these properties can be made a function of volumetric strain via a *FISH* function. As a consequence, two-way coupling of mechanical stress and groundwater flow can be modeled with *FLAC3D*.

Other types of interaction, such as capillary, electrical or chemical forces between particles of a partially saturated material, are not modeled directly by *FLAC3D*. But some of the effects may be included by providing suitable *FISH* functions. Similarly, a *FISH* function may be used to vary the local fluid modulus as a function of other quantities such as pressure or time.

Thermal-Mechanical Coupling — The thermal-mechanical coupling in *FLAC3D* is one-way: temperature change may induce a mechanical stress change as a function of the thermal-expansion coefficient. Mechanical changes in the body, however, do not result in temperature change or changes to thermal properties. Additionally, mechanical properties can be made a function of temperature change, since *FISH* permits access to both temperatures and properties.

Thermal-Groundwater Flow Coupling — The thermal calculation may be coupled to the groundwater flow calculation by making pore pressures a function of temperature change. Volumetric strain can arise from thermal expansion of both the fluid and the grains within a saturated matrix. Pore pressure change results from this volumetric strain, as well as from mechanical volumetric strain. Groundwater flow can also influence heat transfer; an advection model that takes the transport of heat by convection into account is provided. The advection model can also simulate temperature-dependent fluid density and thermal advection in the fluid.

As with mechanical properties, groundwater properties can be made a function of temperature change by accessing temperature and property values via *FISH*.

1.4 Summary of Updates from Version 3.0

FLAC3D 3.1 contains several improvements; the new features are summarized in the following sections. Existing data files created for Versions 3.0 and 2.1 should still operate as before. *FLAC3D* 3.1 will not be able to restore files saved by versions earlier than *FLAC3D* 2.1.

1.4.1 Parallel Processing on Multiprocessor Computers

Mechanical calculations of the main grid are now multithreaded and take advantage of multiple processors (e.g., dual processors or a dual core processor). On a two dual-core processor system, *FLAC3D* would split the mechanical computations among four cores. Parallel processing is a standard feature of *FLAC3D* 3.1, and a speed increase of approximately 1.8 times has been noted on two processor systems. Parallel processing also seamlessly integrates with user-defined models (UDMs). The mechanical calculations are automatically multithreaded when running *FLAC3D* 3.1 on a multiprocessor computer. The number of processors used for the multithreaded calculations can also be specified manually by issuing the **SET processors *n*** command, in which ***n*** is the number of processors to be used.

1.4.2 64-Bit Version

In addition to the 32-bit version of *FLAC3D* 3.1, a 64-bit version is available (at no additional cost). *FLAC3D* 32-bit is capable of creating models up to 2 GB in size. *FLAC3D* 64-bit will allow a virtually unlimited model size (17 billion GB of addressable memory). *FLAC3D* 64-bit does not offer a computational speed increase over the 32-bit version, but does allow extremely large models to be created. *FLAC3D* 64-bit has features identical to those in the 32-bit version, and save files created by either version are compatible. The 64-bit version will only operate on a 64-bit processor computer running the Windows XP X64 operating system.

1.4.3 Embedded Liner

The **SEL liner** implementation in *FLAC3D* only provides for interaction with the grid on one side of the liner. The new embedded liner logic (**SEL liner embedded**) extends the single-sided liner interaction to two sides. Shear-directed frictional interaction occurs independently on both sides of the embedded liner, and compressive and tensile forces are calculated separately on both sides in the normal direction. The embedded liner supports the following independent properties on each side: normal coupling-spring tensile strength and stiffness, shear coupling-spring cohesion, residual cohesion, friction angle and stiffness.

An embedded liner allows more accurate modeling of problems such as retaining walls, where interaction is required between the main grid and both sides of the retaining wall, with different properties on each side of the wall. See Section 1.9 in **Structural Elements** for additional information and an example application of the embedded liner.

1.4.4 Two-Dimensional Grid Extrusion Tool

A special grid-generation tool is available in Version 3.1 to create a three-dimensional *FLAC3D* mesh by extruding a two-dimensional *FLAC* grid. The grid-generation tool is a menu-driven graphical interface. A two-dimensional grid can be created directly within the tool, or a *FLAC3D* Version 5.0 data file can be loaded into the tool to create the extruded *FLAC3D* mesh. Two types of grid extrusions are available: a linear extrusion orthogonal to the two-dimensional grid plane, and an extrusion that revolves about an axis of revolution.

The powerful graphical user interface available with *FLAC* 5.0 (the *GIIC*) can be used to construct a complicated 2D cross-section (e.g., a tunnel with excavation sequence geometry). This 2D tunnel can then be extruded into a 3D model for use in *FLAC3D* 3.1. The *FLAC* 5.0 extrusion *GIIC* is directly accessible from a *FLAC3D* 3.1 menu item (FILE/FLAC EXTRUDE) or a command (**FLACEXTRUDE**). *FLAC* 5.0 needs to be installed, but a *FLAC* 5.0 license is not necessary to access this feature. See Section 3.2.4 for a description and example applications of the grid-extrusion tool.

1.4.5 Nodal Mixed Discretization

A Nodal Mixed Discretization (NMD) technique for use with linear tetrahedra has been implemented in *FLAC3D* 3.1. NMD overcomes the over-stiff behavior observed by these zones during plastic flow, due to the volumetric constraint introduced by plasticity. In this technique, the zone's volumetric behavior is averaged over the zones sharing its gridpoints. The effect of applying the NMD scheme is to increase the number of degrees of freedom per zone, thus accommodating the additional constraint imposed on each zone by, for example, the classical incompressibility condition for frictionless material. The advantage of the technique, compared to the standard mixed discretization scheme currently implemented in *FLAC3D*, is that it does not require a discretization of the domain into hexahedral zones. The logic thus allows for the use of tetrahedral mesh generation capabilities existing today. The NMD technique is described in detail in Section 1.2.2 in **Theory and Background**. The technique is invoked by specifying the **SET nmd on** command. (NMD is experimental at this stage.)

1.4.6 Built-in Help

In addition to the complete set of PDF manuals that is provided with *FLAC3D* 3.1, the **Command Reference**, **FISH in FLAC3D** and **Example Applications** volumes are available as built-in, searchable help through the *FLAC3D* 3.1 help menu or the **HELP** command.

1.4.7 New Features in FISH

The following new *FISH* variables have been added to *FLAC3D* 3.1 (see the ***FISH* in *FLAC3D*** volume for more details):

z_numoverlays	returns number of overlays (0, 1, or 2) in a zone
z_numtets	returns the number of tetrahedra in a specified overlay

z_gettetstress	gets the stress components from a specific tetrahedra in an overlay
z_puttetstress	puts stress components into a specific tetrahedra in an overlay
z_tetgps	gets the gridpoints associated with a specific tetrahedra in an overlay
z_nsmalltetvol	returns the volume of the smallest tetrahedra in an overlay
z_geomtest	returns 0 if zone has bad geometry, 1 if good
z_islive	returns 1 if the zone contains any "live" mechanical, fluid or thermal model
gp_near_live	returns a "live" gridpoint nearest to an ***x,y,z*** location
zone_near_live	returns a "live" zone nearest to an ***x,y,z*** location

The following *FISH* property functions have been added to support the embedded liner:

sl_csncut2	side 2 coupling spring tensile strength
sl_csnk2	side 2 normal coupling spring stiffness
sl_csscoh2	side 2 shear coupling spring cohesion
sl_csscohres2	side 2 shear coupling spring residual cohesion
sl_csscoh2	side 2 shear coupling spring friction angle
sl_cssk2	side 2 shear coupling spring stiffness
sl_embedded	returns 1 if the liner is embedded, 0 if not
nd_link2	returns the side2 link associated with an embedded liner node
lk_side	returns 1 if the link is a side1 link, returns 2 if it is a side2 link

1.4.8 New Commands

The following new commands have been added to *FLAC3D* 3.1 (see the **Command Reference** volume for more details):

SET **visible** keyword

Prior to *FLAC3D* 3.1, it was awkward to contour zone or gridpoint-related quantities when the model contained a null mechanical model, and a fluid or thermal-related quantity was being contoured (null mechanical zones were never plotted). With a keyword of **mechanical**, **fluid** or **thermal**, this command tells *FLAC3D* which zones to consider as visible when plotting.

SEL **join**

links two separate structural elements together. For example, a cable can be connected to a liner with this command.

SEL **refine**

subdivides existing segments of a 1D structural element (cable, beam or pile) into more segments.

SET **processor**

On a multiple processor system, this command will limit the number of processors used by *FLAC3D* 3.1 when performing mechanical calculations on the main grid.

FLACEXTRUDE

calls the *FLAC* 5.0 grid extrusion tool.

SET **nmd on/off**

For grids containing tetrahedral zones, the nodal mixed discretization technique can be enabled or disabled during the mechanical computations.

1.4.9 Revised Example Applications

Several existing examples were modified to use the NMD feature. In the **Verification Problems** volume, the following problems have been extended to use NMD: Section 1, Section 3, and Section 5.

Also, a user-defined *FISH* function for relaxing stresses in excavations is provided (see "ZONK3D.FIS" in Section 3.3.1.2).

1.5 Fields of Application

FLAC3D was developed primarily for geotechnical engineering applications. Section 6 contains a bibliography of publications on the application of *FLAC3D* to geotechnical problems in the fields of mining, underground engineering, rock mechanics and research.

Some possible applications of *FLAC3D* are noted below. Because *FLAC3D* now has essentially the same capabilities of *FLAC*, many of the *FLAC* applications can now be extended into three dimensions with *FLAC3D*:

- mechanical loading capacity and deformations — in slope stability and foundation design;
- evolution of progressive failure and collapse — in hard rock mine and tunnel design;
- factor-of-safety calculation — in stability analyses for earth structures, embankments and slopes;
- evaluation of the influence of fault structures — in mine design;
- restraint provided by cable support on geologic materials — in rock bolting, tiebacks and soil nailing;
- fully and partially saturated fluid flow, and pore-pressure build-up and dissipation for undrained and drained loading — in groundwater flow and consolidation studies of earth-retaining structures;
- time-dependent creep behavior of viscous materials — in salt and potash mine design;
- dynamic loading on slip-prone geologic structures — in earthquake engineering and mine rockburst studies;
- dynamic effects of explosive loading and vibrations — in tunnel driving or in mining operations;
- seismic excitation of structures — in earth dam design;
- deformation and mechanical instability resulting from thermal-induced loads — in performance assessment of underground repositories of high-level radioactive waste; and
- analysis of highly deformable materials — in bulk flow of materials in bins and mine caving.

1.6 Guide to the *FLAC3D* Manual

The *FLAC3D* Version 3.1 manual consists of ten documents. This document, the **User's Guide**, is the main guide to using *FLAC3D* and contains descriptions of the features and capabilities of the program, along with recommendations on the best use of *FLAC3D* for problem solving. The remaining documents cover various aspects of *FLAC3D*, including theoretical background information, verification testing and example applications. The complete manual is available in electronic format on the *FLAC3D* CD-ROM (viewed with Acrobat Reader*), as well as in paper format. Specific topics or keywords can be found across all volumes by implementing the search facility available in Acrobat.

The organization of the ten documents, and brief summaries of the contents of each section, follows. Please note that if you are viewing the manual in the Acrobat Reader, double-clicking on a section number given below will immediately open that section for viewing.

User's Guide

Section 1 Introduction

This section introduces you to *FLAC3D* and its capabilities and features. An overview of the new features in the latest version of *FLAC3D* is also provided.

Section 2 Getting Started

If you are just beginning to use *FLAC3D*, or use it only occasionally, we recommend that you read Section 2. This section provides instructions on installation and operation of the program, as well as recommended procedures for running *FLAC3D* analyses.

Section 3 Problem Solving

Section 3 is a guide to practical problem solving. Turn to this section once you are familiar with the program operation. Each step in a *FLAC3D* analysis is discussed in detail, and advice is given on the most effective procedures to follow when creating, solving and interpreting a *FLAC3D* model simulation.

Section 4 *FISH* Beginner's Guide

Section 4 provides the new user with an introduction to the *FISH* programming language in *FLAC3D*. This includes a tutorial on the use of the *FISH* language. *FISH* is described in detail in Section 2 in the ***FISH* volume**.

---

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Section 5 Miscellaneous

Various information is contained in this section, including the *FLAC3D* runtime benchmark and procedures for reporting errors and requesting technical support. Descriptions of utility files to assist with *FLAC3D* operation are also given.

Section 6 Bibliography

This section contains a bibliography of published papers describing some uses of *FLAC3D*.

Command Reference

Section 1 Command Reference

All the commands that can be entered in the command-driven mode in *FLAC3D* are described in Section 1 in the **Command Reference**.

FISH in *FLAC3D*

Section 1 *FISH* Beginner's Guide

Section 1 in the ***FISH* volume** provides the new user with an introduction to the *FISH* programming language in *FLAC3D*. This includes a tutorial on the use of the *FISH* language.

Section 2 *FISH* Reference

Section 2 in the ***FISH* volume** contains a detailed reference to the *FISH* language. All *FISH* statements, variables and functions are explained and examples given.

Section 3 Library of *FISH* Functions

A library of common and general purpose *FISH* functions is given in Section 3 in the ***FISH* volume**. These functions can assist with various aspects of *FLAC3D* model generation and solution.

Theory and Background

Section 1 Theoretical Background

The theoretical formulation for *FLAC3D* is described in detail in Section 1 in **Theory and Background**. This includes both the description of the mathematical model that describes the mechanics of a system and the numerical implementation.

Section 2 Constitutive Models: Theory and Implementation

The theoretical formulation and implementation of the various built-in constitutive models are described in Section 2 in **Theory and Background**.

Section 3 Interfaces

The interface logic is described and example applications are given in Section 3 in **Theory and Background**. A discussion on interface properties is also provided.

Fluid-Mechanical Interaction

Section 1 Fluid-Mechanical Interaction

The formulation for the fluid-flow model is described, and the various ways to model fluid flow, both with and without solid interaction, are illustrated in Section 1 in **Fluid-Mechanical Interaction**.

Structural Elements

Section 1 Structural Elements

Section 1 in **Structural Elements** describes the various structural element models available in *FLAC3D*. These include beams, cables, piles, shells, liners and geogrids.

Optional Features

Section 1 Thermal Option

Section 1 in **Optional Features** describes the thermal model option, and presents several verification problems that illustrate its application both with and without interaction with mechanical stress and pore pressure.

Section 2 Creep Material Models

The different creep material models available as an option in *FLAC3D* are described, and verification and example problems are provided in Section 2 in **Optional Features**.

Section 3 Dynamic Analysis

The dynamic analysis option is described, and considerations for running a dynamic model are provided in Section 3 in **Optional Features**. Several verification examples are also included in this section.

Section 4 Writing New Constitutive Models

Users can write their own constitutive models for incorporation into *FLAC3D*. The models are written in C++, and compiled as a DLL file (dynamic link library) that can be loaded whenever it is needed. The procedure to create new models is described in Section 4 in **Optional Features**.

Hexahedral-Meshing Preprocessor — *3DShop*

Section 1 *3DShop*

3DShop is a hexahedral-meshing preprocessor that enables the creation of complex meshes for *FLAC3D*. *3DShop* uncouples the model building from the meshing process. The model is built via a menu-driven graphical interface, and then meshed using a fully automatic all-hexahedral mesh generator. See Section 1 in the **Hexahedral-Meshing Preprocessor — *3DShop* volume** for details.

Verification Problems

This volume contains a collection of *FLAC3D* verification problems. These are tests in which a *FLAC3D* solution is compared directly to an analytical (i.e., closed-form) solution. See Table 1 in the **Verifications volume** for a list of the verification problems.

Example Applications

This volume contains example applications of *FLAC3D* that demonstrate the various classes of problems to which *FLAC3D* may be applied. See Table 1 in the **Examples volume** for a list of the example applications.

1.7 Itasca Consulting Group, Inc.

Itasca Consulting Group, Inc. is more than a developer and distributor of engineering software. Itasca is a consulting and research firm comprised of a specialized team of civil, geotechnical and mining engineers with an established record in solving problems in the areas of:

Civil Engineering

Mining Engineering and Energy Resource Recovery

Nuclear Waste Isolation and Underground Space

Defense Research

Software Engineering

Groundwater Analysis and Dewatering

Itasca was established in 1981 to provide advanced rock mechanics services to the mining industry. Today, Itasca is a multidisciplinary geotechnical firm with 60 professionals in offices worldwide. The corporate headquarters for Itasca is located in Minneapolis, Minnesota. Worldwide offices of Itasca are operated as subsidiaries of HCItasca, Inc.: Hydrologic Consultants, Inc. (Denver, Colorado); Itasca Geomekanik AB (Stockholm, Sweden); Itasca Consultants S.A. (Ecully, France); Itasca Consultants GmbH (Gelsenkirchen, Germany); Itasca Consultores S.L. (Llanera, Spain); Itasca S.A. (Santiago, Chile); Itasca Africa (Johannesburg, South Africa); Itasca Consultants Canada Inc. (Sudbury, Canada); and Itasca Consulting China, Ltd. (Wuhan, China).

Itasca's staff members are internationally recognized for their accomplishments in geological, mining and civil engineering projects. Itasca staff consists of geological, mining, hydrological and civil engineers who provide a range of comprehensive services such as (1) computational analysis in support of geo-engineering designs, (2) design and performance of field experiments and demonstrations, (3) laboratory characterization of rock properties, (4) data acquisition, analysis, and system identification, (5) groundwater modeling, and (6) short courses and instruction in the geomechanics application of computational methods. If you should need assistance in any of these areas, we would be glad to offer our services.

Itasca Consulting Group is a subsidiary of HCItasca, Inc. HCItasca was formed in 1999 with the merger of Hydrologic Consultants, Inc. (HCI) of Denver, Colorado with Itasca Consulting Group, Inc. of Minneapolis, Minnesota. HCI adds advanced groundwater modeling and dewatering expertise to Itasca.

1.8 User Support

We believe that the support Itasca provides to code users is a major reason for the popularity of our software. We encourage you to contact us when you have a modeling question. We provide a timely response via telephone, electronic mail or fax. General assistance in the installation of *FLAC3D* on your computer, plus answers to questions concerning capabilities of the various features of the code, are provided free of charge. Technical assistance for specific user-defined problems can be purchased on an as-needed basis.

If you have a question, or desire technical support, please contact us at:

Itasca Consulting Group, Inc.
Mill Place
111 Third Avenue South, Suite 450
Minneapolis, Minnesota 55401 USA

Phone: (+1) 612-371-4711
Fax: (+1) 612·371·4717
Email: software@itascacg.com
Web: www.itascacg.com

We also have a worldwide network of code agents who provide local technical support. Details may be obtained from Itasca.

1.9 References

Byrne, P. "A Cyclic Shear-Volume Coupling and Pore-Pressure Model for Sand," in ***Proceedings: Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics (St. Louis, Missouri, March, 1991)***, Paper No. 1.24, 47-55.

Marti, J., and P. A. Cundall. "Mixed Discretization Procedure for Accurate Solution of Plasticity Problems," *Int. J. Num. Methods and Anal. Methods in Geomech.*, ***6***, 129-139, 1982.

2 GETTING STARTED

This section provides the first-time user with an introduction to *FLAC3D*. *Getting Started* contains instructions for program installation and start-up on your computer. It also outlines the recommended procedure for applying *FLAC3D* to problems in geo-engineering and includes simple examples that demonstrate each step of this procedure.

If you are familiar with the program but only use it occasionally, you may find this section (in particular, Section 2.7) helpful in refreshing your memory on the mechanics of running *FLAC3D*. More complete information on problem solving is provided in Section 3.3.

FLAC3D can be operated in either a *command-driven* or graphical, *menu-driven* mode.* For most of the examples in this manual, input is entered and results are viewed using the command-driven mode. We believe this is the clearest way for you to understand the operating procedures for *FLAC3D*. As explained previously in Section 1.1, the command-driven structure allows *FLAC3D* to be a very versatile tool for use in engineering analysis. However, this structure can present difficulties for new or occasional users. Command lines must be entered as input to *FLAC3D*, either interactively via the keyboard or from a remote data file, in order for the code to operate. There are over 40 main commands and over 400 command modifiers (called *keywords*) that are recognized by *FLAC3D*.

Getting Started contains the following information.

1. A step-by-step procedure to install and start up *FLAC3D* on your computer is given in Section 2.1. This includes the system requirements for operating *FLAC3D*, a description of the components of the *FLAC3D* program and related files, the memory allocation, utility software and graphics devices, start-up and operation procedures, program initialization, identification of version number, and installation tests.

2. This is followed in Section 2.2 with a simple tutorial to help you become familiar with common input commands.

3. There are a few things you will need to know before creating and running your own *FLAC3D* model — i.e., you need to know the *FLAC3D* terminology. The nomenclature used for this program is described in Section 2.3. The definition of a *FLAC3D* finite difference grid is given in Section 2.4. You should also know the syntax for the *FLAC3D* input language; an overview is provided in Section 2.5.

4. A special feature of *FLAC3D* — i.e., the capability to create, name and use objects in a model — can greatly facilitate problem solving; this is introduced in Section 2.6.

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* The graphical user interface is only partially implemented at this time. The primary use of the current version is in accessing plotting functions and handling files. The last section of *Getting Started* (Section 2.12) is an introduction to the graphical user interface in *FLAC3D*, and provides an example that is run in the menu-driven mode.

5. The mechanics of running a *FLAC3D* model are described in separate steps; in Section 2.7, each step is discussed separately and simple examples are provided.
6. The sign conventions, systems of units and precision limits used in the program appear in Sections 2.8, 2.9 and 2.10, respectively.
7. The different types of files used and created by *FLAC3D* are described in Section 2.11.
8. An introduction to the graphical user interface is provided in Section 2.12.

2.1 Installation and Start-up Procedures

2.1.1 System Requirements

To install and operate *FLAC3D*, your computer must meet the following minimum requirements.

Processor — A processor with a minimum clock speed of 2 GHz is recommended. The speed of calculation for a *FLAC3D* model is directly related to the processor's speed. Therefore, the selection of a high-speed processor is a key factor for improving computation efficiency.

Hard Drive — At least 15 MB of hard disk space must be available to install *FLAC3D*. If the online *FLAC3D* manual is copied to the hard disk, an additional 21 MB are required. (Note that, by default, the manual will be installed on the hard drive.) Also, a minimum of 100 MB disk space should be available for model save files.

RAM — The minimum amount of RAM required to load *FLAC3D* is 3 MB. The memory allocated for a *FLAC3D* model is adjusted dynamically to take up the required RAM for a model at the time the model is created (see Table 2.1).

Generally, the combined RAM needed by *FLAC3D* and its model storage should leave 0.5 to 1 GB available to Windows; otherwise, Windows starts swapping into virtual RAM (on disk) — this swapping causes a dramatic performance loss in *FLAC3D*. The more applications there are running simultaneously, the smaller the *FLAC3D* model should be.

Finally, it should be noted that the Windows 32-bit operating systems impose an upper limit of 2 GB RAM on *FLAC3D* models. *FLAC3D* (64-bit) models can access a much larger amount of memory (theoretically 2^{64} bytes are accessible).

Display — For best performance, a screen resolution of 1024 × 768 pixels and a 16-bit color palette is recommended.

Operating System — *FLAC3D* is available as a 32-bit or 64-bit native Windows application. *FLAC3D* running on Microsoft Windows 2000, Windows XP and XP x64 Edition are currently supported by Itasca.

Output Device — By default, plots from *FLAC3D* are sent directly to the Windows native printer. Plots can also be directed to the Windows clipboard, or to files encoded in PostScript, Enhanced Metafile format and bitmap formats (PCX or BMP). See the **SET plot command** for the selections of output format.

Operation on PC Networks — A network version of *FLAC3D* is available. The network key allows a single hardware dongle to be placed at a central location. Individual users can then run *FLAC3D* from any computer on the network. Network keys require a special licensing arrangement and installation. Contact Itasca for details.

2.1.2 Installation of FLAC3D

FLAC3D is installed from a CD-ROM and is designed specifically to operate on Microsoft Windows systems (Windows 2000, Windows XP and XP x64 Edition are currently supported).

A default installation of *FLAC3D* from the CD-ROM will install the program, its example files, and the complete *FLAC3D* manual. The Adobe Reader is necessary for viewing the manual; this program is available to download for free from the Adobe Corporation (http://www.adobe.com).

To begin installation, insert the CD-ROM into the appropriate drive. If the autorun feature for the CD drive is enabled, a menu providing options for using the CD will appear automatically. If this menu does not appear, type "`[cd drive]:\start.exe`" at the command line (START –> RUN in Windows) to access the CD-ROM menu. The option to install *FLAC3D* may be selected from this menu.

The installation program will guide you through installation. When the installation is finished, a file named "INSTNOTE.PDF" will be found in the program sub-folder ("FLAC3D310") that resides in the main installation folder. (This is the folder that is specified during the installation process as the location to which files will be copied; by default, this is "c:\Program Files\Itasca.") The "INSTNOTE.PDF" file provides a listing of the directory structure that is created on installation, and a description of the actions that have been performed as part of the installation. This information may be used, in the unlikely event it is necessary or desirable, to either manually install or manually uninstall *FLAC3D*. The recommended method for uninstalling *FLAC3D* is to use the Windows "Add/Remove Programs" applet (START –> SETTINGS –> CONTROL PANEL –> ADD/REMOVE PROGRAMS). Please note that references made to files in the *FLAC3D* manual presume the default directory structure described in "INSTNOTE.PDF"; all data files described in the manual are contained in these folders.

The first time you load *FLAC3D* you will be asked to enter a customer title. This two-line title will appear on graphics screen plots and hardcopy plots. The title can be changed by using the **SET cust1** and **SET cust2** commands. The customer title is stored with the configuration settings in your computer's system registry.

After installing the software, connect the *FLAC3D* hardware key to the LPT1 or USB port on the computer before using the code.

2.1.3 Components of FLAC3D

The executable file for *FLAC3D* is "F3310.EXE," which is stored, by default, in the directory "\ITASCA\FLAC3D310." *FLAC3D* is compiled with the Microsoft Visual C++ (VC++) Version 8.0 compiler. In addition to the executable code, two sets of dynamic linked libraries (DLLs) are provided. One set of DLLs is used to access the various graphics formats in *FLAC3D*. The other set corresponds to the built-in constitutive models provided with *FLAC3D*. All of these DLLs are located in the "\ITASCA\FLAC3D310" directory.

2.1.4 Utility Software and Graphics Devices

Several types of utility software and graphics devices that can be of great help while operating *FLAC3D* are available.

Editors — A text editor is used to create *FLAC3D* input data files. Any text editor that produces standard ASCII text files may be used. Care must be taken if more "advanced" word-processing software (e.g., WordPerfect, Word) is used: this software typically encodes format descriptions into the standard output format; these descriptions are not recognized by *FLAC3D* and will cause an error. *FLAC3D* input files must be in standard ASCII format.

Graphic Output — FLAC3D supports several different types of graphics devices. By default, plots generated with the **PLOT hardcopy** command (or via the File Print View menu item from the main *FLAC3D* window) will be directed to the default Windows printer. (Note that the default printer is changed outside *FLAC3D* using the Printers folder in the My Computer object.) The Windows printer output is also selected with the **SET plot windows** command.

The command **PLOT clipboard** directs the current plot to the Windows clipboard (no file is generated). The image is in Enhanced Metafile format and subsequently may be pasted into another Windows application that is compatible with that format.

The **SET plot metafile** command directs output to an Enhanced Metafile format file on disc, where it can be saved for reference or later embedded in a Windows document. The **SET output** command should be used to set the output filename to one with an ".EMF" extension.

Either a black-and-white or color PostScript printer may be specified with the **SET plot postscript** command. The PostScript output may be written to a file for subsequent modification by a graphics program that will read the PostScript format.

PCX and BMP graphics formats can be accessed via the keywords **pcx**, **bitmap** or **bmp** with the **SET plot** command. Image resolution for these bitmap formats may be set using the **SET plot** <**output type**> **size** command. Also, the **SET plot avi** (AVI), **SET plot dcx** (DCX) and **MOVIE** commands enable one to make movies from graphic output.

Note that the different graphic output types can also be selected from the File Output Type menu item in the main *FLAC3D* window.

2.1.5 Start-up

A default installation will create an Itasca group under Programs on the user's Start menu in Windows. The Itasca group contains the FLAC3D –> FLAC3D310 shortcut that may be used to start the code. Be sure that the *FLAC3D* hardware key is attached to the LPT1 or USB port on the computer before starting the code.

A *FLAC3D* window is created when *FLAC3D* is loaded. A command window is also created within the main window, and command input can then be entered directly on the command line following the `Flac3D>` prompt.

When loaded, *FLAC3D* allocates memory dynamically (i.e., memory usage increases as the model is constructed). As a rule-of-thumb, it is recommended that 4 to 6 MB RAM be available to Windows after a complete *FLAC3D* model is generated. Otherwise, Windows will start swapping into virtual RAM — this swapping can cause a dramatic performance-loss in *FLAC3D*. Also, if other applications are running simultaneously, less RAM will be available for *FLAC3D*.

After loading *FLAC3D*, type

```
print memory system
```

This command will output the amount of memory currently used by *FLAC3D* (this is the same amount of memory as reported by Windows Task Manager). This number will vary with the model size.

Table 2.1 summarizes the approximate amount of RAM used when creating a number of zones of Mohr-Coulomb material with *FLAC3D* (32-bit). RAM usage increases by approximately 15% for the same model with *FLAC3D* (64-bit). Save file sizes are identical with both 32- and 64-bit versions, and are interchangeable between versions. *FLAC3D* (32-bit) can access up to 2 GB of memory (a 32-bit Windows operating system restriction). *FLAC3D* (64-bit) is able to accesses a virtually unlimited amount of memory (2^{64} bytes of addressable memory). It is advisable to have enough RAM available to accommodate the entire *FLAC3D* model, and to have some available for the operating system to function. If this is not the case, then the calculation performance may suffer due to excessive disk swapping (page-faults) in the Windows virtual memory system.

Table 2.1 FLAC3D RAM usage

Number of Zones	RAM Used (MB)
20^3	30
30^3	82
40^3	182
50^3	340

FLAC3D may be run from the command line, and will support command-line arguments, which may follow the executable name. If such arguments are present, each argument is interpreted as either a save file or a data file. If the file is not a valid save file, then it is assumed to be a data file. For save files, a **RESTORE** command is executed automatically. For data files, a **CALL** command is executed automatically. Multiple arguments are called or restored in the order specified. Also, to enable easier use of batch-file processing of multiple data files, the keyword **quit** can be given on the command line, which will cause the code to execute a **STOP** command and exit completely.

2.1.6 Version Identification

The version number of *FLAC3D* follows a simple numbering system that identifies the level of updates in the program. There are three numerical identifiers in the version number — that is,

```
Version I.JK
```

where:

- `I` is an integer starting with 1 that identifies a major release of the code;
- `J` is an integer that is incremented whenever a modification is made that requires a major change to the code structure for a supplemental upgrade release of *FLAC3D*; and
- `K` is an integer that is incremented when minor modifications are officially released as an update to the current version.

Note that *FLAC3D* Version 3.1 will restore save files from Version 3.0 and Version 2.1, but not versions earlier than 2.1. This is a result of the change from the Watcom C/C++ compiler to the Microsoft Visual C++ compiler. Existing data files should run correctly.

In addition to the version number, *sub-version* numbers are also used to identify minor changes to *FLAC3D* that have been made since the official version was released. Users may obtain the latest sub-version of the current version of *FLAC3D* from Itasca's web site (www.hcitasca.com). However, *FLAC3D* with a sub-version number greater than that of the officially released version should be used with caution, because all features have not been tested.

The version number for *FLAC3D* appears in the title bar of the *FLAC3D* main window. By typing the command

```
print version
```

the complete version number, including the sub-version number, can be obtained.

2.1.7 Program Initialization

On start-up, *FLAC3D* will look for the file named "FLAC3D.INI" in the current folder and then, if not found, in the "c:\Program Files\Itasca" folder. The "FLAC3D.INI" file can contain any *FLAC3D* commands that preset attributes of the program that you may wish to apply every time *FLAC3D* is used.

If the file "FLAC3D.INI" does not exist, *FLAC3D* simply continues without error. Note that some commands in a "FLAC3D.INI" file may result in an error message if they are inappropriate for the initial stage of a run.

2.1.8 Running FLAC3D

FLAC3D can be run interactively or from an input data file in command-driven mode. If you wish to run the code interactively, just begin typing in commands in the command window. *FLAC3D* will execute each command as the <ENTER> key is pressed. If an error arises, an error message will be displayed on the screen.

As an alternative, an input data file may be created using a text editor (see Section 2.1.4). This file contains a set of commands just as they would be entered in the interactive mode. Although the data file may have any name, a common identifying extension (e.g., ".DAT") will help to distinguish it from other *FLAC3D* files (see Section 2.11).

The data file can be read into *FLAC3D* by typing the command

```
call  file.dat
```

on the command line in the command window, in which "FILE.DAT" is the user-assigned name for the data file. You will see the data entries scroll up the screen as *FLAC3D* reads each line.

If the called file is located in the same folder as that from which "FLAC3D.EXE" is currently running, then only the file name need be entered with the **CALL** command. Otherwise, the file may be called by specifying its complete path (e.g., c:\myfolder\file.dat). Alternatively, a file can be called from any directory by using the FILE CALL menu (see Section 2.12).

It is also possible to create a shortcut to *FLAC3D* from a different directory. In the Windows Explorer, navigate to "F3310.EXE" (by default, in "c:\Program Files\Itasca\FLAC3D310"). Right-click on "F3310.EXE" and drag the file to the location where the shortcut is to be created (e.g., the directory containing the *FLAC3D* data files). When you release the right mouse button, a context menu will appear. Select "Create Shortcut Here" and a shortcut will be created. Double-click on the shortcut to start *FLAC3D*.

In order for *FLAC3D* to search for files in the shortcut directory instead of the directory containing "F3310.EXE," right-click on the shortcut and select "Properties." Delete the contents in the "Start In" edit box. This will cause *FLAC3D* to search the local folder for data files rather than the folder in which the executable is installed.

2.1.9 Installation Tests

Three simple data files, "TEST1.DAT," "TEST2.DAT" and "TEST3.DAT," are included in the "\FLAC3D310" directory so that you can test whether *FLAC3D* is installed properly on your computer. These files test the calculation kernel, the graphics screen-plotting and the hardcopy plotting facilities for your computer. In order to run the third test, your computer must be connected to a Windows printer.*

---

* For users who have printers connected to the LPT1 port: the *FLAC3D* hardware key is transparent to other uses of the LPT1 port; your printer can be attached directly to the key.

To run these tests, load the file "TEST1.DAT" from the "\FLAC3D310" directory via the FILE CALL menu, or type

```
call test1.dat
```

at the Flac3D> prompt and press <ENTER>.

Several data entries should scroll up the screen, and a simple model will be executed for 100 calculation steps. Example 2.1 contains the results of a successful "TEST1.DAT" run.

Example 2.1 FLAC3D output from "TEST1.DAT"

```
Zone Principal Stresses ...
   id      Maximum    Intermediate     Minimum
 ------ ------------- ------------- -------------
      1 -4.92673e+005 -4.92673e+005 -8.62177e+005
```

Now, load the file "TEST2.DAT" from the "\FLAC3D310" directory, or enter the command

```
call test2.dat
```

A screen plot of this model should appear. The plot is a color-rendered contour plot of displacements. Press the <ENTER> key to return to the Flac3D> prompt.

If your computer is connected to a Windows printer, load the file "TEST3.DAT" from the "\FLAC3D310" directory, or type

```
call test3.dat
```

and the plot shown in Figure 2.1 should be sent to your printer, and the program should exit. If you do not have a printer connected, do not load "TEST3.DAT." Type

```
quit
```

to exit *FLAC3D*.

If you are not able to reproduce the results of any or all of these three tests, you should review the system requirements and installation steps in Section 2.1. If you are still having difficulty, we recommend that you contact Itasca and describe the problem you have encountered and the type of computer you are using (see Section 5.2 for error-reporting procedures).

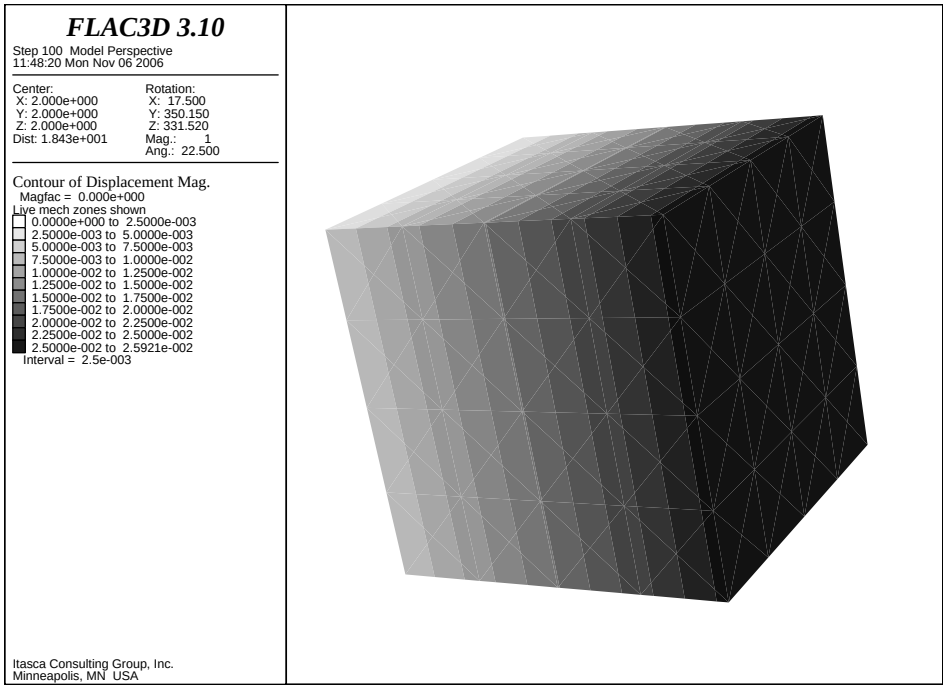

Figure 2.1 Windows plot from "TEST3.DAT"

2.2 A Simple Tutorial — Use of Common Commands

This section is provided for the new user who wishes to begin experimenting with *FLAC3D* right away. A simple example is presented to help you learn some of the basic aspects of solving problems with *FLAC3D*.

The example problem is a 2 m × 4 m trench excavated to a depth of 4 m in a soil mass. For this tutorial, we excavate the entire trench instantaneously and monitor the resulting movement of the material around the trench. For your convenience, the data file "TUT.DAT," included in the "\Tutorial\Beginner" directory, contains all the commands we are about to enter.

We run this problem interactively (i.e., by typing the commands from the keyboard, pressing <ENTER> at the end of each command line, and seeing the results directly). To begin, load *FLAC3D* by clicking the appropriate icon in the ITASCA group. Your computer will load the program and display the *FLAC3D* main window containing the command window with a command line beginning with the interactive prompt `Flac3D>`.

To set up the initial finite difference grid, use the **GENERATE** command:*

```
gen zone brick size 6 8 8
```

This command will create an initial mesh that is six zones in the x-direction, eight zones in the y-direction and eight zones in the z-direction. For our model, the z-axis is oriented in the vertical direction.

The model grid can be viewed by entering the plotting mode in *FLAC3D*. Type the command

```
plot
```

and the `Plot Base/0>` prompt will appear. As long as this prompt appears, any subsequent commands will be associated with the **PLOT** command. The plot view is identified as `Base/0`, which is the default view.

In order to create a view containing a color-rendered surface plot of the model, along with the model axes, type the commands shown in Example 2.2:

Example 2.2 Creating and using a plot view

```
create Trench
add surface yellow
add axes black
show
```

* See the command reference list in Section 1 in the **Command Reference** for further details. Note that command words can be abbreviated, and that words and values can be separated by any number of spaces and "=" signs (see Section 2.5).

This creates a plot view called `Trench`, and adds a surface plot item (in yellow) and an axes plot item (in black) to the view. The **show** keyword displays the current view (in a plot window with the view name `Trench` in the title bar); a view is automatically made current when it is created. A perspective view of the model, seen in elevation, will appear in the view window. This plot can be rotated in the *x*-, *y*- and *z*-directions by pressing the <X>, <Y> and <Z> keys on the keyboard. Use the <M> key to change the magnification, and the arrow keys to move the plot around. (To reverse the rotation and magnification, hold down the <SHIFT> key when pressing the appropriate key. Also, see Table 1.2 in the **Command Reference** for other keystrokes to manipulate the view of the model.) A plot similar to that shown in Figure 2.2 will appear on your screen. The orientation in the figure was achieved by reducing the magnification (<SHIFT-M> once) and rotating the plot about the *x*- (<X> twice) and *z*- (<Z> three times) axes.

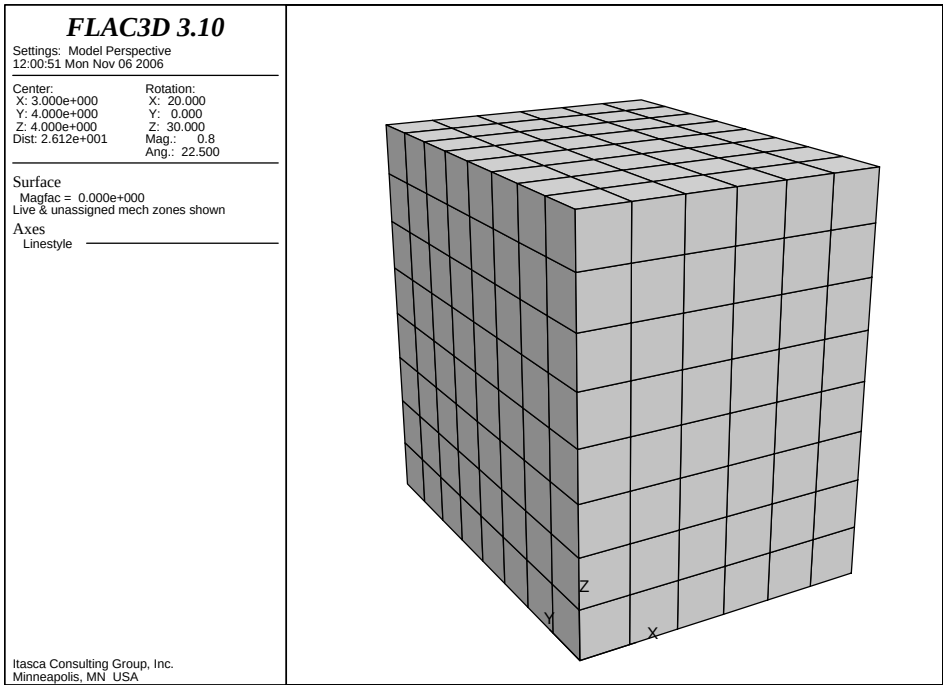

Figure 2.2 Brick-type mesh for trench example

Note that we can specify the magnification and orientation with **PLOT** commands directly. The caption of the plot shown in Figure 2.2 gives the data under the headings "Center:," "Rotation:," "Dist:" and "Mag:." So, after we interactively set up the view we want, we can transfer the data to a data file to facilitate the comparison of like views. Let's create another view, building on Example 2.2 — the new commands added in Example 2.3 are in **boldface** for clarity. (We are assuming that the `Plot Trench>` prompt in the command window is active; if not, move and click the mouse on the command window before typing the commands in Example 2.3.)

Example 2.3 Specifying view parameters

```
create Trench2
add surface yellow
add axes black
set rotation 20.0 0.0 30.0
set center 3 4 4
set dist 26.12
set magnification 0.8
show
```

Compare this view with that in Figure 2.2; they should be identical.

Now, we introduce some plotting features to enhance the output. The command

```
title 'Tutorial Examples'
```

was given at the start of the series of runs to produce the plots in this section. This title appears as a job title on all the plots. For individual plots, the command

```
plot set title text 'string'
```

will set the view title to *string*. For example, the command

```
plot set title text 'Mesh for trench example'
```

creates the title shown in Figure 2.2. These titles can be positioned at the top or bottom of the plot, or turned off completely. The **PLOT** command, described in Section 1.3 in the **Command Reference**, lists all of the options.

In order to make a hardcopy output of this plot, return to the `Plot Trench2>` prompt by moving and clicking the mouse on the command window, or by pressing the <ENTER> key. Then type

```
hard
```

By default, this will send the plot to the current Windows printer connected to the LPT1 port. The output type can be changed, if desired, as discussed in Section 2.1.4.

To close plot view `Trench2`, type

```
close
```

Now, only view `Trench` is displayed.

The mesh in Figure 2.2 is 6 m × 8 m × 8 m in size, with origin (x = 0, y = 0, z = 0) at the bottom-left corner. The dimensions, origin and mesh grading of the model can be changed with additional keywords specified after the **GENERATE** command. This will be explained later in this section.

Now give the zones a material model and properties. For this example, we use the Mohr-Coulomb elastic-plastic model. Go back to the `Flac3D>` prompt in the command window and type in

```
model mohr
```

This will specify the Mohr-Coulomb model. Every zone in the grid could conceivably have a different material model and property. However, if a range of zones is not specified after the **MODEL** command, *FLAC3D* assumes that all zones are to be Mohr-Coulomb material.

Each zone is automatically subdivided into tetrahedral "sub-zones." Two sets of five tetrahedra are overlaid in each zone ("double-overlay") in order to provide accurate solutions for plasticity analyses (see Section 1 in **Theory and Background** for an explanation of the numerical formulation for plasticity).

The amount of memory required to run this problem can be found by typing

```
print mem sav mem sys
```

This will give a listing of the memory statistics for the model at this state. Our problem requires approximately 0.8 MB to save the current state and approximately 13 MB to run this model.

The material properties are given next with the commands

```
prop bulk = 1e8 shear = 0.3e8 fric = 35
prop coh = 1e10 tens = 1e10
```

The bulk modulus (in Pa), shear modulus, angle of internal friction, cohesion and tensile strength are specified. You see that very high cohesion and tensile strength values are given. These are only initial values that are used during the development of gravitational stresses within the body. In effect, we are forcing the body to behave elastically during the development of the initial in-situ stress state.* This prevents any plastic yield during the initial loading phase of the analysis. The reasons for this will become obvious once you gain experience with the explicit simulation procedure.

For this problem, loading is due to gravity. To apply gravity, use the commands

```
set grav 0, 0, -9.81
ini dens = 1000
```

A gravitation acceleration vector of 9.81 m/sec^2 is applied in the negative z-direction. (Gravity is taken as positive in a positive axis direction.) In order to develop a gravitational body force, the

---

* There are several ways to establish an initial stress state for an analysis. For example, an elastic model (**MODEL elastic**) could initially be used to set up the virgin stresses, followed by a change to the Mohr-Coulomb model prior to any excavation, applied loads, or other alterations to the model. A special command, **SOLVE elastic**, which performs this two-step calculation automatically, is also available.

mass density must also be initialized. The **INI** command is used to initialize the mass density to 1000 kg/m^3 for all zones in the model.*

Next, the boundary conditions for the problem are set. At the `Flac3D>` prompt, type

```
fix x range x -0.1 0.1
fix x range x 5.9 6.1
fix y range y -0.1 0.1
fix y range y 7.9 8.1
fix z range z -0.1 0.1
```

With these commands, roller boundaries are placed on five sides of the model. The boundaries are "fixed" only in the specified direction (i.e., no displacement or velocity is allowed). The **FIX** commands perform the following functions.

1. The gridpoints along the boundary planes at $x = 0$ and $x = 6$ are fixed in the x-direction. These two planes fall within the coordinate ranges specified by the **range** keywords for the first two **FIX** commands.

2. The gridpoints along the boundary planes at $y = 0$ and $y = 8$ are fixed in the y-direction. These planes fall within the ranges specified for the third and fourth **FIX** commands.

3. The gridpoints along the bottom boundary ($z = 0$) are fixed in the z-direction. This plane falls within the range for the fifth **FIX** command.

We wish to monitor the change in the values of selected variables in the model during the calculational stepping. A **HISTORY** command can assist determining whether a stable equilibrium solution or unstable collapse is occurring. We type the commands

```
hist  n = 5
hist unbal
hist gp zdisp 4,4,8
```

We choose to monitor the change in variables every five calculation steps. (The default is every ten steps.) The selected values are then stored in a history array at every fifth step. Two variables are monitored: the maximum unbalanced force, and the z-displacement at gridpoint ($x = 4$, $y = 4$, $z = 8$). It is always a good idea to monitor the maximum unbalanced force in a model. If the unbalanced force approaches a very small value and displacement histories become constant, this indicates that an equilibrium state is reached.

Now, we are ready to bring the model to an initial equilibrium state. Because *FLAC^{3D}* is an explicit dynamic code, we step the model through "time,"† allowing the kinetic energy of the mesh to damp

---

* Note that it is only necessary to specify density if gravitational loading is applied to a *FLAC^{3D}* model. For static analyses not involving gravity, density is not required. (This differs from two-dimensional *FLAC*.)

† calculation time — not real time

out (thus providing the static solution we seek). To allow gravitational stresses to develop within the body, we timestep the simulation to equilibrium. Here the **SOLVE** command is used to detect equilibrium automatically.

Type the commands

```
set mech force=50
solve
```

The calculation process will begin, and the timestep number and maximum unbalanced force will be displayed on the screen. When the unbalanced force falls below the limiting value (a limiting force of 50 N is specified with the **SET** command), the run will stop.* The plots are updated, since they are still visible on the screen. Shutting down the plots will cause the model to cycle faster.

For our model, the calculation stops at step 351.† On a 2.8 GHz Pentium 4 computer, this calculation takes approximately 2 seconds.

We can verify that equilibrium is reached by examining the histories of the unbalanced force and z-displacement. Type

```
plot
hist 1
```

for the unbalanced force history (see Figure 2.3). Press <ENTER> to return to the command prompt and then type

```
hist 2
```

for the z-displacement history (see Figure 2.4). The unbalanced force history approaches zero, and the displacement history becomes constant; both are indicators that an equilibrium state has been reached.

The last two plots were displayed on *FLAC3D*'s base view (`Base/0`). Any plot items not explicitly **add**ed to a view are displayed immediately on the base view. This has no effect on any other created view — the base view is simply a sort of "scratch" view where plots can be examined quickly.

---

* The selection of solution limits is discussed later in Section 2.7.4.

† The step number at which this calculation stops may vary slightly, depending upon the precision limits of your co-processor.

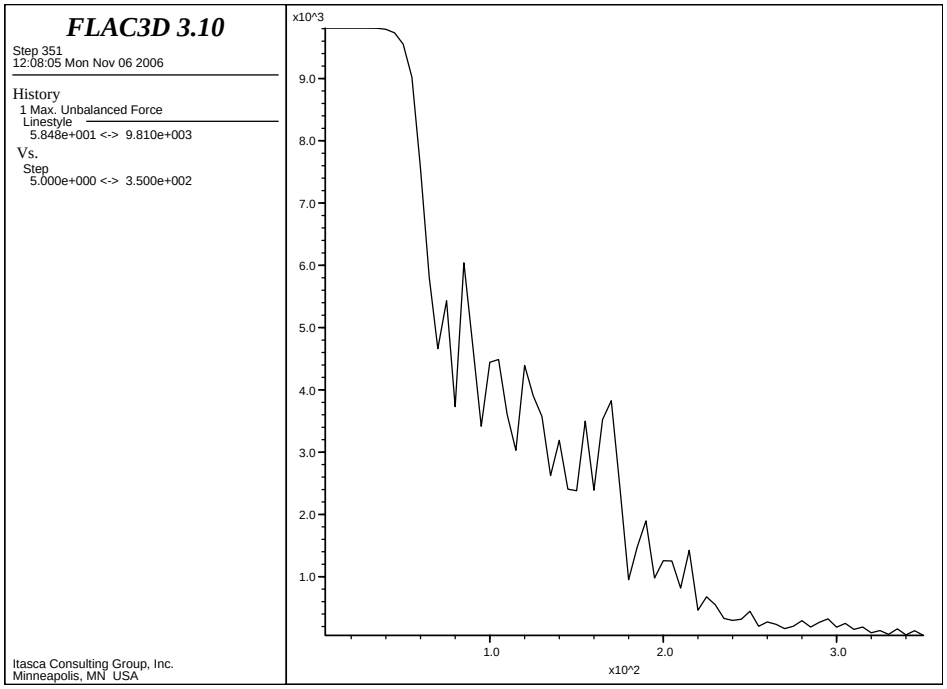

Figure 2.3 Maximum unbalanced force history

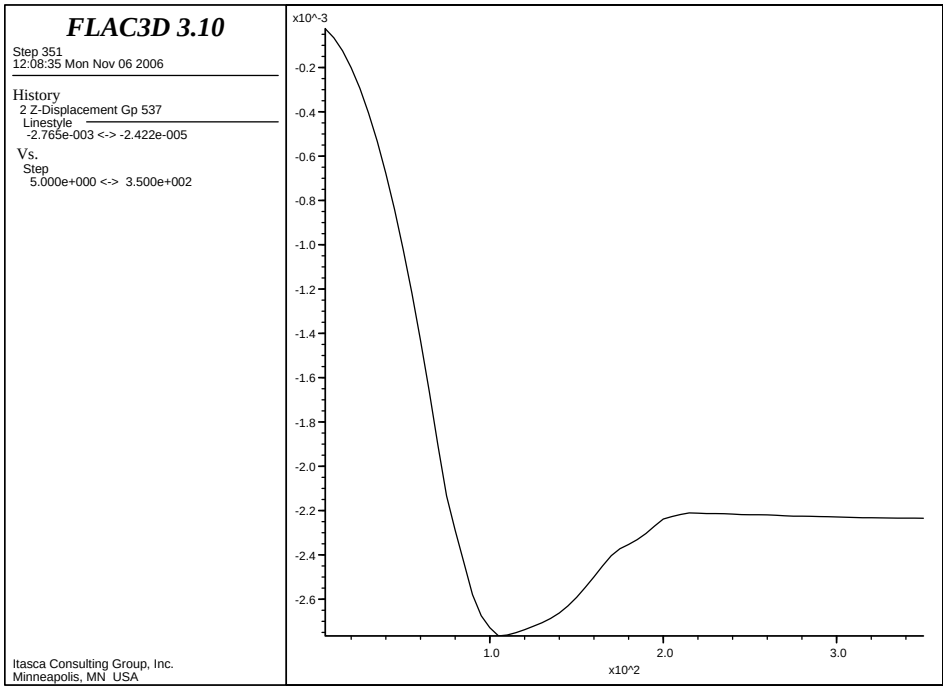

Figure 2.4 z-displacement history at (x = 4, y = 4, z = 8)

Note that each history is numbered sequentially from 1 as it is entered via the **HIST** command. Return to the `Flac3D>` prompt and type

```
print hist
```

for a listing of the histories and their corresponding numbers.

It is also possible to examine the gravitational stresses that have developed in the model. Here, we will create a complex view containing a number of plot items:

```
plot create GravV
plot set plane dip=90 dd=0 origin=3,4,0
plot set rot 15 0 20
plot set center 2.5 4.2 4.0
plot add bound behind
plot add bcont szz plane
plot add axes
plot show
```

This sequence will create a view, which we have called `GravV`, and make it the current view. We then set a plane for that view oriented at a dip angle of 90° (from the xy-plane, assuming that negative-z is "down"), a dip direction of 0° (measured clockwise from the positive y-axis in the xy-plane) and with one point on the plane at (x = 3, y = 4, z = 0). We add a wire-frame boundary plotted *behind* the plane, and a block contour plot of the vertical stress component σ_{zz} on the plane. Finally, the model axes are added. The block contour plot, as opposed to an interpolated contour plot, displays the value of the stress calculated at each zone centroid. The color of each zone corresponds directly to the zone-based stress. When **show** is typed, the view we have created is displayed. You should see a perspective view similar to that in Figure 2.5.

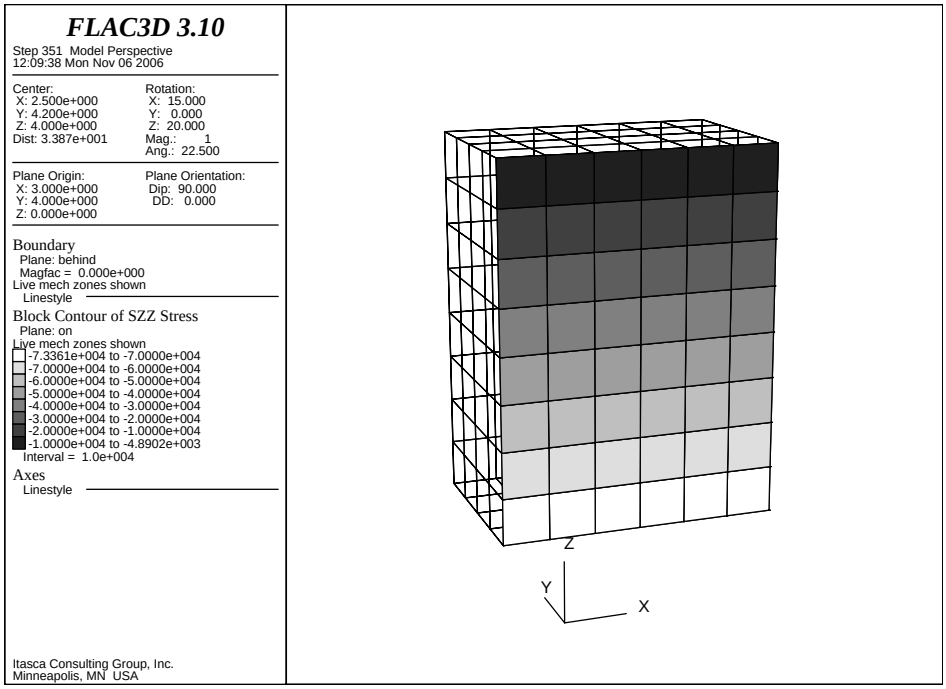

Figure 2.5 Gravitational stress contours at initial equilibrium

It is wise to save the initial state so that you can restore it at any time to perform parameter studies. To save this state, return to the `Flac3D>` prompt and type

```
save trench.sav
```

A save file, “TRENCH.SAV,” will be created on the default drive.

We have now created two plot views of our model. The command

```
plot print
```

will display a list of the views; the active view will be indicated with an arrow. The command

```
plot print view
```

will display details of the current view. Adding a view name or number to the preceding command will produce a detailed description of that view, including all the settings and the plot items on the view. We can change the current view from `GravV` to `Trench` with the command

```
plot current Trench
```

which will cause the view `Trench` to accept setting or item alterations. Any existing view may be plotted directly, without first making it current; the command sequence is

```
plot show <viewname>
```

where viewname is the selected view to be plotted. All available views are also listed as menu items under PLOT on the main menu bar when the command window is active.

Now we can excavate a trench in the soil. First, type

```
prop coh=1e3 tens=1e3
```

This will set the cohesion and tensile strength for all zones to 1000 Pa. These values for strength are high enough to prevent failure in our initial state (i.e., unexcavated), but you should always check for possible failure in the initial state by performing a few calculation steps. To excavate the trench, enter

```
model null range x=2,4 y=2,6 z=5,10
```

The dimensions of the excavation region (i.e., the null material) are defined by the x-, y- and z-coordinate range.

With a low cohesion and vertical unsupported trench walls, collapse should occur. Because we want to examine this process realistically, the large-strain logic is specified. This is done by typing

```
set large
```

For plotting purposes, we wish to see only the change in displacements from the trench excavation, and not from the previous gravitational loading, so we zero out the x-, y- and z-displacement components:*

```
ini xdis=0  ydis=0  zdis=0
```

We purposely set the cohesion low enough to result in failure, so we do not want to use the **SOLVE** command with a limit for out-of-balance force (which checks for equilibrium). Our simulation will never converge to the equilibrium state. Instead, we can step through the simulation process one timestep at a time, and plot and print the results of the collapse as it occurs. This is the real power of the explicit method. The model is not required to converge to equilibrium at each calculation cycle because we never have to solve a set of linear algebraic equations simultaneously, as is the case for implicit codes, with which many engineers are familiar.

In *FLAC3D*, we use the **STEP** command

```
step 2000
```

FLAC3D will now step through 2000 timesteps. (This takes approximately 15 seconds on a 2.8 GHz Pentium 4 computer) Examine the calculation thus far by plotting some results. For example, repeat the plot sequence to produce the rendered contour plot on a plane. But, this time, plot displacement contours. Type the sequence

```
plot
create DispCont
```

---

* This will not affect the calculations, since the model does not require displacement in the calculation process. They are kept only as a convenience to the user.

```
copy GravV DispCont settings
add cont disp plane behind shade on
add axes
show
```

A plot similar to that in Figure 2.6 should appear. We have copied the settings from the previous view (specifically, the plane-orientation settings), since we want to produce comparable plots. We can copy either the view contents or the view settings (or both) from one view to another, allowing us to produce a series of similar views.

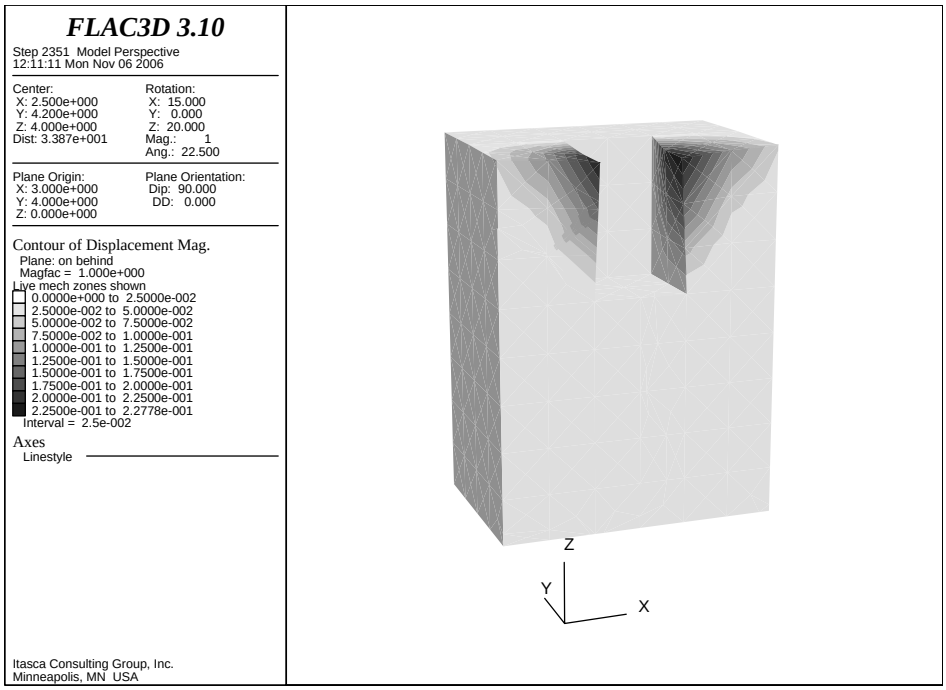

Figure 2.6 Displacement contours at 2000 steps after excavation

You will notice in Figure 2.6, some mesh distortion beginning at the trench. Also, the displacement contours indicate the extent of surface settlement that results from the excavation.*

This ends the initial tutorial. In the following sections in *Getting Started*, we will present other features in *FLAC3D* that can be used to add more complexity to this example, including ways to stabilize the excavation. We recommend that you read the rest of *Getting Started* for a beginner's guide to the mechanics of using *FLAC3D*. As you become more familiar with the code, turn to Section 3.3 for additional details on problem solving with *FLAC3D*.

---

* Note that we have made our boundaries on this problem small, in order to speed operation. Thus, some effect of the boundaries on model results is expected.

2.3 Nomenclature

FLAC3D uses nomenclature that is consistent, in general, with that used in conventional finite difference or finite element programs for stress analysis. The basic definitions of terms are reviewed here for clarification. Figure 2.7 is provided to illustrate the *FLAC3D* terminology.

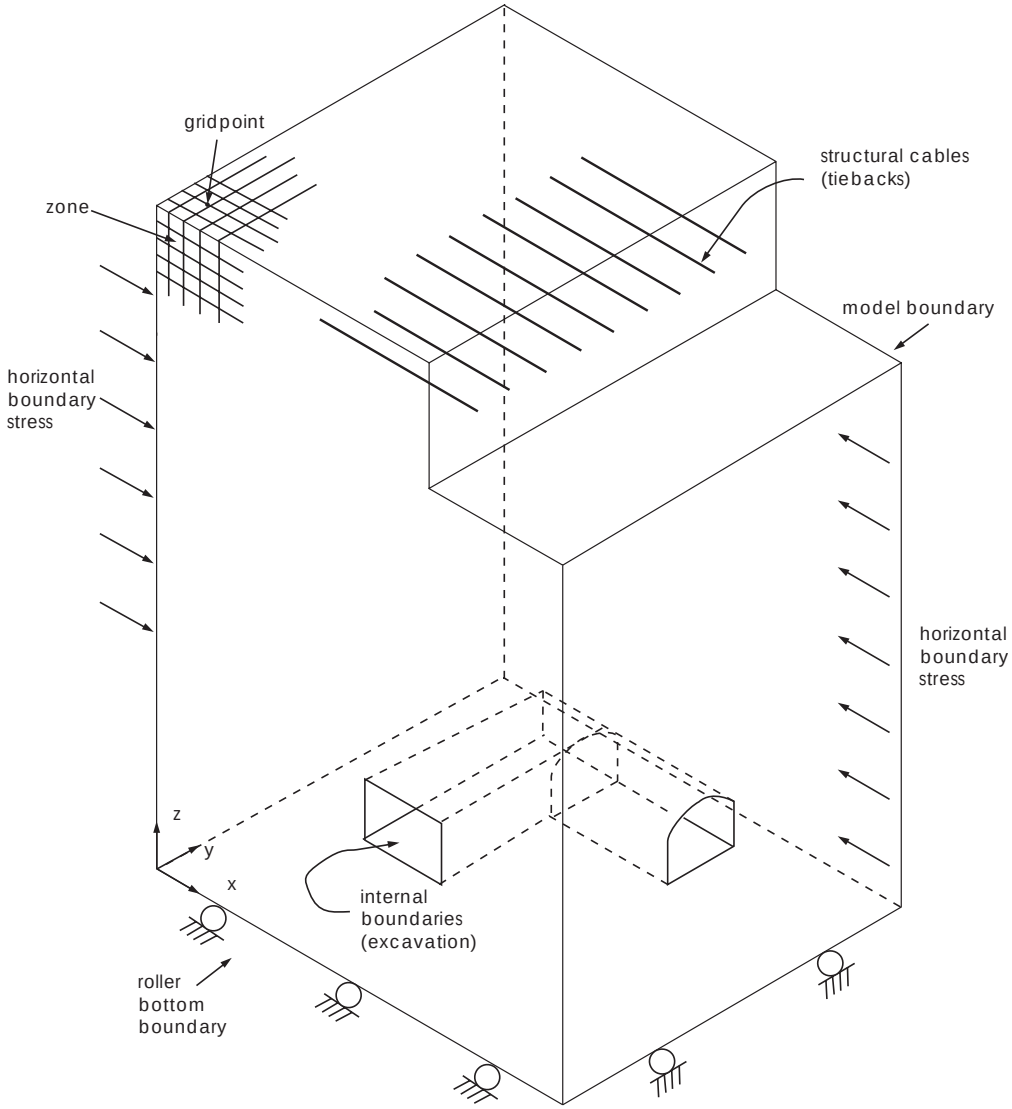

Figure 2.7 Example of a FLAC3D model

FLAC3D MODEL — The *FLAC3D* model is created by the user to simulate a physical problem. When referring to a *FLAC3D* model, the user implies a sequence of *FLAC3D* commands (see Section 1 in the **Command Reference**) that define the problem conditions for numerical solution.

ZONE — The finite difference zone is the smallest geometric domain within which the change in a phenomenon (e.g., stress versus strain) is evaluated. Polyhedral zones of different shapes (e.g., brick, wedge, pyramid and tetrahedral-shaped zones) are used to create models, and can be viewed upon plotting. Each polyhedral zone contains two overlaid sets of five tetrahedral sub-zones, but the user is not normally aware of these. Another term for zone is element.

GRIDPOINT — Gridpoints are associated with the corners of the finite difference zones. There are five, six, seven or eight gridpoints associated with each polyhedral zone, depending on the zone shape. A set of x-, y-, z-coordinates is assigned to each gridpoint, thus specifying the exact location of the finite difference zones. Other terms for gridpoint are nodal point and node.

FINITE DIFFERENCE GRID — The finite difference grid is an assemblage of one or more finite difference zones across the physical region that is being analyzed. Another term for grid is mesh. The finite difference grid also identifies the storage locations of all state variables in the model. The procedure followed in *FLAC3D* is that all the vector quantities (e.g., forces, velocities, displacements) are stored at gridpoint locations, while all scalar and tensor quantities (e.g., stress and material properties) are stored at zone centroid locations.

MODEL BOUNDARY — The model boundary is the periphery of the finite difference grid. Internal boundaries (i.e., holes within the grid) are also model boundaries.

BOUNDARY CONDITION — A boundary condition is the prescription of a constraint or controlled condition along a model boundary (e.g., a fixed displacement or force for mechanical problems, an impermeable boundary for groundwater flow problems, adiabatic boundary for heat transfer problems, etc.).

INITIAL CONDITIONS — This is the state of all variables in the model (e.g., stresses or pore pressures) prior to any loading change or disturbance (e.g., excavation).

CONSTITUTIVE MODEL — The constitutive (or material) model represents the deformation and strength behavior prescribed to the zones in a *FLAC3D* model. Several constitutive models to assimilate different types of behavior commonly associated with geologic materials are available in *FLAC3D*. Constitutive models and material properties can be assigned individually to every zone in a *FLAC3D* model.

NULL ZONE — Null zones are zones that represent voids (i.e., no material present) within the finite difference grid.

SUB-GRID — The finite difference grid can be composed of sub-grids. Sub-grids can be used to create regions of different shapes in the model (e.g., a dam sub-grid can be placed on a foundation sub-grid). Sub-grids are generated separately and then moved together and attached.

ATTACHED FACES — Attached faces are grid faces of separated sub-grids that are attached or joined together. Attached faces must be coplanar and touching, but gridpoints on each face do not have to match. Sub-grids of different zone densities can be attached.

INTERFACE — An interface is a connection between sub-grids that can separate (e.g., slide or open) during the calculation process. An interface can represent a physical discontinuity such as a fault, contact plane, or interface between two different materials.

RANGE — A range in a *FLAC3D* model is a description of a specific volume of space. A range delimits a volume to which a command operation will apply. A range, or element of a range, specified in terms of *x*-, *y*-, *z*-coordinates remains fixed in space even if the model is moving — it is not connected to the zones and gridpoints in the model. A range, or element of a range, specified in terms of groups includes the space inside all the encompassed zones and is connected to the model. An ID number can also be an element of a range, indicating that the range includes, and is connected to, the zone, gridpoint or structural element entity with the specified ID number.

GROUP — A group in a *FLAC3D* model refers to a collection of zones identified by a unique name. Groups are used to limit the range of certain *FLAC3D* commands, such as the **MODEL** command that assigns material models to designated groups. Any command reference to a group name indicates that the command is to be executed on that group of zones.

ID NUMBER — Individual elements of a *FLAC3D* model are identified by identification (ID) numbers. The following model elements have ID numbers: interfaces, gridpoints, zones, volumes, reference points, histories, tables, plot items and structural element entities (i.e., beams, cables, piles, shells, liners and geogrids). These are unique numbers that assist the user in identifying specific elements in a model. The **PRINT** command is used to obtain the ID numbers. ID numbers can be assigned to interfaces, structural element entities, reference points, histories, tables and plot items by the user.

Component identification (CID) numbers are also assigned to individual elements of a structural element entity. A unique CID number is created for each node, element and node/grid link that comprise a beam, cable, pile, shell, liner or geogrid entity.

STRUCTURAL ELEMENT — Two types of structural element are available in *FLAC3D*. Two-noded, linear elements represent the behavior of beams, cables and piles. Three-noded, flat triangular elements represent shells, liners and geogrids. Structural elements are used to simulate the interaction of structural support within a soil or rock mass. Nonlinear material behavior can be represented with the elements.

Each structural element entity (beam, cable, pile, shell, liner or geogrid) is composed of three components: nodes; individual elements (called SELs); and node/grid links. The characteristics of each of these components distinguish the behavior of the beam, cable, pile, shell, liner and geogrid entities.

STEP — Because *FLAC3D* is an explicit code, the solution to a problem requires a number of computational steps. During computational stepping, the information associated with the phenomenon under investigation is propagated across the zones in the finite difference grid. A certain number of steps is required to arrive at an equilibrium (or steady-flow) state for a static solution. Typical problems are solved within 2000 to 4000 steps, although large complex problems can require tens of thousands of steps to reach a steady state. When using the dynamic analysis option, **STEP** refers to the actual timestep for the dynamic problem. Other terms for step are timestep and cycle.

STATIC SOLUTION — A static or steady-state solution is reached in *FLAC3D* when the rate of change of kinetic energy in a model approaches a negligible value. This is accomplished by damping the equations of motion. At the conclusion of the static solution stage, the model will either be at a state of equilibrium or at a state of steady flow of material, if a portion (or all) of the model is unstable (i.e., fails) under the applied loading conditions. This is the default calculation in *FLAC3D*.* Static mechanical solutions can be coupled to transient groundwater flow or heat transfer solutions. (As an option, fully dynamic analysis can also be performed by inhibiting the static solution damping.)

UNBALANCED FORCE — The unbalanced force indicates when a mechanical equilibrium state (or the onset of plastic flow) is reached for a static analysis. A model is in exact equilibrium if the net nodal-force vector (the resultant force) at each gridpoint is zero. The maximum nodal-force vector is monitored in *FLAC3D*, and printed to the screen when the **STEP** or **SOLVE** command is invoked. The maximum nodal force vector is also called the *unbalanced* or *out-of-balance* force. The maximum unbalanced force will never exactly reach zero for a numerical analysis, but the model is considered to be in equilibrium when the maximum unbalanced force is small compared to the total applied forces in the problem. If the unbalanced force approaches a constant nonzero value, this probably indicates that failure and plastic flow are occurring within the model. When a gridpoint is fixed in a given direction, the component of the unbalanced force in that direction is equivalent to the reaction force.

DYNAMIC SOLUTION — For a dynamic solution, the full dynamic equations of motion (including inertial terms) are solved; the generation and dissipation of kinetic energy directly affect the solution. Dynamic solutions are required for problems involving high frequency and short duration loads (e.g., seismic or explosive loading). The dynamic calculation is an optional module for *FLAC3D* (see Section 3 in **Optional Features**).

LARGE STRAIN/SMALL STRAIN — By default, *FLAC3D* operates in small-strain mode: that is, gridpoint coordinates are not changed even if computed displacements are large (compared to typical zone sizes). In large-strain mode, gridpoint coordinates are updated at each step according to computed displacements. In large-strain mode, geometric nonlinearity is possible.

---

* In some finite element (FE) literature, the mistaken notion exists that a dynamic solution method cannot produce a true equilibrium state, compared to an FE solution, which is believed to satisfy perfectly the set of governing equations at equilibrium. In fact, *both* methods only satisfy the equations approximately, but the level of residual errors can be made as small as desired. In *FLAC3D*, the level of error is objectively quantified as the ratio of unbalanced force at a gridpoint to the mean of the set of absolute forces acting at the gridpoint. This measure of error is very similar to the convergence criteria used in FE solutions. In both cases, the solution process is terminated when the error is below a desired value.

2.4 The Finite Difference Grid

The finite difference grid spans the physical domain being analyzed. The smallest possible grid that can be analyzed with *FLAC3D* consists of only one zone. Most problems, however, are defined by grids that consist of hundreds or thousands of zones.

The *FLAC3D* grid is specified in terms of global x-, y- and z-coordinates. All gridpoints and zone centroids are located by their (x,y,z) position vector. A simple cubic grid is shown in Figure 2.8.

Each gridpoint and zone is also identified by an identification number (ID). The ID number and global coordinates for gridpoints can be found by typing

```
print gp position
```

and the zone ID numbers and global coordinates of their centroids can be found by typing

```
print zone
```

Grid generation with *FLAC3D* involves adjusting and shaping the mesh to fit the shape of the physical domain. The generation process is performed via the **GENERATE** command; the recommended procedure for grid generation is discussed in Section 3.3.

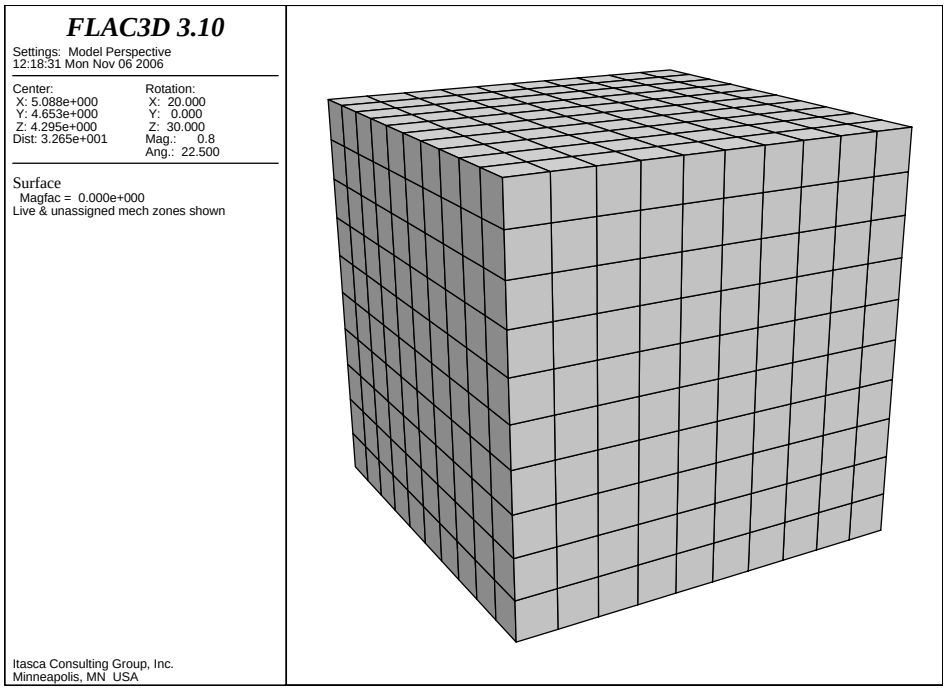

Figure 2.8 Finite difference grid with 1000 zones

2.5 Command Syntax

All input commands* to *FLAC3D* are word-oriented and consist of a primary command word followed by one or more keywords and values, as required. Some commands accept switches — that is, keywords that modify the action of the command. Each command has the following format:

COMMAND **key**word ***value*** . . . <**key**word ***value*** . . . > . . .

Here, optional parameters are denoted by < >, while the ellipses (. . .) indicate that an arbitrary number of such parameters may be given. The commands are typed literally on the command line. You will note that only the first few letters are in bold type. The program requires these letters, at a minimum, to be typed to recognize the command; command input is not case-sensitive. The entire word for commands and keywords may be entered if the user so desires.

Many of the keywords are followed by a series of values which provide the numeric input required by the keyword. The decimal point may be omitted from a real value, but may not appear in an integer value.

Commands, keywords and numeric values may be separated by any number of spaces, or by any of the following delimiters:

( ) , =

A semicolon (;) may be used to precede comments; anything that follows a semicolon in an input line is ignored. It is useful, and strongly recommended, to include comments in data files. Not only is the input documented in this way, the comments are echoed to the output as well, providing the opportunity for quality assurance in your analysis.

A single input line, including comments, may contain up to 80 characters.

If more than 80 characters are required to describe a particular command sequence, then an ampersand (&) can be given at the end of an input line to denote that the next line will be a continuation of that line. A total of 1024 characters per command sequence are allowed.

Please note that the typographical conventions listed in Table 2.2 are used throughout this manual.

---

* The commands and their meanings are presented in Section 1 in the **Command Reference**.

Table 2.2 Typographical conventions

Type style	Used for
BOLD	*FLAC3D* commands and *FISH* statements
bold	*FLAC3D* keywords and *FISH* internal variables and functions
bold	user-defined *FISH* variables and functions
INITIAL CAPS	menu items and buttons with the hot-keys underlined
var	place-holders for variables
PRESS ME	button with the hot-key underlined
<A>	type the key between < > (here, <A>) on the keyboard
<SHIFT-A>	hold down the first key while pressing the second (here, <SHIFT> and the <A> key)

2.6 Named Objects

FLAC3D gives the user the power to create, name and use objects. For example, if a number of plot views are created, they can be given descriptive names like "TopView" or "Velocity_Vectors." In Example 2.2, we created a new plot view, naming it "Trench" in the process. Parts of a model can be given names such as "Excavate_1," which can identify a volume to be removed during an excavation sequence. While the code can certainly be run without using names for objects, the entire process of modeling and reporting can be eased considerably by using these facilities. This section gives some ideas of how named objects can be used, and illustrates the differences between the types of objects in *FLAC3D*.

There are two categories of named objects: first, *macro objects*, which are interpreted before being seen by *FLAC3D*'s command processor; and second, *model objects*, which are interpreted by *FLAC3D*'s command processor. Any command that is entered by the user is first passed to the command pre-processor, where objects belonging in the first category are expanded. The pre-processor creates a string that is then sent to the command interpreter, which directs the actions to be performed by the code. It is at this point that objects belonging in the second category are interpreted. Note that the names of macro and model objects are case-sensitive.

2.6.1 Macro Object

The **MACRO** command allows the user to create macro objects that will be expanded by the command pre-processor. Typically, such an object contains a long, complex string that may be used repeatedly in the model. The pre-processor compares a string of command tokens to the list of defined macros and replaces any matching macro object with its fully expanded contents. The process continues, including the examination of the expanded tokens, until the entire string has been checked. Example 2.4 shows how macros could be used. Note the use of nested macros.

Example 2.4 Using macros

```
macro Pt0 'p0      0  0  0'
macro Pt1 'p1 add 10  0  0'
macro Pt2 'p2 add  0 10  0'
macro Pt3 'p3 add  0  0 10'
macro Model_Size 'size 4 5 6'
macro Big_Brick 'zone brick Pt0 Pt1 Pt2 Pt3 Model_Size'

gen Big_Brick

macro 'Pt0' 'p0 15 15 15'
gen Big_Brick
```

When redefining a macro, as in the last use of the **MACRO** command in Example 2.4, we have to put single quotes around the macro name (as shown). Otherwise, the pre-processor would expand

the name since it has already been defined — not quite the result we intended. The pre-processor skips over quoted strings, leaving them to the command interpreter.

This pre-processing has two effects:

(1) macro objects may be nested (but not recursively); and

(2) the macro object name is removed from the command string.

The implication of this second effect is that if a macro object has the same name as a model object or a code command, that object or command will never be seen by the command interpreter. While the user may elect to do something like this, it is generally inadvisable.

There is a special macro object, the ampersand (&), which indicates a line continuation. In many cases, a single command with all its keywords and data will not fit on one input line. Example 2.5 demonstrates how command lines could be broken. The command pre-processor locates any ampersands, concatenates the strings on either side, and passes one long string to the command interpreter. The maximum length of such an expanded string is 1024 characters.*

Example 2.5 Using line continuations

```
gen zone brick p0  0  0  0   &
               p1 10  0  0   &
               p2  0 10  0   &
               p3  0  0 10   &
               size 4 5 6
```

Macros cannot contain multi-line arguments. If an ampersand (&) character is used in a macro, the command pre-processor will tag the line as having a continuation when that macro is used. Anything on the line following the macro use will be taken as part of the current command. This could cause difficulty and should be avoided. If you find you need multiple lines, write a *FISH* function.

2.6.2 Model Object

Model objects such as ranges in space, groups of zones in a model, or plot views can be given user-defined names. Those objects can then be referred to by their names, wherever the identification of such objects is needed by the code, and are processed directly by the code when their names are used. A routine use of the **GROUP** command is to identify (i.e., name) parts of the grid which are to be excavated at some stage in the modeling process. The null constitutive model can then simply be applied to the zones identified by that group name. Execute Example 2.6 for a demonstration of this.

---

* If this proves to be restrictive, the length of this string may be increased in later versions of *FLAC3D*.

Example 2.6 Using a named model object

```
gen zone brick size 6 6 6
group Tunnel range x 1 5 y 0 6 z 1 5
model mohr
.
.
model nul range group Tunnel
.
```

The named *range* and the named *group* are two very different model objects. The range pertains to a specified volume of space (or range of values), whereas the group identifies a collection of finite difference zones in the model. For example (and since geo-engineering involves digging holes), the planet Earth can be viewed as a range (**RANGE Earth** . . .) in space within which we can place a structure (**GROUP Shaft** . . .) which would be a group in our model. It does not matter where in the range named **Earth** the group **Shaft** is placed; the range retains its geometric attributes. In Example 2.7,* we have created a simple 2-layered geology with ranges named “Layer1” and “Layer2.” We have created two macros, “Sand” and “Clay,” which define our soil properties. Our model contains two groups: “Tunnel,” for the group which will be excavated at some point; and “Matrix,” which represents the rest of the model around the tunnel. The macros are used to clearly identify the type of soil we are assigning to our stratigraphy, while the intersections of our groups with the stratigraphy ensure that the appropriate zones take on the appropriate properties. Do not worry about the details of the commands used here; they will all be covered later in this section and in Section 3. The commands related to naming objects are in **`boldface`** for easy identification.

Example 2.7 Illustrating the behavior of* RANGE, GROUP *and* MACRO *model objects

```
; generate the model geometry
gen zone radc          &
  dim   3  3  3  3     &
  ratio 1  1  1  1.2   &
  size  3  8  8  5     &
  edge 10              &
  p0  100 95 100       &
  fill
gen zone reflect dip 90 dd 90 ori 100 100 100
gen zone reflect dip  0 dd  0 ori 100 100 100
;
; naming fixed GROUPS within the model, which will stay
; with the model as the model is moved through space
; - made to represent physical model components here...
```

* The file “NAMES.DAT” contains a version of Example 2.7 that will create plot views to allow the user to see the development of this model.

```
group Tunnel range cylinder end1 100 105 100 end2 100 95 100 radius 3
group Matrix range group Tunnel not
;
; naming RANGES that are fixed in space and unrelated
; to the model geometry - represents stratigraphy...
; (this is a two-layer system split on a horizontal plane
; through the origin)
range name Layer1 plane dip 0 dd 0 ori 0 0 0 above
range name Layer2 plane dip 0 dd 0 ori 0 0 0 below
;
; using MACROS to create soil types as defined by their
; material properties - this is completely independent of
; their location in space...
macro Sand 'bulk 1e8 shear 0.5e8 coh 0 tens 0 fric 35'
macro Clay 'bulk 1e7 shear 0.3e7 coh 1e7 tens 0 fric 0'
;
; bring the model to the axes origin...
; (change these coordinates if you want to see the grid positioned
; elsewhere within the region - remember the model is 10*10*10m)
ini x add -100 y add -100 z add -100
;
; we specify material models according to GROUP...
mo null range group Tunnel
mo mohr range group Matrix
;
; ... and soil properties (via the MACRO names) to whatever parts
; of the model coincide with our stratigraphy (defined with RANGE)...
prop Sand range Layer1
prop Clay range Layer2
```

2.6.3 General Advice

The user is encouraged to view objects as entities that can be used (nouns), rather than entities that do something (verbs). For example, as shown in Example 2.8, if the **GENERATE** command is included in the macro definition of **Big_Brick**, it is quite likely that **Big_Brick** will be used as a noun in one instance, and a verb in another.

Example 2.8 Using macros

```
macro Pt0 'p0      0  0  0'
macro Pt1 'p1 add 10  0  0'
macro Pt2 'p2 add  0 10  0'
macro Pt3 'p3 add  0  0 10'
macro Model_Size 'size 4 5 6'
```

```
macro Big_Brick 'gen zone brick Pt0 Pt1 Pt2 Pt3 Model_Size'
;
Big_Brick
.
.
macro 'Pt0' 'p0 15 15 15'
gen Big_Brick       ; this will cause an error
.
```

New commands (i.e., verbs) can be created with macros. For example, the **PLOT add** sequence can be replaced by the shorter sequence **PA** — see Example 2.9. Note that we have not mixed any nouns into this definition.

Example 2.9 Creating new commands

```
macro PA 'plot add'
.
.
PA history 1 ...
.
```

Mixing uppercase and lowercase in object names will prevent the accidental use of *FLAC3D* commands or keywords. Remember that macro names take precedence over range names and commands.

It is possible to use a range, a group or a macro object to achieve the same result. Example 2.10 shows how each of these could be used in identifying a part of a model to which a property value is assigned.

Example 2.10 Using different object types to do the same job

```
    using a RANGE object ...
range name Big_Brick x = (-3,3) y = (-2,2) z = (-1,1)
model null range Big_Brick

    using a GROUP object ...
group Big_Brick range x = (-3,3) y = (-2,2) z = (-1,1)
model null range group Big_Brick

    using a macro object ...
macro Big_Brick 'x = (-3,3) y = (-2,2) z = (-1,1)'
model null range Big_Brick
```

Notice that the **GROUP** command uses a **range** keyword in the creation of the group object called "Big_Brick." The only difference between the **RANGE** command and the **range** keyword is that the command can be issued on a line of its own, allowing the user to create a number of range objects directly. Otherwise, a range can be used as a part of a command and named at the same time. Example 2.11 illustrates the different techniques. All of this is aimed at providing powerful, flexible tools for model construction.

Example 2.11 Creating named ranges

```
    naming as a RANGE command ...
range name Big_Brick x -3 3 y -2 2 z -1 1
model elastic range Big_Brick
prop bulk 1e8 shear 1e8 range Big_Brick

    using the first RANGE keyword to name the object ...
model elastic range name Big_Brick x -3 3 y -2 2 z -1 1
prop bulk 1e8 shear 1e8 range Big_Brick
```

Named ranges are particularly useful in plotting. Named groups should be used when a specific collection of zones needs to be addressed, whether they manage to remain at their original coordinates throughout the modeling process or not. Think of components of the model as groups, and the space they occupy as ranges.

2.7 Mechanics of Using *FLAC3D*

FLAC3D is based upon a command-driven format because most analyses require the use of data input files. Word commands control the operation of the program. Graphical controls are available where user-interaction is potentially more desirable, specifically in the plotting. This section provides an introduction to the basic commands a new user needs to perform simple *FLAC3D* calculations. If you have not done so already, run the tutorial problem in Section 2.2 for an example of a command-driven analysis with *FLAC3D*.

The tutorial problem — a trench excavated in a soil with low cohesion — is used here to demonstrate the general solution procedure. The procedure can be divided into distinct stages, as illustrated in Figure 2.9. Each stage is discussed separately. Example commands are provided to illustrate each analysis step.

In order to set up a model to run a simulation with *FLAC3D*, three fundamental components of a problem must be specified:

(1) a finite difference grid;

(2) constitutive behavior and material properties; and

(3) boundary and initial conditions.

The grid defines the geometry of the problem. The constitutive behavior and associated material properties dictate the type of response the model will display upon disturbance (e.g., deformational response due to excavation). Boundary and initial conditions define the in-situ state (i.e., the condition before a change or disturbance in the problem state is introduced).

After these conditions are defined in *FLAC3D*, the initial equilibrium state is calculated for the model. An alteration is then made (e.g., excavate material or change boundary conditions), and the resulting response of the model is calculated. The actual solution of the problem is different for an explicit finite difference program like *FLAC3D* than it is for conventional implicit-solution programs. (See the background discussion in Section 1 in **Theory and Background**.) *FLAC3D* uses an explicit time-marching method to solve the algebraic equations. The solution is reached after a series of computational steps. In *FLAC3D*, the number of steps required to reach a solution can be controlled automatically by the code *or* manually by the user. However, the user ultimately must determine if the number of steps is sufficient to reach the solved state. The way this is done will be covered later, in Section 2.7.4.

The general solution procedure, illustrated in Figure 2.9, is convenient because it represents the sequence of processes that occurs in the physical environment. The basic *FLAC3D* commands needed to perform simple analyses with this solution procedure are described below.

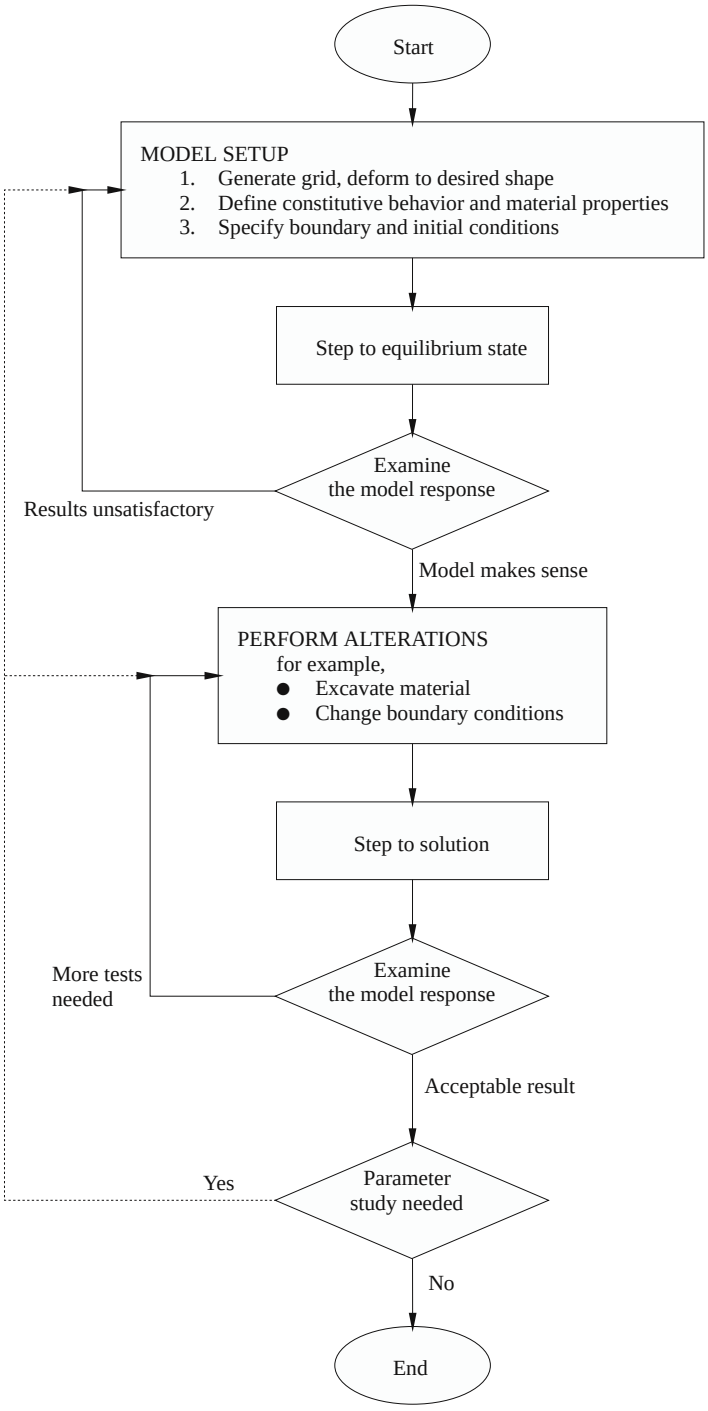

Figure 2.9 General solution procedure

2.7.1 Simple Grid Generation

Grid generation is performed via the **GENERATE** command and associated keywords that both define the number of zones in a model and shape the grid to fit a specified problem region.

Several primitive shapes are built into the generator to expedite mesh generation for simple problem shapes. These include brick, wedge, pyramid and cylinder shapes. Example 2.12 illustrates the command used in the tutorial problem to create a brick-shaped grid containing six zones in the x-direction, eight zones in the y-direction, and eight zones in the z-direction.*

Example 2.12 Generating a simple brick element

```
gen zone brick size 6,8,8
plot surf
```

The number of zones is specified by the **size** keyword. Be careful when selecting the number of zones for a model, because a balance must be struck between the accuracy required and the solution speed. Although there are many aspects of the numerical model that affect the calculation speed, once the basic parameters are defined, the speed varies directly as a function of the number of elements. As a rule-of-thumb, models containing up to roughly 5000 elements will typically reach a solution state for a given alteration in approximately 2000 to 4000 steps. On a 4 GHz Pentium 4 computer, the runtime for a 5000 element model to perform 4000 steps is roughly 5 minutes. Check the speed of calculation on your computer for the specific model, to estimate the runtime required.

It is best to start with a grid that has few zones (say, 1000 to 1500) to perform simple test runs and make refinements to the grid. Then, increase the number of zones to improve the accuracy.

In its simplest form, the **GENERATE** command can supply new coordinates to a grid. For example, assume that the actual coordinates of the trench model run from -10.0 to 10.0 in the x-direction, -10.0 to 10.0 in the y-direction, and −20.0 to 0.0 in the (vertical) z-direction. Example 2.3 shows how this would be specified.

---

* If you want to try entering the command examples interactively, type **NEW** each time you start a new example. This will initialize *FLAC3D* without having to exit and reload the program for a new model. Enter the **PLOT** mode after typing each example, to view the result.

Example 2.13 Using actual coordinates

```
gen zone brick size 6,8,8 p0 -10, -10, -20 &
                          p1  10, -10, -20 &
                          p2 -10,  10, -20 &
                          p3 -10, -10,   0
plot surf
```

In Example 2.13, **p0**, **p1**, **p2** and **p3** are keywords that denote four of the corners of a standard *FLAC3D* mesh (see Figure 2.10). You will notice that an ampersand (&) is given at the end of the first line of the **GEN** command. This denotes that the next line is a continuation of the same command.

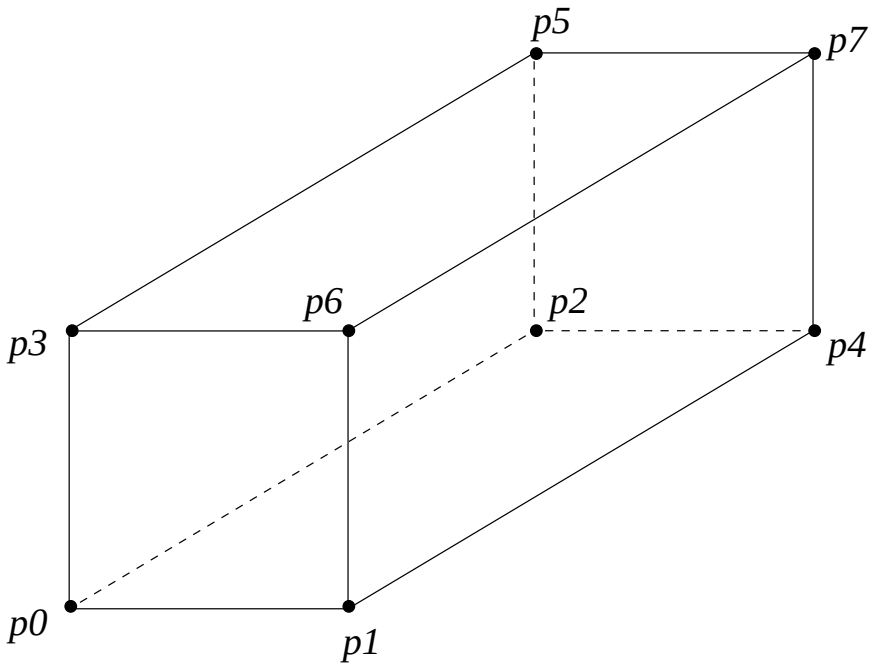

Figure 2.10 Corner coordinate keywords for a standard FLAC3D mesh shape

Only four corners are required to define a parallelepiped-shaped mesh. More corners can be specified to define an irregular surface. Example 2.14 shows how to make a sloping surface at the top of the mesh.

Example 2.14 A sloping surface at the top of a mesh

```
gen zone brick size 6,8,8   p0 -10, -10, -20 &
          p1  10, -10, -20  p2 -10,  10, -20 &
          p3 -10, -10,   0  p4  10,  10, -20 &
          p5 -10,  10,  10  p6  10, -10,   0 &
          p7  10,  10,  10
plot surf
```

The coordinates corresponding to the keywords **p0**, **p1**, **p2**, **p3**, **p4**, **p5**, **p6** and **p7** can be located at arbitrary points in space. However, the eight corners must have the topological sense shown in Figure 2.10 (i.e., **p0**, **p1**, **p2**, **p3** must form a right-handed system) to create positive zone volumes. Non-coplanar faces are permitted, but they should be avoided if possible because a small volume error may be introduced.

In the tutorial example, we noted that the boundaries of the model were influencing the results (see Figure 2.6). The boundary must be placed far enough away from the excavation to reduce these effects. A gradually graded mesh can be created in *FLAC3D* to move the model boundaries farther out without significantly increasing the number of zones. For example, the command **GEN zone radbrick** creates a radially graded mesh around a brick-shaped mesh. The command in Example 2.15 creates a $3 \times 5 \times 5$ zone brick-shaped mesh surrounded by a 7-zone radially graded mesh.

Example 2.15 Combining a regular and a radially graded mesh

```
gen zone radbrick &
    p0 (0,0,0)  p1 (10,0,0)  p2 (0,10,0)  p3 (0,0,10) &
    size  3,5,5,7   &
    ratio 1,1,1,1.5 &
    dim  1 4 2 fill
plot surf
```

The *x,y,z* coordinate system in *FLAC3D* is always right-handed and, as a default, the z-axis is drawn in the vertical direction on the screen. In Example 2.14, we assumed the z-axis was pointing in the vertical direction. However, we do not have to interpret the z-axis to mean the up direction. For Example 2.15, we will assume that the y-axis is the vertical direction. As long as we define the model in a right-handed system, we can create the grid in any direction we desire.

The **size** keyword, as used in Example 2.15, specifies the number of zones in the brick, and the number radially surrounding the brick (see Figure 2.11). The keyword **ratio** is given to manipulate the grid spacing. The four values that follow **ratio** are geometric ratios between successive zone sizes. The first three values are ratios for the zones in the brick, and the fourth value is the ratio for the zones surrounding the brick. In Example 2.15, the ratio is 1.0 for the brick zones and 1.5 for the zones surrounding the brick. This causes each successive ring of zones surrounding the brick to be 1.5 times larger in the radial direction. The **dim** keyword defines the dimensions of the brick

region (i.e., 1 m × 4 m × 2 m). The **fill** keyword fills the brick region with zones. If **fill** is omitted, no zones will be generated within the brick region.

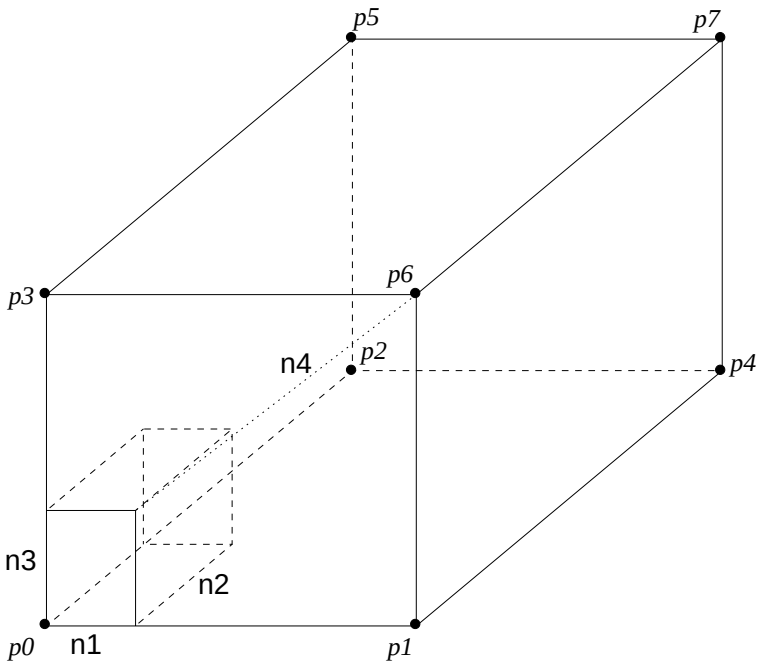

Figure 2.11 Element numbering for a radially graded mesh around brick (size n1 n2 n3 n4)

Several **GENERATE** commands can be given to create different regions of a model. For example, the **GENERATE** command in Example 2.15 creates one-quarter of the trench model. Example 2.16 shows how a series of **GENERATE** commands can be given to create the entire model.

Example 2.16 Combining GEN commands

```
gen zone radbrick &
         p0 (0,0,0)  p1 (10,0,0)  p2 (0,10,0)  p3 (0,0,10) &
         size 3 5 5 7                                      &
         rat 1 1 1 1.5                                     &
         dim 1 4 2 fill
gen zone radbrick &
         p0 (0,0,0)  p1 (0,0,10)  p2 (0,10,0)  p3 (-10,0,0) &
         size 5 5 3 7                                       &
         rat 1 1 1 1.5                                      &
         dim 2 4 1 fill
gen zone radbrick &
         p0 (0,0,0)  p1 (-10,0,0)  p2 (0,10,0)  p3 (0,0,-10) &
         size 3 5 5 7                                        &
```

```
          rat 1 1 1 1.5                                          &
          dim 1 4 2 fill
gen zone radbrick &
        p0 (0,0,0)  p1 (0,0,-10)  p2 (0,10,0)  p3 (10,0,0) &
        size 5 5 3 7                                           &
        rat 1 1 1 1.5                                          &
        dim 2 4 1 fill
plot surf lblue
```

Notice that **size**, **ratio** and **dim** all refer to local axes as defined by **p0, p1, p2, p3** in Figure 2.11, *not* to the global x,y,z-axes. The values will change, depending on the specification of **p0**, **p1**, **p2** and **p3**. The radially graded trench model is shown in Figure 2.12. Be sure that *all* gridpoints match at boundaries between shapes. Errors will occur in your analysis if gridpoints of connected shapes are not at the same locations along boundaries. Refer to Section 3 for further discussion on the creation of meshes and the proximity tolerances of adjacent gridpoints.

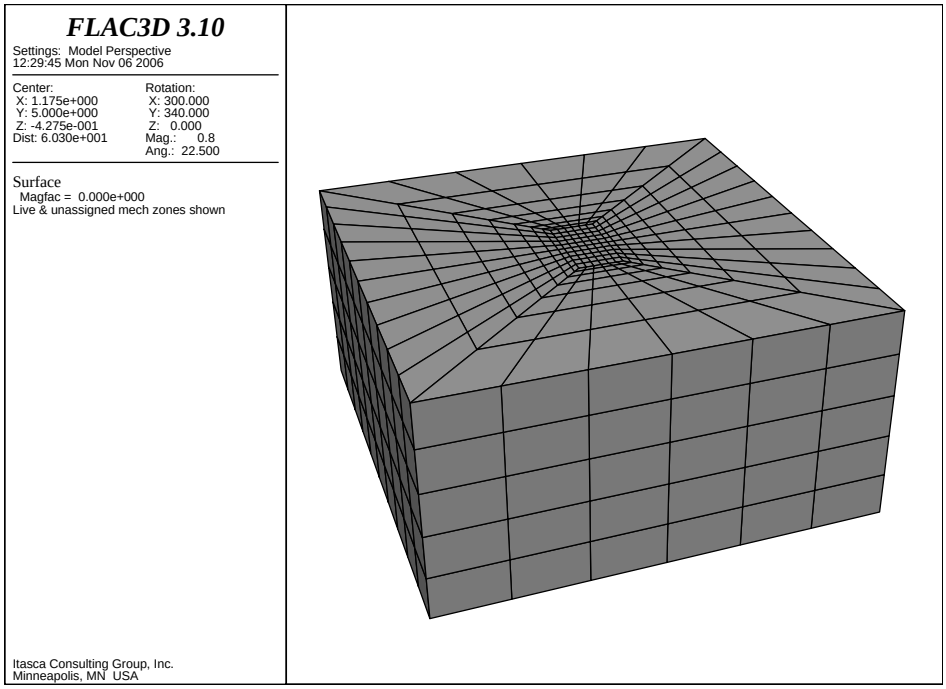

Figure 2.12 Radially graded trench model

Example 2.16 serves to illustrate the requirement of accurate mapping of adjacent elements in *FLAC3D*. There are other ways to achieve the same result shown in Figure 2.12, since we can take advantage of planes of symmetry. Parts of the model can be reflected about specified planes to produce a larger model. Example 2.17 shows how this can be achieved.

Example 2.17 Creating a model by reflecting elements on planes of symmetry

```
gen zone radbrick  &
         p0 (0,0,0)  p1 (10,0,0)  p2 (0,10,0)  p3 (0,0,10)  &
         size  3,5,5,7   &
         ratio 1,1,1,1.5 &
         dim 1 4 2 fill
gen zone reflect dip  0 dd 90
gen zone reflect dip 90 dd 90
plot surf
```

When selecting a value for the geometric ratio, there are a number of criteria that should be considered.

- Finer meshes lead to more accurate results in that they provide a better representation of high stress gradients.
- Accuracy increases as zone aspect ratios tend to unity.
- If different zone sizes are needed, a more gradual change from the smallest to the largest will improve the results; abrupt changes in zone size should be avoided.

However, as the mesh is made finer and the number of zones increase, more RAM is required and the computation time lengthens. Improving the mesh geometry by adjusting the zone size will certainly improve RAM efficiency and will reduce computation time. It will also take some time to plan and set up. Moving from a "brute force" approach (i.e., single-sized elements in a *large* uniform mesh) to a more elegant solution will improve RAM use and calculation speed when dealing with a more complicated geometry. Methods to assist with grid generation are discussed in Section 3.3.

2.7.2 Assigning Material Models

Once the grid generation is complete, one or more material models and associated properties must be assigned to all zones in the model. This is done by using two commands: **MODEL** and **PROPERTY**. *FLAC3D* has twelve built-in material models (described in Section 2.1 in **Theory and Background**). Three models are sufficient for most analyses the new user will make: **MODEL null**, **MODEL elastic**, and **MODEL mohr**.

MODEL null represents material which is removed or excavated from the model. **MODEL elastic** assigns isotropic elastic material behavior. **MODEL mohr** assigns Mohr-Coulomb plasticity behavior.

MODEL elastic and **MODEL mohr** require that material properties be assigned via the **PROPERTY** command. For the elastic model, the required properties are bulk and shear modulus.

NOTE: Bulk modulus, K, and shear modulus, G, are related to Young's modulus, E, and Poisson's ratio, ν, by the following equations:

$$K = \frac{E}{3(1-2\nu)} \tag{2.1}$$

$$G = \frac{E}{2(1+\nu)} \tag{2.2}$$

or

$$E = \frac{9KG}{3K+G} \tag{2.3}$$

$$\nu = \frac{3K-2G}{2(3K+G)} \tag{2.4}$$

For the Mohr-Coulomb plasticity model, the required properties are:

(1) bulk and shear moduli;

(2) friction and dilation angles;

(3) cohesion; and

(4) tensile strength.

If any of these properties is not assigned, its value is set to zero by default.

Zones may be assigned different material models. For example, an elastic model may be prescribed for the upper half of a 10 m × 10 m × 10 m grid, and a Mohr-Coulomb model for the lower half of the grid. Example 2.18 shows how this is done using range coordinates. Incidentally, note the use of the **MACRO** command in labeling soil types. The **range** keyword and parameters could have been included within the macro. However, keeping the properties and geometry separate makes good sense: we can use the same macros to apply those material properties anywhere in our model. We will be discussing similar naming strategies related to the geometry shortly.

Example 2.18 Assigning different material models in different areas of a single grid

```
gen zone brick size 10,10,10
macro SiltySand 'bulk 1.5e8 shear 0.3e8'
macro ClayeyGravel ' bulk 1.5e8 shear 0.6e8 fric 30 coh 5e6 ten 8.66e6'
; elastic in upper half of grid
model elas range z=5,10
prop SiltySand range z=5,10
; mohr-coulomb in lower half
model mohr range z=0,5
prop ClayeyGravel range z=0,5
plot block model lmagenta lgreen
```

Instead of using global coordinates with each **range** keyword, a range can be defined and named with the **RANGE** command. The named range can then be used as a parameter for the **range** keyword. This is demonstrated in Example 2.19, where we first identify and name a range with the **RANGE** command, followed by the use of that named range in applying a material model.

Example 2.19 Creating and using a named range

```
gen zone radbrick  &
         p0 (0,0,0)  p1 (10,0,0)  p2 (0,10,0)  p3 (0,0,10)  &
         size  3,5,5,7   &
         ratio 1,1,1,1.5 &
         dim 1 4 2 fill
gen zone reflect dip  0 dd 90
gen zone reflect dip 90 dd 90
;
; identify the trench
range name trench x=-1,1 y=0,4 z=-2,2
;
; excavate the trench
model null range trench
plot surf lblue
```

The trench excavation for the model shown in Figure 2.12 is plotted in Figure 2.13. Note that the excavation can be filled by material of any constitutive model, with properties appropriate to the model.

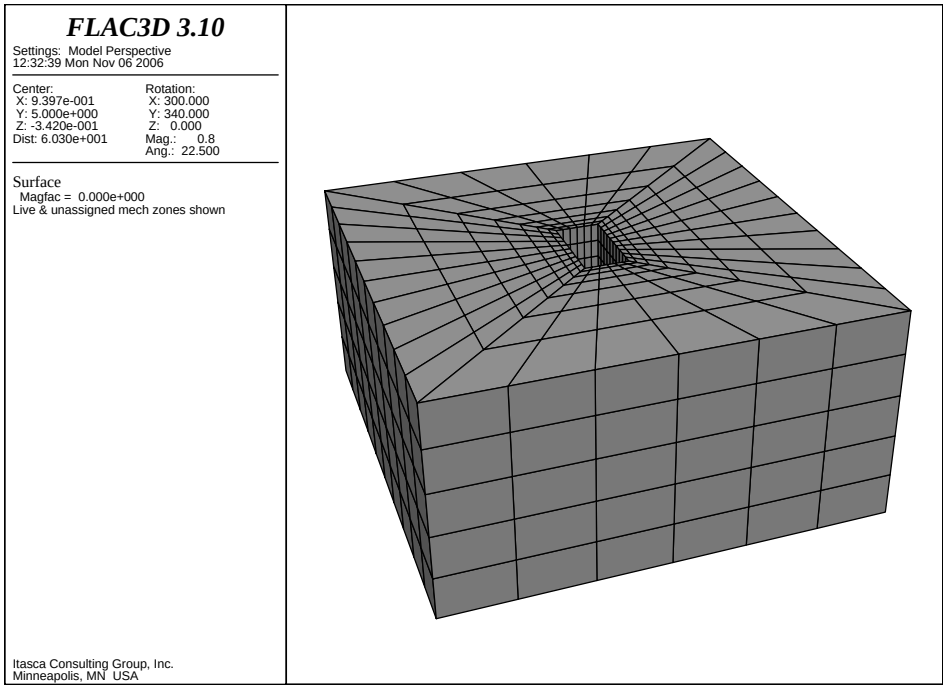

Figure 2.13 Radially graded trench model with trench excavated

2.7.3 Applying Boundary and Initial Conditions

After the grid is generated, boundary and initial conditions are applied. Boundary conditions are normally specified with the **APPLY** and **FIX/FREE** commands, and initial conditions are assigned with the **INITIAL** command. Table 2.3 provides a summary of common boundary-condition commands and their effects. Table 2.4 provides a similar table for initial condition commands.

The boundary conditions in a numerical model consist of the values of field variables that are prescribed at the boundary of the numerical grid. Note that by using a boundary condition command, a condition or constraint that will not change while *FLAC3D* is calculating a solution (unless specifically changed by the user) is imposed. Boundaries can be either real or artificial — real boundaries exist in the physical object being modeled, whereas artificial boundaries are introduced to enclose the chosen number of zones.

Artificial boundaries fall into two categories: planes of symmetry and planes of truncation. A symmetry plane takes advantage of the fact that the geometry and loading in a system are symmetrical about one or more planes. A truncation plane is a boundary sufficiently far from the area of interest that the behavior in that area is not greatly affected. It is important to know how far away to place these boundaries, and what errors they might precipitate in the stresses and displacements computed for the area of interest.

Table 2.3 Summary of common boundary-condition commands

COMMAND		EFFECT
		Gridpoint Condition:
APPLY	**xforce**	x-component of force applied at boundary gridpoints
	xvelocity	x-velocity applied at boundary gridpoints
	yforce	y-component of force applied at boundary gridpoints
	yvelocity	y-velocity applied at boundary gridpoints
	zforce	z-component of force applied at boundary gridpoints
	zvelocity	z-velocity applied at boundary gridpoints
		Face Condition:
	sxx	xx-component of total stress tensor applied at boundary faces
	sxy	xy-component of total stress tensor applied at boundary faces
	sxz	xz-component of total stress tensor applied at boundary faces
	syy	yy-component of total stress tensor applied at boundary faces
	syz	yz-component of total stress tensor applied at boundary faces
	szz	zz-component of total stress tensor applied at boundary faces
FIX	**x**	x-velocity fixed at boundary gridpoints
	y	y-velocity fixed at boundary gridpoints
	z	z-velocity fixed at boundary gridpoints

NOTE:

1. The **FREE** command is used to release the constraint set by the **FIX** command.
2. In order to assign a fixed-displacement boundary condition, only the **FIX x**, **FIX y** and/or **FIX z** commands are needed, provided that the velocity at the selected gridpoint is zero.
3. See Section 1 in the **Command Reference** for a complete listing of **APPLY** keywords.
4. Compressive stresses have a negative sign; see Section 2.8 for sign conventions.

Table 2.4 Summary of common initial condition commands

COMMAND		EFFECT
		Gridpoint Condition:
INITIAL	**xdis**	initialize x-displacement at a gridpoint
	xvel	initialize x-velocity at a gridpoint
	ydis	initialize y-displacement at a gridpoint
	yvel	initialize y-velocity at a gridpoint
	zdis	initialize z-displacement at a gridpoint
	zvel	initialize z-velocity at a gridpoint
		Zone Condition:
	density	initialize mass density for a zone
	sxx	initialize xx-component of total stress for a zone
	sxy	initialize xy-component of total stress for a zone
	sxz	initialize xz-component of total stress for a zone
	syy	initialize yy-component of total stress for a zone
	syz	initialize yz-component of total stress for a zone
	szz	initialize zz-component of total stress for a zone

By default, the boundaries in *FLAC3D* are free of stress and are unconstrained. Forces or stresses may be applied to any boundary, or portion of a boundary, by means of the **APPLY** command. Individual components of the stress tensor are specified by the keywords listed in Table 2.3. For example, a constant, compressive xx-stress component of 10 MPa can be applied to a boundary located at x = 10 with the command

```
apply sxx -10e6 range x 9.9 10.1
```

Remember that compressive stresses are negative. The **range** keyword is used at the end of the command line to specify the range of action for the **APPLY** command. In this case, the boundary condition applies to any boundary faces that fall between x = 9.9 and 10.1.

A linearly varying yy-stress component can be applied with the **gradient** keyword — for example,

```
apply syy = -20e6 grad 0,0,20e5 range y -20.1,-19.9 z 0,10
```

With this command, a yy-stress component is applied to boundary faces located between $y = -20.1$ and -19.9. The yy-stress varies linearly with z from $\sigma_{yy} = 0$ at $z = 10$, to $\sigma_{yy} = -20 \times 10^6$ at $z = 0$.

When **gradient** is used, a value varies according to the relation

$$S = S^{(o)} + g_x x + g_y y + g_z z \tag{2.5}$$

in which $S^{(o)}$ is the value at the global coordinate origin at (x = 0, y = 0, z = 0) and is the value immediately following the **syy** keyword, and g_x, g_y and g_z specify the variation of the value in the x-, y- and z-directions and are the three numbers following the **gradient** keyword.

Displacements cannot be controlled directly in *FLAC3D*. In fact, they play no part in the calculation process. In order to apply a given displacement to a boundary, it is necessary to prescribe the boundary's velocity for a given number of steps. If the desired displacement is D, a velocity V over N steps (where $N = D/V$) may be applied.* In practice, V should be kept small, and N large, in order to minimize shocks to the system being modeled. The **APPLY** command or the **FIX** and **INITIAL** commands can be used to specify the velocities; gradients may also be specified.

The following command shows the use of the **FIX** command to fix the x-displacement to zero along a boundary located at x = 0:

```
fix x range x -0.1 0.1
```

This, in effect, creates a roller boundary at which the boundary plane is fixed in the x-direction, but free to move in the y- and z-directions. Only the **FIX** command is needed if the model is at the start-up state and velocities are (by default) zero. Otherwise it would be necessary to either initialize velocities with the **INITIAL** command, or use the **APPLY** command.

A pinned boundary condition (i.e., constrained in the x-, y- and z-directions) can be specified with the command

```
fix x y z  range x -0.1 0.1
```

For real boundaries, the choice of stress or displacement boundary conditions is usually clear. However, for artificial boundaries, such as planes of truncation, either type may be selected. Experience has shown that, generally:

(1) a fixed boundary causes both stresses and displacements to be underestimated;

(2) a stress boundary causes both stresses and displacements to be overestimated; and

(3) the two types of boundary conditions bracket the true solution, so that it is possible to do tests with both boundaries and get a reasonable estimate of the true solution by averaging the two results.

Unlike the boundary condition commands, the initial condition commands assign *initial* values to selected variables; these *can* change while the computation proceeds. For example, in geological

---

* Note that velocity has units of *displacement per timestep* for the static solution mode, and *displacement per unit time* for the dynamic mode.

materials, there is an in-situ state of stress in the ground before any excavation or construction is started. By setting the initial conditions in a *FLAC3D* grid, an attempt to reproduce this in-situ state is made because it will influence the subsequent behavior of the model. (This influence is discussed in more detail in Section 3.3.)

To prescribe an initial stress state, we use the **INITIAL** command — e.g.,

```
ini sxx -50e6 syy -40e6 szz -10e6
```

This assigns initial compressive stress components of

σ_{xx} = -50e6
σ_{yy} = -40e6
σ_{zz} = -10e6

to all zones in the model. All six stress components can be initialized, and a stress gradient can be specified for boundary stresses in the same manner as previously discussed.

If the initial stress state is subjected to gravitational loading, this may be added via the **SET gravity** command — e.g.,

```
set gravity = 0, -9.81, 0
```

in which a gravitational acceleration vector of 9.81 m/sec^2 is applied in the negative y-direction. If gravitational loading is specified, the material mass density must also be initialized with the command **INI density**.

Let us now apply the information we have covered thus far to revise the trench model presented in Section 2.2. We can identify two planes of symmetry for this problem: one is the xy-plane; and the other is the yz-plane through the center of the trench (see Figure 2.12). The following commands (in Example 2.20) create the quarter-symmetry model, assign a Mohr-Coulomb material model and properties, prescribe boundary conditions, and apply the initial stress state with gravity acting in the positive y-direction. The model is shown in Figure 2.14.

In this example, σ_{xx} and σ_{zz} stresses and gradients are equal to half the σ_{yy} stresses and gradients. Stresses may be initialized to any value, but you must check the stress state to ensure that it does not violate the yield criterion (Mohr-Coulomb, in this case). The initial equilibrium state is discussed further in the next section.

Example 2.20 Trench problem — quarter-symmetry model

```
gen zone radbrick &
        p0 (0,0,0) p1 (10,0,0) p2 (0,10,0) p3 (0,0,10) &
        size 3,5,5,7 &
        ratio 1,1,1,1.5 &
        dim 1 4 2 fill
mod moh
prop bulk 1e8 shear 3e8 fric 35 coh 1e3 tens 1e3
fix x range x -0.1  0.1
```

```
fix z range z -0.1  0.1
fix y range y  9.9 10.1
set grav 0 10 0
ini dens 1000
ini syy 0.0 grad 0 -10000 0
ini sxx 0.0 grad 0  -5000 0
ini szz 0.0 grad 0  -5000 0
apply sxx 0.0 grad 0 -5000 0 range x 9.9 10.1
apply szz 0.0 grad 0 -5000 0 range z 9.9 10.1
```

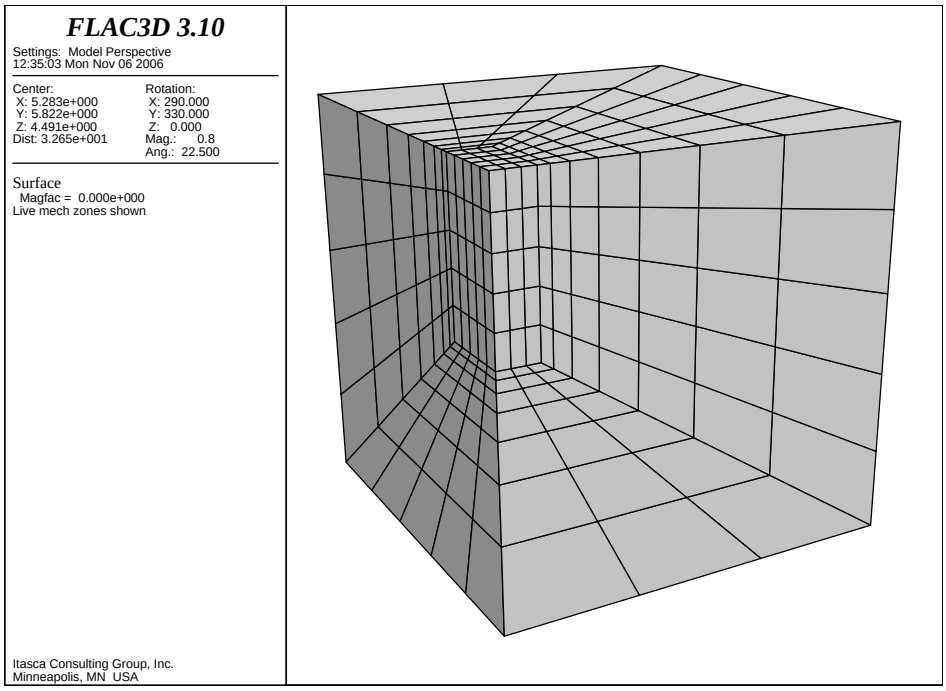

Figure 2.14 Quarter-symmetry model of trench excavation

2.7.4 Stepping to Initial Equilibrium

The *FLAC3D* model must be at an initial force-equilibrium state before alterations can be performed. For simple model geometries, the boundary conditions and initial conditions may be assigned such that the model is exactly at equilibrium initially. However, in most cases, it is necessary to step the model to the initial equilibrium state under the given boundary and initial conditions, particularly for problems with complex geometries or multiple materials. This is done using either the **STEP** or **SOLVE** command. With the **STEP** command, the user specifies a number of calculation steps to perform in order to bring the model to equilibrium. The model is in perfect equilibrium when the net nodal-force vector at each gridpoint is zero (see Section 1 in **Theory and Background**). The maximum nodal-force vector (called the maximum "out-of-balance" or "unbalanced" force) is

monitored in *FLAC3D* and printed to the screen when the **STEP** command is invoked. In this way, the user can assess when equilibrium has been reached.

For a numerical analysis, the out-of-balance force will never reach exactly zero. It is sufficient, though, to say the model is in equilibrium when the maximum unbalanced force is small compared to the representative zone forces in the problem. For example, if the maximum unbalanced force is initially 1 MN and drops to approximately 100 N, then the model can be considered to be at equilibrium, within 0.01% of the initial maximum unbalanced force.

This is an important aspect of numerical problem-solving with *FLAC3D*. The user must decide when the model has reached equilibrium. There are several features built into *FLAC3D* to assist in making this decision. The history of the maximum unbalanced force may be recorded with the command

```
hist unbal
```

Additionally, the history of selected variables (e.g., velocity or displacement at a gridpoint) may be recorded. The following commands are examples.

```
hist gp xvel 5,4,4
hist gp zdisp 0,0,8
```

This first history records x-velocity at location (x = 5, y = 4, z = 4), while the second records z-displacement at location (x = 0, y = 0, z = 8).

After running several hundred (or thousand) calculation steps, a history of these records may be plotted to indicate the equilibrium condition. The data file in Example 2.21 illustrates this process.

Example 2.21 Stepping to initial equilibrium

```
gen zone brick size 6 8 8
mo elas
prop bulk 1e8 shear 0.3e8
fix x range x -0.1 0.1
fix x range x  5.9 6.1
fix y range y -0.1 0.1
fix y range y  7.9 8.1
fix z range z -0.1 0.1
apply szz -1e6 range z 7.9 8.1
hist unbal
hist gp xvel 3 4 4
hist gp zdisp 0 0 8
step 1500
; solve
```

The initial maximum unbalanced force is 1 MN. After 1500 steps, this force has dropped to approximately 270 N. By plotting the first history, it can be seen that the maximum unbalanced force is approaching zero. The following command produces the plot in Figure 2.15.

```
plot hist 1
```

The velocity also approaches zero, and the displacement history becomes constant; these are indicators that an equilibrium state is reached. The x-velocity history plot in Figure 2.16 and z-displacement history plot in Figure 2.17 are produced with the commands

```
plot hist 2
plot hist 3
```

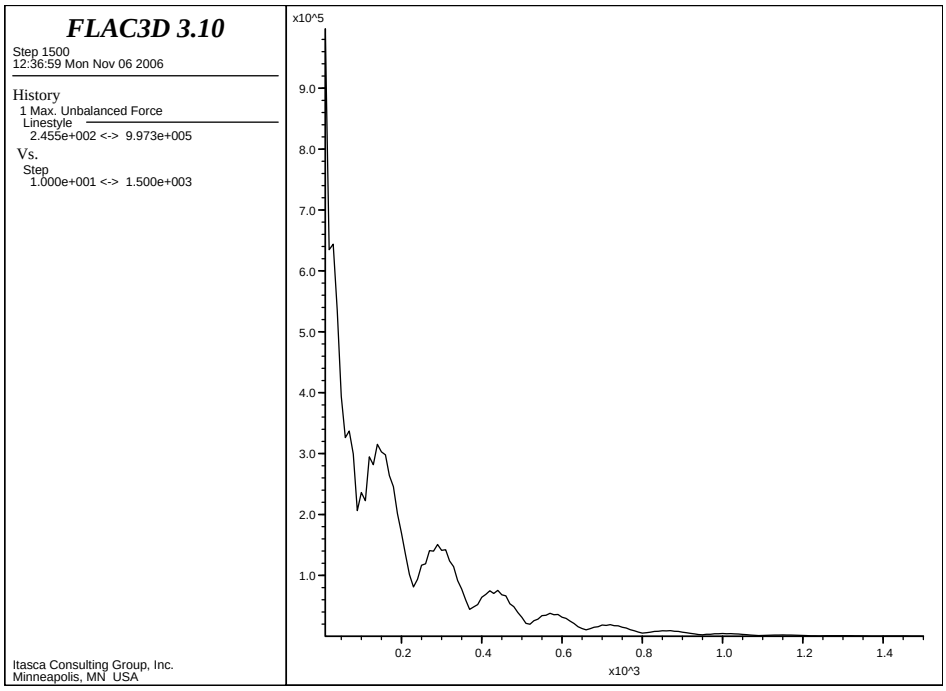

Figure 2.15 Maximum unbalanced force history

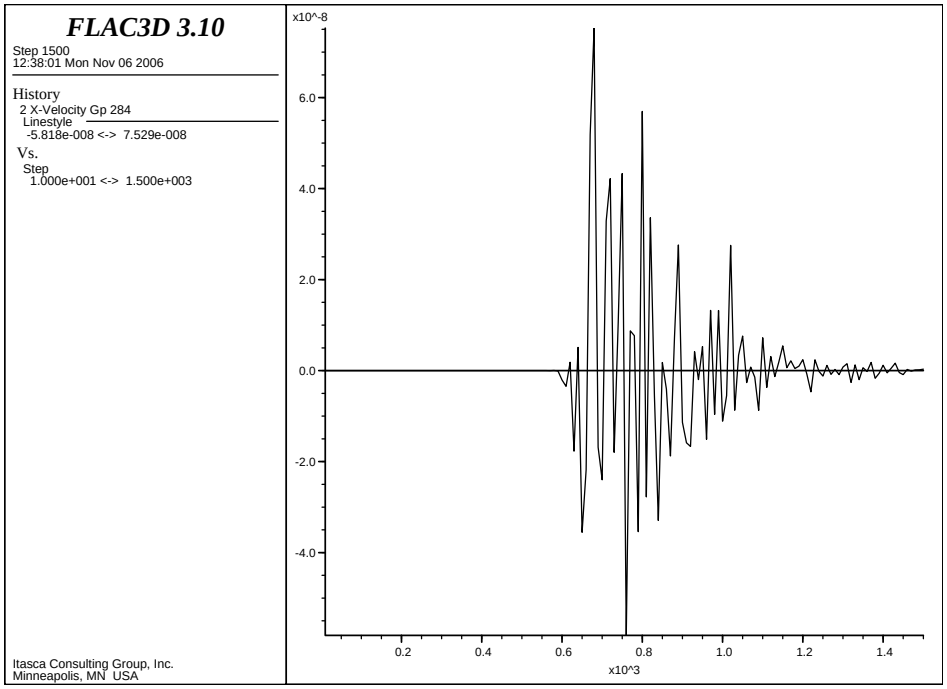

Figure 2.16 x-velocity history at (x = 3, y = 4, z = 4)

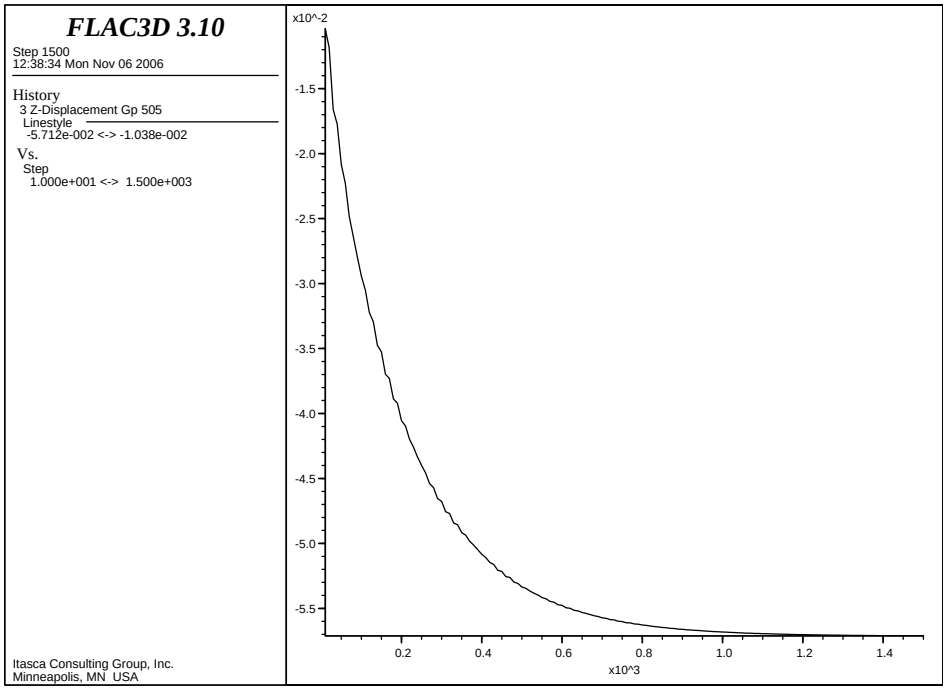

Figure 2.17 z-displacement history at (x = 0, y = 0, z = 8)

The **SOLVE** command can be used in place of **STEP** if the user wishes *FLAC3D* to stop automatically when the maximum unbalanced force falls below a specified limit. Replace **STEP 1500** with **SOLVE** and repeat the preceding problem. This time, *FLAC3D* should stop the calculation at step 1650. If the plots are made again, essentially the same results as given in Figures 2.15, 2.16 and 2.17 will be seen.

By default, a force-limit ratio controls the stepping when **SOLVE** is issued. When the ratio of the maximum unbalanced force for all the gridpoints in the model divided by the average applied gridpoint force falls below the value of 1.0×10^{-5}, then the calculation will stop. The ratio can be changed by typing

```
set mech ratio = f
```

before giving the **SOLVE** command. Here *f* is a user-supplied value for the force-limit ratio.

For Example 2.21, the initial equilibrium stage can be achieved without stepping by simply inserting an **INITIAL** command,

```
ini sxx=-1e6 syy=-1e6 szz=-1e6
```

Now, the unbalanced force is nearly zero.* Type **SOLVE** to confirm this. Note that, in this case, the initial displacements in the model are automatically zero.

If we return to the trench problem, the model described by the data file (Example 2.20) should be at a stress equilibrium state. After entering the data file, type

```
step 1
```

and you will find that the unbalanced force is approximately 7000 N. This is small relative to the maximum gravitational force for this problem (approximately 2.7×10^5 N). There is some force unbalance, however, because of the graded mesh. If the zones were all of equal size, the unbalanced force would be nearly zero. However, with graded meshes, it is usually necessary to perform some stepping to bring the model to an initial equilibrium state. Type

```
solve
```

and Example 2.20 will step to equilibrium, at an unbalanced force ratio limit of 1×10^{-5}, within 1040 steps.

In an analysis, it is very important that the model be at equilibrium before alterations are made. Several histories should be recorded throughout a model to ensure that a large force imbalance does not exist. It does not adversely affect the analysis if more steps are taken than are needed to reach equilibrium. However, it will affect the analysis if an insufficient number of steps is taken.

A *FLAC3D* calculation can be interrupted at any time during stepping by pressing the <Esc> key. It often is convenient to use the **STEP** command with a high step-number and periodically interrupt the stepping, check the histories, and resume stepping until the equilibrium condition is reached.

---

* The force is not exactly zero because of the difference between single- and double-precision calculations made in the code.

2.7.5 Performing Alterations

FLAC3D allows model conditions to be changed at any point in the solution process. These changes may take the following forms:

- excavation of material;
- addition or deletion of gridpoint loads or stresses;
- change of material model or properties for any zone; and
- fix or free velocities for any gridpoint.

Excavation is performed with the **MODEL null** command. Gridpoint loads can be applied at any gridpoint with the **APPLY xforce**, **APPLY yforce** and **APPLY zforce** commands. Stress alterations can be made at model boundaries with the **APPLY** command, as discussed previously. Material models and properties* are changed with the **MODEL** and **PROPERTY** commands. Gridpoint velocities are fixed or freed via the **FIX**/**FREE** commands. It should be evident that several commands can be repeated to perform various model alterations.

If model zones contain a plasticity model (e.g., **MODEL mohr**), it is possible that an alteration may be such that force equilibrium cannot be achieved. In other words, the unbalanced forces in part or all of the model cannot approach zero — in which case, the maximum unbalanced force will approach a constant nonzero value, indicating that steady-state flow of material is occurring (i.e., a portion (or all) of the model is failing).

In our trench model, Example 2.20, we define and excavate the trench and monitor the response with the commands in Example 2.22.

Example 2.22 Excavating the trench and monitoring the response

```
range name trench x=0,1  y=0,4  z=0,2
model null range trench
set large
hist gp xdisp 1,0,0
; ... and then calculate the response:
step 1000
```

The trench fails as indicated by the plot in Figure 2.18. The displacement history at the trench wall, Figure 2.19, also indicates failure by a continuously increasing displacement.

---

* If moduli (bulk or shear) are changed in a model that is in equilibrium, no immediate effect will be observed because *FLAC3D* uses *tangent*, rather than *secant*, moduli.

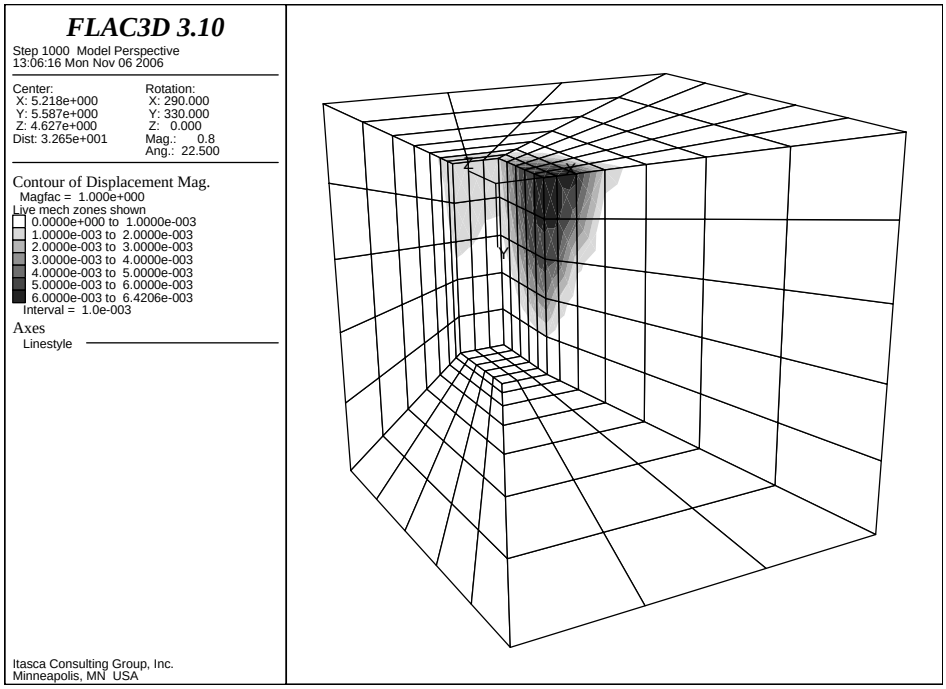

Figure 2.18 Displacement contours for trench excavation

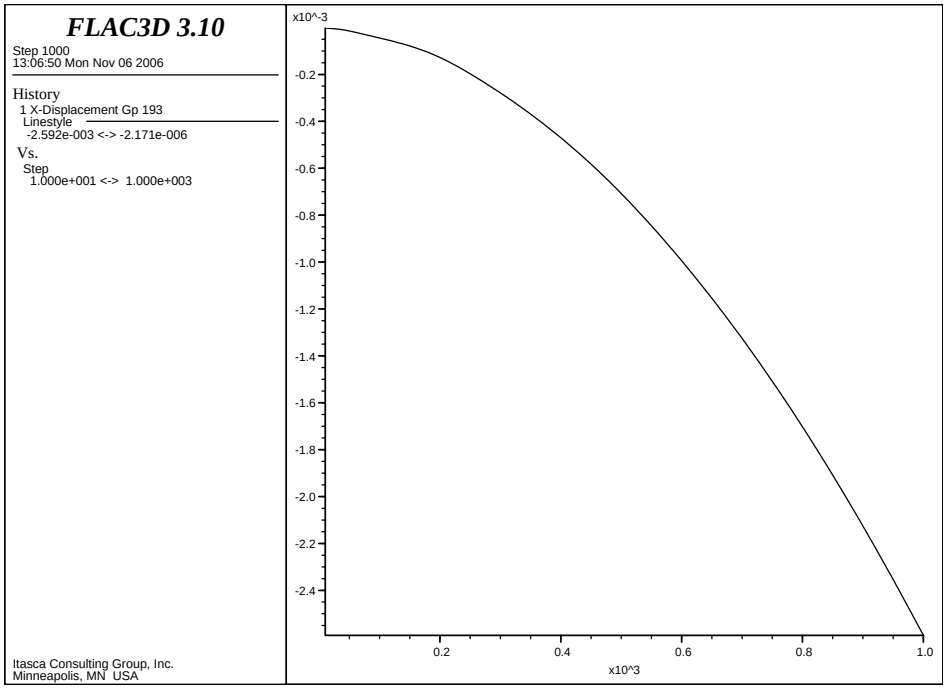

Figure 2.19 Displacement history at trench wall

2.7.6 Saving/Restoring the Problem State

Two other commands, **SAVE** and **RESTORE**, are helpful when performing analyses in stages (also available under the FILE menu). At the end of one stage (e.g., initial equilibrium), the model state can be saved (as a binary file) by typing

```
save file.sav
```

in which file is a user-specified filename. The (default) extension ".SAV" identifies this file as a saved file (see Section 2.11). This file can be restored at a later time by typing

```
rest file.sav
```

and the model state at the point at which the model was saved will be restored. It is not necessary to build a model from scratch every time a change is made; simply save the model before the change, and restore it whenever a new change is to be analyzed.

For example, in our trench problem we will excavate the trench in 2 m-deep stages and save the state at each stage, beginning with the initial equilibrium stage ("TR_EQ.SAV"). We can then determine the stage at which the trench fails and investigate the influence of support (e.g., tiebacks or soil nails) on stabilizing the trench.

We repeat the data file given in Example 2.20, but this time we insert save files at the equilibrium stage and at each excavation stage.

Example 2.23 Trench problem — excavation in stages and support

```
;-----------------------------------------------------------------
;            Trench Problem
;            Excavation in Stages and Support
;-----------------------------------------------------------------
new
gen zone radbrick &
         p0 (0,0,0)  p1 (10,0,0)  p2 (0,10,0)  p3 (0,0,10) &
         size 3 5 5 7                                       &
         rat 1 1 1 1.5                                      &
         dim 1 4 2  fill
model mohr
prop bulk 1e8 shear .3e8 fric 35
prop coh 1e3 tens 1e3
fix x range x -0.1 0.1
fix z range z -0.1 0.1
fix y range y  9.9 10.1
set grav 0 10 0
ini dens 1000
ini syy=0.0 grad 0,-10000,0
ini sxx=0.0 grad 0,-5000,0
ini szz=0.0 grad 0,-5000,0
```

```
apply sxx=0.0 grad 0,-5000,0 range x 9.9,10.1
apply szz=0.0 grad 0,-5000,0 range z 9.9,10.1
set large
hist unbal
solve
save tr_eq.sav
;
; monitor trench excavation
ini xdis=0 ydis=0 zdis=0
hist gp xdisp 1,0,0
hist gp zdisp 0,0,2
;
; excavation steps
range name exc1 x 0 1 y 0.0 0.8 z 0 2
range name exc2 x 0 1 y 0.8 1.6 z 0 2
range name exc3 x 0 1 y 1.6 2.4 z 0 2
range name exc4 x 0 1 y 2.4 3.2 z 0 2
range name exc5 x 0 1 y 3.2 4.0 z 0 2
; excavation step 1
model null range exc1
step 1000
save exc1.sav
; excavation step 2
model null range exc2
step 1000
save exc2.sav
; excavation step 3
model null range exc3
step 1000
save exc3.sav
; excavation step 4
model null range exc4
step 1000
save exc4.sav
; excavation step 5
model null range exc5
step 1000
save exc5.sav
;
; install cable support
rest exc2.sav
sel cable beg 1.0,0.4,1.5 end 5.0,0.4,1.5 nseg 4
sel cable beg 1.0,0.4,0.5 end 5.0,0.4,0.5 nseg 4
sel cable beg 1.0,1.2,1.5 end 5.0,1.2,1.5 nseg 4
sel cable beg 1.0,1.2,0.5 end 5.0,1.2,0.5 nseg 4
sel cable prop emod 2e9 ytens 1e8 xcarea 1.0 &
```

```
    gr_coh 1e10 gr_k 2e9 gr_per 1.0
model null range exc3
step 1000
save cab3.sav
sel cable beg 1.0,2.0,1.5 end 5.0,2.0,1.5 nseg 4
sel cable beg 1.0,2.0,0.5 end 5.0,2.0,0.5 nseg 4
sel cable prop emod 2e9 ytens 1e8 xcarea 1.0 &
    gr_coh 1e10 gr_k 2e9 gr_per 1.0
model null range exc4
step 1000
save cab4.sav
sel cable beg 1.0,2.8,1.5 end 5.0,2.8,1.5 nseg 4
sel cable beg 1.0,2.8,0.5 end 5.0,2.8,0.5 nseg 4
sel cable prop emod 2e9 ytens 1e8 xcarea 1.0 &
    gr_coh 1e10 gr_k 2e9 gr_per 1.0
model null range exc5
step 1000
save cab5.sav
plot create TrenchSupport
plot set rot 290,350,0
plot set cent 2.579,3.855,6.1
plot set mag 1.56
plot set dist 32.65
plot add cont disp out on
plot add sel cable force
plot show
ret
```

Upon running this example, we find that the trench fails at the third excavation stage (see the x- and z-displacement history plot in Figure 2.20). We restart the save file at the second excavation stage ("EXC2.SAV"), install cables and then proceed with the excavation. (See the **SEL cable** command in Section 1 in the **Command Reference**.) This time, the trench walls are stable (see Figure 2.21). The forces in the cables and displacements of the trench are shown in Figure 2.22.

By using save files, we can perform series of different calculations, starting from whatever stage we desire, and investigate various problem conditions such as spacing and properties of cable elements.

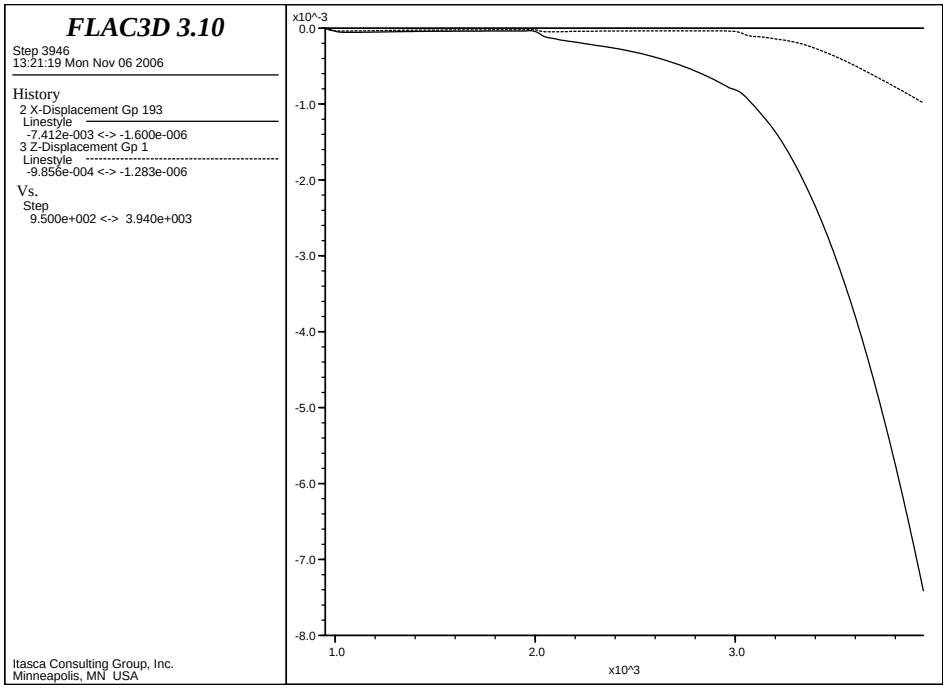

Figure 2.20 Displacement histories indicating failure at the third excavation stage

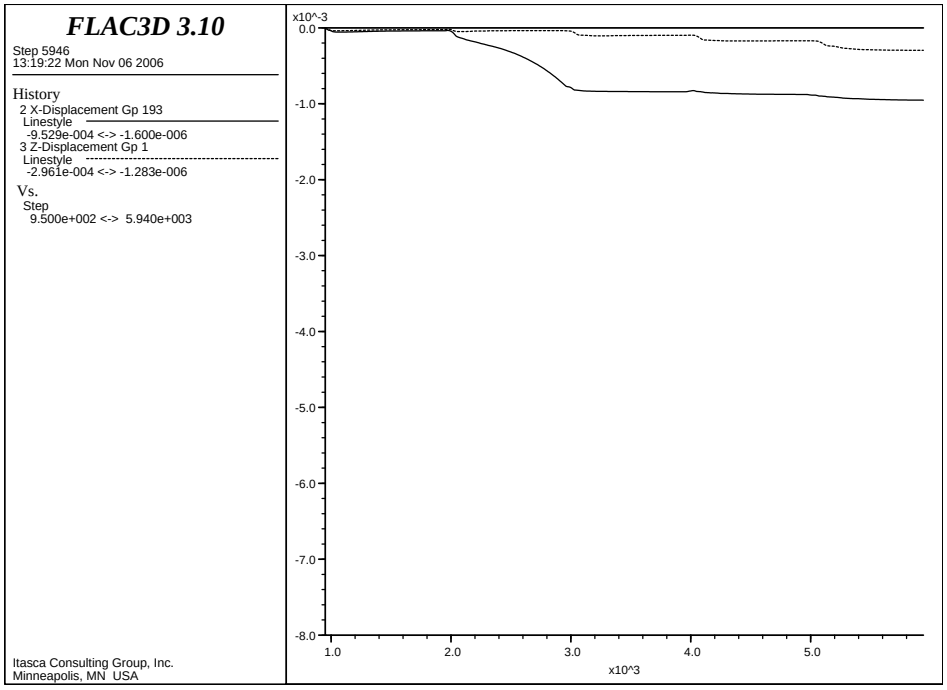

Figure 2.21 Displacement histories indicating trench is stable with cable support

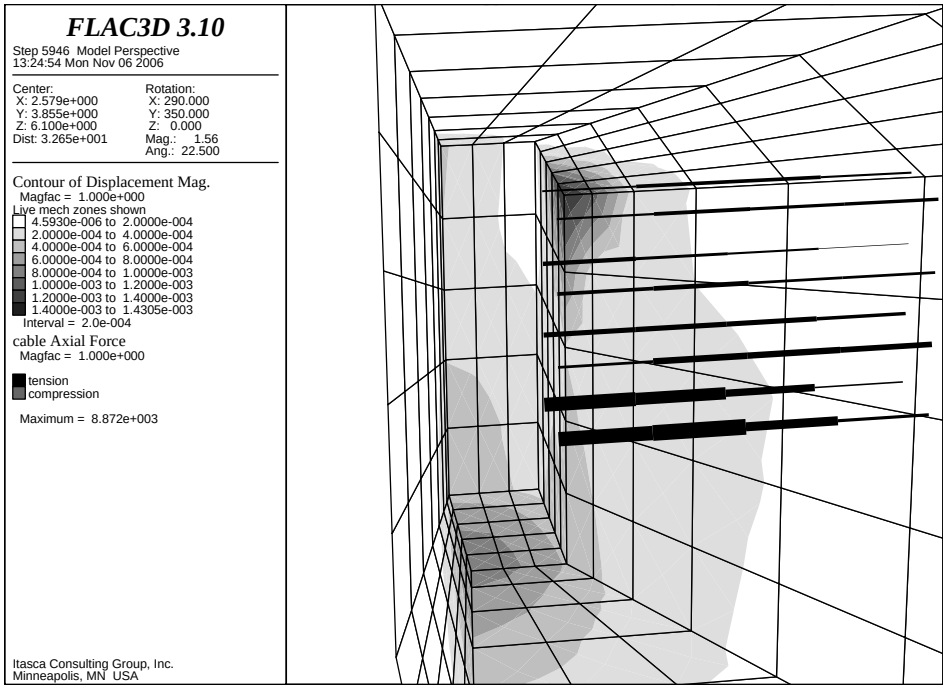

Figure 2.22 Forces in cables and displacement contours around trench excavation

2.7.7 Summary of Commands for Simple Analysis

The major command words described in Section 2.7 are summarized in Table 2.5. This table also illustrates the recommended command sequence for creating and running a model. These commands are all that are needed to begin performing simple analyses with *FLAC3D*. Start by running simple tests with these commands (e.g., uniaxial and confined compression tests or simple excavation-stability analyses). It may be helpful to review the detailed description of these commands in Section 1 in the **Command Reference**. Then try adding more complexity to the model. Before attempting very detailed simulations, we recommend that you read Section 3.3, which provides guidance on problem solving in general.

Table 2.5 Basic commands for simple analyses

FUNCTION	COMMAND
Grid generator	**GEN**
Material model and properties	**MODEL** **PROPERTY**
Boundary/initial conditions	**APPLY** **FIX** **INITIAL**
(with gravity)	**SET gravity**
Initial equilibrium	**STEP** **SOLVE**
Perform alterations	**MODEL** **PROPERTY** **APPLY** **FIX** **FREE**
(with support)	**SEL cable**
Save/restore problem state	**SAVE** **RESTORE**

2.8 Sign Conventions

The following sign conventions are used in *FLAC3D*, and must be kept in mind when entering input or evaluating results.

DIRECT STRESS — Positive stresses indicate tension; negative stresses indicate compression.

SHEAR STRESS — With reference to Figure 2.23, a positive shear stress points in the positive direction of the coordinate axis of the second subscript if it acts on a surface with an outward normal in the positive direction. Conversely, if the outward normal of the surface is in the negative direction, then the positive shear stress points in the negative direction of the coordinate axis of the second subscript. The shear stresses shown in Figure 2.23 are all positive. The stress tensor is symmetric — i.e., complementary shear stresses are equal.

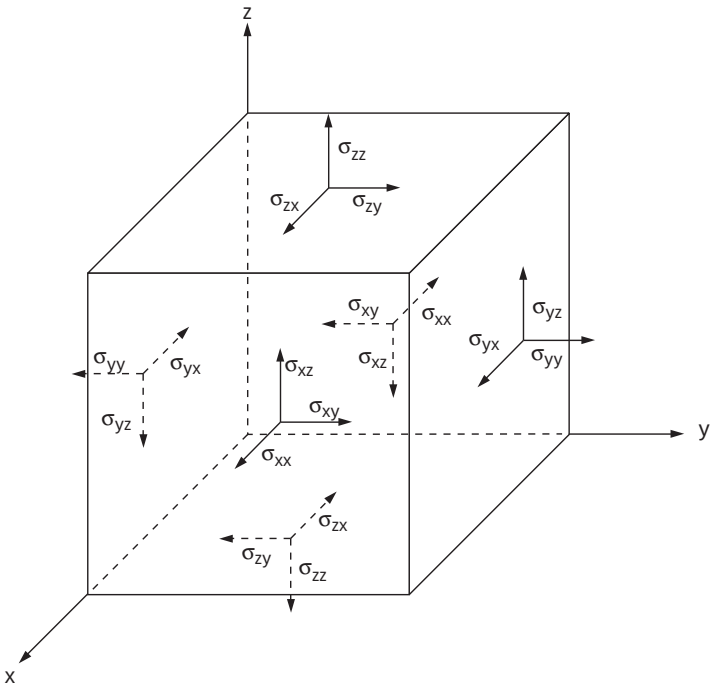

Figure 2.23 Sign convention for positive stress-components

DIRECT STRAIN — Positive strain indicates extension; negative strain indicates compression.

SHEAR STRAIN — Shear strain follows the convention of shear stress (see above).

PRESSURE — A positive pressure will act normal to, and in a direction toward, the surface of a body (i.e., push). A negative pressure will act normal to, and in a direction away from, the surface of a body (i.e., pull). Figure 2.24 illustrates this convention.

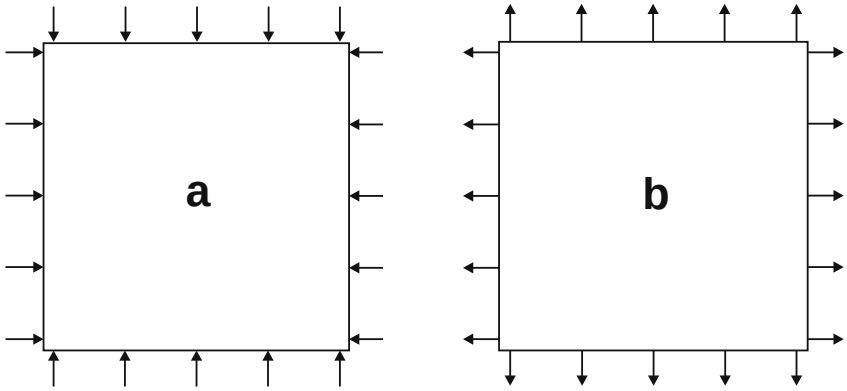

Figure 2.24 Mechanical pressure: (a) positive; (b) negative

PORE PRESSURE — Fluid pore pressure is positive in compression. Negative pore pressure indicates fluid tension.

DIP, DIP DIRECTION — Dip and dip direction assume that the x-direction corresponds to "East," the y-direction to "North," and the z-direction to "Up." The dip angle is measured in the negative z-direction from the global xy-plane. The dip direction angle is measured in the global xy-plane, clockwise from the positive y-axis. The x-, y- and z-components of vector quantities, such as forces, displacements and velocities, are positive when pointing in the directions of the positive x-, y- and z-coordinate space.

2.9 Systems of Units

FLAC3D accepts any consistent set of engineering units. Examples of consistent sets of units for basic parameters are shown in Tables 2.6 and 2.7. The user should apply great care when converting from one system of units to another. An excellent reference on the subject of units and conversion between the Imperial and SI systems can be found in the *Journal of Petroleum Technology* (December 1977). No conversions except for friction and dilation angles, which are entered in degrees, are performed in *FLAC3D*.

Table 2.6 Systems of units — mechanical parameters

	SI				Imperial	
Length	m	m	m	cm	ft	in
Density	kg/m^3	10^3 kg/m^3	10^6 kg/m^3	10^6 g/cm^3	slugs/ft^3	snails/in^3
Force	N	kN	MN	Mdynes	lb_f	lb_f
Stress	Pa	kPa	MPa	bar	lb_f/ft^2	psi
Gravity	m/sec^2	m/sec^2	m/sec^2	cm/s^2	ft/sec^2	in/sec^2

where 1 bar = 10^6 dynes/cm^2 = 10^5 N/m^2 = 10^5 Pa;
1 atm = 1.013 bars = 14.7 psi = 2116 lb_f/ft^2 = 1.01325 × 10^5 Pa;
1 slug = 1 lb_f - s^2/ft = 14.59 kg;
1 snail = 1 lb_f -s^2/in; and
1 gravity = 9.81 m/s^2 = 981 cm/s^2 = 32.17 ft/s^2.

Table 2.7 Systems of units — groundwater flow parameters

	SI		Imperial	
Water bulk modulus	Pa	bar	lbf/ft^2	psi
Water density	kg/m^3	10^6 g/cm^3	slugs/ft^3	snails/in^3
Permeability	m^{3}sec/kg	10^{-6} cm sec/g	ft^3 sec/slug	in^3 sec/snail
Intrinsic permeability	m^2	cm^2	ft^2	in^2
Hydraulic conductivity	m/sec	cm/sec	ft/sec	in/sec

NOTE: *FLAC3D* permeability (in SI units) ≡ intrinsic permeability (in cm^2) × 9.9 × 10^{-2}
≡ hydraulic conductivity (in cm/sec) × 1.02 × 10^{-6}

FLAC3D permeability is the *mobility coefficient* (coefficient of pore pressure term in Darcy's law).

Systems of units for parameters associated with structural elements and heat transfer are given in Section 1 in **Structural Elements** and Section 1 in **Optional Features**, respectively.

2.10 Precision Limits

When selecting a system of units, care should be taken to avoid calculations that approach the precision limits of the computer hardware. For 80386/387-based computers, the range is approximately 10^{-300} to 10^{300} in double-precision. If numbers exceed these limits, it is likely that the program will crash, or at least produce artifacts in the model that may be difficult to identify or detect.

2.11 Files

There are six types of files that are either used or created by *FLAC3D*. The files are distinguished by their extensions and are described below.

INITIALIZATION FILE

"FLAC3D.INI" — This is a formatted ASCII file, created by the user, that *FLAC3D* will automatically access upon start-up or when a **NEW** command is issued. *FLAC3D* searches for the file "FLAC3D.INI" in the directory in which the code is executed and, if not found, in the directory pointed to by the ITASCA environment variable. The file may contain any valid *FLAC3D* command(s) (see Section 1 in the **Command Reference**). Although this file does not need to exist (i.e., no errors will result if it is absent), it is normally used to change default options in *FLAC3D* to those preferred by the individual user each time a new analysis is run (see Section 2.1.7).

DATA FILES

The user has a choice of running *FLAC3D* interactively (i.e., entering *FLAC3D* commands while in the *FLAC3D* environment) or via a data file (also called a "batch file"). The data file is a formatted ASCII file created by the user which contains the set of *FLAC3D* commands that represents the problem being analyzed. In general, creating data files is the most efficient way to use *FLAC3D*. To use data files with *FLAC3D*, see the **CALL** command in Section 1 in the **Command Reference**. Data files can have any filename and any extension. It is recommended that a common extension (e.g., ".DAT" for *FLAC3D* input commands, and ".FIS" for *FISH* function statements) be used to distinguish these files from other types of files.

SAVE FILES

"FLAC3D.SAV" — This file is created by *FLAC3D* at the user's request when issuing the command **SAVE**. The default file name is "FLAC3D.SAV," which will appear in the default directory when quitting *FLAC3D*. The user may specify a different file name by issuing the command **SAVE** filename, where filename is a user-specified file name. "FLAC3D.SAV" is a binary file containing the values of all state variables and user-defined conditions. The primary reason for creating save files is to allow one to investigate the effect of parameter variations without having to rerun a problem completely. A save file can be restored and the analysis continued at a subsequent time (see the **RESTORE** command in Section 1 in the **Command Reference**). Normally, it is good practice to create several save files during a *FLAC3D* run.

LOG FILES

"FLAC3D.LOG" — This file is created by *FLAC3D* at the user's request when issuing the command **SET log on**. It is a formatted ASCII file. The default name of the file is "FLAC3D.LOG," which will appear in the default directory after quitting *FLAC3D*. The user may specify a different file name by issuing the command **SET logfile** filename, where filename is a user-supplied file name. The command may be issued interactively or be part of a data file. Subsequent to the **SET log on** command, all text appearing on the screen will be copied to the log file. The log file is useful in

providing a record of the *FLAC3D* work session; it also provides a document for quality-assurance purposes.

HISTORY FILES

"FLAC3D.HIS" — This file is created by *FLAC3D* at the user's request when issuing the command **HISTORY write *n***, where ***n*** is a history number (see the **HISTORY** command, Section 1 in the **Command Reference**). It is a formatted ASCII file. The default name of the file is "FLAC3D.HIS," which will appear in the default directory after quitting *FLAC3D*. The user may specify a different file name by issuing the keyword phrase **file** myfile.his at the end of the **HISTORY write** command.

The command may be issued interactively or be part of a data file. A record of the history values is written to the file, which can be examined using any text editor that can access formatted ASCII files. Alternatively, the file may be processed by a commercial graph-plotting or spreadsheet package.

PLOT FILES

Plot files are created at the user's request by issuing the command **PLOT hardcopy** in the command mode, or by pressing the FILE PRINT menu item from the main *FLAC3D* window. In both cases, a plot will be directed to the current Windows printer. The user may specify a plot file name by giving the command **SET output** myfile.ps, where "MYFILE.PS" is a user-specified filename. Other graphics output options are described in Section 2.1.4.

MOVIE FILES

DCX Movie — This file is created by *FLAC3D* at the user's request when issuing the commands **SET movie dcx** and **MOVIE**. Its purpose is to capture graphics images for playback as a movie using the movie utility supplied with the Itasca software product ("MOVIE.EXE," located in "c:\Program Files\Itasca\Shared\Utility). The default file name is "FLAC3D.DCX," which will appear in the default directory when quitting *FLAC3D*. The user may specify a different file name by issuing the command **SET movie file** filename, where filename takes the place of "FLAC3D.DCX." A DCX file format is used for the movie file when **SET movie dcx** is specified. DCX files are a collection of PCX files and include an index to the PCX files. A DCX file can contain up to 1024 PCX images. See the **MOVIE** and **SET movie** commands in Section 1 in the **Command Reference**.

AVI Movie — This file is created by *FLAC3D* at the user's request when issuing the commands **SET movie avi** and **MOVIE**. Its purpose is to capture graphics images for playback as a movie using the standard Windows Media Player. The default file name is "FLAC3D.AVI," which will appear in the default directory when quitting *FLAC3D*. The user may specify a different file name by issuing the command **SET movie file** filename, where filename takes the place of "FLAC3D.AVI." The AVI file format is used for the movie file when **SET movie avi** is specified. See the **MOVIE** and **SET movie** commands in Section 1 in the **Command Reference**.

FISH I/O FILES

A user-written *FISH* function may create, write and read files (see Section 2.7.2 in the ***FISH* volume**) of two forms. If the binary form is selected, the exact binary representation of a *FISH*

variable is stored on file. If the ASCII form is selected, numeric or character data may be written, or read from, a file. The latter form is a useful way to process ASCII data in a non-standard way on file.

2.12 Introducing the *FLAC3D* Graphical User Interface

This section is intended to provide a brief introduction to the use of the *FLAC3D* Graphical User Interface, or GUI. The primary uses of the GUI at this time are in accessing the powerful plotting functions in *FLAC3D*, and in file handling. The GUI allows the user to switch directly from keyboard (command-line) control to mouse control of *FLAC3D*. It is assumed that a mouse is attached to the computer, and that both the hardware and software components of the mouse are working correctly.

When *FLAC3D* is loaded, the main *FLAC3D* window will appear (Figure 2.25). The code name and current version number are printed in the title bar at the top of the window, and a menu bar is positioned just below the title bar. A bar with the `Flac3D>` prompt is in a command line window located at the bottom of the main window; any *FLAC3D* commands can be entered here. The command window echoes all the input to, and output from, *FLAC3D*. Moving the mouse should result in the cursor moving around the main window; various components should become highlighted as the mouse pointer moves over them and the mouse button is clicked.

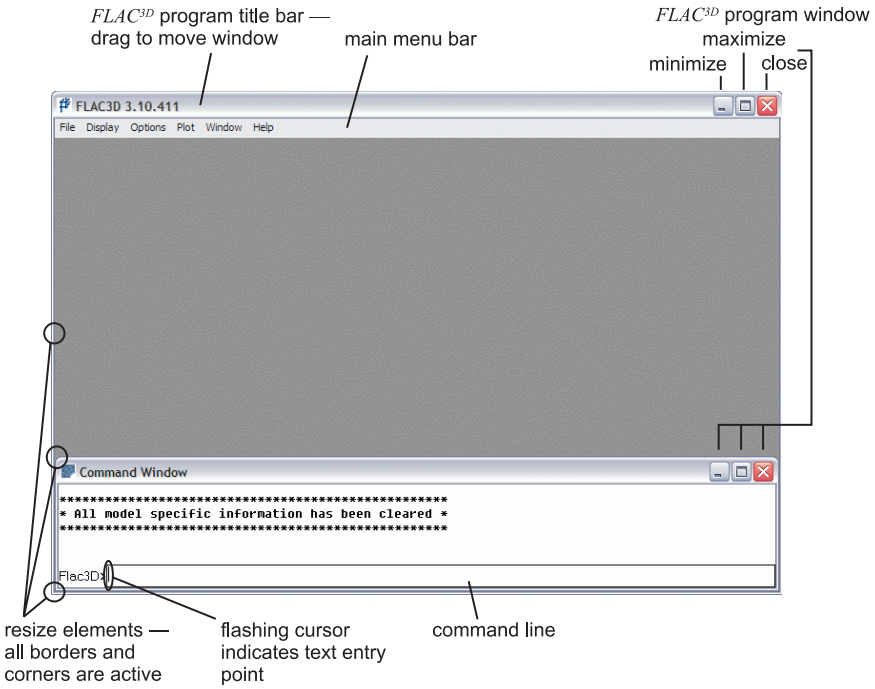

Figure 2.25 The FLAC3D main window

The underlined letters on the menu items represent hot-keys — press <ALT-*key*> to activate a main menu item. Once a main menu item is selected and its drop-down menu appears, as in Figure 2.26, that drop-down menu has the keyboard focus. Pressing the hot-key for any item on the drop-down menu on its own (i.e., without pressing <ALT>) will select that item. This is true for all of the drop-down menus. Pressing <Esc> clears the menu.

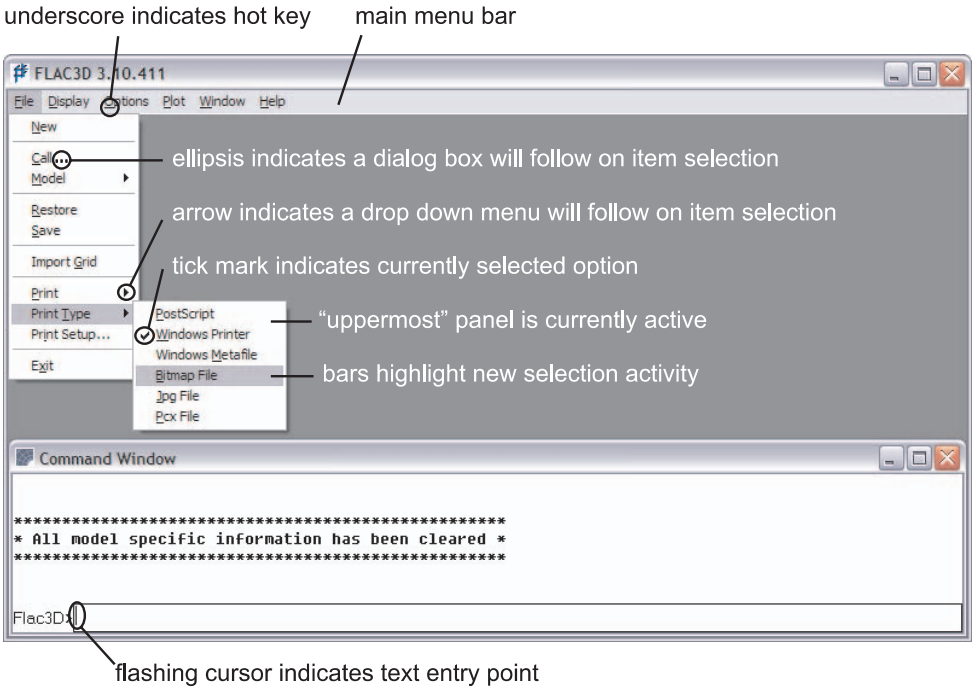

Figure 2.26 The menu items

From the freshly started main window, try pressing

```
Alt-F
C
```

to get the dialog box enabling the selection of a data file. Single clicks with the mouse on the FILE and then the CALL menu options will produce the same result. Your screen should display a dialog box similar to that shown in Figure 2.27.

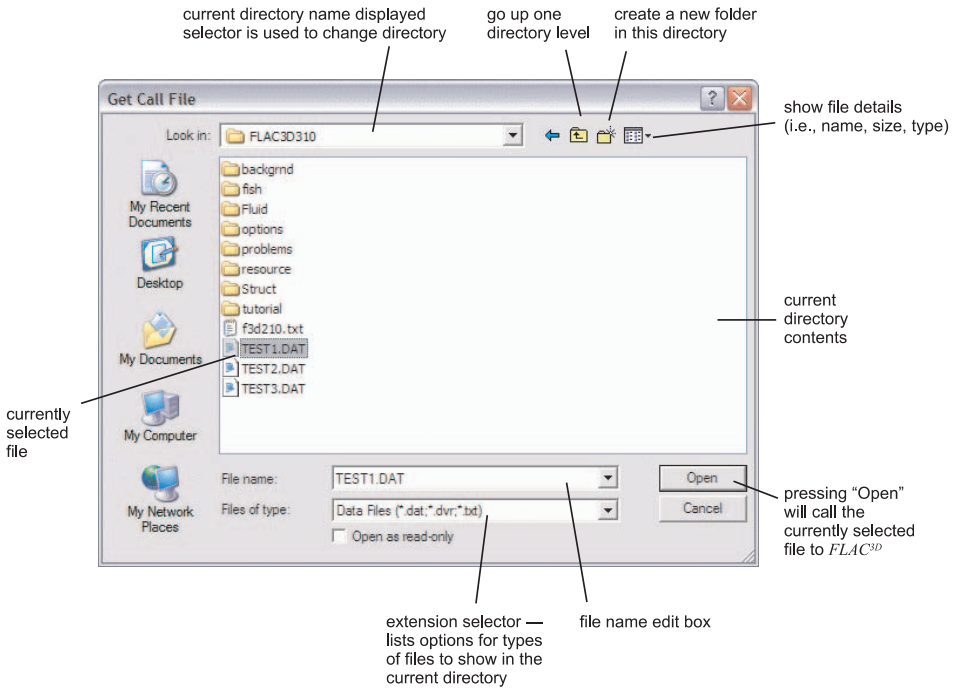

Figure 2.27 The FILE/CALL dialog box

Looking at the FILE/CALL dialog box, we see a list box containing files and sub-directories within the *FLAC3D* directory. With the mouse, clicking on a list name will either open the sub-directory or cause the file to be chosen for calling into *FLAC3D*. For example, we wish to open the data file "TRENCH1.DAT" that is located in the "\Tutorial\Beginner" directory. Double-click on the "Tutorial" directory name in the list box, and then double-click on the "Beginner" directory name. Pick the file "TRENCH1.DAT" from the list; then click on the OPEN button to process the data file.

Pressing <ESC> will remove the dialog box from the screen. The <TAB> key will move the cursor between the edit fields.

The data file is opened and read, just as if we were entering the file with the **CALL** command. We can view a plot of our model while the model itself is still under construction. As any change that affects the current plot is made to the model, the plot is updated. Run the example and watch for the prompts at the bottom of the screen. Figure 2.28 shows the results at one particular position in the run.

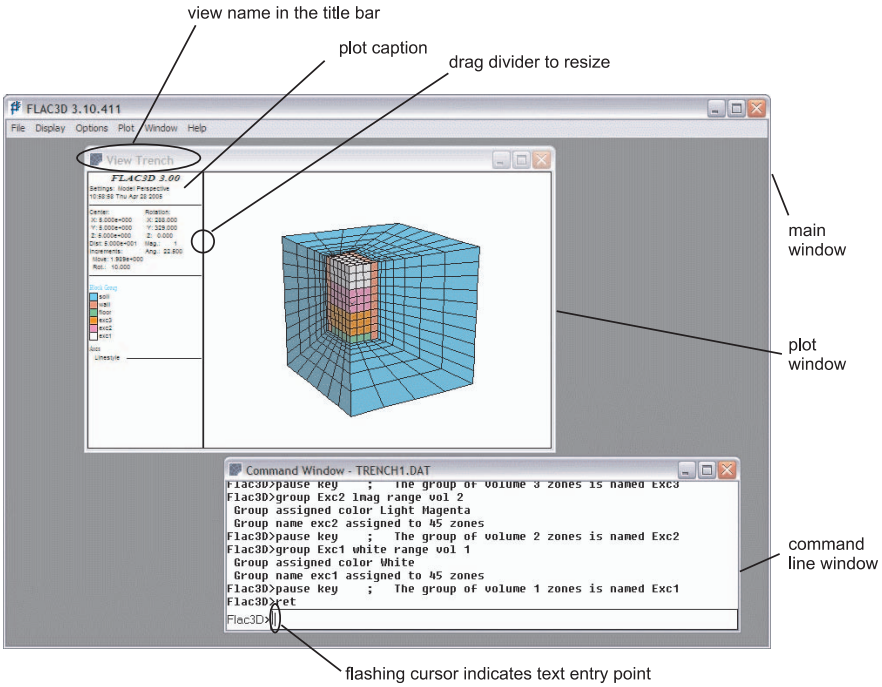

Figure 2.28 A plot window

We are simply examining the construction sequence in our model to see that we have things working in the right order. A tiny error during the copying of lines in the data file creation has corrupted the excavation sequence. To correct it, open the file "TRENCH1.DAT" in your favorite editor, change the comment symbols as shown in Example 2.24, and save the edited file.

Example 2.24 Using comments during model testing

```
change this ...
     model null range region Exc1    ;swap the comment marker at the
     ;model null range region Exc2   ;start of these two lines

to look like this ...
     ;model null range region Exc1   ;swap the comment marker at the
     model null range region Exc2    ;start of these two lines
```

Call "TRENCH1.DAT" again to see whether the excavation now works.

Clicking the mouse button on a plot window will open the plot menu for that view. The plot menu bar replaces the main menu bar below the title bar. Moving the mouse pointer over a selectable button in the plot menu and clicking the mouse causes a drop-down menu to open. For example, by clicking on PLOTITEMS in the plot menu, a menu will open with options to add or modify plot items on the active plot view.

The interactive plotting control keys are available to a plot window that has focus. Try pressing the <M> key — one of two things will happen: if the plot window has focus, the plot image will be magnified; if the command window has focus, an "m" will appear on the command line. A mouse click on an area will pull the focus to that area. Pressing <ENTER> will shift the focus from a plot window to the command window.

Any *FLAC3D* command can be entered at the command line to modify the currently active plot. Click on the command line to give it focus and type

```
plot modi 1 range group Soil not
```

followed by the <ENTER> key. The current plot window is updated automatically every time a command that affects the view contained in that plot window is issued.

The preceding modification can also be made from the plot menu by clicking on the PLOTITEMS menu item, then the 1BLOCK GROUP menu item, and then the MODIFY menu item. This will open a *Block Group* dialog box. To remove a block group from the plot, click on the EDITRANGE button, and this will open a *Get Range* dialog box. The soil group can be removed from the plot by clicking on the ADD button, then double-clicking on the *Group* range element, clicking the *Soil* group, and finally clicking the NOT item. Click OK twice to view the change.

Example 2.25 contains a complete listing of "TRENCH1.DAT" as used in this tutorial.

Example 2.25 The GUI tutorial file "TRENCH1.DAT"

```
;-----------------------------------------------
; FLAC3D tutorial - use of the GUI
;-----------------------------------------------
new
; create a general view of the model --------
; position the command window
mainwin pos 0.3 0.63 size 0.6 0.35
; create and position a plot window
plot create Trench
plot set back white
plot set dis 50
plot set rot 288 329 0
plot set center 5 5 5
plot set cap size 25
plot set window pos 0.19 0.02 size 0.62 0.61
plot add block group lcyan lred lgreen  orange lmagenta white shade on
plot add vol yell yell yell
plot add axes black
plot show
;
; generate the mesh ------------
gen zone radbrick  p0 (0,0,0) p1 (10,0,0) p2 (0,10,0) p3 (0,0,10) &
```

```
                  size 4,10,6,7     ratio 1,1,1,1.5      dim 2 5 3   fill
pause key    ;   Create the model grid
gen sur brick ver 0   0 0 ver 1.5   0 0 ver 0 1.5 0 ver 0   0 2.5
;           Define trench volumes
pause key    ;   This is trench volume 1
gen sur brick ver 0 1.5 0 ver 1.5 1.5 0 ver 0 3.0 0 ver 0 1.5 2.5
pause key    ;   This is trench volume 2
gen sur brick ver 0 3.0 0 ver 1.5 3.0 0 ver 0 4.5 0 ver 0 3.0 2.5
pause key    ;   This is trench volume 3
gen sur brick ver 0 4.5 0 ver 1.5 4.5 0 ver 0 5.0 0 ver 0 4.5 2.5
pause key    ;   This is trench volume 4
plot sub 2
group Soil lcyan
;           Give the different groups of the model unique names
pause key    ;   The entire model group is named Soil
group Wall lred range x 0 2 y 0 5 z 0 3  &
                     vol 1  not vol 2 not vol 3 not vol 4 not
pause key    ;   A group around the trench is named Wall
group Floor lgreen range vol 4
pause key    ;   The bottom of the trench is named Floor
group Exc3 orange range vol 3
pause key    ;   The group of volume 3 zones is named Exc3
group Exc2 lmag range vol 2
pause key    ;   The group of volume 2 zones is named Exc2
group Exc1 white range vol 1
pause key    ;   The group of volume 1 zones is named Exc1
;           Use MODEL NULL to excavate volumes
model null range group Exc1
pause key    ;   Excavate Volume 1
model null range group Exc1    ;swap the comment marker at the
;model null range group Exc2   ;start of these two lines
pause key    ;   Excavate Volume 2
model null range group Exc3
pause key    ;   Excavate Volume 3
model null range group Floor
pause key    ;   Excavate Floor
model mo range group Floor
             ;Place fill in Floor
```

2.13 References

Journal of Petroleum Technology. "The SI Metric System of Units and SPE's Tentative Metric Standard," pp. 1575-1616 (December 1977).

3 PROBLEM SOLVING WITH *FLAC3D*

This section provides guidance in the use of *FLAC3D* in problem solving for static mechanical analysis* in geotechnical engineering. In Section 3.1, an outline of the steps recommended for performing a geomechanics analysis is given, followed in Sections 3.2 through 3.9 by an examination of specific aspects that must be considered in any model creation and solution. These include:

- grid generation (Section 3.2);
- boundary and initial conditions (Sections 3.3 and 3.4);
- loading and sequential modeling (Section 3.5);
- choice of constitutive model and material properties (Sections 3.6 and 3.7);
- ways to improve modeling efficiency (Section 3.8); and
- interpretation of results (Section 3.9).

Each of these modeling aspects is discussed in detail. The user who is familiar with the two-dimensional program *FLAC* will find that the modeling approach is very similar in *FLAC3D*. The major difference is the procedure for grid generation. We recommend that Section 3.2 be studied carefully, and that the example problems in that section be repeated before users create their own model grids. You will note that *FISH* programs are used in this section to assist with model generation and problem solving. If you have not used the *FISH* language before, we recommend that you first read the *FISH* tutorial in Section 4.2.

Finally, the philosophy of modeling in the field of geomechanics is examined in Section 3.10; the novice modeler in this field may wish to consult this section first. The methodology of modeling in geomechanics can be significantly different from that in other engineering fields, such as structural engineering. It is important to keep this in mind when performing any geomechanics analysis.

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* Problem solving for coupled mechanical-groundwater analysis is discussed in Section 1 in **Fluid-Mechanical Interaction**, and for coupled mechanical-thermal analysis in Section 1 in **Optional Features**. Problem solving for dynamic analysis is discussed in Section 3 in **Optional Features**.

3.1 General Approach

The modeling of geo-engineering processes involves special considerations and a design philosophy different from that followed for design with fabricated materials. Analyses and designs for structures and excavations in or on rocks and soils must be achieved with relatively little site-specific data, and an awareness that deformability and strength properties may vary considerably. It is impossible to obtain complete field data at a rock or soil site. For example, information on stresses, properties and discontinuities can only be partially known, at best.

Since the input data necessary for design predictions is limited, a numerical model in geomechanics should be used primarily to understand the dominant mechanisms affecting the behavior of the system. Once the behavior of the system is understood, it is then appropriate to develop simple calculations for a design process.

This approach is oriented toward geotechnical engineering, in which there is invariably a lack of good data. But, in other applications, it may be possible to use *FLAC3D* directly in design if sufficient data, as well as an understanding of material behavior, is available. The results produced in a *FLAC3D* analysis will be accurate when the program is supplied with appropriate data. Modelers should recognize that there is a continuous spectrum of situations, as illustrated in Figure 3.1:

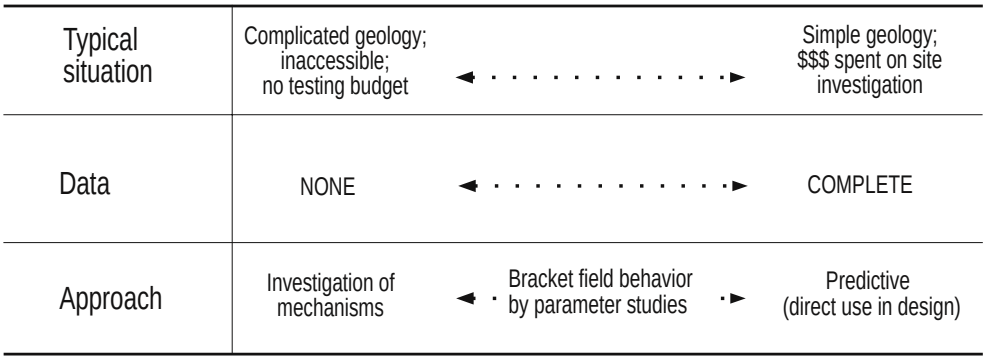


Figure 3.1 Spectrum of modeling situations

FLAC3D may be used either in a fully predictive mode (right-hand side of Figure 3.1) or as a "numerical laboratory" to test ideas (left-hand side). It is the field situation (and budget), rather than the program, that determines the types of use. If enough data of a high quality is available, *FLAC3D* can give good predictions.

Since most *FLAC3D* applications will be for situations in which little data is available, this section discusses the recommended approach for treating a numerical model as if it were a laboratory test. The model should never be considered as a "black box" that accepts data input at one end and produces a prediction of behavior at the other. The numerical "sample" must be prepared carefully, and several samples tested, to gain an understanding of the problem. Table 3.1 lists the steps recommended to perform a successful numerical experiment; each step is discussed separately.

Table 3.1 Recommended steps for numerical analysis in geomechanics

Step 1	Define the objectives for the model analysis
Step 2	Create a conceptual picture of the physical system
Step 3	Construct and run simple idealized models
Step 4	Assemble problem-specific data
Step 5	Prepare a series of detailed model runs
Step 6	Perform the model calculations
Step 7	Present results for interpretation

3.1.1 Step 1: Define the Objectives for the Model Analysis

The level of detail to be included in a model often depends on the purpose of the analysis. For example, if the objective is to decide between two conflicting mechanisms that are proposed to explain the behavior of a system, then a crude model may be constructed, provided that it allows the mechanisms to occur. It is tempting to include complexity in a model just because it exists in reality. However, complicating features should be omitted if they are likely to have little influence on the response of the model, or if they are irrelevant to the model's purpose. Start with a global view and add refinement as (and if) necessary.

3.1.2 Step 2: Create a Conceptual Picture of the Physical System

It is important to have a conceptual picture of the problem to provide an initial estimate of the expected behavior under the imposed conditions. Several questions should be asked when preparing this picture. For example, is it anticipated that the system could become unstable? Is the predominant mechanical response linear or nonlinear? Are movements expected to be large or small in comparison with the sizes of objects within the problem region? Are there well-defined discontinuities that may affect the behavior, or does the material behave essentially as a continuum? Is there an influence from groundwater interaction? Is the system bounded by physical structures, or do its boundaries extend to infinity? Is there any geometric symmetry in the physical structure of the system?

These considerations will dictate the gross characteristics of the numerical model, such as the design of the model geometry, the types of material models, the boundary conditions and the initial equilibrium state for the analysis. They will determine whether a three-dimensional model is required, or a two-dimensional model can be used to take advantage of geometric conditions in the physical system.

3.1.3 Step 3: Construct and Run Simple Idealized Models

When idealizing a physical system for numerical analysis, it is more efficient to construct and run simple test models first, before building the detailed model. Simple models should be created at the earliest possible stage in a project to generate both data and understanding. The results can provide further insight into the conceptual picture of the system; Step 2 may need to be repeated after simple models are run.

Simple models can reveal shortcomings that can be remedied before any significant effort is invested in the analysis. For example, do the selected material models sufficiently represent the expected behavior? Are the boundary conditions influencing the model response? The results from the simple models can also help guide the plan for data collection by identifying which parameters have the most influence on the analysis.

3.1.4 Step 4: Assemble Problem-Specific Data

The types of data required for a model analysis include:

- details of the geometry (e.g., profile of underground openings, surface topography, dam profile, rock/soil structure);
- locations of geologic structure (e.g., faults, bedding planes, joint sets);
- material behavior (e.g., elastic/plastic properties, post-failure behavior);
- initial conditions (e.g., in-situ state of stress, pore pressures, saturation); and
- external loading (e.g., explosive loading, pressurized cavern).

Since typically there are large uncertainties associated with specific conditions (in particular, state of stress, deformability and strength properties), a reasonable range of parameters must be selected for the investigation. The results from the simple model runs (in Step 3) can often prove helpful in determining this range, and in providing insight for the design of laboratory and field experiments to collect the needed data.

3.1.5 Step 5: Prepare a Series of Detailed Model Runs

Most often, the numerical analysis will involve a series of computer simulations that include the different mechanisms under investigation, and span the range of parameters derived from the assembled database. When preparing a set of model runs for calculation, several aspects, such as those listed below, should be considered.

1. How much time is required to perform each model calculation? It can be difficult to obtain sufficient information to arrive at a useful conclusion if model runtimes are excessive. Consideration should be given to performing parameter variations on multiple computers to shorten the total computation time.

2. The state of the model should be saved at several intermediate stages so that the entire run does not have to be repeated for each parameter variation. For example, if the analysis involves several loading/unloading stages, the user should be able to return to any stage, change a parameter and continue the analysis from that stage. The amount of disk space required for save files should be considered.

3. Are there a sufficient number of monitoring locations in the model to provide for a clear interpretation of model results and for comparison with physical data? It is helpful to locate several points in the model at which a record of the change of a parameter (such as displacement, velocity or stress) can be monitored during the calculation. Also, the maximum unbalanced force in the model should always be monitored to check the equilibrium or failure state at each stage of an analysis.

3.1.6 Step 6: Perform the Model Calculations

It is best to first make one or two model runs, split into separate sections, before launching a series of complete runs. The runs should be checked at each stage to ensure that the response is as expected. Once there is assurance that the model is performing correctly, several data files can be linked together to run a complete calculation sequence. At any time during a sequence of runs, it should be possible to interrupt the calculation, view the results, and then continue or modify the model as appropriate.

3.1.7 Step 7: Present Results for Interpretation

The final stage of problem solving is the presentation of the results for a clear interpretation of the analysis. This is best accomplished by displaying the results graphically, either directly on the computer screen or as output to a hardcopy plotting device. The graphical output should be presented in a format that can be directly compared to field measurements and observations. Plots should clearly identify regions of interest from the analysis, such as locations of calculated stress concentrations, or areas of stable movement versus unstable movement in the model. The numeric values of any variable in the model should also be readily available for more detailed interpretation by the modeler.

We recommend that these seven steps be followed to solve geo-engineering problems efficiently. The following sections describe the application of *FLAC3D* to meet the specific aspects of each of these steps in this modeling approach.

3.2 Grid Generation

At first, it may seem that the grid generation scheme in *FLAC3D* is limited to rather simple, regular-shaped regions; the examples given in Section 2.7 are all uniform, polyhedral grids. The *FLAC3D* grid, however, can be distorted to fit arbitrary and complicated volumetric regions. A powerful grid generator is built into *FLAC3D* to manipulate the grid to fit various shapes of three-dimensional problem domains.

The procedure for implementing the grid generator is described in this section. An overview of the generator operation is given first, in Section 3.2.1. This is followed, in Sections 3.2.2 and 3.2.3, by presentations on various aspects of grid generation, along with guidelines to follow in designing the grid for accurate solutions. Examples are given to illustrate each aspect. A special grid-generation tool is described in Section 3.2.4. This tool permits the generation of three-dimensional grids from two-dimensional (*FLAC*) data files by extruding the mesh in the third dimension.

One important aspect in grid generation is that all physical boundaries to be represented in the model simulation (including regions that will be added, or excavations created at a later stage in the simulation) *must* be defined before the solution stepping begins. Shapes of structures that will be added later in a sequential analysis must be defined and then removed (via **MODEL null**) until the appropriate time at which they are to be activated. The purpose of the grid generator is to facilitate the creation of all required physical shapes in the model.

3.2.1 Overview of the Grid Generator

Grid generation in *FLAC3D* involves patching together grid shapes of specific connectivity (referred to as *primitives*) to form a complete model with the desired geometry. Several types of primitives are available, and these can be connected and conformed to create complex three-dimensional geometries.*

Grid generation is invoked with the **GENERATE** command. The generation of zones for each primitive type is performed with the **GENERATE zone** command. Reference points can be defined with the **GENERATE point** command to assist with positioning gridpoints in the model region. The **GENERATE merge** command can be used to ensure that separate primitives are connected properly. All gridpoints along matching faces of zone primitives must fall within a specified tolerance, for two primitives to be merged. Alternatively, the **ATTACH** command is available to connect primitive meshes of different zone sizes. *FISH* can be used to adjust the final mesh, if necessary, to conform to the surfaces of the model region. Separate volume regions within the final mesh can be defined by using the **GENERATE surface** command. The following sections describe the use of each of these facilities to create a *FLAC3D* mesh. See Section 1.3 in the **Command Reference** for a detailed description of the **GENERATE** and **ATTACH** commands.

---

* Previous versions of *FLAC3D* also contained an automatic grid adjustment algorithm that used an iteration process to conform the grid to fit within a specified volume. This approach was found to be less efficient than building the grid using primitive shapes and has been discontinued.

3.2.1.1 Zone Generation

The *FLAC3D* grid is generated with the **GENERATE zone** command. This command actually accesses a library of primitive shapes; each shape has a specific type of grid connectivity. The primitive shapes available in *FLAC3D*, listed in order of increasing complexity, are summarized, with their associated keywords, in Table 3.2.

Table 3.2 Primitive mesh shapes available with the* GENERATE zone *command

Keyword	Definition
brick	brick-shaped mesh
wedge	wedge-shaped mesh
uwedge	uniform wedge-shaped mesh
tetra	tetrahedral-shaped mesh
pyramid	pyramid-shaped mesh
cylinder	cylindrical-shaped mesh
dbrick	degenerate brick-shaped mesh
radbrick	radially graded mesh around brick
radtunnel	radially graded mesh around parallelepiped-shaped tunnel
radcylinder	radially graded mesh around cylindrical-shaped tunnel
cshell	cylindrical shell mesh
cylint	intersecting cylindrical-shaped tunnels
tunint	intersecting parallelepiped-shaped tunnels

As you have already seen in Section 2.2, **GENERATE zone** commands can be used alone to create a zoned model. If the 3D domain consists of simple shapes, the primitives can be applied individually, or connected together to create the *FLAC3D* grid.

As an example, a quarter-symmetry model can be created for a cylindrical tunnel with the command

```
gen zone radcyl size 5 10 6 12 fill
```

The **size** keyword defines the number of zones in the grid. For the cylindrical tunnel, each entry following the **size** keyword corresponds to the number of zones in a specific direction. In this case, there are five zones along the inner radius of the cylindrical tunnel, ten zones along the axis of the tunnel, six zones along the circumference of the tunnel, and twelve zones between the periphery of the tunnel and the outer boundary of the model. Figure 3.2 shows the model grid. The **fill** keyword is given to fill the tunnel with zones.

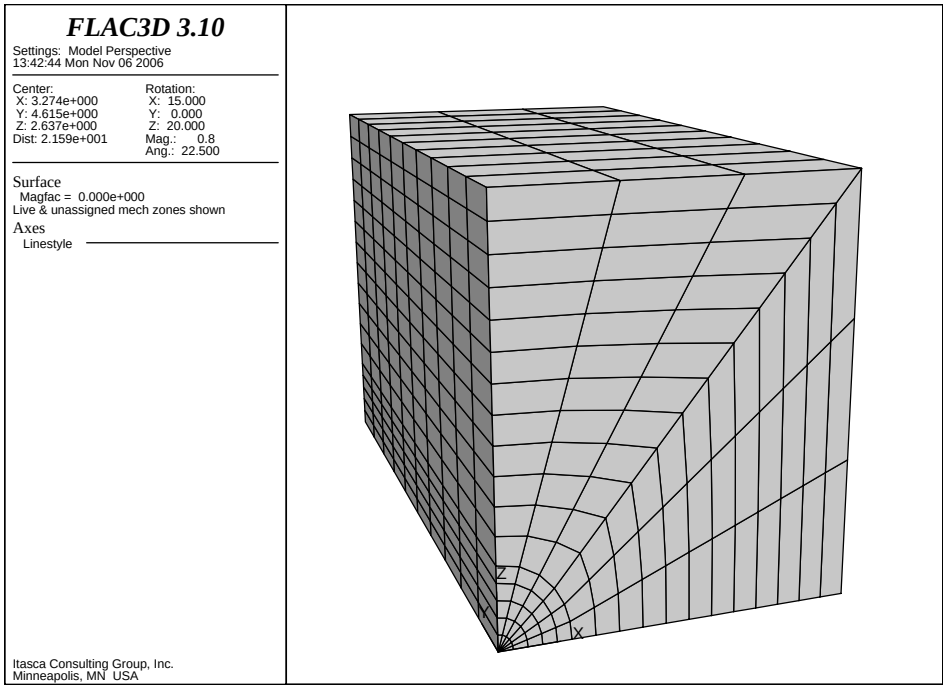


Figure 3.2 Grid for cylindrical tunnel model

In addition to **size** and **fill**, there are several other keywords available to define the characteristics of the primitive shapes. The available characteristic keywords for primitive shapes are summarized in Table 3.3. You should refer to Figures 1.4 through 1.16 in the **Command Reference** to identify which keywords and numerical entries are applicable for each primitive shape. For example, refer to Figure 1.13 in the **Command Reference** to check the order in which the **size** entries (*n1*, *n2*, *n3* and *n4*) should be entered for the cylindrical tunnel.

Table 3.3 Characteristics keywords for* GENERATE zone *primitive shapes

Keyword	Definition
dimension	dimensions of the interior regions
edge	edge length for the sides of the mesh
fill	fill the interior region with zones
p0 through **p16**	reference (corner) points for the shape
ratio	geometric ratio used to space zones
size	number of zones for each shape

The **ratio** keyword is of particular significance when designing a grid to provide an accurate solution without requiring an excessive number of zones. For example, if fine zoning is required immediately around the periphery of the cylindrical tunnel in order to provide a more accurate representation of high-stress gradients, **ratio** can be used to adjust the zone size to be small close to the tunnel, and gradually increase in size away from the tunnel.

To see the effects of using the **ratio** keyword, type the command

```
gen zone radcyl size 5 10 6 12 ratio 1 1 1 1.2
```

Each **size** entry is controlled by a **ratio**. In this example, the fourth **size** entry has a geometric ratio of 1.2 — i.e., each successive zone is 1.2 times larger than the preceding zone, moving from the tunnel periphery to the outer boundary (see Figure 3.3). A ratio smaller than 1.0 can be given to change from an increasing to a decreasing geometric ratio.

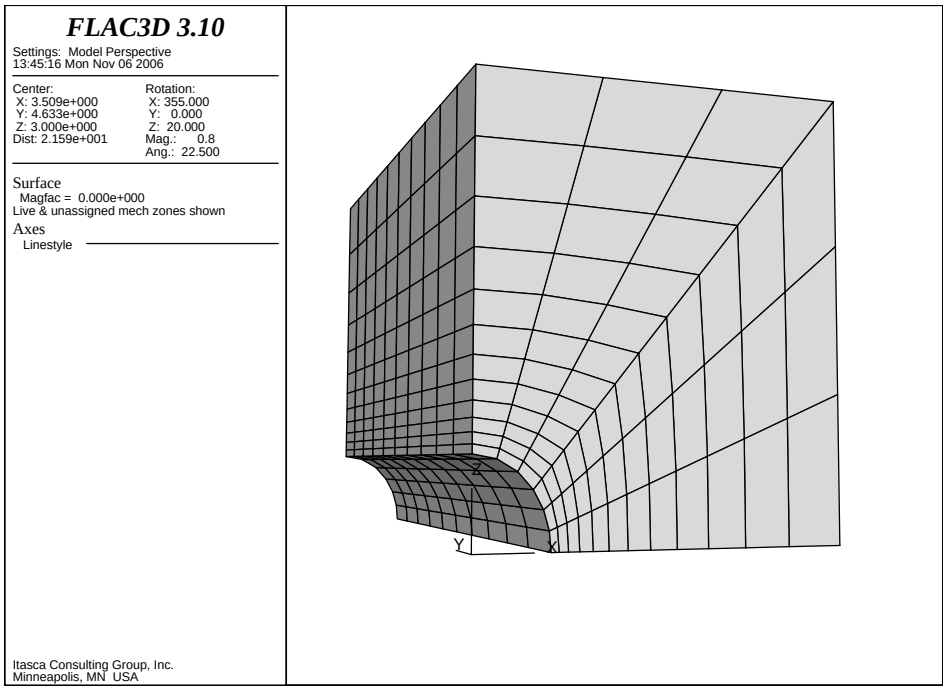


Figure 3.3 Radially graded grid around cylindrical tunnel

Sizing the grid for accurate results, but with a reasonable number of zones, can be complicated. Three factors should be remembered:

1. Finer meshes lead to more accurate results in that they provide a better representation of high-stress gradients.

2. Accuracy increases as zone aspect ratios tend to unity.

3. If different zone sizes are needed, then the more gradual the change from the smallest to the largest, the better the results.

The examples in the following sections illustrate some applications of these factors.

Several **GENERATE zone** commands can be given to connect two or more primitive shapes together to build a grid. For example, to build a horseshoe-shaped tunnel, the **radcylinder** and **radtunnel** shapes can be used as demonstrated in Example 3.1.

Example 3.1 Building a horseshoe-shaped tunnel — half model

```
gen zone radcyl size 5 10 6 12 rat 1 1 1 1.2 &
                p0 0,0,0 p1 100,0,0 p2 0,200,0 p3 0,0,100
gen zone radtun size 5 10 5 12 rat 1 1 1 1.2 &
                p0 0,0,0 p1 0,0,-100 p2 0,200,0 p3 100,0,0
```

Figures 1.12 and 1.13 in the **Command Reference** should be consulted when building these shapes. The model boundary dimensions are 100 × 200 × 100; the boundary coordinates are defined with the **p0**, **p1**, **p2** and **p3** keywords. The grid is shown in Figure 3.4. Note that the **radtunnel** shape is turned 90° to fit beneath the **radcylinder** shape. This is accomplished by specifying different p1-, p2- and p3-coordinate entries for the **radtunnel** shape.

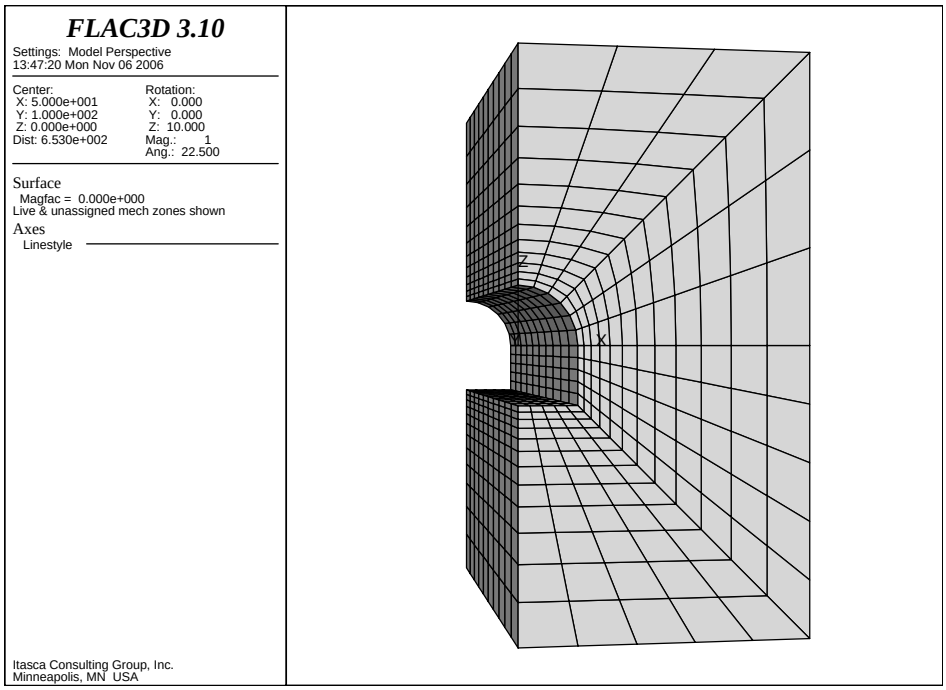


Figure 3.4 Horseshoe-shaped tunnel made from* radcylinder *and* radtunnel *primitives

With **GENERATE zone**, two additional options are available to assist with the creation of a grid composed of multiple shapes: **GENERATE zone copy** and **GENERATE zone reflect**. The **copy** keyword is used to copy a shape or shapes to a new position by adding an offset vector to all the gridpoints. The **reflect** keyword is used to reflect the shape or shapes across a symmetry plane. Example 3.2 shows the additional command needed to reflect the geometry created by the earlier commands.

Example 3.2 Building a horseshoe-shaped tunnel — full model

```
gen zone radcyl size 5 10 6 12 rat 1 1 1 1.2 &
                p0 0,0,0 p1 100,0,0 p2 0,200,0 p3 0,0,100
gen zone radtun size 5 10 5 12 rat 1 1 1 1.2 &
                p0 0,0,0 p1 0,0,-100 p2 0,200,0 p3 100,0,0
gen zone reflect dip 90 dd 270 origin 0,0,0
```

The resulting grid is shown in Figure 3.5. The symmetry plane is a vertical plane (located by the **dip**, **dd** and **origin** keywords) coincident with the x = 0 plane. Note that dip angle (**dip**) and dip direction (**dd**) assume that x corresponds to "East," y to "North" and z to "Up."

A third option, the **GENERATE point** command, is available to position single points in the model region. This is useful for positioning gridpoints of zones. The **point** can be assigned directly to a gridpoint, rather than specifying global coordinates. Section 3.2.2 presents an example use of **GENERATE point** to position the invert of two tunnels of different sizes at the same elevation.

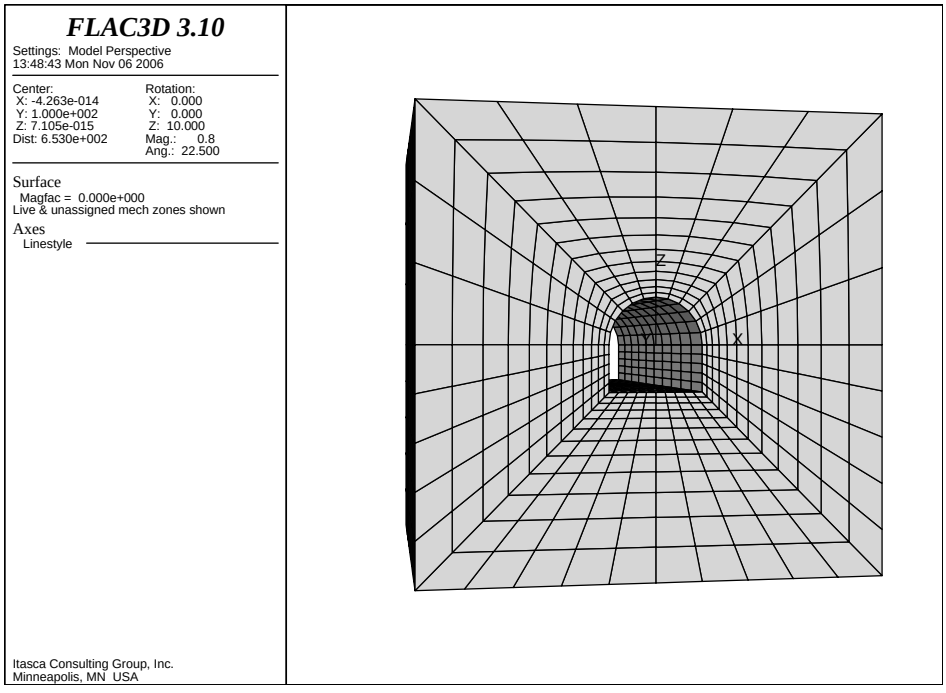


Figure 3.5 Complete horseshoe-shaped tunnel made from the* reflect *keyword

3.2.1.2 Connecting Adjoining Primitive Shapes

When building a geometry out of primitives, the sides of the primitives *must* connect to form an unbroken continuum. During execution of a **GENERATE zone** command, a check is made for each boundary gridpoint against the boundary gridpoints of zones that already exist. Internal gridpoints are not checked. If two boundary gridpoints fall within a tolerance of 1×10^{-7} (relative to the magnitude of the gridpoints position vector) of each other, they are assumed to be the same point, and the first gridpoint is used rather than creating a new one for all subsequent calculations.

The user is responsible for ensuring that all gridpoints along adjoining primitives correspond to one another. The use of reference points with the command **GENERATE point** during model creation can be useful to make sure that the bounding brick is specified correctly for both primitives. Make sure that the number of zones is correct and that the **ratio**s used for the zone distribution are consistent. Note that if the ratio for one primitive is going the opposite direction of the other, the inverse ratio should be used for one of the primitives to ensure that boundary gridpoints match.

This version of *FLAC3D* does not issue a warning message if gridpoints at boundaries do not match. It is helpful to use the **PLOT sketch** or **PLOT boundary** command to check boundary gridpoints visually. Localized velocity anomalies will be observed at non-matching gridpoints in the model when the calculation is started. If some gridpoints are found not to match, the **GENERATE merge** command can be used to merge these gridpoints after the **GENERATE zone** command has been applied.

The **ATTACH** command can be used to connect primitives with different zone sizes. There are some restrictions, though, to the range in zone size that may be specified with this approach. For the most accurate calculations, the ratio of zone sizes should be a multiple integer ratio (e.g., 2 to 1, 3 to 1, 4 to 1). It is recommended that the ratio be tested first by running the model under elastic conditions. If a discontinuity is observed in the displacement, or stress distribution across the attached grids, then the ratio of zone sizes may need to be adjusted. However, if the discontinuity is small and far from the region of interest, it may not have a significant influence on the calculation.

Example 3.3 illustrates the use of the **ATTACH** command and the effect of different zone sizes. A brick primitive with a zone dimension of 0.5 is connected to a brick primitive with a zone dimension of 1. The resulting z-displacement contours are shown in Figure 3.6.

Example 3.3 Two unequal sub-grids

```
gen zone brick size 4 4 4 p0 0,0,0 p1 4,0,0 p2 0,4,0 p3 0,0,2
gen zone brick size 8 8 4 p0 0,0,2 p1 4,0,2 p2 0,4,2 p3 0,0,4
attach face range z 1.9 2.1
model elas
prop bulk 8e9 shear 5e9
fix z range z -.1 .1
fix x range x -.1 .1
fix x range x 3.9 4.1
fix y range y -.1 .1
fix y range y 3.9 4.1
apply szz -1e6 range z 3.9 4.1 x 0,2 y 0,2
hist unbal
solve
save att.sav
```

To test the accuracy, we do a similar run, but for a single grid with a constant zone dimension of 0.5. The data file is given in Example 3.4. The results are shown in Figure 3.7. This plot is almost identical to that in Figure 3.6.

Example 3.4 A single grid for comparison to two sub-grids

```
gen zone brick size 8 8 8 p0 0,0,0 p1 4,0,0 p2 0,4,0 p3 0,0,4
model elas
prop bulk 8e9 shear 5e9
fix z range z -.1 .1
fix x range x -.1 .1
fix x range x 3.9 4.1
fix y range y -.1 .1
fix y range y 3.9 4.1
apply szz -1e6 range z 3.9 4.1 x 0,2 y 0,2
hist unbal
solve
save noatt.sav
```

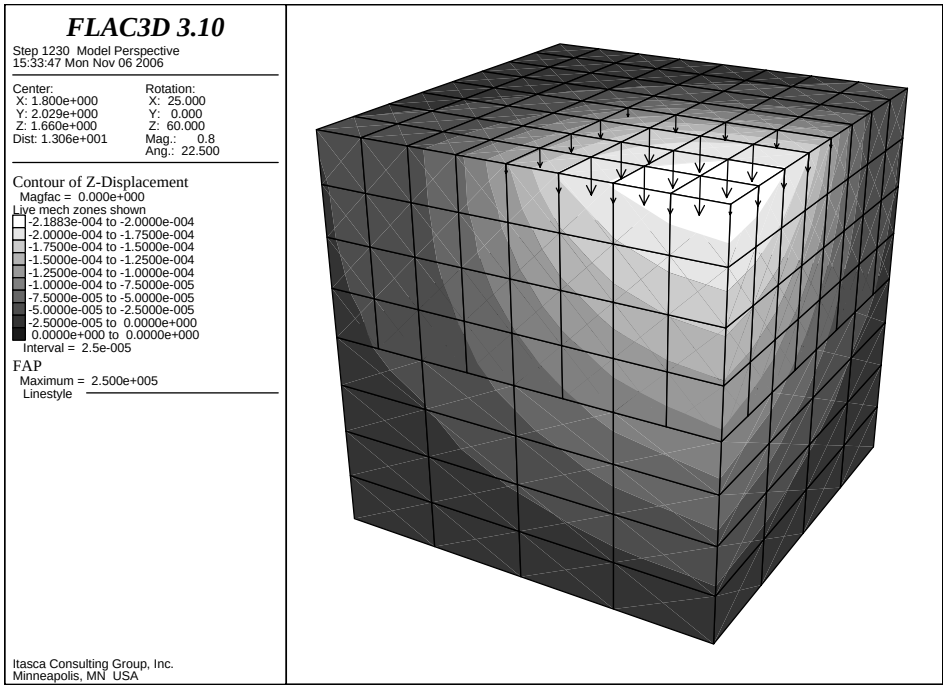


Figure 3.6 z-displacement contours in two attached grids with zone ratio of 2 to 1

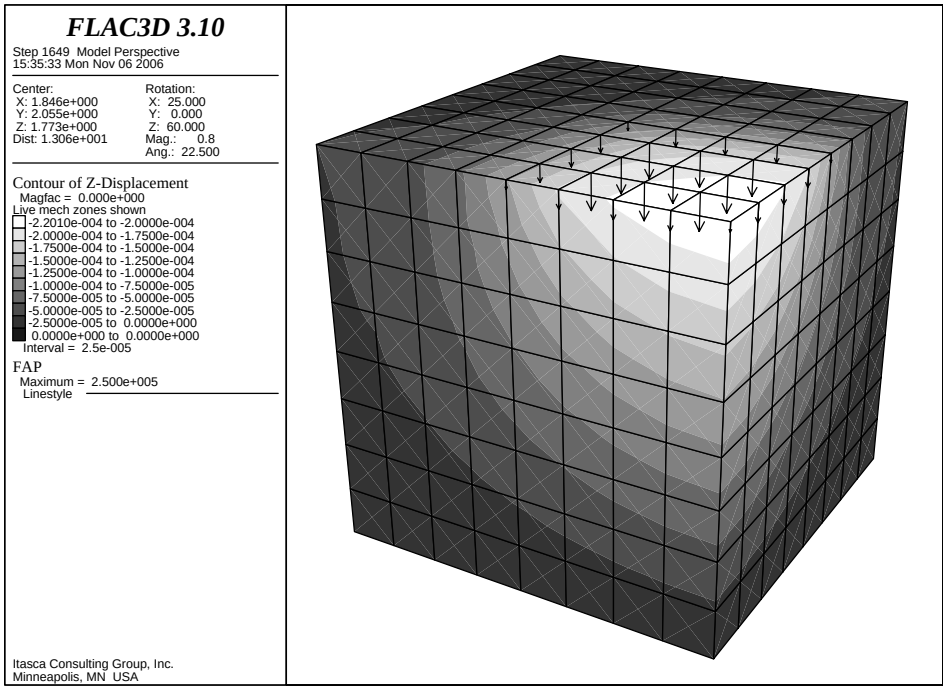


Figure 3.7 z-displacement contours in single grid

3.2.2 Fitting the Grid to Simple Shapes

The intention of grid generation is to fit the model grid to the physical region under study. For simple geometries, the **GENERATE zone** command is all that is required to generate a model grid to fit the problem domain. To determine whether **GENERATE zone** is sufficient, try defining the problem domain by one or more of the primitive shapes listed in Table 3.2 (see Table 1.3 in the **Command Reference** for sketches of these shapes).

For example, consider a problem geometry involving three parallel tunnels (a service tunnel located midway between two larger main tunnels). The three tunnels are all cylindrical in shape, so the **radcylinder** primitive shape is the logical choice to build the tunnel grids. A vertical symmetry plane may be assumed to exist along the centerline of the service tunnel. Thus, it is only necessary to create a mesh for one main tunnel and half of the service tunnel.

We have two important concerns when building any model: (1) the density of zoning required for an accurate solution in the region of interest; and (2) how the location of the grid boundaries influence model results.

It is important to have a high density of zoning in regions of high stress- or strain-gradients. Often, it is possible to perform two-dimensional analyses to define these regions. For this problem, a 2D *FLAC* calculation can easily be run to determine an acceptable density of zones around the tunnels. For demonstration purposes, we select a zone size of roughly one-half the service tunnel radius for the zones surrounding the tunnels.

The first step in grid generation for this problem is to use **radcylinder** primitives to create the grids for the tunnels. The complicating factor is that the tunnels are of different sizes and have the same invert elevation. The service tunnel has a radius of 3 m, and the main tunnels have a radius of 4 m. The length of the model corresponds to a 50 m length of the tunnels. Example 3.5 shows the commands to create the grid surrounding the tunnels.

Example 3.5 Creating a grid for two tunnels with the same invert elevation

```
; main tunnel
gen zon radcyl  p0 15 0 0 p1 23 0 0 p2 15 50 0 p3 15 0 8 &
                size 4 10 6 4 dim 4 4 4 4 rat 1 1 1 1 fill
gen zon reflect dip 90 dd 90 orig 15 0 0
gen zon reflect dip 0 ori 0 0 0
; service tunnel
gen point id 1 (2.969848,0.0,-0.575736)
gen point id 2 (2.969848,50.0,-0.575736)
gen zon radcyl  p0 0 0 -1 p1 7 0 0 p2 0 50 -1 p3 0 0 8 p4 7 50 0 &
                p5 0 50 8 p6 7 0 8 p7 7 50 8 p8 point 1 p10 point 2 &
                size 3 10 6 4 dim 3 3 3 3 rat 1 1 1 1
gen zon radcyl  p0 0 0 -1 p1 0 0 -8 p2 0 50 -1 p3 7 0 0 p4 0 50 -8 &
                p5 7 50 0 p6 7 0 -8 p7 7 50 -8 p9 point 1 p11 point 2 &
                size 3 10 6 4 dim 3 3 3 3 rat 1 1 1 1
```

The main tunnel grid is created first: one-quarter of the grid is generated; then the grid is reflected across horizontal and vertical planes to create the grid for the entire tunnel. The **reflect** option cannot be used for the service tunnel, because the invert of the service tunnel is required to be at the same elevation as the main tunnel. The vertices locating the service tunnel radius must be adjusted in the **radcylinder** primitive. This is done by first defining these locations using the **GENERATE point** command. The corner points **p8** and **p10** in one **radcylinder** primitive, and **p9** and **p11** in the other primitive, are located at the reference points. This ensures that the two primitives will match at boundary gridpoints when the grid is generated. Figure 3.8 shows the grid for the tunnels. The vertical plane at $x = 0$ is a symmetry plane.

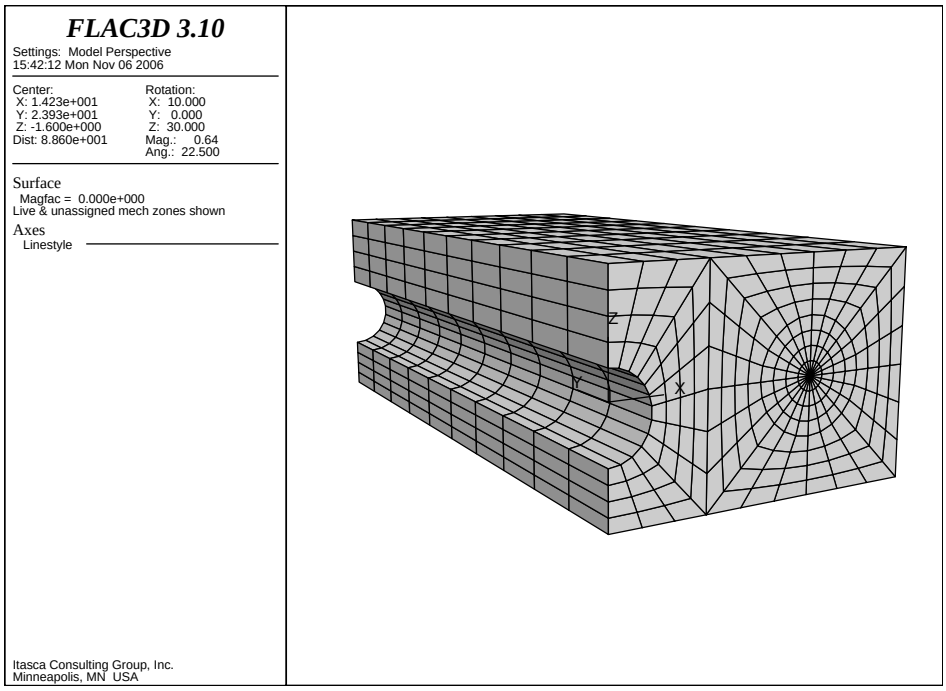


Figure 3.8 Inner grid for the service and main tunnels

For this model, we begin with the main tunnel filled with zones and the service tunnel not filled. The excavation and construction stages analyzed with this model are described later, in Section 3.5. Before the main tunnel is excavated, we define a liner for the service tunnel; this is accomplished with the **SEL shell** command, which creates a tunnel lining composed of structural shell elements*. Structural elements should generally be used to represent thin tunnel liners because they provide a more accurate representation of liner bending than a liner composed of finite-difference zones. See Section 1 in **Structural Elements** for detailed information on the structural element logic in *FLAC3D*. Example 3.6 gives the command to create the liner.

---

* This creates a liner that is rigidly attached to the grid. A liner with a connection to the grid that can slide/separate can be specified with the **SEL liner** command.

Example 3.6 Creating a liner in the service tunnel

```
; liner
sel shell range cyl end1 0 0 -1  end2 0 50 -1  rad 3
```

The liner contains 240 structural shell elements and is connected to the *FLAC3D* grid at 143 structural-node links. The grid with the liner is shown in Figure 3.9.

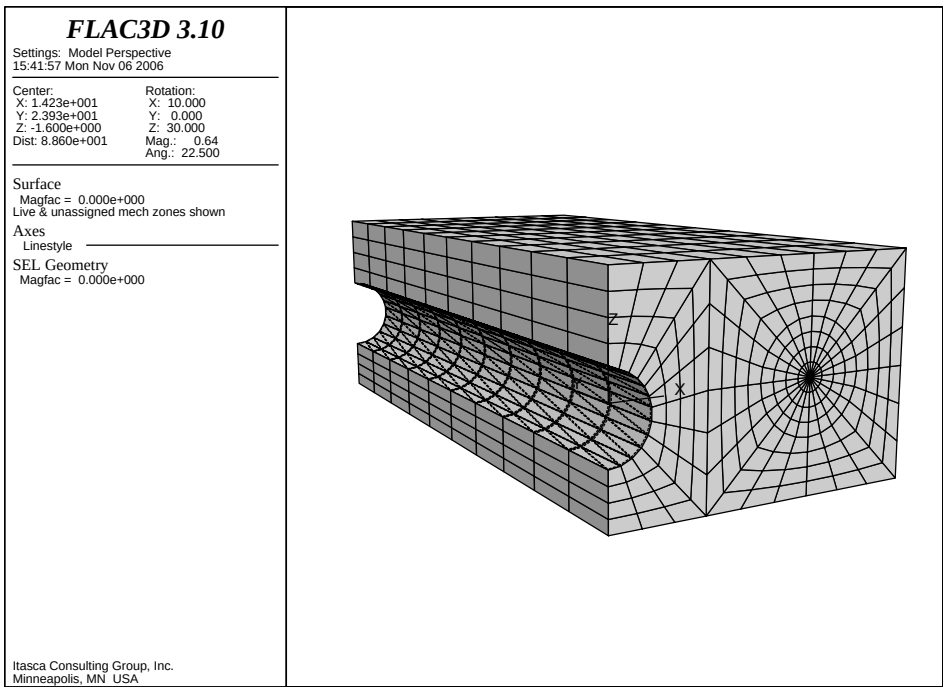


Figure 3.9 Liner elements in service tunnel

Finally, the outer-boundary grid is created around the tunnel grid. For analyses of underground excavations, boundaries should be located roughly ten excavation diameters from the excavation periphery. The distance, however, can vary depending on the purpose of the analysis. If failure is of primary concern, then the model boundaries may be closer; if displacements are important, then the distance to the boundaries may need to be increased.

It is important to experiment with the model to assess boundary effects. Begin with a coarse two-dimensional grid, using *FLAC*, and bracket the boundary effect using fixed and free boundary-conditions while changing the distance to the boundary. The resulting effect of changing the boundary can then be evaluated in terms of differences in stress or displacement calculated in the region of interest. The boundary location should then be tested with a coarse grid in *FLAC3D*.

We create the boundary grid with the **radtunnel** and **brick** primitives for this model. The **reflect** option is used to reflect the grid across the plane at $z = 0$. We use the **range** keyword to restrict the action of **reflect**. See Example 3.7.

The final grid for this problem is shown in Figure 3.10. The **GROUP** command is used to identify the main tunnel in the figure.

Example 3.7 Creating the boundary grid

```
; outer boundary
gen zone radtun p0 7 0 0 p1 50 0 0 p2 7 50 0 p3 15 0 50 p4 50 50 0 &
                p5 15 50 50 p6 50 0 50 p7 50 50 50 &
                p8 23 0 0 p9 7 0 8 p10 23 50 0 p11 7 50 8 &
                size 6 10 3 10 rat 1 1 1 1.1
gen zone brick  p0 0 0 8 p1 7 0 8 p2 0 50 8 p3 0 0 50 &
                p4 7 50 8 p5 0 50 50 p6 15 0 50 p7 15 50 50 &
                size 3 10 10 rat 1 1 1.1
gen zon reflect dip 0 ori 0 0 0 range x 0 23 y 0 50 z 8 50
gen zon reflect dip 0 ori 0 0 0 range x 23 50 y 0 50 z 0 50
group service range cyl end1   0 0 -1  end2   0 50 -1 rad 3
group main    range cyl end1  15 0  0  end2  15 50  0 rad 4
```

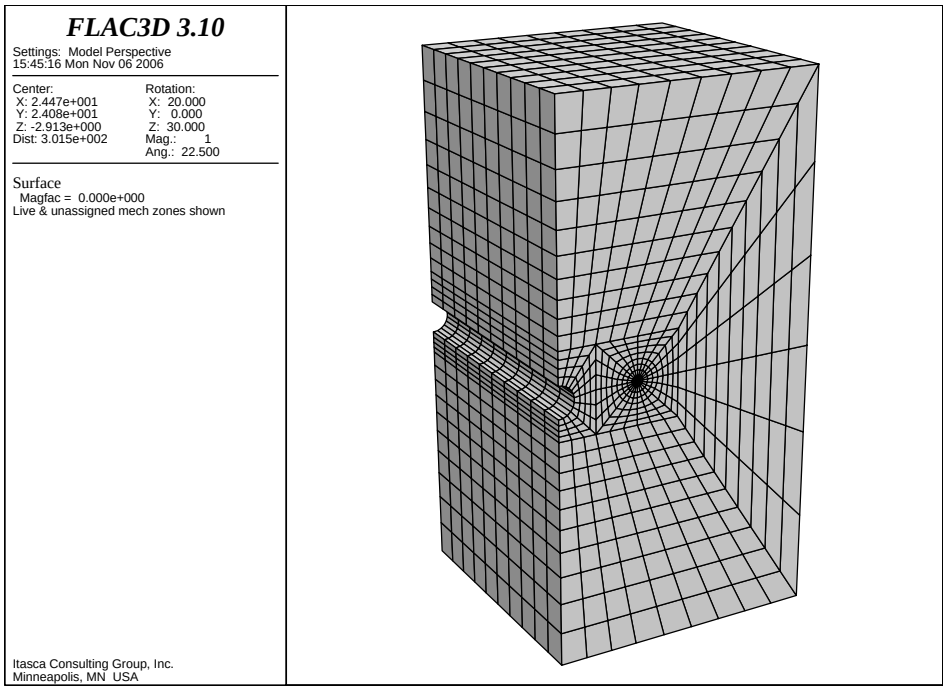


Figure 3.10 Complete grid for service and main tunnels

3.2.3 Grid Generation with FISH

FISH can be used to specify a geometric shape that is not readily available by using the built-in primitives in *FLAC3D*. For example, an irregular surface on a model can be made by using *FISH* to adjust gridpoints via a user-specified topology function (see Example 3.26).

It is also possible to create your own primitive shapes using *FISH*. In the following example, we create a radially graded mesh around a spherical cavity. Only one-eighth of the grid is generated. The grid can be reflected to create the complete spherical cavity.

A **radbrick** primitive is the basis for creating our "radsphere" shape. We first define parameters that describe the sphere within a cube: the radius of the spherical cavity; the length of the outer cube edge; the number of zones along the outer cube edge; and the number of zones in the radial direction from the inner cube to the outer cube. Then we define a **radbrick** such that the spherical cavity will be inscribed in the inner cube. Example 3.8 lists the commands to create the initial grid for a geometric ratio of 1.2. The grid is shown in Figure 3.11.

Example 3.8 Parameters to create a radially graded mesh around a spherical cavity

```
def parm
  rad=4.0     ; radius of spherical cavity
  len=10.0    ; length of outer box edge
  in_size=6   ; number of zones along outer cube edge
  rad_size=10 ; number of zones in radial direction
end
parm
gen zone radbrick edge len size in_size in_size in_size rad_size &
  rat 1.0 1.0 1.0 1.2 dim rad rad rad
```

The gridpoints within the radbrick are now relocated to form the mesh around a spherical cavity. The *FISH* function **make_sphere** loops through all the gridpoints and remaps their coordinates using a linear interpolation along radial lines from the sphere origin to the gridpoints along the outer box sides. Example 3.9 shows the **make_sphere** *FISH* function, and Figure 3.12 shows the final grid.

Example 3.9 FISH function to position gridpoints for a mesh around a spherical shape

```
def make_sphere
; Loop over all GPs and remap their coordinates:
;  assume len>rad
  p_gp=gp_head
  loop while p_gp#null
; Get gp coordinate: P=(px,py,pz)
    px=gp_xpos(p_gp)
    py=gp_ypos(p_gp)
```

```
    pz=gp_zpos(p_gp)
; Compute A=(ax,ay,az)=point on sphere radially "below" P.
    dist=sqrt(px*px+py*py+pz*pz)
    if dist>0 then
      k=rad/dist
      ax=px*k
      ay=py*k
      az=pz*k
; Compute B=(bx,by,bz)=point on outer box boundary radially "above" P.
      maxp=max(px,max(py,pz))
      k=len/maxp
      bx=px*k
      by=py*k
      bz=pz*k
; Linear interpolation: P=A+u*(B-A)
      u=(maxp-rad)/(len-rad)
      gp_xpos(p_gp)=ax+u*(bx-ax)
      gp_ypos(p_gp)=ay+u*(by-ay)
      gp_zpos(p_gp)=az+u*(bz-az)
    end_if
    p_gp=gp_next(p_gp)
  end_loop
end
make_sphere
```

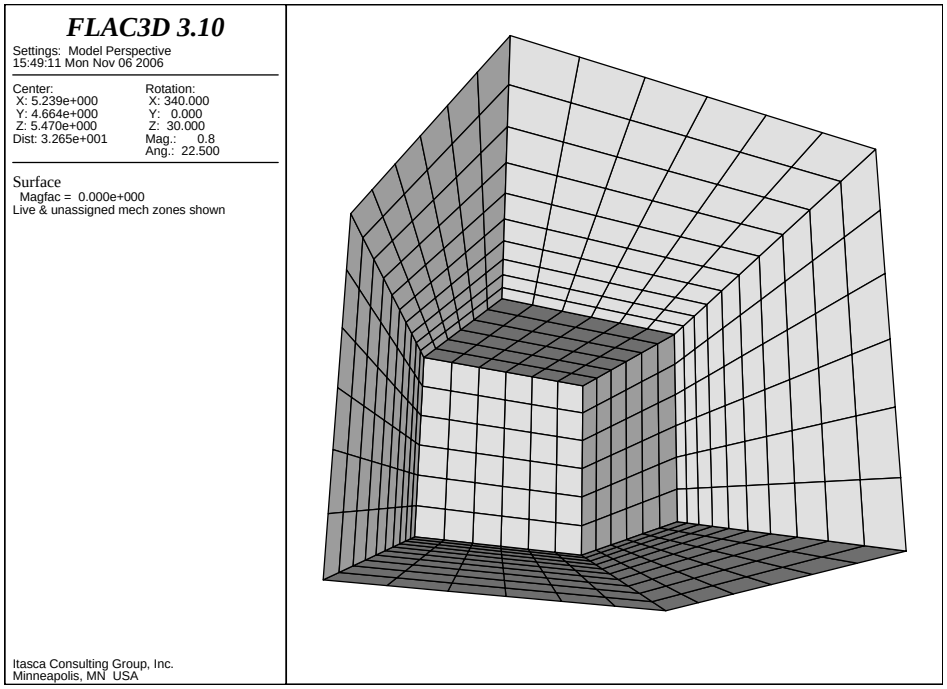


Figure 3.11 Initial radial-brick primitive to create a radially graded mesh around a spherical cavity

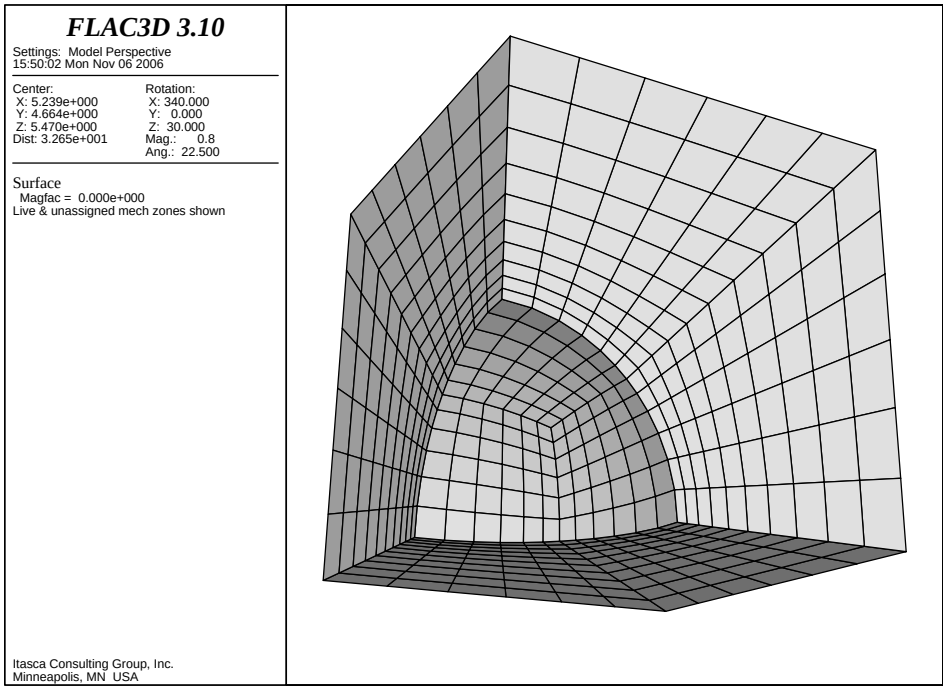


Figure 3.12 Radially graded mesh around a spherical cavity

3.2.4 Grid-Extrusion Tool

A special grid-generation tool is available to create a three-dimensional *FLAC3D* mesh by extruding a two-dimensional *FLAC* grid. The two-dimensional grid can be created directly within the grid-extrusion tool, or a *FLAC* data file can be loaded into the tool to create the extruded *FLAC3D* mesh. The grid-extrusion tool is accessed by pressing the FILE/FLAC EXTRUDE menu item. This brings up the *FLAC –> FLAC3D extrusion tool* as shown in Figure 3.13.

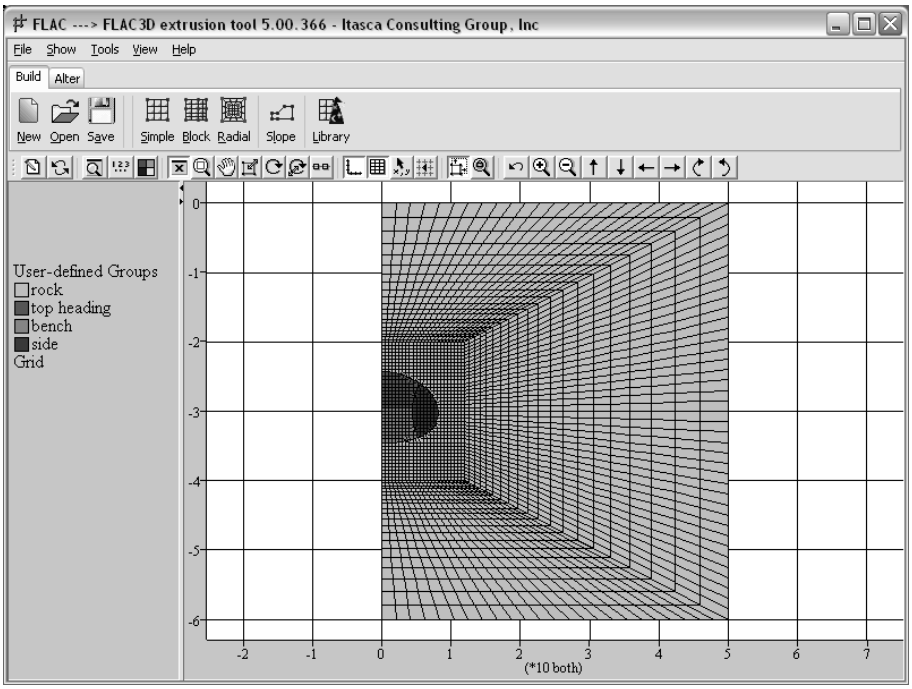


Figure 3.13 FLAC –> FLAC3D extrusion tool

The *FLAC –> FLAC3D extrusion tool* contains two toolbars to first create the grid (using the tools accessed from the BUILD tool tab) and then alter and extrude the grid (using the tools accessed from the ALTER tool tab).

The BUILD tab contains five tools to create a two-dimensional mesh. These tools are: SIMPLE, BLOCK, RADIAL, SLOPE and LIBRARY. The grid-generation tools define the general shape, spacial dimensions, zone density and gradation for a two-dimensional section. The operation of each of these tools is described in Section 1.2.1 in the ***FLAC-GIIC* Reference**.

After the two-dimensional grid is created, additional alterations or shape forming is done using the tools accessed from the ALTER tab. These tools are: MARK, SHAPE, TABLE, DELETE and GROUP. The MARK and SHAPE tools are used to define sub-regions and add additional shapes (e.g., excavation boundaries and layered materials) to the grid. The operation of these two tools is described in Section 1.2.2 in the ***FLAC-GIIC* Reference**. The TABLE tool can also be used to create a geometric table to locate

boundaries within a model grid; the geometric table can then be used to shape the model in the SHAPE tool. The TABLE tool operation is described in Section 1.2.6.2 in the ***FLAC-GIIC* Reference**.

The GROUP tool is used to assign group names to sets of zones within the grid. Each group is prescribed a group name that will be recognized as a *FLAC3D* **group**. The DELETE tool is used to remove (null) zones from the model. The operation of group assignment and zone deletion is similar to that for the assignment of materials (MATERIAL/ASSIGN) as described in Section 1.2.3.1 in the ***FLAC-GIIC* Reference**.

The two-dimensional grid can be "saved" at any time by either pressing the SAVE button in the BUILD tab, or by selecting the FILE/SAVE AS menu item. This will create a data file that contains all of the *FLAC* commands used to generate this grid.

The data file can be re-opened within the extrusion tool by using the OPEN button in the BUILD tab, or by selecting the FILE/OPEN menu item. A *FLAC*-generated data file can also be opened within the grid-extrusion tool. In this case, only the *FLAC* commands related to grid generation are recognized by the grid-extrusion tool; all other *FLAC* commands are ignored.

After the two-dimensional mesh is complete, the EXTRUDE tool is selected in order to extrude the grid to create a three-dimensional *FLAC3D* mesh. This opens a *Extrude 2D mesh to FLAC3D* dialog as shown in Figure 3.14. In order to extrude the mesh in a direction orthogonal to the two-dimensional plane, click on the EXTRUDE INTO ORTHOGONAL AXIS button. Parameters are then set in the dialog to select the length of the extruded mesh, and the number of zones and grid ratio in the extruded direction. The orientation of the two-dimensional mesh with respect to the *FLAC3D* global axes can also be specified. Note that *u* and *v* in the dialog correspond to the *x*- and *y*-directions, respectively, in the *FLAC* plane, and * is one of the three directions for extrusion in the *FLAC3D* coordinate system.

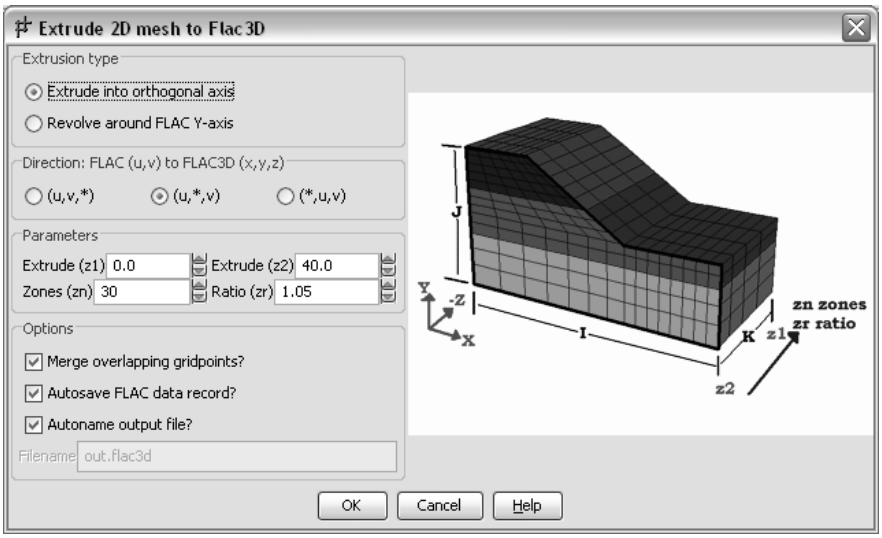


Figure 3.14 Extrude 2D mesh to FLAC3D dialog

If the two-dimensional grid is composed of sub-grids that are connected via **ATTACH** or **INTERFACE** *FLAC* commands, these commands are not transferred to equivalent *FLAC3D* commands. This must be done manually by the user after the *FLAC3D* mesh is created. Alternatively, if gridpoints along sub-grid boundaries coincide, these gridpoints can be merged when creating the *FLAC3D* mesh by checking the optional MERGE OVERLAPPING GRIDPOINTS? box in the *Extrude 2D mesh to FLAC3D* dialog.

When OK is pressed in the dialog, a grid output file (with the default filename "OUT.FLAC3D") is created and automatically imported into *FLAC3D* (using the procedure defined for the **IMPGRID** command). The *FLAC –> FLAC3D extrusion tool* is closed and operation returns to the *FLAC3D* command line.

Figures 3.13 through 3.15 illustrate the steps of importing a *FLAC* data file to create a two-dimensional grid, extruding the grid and creating a *FLAC3D* grid. (The input file is the grid-generation segment of the file "MSTUNNEL.DAT" for the multi-stage tunnel excavation described in Example Application 12 in the **Example Applications** volume of the *FLAC* manual.) The final *FLAC3D* mesh is shown in Figure 3.15.

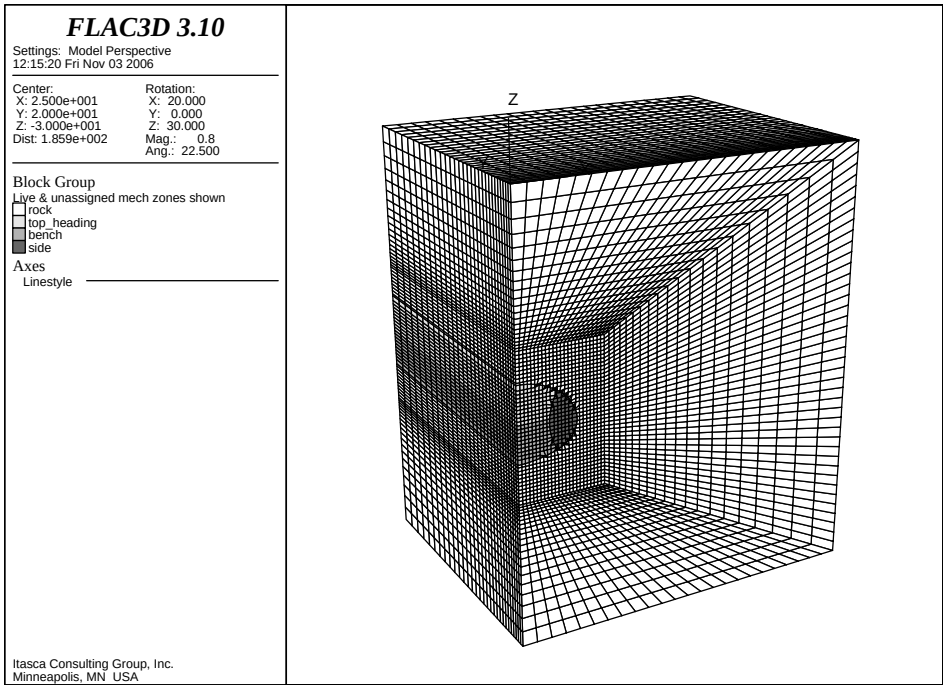


Figure 3.15 FLAC3D extruded mesh created from the FLAC data file for Example Application 12 in the FLAC manual

In addition to a linear extrusion of the two-dimensional grid, an extrusion can be made to revolve around the *FLAC* *y*-axis. As an example, the rock slope grid of Example Application 10 in the **Example Applications** volume of the *FLAC* manual is used to create a circular-shaped pit. The data file is the grid-generation segment of the file "ROCKSL.DAT" in Example Application 10. The file opened in the *FLAC –> FLAC3D extrusion tool* produces the grid shown in Figure 3.16. Note that the dimensions in the data file are translated by +40 m in both the *x*- and *y*-directions because positive coordinates are required when extruding about an axis of revolution.

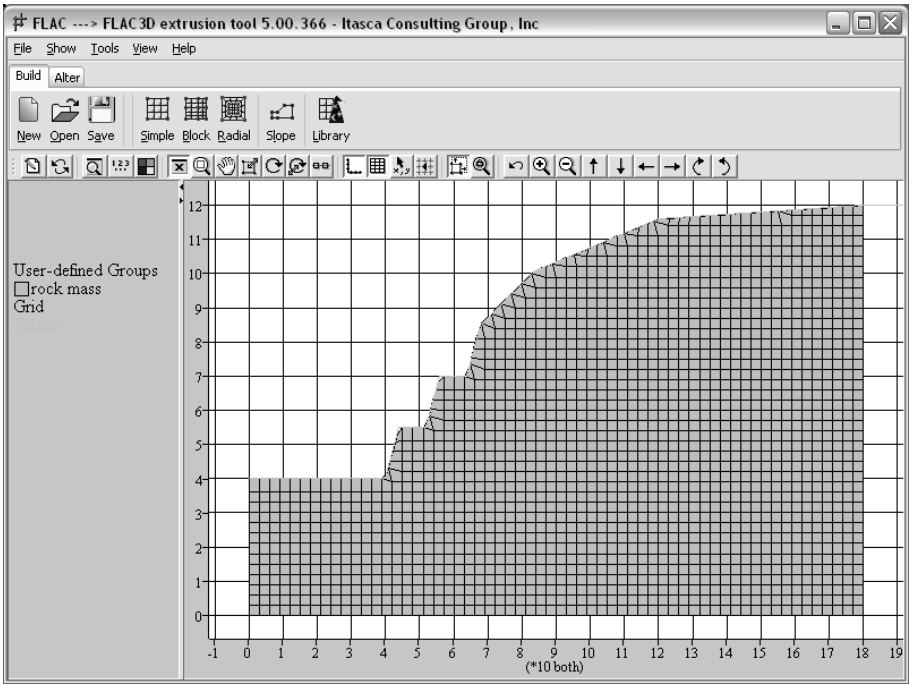


Figure 3.16 Rock Slope data file opened in the FLAC –> FLAC3D extrusion tool

The REVOLVE AROUND FLAC Y-AXIS box is checked in the *Extrude 2D mesh to FLAC3D* dialog as shown in Figure 3.17. The contents of the dialog change so that the angle of revolution and number of zones along the revolution axis can be entered. The orientation of the *FLAC3D* mesh relative to the axis of revolution can also be selected. Note that *u* and *v* in the dialog correspond to the *x*- and *y*-directions, respectively, in the *FLAC* plane, and * corresponds to one of the three directions for revolution in the *FLAC3D* coordinate system.

A 90° angle of revolution about the *y*-axis in *FLAC3D* is selected, as shown in Figure 3.17. The resulting three-dimensional mesh is shown in Figure 3.18.

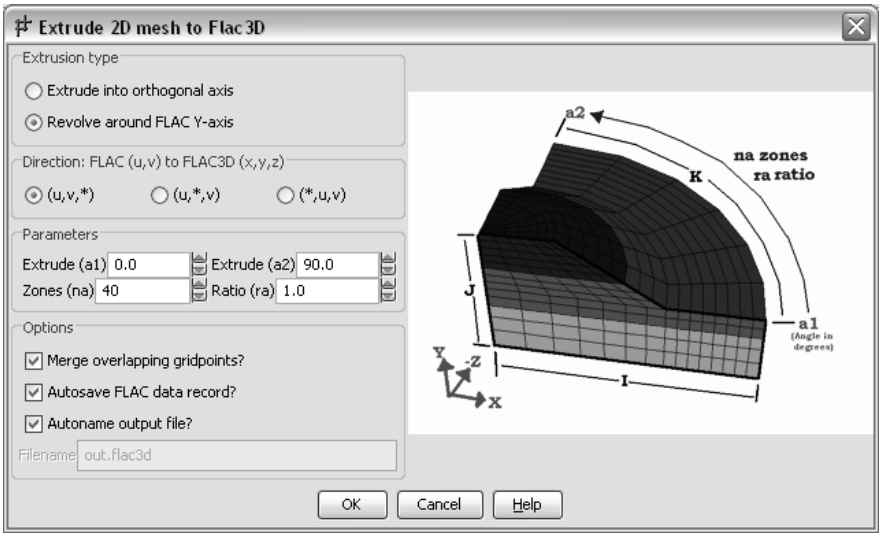


Figure 3.17 Extrude 2D mesh to FLAC3D dialog with extrusion set to revolve around FLAC y-axis

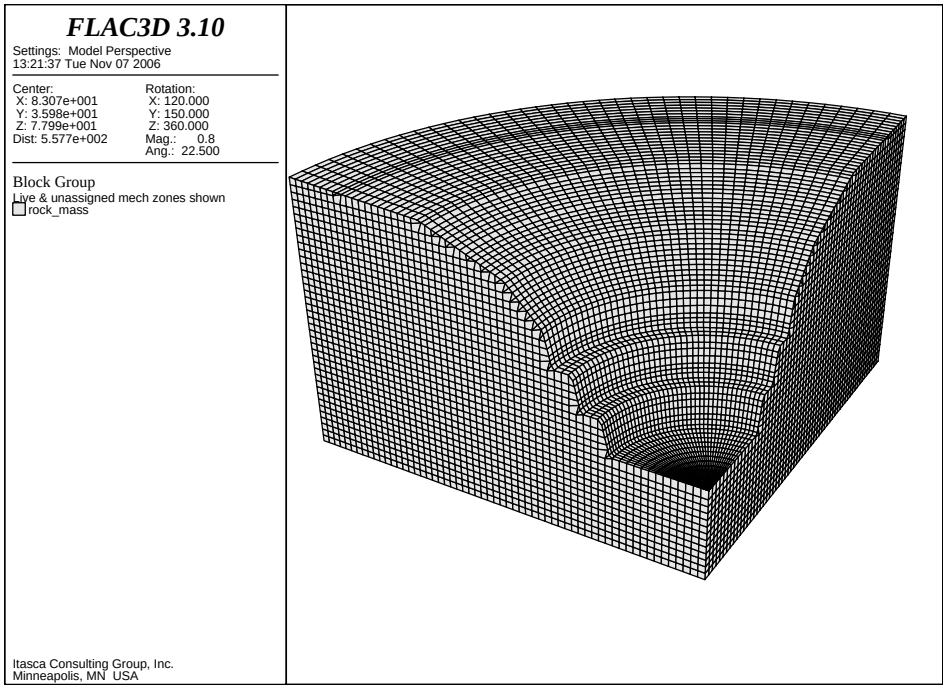


Figure 3.18 FLAC3D extruded mesh created from the FLAC data file for Example Application 10 in the FLAC manual

3.3 Boundary Conditions

The boundary conditions in a numerical model consist of the values of field variables (e.g., stress and displacement) that are prescribed at the boundary of the numerical grid. Boundaries are of two categories: real and artificial. Real boundaries exist in the physical object being modeled — e.g., a tunnel surface or the ground surface. Artificial boundaries do not exist in reality, but they must be introduced in order to enclose the chosen number of zones. The conditions that can be imposed on each type are similar; these conditions are discussed first. Then (in Section 3.3.4) some suggestions concerning the location and choice of artificial boundaries and the effect they have on the solution are made.

Mechanical conditions that can be applied at boundaries are of two main types: prescribed displacement or prescribed stress. A free surface is a special case of the prescribed-stress boundary. The two types of mechanical conditions are described in Sections 3.3.1 and 3.3.2.

3.3.1 Stress Boundary

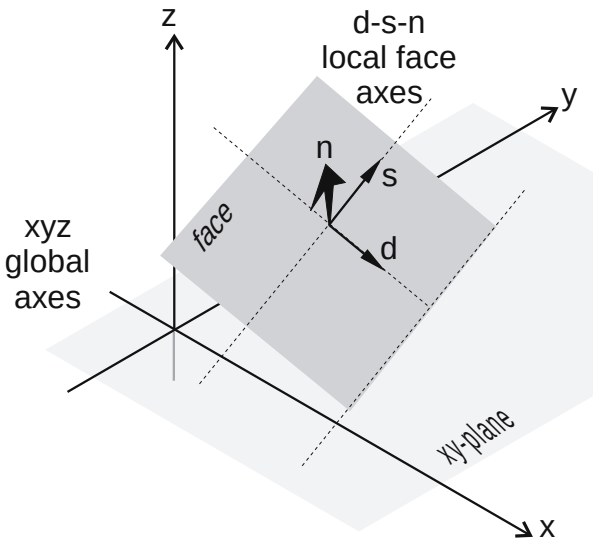
By default, the boundaries of a *FLAC3D* grid are free of stress and any constraint. Forces or stresses may be applied to any boundary, or part of a boundary, by means of the **APPLY** command. Individual components of the stress tensor are specified with the **sxx**, **syy**, **sxy**, **sxz** and **syz** keywords. For example, the command

```
apply szz = -1e5  sxz = -.5e5  range z -.1,.1
```

applies the given σ_{zz} and σ_{xz} components of a stress tensor to the model boundary falling within the range $-0.1 \leq z \leq 0.1$. All other stress components are zero.

Stress can be applied either in the global model x,y,z-directions, or in directions normal and tangential to the local boundary face. The keyword **nstress** applies a normal stress to a face, while keywords **dstress** and **sstress** apply shear stresses to the face. **dstress** is the stress component applied in the dip direction of the local face, and **sstress** is the stress component applied in the strike direction. The orientation of the local face axes is illustrated in Figure 3.19. Note that global (x,y,z)-axes stresses and local (d,s,n)-axes stresses cannot both be applied to the same face.

There are several things to note about this use of **APPLY** command. First, only those faces whose centroids lie within the coordinate range defined by **range** will be affected by the **APPLY** command. Second, compressive stresses have a *negative* sign, in accordance with the general sign convention for internal stresses in *FLAC3D*. Finally, *FLAC3D* actually applies the stress components as forces, or *tractions*, which result from a stress tensor acting on the given boundary plane; the tractions are computed whenever a **STEP** command is issued, and again every tenth step in large-strain mode.



The **d-s-n axes** form a right-handed coordinate system in which:

The **n-axis** is the outward normal to the face.

The **s-axis** is parallel to the projected intersection between the xy-plane and the face.

The **d-axis** is the line with the greatest negative z-component on the face (i.e., the direction of steepest descent on the plane).

Figure 3.19 Local face axes defined by (d) dip direction, (s) strike direction and (n) normal direction

Individual forces can also be applied to the grid by using the **xforce**, **yforce** and **zforce** keywords, which specify the *x*-, *y*- and *z*-components of an applied force vector. In this case, no account is taken of the boundary face area; the specified forces are simply applied to the given gridpoints.

The applied forces, or tractions calculated from applied stresses, can be viewed with the command **PLOT fap**. It is necessary to perform a **STEP 1** first in order to calculate the applied forces for viewing. For example, a stress boundary condition is applied normal to a boundary plane that has a dip angle of 60° and dip direction of 270°. Type the commands shown in Example 3.10.

Example 3.10 Applying a normal stress to a dipping boundary

```
gen zone brick size (4,4,4) p0 (0,0,0) p1 (4,0,0) &
     p2 (0,4,0) p3 (2,0,3.464)
model elastic
prop bulk 1e8 shear .3e8
apply nstress -1e6 range plane dip 60 dd 270 origin 0.1,0,0 above
```

The normal stress of -1×10^6 is applied to a boundary plane falling within the range defined by a plane with a dip direction of 270°, a dip angle of 60°, and above the position $x = 0.1$, $y = 0$, $z = 0$. The resulting applied forces can be seen by typing

```
step 1
plot grid green fap black
```

The plot in Figure 3.20 shows the forces applied to the grid as calculated from the normal stress and the boundary face areas. Note that the size of the force vectors is a function of the face areas over which the stress is applied.

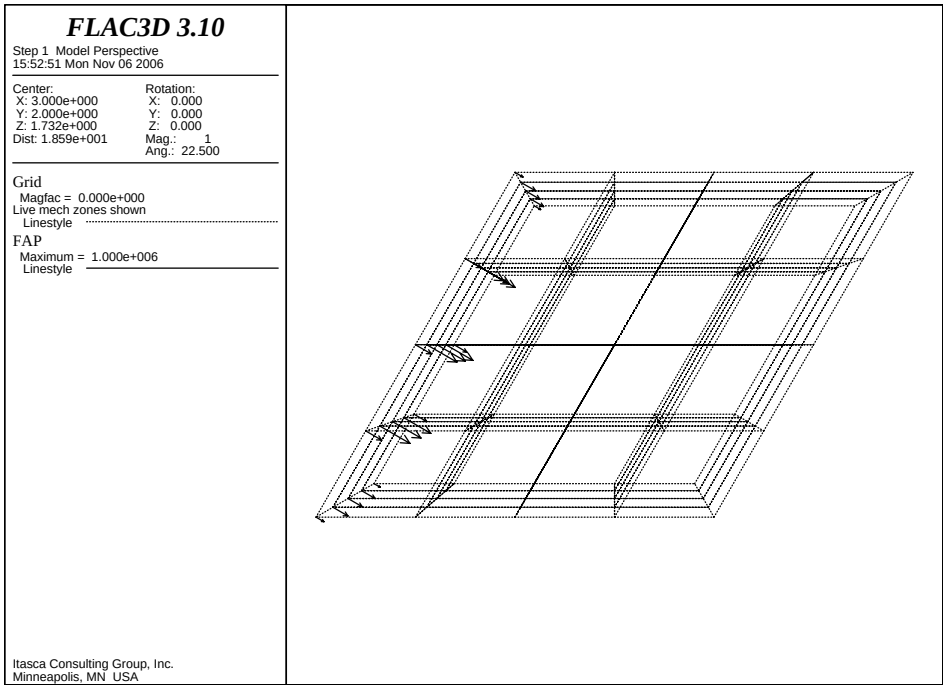


***Figure 3.20 Applied forces resulting from* APPLY nstress**

3.3.1.1 Applied Stress Gradients

The **APPLY** command may take the optional keyword **gradient**, which allows the applied stresses or forces to vary linearly over the specified range. The parameters following **gradient**, ***gx***, ***gy*** and ***gz***, specify the x-, y- and z-variation, respectively, for the stress- or force-component. The value varies linearly with distance from the global coordinate origin at (x = 0, y = 0, z = 0) — i.e.,

$$S = S^{(o)} + g_x x + g_y y + g_z z \tag{3.1}$$

in which $S^{(o)}$ is the value at the global coordinate origin at (x = 0, y = 0, z = 0), and g_x, g_y and g_z specify the variation of the value in the x-, y- and z-directions.

The operation of this feature is best explained by an example:

```
apply sxx -10e6 gradient 0,0,1e5 range z -100,0
```

The equation for the z-variation in stress-component σ_{xx} is

$$\sigma_{xx} = -10 \times 10^6 + (10^5)z$$

The σ_{xx}-stress at the origin (x = 0, y = 0, z = 0) is $\sigma_{xx} = -10 \times 10^6$; at $z = -100$, it is -20×10^6. At points in between, the stress is linearly scaled to the relative z-distance from the origin.

Typically, applied stress gradients are used to reproduce the effects of increasing stress with depth caused by gravity. It is important to make sure that the applied gradient is compatible with the stress gradient specified with the **INITIAL** command, and the value of gravitational acceleration given by the **SET gravity** command. See Section 3.4 for further comments on stress gradients.

3.3.1.2 Changing Boundary Stress

It may be necessary to alter the values of applied stresses during the course of a *FLAC3D* simulation. For example, the load on a footing may change. To effect a sudden change in an existing applied stress or load, a new **APPLY** command is given, with the range and stress component given *exactly as in the original command*, but with a changed value or variation. In this case, *FLAC3D* simply updates the stored stresses for that item on the list of applied loads. New values will replace existing values for any overlapping **APPLY** commands. It may be necessary to first remove boundary conditions (with **APPLY remove**) before updating a boundary stress.

In many instances, it may be necessary to change a boundary stress gradually. This is often required to minimize the shock to a sensitive system, especially if "path-dependence" of the solution is important (see Section 3.10.3). The data file in Example 3.11 causes the applied stress on the upper yz-face of a grid to be increased incrementally over a total of 100 steps, from an initial value of -1×10^3 to a final value of -1×10^5. We specify 100 *sub-steps* for each *super-step* in order to equilibrate the model at each load increment.

Example 3.11 Apply changing stress boundary with a FISH function

```
gen zone brick size 6 6 6
model elas
prop bulk 1e8 shear 7e7
fix x range x -0.1 0.1
def superstep
   loop ns (1,n_steps)
      x_stress = stress_inc
      command
         apply sxx add x_stress range x 5.9,6.1 y 0,6 z 0,2
         step 100
      end_command
   end_loop
end
set n_steps=100 stress_inc=-1e3
hist zone sxx 6,0,0
plot create sxx_hist
```

```
plot add hist 1
plot show
superstep
```

The stepping process is controlled from within the *FISH* function, because the **APPLY** command only takes effect when a **STEP** command is given. (See the discussion in Section 3.3.1.) The **WHILE_STEPPING** *FISH* statement cannot be used, because the applied forces will not be updated.

With the **history** multiplier keyword, the changing stress conditions can be described either by a *FISH* function or with a table. Example 3.11 can be altered to use a *FISH* history, as shown in Example 3.12.

Example 3.12 Apply changing stress boundary with a FISH history

```
gen zone brick size 6 6 6
model elas
prop bulk 1e8 shear 7e7
fix x range x -0.1 0.1
def x_stress
     x_stress = stress_inc * step
end
set stress_inc = -1e3
apply sxx 1.0 hist x_stress range x 5.9,6.1 y 0,6 z 0,2
hist zone sxx 6,0,0
hist x_stress
step 100
```

The *FISH* function **x_stress** is a multiplier applied at every calculation step. Note that a history of the multiplier can also be recorded.

Alternatively, the history can be specified via the **TABLE** command. The following data file performs the same function as the one above.

Example 3.13 Apply changing stress boundary with a table history

```
gen zone brick size 6 6 6
model elas
prop bulk 1e8 shear 7e7
fix x range x -0.1 0.1
table 1 0,0 100,-1e5
apply sxx 1.0 hist table 1 range x 5.9,6.1 y 0,6 z 0,2
hist zone sxx 6,0,0
step 100
```

By plotting the σ_{xx} history for Examples 3.11, 3.12 and 3.13, you will see that the three approaches for applying a changing bounding stress produce identical results. You will note that the calculation time is shorter for Examples 3.12 and 3.13 than for Example 3.11.

Stresses may also be applied to interior boundaries (e.g., tunnel walls). The rate of excavation of a tunnel can be simulated by controlling the rate at which the boundary stress is relaxed. This is shown by the following example for a gradual excavation of a circular tunnel in a Mohr-Coulomb material.

Example 3.14 Gradual excavation of a circular tunnel

```
gen zone radcyl p0 0 0 0 p1 add 18 0 0 p2 add 0 8 0 p3 add 0 0 18 &
    dim 1.75 1.75 1.75 1.75 ratio 1.0 .83 1.0 1.2 size 6 6 6 10
gen zone radcyl p0 0 8 0 p1 add 18 0 0 p2 add 0 8 0 p3 add 0 0 18 &
    dim 1.75 1.75 1.75 1.75 ratio 1.0 1.2 1.0 1.2 size 6 6 6 10 fill
mo mo
pro bulk 33.33e9 she 25e9 fric 45 coh 15e6 ten 5e6
ini sxx -65e6 syy -65e6 szz -65e6
fix x range x -.1 .1
fix x range x 17.9 18.1
fix y range y -.1 .1
fix y range y 15.9 16.1
fix z range z -.1 .1
fix z range z 17.9 18.1
def relax
   if step<ncyc then
      relax=1.0-(float(step)/float(ncyc))
   else
      relax=0.0
   end_if
end
set ncyc=1000
app nstress -65e6 hist relax range cyl end1 0,0,0 end2 0,8,0 r 1.75
hist unbal
hist gp xdisp 1.75 0 0
hist gp zdisp 0 0 1.75
cyc 2000
```

No material failure is calculated in the tunnel walls when the boundary stress is relaxed. However, if the excavation is made instantaneously (i.e., the **APPLY nstress** command is removed from the data file), then the stress state in the first ring of zones reaches the failure surface during the unloading process (see Figure 3.21). Please note that this grid is too coarse to model plasticity accurately; a finer mesh is required around the tunnel because of the high-stress gradient. The purpose of the example is only to demonstrate the effect of different rates of change in boundary stress.

Another technique to relax stresses is demonstrated in Example 3.15. The geometry of this example is similar to that of Example 3.14 except that the interior of the tunnel to be excavated originally contains zones (i.e., the tunnel hasn't been excavated yet). The entire model is first brought to equilibrium, and then the material inside the tunnel is gradually softened. This softening is done through user defined *FISH* functions found in "ZONK3D.FIS" (see Example 3.16). ZONK3D will perform this softening process on all zones belonging to a group with a name of 'zonk'. It starts by replacing all of the zonk group zones with an elastic model with the same bulk and shear modulus as originally stored in the zone. The modulus and stresses in the zonk group zones are reduced by a constant factor (*FISH* variable factor) during an iterative process. The stresses are reduced to introduce a slight perturbation into the system so that it is no longer in equilibrium. The model is successively solved until the maximum Young's modulus (of one of the zonk zones) is below 5% of its maximum initial value. Once the model has passed this threshold, the zonk zones are made null (they could also be deleted). The user should experiment with the reduction factor and threshold value for Young's modulus for their specific case. ZONK3D.FIS is extremely useful for relaxing stresses in complicated geometries.

Example 3.15 Gradual excavation of a circular tunnel using "ZONK3D.FIS"

```
new
gen zone radcyl p0 0 0 0 p1 add 18 0 0 p2 add 0 8 0 p3 add 0 0 18 &
    dim 1.75 1.75 1.75 1.75 ratio 1.0 .83 1.0 1.2 size 6 6 6 10 &
    fill group zonk
gen zone radcyl p0 0 8 0 p1 add 18 0 0 p2 add 0 8 0 p3 add 0 0 18 &
    dim 1.75 1.75 1.75 1.75 ratio 1.0 1.2 1.0 1.2 size 6 6 6 10 fill

mo mo
pro bulk 33.33e9 she 25e9 fric 45 coh 15e6 ten 5e6
ini sxx -65e6 syy -65e6 szz -65e6
fix x range x -.1 .1
fix x range x 17.9 18.1
fix y range y -.1 .1
fix y range y 15.9 16.1
fix z range z -.1 .1
fix z range z 17.9 18.1

hist unbal
hist gp xdisp 1.75 0 0
hist gp zdisp 0 0 1.75

; Gradually relax the stresses around an excavated area (the zones
; belonging to group 'zonk').
call zonk3d.fis

ret
```

Example 3.16 "ZONK3D.FIS"

```
; Gradually relax the stresses around an excavated area (the zones
; belonging to group 'zonk').


; find max young's modulus
; replace material model in zonked zones with elastic material
def setup
  factor = 0.95   ; factor for reducing modulus and stress values
  array pzz(1000) ; pointers to zonked zones
  inzz = 0        ; number of zonked zones
  emax  = 0.0
  pz = zone_head

  loop while pz # null
    if z_group(pz) = 'zonk' then
       if z_model(pz) # 'null' then
         inzz = inzz + 1
         pzz(inzz) = pz
         k = z_prop(pz,'bulk')
         g = z_prop(pz,'shear')
         e = 9*k*g/(3*k+g)
         if e > emax then
           emax = e
           pz_emax = pz
         endif
         z_model(pz) = 'elastic'
         z_prop(pz, 'bulk')  = k
         z_prop(pz, 'shear') = g
       endif
    endif
    pz = z_next(pz)
  endloop
end
setup


; gradually reduce the stiffness and stress in zonked zones
def reduce
  emax = emax * factor
  loop ii(1,inzz)
    pz = pzz(ii)
    z_prop(pz,'bulk')  = factor * z_prop(pz,'bulk')
    z_prop(pz,'shear') = factor * z_prop(pz,'shear')
    z_sxx(pz) = factor * z_sxx(pz)
    z_sxy(pz) = factor * z_sxy(pz)
```

```
    z_sxz(pz) = factor * z_sxz(pz)
    z_syy(pz) = factor * z_syy(pz)
    z_syz(pz) = factor * z_syz(pz)
    z_szz(pz) = factor * z_szz(pz)
  endloop
end



def dozonk
; stop reducing when max Young's modulus is below 5% of its max
; initial value
  emin = emax * 0.05

  loop while emax > emin
  reduce
  command
    solve
  endcommand
  endloop

  ; make all zonked zones null material
  loop ii(1,inzz)
    pz = pzz(ii)
    z_model(pz) = 'null'
  endloop
  command
    solve
  endcommand
end
dozonk
```

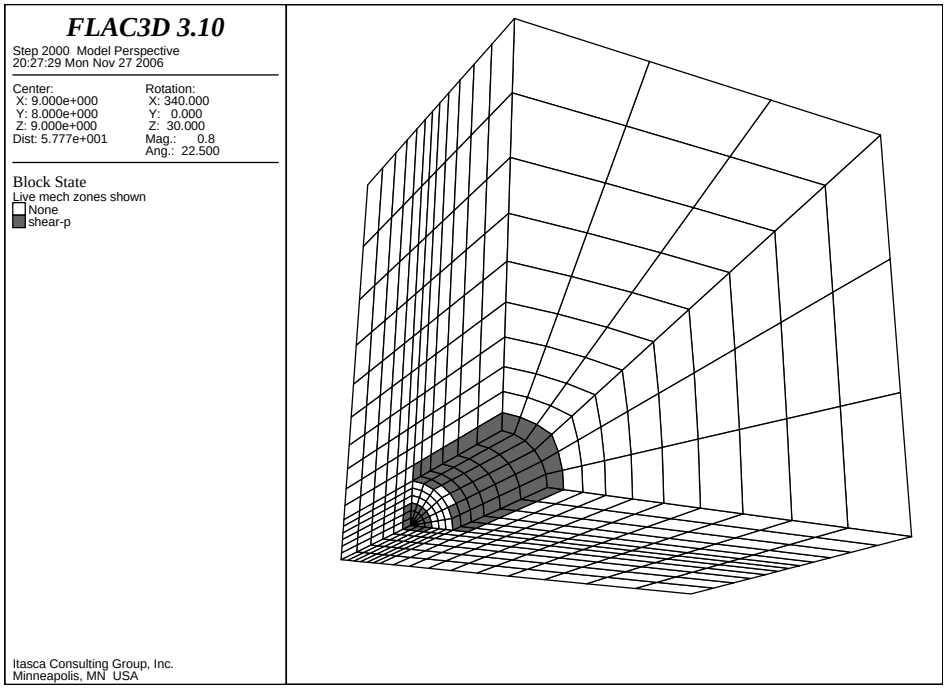


Figure 3.21 Plasticity state for instantaneous excavation of tunnel

3.3.1.3 Cautions and Advice

In this section, some miscellaneous difficulties with stress boundaries are described.

With *FLAC3D*, it is possible to apply stresses to the boundary of a body that has no displacement constraints (unlike many finite-element programs, which require some constraints). The body will react in exactly the same way as a real body would — i.e., if the boundary stresses are not in equilibrium, then the whole body will start moving. The following data file illustrates the effect.

Example 3.17 Spin when grid is not in equilibrium

```
gen zone brick size 6,6,6 p1 6,0,-1
model elas
prop bulk 8e9 shear 5e9
apply sxx -2e6 range x -0.1 0.1
apply sxx -2e6 range x 5.9 6.1
step 500
plot bound fap
plot grid disp
```

The plots produced from this example are given in Figures 3.22 and 3.23. The applied σ_{xx} stress causes horizontal forces to act on the body. Since the body is tilted, these forces give rise to a moment which causes the body to spin.

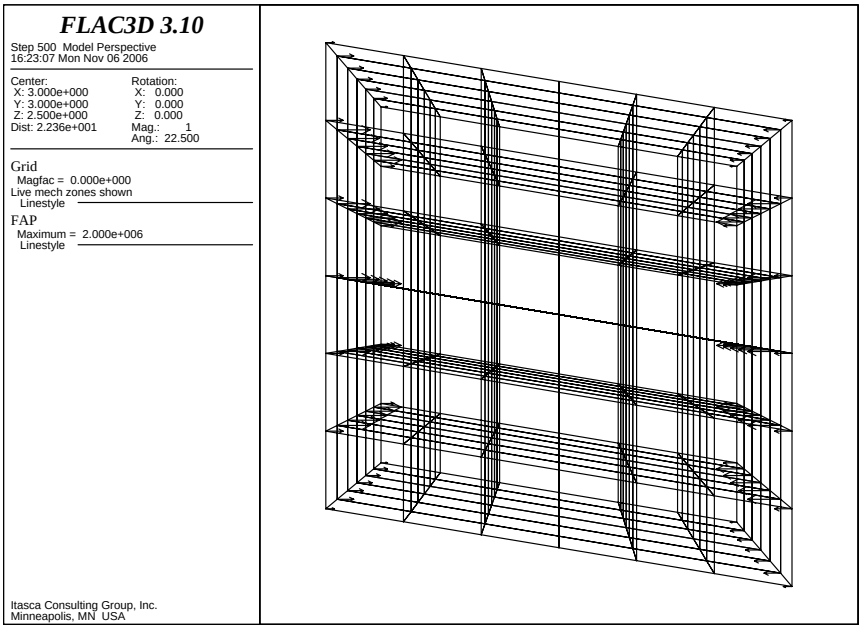


Figure 3.22 Applied horizontal forces on tilted body

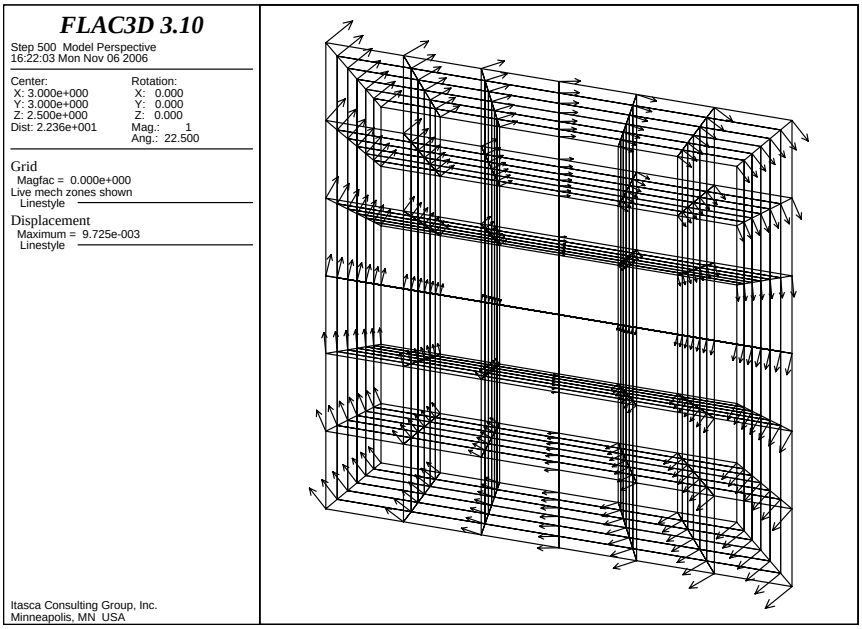


Figure 3.23 Rotational displacement induced by forces on tilted body

A similar, but more subtle, effect arises when material is excavated from a body that is supported by a stress boundary condition: the body is initially in equilibrium under gravity, but the removal of material reduces the weight. The whole body then starts moving upward, as demonstrated by the data file in Example 3.18.

Example 3.18 Uplift when material is removed

```
gen zone brick size 5,5,5
model elas
prop bulk 8e9 shear 5e9
set grav 0 0 -10
ini dens 1000
fix x range x -.1 .1
fix x range x 4.9 5.1
fix y range y -.1 .1
fix y range y 4.9 5.1
ini szz -5e4 grad 0 0 -1e4
app szz -5e4 range z -.1 .1
solve
model null range x 1,4 y 1 4 z 3 5
step 100
plot set plane dip 90 dd 180 origin 0,2.5,0
plot add surf plane behind yell
plot add vel plane behind black
plot show     ;body no longer in equilibrium
```

The uplift is shown in Figure 3.24. The difficulty encountered in running this data file can be eliminated by fixing the bottom boundary, rather than supporting it with stresses. Section 3.3.4 contains some information relating to the location of such artificial boundaries.

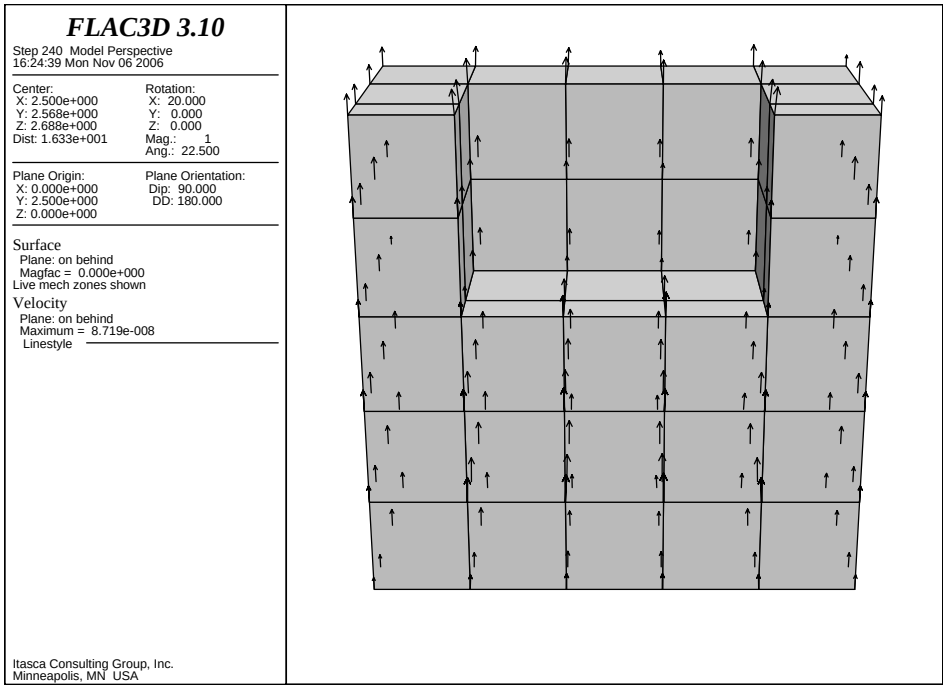


Figure 3.24 Uplift of model when material is removed

3.3.2 Displacement Boundary

Displacements cannot be controlled directly in *FLAC3D*; in fact, they play no part in the calculation process. In order to apply a given displacement to a boundary, it is necessary to prescribe the boundary's velocity for a given number of steps. If the desired displacement is D, a velocity V over N steps (where $N = D/V$) may be applied. In practice, V should be kept small and N large, in order to minimize shocks to the system being modeled. The **APPLY** command or the **FIX** and **INI** commands can be used to specify the velocities; gradients may also be specified.

Applied velocity conditions always refer to gridpoints. The velocities can be applied in terms of the x,y,z-global axes (i.e., with keywords **xvel**, **yvel** or **zvel**), or in terms of a local axes (with keywords **nvel**, **dvel** or **svel**). The local axes are defined by the normal vector at each gridpoint. The gridpoint normal direction is the average of the normal vectors of the faces meeting at the gridpoint. The d-s-n-axes at the gridpoint form a right-handed coordinate system (see Figure 3.25). At each gridpoint, all prescribed velocities must be on the same axes, either global axes or local axes.

Velocity conditions can be applied at any orientation by using the local axes. A normal gridpoint direction can be specified arbitrarily for the local axes by using the **plane** keyword; this will override the default normal direction. This feature is useful when specifying velocity conditions along corner boundaries. In the following example, it is required that velocities be applied, in the normal direction only, to each of two boundary planes.

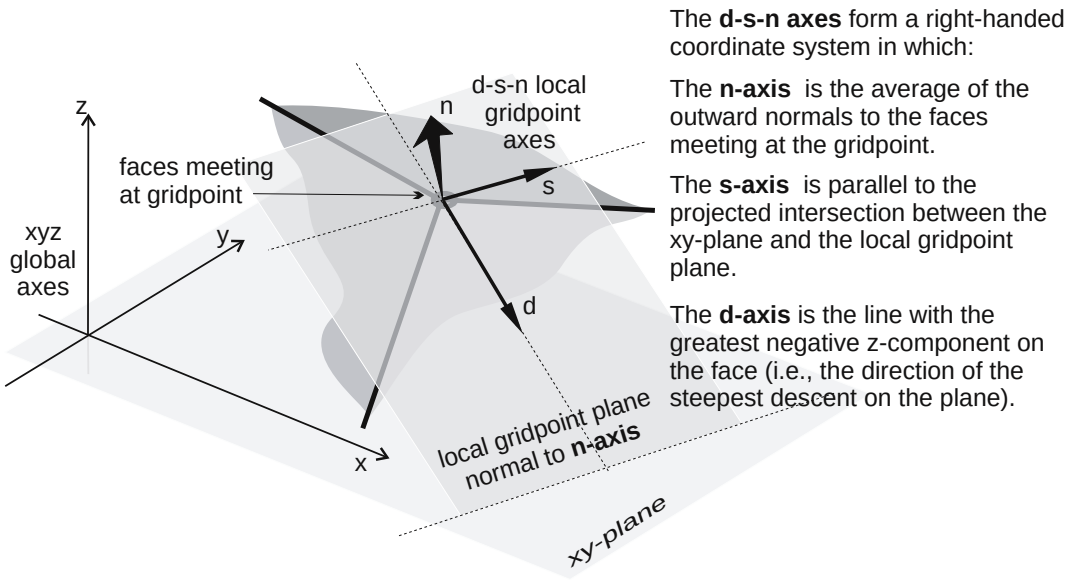


Figure 3.25 Local gridpoint axes defined by (d) dip direction, (s) strike direction and (n) normal direction

Example 3.19 Applying normal velocities at corners

```
gen zone brick size 4,4,4 p3 2,0,3.464
model elas
prop bulk 1e8 shear .3e8
macro left_boun  'plane dip 60 dd 270 origin 0.1,0,0 above'
macro right_boun 'plane dip 60 dd 270 origin 3.9,0,0 below'
apply nvel 0.1 plane dip 60 dd 270 range left_boun
apply nvel 0.1 plane dip 120 dd 90 range right_boun
; apply nvel 0.1 range left_boun
; apply nvel 0.1 range right_boun
step 1
plot grid vel
```

If the **plane dip 60 dd 270** keyword phrase and the **plane dip 120 dd 90** keyword phrase are removed from the **APPLY nvel** commands, then the velocities at the grid corners will not be applied in the desired directions. The default normal direction at the corner gridpoints is determined by all faces meeting at the gridpoint. (Compare Figure 3.26 to Figure 3.27.)

Applying different local axes at the same gridpoint is not permissible. This can require a variation in applied-velocity boundary conditions if the model is not oriented parallel with the x,y,z-coordinate axis. This is shown, for example, in the application of two roller boundary planes that intersect at the model edges. Example 3.20 illustrates the problem.

Example 3.20 Applying local axes velocities along model edges

```
gen zone brick size 4 4 4
model elastic
prop bulk 1e8 shear .3e8
apply nstress -1e6 range y 3.9 4.1
apply nvel 0.0 plane dip 90 dd 180 range y -.1 .1
apply nvel 0.0 plane dip 90 dd 270 range x -.1 .1
```

An error message will appear for the second **APPLY nvel** command, because the gridpoints along the model edge $x = 0$, $y = 0$ can only have one local coordinate system defined. The local coordinate systems must have the same **dip** and **dd** in order to avoid this problem. This problem can be overcome by using the same local axis system for both assign commands, and assigning the velocities in the strike direction in the first command and in the dip direction in the second command. Replace the two **APPLY nvel** commands with the following commands:

```
apply svel 0.0 plane dip 0 dd 0 range y -.1 .1
apply dvel 0.0 plane dip 0 dd 0 range x -.1 .1
```

The velocity boundary conditions are now correct along the model edge.

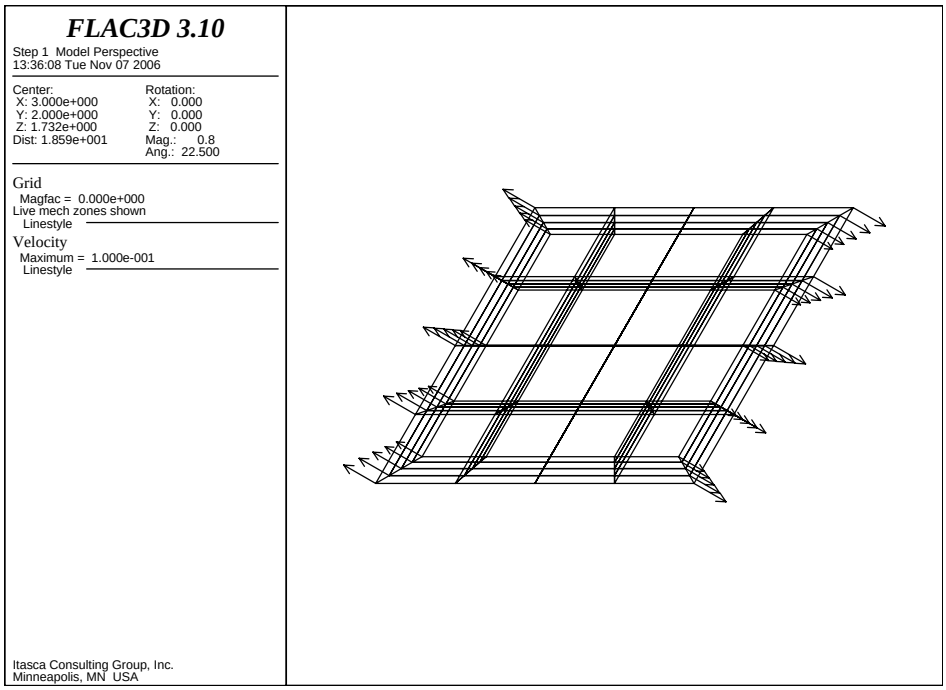


Figure 3.26 Applied velocities using the local axes plane

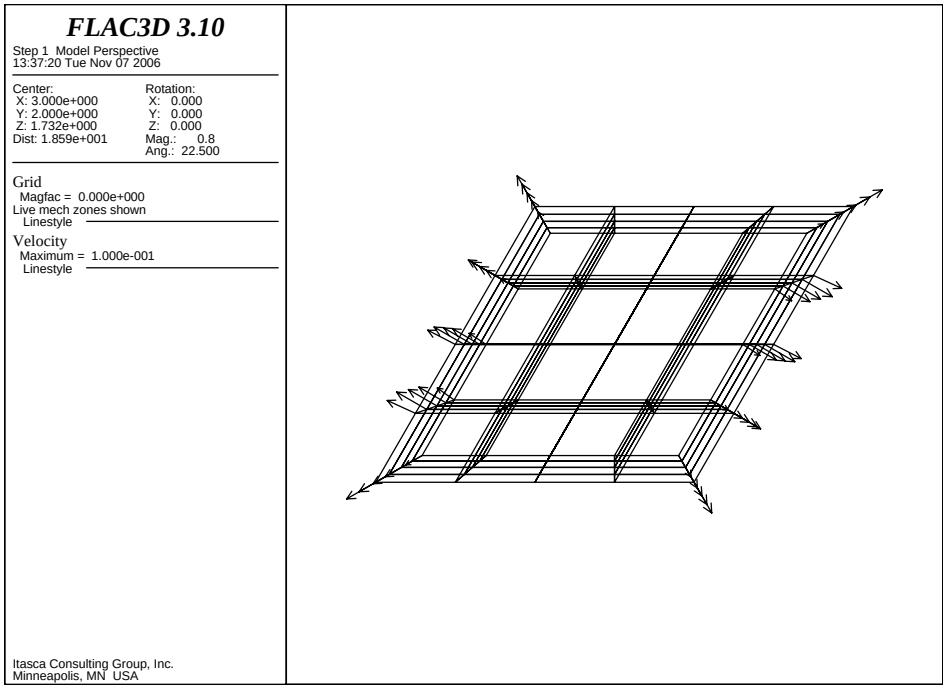


Figure 3.27 Applied velocities without the local axes plane

Local axes velocities cannot be applied to any gridpoints that are already **FIX**ed in any direction. Also, a global-axes velocity cannot be applied to a gridpoint with a **FIX**ed velocity in the same direction (i.e., **APPLY xvel** is not compatible with **FIX x**).

Alternatively, the **FIX** and **INI** commands can be used to fix the velocity in one or more of the x,y,z-directions at a gridpoint. During the calculation process, the velocity at the start of stepping is retained regardless of what forces act on the **FIX**ed gridpoints. If a zero displacement boundary is required later in a calculation, the appropriate gridpoint velocities can be set to zero before the gridpoints are **FIX**ed.

As an example, in order to simulate rigid movement of a rough platen on a test specimen, one of the following code snippets can be used:

```
fix x z range y -0.1 0.1
apply yvel = 1e-5 range y -0.1 0.1
```

or

```
fix x y z range y -0.1 0.1
ini yvel = 1e-5 range y -0.1 0.1
```

or

```
apply svel = 0 plane dip = 0 range y -0.1 0.1
apply dvel = 0 plane dip = 0 range y -0.1 0.1
apply nvel = 1e-5 plane dip = 0 range y -0.1 0.1
```

The **APPLY** command applies velocities at external or internal boundary gridpoints. The **APPLY** . . . **interior** command can be used to apply velocities to interior gridpoints. **FIX** and **INI** can operate on *any* gridpoints, boundary or interior.

When gridpoints are moved rigidly, the reaction forces at the gridpoints can be monitored using *FISH*. The sum of the reaction forces along a boundary may be obtained with a simple *FISH* function that adds up the *FISH* variables that correspond to **xforce**, **yforce** and/or **zforce** over the required range. (See Example 4.5.)

If nonuniform prescribed velocities are required, the **gradient** keyword may be used. For a more complicated velocity profile, or one that changes as the simulation proceeds, it will be necessary to write a *FISH* function. Example 3.21 demonstrates this for the model of a rotating retaining wall on the right-hand side of a block of soil.

Example 3.21 Rotating retaining wall

```
gen zone brick size 10 5 5
mod el
prop shear 1e8 bulk 2e8
fix x y z range x -.1 .1   y 0 5  z   0 5
fix x y z range x   0 10   y 0 5  z -.1 .1
fix x y z range x 9.9 10.1 y 0 5  z   0 5
table 1
def find_add
   head = null
   p_gp = gp_head
   loop while p_gp # null
      x_pos = gp_xpos(p_gp)
      if x_pos = width then
         new  = get_mem(2)
         mem(new)   = head
         mem(new+1) = p_gp
         head = new
      endif
      p_gp = gp_next(p_gp)
   endloop
end
set width=10.0
find_add
def apply_vel
   while_stepping
```

```
    ad = head
    loop while ad # null
       p_gp = mem(ad+1)
       gp_xvel(p_gp) =  vel_max * gp_zpos(p_gp) / height
       gp_zvel(p_gp) = -vel_max * (gp_xpos(p_gp) - width) / height
       ad = mem(ad)
    endloop
end
set large vel_max=1e-2  height=5.0
step 100
```

The gridpoints on the right boundary have their velocities adjusted at every timestep. The *FISH* function **find_add** is invoked before stepping, to store the addresses of the right boundary gridpoints in *FLAC3D*'s main memory, in order to avoid searching during the calculation. (See Section 2.5.5.2 in the ***FISH* volume** for further explanation on accessing memory directly.) Then, function **apply_vel** is called at every step to update the velocities of only those gridpoints whose addresses are stored. The velocity profile of the wall is adjusted as the geometry changes in large-strain mode. Note that the given velocity in this example is much too high for a realistic simulation; it is for demonstration purposes only.

3.3.3 Real Boundaries — Choosing the Right Type

It is sometimes difficult to know the type of boundary condition to apply to a particular surface of the body being modeled. For example, in modeling a laboratory triaxial test, should the load applied by the platen be regarded as a stress boundary, or should the platen be treated as a rigid displacement boundary? Of course, the whole testing machine, including the platen, could be modeled, but that might be very time-consuming. (Remember that *FLAC3D* takes a long time to converge if there is a large contrast in stiffnesses.) In general, if the object applying the load is very stiff compared with the sample (say, more than 20 times stiffer), then it may be treated as a rigid boundary. If it is soft compared with the sample (say, 20 times softer), then it may be modeled as a stress-controlled boundary. Clearly, a fluid pressure acting on the surface of a body is of the latter category. Footings on soil can often be represented as rigid boundaries that move with constant velocity for the purpose of finding the collapse load of the soil. This approach has another advantage — it is much easier to control the test and obtain a good load/displacement graph. It is well-known that stiff testing machines are more stable than soft testing machines.

3.3.4 Artificial Boundaries

Artificial boundaries fall into two categories: planes of symmetry and planes of truncation.

3.3.4.1 Symmetry Planes

Sometimes it is possible to take advantage of the fact that the geometry and loading in a system are symmetrical about one or more planes. For example, if everything is symmetrical about a vertical plane, then the horizontal displacements on that plane will be zero. Therefore, we can make that plane a boundary and fix all gridpoints in the horizontal direction using the **FIX** command (e.g., **FIX x**). If velocities on the plane of symmetry are not already zero, they should be set to zero with the **INI** command (e.g., **INI xvel = 0.0**). Both commands should have their range given as the boundary plane. In the case considered, the y- and z-components of velocity on the vertical plane of symmetry are not affected and should not be fixed. Similar considerations apply to other planes of symmetry. Planes of symmetry can also be set along boundaries that lie at angles to the x,y,z-coordinate axes. Use the command **APPLY nvel** = 0, for example. However, it will be necessary to also specify the **plane** keyword to correctly provide the symmetry plane for corner gridpoints (see Examples 3.19 and 3.20).

3.3.4.2 Boundary Truncation

When modeling infinite bodies (e.g., tunnels underground) or very large bodies, it may not be possible to cover the whole body with zones, due to constraints on memory and computer time. Artificial boundaries are placed sufficiently far away from the area of interest that the behavior in that area is not greatly affected. It helps to know how far away to place these boundaries, and what errors might be expected in the stresses and displacements computed for the area of interest.

Several points should be considered when selecting the location for artificial boundaries:

1. A fixed boundary causes both stresses and displacements to be underestimated, while a stress boundary does the opposite.

2. The two types of boundary condition “bracket” the true solution, so that it is possible to do two tests with small boundaries, and get a reasonable estimate of the true solution by averaging the two results.

3. The effect of boundary location is most noticeable for elastic bodies because the displacements and stress changes are more confined when plastic behavior is present; there is a natural cutoff distance within which most of the action occurs. The artificial boundary may be placed slightly farther away without serious error. However, any artificial boundary must not be sufficiently close that it attracts plastic flow and thereby invalidates the solution.

It is always best to run several (coarse) models first, with different boundary locations, to evaluate the potential influence of the boundary on the calculated response, before performing the detailed analysis. An example evaluation of this type is presented in the **Problem Solving** section of the two-dimensional *FLAC* **User’s Guide**.

3.4 Initial Conditions

In all civil or mining engineering projects, there is an in-situ state of stress in the ground, before any excavation or construction is started. In *FLAC3D*, an attempt is made to reproduce this in-situ state by setting initial conditions. Ideally, information about the initial state comes from field measurements but, when these are not available, the model can be run for a range of possible conditions. Although the range is potentially infinite, there are a number of constraining factors (e.g., the system must be in equilibrium, and the chosen yield criteria must not be violated anywhere).

In a uniform layer of soil or rock with a free surface, the vertical stresses are usually equal to $g\rho z$, where g is the gravitational acceleration, ρ is the mass density of the material, and z is the depth below the surface. However, the in-situ horizontal stresses are more difficult to estimate. There is a common — but erroneous — belief that there is some "natural" ratio between horizontal and vertical stress, given by $\nu/(1-\nu)$, where ν is the Poisson's ratio. This formula is derived from the assumption that gravity is suddenly applied to a mass of elastic material in which lateral movement is prevented. This condition hardly ever applies in practice, due to repeated tectonic movements, material failure, overburden removal and locked-in stresses due to faulting and localization (see Section 3.10.3). Of course, if we had enough knowledge of the history of a particular volume of material, we might simulate the whole process numerically to arrive at the initial conditions for our planned engineering works, but this approach is not often feasible. Typically, we compromise: a set of stresses is installed in the grid, and then *FLAC3D* is run until an equilibrium state is obtained. It is important to realize that there are an infinite number of equilibrium states for any given system.

In the following sections, we examine progressively more complicated situations and the ways in which the initial conditions may be specified. The user is encouraged to experiment with the various data files presented.

3.4.1 Uniform Stresses — No Gravity

For an excavation deep underground, the gravitational variation of stress from top to bottom of the excavation may be neglected because the variation is small in comparison with the magnitude of stress acting on the volume of rock to be modeled. The **SET gravity** command may be omitted, causing the gravitational acceleration to default to zero. The initial stresses are installed with the **INI** command — e.g.,

```
ini sxx=-5e6 syy=-1e7 szz=-5e6
```

The components σ_{11} (or σ_{xx}), σ_{22} (or σ_{yy}) and σ_{33} (or σ_{zz}) are set to compressive stresses of -5×10^6, -10^7 and -5×10^6, respectively, throughout the grid. Range parameters may be added if the stresses are to be restricted to a sub-grid. The **INI** command sets all stresses to the given values, but there is no guarantee that the stresses will be in equilibrium. There are at least two possible problems. First, the stresses may violate the yield criterion of a nonlinear model that has been assigned to the grid. In this case, plastic flow will occur immediately after the **STEP** command is given, and the stresses will readjust. This possibility should be checked by doing one trial step and examining the response (e.g., **PLOT block state**). Second, the prescribed stresses at the grid boundary may not equal the given initial stresses. In this case, the boundary gridpoints will start

to move as soon as a **STEP** command is given. Again, output should be checked (e.g., **PLOT vel**) for this possibility. Example 3.22 shows a set of commands that produce initial stresses that are in equilibrium with prescribed boundary stresses.

Example 3.22 Initial and boundary stresses in equilibrium

```
gen zone brick size 6 6 6
model elas
ini sxx=-5e6 syy=-1e7 szz=-2e7
apply sxx=-5e6 range x -0.1 0.1
apply sxx=-5e6 range x 5.9  6.1
apply syy=-1e7 range y -0.1 0.1
apply syy=-1e7 range y 5.9  6.1
apply szz=-2e7 range z -0.1 0.1
apply szz=-2e7 range z 5.9  6.1
```

Of course, if the boundary is **FIX**ed, rather than stress-controlled, the initial stresses will be in equilibrium automatically: the **APPLY** command is not necessary. See Section 3.3 for more details on boundary conditions and the **APPLY** command in particular.

3.4.2 Stresses with Gradients — Uniform Material

Near the ground surface, the variation in stress with depth cannot be ignored. The **SET grav** command is used to inform *FLAC3D* that gravitational acceleration operates on the grid. It is important to understand that the **SET grav** command does not directly cause stresses to appear in the grid; it simply causes *body forces* to act on all gridpoints. These body forces correspond to the weight of material surrounding each gridpoint. If no initial stresses are present, the forces will cause the material to move (during stepping) in the direction of the forces until equal and opposite forces are generated by zone stresses. Given the appropriate boundary conditions (e.g., fixed bottom, roller side boundaries), the model will, in fact, generate its own gravitational stresses that are compatible with the applied gravity. However, this process is inefficient, since many hundreds of steps may be necessary for equilibrium. It is better to initialize the internal stresses such that they satisfy both equilibrium and the gravitational gradient. The **grad** parameters on the **INI** command must be given so that the stress gradient matches the gravitational gradient, $g\rho$. The internal stresses must also match boundary stresses at stress boundaries. As mentioned in Section 3.3, there are several boundary conditions that could be used. Consider, for example, a 20 m $\times$ 20 m $\times$ 20 m box of homogeneous material at a depth of 200 m underground, with fixed base and stress boundaries on the other sides. The data file in Example 3.23 produces an equilibrium system.

Example 3.23 Initial stress state with gravitational gradient

```
gen zone brick size 10 10 10 p1 20,0,0 p2 0,20,0 p3 0,0,20
model mohr
prop bulk 5e9 shear 3e9 fric 35
```

```
ini density 2500
set gravity 0,0,-10
fix x y z range z -0.1 0.1
ini szz -5.0e6 grad 0,0,2.5e4
ini syy -2.5e6 grad 0,0,1.25e4
ini sxx -2.5e6 grad 0,0,1.25e4
apply szz -4.5e6 range z 19.9 20.1
apply szz -5.0e6 range z -0.1 0.1
apply sxx -2.5e6 grad 0,0,1.25e4 range x -0.1 0.1
apply sxx -2.5e6 grad 0,0,1.25e4 range x 19.9 20.1
apply syy -2.5e6 grad 0,0,1.25e4 range y -0.1 0.1
apply syy -2.5e6 grad 0,0,1.25e4 range y 19.9 20.1
```

In this example, horizontal stresses and gradients are equal to half the vertical stresses and gradients, but they may be set at any value that does not violate the yield criterion (Mohr-Coulomb, in this case). After preparing a data file such as in Example 3.23, one calculation step should be executed and the velocity field plotted; any failure to match internal stresses with boundary stresses will show up as a systematic movement at one or more boundaries. Small, chaotic velocities may be ignored — see Section 3.9.2. The unbalanced force after one step will be very small, but may not be exactly zero. This is a function of round-off error. Unbalanced force is calculated as a single-precision number, while applied forces are double-precision numbers.

It is worth noting that the gradient specified with the **grad** keyword associates stresses with zone centroids (i.e., the global location of the centroid determines the stress value from the gradient). Thus, although the applied σ_{zz}-stress varies from -5.0×10^6 to -4.5×10^6 in Example 3.23, the actual zone stresses in this example vary from -4.975×10^6 to -4.525×10^6. The stress-contour plot interpolates the zone stress from the centroid to the boundary; the stress at the boundary is *not* exactly the stress in the boundary zone. In order to plot the actual stresses in the zones, use the block-contour plot. This difference can be seen by comparing a plot using the command **PLOT contour szz** to one using the command **PLOT bcontour szz** for Example 3.23.

3.4.3 Stresses with Gradients — Nonuniform Material

It is more difficult to give the initial stresses when materials of different densities are present. Consider a layered system with a free surface, enclosed in a box with roller side boundaries and fixed base. Suppose that the material has the following density distribution:

1600 kg/m^3 from 0 to 10 m depth

2000 kg/m^3 from 10 to 15 m

2200 kg/m^3 from 15 to 25 m

An equilibrium state is produced by the data file in Example 3.24.

Example 3.24 Initial stress gradient in a nonuniform material

```
gen zone brick size 10 10 10 &
    p0 0,-25,0 p1 20,-25,0 p2 0,0,0 p3 0,-25,20
model elas
prop bulk 5e9 shear 3e9
ini density 1600 range y -10,0
ini density 2000 range y -15,-10
ini density 2200 range y -25,-15
set gravity 0,-10,0
fix x range x -.1 .1
fix x range x 19.9 20.1
fix z range z -.1 .1
fix z range z 19.9 20.1
fix y range y -25.1 -24.9
ini syy 0.0    grad 0,1.6e4,0 range y -10,0
ini syy 4e4    grad 0,2.0e4,0 range y -15,-10
ini syy 7e4    grad 0,2.2e4,0 range y -15,-25
```

The stress at each material interface must be calculated manually from the known overburden above it. This is used in the gradient formula (Eq. (3.1)) to calculate the value following **syy** on the **INI** command. The **grad** values are simply the variations across each layer due to the gravitational gradient. Note that the example is simplified — in a real case, the elastic moduli would vary, and there would be horizontal stresses. If high horizontal stresses exist in a layer, these may be installed with the **INI** command.

In a more complicated situation, it is best to use a *FISH* function to compute initial stress values from a known material property distribution.

3.4.4 Stress Initialization in a Nonuniform Grid

The existence of *internal* nonuniformities in a *FLAC3D* grid should not change the way in which stresses are initialized. However, some minor adjustment may be necessary, because forces do not balance exactly if the grid is irregular. For example, a grid may be distorted internally into the shape of a cylinder, with a view to "excavating" a tunnel at some later stage in the run. There will be a very slight initial imbalance in forces, but this may be relaxed with a few steps, as illustrated in Example 3.25.

Example 3.25 Initial stress state for a nonuniform grid

```
gen zone radcyl size 3 8 4 5 fill  p1 10,0,0 p2 0,10,0 p3 0,0,10
mode elastic
prop shear 3e8 bulk 5e8
fix x range x -.1 .1
fix x range x 9.9 10.1
```

```
fix y range y -.1 .1
fix y range y 9.9 10.1
fix z range z -.1 .1
ini szz = -2.5e5 grad 0,0,2.5e4
ini density 2500
set grav 0,0,-10
```

At one calculation step, an unbalanced force of approximately 8000 exists. This imbalance can be reduced by executing 250 steps. Now the unbalanced force is less than 100.

More complications arise when a free surface has an irregular geometry. Example 3.26 produces the "mountain range" shown in Figure 3.28. (The details of the generation process are not important in this context.)

Example 3.26 Initial stress state for an irregular free surface

```
gen zone brick size 15 15 10 p0 0,0,0 edge=100.0
model elastic
prop shear 3e8 bulk 5e8
def mountain
  gp = gp_head
  loop while gp # null
    zz = sqrt(gp_xpos(gp)^2 + gp_ypos(gp)^2)
    dz = 0.06 * sin(0.2 * zz + 100.0)      ; Sum Fourier terms for
    dz = dz + 0.06 * sin(0.22 * zz - 20.3) ; quasi-random surface
    dz = dz - 0.04 * sin(0.33 * zz + 33.3) ; topology.
    gp_zpos(gp) = 0.5 * gp_zpos(gp) * (1.0 + dz)
    gp = gp_next(gp)
  end_loop
end
mountain

fix x range x -.1 .1
fix x range x 99.9 100.1
fix y range y -.1 .1
fix y range y 99.9 100.1
fix z range z -.1 .1
set grav 0,0,-10
ini density=2000
ini szz=-2.0e6 (grad 0,0,2.0e4)
ini sxx=-4.0e6 (grad 0,0,4.0e4) syy=-4.0e6 (grad 0,0,4.0e4)
solve
```

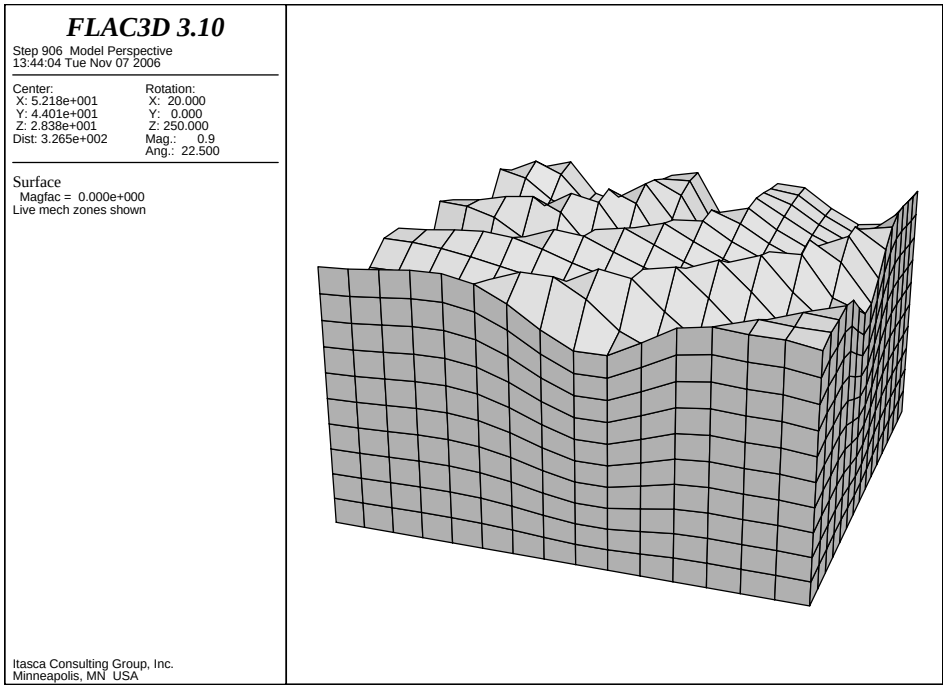


Figure 3.28 FLAC3D grid of mountain range

There is no simple way to deduce an equilibrium stress distribution for this grid: it must be modeled as a boundary-value problem. However, we may insert initial stresses in order to speed up the convergence and influence the final stress distribution. For example, if we know that there is a high horizontal in-situ stress, with only a small decrease in stress near the surface, we can initialize σ_{xx} and σ_{yy} to -2×10^5 at the approximate location of the surface, increasing to -4×10^6 at the bottom. The vertical stress σ_{zz} can be set to correspond to the average overburden.

The resulting horizontal stress distribution is shown in Figure 3.29. This represents just one of many ways to obtain an equilibrium solution; each one will produce a different, but physically valid, stress distribution. Several schemes are listed below.

1. Do not initialize stresses; allow gravity to compact the layer.
2. Initialize horizontal stress only, not vertical stress.
3. Impose constant stress at the lateral boundaries rather than zero horizontal displacement.
4. Remove irregular overburden from initial grid of uniform thickness.
5. Allow plastic flow to occur, thus removing stress concentrations.
6. Build up the profile layer by layer; equilibrate each layer.

There are probably many other possible schemes, particularly for a nonlinear, path-dependent material. No initial state is the "correct one" — the choice may depend on the type of geological process that is believed to have occurred in the field.

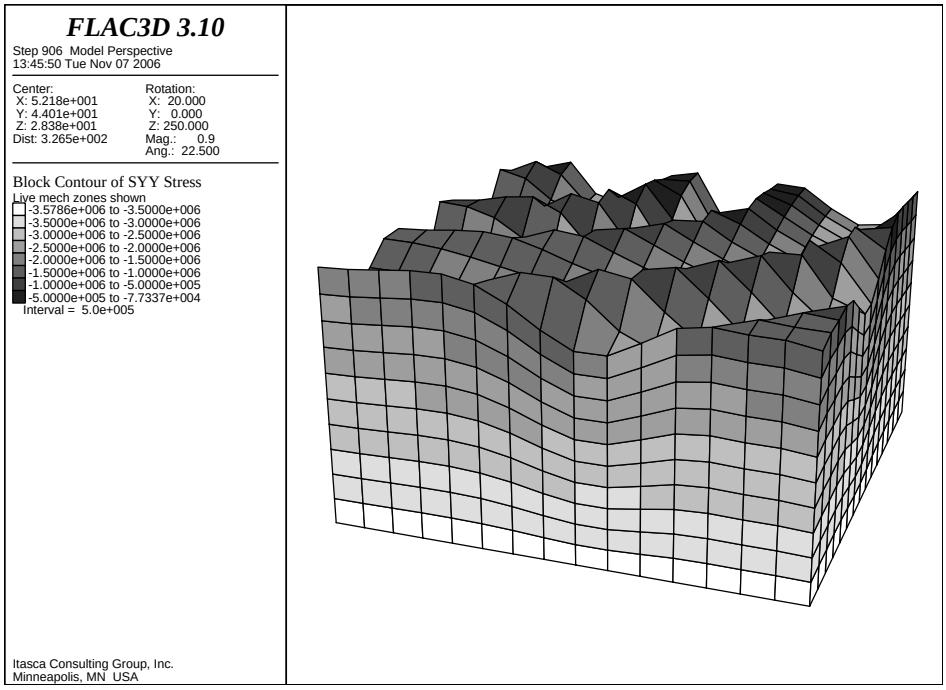


Figure 3.29 Horizontal stress contours in mountain range

3.4.5 Compaction within a Nonuniform Grid

Puzzling results are sometimes observed when a model is allowed to come to equilibrium under gravity, using a nonuniform grid. When a Mohr-Coulomb or other nonlinear constitutive model is used, the final stress state and displacement pattern are not uniform, even though the boundaries are straight and the free surface is flat. The data file in Example 3.27 illustrates the effect — see Figure 3.30 for the generated plot showing displacement vectors and vertical stress contours.

Example 3.27 Nonuniform stress initialized in nonuniform grid

```
gen zone brick  size 8 8 10 ratio 1.2 1 1
model mohr
ini dens 2000
prop bulk 2e8 shear 1e8
prop fric 30
fix x  range x -.1 .1
fix x  range x 7.9 8.1
```

```
fix y  range y -.1 .1
fix y  range y 7.9 8.1
fix z  range z -.1 .1
;ini szz -2.0e5 grad 0,0,2e4
;ini sxx -1.5e5 grad 0,0,1.5e4
;ini syy -1.5e5 grad 0,0,1.5e4
set grav 10
step 1000
;pause
;prop tens 1e10 coh 1e10
;step 750
;prop tens 0 coh 0
;step 250
```

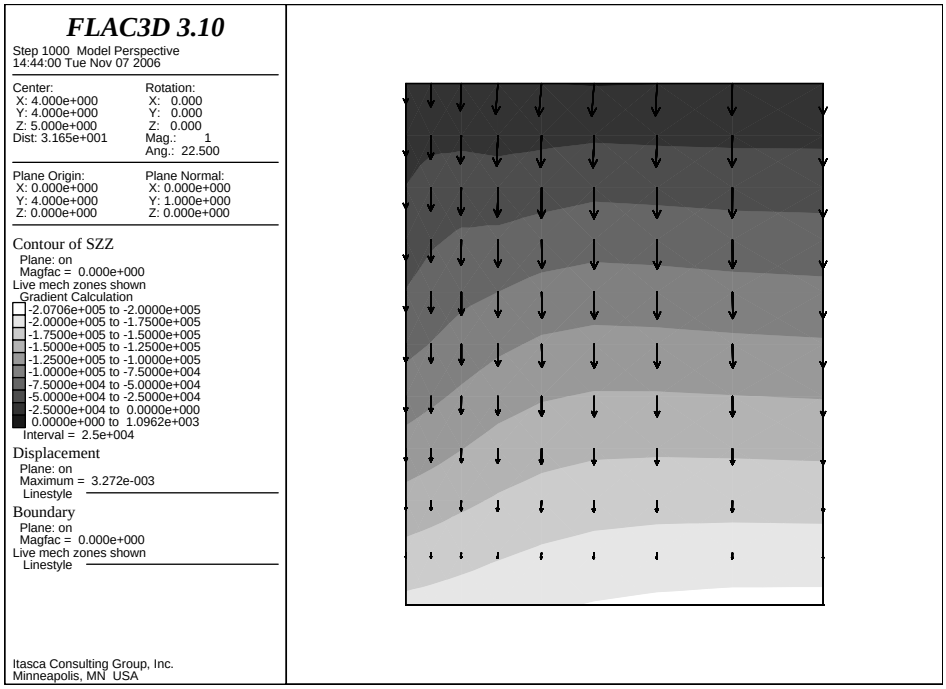


Figure 3.30 Nonuniform stresses and displacements

Since we have roller boundaries on the vertical sides, we might expect the material to move down equally on these sides. However, the grid is finer near the origin. *FLAC3D* tries to keep the local timestep equal for all zones, so it increases the inertial mass for the gridpoints near the $x = 0$ boundary to compensate for the smaller zone sizes. These gridpoints then accelerate more slowly than those near the $x = 8$ boundary. This will have no effect on the final state of a linear material, but it causes nonuniformity in a material that is path-dependent. For a Mohr-Coulomb material without cohesion, the situation is similar to dropping sand from some height into a container and expecting the final state to be uniform. In reality, a large amount of plastic flow would occur because the

confining stress does not build up immediately. Even with a uniform grid, this approach is not a good one because the horizontal stresses depend on the dynamics of the process.

The best solution is to use the **INITIAL** command to set initial stresses to conform to the desired K_0 value (ratio of horizontal to vertical stresses). For example, the **STEP 1000** command in the previous data file could be replaced by the lines

```
ini szz -2.0e5 grad 0,0,2e4
ini sxx -1.5e5 grad 0,0,1.5e4
ini syy -1.5e5 grad 0,0,1.5e4
```

A stable state is achieved with K_0 = 0.75; no stepping is necessary. (Invoke the **SOLVE** command to verify that the model is in equilibrium.)

If for some reason it is desirable to use *FLAC3D* to compute the final state, then the **STEP 1000** line could be replaced by the lines

```
prop tens 1e10 coh 1e10
step 750
prop tens 0 coh 0
step 250
```

Figure 3.31 shows the displacement vectors and vertical stress contours for this case. The material is prevented from yielding during the compaction process, but the original properties are restored when equilibrium is achieved.

The command **SOLVE elastic** automatically performs the same functions as the preceding commands: the mechanical calculation is first solved assuming high strength properties, and then solved using the actual strength properties. Presently, **SOLVE elastic** can only be applied for Mohr-Coulomb materials.

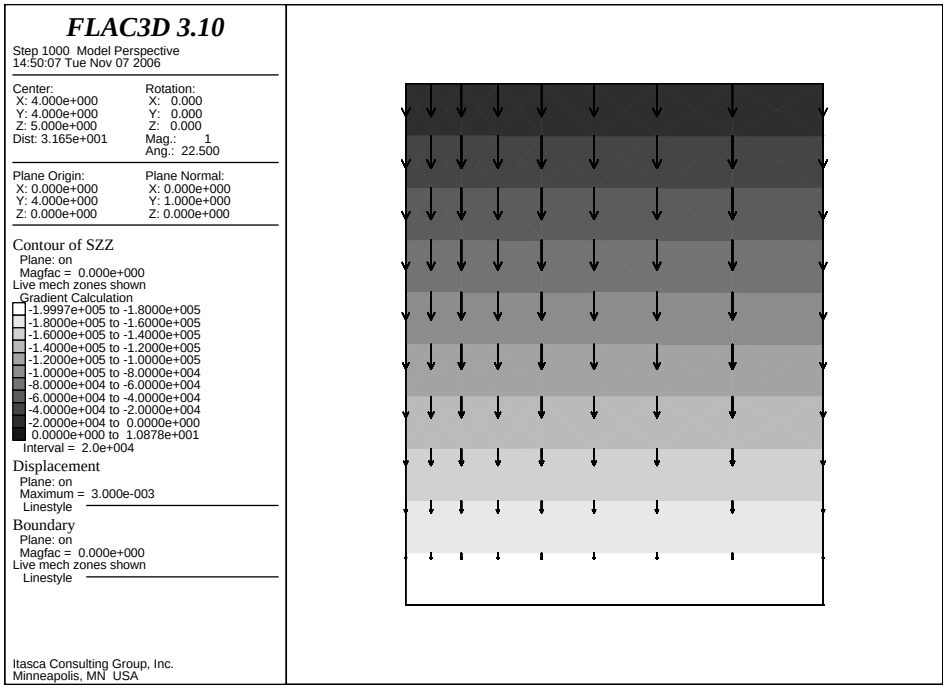


Figure 3.31 Uniform stresses and displacements

3.4.6 Initial Stresses following a Model Change

There may be situations in which one model is used in the process of reaching a desired stress distribution, but another model is used for the subsequent simulation. If one model is replaced by another non-null model, the stresses in the affected zones are preserved, as in Example 3.28.

Example 3.28 Initial stresses following a model change

```
gen zone brick size 5 5 5
model elas
prop sh 2e8 bu 3e8
fix x y z range  z -.1 .1
set grav 0 0 -10
ini dens 2000
solve
model mohr range x 0 2 y 0 5 z 0 2
prop sh 2e8 bu 3e8 fric 35 range x 0 2 y 0 5 z 0 2
```

At this point in the run, the stresses generated by the initial elastic model still exist and act as initial stresses for the region containing the new Mohr-Coulomb model.

Two points should be remembered. First, if a null model is installed in any zones (even if it is subsequently replaced by another model), all stresses are removed from the affected zones. Second, if one model is replaced by another and the stresses should physically be zero in the new model, then an **INI** command must be used to reset the stresses to zero. This situation would occur if rock is mined out and replaced by backfill; the backfill would have its own stress state, unrelated to the rock it is replacing.

3.4.7 Stress and Pore-Pressure Initialization with a Phreatic Surface

Pore pressures are initialized in the same way as stresses. However, the *gridpoint* pore pressures, rather than the *zone* pore pressures, are initialized, regardless of whether **CONFIG fluid** is specified.* Zone pore pressures are derived from gridpoint pore pressures by averaging. Zone pore pressures are then used to calculate effective stresses needed by the constitutive models.

Initialization of a partially saturated grid can be confusing; it may be easier to set the boundary conditions and let *FLAC3D* compute the phreatic surface and corresponding variations in stress gradients that occur because of differing zone densities. If pressures and stresses are to be initialized manually, often the procedure illustrated below can be used. The following example demonstrates the procedure for both the case of the grid configured for groundwater (**CONFIG fluid**) and the case not configured for groundwater.

Consider an impermeable box of height 10 m, which contains a solid, elastic material, fixed at the sides and base. Assume that only the bottom 5 m (z = 0 to 5 m) are fully saturated. The dry density of the solid is 2000 kg/m^3, and its porosity is 0.5. In the model for this example, we specify a grid with ten zones in the vertical direction.

It is best to work out the stress conditions for the zones from the top downward, based upon the different zone densities and the location of the phreatic surface. The influence of the fluid on zone density is calculated using the formula

$$\rho^{\mathrm{TOT}} = \rho^{\mathrm{DRY}} + n\, s\, \rho_w \tag{3.2}$$

where n is the porosity, s is the saturation, and ρ_w is the density of water.

For the specified zone size of 1 m, the saturation is zero from z = 6 m to z = 10 m. (Recall that saturation is a gridpoint variable.) Hence, the total density of each zone in this region is equal to the dry density of 2000 kg/m^3. The next row of zones (from z = 5 m to z = 6 m) has an *average* saturation of 0.5. Hence, the average density ρ^{TOT} is 2250 kg/m^3, using Eq. (3.2). For the zones in the region z = 0 to 5 m, the saturation is 1.0, so the total density is 2500 kg/m^3.

We calculate the total vertical stress gradient by adding the stresses due to the different zone densities. The change in vertical stress due to the density of 2000 kg/m^3 is applied with the command

---

* This differs from two-dimensional *FLAC*, in which gridpoint pore pressures are only initialized if **CONFIG gw** is specified.

```
ini szz -20e4  grad 0,0,20e3
```

An additional stress is added due to the zones between z = 5 m and 6 m with density of 2250 kg/m^3. This increment adds a stress gradient varying from zero at z = 6 m to -0.25×10^4 at z = 5 m. The increment remains constant at -0.25×10^4 from z = 5 m to z = 0.

```
ini szz add -1.5e4  grad 0,0,0.25e4  range z 5,6
ini szz add -0.25e4                  range z 0,5
```

The stress change is then added due to the zones between z = 5 m and z = 0 with density of 2500 kg/m^3. This increment adds a gradient varying from zero at z = 5 m to -2.5×10^4 at z = 0.

```
ini szz add -2.5e4  grad 0,0,0.5e4  range z 0,5
```

The grid pore pressure varies linearly from 5×10^4 at the base (z = 0), to zero at z = 5 m; above this, the material is unsaturated and the pore pressure is zero. We add the pore pressure with the command

```
ini pp 5.0e4   grad 0,0,-1.0e4  range z  0,5
```

The data file in Example 3.29 creates the initial conditions that are in equilibrium for this case (**CONFIG fluid**). Note that only the dry density of the material needs to be specified; the total densities will be calculated automatically.

Example 3.29 Stress and pore pressure initialization with a phreatic surface — grid configured for groundwater

```
config fluid
gen zone brick  size 8 5 10
model elas
model fl_iso
ini dens 2000
prop bulk 1e9 shear 5e8
prop poros 0.5 perm 1e-10
ini fmod 2e9
ini fdensity 1e3
ini sat 0
ini  sat 1 range z -.1 5.1
set grav 0 0 -10
fix x  range x -.1 .1
fix x  range x 7.9 8.1
fix y  range y -.1 .1
fix y  range y 4.9 5.1
fix z  range z -.1 .1
ini pp  5.e4        grad 0,0,-1.e4  range z 0.0 5.
ini szz -20e4       grad 0,0,20e3
ini szz add -1.5e4 grad 0,0,.25e4  range z 5,6
ini szz add -2.5e4 grad 0,0,.5e4   range z 0,5
```

```
ini szz add -.25e4                range z 0,5
solve
```

If the grid is not configured for groundwater, the different densities above and below the phreatic surface must be entered manually. The pore pressure gradient can be specified with either the **INI pp** or the **WATER table** command. The data file in Example 3.30 creates the initial conditions for the same example, but with the grid *not* configured for groundwater.

This example only illustrates the procedure for initializing vertical stresses. Horizontal stresses, in both the x- and y-directions, should also be initialized in a similar manner.

This procedure is admittedly complicated. If an error is made, then movement will start to occur from the first step, and fluid will flow. If further steps are taken, an equilibrium condition will be reached eventually, at the point at which densities, stresses and pressures are all compatible.

Example 3.30 Stress and pore pressure initialization with a phreatic surface — grid not configured for groundwater

```
gen zone brick  size 1 1 10
model elas
ini dens 2500 range z 0 5
ini dens 2250 range z 5 6
ini dens 2000 range z 6 10
prop bulk 1e9 shear 5e8
set grav 10
water dens 1000
water table ori 0 0 5 normal 0 0 1
fix x  range x -.1 .1
fix x  range x 7.9 8.1
fix y  range y -.1 .1
fix y  range y 4.9 5.1
fix z  range z -.1 .1
ini szz -20e4       grad 0,0,20e3
ini szz add -1.5e4 grad 0,0,.25e4  range z 5,6
ini szz add -2.5e4 grad 0,0,.5e4   range z 0,5
ini szz add -.25e4                 range z 0,5
solve
```

3.4.8 Initialization of Velocities

Until now, we have concentrated on initialization of stresses. Normally, the velocities *inside* the grid are not set explicitly: they default to zero initially. If, however, a velocity loading condition is specified at the boundary of a body, it is sometimes beneficial to initialize the velocities throughout the body to minimize the shock to the system. For example, in a simulated triaxial test with rigid platens, the velocities can be initialized to achieve an initial linear gradient throughout the sample, as shown in Example 3.31.

Example 3.31 Velocity gradient in a triaxial test

```
gen zone cyl p0 0 0 0 p1 1 0 0   p2 0 2 0  p3 0 0 1   size 4 5 4
gen zone reflect norm 1,0,0
gen zone reflect norm 0,0,1
model mohr
prop bulk 1.19e10 shear 1.1e10
prop coh 2.72e5 fric 44 ten 2e5
fix x y z range y -.1 .1
fix x y z range y 1.9 2.1
apply sxx =-1e5 szz=-1e5 range cyl end1 0,0,0 end2 0,2,0 radius 1
ini yvel 0 grad 0 -1e-4 0 range y 0 2
```

If the linear gradient is not applied, the internal gridpoints will receive an initial shock because they must accelerate to produce a negative velocity through the sample. The subsequent motion of the internal gridpoints is not controlled, since only the ends are fixed.

3.5 Loading and Sequential Modeling

By applying different model loading conditions at different stages of an analysis, it is possible to simulate changes in physical loading, such as sequences of excavation and construction. Changes in loading may be specified in a number of ways — e.g., by applying new stress or displacement boundaries, by changing the material model in zones to either a null material or to a different material model, or by changing material properties.

It is important to recognize that sequential modeling follows the stages of an engineering work — e.g., the stages in excavation and construction of a sheet pile wall. This modeling does *not*, however, include physical time as a parameter, and time-dependent behavior *cannot* be simulated.* Some engineering judgment must be used to estimate the effects of time. For example, a model parameter may be changed after a predetermined amount of displacement or strain has occurred. This displacement may be estimated to have occurred over a given period of time.

The following guidelines should be followed when performing loading changes or defining stages in a sequential analysis.

1. As discussed in Section 3.2, all zones must be defined initially, and those zones corresponding to future construction should be changed to null zones. Gridpoints must *not* be moved after solution stepping starts: displacements and stresses will not be adjusted to account for the change in element size or shape.

2. When material models are changed during a simulation sequence, all properties must be re-specified for the new model, even if the affected zones were previously assigned the same properties. Properties are lost when models are changed. Stresses in zones are preserved when models are changed, unless the zones are changed to null zones; in this case, all stresses in the affected zones are set to zero.

3. If the model is in equilibrium, a change in elastic properties will have no effect on the response of the model because elastic moduli are *tangent* moduli, not *secant* moduli. The model must be subjected to a change that causes unbalanced forces to develop. This may be caused, for example, by a change in strength properties if the current stresses exceed the new strength limit.

The recommended approach to sequential modeling is demonstrated by the following example. This problem involves the analysis of the loading on three tunnels (a service tunnel and two main tunnels) that are sequentially excavated and lined. The grid generation for this problem was described previously in Section 3.2.2.

---

* Of course, here we are referring to static mechanical processes. Transient calculations can be performed for groundwater flow and creep and thermal analyses with *FLAC3D*. Dynamic analysis can be performed with the dynamic option described in Section 3 in **Optional Features**.

The construction sequence to be analyzed consists of two modeling stages:

(1) excavation of the service tunnel; and

(2) installation of the liner for the service tunnel and excavation of the main tunnels.

The objective of the analysis is to investigate the influence of the main tunnel excavation on the response of the service tunnel.

The model is constructed to take advantage of symmetry in the problem. The service tunnel is located midway between the main tunnels, so a vertical plane of symmetry may be assumed to exist along the centerline of the service tunnel. The model grid is created in Example 3.32.

Example 3.32 Sequential excavation and lining of tunnels — initial grid

```
; main tunnel
gen zon radcyl  p0 15 0 0 p1 23 0 0 p2 15 50 0 p3 15 0 8 &
                size 4 10 6 4 dim 4 4 4 4 rat 1 1 1 1 fill
gen zon reflect dip 90 dd 90 orig 15 0 0
gen zon reflect dip 0 ori 0 0 0
; service tunnel
gen point id 1 (2.969848,0.0,-0.575736)
gen point id 2 (2.969848,50.0,-0.575736)
gen zon radcyl  p0 0 0 -1 p1 7 0 0 p2 0 50 -1 p3 0 0 8 p4 7 50 0 &
                p5 0 50 8 p6 7 0 8 p7 7 50 8 p8 point 1 p10 point 2 &
                size 3 10 6 4 dim 3 3 3 3 rat 1 1 1 1 fill
gen zon radcyl  p0 0 0 -1 p1 0 0 -8 p2 0 50 -1 p3 7 0 0 p4 0 50 -8 &
                p5 7 50 0 p6 7 0 -8 p7 7 50 -8 p9 point 1 p11 point 2 &
                size 3 10 6 4 dim 3 3 3 3 rat 1 1 1 1 fill
; outer boundary
gen zone radtun p0 7 0 0 p1 50 0 0 p2 7 50 0 p3 15 0 50 p4 50 50 0 &
                p5 15 50 50 p6 50 0 50 p7 50 50 50 &
                p8 23 0 0 p9 7 0 8 p10 23 50 0 p11 7 50 8 &
                size 6 10 3 10 rat 1 1 1 1.1
gen zone brick  p0 0 0 8 p1 7 0 8 p2 0 50 8 p3 0 0 50 &
                p4 7 50 8 p5 0 50 50 p6 15 0 50 p7 15 50 50 &
                size 3 10 10 rat 1 1 1.1
gen zon reflect dip 0 ori 0 0 0 range x 0 23 y 0 50 z 8 50
gen zon reflect dip 0 ori 0 0 0 range x 23 50 y 0 50 z 0 50
group main1   range cyl end1  15 0  0  end2  15 25  0 rad 4
group main2   range cyl end1  15 25 0  end2  15 50  0 rad 4
group service range cyl end1 0.0,0.0,-0.575736  &
                        end2  0.0,50.0,-0.575736 rad 3.0
save tun0.sav
```

The resulting grid is shown in Figure 3.32. The grid is manipulated such that the invert of the service tunnel is at the same elevation as that of the main tunnel (see Section 3.2.2).

Note that this model, including the structural element liner added at stage 2, requires approximately 10 MB memory to create and run. However, the size of the save file is approximately 7 MB because the structural-element stiffness matrix is not saved, but is recomputed from the current saved state.

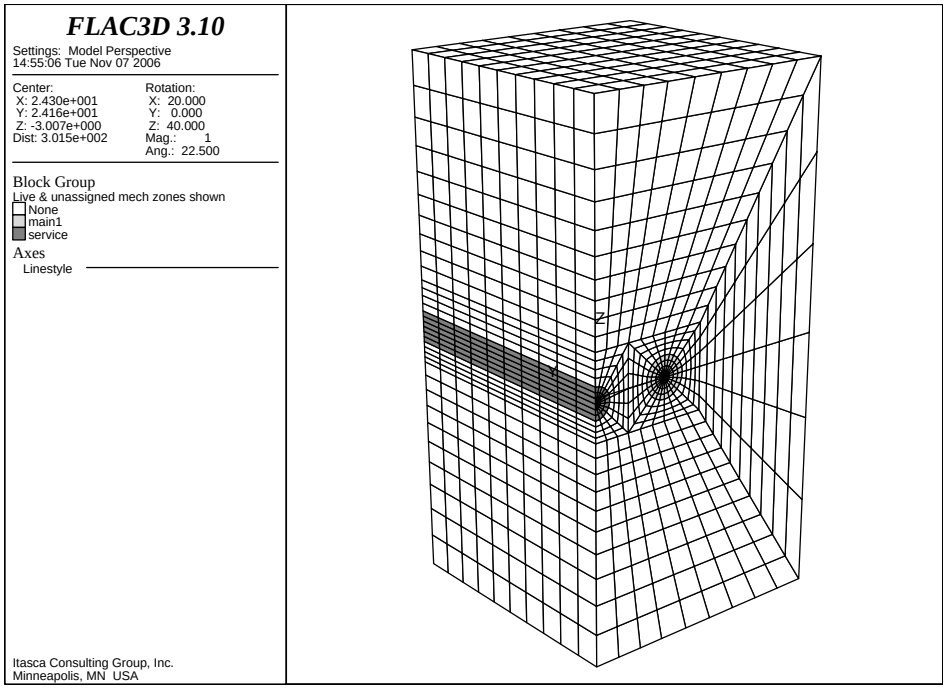


Figure 3.32 FLAC3D grid of main tunnels and service tunnel

A Mohr-Coulomb material model is initially defined for all zones. The plane of symmetry is specified, and an isotropic initial stress is assigned to the model. The model is in force equilibrium before an excavation is made. Note that only one calculational step is taken when the **SOLVE** command is issued, because the model is in equilibrium for the specified boundary and initial conditions. Example 3.33 lists the commands for this stage.

Example 3.33 Sequential excavation and lining of tunnels — initial state

```
rest tun0.sav
; mohr-coulomb model
model mohr
prop shear 0.36e9 bulk 0.6e9 coh 1e5 fric 20 tens 1e5
; boundary and initial conditions
apply szz -1.4e6 range z 49.9 50.1
fix z range z -50.1 -49.1
fix x range x -.1 .1
```

```
fix x range x 49.9 50.1
fix y range y -.1 .1
fix y range y 49.9 50.1
ini sxx -1.4e6 syy -1.4e6 szz -1.4e6
hist unbal
hist gp xdis 3,0,-1
hist gp zdis 0,0,2
hist gp xdis 3,25,-1
hist gp zdis 0,25,2
solve
save tun1.sav
```

In the first stage, the solution is found with a 25 m section of the service tunnel excavated. The excavation is made instantaneously (with the command **MODEL null range group service y 0,25**).* This assumes that the actual excavation is done suddenly (e.g., by blasting). The resulting nonlinear response of the model will depend on the rate of unloading, so the modeler must decide whether this method of excavation in *FLAC3D* is appropriate to the physical problem. Alternatively, the excavation can be made by reducing the stresses along the excavation gradually. (For example, see Example 3.14.) The stage 1 commands are listed in Example 3.34.

Example 3.34 Sequential excavation and lining of tunnels — stage 1

```
; exacavate 25 m section of service tunnel
rest tun1.sav
model null range group service y 0,25
solve
save tun2.sav
```

The gridpoint history plots in Figure 3.33 for displacement at the springline and crown of the service tunnel indicate that the model has reached equilibrium within approximately 2300 calculation steps for stage 1.

---

* This approach is a simplistic simulation of the progressive advancement of the tunnel. For a more realistic model of sequential tunnel construction, see Section 4 in the **Examples volume**.

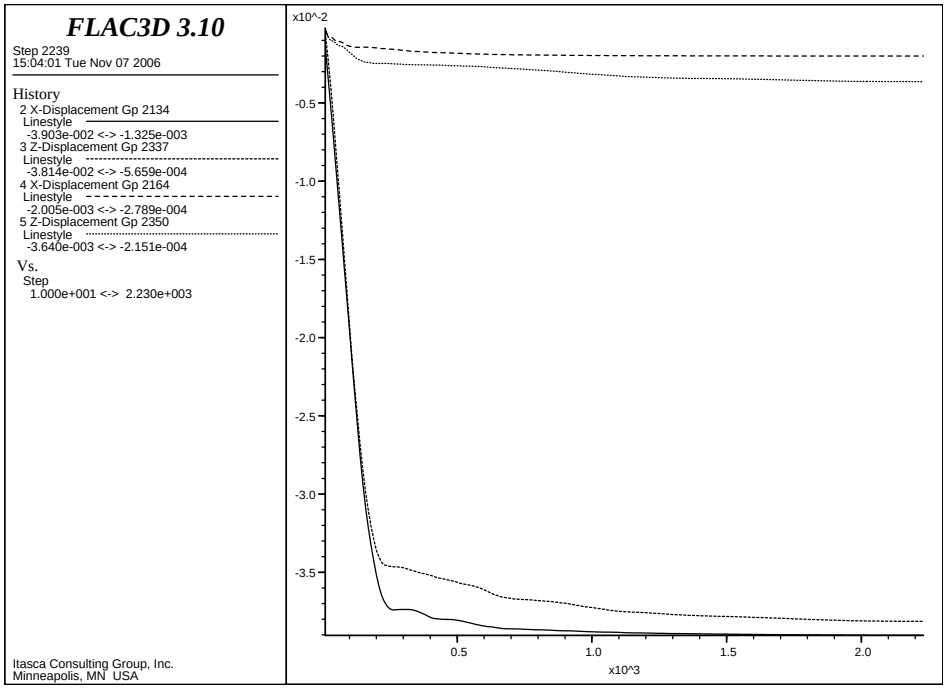


Figure 3.33 Displacement histories at crown and springline of service tunnel for stage 1 — Gp 2799 at (x=3, y=0, z=-1); Gp 2337 at (x=0, y=0, z=2); Gp 2812 at (x=3, y=25, z=-1); Gp 2350 at (x=0, y=25, z=2)

In the second stage, the lining is installed along the excavated section of the service tunnel. The lining is modeled using structural shell elements, and an elastic liner is assumed. Fixity conditions are specified for structural element nodes located on the symmetry plane of the grid to correspond to the same symmetry condition for the liner.

A 25 m section of the main tunnel is then excavated, and the solution is calculated for support provided by the lining (see Example 3.35).

Example 3.35 Sequential excavation and lining of tunnels — stage 2

```
restore tun2.sav
ini xdis 0.0 ydis 0.0 zdis 0.0
hist purge
;
model null range group service y 25 50
; liner
sel shell id=1 range cyl end1 0 0 -1  end2 0 25 -1  rad 3
sel shell prop iso=(25.3e9, 0.266)  thick = 0.5
sel node fix y xr zr range y -0.1 0.1   ; symmetry cond.
sel node fix x yr zr range x -0.1 0.1   ; symmetry cond.
```

```
;
model mohr range group service y 25 50
prop shear 0.36e9 bulk 0.6e9 coh 1e5 fric 20 tens 1e5
;
; excavate main tunnel - main1
model null range group main1
solve
save tun3.sav
```

We initialize the displacements in the model so that we can focus on the response due only to the excavation. The displacement histories at the two ends of the lined section of the service tunnel (i.e., at $y = 0$ and $y = 25$) indicate a nonsymmetric response of the service tunnel as a result of the partial excavation (see Figure 3.34). This is also evident in the contour plot of the displacement magnitude in the grid, and the minimum (i.e., major) principal stress (σ_1) in the lining (see Figure 3.35).

The modeling sequence may be repeated with different conditions of material properties, or locations of main tunnels relative to the service tunnel. If new tunnel locations are investigated, the grid must be regenerated and the model brought to an initial equilibrium state again. If different material properties are used, the model must be solved first for the response of the unlined service tunnel. Always remember that the model *must* be at an equilibrium state when the loading change is made.

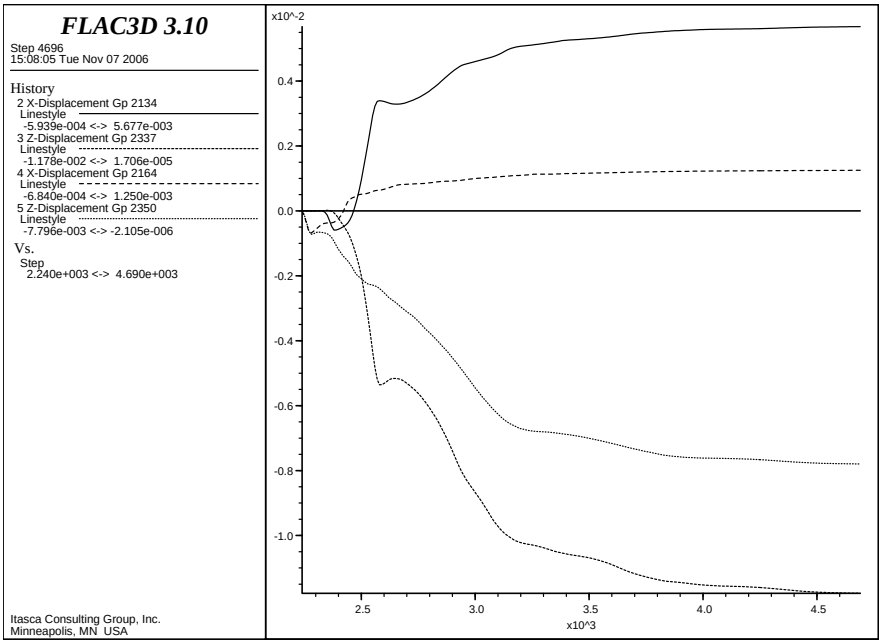


Figure 3.34 Displacement histories at crown and springline of service tunnel for stage 2 — Gp 2799 at (x=3, y=0, z=-1); Gp 2337 at (x=0, y=0, z=2); Gp 2812 at (x=3, y=25, z=-1); Gp 2350 at (x=0, y=25, z=2)

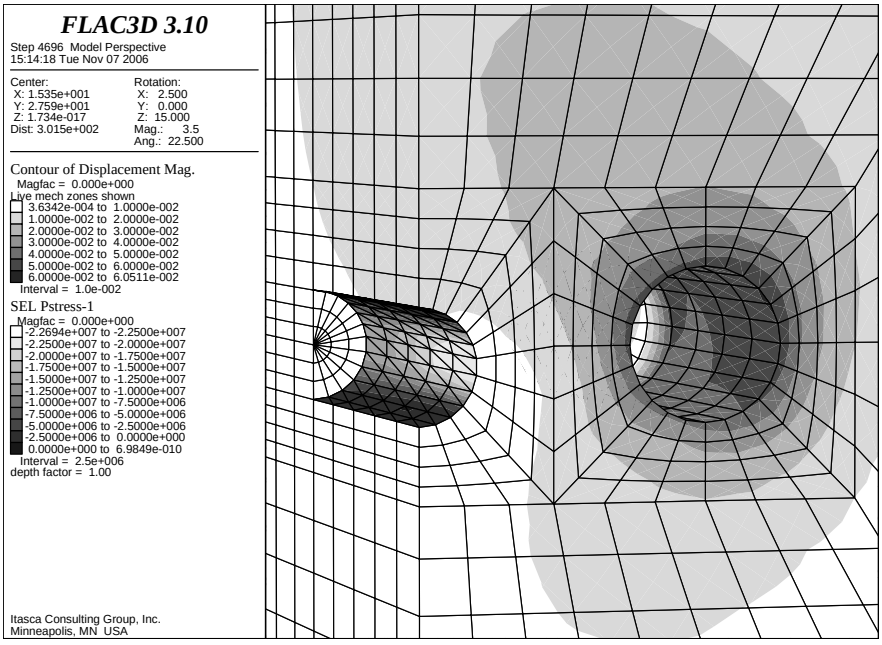


Figure 3.35 Contour plot of displacement magnitude in the grid and minimum principal stress in the lining after partial excavation of the main tunnel

3.6 Choice of Constitutive Model

3.6.1 Overview of Constitutive Models

This section provides an overview of the constitutive models in *FLAC3D* and makes recommendations concerning their appropriate application. Section 2.1 in **Theory and Background** presents background information on the model formulations.

There are twelve built-in material models in *FLAC3D* :*

(1) null;

(2) elastic, isotropic;

(3) elastic, orthotropic;

(4) elastic, transversely isotropic;

(5) Drucker-Prager plasticity;

(6) Mohr-Coulomb plasticity;

(7) ubiquitous-joint plasticity;

(8) strain-hardening/softening Mohr-Coulomb plasticity;

(9) bilinear strain-hardening/softening ubiquitous-joint plasticity;

(10) double-yield plasticity;

(11) modified Cam-clay plasticity; and

(12) Hoek-Brown plasticity.

Each model is developed to represent a specific type of constitutive behavior commonly associated with geologic materials. The *null* model is used to represent material that is removed from the model. The *elastic, isotropic* model is valid for homogeneous, isotropic, continuous materials that exhibit linear stress-strain behavior. The *elastic, orthotropic* model and the *elastic, transversely isotropic* model are appropriate for elastic materials that exhibit well-defined elastic anisotropy. The *Drucker-Prager plasticity* model is a simple failure criterion in which the shear yield stress is a function of isotropic stress. The *Mohr-Coulomb plasticity* model is used for materials that yield when subjected

---

* These models are provided as *dynamic-linked libraries* (DLLs) that are loaded when *FLAC3D* is first executed. Users can modify the built-in models or create their own constitutive models as DLLs by following the procedures given in Section 4 in **Optional Features**. Also available are eight optional models that simulate viscoelastic and viscoplastic, time-dependent (creep) behavior (see Section 2 in **Optional Features**), and two optional models to simulate dynamic pore-pressure generation (see Section 3 in **Optional Features**).

to shear loading, but the yield stress depends on the major and minor principal stresses only; the intermediate principal stress has no effect on yield. The *ubiquitous-joint* model corresponds to a Mohr-Coulomb material that exhibits a well-defined strength anisotropy due to embedded planes of weakness. The *strain-hardening/softening Mohr-Coulomb* model is based upon the Mohr-Coulomb model, but is appropriate for materials that show an increase or degradation in shear strength when loaded beyond the initial failure limit. The *bilinear strain-softening ubiquitous-joint* model is a generalization of the ubiquitous-joint model that allows the strength properties for the matrix and the joint to harden or soften. The *double-yield* model is an extension of the strain-softening model to simulate irreversible compaction as well as shear yielding. The *modified Cam-clay* model accounts for the influence of volume change on deformability and on resistance to failure. The *Hoek-Brown* model is an empirical relation that is a nonlinear failure surface representing the strength limit for isotropic intact rock and rock masses. This model also includes a plasticity flow rule that varies as a function of the confining stress level.

The material models in *FLAC3D* are primarily intended for applications related to geotechnical engineering — e.g., underground construction, mining, slope stability, foundations, earth and rock-fill dams. When selecting a constitutive model for a particular engineering analysis, the following two considerations should be kept in mind.

1. What are the known characteristics of the material being modeled?

2. What is the intended application of the model analysis?

Table 3.4 presents a summary of the *FLAC3D* models along with examples of representative materials and possible applications of the models. The Mohr-Coulomb model is the most applicable for general engineering studies. Also, Mohr-Coulomb parameters for cohesion and friction angle are usually available more often than other properties for geo-engineering materials. The ubiquitous-joint, strain-softening, bilinear strain-softening/ubiquitous-joint and double-yield plasticity models are actually variations of the Mohr-Coulomb model. These models will produce results identical to those for Mohr-Coulomb if the additional material parameters are set to high values. The Drucker-Prager model is a simpler failure criterion than Mohr-Coulomb, but it is not generally suitable for representing failure of geologic materials. It is provided mainly to allow comparison of *FLAC3D* to other numerical programs that have the Drucker-Prager model but not the Mohr-Coulomb model. Note that, at zero friction, the Mohr-Coulomb model degenerates to the Tresca model, while the Drucker-Prager model degenerates to the von Mises model.

The Drucker-Prager and Mohr-Coulomb models are the most computationally efficient plasticity models; the other plasticity models require increased memory and additional time for calculation. For example, plastic strain is not calculated directly in the Mohr-Coulomb model (see Section 2.5.2 in **Theory and Background**). If plastic strain is required, the strain-softening, bilinear ubiquitous-joint or double-yield model must be used. These three models are primarily intended for applications in which the post-failure response is important — e.g., yielding pillars, caving or backfilling studies.

Table 3.4 FLAC3D constitutive models

Model	Representative Material	Example Application
null	void	holes, excavations, regions in which material will be added at later stage
elastic	homogeneous, isotropic continuum; linear stress-strain behavior	manufactured materials (e.g., steel) loaded below strength limit; factor-of-safety calculation
orthotropic elastic	materials with three mutually perpendicular planes of elastic symmetry	columnar basalt loaded below strength limit
transversely isotropic elastic	thinly laminated material exhibiting elastic anisotropy (e.g., slate)	laminated materials loaded below strength limit
Drucker-Prager plasticity	limited application; soft clays with low friction	common model for comparison to implicit finite-element programs
Mohr-Coulomb plasticity	loose and cemented granular materials; soils, rock, concrete	general soil or rock mechanics (e.g., slope stability and underground excavation)
strain-hardening / softening Mohr-Coulomb	granular materials that exhibit nonlinear material hardening or softening	studies in post-failure (e.g., progressive collapse, yielding pillar, caving)
ubiquitous-joint	thinly laminated material exhibiting strength anisotropy (e.g., slate)	excavation in closely bedded strata
bilinear strain-hardening/softening ubiquitous-joint	laminated materials that exhibit nonlinear material hardening or softening	studies in post-failure of laminated materials
double-yield	lightly cemented granular material in which pressure causes permanent volume decrease	hydraulically placed backfill
modified Cam-clay	materials for which deformability and shear strength are a function of volume change	geotechnical construction on clay
Hoek-Brown plasticity	isotropic rock material	geotechnical construction in rock

The tensile failure criterion is identical in the Drucker-Prager, Mohr-Coulomb, ubiquitous-joint, strain-softening, bilinear strain-softening/ubiquitous-joint and double-yield models. This criterion defines a tensile strength separately from the shear strength, and an associated flow rule for the onset of tensile failure. For the Drucker-Prager, Mohr-Coulomb and ubiquitous-joint models, the value assigned to the tensile strength remains constant when tensile failure occurs. Tensile softening can be modeled with the strain-softening, bilinear strain-softening ubiquitous-joint and double-yield models. (See Section 3.7.4.) Note that no record is made of notional voids that may open after tensile failure and tensile strain; if the strain rate becomes compressive, all models start to take compressive load immediately.

The double-yield and modified Cam-clay models both take into account the influence of volumetric change on material deformability and failure characteristics. In both models, tangential bulk and shear moduli are functions of plastic volumetric deformation.

The differences between the two models are summarized as follows.

In the Cam-clay model:

1. The elastic deformation is nonlinear, with the elastic moduli depending on mean stress.
2. Shear failure is affected by the occurrence of plastic volumetric deformation: the material can harden or soften depending on the degree of preconsolidation.
3. As shear loading increases, the material evolves toward a critical state at which unlimited shear strain occurs with no accompanying change in specific volume or stress.
4. There is no resistance to tensile mean stress.

In the double-yield model:

1. Elastic moduli remain constant during elastic loading and unloading.
2. Shear and tensile failure are not coupled to plastic volumetric change, due to volumetric yielding. The shear yield function corresponds to the Mohr-Coulomb criterion, and the tensile yield is evaluated based on a tensile strength.
3. Material hardening or softening, upon shear or tensile failure, is defined by tables relating friction angle and cohesion to plastic shear strain, and tensile strength to plastic tensile strain.
4. Volumetric yielding occurs; the isotropic stress at which yield occurs (*the cap pressure*) is not influenced by the amount of shear or tensile plastic deformation, but it increases (or hardens) with volumetric plastic strain.
5. A tensile strength limit and tensile softening can be defined.

The double-yield model was initially developed to represent the behavior of mine backfill material, for which preconsolidation pressures are low. The modified Cam-clay model is more applicable to soils such as soft clays for which preconsolidation pressures can have a significant effect on material behavior.

The Hoek-Brown model combines the generalized Hoek-Brown criterion with a plasticity flow rule that varies as a function of the confining stress level. At low confining stress, the volumetric expansion at yield is high, associated with axial splitting and wedging effects. At high confining stress, the material approaches a non-dilatant condition.

3.6.2 Selection of an Appropriate Model

A problem analysis should always start with the simplest material model; in most cases, an elastic model should be used first. This model runs the fastest and only requires two material parameters: bulk modulus and shear modulus (see Section 3.7). The model provides a simple perspective of stress-deformation behavior in the *FLAC3D* grid, and can define locations where stress concentrations may develop. This may assist the definition of zoning density for the grid.

It is often helpful to run a simple test of the selected material model before using it to solve the full-scale, boundary-value problem. This can provide insight into the expected response of the model compared to the known response of the physical material.

The following example illustrates the use of a simple test model. The problem application is the analysis of yielding mine pillars. A simple model is created to evaluate the implementation of the Mohr-Coulomb model versus the strain-softening model. This test also illustrates the effect of the selected measurement location on the reported results. The model is a compression test performed on a cylindrical grid composed of Mohr-Coulomb material.

Example 3.36 Compression test on Mohr-Coulomb material

```
gen zone cyl p0 0 0 0 p1 1 0 0   p2 0 2 0  p3 0 0 1   size 4 5 4
gen zone reflect norm 1,0,0
gen zone reflect norm 0,0,1
model mohr
prop bulk 1.19e10 shear 1.1e10
prop coh 2.72e5 fric 44 ten 2e5
fix x y z range y -.1 .1
fix x y z range y 1.9 2.1
ini yvel  1e-7 range y -.1 .1
ini yvel -1e-7 range y 1.9 2.1
;ini pp 1e5
hist gp ydisp 0,0,0
hist zone syy 0,1,0
hist zone syy 1,1,0
step 3000
```

The axial (*y*-direction) stress-displacement response is monitored at the center and outer boundary in the grid. The results shown in Figure 3.36 are obtained from the command

```
plot his -2 -3 vs 1
```

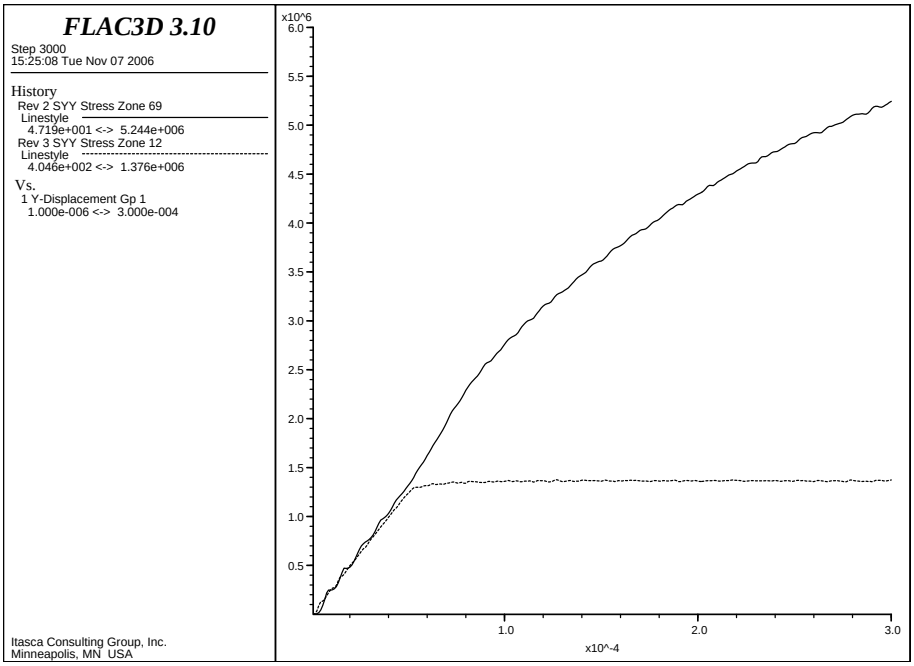


Figure 3.36 Stress-displacement plots for compression of Mohr-Coulomb material. Response is shown for an interior location (upper curve) and a boundary location (lower curve).

The test is now repeated with the strain-softening model:

Example 3.37 Compression test on strain-softening material

```
gen zone cyl p0 0 0 0 p1 1 0 0   p2 0 2 0  p3 0 0 1   size 4 5 4
gen zone reflect norm 1,0,0
gen zone reflect norm 0,0,1
model ss
prop bulk 1.19e10 shear 1.1e10
prop coh 2.72e5 fric 44 ten 2e5
prop ctab 1 ftab 2
table 1 0,2.72e5 1e-4,2e5 2e-4,1.5e5 3e-4,1.03e5 1,1.03e5
table 2 0,44 1e-4,42 2e-4,40 3e-4,38 1,38
fix x y z range y -.1 .1
fix x y z range y 1.9 2.1
ini yvel  1e-7 range y -.1 .1
ini yvel -1e-7 range y 1.9 2.1
hist gp ydisp 0,0,0
hist zone syy 0,1,0
hist zone syy 1,1,0
step 3000
```

The horizontal stress-displacement response is monitored again, as shown in Figure 3.37. This test produces distinct peak and residual failure stress levels.

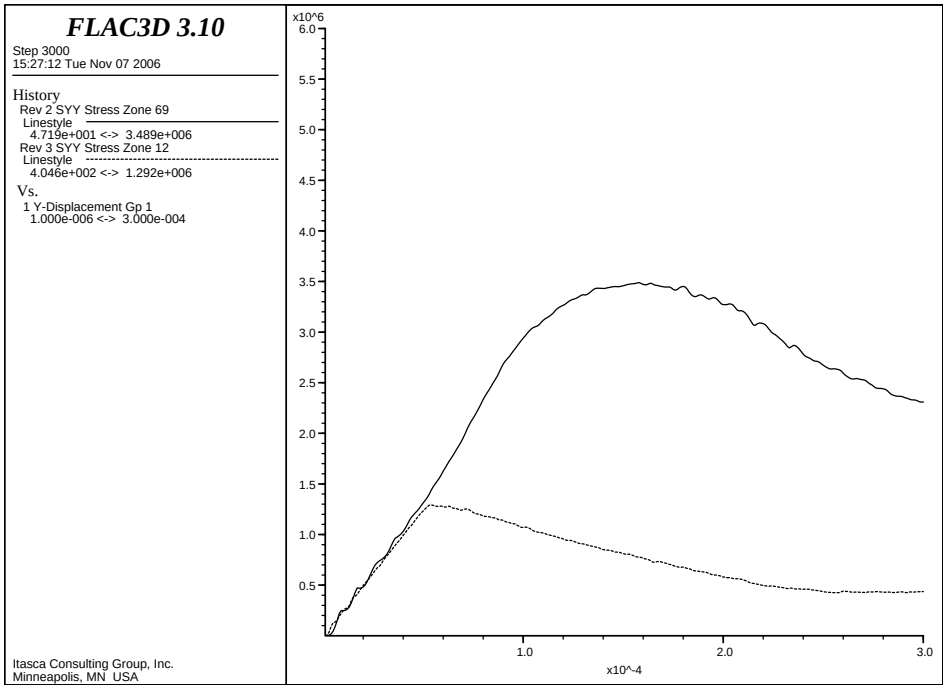


Figure 3.37 Stress-displacement for compression test of strain-softening material (similar monitoring points to Figure 3.36)

The strain-softening model assumes both a brittle softening (due to reduction in cohesion) and a gradual softening (due to a reduction in friction angle). The selection of the properties is discussed further in Section 3.7.

Comparison of Figures 3.36 and 3.37 illustrates the different responses of the two models. The initial response up to the onset of failure is identical, but post-failure behavior is quite different. Clearly, more data is required to use the strain-softening model and, typically, the softening model must be calibrated for each specific problem.

The effect of confinement on the “measured” response is also demonstrated from these plots. The history recorded in the middle of the grid shows that a higher stress level develops in the center of the model than at the free side. The location of monitoring points should correspond as closely as possible to the location of measurements in the physical problem.

3.6.3 The Effect of Water

Geologic materials generally appear weaker when the pore spaces contain a pore fluid under pressure. This is represented in *FLAC3D* by the incorporation of an effective stress that accounts for the presence of pore pressure in a zone. The pore pressures in *FLAC3D* are taken to be positive in compression. Thus, the effective stress σ' is related to the total stress σ and pore pressure p by

$$\sigma' = \sigma + p \tag{3.3}$$

Effective stresses are used in all of the plasticity models.

The effect of water can be seen by repeating Example 3.36 with constant pore pressure in the zones (i.e., an undrained compression test). Add the command

```
ini pp 1e5
```

to Example 3.36 before stepping. The lower strength is seen by comparing Figure 3.38 to Figure 3.36.

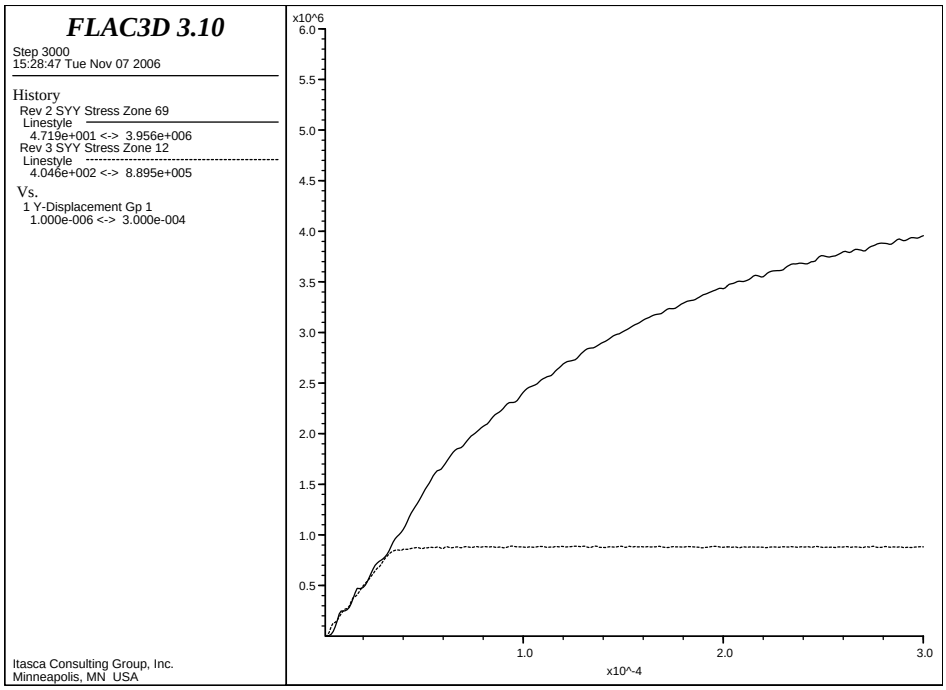


Figure 3.38 Stress-displacement plots for compression test of Mohr-Coulomb material at constant pore pressure

3.6.4 Ways to Implement Constitutive Models

There are several different ways in which a constitutive model can be implemented in *FLAC3D*. The standard way is to invoke one of the built-in models with the **MODEL** command. The user-defined models described in Section 4 in **Optional Features** are also invoked with the **MODEL** command.

As discussed in Section 3.6.1, the built-in models are provided as DLLs that are loaded when *FLAC3D* is first executed. The individual DLL files are contained in the "\FLAC3D310" directory with the executable code. The source codes for the built-in models are included in the "\Shared\Models\Source" sub-directory. These files should be reviewed as examples for users who wish to write and implement their own models. User-defined models are written in C++ and are implemented as DLLs that are loaded with the *FLAC3D* executable file in the same manner as the built-in models.* (See Section 4 in **Optional Features**.)

Often, it is desirable to modify an existing constitutive model (either a built-in model or a user-defined model) to make material properties dependent on other model parameters. There are three ways this can be done:

1. change properties of the built-in model via a *FISH* function that scans all the zones and is called at a specified step increment (say, every ten steps);
2. change properties in a user-defined constitutive model function at every step by reference to a formula; and
3. change properties via look-up tables (with the **TABLE** command) that modify strength properties as a function of plastic strain for the built-in strain-softening and double-yield models.

The third approach is the most efficient way to change properties in a *FLAC3D* model. The first approach is the least efficient.

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* Note that this approach differs from the *FISH* constitutive model used in two-dimensional *FLAC*. With the DLL approach, user-defined models run at the same calculational speed as built-in models.

3.7 Material Properties

The material properties required in *FLAC3D* are generally categorized in one of two groups: elastic deformability properties and strength properties. This section provides an overview of the deformability and strength properties, and presents guidelines for selecting the appropriate properties for a given model. Additionally, there are special considerations such as the definition of post-failure properties, the extrapolation of laboratory-measured properties to the field scale, the spatial variation of properties and randomness of the property distribution, and the dependence of properties on confinement and strain. These topics are also discussed.

The selection of properties is often the most difficult element in the generation of a model because of the high uncertainty in the property database. When performing an analysis, especially in geomechanics, keep in mind that the problem will always involve a data-limited system – the field data will never be known completely. However, with the appropriate selection of properties based upon the available database, important insight to the physical problem can still be gained. This approach to modeling is discussed further in Section 3.10.

Material properties are conventionally derived from laboratory testing programs. The following sections describe intrinsic (laboratory-scale) properties and list common values for various rocks and soils.

3.7.1 Mass Density

The mass density is only required in a *FLAC3D* model if loading due to gravity is specified. The mass density is used to calculate the gravitational stresses within the model. Mass density has the units of mass divided by volume, and does *not* include the gravitational acceleration. Often in the literature, the *unit weight* of a material is given. If the unit weight is defined with units of force divided by volume, then this value must be divided by the gravitational acceleration before entering the value as *FLAC3D* input for density.

If a fluid-flow calculation is performed and *FLAC3D* is configured for fluid flow (**CONFIG fluid**), then the *dry* density of the solid material must be used. *FLAC3D* will compute the saturated density of each element using the known density of water and the porosity.

If not in **CONFIG fluid** mode, the saturated density should be used in elements below the phreatic surface. The following equation relates the total (saturated) density to the dry density:

$$\rho^{\mathrm{TOT}} = \rho^{\mathrm{DRY}} + n\, s\, \rho_w \tag{3.4}$$

where n is the porosity, s is the saturation and ρ_w is the density of water. s equals 1.0 if the element is fully saturated. The assignment of mass density for a partially saturated material is illustrated in Example 3.29 for a grid configured for fluid flow, and in Example 3.30 for a grid not configured for fluid flow.

3.7.2 Intrinsic Deformability Properties

Isotropic Elastic Properties — All material models in *FLAC3D*, except for the transversely isotropic elastic and orthotropic elastic models, assume an isotropic material behavior in the elastic range described by two elastic constants: bulk modulus (K) and shear modulus (G). The elastic constants K and G, rather than Young's modulus E, and Poisson's ratio ν, are used in *FLAC3D* because it is believed that bulk and shear moduli correspond to more fundamental aspects of material behavior than do Young's modulus and Poisson's ratio. (See note 13 in Section 3.8 for justification of using (K, G) rather than (E, ν).)

The equations to convert from (E, ν) to (K, G) are

$$K = \frac{E}{3(1-2\nu)}$$
$$G = \frac{E}{2(1+\nu)} \tag{3.5}$$

Eq. (3.5) should not be used blindly when ν is near 0.5, because the computed value of K will be unrealistically high and convergence to the solution will be very slow. It is better to fix the value of K at its known physical value (estimated from an isotropic compaction test or from the p-wave speed), and then compute G from K and ν.

Some typical values for elastic constants are summarized in Table 3.5 for selected rocks, and in Table 3.6 for selected soils.

Table 3.5 Selected elastic constants (laboratory-scale) for rocks (adapted from Goodman 1980)

	Dry Density (kg/m^3)	E (GPa)	ν	K (GPa)	G (GPa)
sandstone		19.3	0.38	26.8	7.0
siltstone		26.3	0.22	15.6	10.8
limestone	2090	28.5	0.29	22.6	11.1
shale	2210 - 2570	11.1	0.29	8.8	4.3
marble	2700	55.8	0.25	37.2	22.3
granite		73.8	0.22	43.9	30.2

Table 3.6 Selected elastic constants (laboratory-scale) for soils (adapted from Das 1994)

	Dry Density (kg/m^3)	Elastic Modulus E (MPa)	Poisson's Ratio
loose uniform sand	1470	10 - 26	0.2 - 0.4
dense uniform sand	1840	34 - 69	0.3 - 0.45
loose, angular-grained, silty sand	1630		
dense, angular-grained, silty sand	1940		0.2 - 0.4
stiff clay	1730	6 - 14	0.2 - 0.5
soft clay	1170 - 1490	2 - 3	0.15 - 0.25
loess	1380		
soft organic clay	610 - 820		
glacial till	2150		

Anisotropic Elastic Properties — For the special case of elastic anisotropy, the transversely isotropic, elastic model requires five elastic constants: E_1, E_3, ν_{12}, ν_{13} and G_{13}; and the orthotropic elastic model requires nine elastic constants: E_1, E_2, E_3, ν_{12}, ν_{13} ν_{23}, G_{12}, G_{13} and G_{23}. These constants are defined in Section 2.4.2 in **Theory and Background**.

Transversely isotropic elastic behavior is commonly associated with uniformly jointed or bedded rock. Several investigators have developed expressions for the elastic constants in terms of intrinsic isotropic elastic properties and joint stiffness and spacing parameters. A short summary of typical values for anisotropic rocks is given in Table 3.7.

Table 3.7 Selected elastic constants (laboratory-scale) for transversely isotropic rocks (Batugin and Nirenburg, 1972)

Rock	E_x (GPa)	E_y (GPa)	ν_{yx}	ν_{zx}	G_{xy} (GPa)
siltstone	43.0	40.0	0.28	0.17	17.0
sandstone	15.7	9.6	0.28	0.21	5.2
limestone	39.8	36.0	0.18	0.25	14.5
gray granite	66.8	49.5	0.17	0.21	25.3
marble	68.6	50.2	0.06	0.22	26.6
sandy shale	10.7	5.2	0.20	0.41	1.2

Fluid Elastic Properties — Models created for groundwater analysis also require the bulk modulus of the water, K_f, if the calculation involves incompressible grains, or the Biot modulus, M, if the grains are compressible. The physical value of K_f is 2 GPa for pure water at room temperature. The value selected should depend on the purpose of the analysis. If only steady-state flow or an initial pore pressure distribution is required (see Section 1.7 in **Fluid-Mechanical Interaction**), then as low a value of K_f as possible should be used, without compromising the physics. This is because the fluid timestep will be small for high K_f; also, the mechanical convergence will be very slow for high K_f. The fluid timestep, Δt_f, used by *FLAC3D* is related to porosity, n, permeability, k' and K_f:

$$\Delta t_f \propto \frac{n}{K_f k'} \tag{3.6}$$

We can determine the effect of changing K_f by deriving the coefficient of consolidation, C_v, for the case of a deformable fluid. (The fluid is assumed incompressible in most textbook solutions.)

$$C_v = \frac{k'}{m_v + \frac{n}{K_f}} \tag{3.7}$$

where

$$m_v = \frac{1}{K + 4G/3}$$

and

$$k = k' \gamma_f$$

where k' = permeability used in *FLAC3D*;
k = hydraulic conductivity in velocity units (e.g., m/sec); and
γ_f = the unit weight of water.

Since the consolidation time constant is directly proportional to C_v, the expression allows us to see how much error is introduced by reducing K_f from its real value (of 2×10^9 Pa).

The fluid bulk modulus will also affect the rate of convergence for a model with no flow, but with mechanical generation of pore pressure (see Section 1.7.5 in **Fluid-Mechanical Interaction**). If K_f is given a value comparable with the mechanical moduli, pore pressures will be generated as a result of mechanical deformations. If K_f is much greater than K, then convergence will be slow, but often it is possible to reduce K_f without significantly affecting the behavior. In real soils, for

example, pore water will contain some dissolved air, which substantially reduces its apparent bulk modulus.

In the case of no flow, the undrained saturated bulk modulus is

$$K_u = K + \frac{K_f}{n} \tag{3.8}$$

and the undrained Poisson's ratio is

$$\nu_u = \frac{3K_u - 2G}{2(3K_u + G)} \tag{3.9}$$

These values should be compared to the drained constants K and ν to evaluate the effect on the rate of convergence. It is important to remember that *drained* properties are used for coupled, mechanical fluid-flow calculations in *FLAC3D*.

For the case of compressible grains, the influence of Biot modulus, M, on the rate of convergence for a model is similar to that of fluid bulk modulus.

3.7.3 Intrinsic Strength Properties

The basic criterion for material failure in *FLAC3D* is the Mohr-Coulomb relation, which is a linear failure surface corresponding to shear failure:

$$f_s = \sigma_1 - \sigma_3 N_\phi + 2c\sqrt{N_\phi} \tag{3.10}$$

where $N_\phi = (1 + \sin\phi)/(1 - \sin\phi)$;
σ_1 = major principal stress (compressive stress is negative);
σ_3 = minor principal stress;
ϕ = friction angle; and
c = cohesion.

Shear yield is detected if $f_s < 0$. The two strength constants, ϕ and c, are conventionally derived from laboratory triaxial tests.

The Mohr-Coulomb criterion loses its physical validity when the normal stress becomes tensile but, for simplicity, the surface is extended into the tensile region to the point at which σ_3 equals the uniaxial tensile strength, σ^t. The minor principal stress can never exceed the tensile strength — i.e.,

$$f_t = \sigma_3 - \sigma^t \tag{3.11}$$

Tensile yield is detected if $f_t > 0$. Tensile strengths from rock and concrete are usually derived for a Brazilian test. Note that the tensile strength cannot exceed the value of σ_3, corresponding to the apex limit for the Mohr-Coulomb relation. This maximum value is given by

$$\sigma^t_{max} = \frac{c}{\tan\phi} \tag{3.12}$$

Typical values of cohesion, friction angle and tensile strength for a representative set of rock specimens are listed in Table 3.8. Cohesion and friction angle values for soil specimens are given in Table 3.9. Strength is often described in terms of the unconfined compressive strength, q_u. The relation between q_u and cohesion, c, and friction angle, ϕ, is given by

$$q_u = 2\ c\ \tan(45 + \phi/2) \tag{3.13}$$

Table 3.8 Selected strength properties (laboratory-scale) for rocks (adapted from Goodman 1980)

	Friction Angle (degrees)	Cohesion (MPa)	Tensile Strength (MPa)
Berea sandstone	27.8	27.2	1.17
Repetto siltstone	32.1	34.7	—
Muddy shale	14.4	38.4	—
Sioux quartzite	48.0	70.6	—
Indiana limestone	42.0	6.72	1.58
Stone Mountain granite	51.0	55.1	—
Nevada Test Site basalt	31.0	66.2	13.1

Table 3.9 Selected strength properties (drained, laboratory-scale) for soils (Ortiz et al., 1986)

	Cohesion	Friction Angle	
		Peak	Residual
	(kPa)	(degrees)	(degrees)
gravel	—	34	32
sandy gravel with few fines	—	35	32
sandy gravel with silty or clayey fines	1.0	35	32
mixture of gravel and sand with fines	3.0	28	22
uniform sand — fine	—	32	30
uniform sand — coarse	—	34	30
well-graded sand	—	33	32
low-plasticity silt	2.0	28	25
medium- to high-plasticity silt	3.0	25	22
low-plasticity clay	6.0	24	20
medium-plasticity clay	8.0	20	10
high-plasticity clay	10.0	17	6
organic silt or clay	7.0	20	15

Drucker-Prager strength parameters can be estimated from cohesion and friction angle properties. For example, assuming that the Drucker-Prager failure envelope circumscribes the Mohr-Coulomb envelope, the Drucker-Prager parameters q_ϕ and k_ϕ are related to ϕ and c by

$$q_\phi = \frac{6}{\sqrt{3}(3 - \sin\phi)} \sin\phi \tag{3.14}$$

$$k_\phi = \frac{6}{\sqrt{3}(3 - \sin\phi)} c \cos\phi \tag{3.15}$$

For further explanation on the relations between parameters, see Section 2.5.1.6 in **Theory and Background**.

The ubiquitous-joint model also requires strength properties for the planes of weakness. Joint properties are conventionally derived from laboratory testing (e.g., triaxial and direct shear tests).

These tests can produce physical properties for joint friction angle, cohesion, dilation angle and tensile strength.

Published strength properties for joints can be found, for example, in Jaeger and Cook (1969), Kulhawy (1975) and Barton (1976). Friction angles can vary from less than 10° for smooth joints in weak rock, such as tuff, to over 50° for rough joints in hard rock, such as granite. Joint cohesion can range from zero cohesion to values approaching the compressive strength of the surrounding rock.

It is important to recognize that joint properties measured in the laboratory typically are not representative of those for real joints in the field. Scale dependence of joint properties is a major question in rock mechanics. Often, comparison to similar joint properties derived from field tests is the only way to guide the choice of appropriate parameters. However, field test observations are extremely limited. Some results are reported by Kulhawy (1975).

3.7.4 Post-Failure Properties

In many instances, particularly in mining engineering, the response of a material after failure has initiated is an important factor in the engineering design. Consequently, the post-failure behavior must be simulated in the material model. In *FLAC3D*, this is accomplished with properties that define four types of post failure response:

(1) shear dilatancy;

(2) shear hardening/softening;

(3) volumetric hardening/softening; and

(4) tensile softening.

These properties are only activated after failure is initiated, as defined by the Mohr-Coulomb relation or the tensile-failure criterion. Shear dilatancy is simulated with the Mohr-Coulomb, ubiquitous-joint and strain-softening Mohr-Coulomb and ubiquitous-joint models. Shear hardening/softening is simulated with the strain-softening Mohr-Coulomb and ubiquitous-joint models, and volumetric hardening/softening is simulated with the modified Cam-clay model. Tensile softening is simulated with the strain-softening Mohr-Coulomb and ubiquitous-joint models.

3.7.4.1 Shear Dilatancy

Shear dilatancy, or dilatancy, is the change in volume that occurs with shear distortion of a material. Dilatancy is characterized by a dilation angle, ψ, which is related to the ratio of plastic volume change to plastic shear strain. This angle can be specified in the Mohr-Coulomb ubiquitous-joint and strain-hardening/softening models in *FLAC3D*. Dilation angle is typically determined from triaxial tests or shear-box tests. For example, the idealized relation for dilatancy, based upon the Mohr-Coulomb failure surface, is depicted for a triaxial test in Figure 3.39. The dilation angle is found from the plot of volumetric strain versus axial strain. Note that the initial slope for this plot

corresponds to the elastic regime, while the slope used to measure the dilation angle corresponds to the plastic regime.

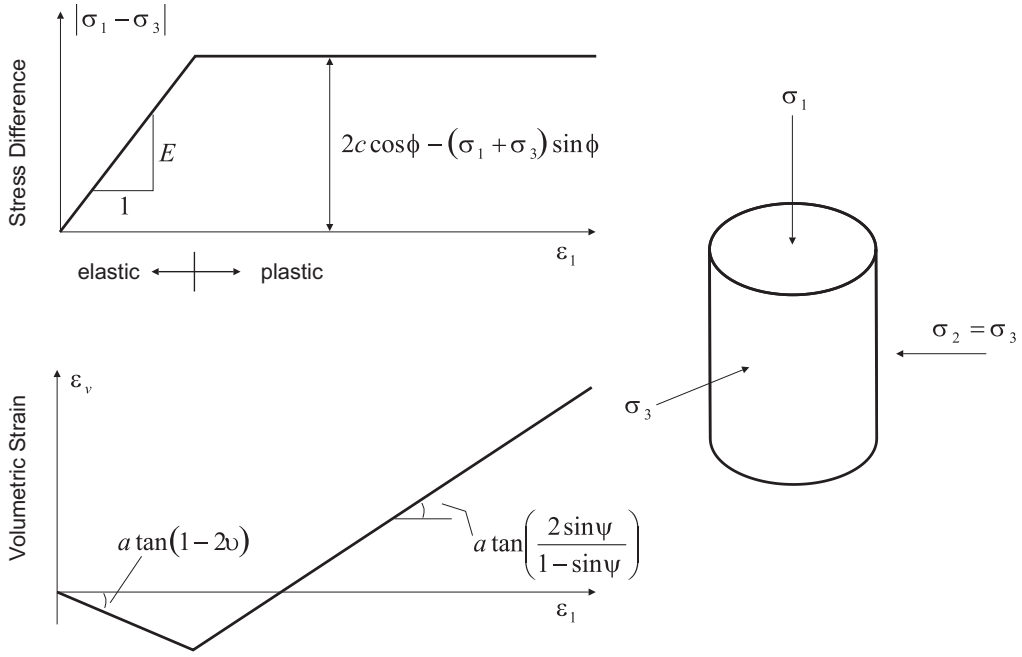


Figure 3.39 Idealized relation for dilation angle, ψ, from triaxial test results (Vermeer and de Borst, 1984)

For soils, rocks and concrete, the dilation angle is generally significantly smaller than the friction angle of the material. Vermeer and de Borst (1984) report the following typical values for ψ.

Table 3.10 Typical values for dilation angle (Vermeer and de Borst, 1984)

dense sand	15°
loose sand	$< 10°$
normally consolidated clay	0°
granulated and intact marble	$12° - 20°$
concrete	12°

Vermeer and de Borst observe that values for the dilation angle are approximately between 0° and 20°, whether the material is soil, rock or concrete. The default value for dilation angle is zero for all the constitutive models in *FLAC3D*.

Dilation angle can also be prescribed for the joints in the ubiquitous-joint model. This property is typically determined from direct shear tests, and common values can be found in the references discussed in Section 3.7.3.

3.7.4.2 Shear Hardening/Softening

The initiation of material hardening or softening is a gradual process once plastic yield begins. At failure, deformation becomes more and more inelastic as a result of micro-cracking in concrete and rock, and particle sliding in soil. This also leads to degradation of strength in these materials and the initiation of shear bands. These phenomena, related to localization, are discussed further in Section 3.10.

In *FLAC3D*, shear hardening and softening are simulated by making Mohr-Coulomb properties (cohesion and friction, along with dilation) functions of plastic strain (see Section 2.5.4 in **Theory and Background**). These functions are accessed from the strain-softening model, and can be specified either by using the **TABLE** command or via a *FISH* function.

Hardening and softening parameters must be calibrated for each specific analysis, and the values are generally back-calculated from results of laboratory triaxial tests. This is usually an iterative process. Investigators have developed expressions for hardening and softening. For example, Vermeer and de Borst (1984) propose the frictional hardening relation

$$\sin\phi_m = 2\frac{\sqrt{e_p\, e_f}}{e_p + e_f}\,\sin\phi \qquad \text{for } e_p \le e_f \tag{3.16}$$

$$\sin\phi_m = \sin\phi \qquad \text{for } e_p > e_f$$

where ϕ = ultimate friction angle;
ϕ_m = mobilized friction angle;
e_p = plastic strain; and
e_f = parameter.

Cundall (1989) incorporates this relation into two-dimensional *FLAC* to study localization in a frictional material. This is accomplished by approximating the function with a table relating friction angle to plastic strain (i.e., **TABLE** accessed from **PROP ftable**). This approach is demonstrated for the compression test described previously in Example 3.37.

Numerical testing conditions can influence the model response for shear hardening/softening behavior. The rate of loading can introduce inertial effects. The results are also grid-dependent. Thus, it is important to evaluate the model behavior for differing zone size and grid orientation whenever performing an analysis involving shear hardening or softening.

The following example, Example 3.38, illustrates the application of a shear-softening material in a uniaxial compression test. A low velocity is applied to the top and bottom of the specimen, and the grid contains fine zoning. The softening response is shown in the stress-displacement plot in

Figure 3.40. The development of localization and shear bands can be observed in Figures 3.41 and 3.42. The plastic region is identified as hourglass-shaped with spiral structures radiating from the hourglass cones.

Example 3.38 Uniaxial test of a shear-softening material

```
; Uniaxial test of strain-softening material
title
  Uniaxial test of strain-softening material
gen zone cyl p0 0 0 0 p1 1 0 0   p2 0 4 0  p3 0 0 1   size 12 30 12
gen zone reflect norm 1,0,0
gen zone reflect norm 0,0,1
model ss
pro den 2500 bulk 2e8 she 1e8 co 2e6 fric 45 ten 1e6 dil 10
pro ftab 1 ctab 2 dtab 3
table 1 0 45 .05 42 .1 40 1 40
table 2 0 2e6 .05 1e6 .1 5e5 1 5e5
table 3 0 10 .05 3 .1 0
fix x y z range y -.1 .1
fix x y z range y 3.9 4.1
ini yvel  2.5e-5 range y -.1 .1
ini yvel -2.5e-5 range y 3.9 4.1
def ax_str
  str = 0
  pnt = gp_head
  loop while pnt # null
    if gp_ypos(pnt) < 0.1 then
      str = str + gp_yfunbal(pnt)
    endif
    pnt = gp_next(pnt)
  endloop
  ax_str = str / pi   ;  cylinder radius = 1
end
hist n 1
hist gp ydisp 0,0,0
hist ax_str
hist gp xdisp 1,1,0
plot hist -2 vs 1 ;axial stress vs axial disp.
step 5000
save beforeplzones.sav
; Plot of plastic region as zones with strain > 0.2
def ShowPlasticZones
  zp = zone_head
  loop while zp # null
    if z_prop(zp,'es_plastic') > 0.2
      z_group(zp) = 'yield'
```

```
    else
      z_group(zp) = 'other'
    endif
    zp = z_next(zp)
  endLoop
end
ShowPlasticZones
plo crea qqq
plo add surf red range group yield
plo add axes green
plo set rot 123 313 3
plo set mag 1.5
ret
```

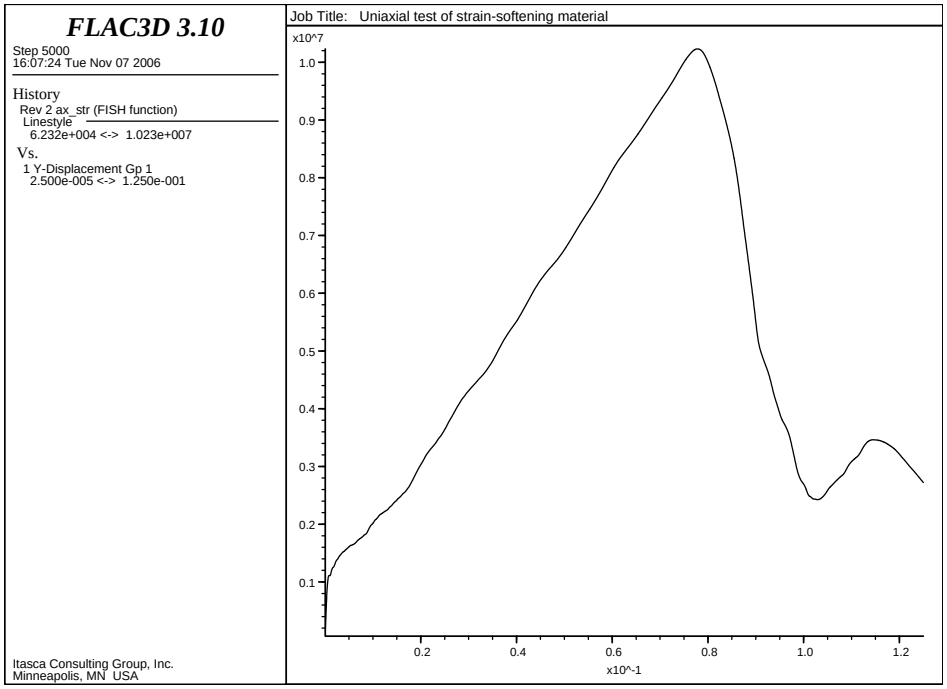


Figure 3.40 Stress-displacement plot for uniaxial test of shear-softening material

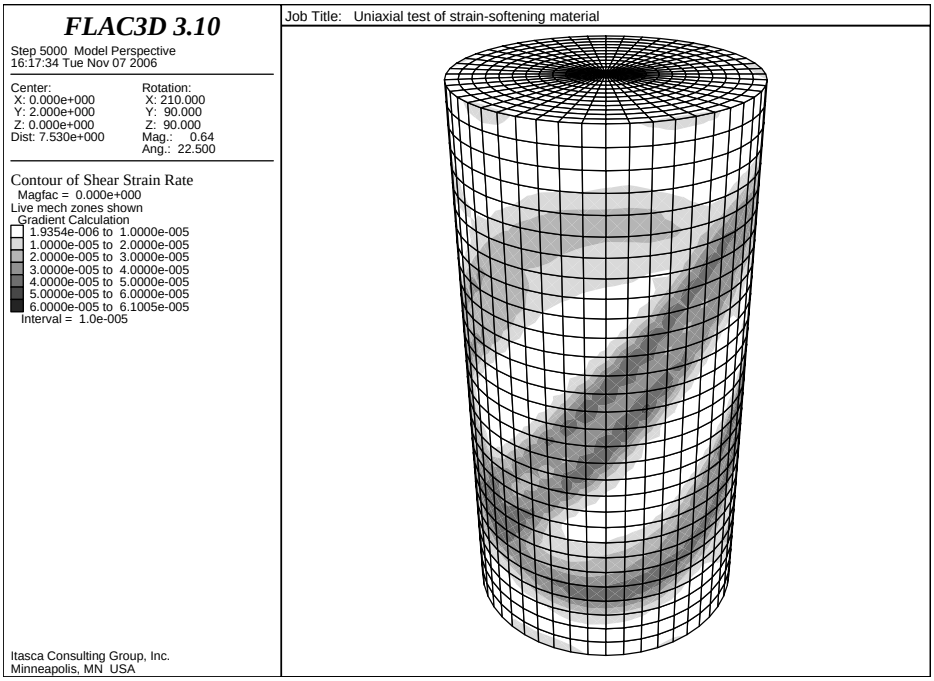


Figure 3.41 Contours of shear-strain rate indicating shear bands in strain-softening material

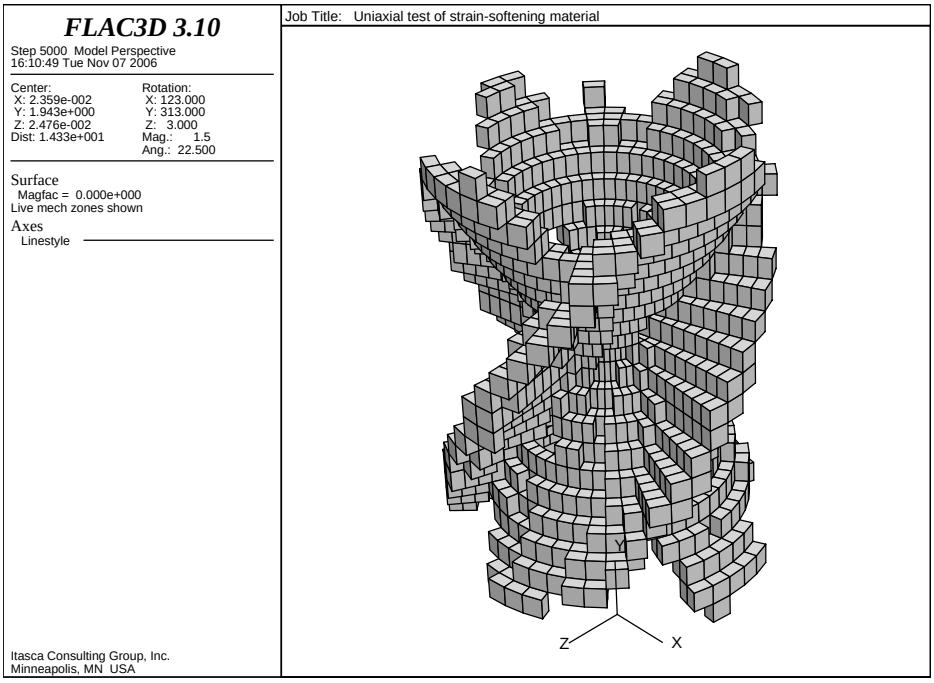


Figure 3.42 Yielded region identified as zones with plastic shear strain > 0.2

3.7.4.3 Volumetric Hardening/Softening

Volumetric hardening corresponds to irreversible compaction; increasing the isotropic pressure can cause permanent volume decrease. This behavior is common in materials such as lightly cemented sands and gravels and over-consolidated clays.

Volumetric hardening/softening may be simulated in the double-yield model and the Cam-clay model. The double-yield model assumes that the hardening depends on plastic volume strain, while the Cam-clay model treats volumetric hardening as a function of both shear and volume strain.

The double-yield model takes its hardening rule from either a **TABLE** command or a *FISH* function. Section 2.3 in **Theory and Background** describes a recommended test procedure to develop these parameters from triaxial tests performed at constant mean stress, and for loading in which axial stress and confining pressure are kept equal. Typically, though, this data is not available. An alternative is to back-calculate the parameters from a uniaxial strain (or oedometer) test.

The modified Cam-clay model is defined by initial elastic moduli plus parameters that prescribe the nonlinear elasticity and hardening/softening behavior. The properties are:

κ	slope of the elastic swelling line
λ	slope of the normal consolidation line
M	material constant
p_c	preconsolidation pressure
p_1	reference pressure
v_0	initial specific volume
v_λ	specific volume at reference pressure on normal consolidation line

The definition of these properties can be found in soil mechanics texts (e.g., Wood 1990). The procedures for determining these properties from laboratory tests are described in Section 2.5.7.8 in **Theory and Background**. It is recommended that single-zone tests be conducted with *FLAC3D* to exercise the modified Cam-clay model, and verify whether the choice of model properties is adequate. An example test is provided in Section 2.5.7.9 in **Theory and Background**.

3.7.4.4 Tensile Softening

At the initiation of tensile failure, the tensile strength of a material will generally drop to zero. The rate at which the tensile strength drops, or tensile softening occurs, is controlled by the plastic tensile strain in *FLAC3D*. This function is accessed from the strain-softening model, and can be specified either by using the **TABLE** command or via a *FISH* function.

A simple tension test illustrates the tensile-softening behavior. The model is the same as that used previously in Examples 3.36 and 3.37. The ends of the cylindrical sample are now pulled apart at a constant velocity.

Example 3.39 Tension test on tensile-softening material

```
gen zone cyl p0 0 0 0 p1 1 0 0   p2 0 2 0  p3 0 0 1   size 4 5 4
gen zone reflect norm 1,0,0
gen zone reflect norm 0,0,1
model ss
prop bulk 1.19e10 shear 1.1e10
prop coh 2.72e5 fric 44 ten 2e5
prop ttab 1
table 1 0,2e5 2e-5,0
fix x y z range y -.1 .1
fix x y z range y 1.9 2.1
ini yvel -1e-8 range y -.1 .1
ini yvel  1e-8 range y 1.9 2.1
def ax_str
  str = 0
  pnt = gp_head
  loop while pnt # null
    if gp_ypos(pnt) < 0.1 then
      str = str + gp_yfunbal(pnt)
    endif
    pnt = gp_next(pnt)
  endloop
  ax_str = str / pi   ;  cylinder radius = 1
end
hist n 1
hist gp ydisp 0,0,0
hist ax_str
hist gp xdisp 1,1,0
step 1500
plot hist 2 vs -1 ;axial stress vs axial disp.
pause
plot hist 3 vs -1 ; circumferential disp. vs axial disp.
ret
```

The plot of axial stress versus axial displacement (Figure 3.43) shows that the average axial stress through the center of the model drops to zero. (The stress will remain constant in the non-softening Mohr-Coulomb model.) The model decreases in diameter until tensile failure initiates, then expands as tensile softening occurs (see Figure 3.44). The brittleness of the tensile softening is controlled by the plastic tensile-strain function. As with the shear hardening/softening model, the tensile-softening model must be calibrated for each specific problem and grid size.

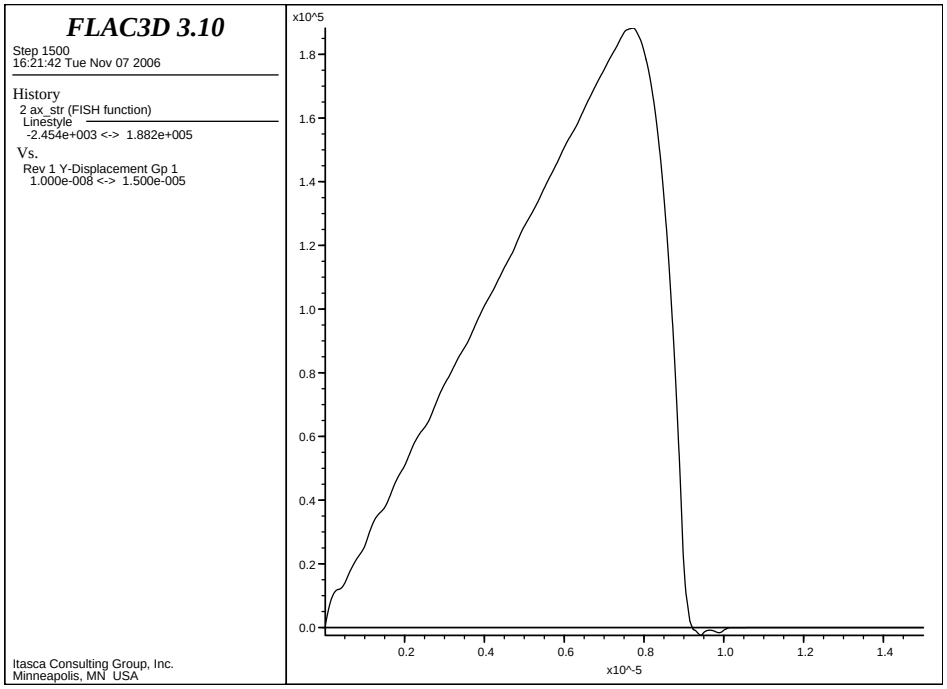


Figure 3.43 Axial stress versus axial displacement, for tensile test of tension-softening material

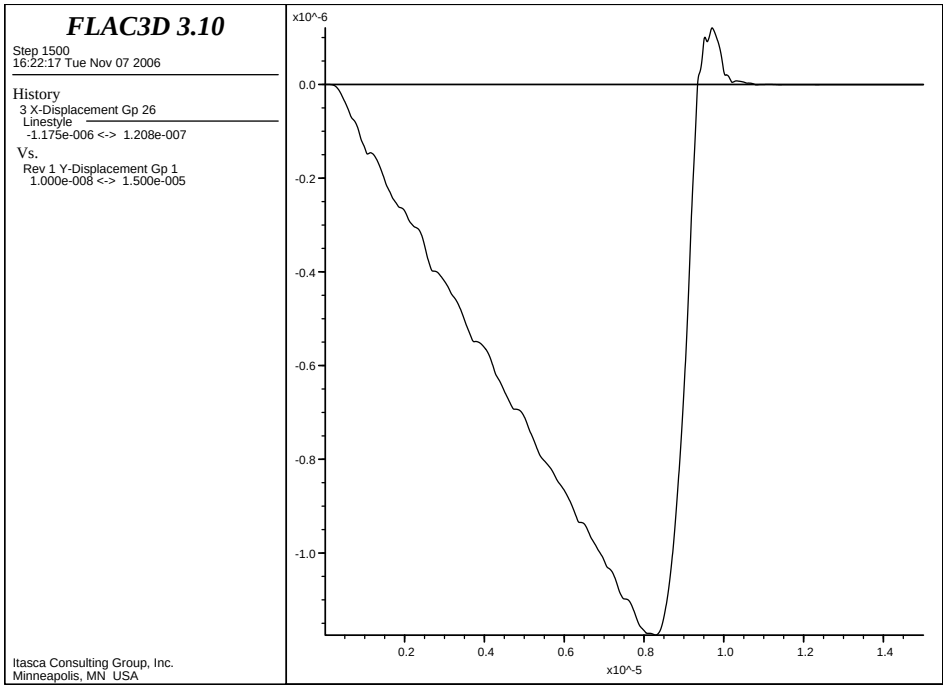


Figure 3.44 Circumferential displacement versus axial displacement, for tensile test of tension-softening material

3.7.4.5 Volume-Pressure Properties

The double-yield and modified Cam-clay models require material properties that relate pressure to volumetric change. For both models, the preconsolidation pressure is the maximum past consolidation pressure. In the double-yield model, the relation between pressure and volumetric change is expressed by a table relating the cap pressure to plastic volume strain. In the Cam-clay model, the pressure-volume relation is expressed by the slopes of the initial compression line and the reloading-unloading line for the plot of volumetric strain versus natural log of pressure. The recommended procedure for selecting volumetric properties for the double-yield model is given in Section 2.5.6.6 in **Theory and Background**, and in Section 2.5.7.8 in **Theory and Background**for the Cam-clay model.

3.7.5 Extrapolation to Field-Scale Properties

The material properties used in the *FLAC3D* model should correspond as closely as possible to the actual values of the physical problem. Particularly in rock, the laboratory-measured properties generally should not be used directly in a *FLAC3D* model for a full-scale problem. These properties should be scaled to account for the presence of discontinuities and heterogeneities present in a rock mass.

Several empirical approaches have been proposed to derive field-scale properties. Some of the more commonly accepted methods are discussed.

Deformability of a rock mass is generally defined by a modulus of deformation, E_m. If the rock mass contains a set of relatively parallel, continuous joints with uniform spacing, the value for E_m can be estimated by treating the rock mass as an equivalent transversely isotropic continuum. The following relation can then be used to estimate E_m in the direction normal to the joint set.

$$\frac{1}{E_m} = \frac{1}{E_r} + \frac{1}{k_n s} \tag{3.17}$$

where E_m = rock mass Young's modulus;

E_r = intact rock Young's modulus;

k_n = joint normal stiffness; and

s = joint spacing.

A similar expression can be derived for shear modulus:

$$\frac{1}{G_m} = \frac{1}{G_r} + \frac{1}{k_s s} \tag{3.18}$$

where G = rock mass shear modulus;

G_r = intact rock shear modulus; and

k_s = joint shear stiffness.

The equivalent continuum assumption, when extended to three orthogonal joint sets, produces the following relations:

$$E_i = \left(\frac{1}{E_r} + \frac{1}{s_i \, k_{ni}} \right)^{-1} \qquad (i = 1,\ 2,\ 3) \tag{3.19}$$

$$G_{ij} = \left(\frac{1}{G_r} + \frac{1}{s_i \, k_{si}} + \frac{1}{s_j \, k_{sj}} \right)^{-1} \qquad (i\ ,\ j = 1,\ 2,\ 3) \tag{3.20}$$

Several expressions have been derived for two- and three-dimensional characterizations and multiple joint sets. References for these derivations can be found in Singh (1973), Gerrard (1982a and b) and Fossum (1985).

In practice, the rock mass structure is often much too irregular, or sufficient data is not available, to use the preceding approach. It is common to determine E_m from a force-displacement curve obtained from an in-situ compression test. Such tests include plate-bearing tests, flatjack tests and dilatometer tests.

Bieniawski (1978) developed an empirical relation for E_m based upon field test results at sites throughout the world. The relation is based upon rock mass rating (RMR). For rocks with a rating higher than 55, the test data can be approximately fit to

$$E_m \ = \ 2(\text{RMR}) - 100 \tag{3.21}$$

The units of E_m are GPa.

For values of E_m between 1 and 10 GPa, Serafim and Pereira (1983) found a better fit, given by

$$E_m \ = \ 10^{\frac{\text{RMR}-10}{40}} \tag{3.22}$$

References by Goodman (1980) and Brady and Brown (1985) provide additional discussion on these methods.

The most commonly accepted approach to estimate rock mass strength is that proposed by Hoek and Brown (1980). The generalized Hoek-Brown failure criterion for jointed rock masses is defined by (Hoek and Brown, 1997):

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b\frac{\sigma_3'}{\sigma_{ci}} + s\right)^a \tag{3.23}$$

where σ_1' and σ_3' are the maximum and minimum effective stress at failure, respectively (compressive stresses are positive), m_b is the value of the Hoek-Brown constant m for the rock mass, s and a are constants which depend upon the characteristics of the rock mass, and σ_{ci} is the uniaxial compressive strength of the intact rock pieces.

The tensile strength of the rock mass is estimated by Hoek and Brown (1997) to be

$$\sigma_{tm} = \frac{\sigma_{ci}}{2}\left(m_b - \sqrt{m_b^2 + 4s}\right) \tag{3.24}$$

Three properties are required in order to use the Hoek-Brown criteria (Eqs. (3.23) and 3.24):

1. the uniaxial compressive strength, σ_{ci}, of the intact rock pieces;
2. the Hoek-Brown constant, m_i, for the intact rock pieces; and
3. the value of the Geological Strength Index, GSI, for the rock mass. This provides an estimate for the Hoek-Brown constants, s, m_b and a.

For the intact rock pieces that compose the rock mass, Eq. (3.23) becomes

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_i\frac{\sigma_3'}{\sigma_{ci}} + 1\right)^{0.5} \tag{3.25}$$

The values for σ_{ci} and the constant m_i should be determined by statistical analysis of the results of a set of triaxial tests. The recommended procedure is given by Hoek and Brown (1997). This paper also presents estimates of σ_{ci} and m for preliminary design calculations when laboratory test results may not be available.

The Geological Strength Index (GSI) provides a system for estimating the reduction in rock mass strength. Two tables from Hoek and Brown (1997) can be used to estimate GSI (see Tables 3.11 and 3.12). Hoek and Brown (1997) then give the following relation between GSI and m_b, s and a.

$$m_b = m_i\, exp\left(\frac{GSI - 100}{28}\right) \tag{3.26}$$

For GSI > 25,

$$s = exp\left(\frac{GSI - 100}{9}\right)$$

and

$$a = 0.5 \tag{3.27}$$

For GSI < 25,

$$s = 0$$

and

$$a = 0.65 - \frac{GSI}{200} \tag{3.28}$$

Hoek and Brown (1997) also provide tables for these equations to facilitate their use.

It is possible to estimate Mohr-Coulomb friction angle and cohesion from the Hoek-Brown criterion (see, for example, Hoek 1990). For a given value of σ_3, a tangent to Eq. (3.23) will represent an equivalent Mohr-Coulomb yield criterion in the form

$$\sigma_1' = N_\phi \sigma_3' + \sigma_c^M \tag{3.29}$$

where $N_\phi = \frac{1+\sin\phi}{1-\sin\phi} = \tan^2(\frac{\phi}{2} + 45°)$.

By substitution, σ_c^M is

$$\sigma_c^M = \sigma_1 - \sigma_3 N_\phi = \sigma_3 + \sqrt{\sigma_3 \sigma_c m + \sigma_c^2 s} - \sigma_3 N_\phi = \sigma_3(1 - N_\phi) + \sqrt{\sigma_3 \sigma_c m + \sigma_c^2 s}$$

σ_c^M is the apparent uniaxial compressive strength of the rock mass for that value of σ_3.

The tangent to Eq. (3.23) is defined by

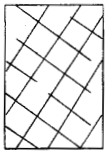
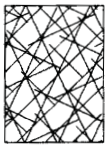
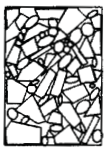
$$N_\phi(\sigma_3) = \frac{\partial \sigma_1}{\partial \sigma_3} = 1 + \frac{\sigma_c m}{2\sqrt{\sigma_3 \cdot \sigma_c m + s\sigma_c^2}} \tag{3.30}$$

The cohesion (c) and friction angle (ϕ) can then be obtained from N_ϕ and σ_c^M:

$$\phi = 2\tan^{-1}\sqrt{N_\phi} - 90^\circ \tag{3.31}$$

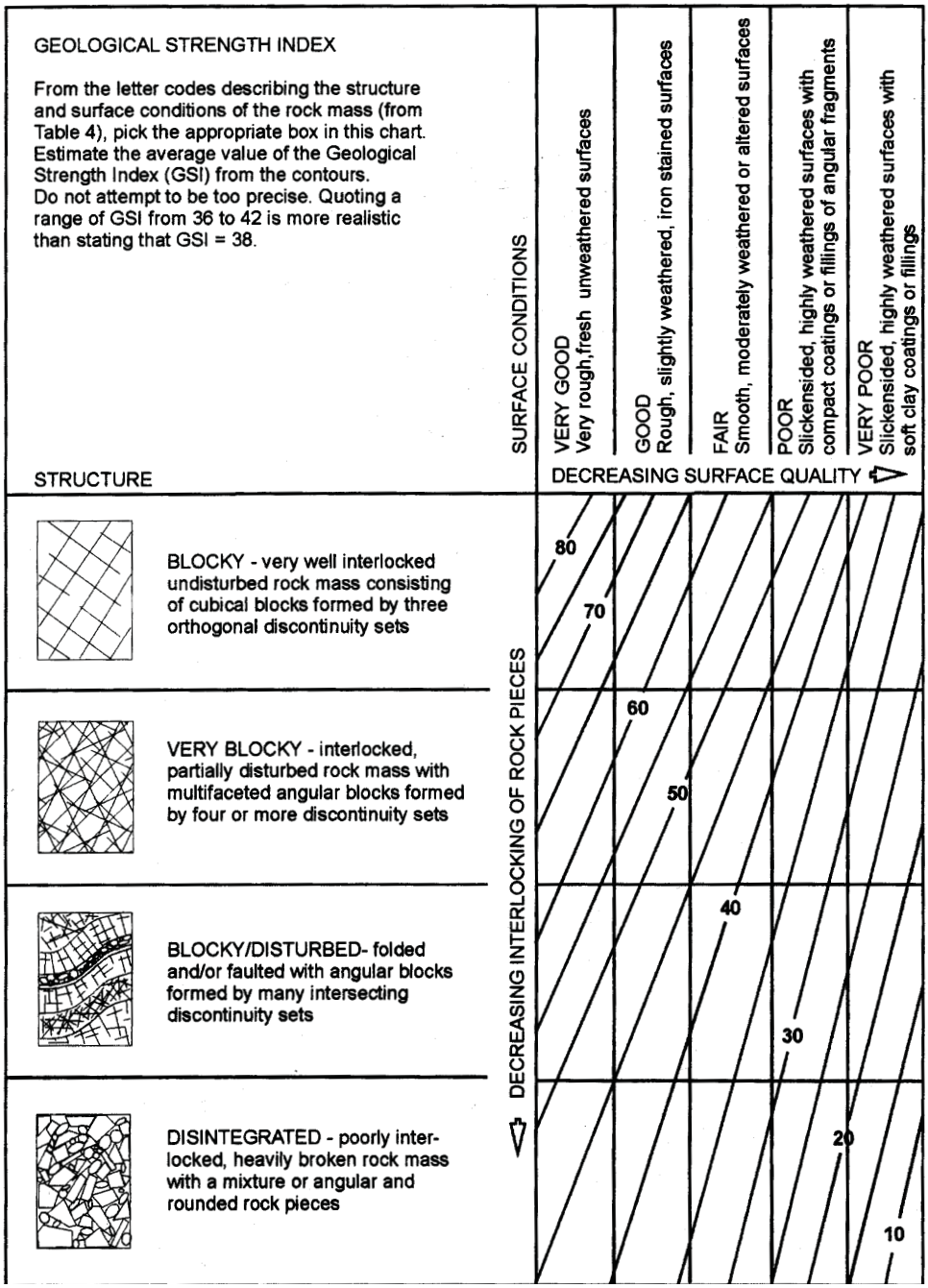
$$c = \frac{\sigma_c^M}{2\sqrt{N_\phi}} \tag{3.32}$$

Table 3.11 Characterization of rock masses on the basis of interlocking and joint alteration — from Hoek and Brown (1997)

ROCK MASS CHARACTERISTICS FOR STRENGTH ESTIMATES Based upon the appearance of the rock, choose the category that you think gives the best description of the 'average' undisturbed in situ conditions. Note that exposed rock faces that have been created by blasting may give a misleading impression of the quality of the underlying rock. Some adjustment for blast damage may be necessary and examination of diamond drill core or of faces created by pre-split or smooth blasting may be helpful in making these adjustments. It is also important to recognize that the Hoek-Brown criterion should only be applied to rock masses where the size of individual blocks is small compared with the size of the excavation under consideration.		SURFACE CONDITIONS					
		VERY GOOD Very rough, fresh unweathered surfaces	GOOD Rough, slightly weathered, iron stained surfaces	FAIR Smooth, moderately weathered or altered surfaces	POOR Slickensided, highly weathered surfaces with compact coatings or fillings of angular fragments	VERY POOR Slickensided, highly weathered surfaces with soft clay coatings or fillings
STRUCTURE		DECREASING SURFACE QUALITY ⇨				
	BLOCKY - very well interlocked undisturbed rock mass consisting of cubical blocks formed by three orthogonal discontinuity sets	B/VG	B/G	B/F	B/P	B/VP
	VERY BLOCKY - interlocked, partially disturbed rock mass with multifaceted angular blocks formed by four or more discontinuity sets	VB/VG	VB/G	VB/F	VB/P	VB/VP
	BLOCKY/DISTURBED- folded and/or faulted with angular blocks formed by many intersecting discontinuity sets	BD/VG	BD/G	BD/F	BD/P	BD/VP
	DISINTEGRATED - poorly interlocked, heavily broken rock mass with a mixture or angular and rounded rock pieces	D/VG	D/G	D/F	D/P	D/VP

DECREASING INTERLOCKING OF ROCK PIECES ⇩

Table 3.12 Estimate of Geological Strength Index (GSI) based on geological descriptions — from Hoek and Brown (1997)



3.7.6 Spatial Variation and Randomness of Property Distribution

Material properties can be specified to vary as a function of grid position. In fact, a different property can be assigned to every zone in a *FLAC3D* model, regardless of model size. The keyword **gradient** is available with the **PROPERTY** command to prescribe a linear variation of properties with position. For example, the following command provides a linear variation of cohesion in the x-direction.

```
prop coh 1e6 grad -1e5,0,0
```

An initial profile of a property can also be assigned via *FISH*.

With *FLAC3D*, it is also possible to study the influence of nonhomogeneity in a material. Any type of statistical property distribution can be introduced, since each element may have a unique property value. Two optional keywords are available with the **PROPERTY** command to apply a random distribution of a selected property. The keyword **gauss_dev** assumes a normal (Gaussian) distribution for the property, with a mean value, ***v***, and standard deviation, ***s***. The keyword **uniform_dev** assumes a uniform distribution with mean value, ***v***, and standard deviation, ***s***. Care should be taken to ensure that properties do not acquire negative values if ***s*** is large. As an example, the following command would give a mean friction angle of 40° with a standard deviation of ±5%.

```
prop friction 40 gauss_dev 2
```

3.8 Tips and Advice

When problem solving with *FLAC3D*, it is important to optimize the model for the most efficient analysis. This section provides several suggestions on ways to improve a model run. Also, some common pitfalls which should be avoided when preparing a *FLAC3D* calculation are listed.

1. **Check Model Runtime**

   The solution time for a *FLAC3D* run is proportional to $N^{4/3}$, where N is the number of zones. This formula holds for elastic problems solved for the equilibrium condition. The runtime will vary somewhat, but not substantially, for plasticity problems, and it may be much larger if continuing plastic flow occurs. It is important to check the speed of calculation on your computer for a specific model. An easy way to do this is to run the benchmark test described in Section 5.1. Then use this speed to estimate the speed of calculation for the specific model, based on interpolation from the number of zones.

2. **Effects on Runtime**

   FLAC3D will take longer to converge if:

   (a) there are large contrasts in stiffness in zone materials or between zones, structural members and interfaces; or

   (b) there are large contrasts in zone sizes.

   The code becomes less efficient as these contrasts become greater. The effect of a contrast in stiffness should be investigated before performing a detailed analysis. For example, a very stiff loading plate can be replaced by a series of fixed gridpoints that are given a constant velocity. (Remember that the **FIX** command fixes velocities, *not* displacements.) The inclusion of groundwater will act to increase the apparent mechanical bulk modulus — see Section 1 in **Fluid-Mechanical Interaction**.

3. **Considerations for Zoning Density**

   FLAC3D uses constant-strain elements. If the stress/strain gradient is high, you will need many zones to represent the varying distribution. Run the same problem with different zoning densities to check the effect. Constant-strain zones are used in *FLAC3D* because a better accuracy is achieved when modeling plastic flow with many low-order elements than with a few high-order elements. (See Section 1.2 in **Theory and Background** and the plasticity verification problems in the **Verifications volume**.)

   Try to keep the zoning as uniform as possible, particularly in the region of interest. Avoid long, thin zones with aspect ratios greater than 5:1, and avoid jumps in zone size (i.e., use smoothly graded grids). Make use of the **ratio** keyword with the **GENERATE** command to grade zone sizes smoothly from regions with fine zoning to regions with coarse zoning.

4. Automatic Detection of an Equilibrium State

By default, a mechanical force equilibrium is detected automatically when the **SOLVE** command is used. The equilibrium state is considered to be achieved when the ratio of the *maximum* unbalanced mechanical force magnitude for all the gridpoints in the model divided by the *average* applied mechanical force magnitude for all the gridpoints in the model drops below the value of 1×10^{-5}. Note that the applied force at a gridpoint results from both internal forces (e.g., due to gravitational loading) and external forces (e.g., due to an applied-stress boundary condition). This definition for unbalanced-to-applied force ratio provides an accurate limit for static equilibrium in most cases and, because the ratio is non-dimensional, the limiting value applies for models created with different systems of units.

Other definitions for the ratio are also provided; these can be applied with the **SET ratio** command. If the default ratio limit does not appear to provide a sufficiently accurate limit for static equilibrium, then the alternative ratio limits should be investigated.

The default ratio limit is also used to detect the steady-state solution for thermal and fluid-flow calculations. For thermal calculations, unbalanced and applied heat flux magnitudes, rather than unbalanced and applied mechanical forces, are evaluated. For fluid-flow calculations, the unbalanced and applied fluid flow magnitudes are evaluated.

5. Considerations for Selecting Damping

The default mechanical damping for static analysis is *local damping* (see Section 1.1.2.7 in **Theory and Background**), which is most efficient for removing kinetic energy when the velocity components of most gridpoints pass through zero periodically. This is because the mass-adjustment process depends on velocity sign changes. Local damping is a very efficient algorithm for achieving a static-equilibrium solution without introducing erroneous damping forces (see Cundall 1987).

If the problem involves significant regions of the grid having nonzero components of velocity at the final state of solution, then the default damping may be insufficient to reach an equilibrium state. A different form of damping, known as *combined damping*, provides better convergence to the steady-state than local damping for situations in which significant rigid-body motion of the grid is occurring. This may occur, for example, in a creep simulation or in the calculation of the ultimate capacity of an axially loaded pile. Use the command **SET mechanical damp combined** to invoke combined damping. Combined damping is not as efficient at removing kinetic energy, so care should be taken to minimize dynamic excitation of the system (see Example 3.14). It is possible to switch back to the default damping with the command **SET mechanical damp local**.

6. Check Model Response

FLAC3D shows how a similar physical system would behave. Make frequent simple tests to verify that you are actually doing what you think you are doing. For example, if a loading condition and geometry are symmetrical, make sure that the response is symmetrical. After making a change in the model, execute a few calculation steps (say, 5 or 10) to verify that the initial response is of the correct sign and in the correct location. Do back-of-the-envelope estimates of the expected order of magnitude of stress or displacements, and compare to the *FLAC3D* output.

If you apply a violent shock to the model, you will get a violent response. If you do nonphysically reasonable things to the model, you must expect strange results. If you get unexpected results at a given stage of an analysis, review the steps you followed up to that stage.

Critically examine the output before proceeding with the model simulation. If, for example, everything appears reasonable except for large velocities in one corner zone, do not go on until you understand the reason. In this case, you may not have fixed a boundary gridpoint properly.

7. Initializing Variables

It is common practice to initialize the displacements of the gridpoints between runs to aid in the interpretation of a simulation in which many different excavation stages are performed. This can be done because the code does not require the displacements in the calculation sequence — they are determined from the velocities of the gridpoints as a convenience to the user.

Initialization of the velocities, however, is a different matter. If the velocities of gridpoints are fixed at a constant value, they will continue to have this value until set otherwise. Therefore, do not initialize the velocities of the grid to zero simply to clear them — this will affect the simulation results. However, sometimes it is useful to set velocities to zero (for example, to remove all kinetic energy).

8. Minimizing Transient Effects on Static Analysis

For static analyses, transient waves can cause plastic models to follow poorly defined stress paths (unrealistic failure could be triggered). For this reason, it is often important to approach the solution (at each stage) gradually (i.e., make the solution more "static" by minimizing the effects of transient waves when problem conditions are changed suddenly.*

The recommended method to make a *FLAC3D* solution more static is to use a *FISH* function or table history to gradually reduce loads when material is removed (e.g., see examples in Section 3.3.1.2). When a sudden change is made (e.g., by nulling zones to simulate excavation), it is *not* advisable to set the strength properties to high values and step to equilibrium (and then reset the properties to realistic values). This latter method does not clearly define a direction in stress space to bring a zone within the yield surface (the entire process is non-physical).

9. Changing Material Models

FLAC3D does not have a limit on the number of different material models you may use during a simulation. The code has been dimensioned to allow the user to have a different material for each zone (if desired) for the maximum size grid for your version of *FLAC3D*.

10. Running Problems with In-situ Field Stresses and Gravity

There are a number of problems in which in-situ field stresses and gravity must be applied to the model. An example of such a problem is deep cut-and-fill mining, in which the rock mass is subjected to high in-situ stress fields (i.e., gravity stresses for the limited mesh size can be ignored), but in which the emplaced backfill pillars develop gravitational stresses that could collapse under the load. The important thing to note in these simulations (as in any simulation in which gravity is applied) is that at least three points on the grid must be fixed in space — otherwise, the entire grid will translate due to gravity. If you ever notice the entire grid translating in the direction of the gravitational acceleration vector, you have probably forgotten to fix the grid in space (e.g., see Example 3.18).

---

* This is not always the case. "Path-dependency" of a changing nonlinear system can be important. See the discussion in Section 3.10.3.

11. Determining Collapse Loads

In order to determine a collapse load, it often is better to use "strain-controlled" rather than "stress-controlled" boundary conditions — i.e., apply a constant velocity and measure the reaction forces, rather than apply forces and measure displacements. A system that collapses becomes difficult to control as the applied load approaches the collapse load. This is true of a real system as well as a model system.

12. Determining Factor of Safety

Factor of safety can be determined in *FLAC3D* for any selected parameter by taking the ratio of the calculated value under given conditions to that value which results in failure. For example,

$$F_w = \frac{\text{water level to cause collapse}}{\text{actual water level}}$$

$$F_L = \frac{\text{applied load to cause failure}}{\text{design load}}$$

$$F_\phi = \frac{\tan(\text{actual friction angle})}{\tan(\text{friction angle at failure})}$$

Note that the larger value is always divided by the smaller value (assuming that the system does not fail under the actual conditions). *The definition of failure must be established by the user.* A comparison of this approach based on strength reduction for determining factor of safety to that based upon limit analysis solutions is given by Dawson and Roth (1999) and Dawson et al. (1999). Also see Section 1 in the **Examples volume**.

The strength reduction method for determining factor of safety is implemented in *FLAC3D* through the **SOLVE fos** command. This command implements an automatic search for factor of safety using the bracketing approach, as described in Dawson et al. (1999). The **SOLVE fos** command may be given at any stage in a *FLAC3D* run, provided that all non-null zones contain the Mohr Coulomb model. During the solution process, properties will be changed, but the original state will be restored on completion, or if the **fos** search is terminated prematurely with the <Esc> key.

When *FLAC3D* is executing the **SOLVE fos** command, the bracketing values for F are printed continuously to the screen so that you can tell how the solution is progressing. If terminated by the <ESC> key, the solution process terminates, and the best current estimate of **fos** is displayed. A save file that corresponds

to the last non-equilibrium state is produced, so that velocity vectors, and so on, can be plotted. This allows a visualization of the failure mode.

Example 3.40, based upon an example stability analysis from Dawson et al. (1999), illustrates how the approach works. The run stops at $F = 1.06$. Figure 3.45 plots shear strain-rate contours and velocity vectors, which allow the failure surface to be identified.

Example 3.40 Factor-of-safety calculation for slope stability analysis

```
gen zone brick  &
p0 0 0 0 p1 2 0 0 p2 0 0.5 0 p3  0 0 2 &
size 3 1 3
gen zone brick  &
p0 2 0 0 p1 13.4 0 0  p2 2 0.5 0 p3 2 0 2 &
size 8 1 3
gen zone brick  &
p0 13.4 0 0 p1 20 0 0  p2 13.4 0.5 0 p3 13.4 0 2 &
size 6 1 3
gen zone brick  &
p0 2 0 2 p1 13.4 0 2 p2 2 0.5 2 p3 12 0 12 &
p4 13.4 0.5 2 p5 12 0.5 12 p6  16 0 12 p7  16 0.5 12 &
size 8 1 17
gen zone brick  &
p0 13.4 0 2 p1 20 0 2 p2 13.4 0.5 2 p3 16 0 12 &
p4 20 0.5 2 p5 16 0.5 12 p6  20 0 12 p7  20 0.5 12 &
size 6 1 17

model mohr
prop density = 2000.0 bulk = 1.0E8 shear = 3.0E7 coh 12380.0 tens 1.0E10 &
friction = 20 dilation = 20
fix x y z range z -0.1 0.1
fix x range x 19.9 20.1
fix x range x -0.1 0.1
fix y
set gravity = 10.0
solve fos file slope3dfos.sav associated
ret
```

It is recommended that the **SOLVE fos** command be given at an equilibrium state of a model (to improve solution time), but — as Example 3.40 demonstrates — this is not essential.

The procedure used by *FLAC3D* during execution of **SOLVE fos** is as follows. First, the code finds a "representative number of steps" (denoted by N_r), which characterizes the response time of the system. N_r is found by setting the

cohesion to a large value, making a large change to the internal stresses, and finding how many steps are necessary for the system to return to equilibrium. Then, for a given factor of safety, F, N_r steps are executed. If the unbalanced force ratio is less than 10^{-3}, then the system is in equilibrium. If the unbalanced force ratio is greater than 10^{-3}, then another N_r steps are executed, exiting the loop if the force ratio is less than 10^{-3}. The mean value of force ratio, averaged over the current span of N_r steps, is compared with the mean force ratio over the previous N_r steps. If the difference is less than 10%, the system is deemed to be in non-equilibrium, and the loop is exited with the new non-equilibrium, F. If the above-mentioned difference is greater than 10%, blocks of N_r steps are continued until: (1) the difference is less than 10%; or (2) 6 such blocks have been executed; or (3) the force ratio is less than 10^{-3}. The justification for case (1) is that the mean force ratio is converging to a steady value that is greater than that corresponding to equilibrium; the system must be in continuous motion. The *FISH* intrinsic variable **`fos_f`** allows access to the current value of F during **SOLVE fos** execution (see Section 2.5.1.1 in the ***FISH* volume**).

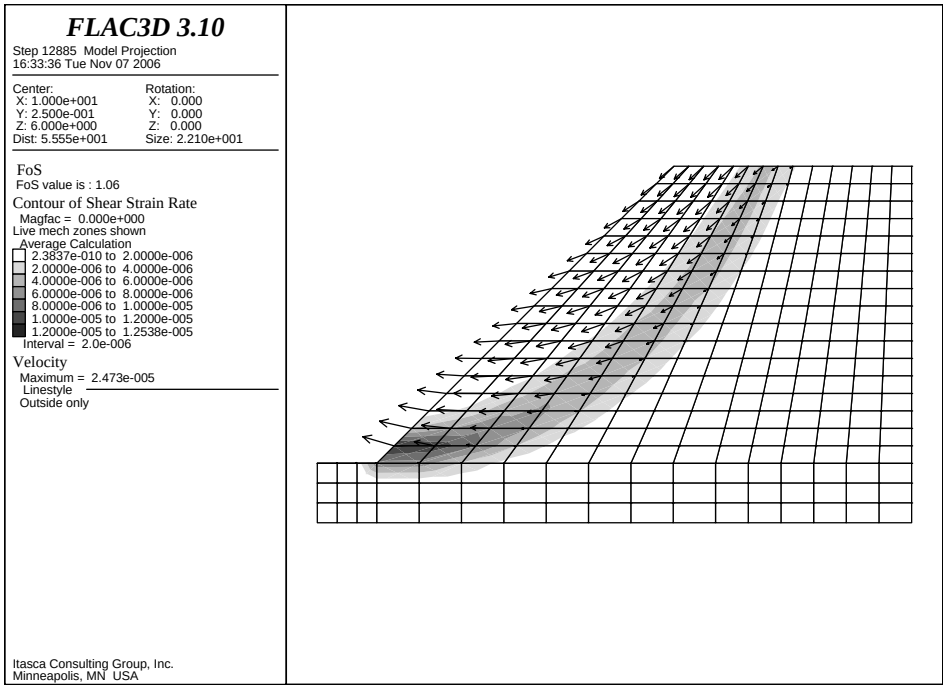


Figure 3.45 Shear strain-rate contours and velocity vectors in slope model at last non-equilibrium state

13. Use Bulk and Shear Moduli

It is better to use bulk modulus, K, and shear modulus, G, than Young's modulus, E, and Poisson's ratio, ν, for elastic properties in *FLAC3D*.

The pair (K, G) makes sense for all elastic materials that do not violate thermodynamic principles. The pair (E, ν) does not make sense for certain admissable materials. At one extreme, we have materials that resist volumetric change but not shear; at the other extreme, materials that resist shear but not volumetric change. The first type of material corresponds to finite K and zero G, and the second to zero K and finite G. However, the pair (E, ν) is not able to characterize either the first or the second type of material. If we exclude the two limiting cases (conventionally, $\nu = 0.5$ and $\nu = -1$), the equations

$$\begin{aligned} 3K(1-2\nu) &= E \\ 2G(1+\nu) &= E \end{aligned} \tag{3.33}$$

relate the two sets of constants. These equations hold, however close we approach (but not reach) the limiting cases. We do not need to relate them to physical tests that may or may not be feasible — the equations are simply the consequence of two possible ways of defining coefficients of proportionality. Suppose we have a material in which the resistance to distortion progressively reduces, but in which the resistance to volume change remains constant. ν approaches 0.5 in this case. The equation $3K(1-2\nu) = E$ must still be satisfied. There are two possibilities (argued on *algebraic*, not physical, grounds): either E remains finite (and nonzero) and K tends to an arbitrarily large value; or K remains finite and E tends to zero. We rule out the first possibility because there is a limiting compressibility to all known materials (e.g., 2 GPa for water, which has a Poisson's ratio of 0.5). This leaves the second, in which E is varying drastically, even though we supposed that the material's principal mode of elastic resistance was unchanging. We deduce that the parameters (E, ν) are inadequate to express the material behavior.

3.9 Interpretation

Since *FLAC3D* models a nonlinear system as it evolves in time, the interpretation of results may be more difficult than with a conventional finite-element program that produces a "solution" at the end of its calculation phase. There are several indicators that can be used to assess the state of the numerical model — e.g., whether the system is stable, unstable, or in steady-state plastic flow. The various indicators are described below.

3.9.1 Unbalanced Force

Each gridpoint is surrounded by up to eight zones that contribute forces to the gridpoint. At equilibrium, the algebraic sum of these forces is almost zero (i.e., the forces acting on one side of the gridpoint nearly balance those acting on the other). If the unbalanced forces approach a constant nonzero value, this indicates that failure and plastic flow are occurring within the model. During timestepping, the maximum unbalanced force is determined for the whole grid; this force is displayed continuously on the screen. It can also be saved as a history and viewed as a graph. The unbalanced force is important in assessing the state of the model, but its magnitude must be compared with the magnitude of typical internal forces acting in the grid. In other words, it is necessary to know what constitutes a "small" force. A representative internal gridpoint force may be found by multiplying stress by zone area perpendicular to the force, using values that are typical in the area of interest in the grid. Denoting R as the ratio of maximum unbalanced force to the representative internal force, expressed as a percentage, the value of R will never decrease to zero. However, a value of 1% or 0.1% may be acceptable as denoting equilibrium, depending on the degree of precision required (e.g., R = 1% may be good enough for an intermediate stage in a sequence of operations, while R = 0.1% may be used if a final stress or displacement distribution is required for inclusion in a report or paper). Note that a low value of R only indicates that forces balance at all gridpoints. However, steady plastic flow may be occurring without acceleration. In order to distinguish between this condition and "true" equilibrium, other indicators, such as those described below, should be examined.

3.9.2 Gridpoint Velocities

The grid velocities may be assessed either by plotting out the whole field of velocities (using the **PLOT vel** command) or by selecting certain key points in the grid and tracking their velocities with histories (**HIS gp xvel**, **yvel** or **zvel**). Both types of plots are useful. Steady-state conditions are indicated if the velocity histories show horizontal traces in their final stages. If they have all converged to near-zero (in comparison to their starting values), then absolute equilibrium has occurred; if a history has converged to a nonzero value, then steady plastic-flow is occurring at the gridpoint corresponding to that history. If one or more velocity history plots show fluctuating velocities, then the system is likely to be in a transient condition. Note that velocities are expressed in units of displacement divided by number of steps.

The plot of the field of velocity vectors is more difficult to interpret, since both the magnitudes and the nature of the pattern are important. As with gridpoint forces, velocities never decrease precisely to zero. The magnitude of velocity should be viewed in relation to the displacement that would

occur if a significant number of steps (e.g., 1000) were to be executed. For example, if current displacements in the system are of the order of 1 cm, and the maximum velocity in the velocity plot is 10^{-8} m/step, then 1000 steps would produce an additional displacement of 10^{-5} m, or 10^{-3} cm, which is 0.1% of the current displacements. In this case, it can be said that the system is in equilibrium even if the velocities all seem to be "flowing" in one direction. More often, the vectors appear to be random (or almost random) in direction and (possibly) in magnitude. This condition occurs when the changes in gridpoint force fall below the accuracy limit of the computer, which is around six decimal digits. A random velocity field of low amplitude is an infallible indicator of equilibrium and no plastic flow.

If the vectors in the velocity field are coherent (i.e., there is some systematic pattern) and their magnitude is quite large (using the criterion described above), then either plastic flow is occurring or the system is still adjusting elastically (e.g., damped elastic oscillation is taking place). To confirm that continuing plastic flow is occurring, a plot of plasticity indicators should be examined, as described below. If, however, the motion involves elastic oscillation, then the magnitude should be observed in order to indicate whether such movement is significant. Seemingly meaningful patterns of oscillation may be seen but, if amplitude is low, then the motion has no physical significance.

3.9.3 Plastic Indicators

For the plasticity models in *FLAC3D*, the command **PLOT block state** displays those zones in which the stresses satisfy the yield criterion. Such an indication usually denotes that plastic flow is occurring, but it is possible for an element simply to "sit" on the yield surface without any significant flow taking place. It is important to look at the whole pattern of plasticity indicators to see whether a *mechanism* has developed.

Two types of failure mechanisms are indicated by the plasticity state plot: shear failure and tensile failure — each type is designated by a different color on the plot.* The plot also indicates whether stresses within a zone are currently on the yield surface (i.e., the zone is at active failure now, **-n**), or the zone has failed earlier in the model run, but now the stresses fall below the yield surface (the zone has failed in the past, **-p**). Initial plastic flow can occur at the beginning of a simulation, but subsequent stress redistribution unloads the yielding elements so that their stresses no longer satisfy the yield criterion, indicated by **shear-p** or **tension-p** (on the plasticity state plot).

A failure mechanism is indicated if there is a contiguous line of active plastic zones (indicated by either **shear-n** or **tension-n**) that join two surfaces. The diagnosis is confirmed if the velocity plot also indicates motion corresponding to the same mechanism.

If there is no contiguous line or band of active plastic zones between boundaries, two patterns should be compared before and after the execution of, say, 500 steps. Is the region of active yield increasing or decreasing? If it is decreasing, then the system is probably heading for equilibrium; if it is increasing, then ultimate failure *may* be possible.

---

* For the ubiquitous-joint model, shear failure along the joint plane is designated by **u:shear** and tensile failure by **u:tension** on the plasticity plot.

If a condition of continuing plastic flow has been diagnosed, one further question should be asked — Does the active flow band(s) include zones adjacent to artificial boundaries? The term "artificial boundary" refers to a boundary that does not correspond to a physical entity, but one that exists simply to limit the size of the grid that is used (see Section 3.3.4). If plastic flow occurs along such a boundary, then the solution is not realistic, because the mechanism of failure is influenced by a nonphysical entity. This comment only applies to the final steady-state solution; intermediate stages may exhibit flow along boundaries.

3.9.4 Histories

In any problem, there are certain variables that are of particular interest — e.g., displacements may be of concern in one problem, but stresses may be of concern in another. Liberal use should be made of the **HIST** command to track these important variables in the regions of interest. After some timestepping has taken place, plots of these histories often provide a way to find out what the system is doing.

3.10 Modeling Methodology

3.10.1 Modeling of Data-Limited Systems

In a field such as geomechanics, where data is not always available, the methodology used in numerical modeling should be different from that used in a field such as mechanical engineering. Starfield and Cundall (1988) provide suggestions for an approach to modeling that is appropriate for a data-limited system. This paper should be consulted before any serious modeling with *FLAC3D* is attempted. In essence, the approach recognizes that field data (such as in-situ stresses, material properties and geological features) will never be known completely. It is futile to expect the model to provide design data, such as expected displacements, when there is massive uncertainty in the input data. However, a numerical model is still useful in providing a picture of the *mechanisms* that may occur in particular physical systems. The model acts to educate the intuition of the design engineer by providing a series of cause-and-effect examples. The models may be simple, with assumed data that is consistent with known field data and engineering judgement. It is a waste of effort to construct a very large and complicated model that may be just as difficult to understand as the real case.

Of course, if extensive field data is available, then this may be incorporated into a comprehensive model that can yield design information directly. More commonly, however, the data-limited model does not produce such information directly, but provides insight into mechanisms that may occur. The designer can then do simple calculations based on these mechanisms that estimate the parameters of interest or the stability conditions.

3.10.2 Modeling of Chaotic Systems

In some calculations, especially in those involving discontinuous materials, the results can be extremely sensitive to very small changes in initial conditions, or trivial changes in loading sequence. At first sight, this situation may seem unsatisfactory and may be taken as a reason to mistrust the computer simulations. However, the sensitivity exists in the physical system being modeled. There appear to be a least two sources for the seemingly erratic behavior:

1. There are certain geometric patterns of discontinuities that force the system to choose, apparently at random, between two alternative outcomes; the subsequent evolution depends on which choice is made. For example, Figure 3.46 illustrates a small portion of a jointed rock mass. If block A is forced to move down relative to B, it can either go to the left or to the right of B; the choice will depend on microscopic irregularities in geometry, properties or kinetic energy.

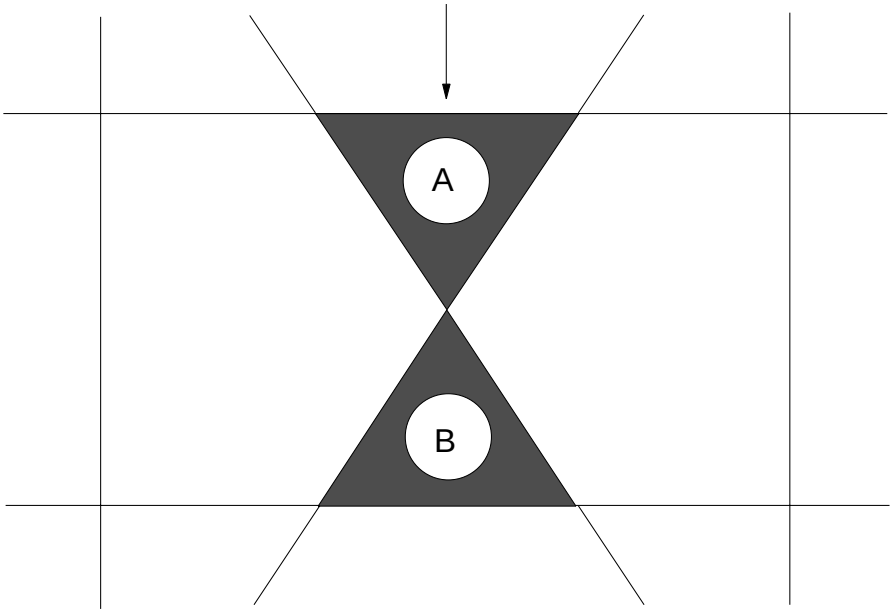


Figure 3.46 A small portion of a jointed rock mass

2. There are processes in the system that can be described as "softening" or, more generally, as cases of positive feedback. In a fairly uniform stress field, small perturbations are magnified in the subsequent evolution because a region that has more strain, softens more and thereby attracts more strain, and so on, in a cycle of positive feedback.

Both phenomena give rise to behavior that is chaotic in its extreme form (Gleick (1987) and Thompson and Stewart (1986)). The study of chaotic systems reveals that the detailed evolution of such a system is not predictable, *even in principle*. The observed sensitivity of the computer model to small changes in initial conditions or numerical factors is simply a reflection of a similar sensitivity in the real world to small irregularities. There is no point in pursuing increasingly more "accurate" calculations, because the resulting model is unrepresentative of the real world, where conditions are not perfect. What should our modeling strategy be in the face of a chaotic system? It appears that the best we can expect from such a model is a finite *spectrum* of expected behavior; the *statistics* of a chaotic system are well-defined. We need to construct models that contain distributions of initial irregularities — e.g., by using *FLAC3D*'s **gauss_dev** or **uniform_dev** parameter on the **PROPERTY** command, or by specifying given distributions with a special *FISH* function. Each model should be run several times, with different distributions of irregularities. Under these conditions, we may expect the fluctuations in behavior to be triggered by the imposed irregularities, rather than by artifacts of the numerical solution scheme. We can express the results in a statistical form.

3.10.3 Localization, Physical Instability and Path-Dependence

In many systems that can be modeled with *FLAC3D*, there may be several paths that the solution may take, depending on rather small changes in initial conditions. This phenomenon is termed *bifurcation*. For example, a shear test on an elastic/plastic material may either deform uniformly, or it may exhibit shear bands, in which the shear strain is localized rather than being uniformly distributed. It appears that if a numerical model has enough degrees-of-freedom (i.e., enough elements), then localization is to be expected. Indeed, theoretical work on the bifurcation process (e.g., Rudnicki and Rice (1975) and Vardoulakis (1980)) shows that shear bands form even if the material does not strain-soften, provided that the dilation angle is lower than the friction angle. The "simple" Mohr-Coulomb material should always exhibit localization if enough elements to resolve one or more localized bands exist. A strain-softening material is more prone to produce bands.

Some computer programs appear incapable of reproducing band formation, although the phenomenon is to be expected physically. However, *FLAC3D* is able to allow bands to develop and evolve, partly because it models the dynamic equations of motion (i.e., the kinetic energy that accompanies band formation is released and dissipated in a physically realistic way). Several papers document the use of two-dimensional *FLAC* in modeling shear band formation (Cundall (1989), (1990) and (1991)). These should be consulted for details concerning the solution process. One aspect that is not treated well by *FLAC3D* is the *thickness* of a shear band. In reality, the thickness of a band is determined by internal features of the material, such as grain size.

These features are not built into *FLAC3D*'s constitutive models. Hence, the bands in *FLAC3D* collapse down to the smallest width that can be resolved by the grid, which is one grid-width if the band is parallel to the grid, or about three grid-widths if the band cuts across the grid at an arbitrary angle. Although the overall physics of band formation is modeled correctly by *FLAC3D*, band thickness and band spacing are grid-dependent. Furthermore, if the strain-softening model is used with a weakening material, the load/displacement relation generated by *FLAC3D* for a simulated test is strongly grid-dependent. This is because the strain concentrated in a band depends on the width of the band (in length units), which depends on zone size, as we have seen. Hence, smaller zones lead to more softening, since we move out more rapidly on the strain axis of the given softening curve. To correct this grid dependence, some sort of length scale must be built into the constitutive model. There is controversy, at present, concerning the best way to do this. It is anticipated that future versions of *FLAC3D* will include a length scale in the constitutive models — probably involving the use of a Cosserat material, in which internal spins and moments are taken into account. In the meantime, the processes of softening and localization may be modeled, but it must be recognized that the grid size and angle affect the results: models must be calibrated for each grid used.

One topic that involves chaos, physical instability and bifurcation is *path-dependence*. In most nonlinear, inelastic systems, there are an *infinite* number of solutions that satisfy equilibrium, compatibility, and the constitutive relations. There is no "correct" solution to the physical problem unless the path is specified. If the path is not specified, all possible solutions are correct. This situation can cause endless debate among modelers and users, particularly if a seemingly irrelevant parameter in the solution process (e.g., damping) is seen to affect the final result. All of the solutions are valid numerically. For example, a simulation of a mining excavation with low damping may show a large overshoot and, hence, large final displacements, while high damping will eliminate the overshoot and give lower final displacements. Which one is more realistic? It depends on the path.

If the excavation is done by explosion (i.e., suddenly), then the solution with overshoot may be the appropriate one. If the excavation is done by pick and shovel (i.e., gradually), then the second case may be more appropriate. For cases in which path-dependence is a factor, modeling should be done in a way that mimics the way the system evolves physically.

3.11 References

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4 *FISH* BEGINNER'S GUIDE

4.1 Introduction

FISH is a programming language embedded within *FLAC3D* that enables the user to define new variables and functions. These functions may be used to extend *FLAC3D*'s usefulness or add user-defined features. For example, new variables may be plotted or printed, special grid generators may be implemented, servo-control may be applied to a numerical test, unusual distributions of properties may be specified and parameter studies may be automated.

FISH was developed in response to requests from users who wanted to do things with Itasca software that were either difficult or impossible with existing program structures. Rather than incorporate many new and specialized features into the standard code, an embedded language was provided so that users could write their own functions. Some useful *FISH* functions have already been written; a library of these is provided with the *FLAC3D* program (see Section 3 in the ***FISH* volume**). It is possible for someone without experience in programming to write simple *FISH* functions or to modify some of the simpler existing functions. Section 4.2 contains an introductory tutorial for non-programmers. However, *FISH* programs can also become very complicated (which is true of code in any programming language) — for more details, refer to Section 2 in the ***FISH* volume**.

As with all programming tasks, *FISH* functions should be constructed in an incremental fashion, checking operations at each level before moving on to more complicated code. *FISH* does less error-checking than most compilers, so all functions should be tested on simple data sets before using them for real applications.

FISH programs are simply embedded in a normal *FLAC3D* data file — lines following the word **DEFINE** are processed as a *FISH* function; the function terminates when the word **END** is encountered. Functions may invoke other functions, which may invoke others, and so on. The order in which functions are defined does not matter, so long as they are all defined before they are used (e.g., invoked by a *FLAC3D* command). Since the compiled form of a *FISH* function is stored in *FLAC3D*'s memory space, the **SAVE** command saves the function and the current values of associated variables.

All of the *FISH* language rules and intrinsic functions are discussed in Section 2 in the ***FISH* volume**. This includes rules for syntax, data types, arithmetic, variables and functions. All *FISH* language names are described in Section 2 in the ***FISH* volume**.

4.2 Tutorial

This section is intended for people who have run *FLAC3D* (at least for simple problems) but have not used the *FISH* language — no programming experience is assumed. To get the maximum benefit from the examples given here, you should try them out with *FLAC3D* running interactively. The short programs may be typed in directly. After running an example, give the *FLAC3D* command **NEW**, to "wipe the slate clean," ready for the next example. Alternatively, the more lengthy programs may be created on file and **CALL**ed when required.

Type the lines in Example 4.1 after *FLAC3D*'s command prompt, pressing <ENTER> at the end of each line.

Example 4.1 Defining a FISH function

```
def abc
  abc = 22 * 3 + 5
end
```

Note that the command prompt changes to **Def>** after the first line has been typed in. Then it changes back to the usual prompt when the **END** command is entered. This change in prompt lets you know whether you are sending lines to *FLAC3D* or to *FISH*. Normally, all lines following the **DEFINE** statement are taken as part of the definition of a *FISH* function (until the **END** statement is entered). However, if you type in a line that contains an error (e.g., you type the **=** sign instead of the **+** sign), then you will get the *FLAC3D* prompt back again. In this case, you should give the **NEW** command and try again from the beginning. Since it is very easy to make mistakes, *FISH* programs are normally typed into a file using an editor. These are then **CALL**ed into *FLAC3D* just like a regular *FLAC3D* data file. We will describe this process later; for now, we'll continue to work interactively. Assuming that you typed in the preceding lines without error, and that you now see the *FLAC3D* prompt `Flac3D>`, you can "execute" the function **abc*** defined earlier in Example 4.1 by typing the line

```
print abc
```

The message

```
abc =  71
```

should appear on the screen. By defining the symbol **abc** (using the **DEFINE – END** construction, as in Example 4.1), we can now refer to it in many ways using *FLAC3D* commands.

For example, the **PRINT** command causes the value of a *FISH* symbol to be displayed; the value is computed by the series of arithmetic operations in the line

```
abc = 22 * 3 + 5
```

---

* We will use **courier boldface** to identify user-defined *FISH* functions and declared variables in the text.

This is an "assignment statement." If an equal sign is present, the expression on the right-hand side of the equal sign is evaluated and given to the variable on the left-hand side. Note that arithmetic operations follow the usual conventions; addition, subtraction, multiplication and division are done with the signs **+**, **-**, ***** and **/**, respectively. The sign ^ denotes "raised to the power of."

We now type in a slightly different program (using the **NEW** command to erase the old one):

Example 4.2 Using a variable

```
new
def abc
  hh = 22
  abc = hh * 3 + 5
end
```

Here we introduce a "variable," **hh**, which is given the value of 22 and then used in the next line. If we give the command **PRINT abc**, then exactly the same output as in the previous case appears. However, we now have two *FISH* symbols; they both have values, but one (**abc**) is known as a "function," and the other (**hh**) as a "variable." The distinction is as follows.

> *When a FISH symbol name is mentioned (e.g., in a* **PRINT** *statement), the associated function is executed if the symbol corresponds to a function. However, if the symbol is not a function name, then the current value of the symbol is used.*

The following experiment may help to clarify the distinction between variables and functions. (Before doing the experiment, note that *FLAC*^{3D}'s **SET** command can be used to set the value of any user-defined *FISH* symbol, independent of the *FISH* program in which the symbol was introduced.) Now type in the following lines without giving the **NEW** command, since we want to keep our previously entered program in memory.

Example 4.3* SET*ting variables

```
set abc=0 hh=0
print hh
print abc
print hh
```

The **SET** command sets the values of both **abc** and **hh** to zero. Since **hh** is a variable, the first **PRINT** command simply displays the current value of **hh**, which is zero. The second **PRINT** command causes **abc** to be executed (since **abc** is the name of a function); the values of both **hh** and **abc** are thereby recalculated. Accordingly, the third **PRINT** statement shows that **hh** has indeed been reset to its original value. As a test of your understanding, you should type in the slightly modified sequence shown in Example 4.4, and figure out why the displayed answers are different.

Example 4.4 Test your understanding of function and variable names

```
new
def abc
  abc = hh * 3 + 5
end
set hh=22
print abc
set abc=0 hh=0
print hh
print abc
print hh
```

At this stage, it may be useful to list the most important *FLAC3D* commands that directly refer to simple *FISH* variables or functions. (In Table 4.1, ***var*** stands for the name of the variable or function.)

Table 4.1 Commands that directly refer to FISH names

PRINT	***var***
SET	***var*** = ***value***
HISTORY	***var***

We have already seen examples of the first two (refer to Examples 4.3 and 4.4); the third case is useful when histories of things that are not provided in the standard *FLAC3D* list of history variables are required. Example 4.5 shows how the total load on the top platen of a triaxial test sample can be stored as a history.

Example 4.5 Capturing the history of a FISH variable

```
new
gen zone brick size 1 2 1
model mohr
prop shear=1e8 bulk=2e8 &
     cohes=1e5 tens=1e10
fix x y z        range y -0.1 0.1
apply yvel -1e-5 range y  1.9 2.1
def get_ad
   ad1 = gp_near(0,2,0)
   ad2 = gp_near(1,2,0)
   ad3 = gp_near(0,2,1)
   ad4 = gp_near(1,2,1)
end
```

```
get_ad
def load
   load=gp_yfunbal(ad1)+gp_yfunbal(ad2)+gp_yfunbal(ad3)+gp_yfunbal(ad4)
end
hist load
hist gp ydis 0,6,0
step 1000
plot his 1 vs -2
```

Note that the *FISH* variable **load** is equal to the sum of four other variables, **gp_yfunbal*(index)***. The *FISH* grid variable **gp_yfunbal()** is an example of a grid quantity that is available within a *FISH* program; there is a complete list of these in Section 2.5.3 in the ***FISH* volume**. Grid variables are simply pre-defined named quantities that relate to the *FLAC3D* grid.

In Example 4.5, **gp_yfunbal()** is the y-component of the unbalanced gridpoint force; each instance of **gp_yfunbal()** must be followed by a gridpoint memory address (or pointer). The address is found with the function **get_ad**, which uses the *FISH* gridpoint variable **gp_near** to find the address of the gridpoint closest to the (x,y,z) global coordinates (0,2,0), (1,2,0), (0,2,1) and (1,2,1). The derived variable **load**, which is the sum of the four top forces, is calculated whenever history points are taken (every ten steps, by default). At the end of the run, we simply plot out the history of **load** (history 1) just like any other history. Similarly, we may use *FISH* functions to plot out a history of any quantity we wish, no matter how complicated the formula to describe it might be.

In addition to the above-mentioned pre-defined variable names, there are many other pre-defined objects available to a *FISH* program. These fall into several classes; one such class consists of *scalar* variables, which are single numbers — for example,

clock	clock time in hundredths of a second
unbal	maximum unbalanced force
xgrav	x-component of gravity
pi	π
step	current step number
urand	random number drawn from uniform distribution between 0.0 and 1.0

This is just a small selection — the full list is given in Section 2.5.2 in the ***FISH* volume**.

Another useful class of built-in objects is the set of *intrinsic functions*, which enables things like sines and cosines to be calculated from within a *FISH* program. A complete list is provided in Section 2.5.4 in the ***FISH* volume**; a few are given below.

abs(*a*)	absolute value of ***a***
cos(*a*)	cosine of ***a*** (***a*** is in radians)

log(*a*)	base-ten logarithm of ***a***
max(*a*,*b*)	returns maximum of ***a***, ***b***
sqrt(*a*)	square root of ***a***

An example in the use of intrinsic functions will be presented later, but now we must discuss one more way in which a *FLAC3D* data file can make use of user-defined *FISH* names.

> *Wherever a number is expected in a FLAC3D input line, you may substitute the name of a FISH variable or function.*

This simple statement is the key to a very powerful feature of *FISH* that allows such things as ranges, applied stresses, properties, etc., to be computed in a *FISH* function and used by *FLAC3D* input in symbolic form. Hence, parameter changes can be made very easily, without the need to change many numbers in an input file.

As an example, let us assume that we know the Young's modulus and Poisson's ratio of a material. Since *FLAC3D* needs the bulk and shear moduli, we may derive these with a *FISH* function, using Eqs. (4.1) and (4.2):

$$G = \frac{E}{2(1+\nu)} \tag{4.1}$$

$$K = \frac{E}{3(1-2\nu)} \tag{4.2}$$

Coding Eqs. (4.1) and (4.2) into a *FISH* function (called **derive**) can then be done as shown in Example 4.6:

Example 4.6 FISH functions to calculate bulk and shear moduli

```
new
def derive
  s_mod = y_mod / (2.0 * (1.0 + p_ratio))
  b_mod = y_mod / (3.0 * (1.0 - 2.0 * p_ratio))
end
set y_mod = 5e8 p_ratio = 0.25
derive
print b_mod s_mod
```

Note that here we execute the function **derive** by giving its name by itself on a line; we are not interested in its *value*, only what it *does*. If you run this example, you will see that values are

computed for the bulk and shear moduli, **b_mod** and **s_mod**, respectively. These can then be used, in symbolic form, in *FLAC3D* input as shown in Example 4.7.*

Example 4.7 Using symbolic variables in FLAC3D input

```
gen zone brick size 2,2,2
model elastic
prop bulk=b_mod shear=s_mod
print zone prop bulk
print zone prop shear
```

The validity of this operation may be checked by printing out **bulk** and **shear** in the usual way. In these examples, our property input is given via the **SET** command — i.e., to variables **y_mod** and **p_ratio**, which stand for Young's modulus and Poisson's ratio, respectively.

Note that there is great flexibility in choosing names for *FISH* variables and functions; the underline character (_) may be included in a name. Names must begin with a non-number and must not contain any of the arithmetic operators (+, –, /, * or ^). See Section 2.2.2 in the ***FISH*** **volume** for a list of symbols to avoid. A chosen name should not be the same as one of the built-in (or reserved) names; Table 2.1 in Section 2.2.2 in the ***FISH*** **volume** contains a complete list of names to be avoided, as well as some rules that should be followed. Also note that parentheses were used in the preceding example. These should be used whenever it is necessary to make clear the order in which arithmetic operations are to be done.

In the preceding examples, we checked the computed values of *FISH* variables by giving their names explicitly as arguments to a **PRINT** command. Alternatively, we can list all current variables and functions. A printout of all current values, sorted alphabetically by name, is produced by giving the command

```
print fish
```

We now examine ways in which decisions can be made, and repeated operations done, in *FISH* programs. The following *FISH* statements allow specified sections of a program to be repeated many times.

LOOP ***var (expr1, expr2)***

ENDLOOP

---

* In **safe** mode, the *FISH* variable must be preceded by an @ symbol — see Section 2.2.2 in the ***FISH*** **volume** and the **SET** command in Section 1.3 in the **Command Reference**.

The words **LOOP** and **ENDLOOP** are *FISH* statements, the symbol ***var*** stands for the loop variable, and ***expr1*** and ***expr2*** stand for expressions (or single variables). Example 4.8 shows the use of a loop (or repeated sequence) to produce the sum and product of the first ten integers.

Example 4.8 Controlled loop in FISH

```
new
def xxx
  sum  = 0
  prod = 1
  loop n (1,10)
    sum  = sum + n
    prod = prod * n
  end_loop
end
xxx
print sum, prod
```

In this case, the loop variable **n** is given successive values from 1 to 10, and the statements inside the loop (between the **LOOP** and **ENDLOOP** statements) are executed for each value. As mentioned, variable names or an arithmetic expression could be substituted for the numbers 1 or 10.

A practical use of the **LOOP** construct is to install a nonlinear initial distribution of elastic moduli in a *FLAC3D* grid. Suppose that the Young's modulus at a site is given by Eq. (4.3):

$$E = E_\circ + c\sqrt{z} \tag{4.3}$$

where z is the depth below surface, and c and $E_\circ$ are constants. We write a *FISH* function to install appropriate values of bulk and shear modulus in the grid, as in Example 4.9.

Example 4.9 Applying a nonlinear initial distribution of moduli

```
new
gen zone brick p0 (0,0,0) p1 (-10,0,0) p2 (0,10,0) p3 (0,0,-10)
model elas
def install
    pnt = zone_head
    loop while pnt # null
        z_depth = -z_zcen(pnt)
        y_mod = y_zero + cc * sqrt(z_depth)
        z_prop(pnt, 'shear') = y_mod / (2.0*(1.0+P_ratio))
        z_prop(pnt, 'bulk')  = y_mod / (3.0*(1.0-2.0*P_ratio))
        pnt = z_next(pnt)
    end_loop
```

```
end
set p_ratio=0.25 y_zero=1e7 cc=1e8
install
plot block prop bulk
```

Again, you can verify correct operation of the function by printing or plotting shear and bulk moduli.

In the function **install**, the loop scans all zones beginning with **zone_head**, which is the address of the first zone in the zone list. The *FISH* statement **LOOP WHILE** is a variation of **LOOP** that executes the loop until the test condition is met — i.e., until the address **pnt** equals zero (**pnt # null** means **pnt** not equal to zero). This condition identifies the last zone in the zone list. Inside the loop, the z-coordinate of each zone centroid is used to calculate the Young's modulus, given in Eq. (4.3). We assume that the datum (or ground surface reference point) is at $z = 0$. Grid values for bulk and shear moduli are calculated as in Example 4.6. The variables **z_zcen(pnt)**, **z_prop(pnt, 'shear')** and **z_prop(pnt, 'bulk')** are *zone* variables. (Recall that we talked about the *gridpoint* variable **gp_yfunbal(pnt)** earlier.) Here, we set properties directly from within a *FISH* function, rather than with a **PROP** command as in our earlier example.

Having seen several examples of *FISH* programs, let's briefly examine the question of program syntax and style. A complete *FISH* statement must occupy one line; there are no continuation lines. If a formula is too long to fit on one line, then a temporary variable must be used to split the formula. Example 4.10 shows how this can be done.

Example 4.10 Splitting lines

```
new
def long_sum  ;example of a sum of many things
  temp = v1 + v2 + v3 + v4 + v5 + v6 + v7 + v8 + v9 + v10
  long_sum = temp + v11 + v12 + v13 + v14 + v15
end
```

In this case, the sum of fifteen variables is split into two parts. Also note the use of the semicolon in line 1 of Example 4.10 to indicate a comment. Any characters that follow a semicolon are ignored by the *FISH* compiler, but they *are* echoed to the log file. It is good programming practice to annotate programs with informative comments. Some of the programs have been shown with *indentation* — that is, space inserted at the beginning of some lines to denote a related group of statements. Any number of space characters may be inserted (optionally) between variable names and arithmetic operations to make the program more readable. Again, it is good programming practice to include indentation to indicate things like loops, conditional clauses and so on. Spaces in *FISH* are "significant" in the sense that space characters may not be inserted into a variable or function name.

One other topic that should be addressed now is that of variable *type*. You may have noticed, when printing out variables from the various program examples, that numbers are either printed without decimal points or in "E-format" — that is, as a number with an exponent denoted by "E." At any

instant in time, a *FISH* variable or function name is classified as one of four types: *integer*, *floating-point*, *string* or *pointer*. These types may change dynamically, depending on context, but the casual user should not normally have to worry about the type of a variable, since it is set automatically. Consider Example 4.11.

Example 4.11 Variable types

```
new
def haveone
  aa = 2
  bb = 3.4
  cc = 'Have a nice day'
  dd = aa * bb
  ee = cc + ', old chap'
end
haveone
print fish
```

The resulting screen display looks like this:

```
                Value    Name
                -----    ----
                    2    aa
           3.4000e+000    bb
            - string -    cc
           6.8000e+000    dd
            - string -    ee
                    0    haveone
```

The variables **aa**, **bb** and **cc** are converted to *integer*, *float* and *string*, respectively, corresponding to the numbers (or strings) that were assigned to them. Integers are exact numbers (without decimal points) but are of limited range; floating-point numbers have limited precision (about 15 decimal places), but are of much greater range; string variables are arbitrary sequences of characters; *pointers* are used to address internal variables in *FLAC3D*. There are various rules for conversion between the four types. For example, **dd** becomes a floating-point number, because it is set to the product of a floating-point number and an integer; the variable **ee** becomes a string because it is the sum (concatenation) of two strings. The topic can get quite complicated, but it is fully explained in Sections 2.2.4 and 2.2.5.

There is another language element in *FISH* that is commonly used — the **IF** statement. The following three statements allow decisions to be made within a *FISH* program.

IF *expr1 test expr2* **THEN**

ELSE

ENDIF

These statements allow conditional execution of *FISH* program segments; **ELSE** and **THEN** are optional. The item ***test*** consists of one of the following symbols or symbol pairs.

= # > < >= <=

The meanings are standard except for #, which means "not equal." The items ***expr1*** and ***expr2*** are any valid expressions or single variables. If the test is true, then the statements immediately following **IF** are executed until **ELSE** or **ENDIF** is encountered. If the test is false, the statements between **ELSE** and **ENDIF** are executed if the **ELSE** statement exists; otherwise, the program jumps to the first line after **ENDIF**. The action of these statements is illustrated in Example 4.12.

Example 4.12 Action of the* IF ELSE ENDIF *construct

```
new
def abc
  if xx > 0 then
    abc = 33
  else
    abc = 11
  end_if
end
set xx = 1
print abc
set xx = -1
print abc
```

The displayed value of **abc** in Example 4.12 depends on the set value of **xx**. You should experiment with different test symbols (e.g., replace > with <).

Until now, our *FISH* programs have been invoked from *FLAC3D*, either by using the **PRINT** command, or by giving the name of the function on a separate line of *FLAC3D* input. It is also possible to do the reverse — that is, to give *FLAC3D* commands from within a *FISH* function. Most valid *FLAC3D* commands can be embedded between the following *FISH* statements.

COMMAND
ENDCOMMAND

There are two main reasons for sending out *FLAC3D* commands from a *FISH* program. First, it is possible to use a *FISH* function to perform operations that are not possible using the pre-defined variables that we already discussed. Second, we can control a complete *FLAC3D* run with *FISH*. As an illustration of the first use of the **COMMAND** statement, we can write a *FISH* program to install a number of cable elements at different depths in a material. When many cable elements are required, it becomes tedious to type many separate **SEL cable** commands, each with different grid values. However, with *FISH*, we can send out the commands from within a loop and assign the location of the cable ends automatically each time around the loop, as illustrated in Example 4.13.

Example 4.13 Automated placing of cable elements

```
new
gen zone brick size 10 3 5
def place_cables
    loop n (1,5)
        z_d = float(n) - 0.5
        command
            sel cable beg 0.0,1.5,z_d end 7.0,1.5,z_d nseg 7
        end_command
     end_loop
end
place_cables
plot grid sel geom red
```

After entering these statements, you should do a printout and plot of the cable data to verify that five cables have been created, and that they are located at the appropriate positions in the grid. In the example, we use variable **z_d** as a parameter in the function **place_cables**; **z_d** is the z-coordinate of the endpoints of each cable.

We can modify this example to perform a construction sequence of excavation and installation of cables. This illustrates the second use of **COMMAND**. We use the **FREE** and **SOLVE** commands to "excavate" the boundary plane at $x = 0$ in five steps. At the end of each step, we install a row of three cables and then excavate the next section of the boundary.

Example 4.14 Sequence of excavation and cable placement

```
new
gen zone brick size 10 3 5
mod mohr
prop bulk 1e8 shear .3e8 fric 35
prop coh 1e3 tens 1e3
ini dens 1000
set grav 0,0,-10
fix x y z range z -.1 .1
fix y     range y -.1 .1
fix y     range y 2.9 3.1
fix x     range x -.1 .1
fix x     range x 9.9 10.1
set large
hist unbal
solve
save cab_str.sav
ini xdis 0 ydis 0 zdis 0
hist gp xdisp 0,1,5
def place_cables
```

```
    loop n (1,5)
        z_d = 5.5 - float(n)
        z_t = z_d + 0.5
        z_b = z_d - 0.5
        command
            free x range  x -.1,.1  z z_b,z_t
            solve
            sel cable beg 0.0,0.5,z_d end 7.0,0.5,z_d nseg 7
            sel cable beg 0.0,1.5,z_d end 7.0,1.5,z_d nseg 7
            sel cable beg 0.0,2.5,z_d end 7.0,2.5,z_d nseg 7
            sel cable prop emod 2e10 ytension 1e8 xcarea 1.0 &
                gr_k 2e10 gr_coh 1e10 gr_per 1.0
        end_command
     end_loop
end

place_cables

save cab_end.sav
plot sketch sel cable force red
```

We have now covered some of the aspects of the *FISH* language and how it interacts with *FLAC*^{3D}. A complete guide to the language is contained in Section 2 in the ***FISH* volume**, detailed information on *FISH* language names is given in Section 2 in the ***FISH* volume**, and some examples are provided in Section 3 in the ***FISH* volume**.

5 MISCELLANEOUS

5.1 *FLAC3D* Runtime Benchmark

FLAC3D has been tested on a number of different computers. The calculation rates are compared here for a 125-zone model of elastic material subject to uniaxial loading. The model is run for 50,000 steps, and the rate is calculated by a *FISH* function. The data file is given in Example 5.1, and Table 5.1 summarizes the calculation rates for different computers.

Example 5.1 Benchmark data file — "TIMING.DAT"

```
def rate
   rate = (t1 - t0) / 6250.0
end
def time0
   t0 = clock / 100.0
end
def time1
   t1 = clock / 100.0
end
gen zone brick size 5,5,5
model elas
prop bulk 1e8 shear 1e7
fix y range y -0.1 0.1
apply syy -1.0e6 range y 4.9,5.1
time0
step 50000
time1
print rate
return
```

Table 5.1 FLAC^{3D} runtime calculation rates

Computer	Processor	speed	sec / zone / 1000 steps	Operating System
GATEWAY GP6-450	Pentium II	.45 GHz	0.0325760	2000
x86 PC	AMD Athlon 1600+	1.3 GHz	0.0226320	2000
HP Pavilion ze5300	Pentium 4	2.4 GHz	0.0091104	XP
GATEWAY 500X	Pentium 4	2.26 GHz	0.0079920	2000
GATEWAY 500X	Pentium 4	2.4 GHz	0.0072608	2000
GATEWAY e-Series	Pentium 4	2.8 GHz	0.0061056	2000
Dell Optiplex GX270	Pentium 4	3.0 GHz	0.0060352	2000
GATEWAY 4520	Pentium M	1.5 GHz	0.0059952	XP
DELL Inspiron 2200	Pentium M	1.5 GHz	0.0058640	XP

5.2 Error Reporting

Although *FLAC3D* has been tested extensively, it is almost impossible to test all available combinations of options in a code as complex as *FLAC3D*. For this reason, some errors may have evaded our notice. If you discover a genuine bug, please let us know as soon as possible so that we may correct it.

5.2.1 Reporting via the Internet

Itasca's current Internet e-mail address is

software@itascacg.com

Please include the same information requested on the error notification form (in Section 5.2.2), followed by the contents of your data file.

5.2.2 Reporting via Fax

A sample form for you to copy and mail or fax to us is given on the next page. Please fill out the form completely, as this is the minimum information we will need to find and correct the error. The sample file should, if possible, contain the minimum number of commands necessary to produce the error. We may have to contact you for further information if we are unable to duplicate the error. Be aware that it is always possible that the error is peculiar to your hardware, making it impossible for us to duplicate.

5.3 Technical Support Service

Itasca and its offices and agents will provide telephone support, at no cost, to assist code owners with the installation of Itasca codes on their computer systems. Additionally, general assistance may be provided to aid the owner in understanding the capabilities of the various features of the code. However, no-cost assistance is *not* provided for help in applying an Itasca code to specific user-defined problems.

Questions should, in the first instance, be directed to the office or agent where *FLAC3D* was purchased.

ERROR NOTIFICATION FORM

Found by: _____

_____

Phone: _____ Fax: _____

Email: _____

Computer: _____ RAM: _____

***FLAC3D* Data**

Serial No.: _____ Version* _____

Options: _____

Description:

* Type **PRINT version** to report your complete version number

---

Please attach a sample input file that produces the error.

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URS

Washington TRU Solutions LLC

RES:12:179
UFC:5822.00

INTER-OFFICE CORRESPONDENCE

DATE: September 4, 2012

FROM: R. F. Kehrman LOCATION: Regulatory Compliance

TO: R. R. Chavez LOCATION: Regulatory Compliance

SUBJECT: REVISED CALCULATIONS TO SUPPORT PANEL CLOSURE

Attached is a paper detailing the information needed to evaluate Panel Closure performance. The paper establishes that the compliance point for Panel Closure is the WIPP Site Boundary and assumes an individual resides at the point of greatest concentration. The risk level to this receptor is one excess cancer death in one million or 10^{-6}. This is consistent with the design criteria in the WIPP Permit (Permit Attachment G1, Section 1.3.2.)

The paper assumes that the repository is filled to capacity. That is, risk is calculated when all panels are filled and closed except for Panel 10, which is filled, but not yet closed. This approach is consistent with the original Panel Closure Design submitted in the original Permit Application.

One major difference from the original application is the recalculation of the VOC source term. While the original modeling relied on samples from 930 drums to TRU mixed waste, the current calculation uses over 130,000 headspace measurements made under the Permit, primarily before October 2006. The calculation of the revised source term is included with the Attachment.

Another difference is that I revised the number of containers per room and the filter diffusion rates to reflect the composite of the disposed waste in Panels 1 through 5.

My calculations are documented in the attached paper. I have updated these calculations to accommodate the most recent EPA recommended risk factors and to correct the exposure frequency and duration for non-waste workers on the surface. Previously, these exposure factors were treated as the same as those for members of the public. I also changed the number of containers in the previous version of the paper from 4,800 to 6,050 per room to reflect the number of filters emitting VOCs. This was necessary since many containers have more than one filter.

For convenience, I have also attached my spreadsheet. The last page of the spreadsheet evaluates the effects of leakage through closed panels. Panels can tolerate a leakage equivalent to about 2,000 times the gas generation rate of 0.5 moles/drum/year. There is a leakage rate that will make compliance difficult. This appears to be on the order of 50 cubic feet per minute.

The attached information may be useful to the Panel Closure design team in that it provides the methodology for determining risk consistent with the RCRA regulations and our original Permit Application.

If you have any questions, please call me at 234-7210.

dg

Attachments

cc: RES Managers ED
T. Klein ED

ATTACHMENTS:

ESTABLISHING VOLATILE ORGANIC COMPOUND LIMITS FOR THE PANEL CLOSURE DESIGN
by R. F. Kehrman

RECALCULATION OF THE VOLATILE ORGANIC COMPOUND SOURCE TERM

CALCULATIONS TO SUPPORT PANEL CLOSURE DESIGN PAPER 8 29 12 Documented (Excel Spread Sheet)

ATTACHMENT 1

ESTABLISHING VOLATILE ORGANIC COMPOUND LIMITS FOR THE PANEL CLOSURE DESIGN

by

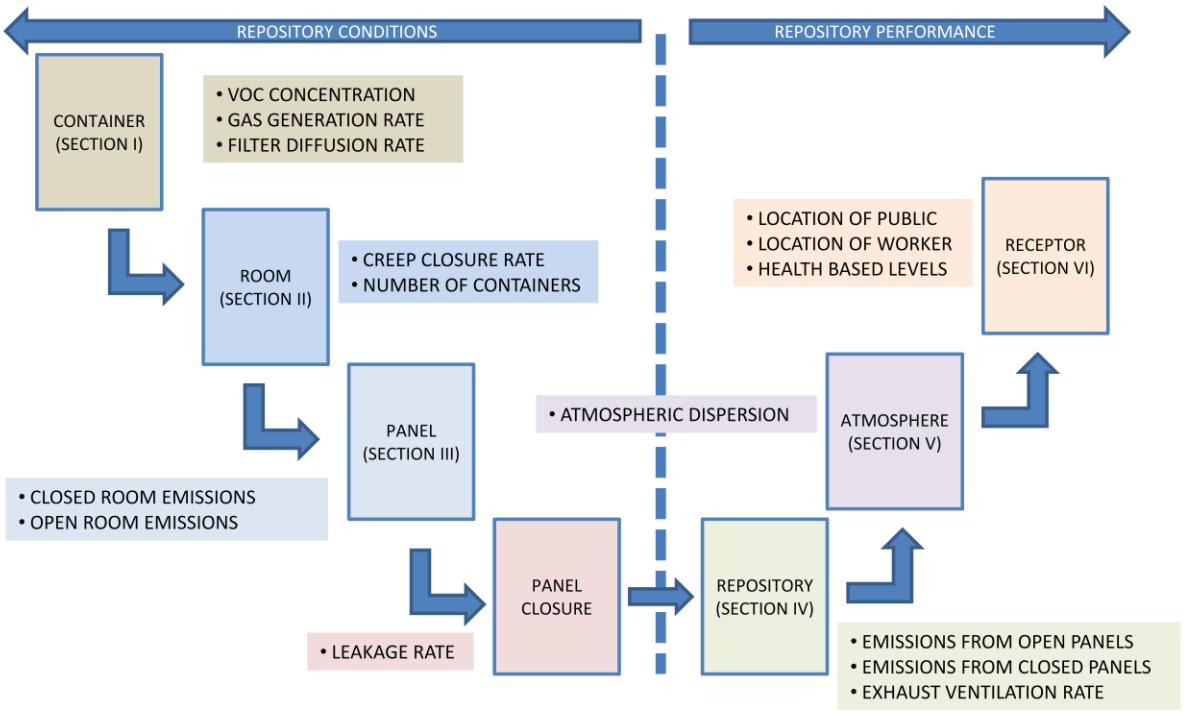
Robert F Kehrman

ESTABLISHING VOLATILE ORGANIC COMPOUND LIMITS FOR THE PANEL CLOSURE DESIGN

R. F. Kehrman

Figure 1 is a block diagram of the elements that go into preparing a risk model to demonstrate operational impacts due to emissions from the Waste Isolation Pilot Plant repository. The goal of this discussion is to provide information needed to specify the design of the Panel Closure which will serve to assure the performance standards to the right on the diagram are met for the conditions in the repository shown on the left in Figure 1. When the original Part B Permit Application for the Waste Isolation Pilot Plant (WIPP) (U. S. Department of Energy, 1996 a) facility was submitted in 1996, one of the design parameters for Panel Closure was that "the panel closure system shall limit the migration of [volatile organic compounds] VOCs to the compliance point so that compliance is achieved by at least one order of magnitude." This criterion has been changed for the current design to only require compliance without an additional compliance margin. The following discusses each element in the order indicated by the Roman Numerals on the Figure.

FIGURE 1: Elements of the Waste Isolation Pilot Plant Air Exposure Pathway



I. Container

VOC CONCENTRATION Information needed on the container scale for air dispersion modeling is the average concentration of VOCs in the headspace of the container which defines the release source term and the gas generation rate which is a driving force to move VOCs from closed rooms and panels into the repository ventilation system. The VOC source term used for the original Panel Closure design effort was developed based on a limited sampling program conducted in Idaho and at Rocky Flats. Subsequent

to that time, a weighted average source term was developed using the same data, however, a weighting process was developed to accommodate the wide variety of waste forms and to weight them in accordance with their prevalence. The process for developing the weighted average source term is described in Appendix C2 of the 1996 Permit Application (U. S. Department of Energy, 1996 a). The results are summarized in Table 1. In 2010, the source term was revised using the same methodology; however, over 130,000 headspace gas measurements were available (Kehrman, 2011). The revised source term is shown in Table 1. The values in Table 1 represent the average concentration that would be expected in a filled, closed room.

TABLE 1: TRU Waste VOC Source Term

Constituent	Original Weighted Average (ppmv)	Revised Weighted Average (ppmv)
ACETONE	79.8	53.1
BENZENE	9.3	4.3
BROMOFORM	9.4	1.8
BUTANOL	78.1	13.8
CARBON DISULFIDE	---	10.5
CARBON TETRACHLORIDE	375.5	921.5
CHLOROBENZENE	12.5	2.7
CHLOROFORM	25.3	16.1
CYCLOHEXANE	27.5	10.8
1,1-DICHLOROETHANE	10.2	9.9
1,2-DICHLOROETHANE	9.1	3.8
1,1-DICHLOROETHYLENE	11.5	12.9
CIS-1,2-DICHLOROETHYLENE	9.0	3.9
TRANS-1,2-DICHLOROETHYLENE	---	4.1
ETHYL BENZENE	11.6	3.6
ETHYL ETHER	13.3	4.8
METHANOL	213.0	71.3
METHYL CHLORIDE	---	15.6
METHYLENE CHLORIDE	368.5	36.0
METHYL ETHYL KETONE	63.7	13.8
METHYL ISOBUTYL KETONE	79.0	12.4
1,1,2,2-TETRACHLOROETHANE	9.4	4.8
TETRACHLOROETHYLENE	9.4	5.1
TOLUENE	19.4	12.2
1,1,1-TRICHLOROETHANE	317.1	739.8
TRICHLOROETHYLENE	25.1	51.2
1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE	33.0	208.9
1,2,4-TRIMETHYLBENZENE	12.2	2.6
1,3,5-TRIMETHYLBENZENE	8.6	3.2
M,P-XYLENE	19.3	6.5
O-XYLENE	16.0	3.8

GAS GENERATION Appendix D11 of the 1996 Permit Application (U. S. Department of Energy, 1996 a) includes information on gas generation by WIPP waste. Of the gas-generating mechanisms described in Appendix D11, microbial degradation will contribute the most to the generation rate during the time periods of interest. The best estimate for gas generation from microbial degradation under humid conditions is 0.1 moles of gas per drum per year.

Although Appendix D11 states that the maximum expected value for any one drum of waste is 0.4 moles per drum per year, the lowest expected value for any one drum is 0 moles per drum per year. A discussion of the relationship between gas generation, brine inflow, and creep closure can be found in Section I-1e(4). In reality, under the conditions that will initially exist in a closed panel, the predominant degradation mechanisms may consume gas at a rate faster than it is produced. This outcome is a function of the availability of nutrients to sustain microbial activities. Indications of gas consumption activities are in Francis and Gillow (Francis, A.J. and J.B. Gillow, 1994), where they reported 200-day experiments (see Appendix D11). These data are summarized in Table 2.

TABLE 2: TRU Waste Container Gas Generation Rates Due to Microbial Degradation

	High	Low	Expected
Gas-Generation Rate moles/drum/year	0.4	0.0	0.1

FILTER DIFFUSION RATE The rate at which VOCs will be emitted from containers is a function of the diffusion rate for the individual filter on the containers. These filters are placed on every container to prevent the buildup of hydrogen as the result of radiolysis. Diffusion is relevant for open rooms only. Closed rooms are assumed to be in equilibrium with the average VOC concentration in the containers. Container filters are specified with a hydrogen diffusion rate. The methodology for calculating the VOC diffusion rate based on the hydrogen rate is given in Chapter 5 of the 1996 No-Migration Variance Petition (U. S. Department of Energy, 1996 b).

At the time the original documents were prepared, the number of filters being used was limited to two. Now there are a large number of filters in use. Since filter diffusivity is a parameter that is tracked in the WIPP Waste Data System, filter diffusion rates were compiled as shown in Table 3. These data yield an average filter H_2 diffusion rate for the repository of 1.25×10^{-5} mole/s/mole fraction/drum.

Table 3: Compilation of Filter H_2 Diffusivity for Disposed Waste (Panels 1 through 5) (mole/s/mole fraction)

Panel	Room	Inner Container Count	Outer Container Count	Outer Container Filter Count	Summation of Filter Diffusivity	Diffusivity/Filter	Diffusivity/Outer Container
1	7	9953	9953	10187	3.12E-02	3.06E-06	3.14E-06
1	6	2392	2393	2441	7.72E-03	3.16E-06	3.23E-06
1	5	2403	2404	2427	7.09E-03	2.92E-06	2.95E-06
1	4	2484	2484	2523	7.97E-03	3.16E-06	3.21E-06
1	3	10691	10691	10911	3.31E-02	3.03E-06	3.09E-06
1	2	8368	8368	9115	2.61E-02	2.86E-06	3.12E-06
PANEL TOTAL		**3737**	**3121**	**3975**	**1.47E-02**	**3.70E-06**	**4.71E-06**
2	7	7111	5158	7455	2.85E-02	3.82E-06	5.53E-06
2	5	6965	4219	7115	3.18E-02	4.47E-06	7.55E-06
2	3	6610	5061	7102	3.26E-02	4.58E-06	6.43E-06
2	2	6727	4981	6967	3.93E-02	5.64E-06	7.88E-06
2	1	2179	1785	2214	3.18E-02	1.43E-05	1.78E-05
PANEL TOTAL		**42831**	**29770**	**44596**	**2.29E-01**	**5.13E-06**	**7.69E-06**
3	7	6022	1599	5657	4.91E-02	8.67E-06	3.07E-05
3	6	6678	2399	3713	4.37E-02	1.18E-05	1.82E-05
3	4	6693	3336	4548	5.33E-02	1.17E-05	1.60E-05
3	3	6476	2857	4501	5.06E-02	1.12E-05	1.77E-05

Panel	Room	Inner Container Count	Outer Container Count	Outer Container Filter Count	Summation of Filter Diffusivity	Diffusivity/Filter	Diffusivity/Outer Container
3	2	6588	2734	4300	5.23E-02	1.22E-05	1.91E-05
3	1	4112	2260	3256	3.82E-02	1.17E-05	1.69E-05
PANEL TOTAL		**42000**	**17760**	**28932**	**3.31E-01**	**1.14E-05**	**1.86E-05**
4	7	6063	2890	4574	5.09E-02	1.11E-05	1.76E-05
4	6	6073	3604	4802	6.40E-02	1.33E-05	1.78E-05
4	5	6621	4137	5728	7.21E-02	1.26E-05	1.74E-05
4	4	5870	3945	4928	7.61E-02	1.54E-05	1.93E-05
4	3	5673	4264	4784	8.16E-02	1.70E-05	1.91E-05
4	2	5535	4687	5236	8.93E-02	1.71E-05	1.91E-05
4	1	3545	3035	3280	5.72E-02	1.74E-05	1.89E-05
PANEL TOTAL		**39380**	**26562**	**33332**	**4.91E-01**	**1.47E-05**	**1.85E-05**
5	7	6512	5576	6169	1.07E-01	1.74E-05	1.92E-05
5	6	6568	5945	6442	1.19E-01	1.85E-05	2.00E-05
5	5	6332	5442	6023	1.03E-01	1.71E-05	1.89E-05
5	4	6524	3972	4423	6.85E-02	1.55E-05	1.73E-05
5	3	7223	4331	5120	8.31E-02	1.62E-05	1.92E-05
5	2	7088	5195	6370	1.05E-01	1.66E-05	2.03E-05
5	1	5007	3997	4449	7.81E-02	1.76E-05	1.96E-05
PANEL TOTAL		**45254**	**34458**	**38996**	**6.65E-01**	**1.70E-05**	**1.93E-05**

II. Room

CREEP CLOSURE RATE The average creep closure rate will result in a reduction of the panel void volume of 812 m^3 per year for each panel. Calculations in Appendix D9 of the 1996 Permit Application (U. S. Department of Energy, 1996 a) convert this rate at which air is "squeezed" out of the room to an equivalent gas generation rate of 0.4 moles/drum/year. This is depicted in Table 4.

TABLE 4: Effective Gas Generation Rate

Gas-Generation Rate	moles/drum/year
Microbial Degradation	0.1
Creep Closure	0.4
Total Effective Gas Generation Rate	0.5

NUMBER OF CONTAINERS The original assumption was that each Panel would contain 81,000 containers. This number is important because emissions are related to the filter diffusivity associated with each container; therefore the number of filters emitting VOCs to a room that is being filled is part of the calculation of releases. Closed rooms are unventilated and are conservatively assumed to be at the average concentration of the containers that were disposed and emissions are only related to the gas generation rate and creep closure rate (i.e., equivalent gas generation rate). Table 5 is a compilation of the actual distribution of containers in the five filled panels and Room 7 of Panel 6. These data indicate that a reasonable average for the number of containers per room is about 4,770. Using the ratio of total filters to total containers in Table 3, this number of containers contains about 6,050 filters per room.

TABLE 5: Number of Containers Disposed in Each Panel

Container Type	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6	Container Total
55-gallon drum	38,139	23,865	8,394	12,858	21,255	3,798	108,309
Standard waste box	1,239	3,176	1,730	1,405	2,200	594	10,344
Ten drum overpack	35	1,451	2,227	1,048	788	103	5,652
85-gallon drum	2	0	0	3	0	0	5
100-gallon drum	0	1,278	5,409	11,050	9,951	879	28,567
Standard large box 2	0	0	0	0	0	2	2
Panel Total	39,415	29,770	17,760	26,364	34,194	5,376	152,879
Rooms filled in Panel	4.8	6.6	6.7	6.7	6.7	1.0	32.0
Containers per room	8,211	4,580	2,691	3,995	5,181	5,376	4,777

Note: A room is considered to have 567 linear feet of disposal space. Since Room 1 only has 367 feet (i.e., no waste is placed in the intake or exhaust drifts, a full panel in Table 5 is considered to have 6.7 Rooms

III. Panel

Emission rates from filled rooms depend on whether or not the room is open to the ventilation system. Emissions from open rooms depend on the emission rates through filters and the ventilation rate; emissions from closed rooms depend on the gas generation rate and the volumetric reduction in room volume due to creep closure. For Panel Closure modeling, the most conservative condition is when a panel has six filled and closed rooms and one filled room that remains open. Note that it is conservatively assumed that the average drum headspace concentrations serve as a constant source of VOCs.

OPEN ROOM EMISSIONS The open room emission rate is dependent on the number of drums that have been emplaced in the room and the diffusion of VOCs across the drum vent filters. Assuming a continuous fresh air flow across the filters, VOCs will diffuse from the drums at a rate that is dependent on the concentration gradient across the filters and the diffusion properties of the VOCs. The open room emission rate is calculated using the equation

where

$AORE_{VOC}$ = average open room VOC emission rate, mole/room/year
ADE_{VOC} = average drum VOC emission rate, mole/drum/year
nD = number of drums in the room, drum/room.

EMISSIONS FROM CLOSED ROOMS During the placement of waste at WIPP, as individual rooms are filled; ventilation barriers will be used to eliminate ventilation through the filled rooms and to isolate these rooms. Similarly, closure systems will be used to isolate wastes in a full panel and to remove these filled panels from ventilation. Consequently, the open panel emission rate is dependent on the number of full rooms that have ventilation barriers and the number of drums in rooms without ventilation barriers.

As described previously, VOCs will diffuse from the drums at a rate dependent on the concentration gradient across these filters. After a room is filled and the ventilation barrier is installed, the assumption is that fresh air will no longer flow across the waste drums, and VOC concentrations in the dead air

space above the filter will begin to build up and approach the concentrations in the drum headspace. Therefore, the concentration of VOCs that would be present in the filled room atmosphere would be equivalent to the average drum headspace concentration. It is conservatively assumed that the average drum headspace concentrations serve as a constant source of VOCs.

The ventilation barrier consists of low-permeability materials that restrict ventilation flow through a room. Thus, migration of VOCs past the barriers is assumed to only occur by displacement due to room volume reduction that results from creep closure and by pressurization of the room due to continued gas generation from the waste. Based on discussions above (Table 4), the total effective gas generation rate is 0.5 mole/drum/year. (Note that this equates to a flow rate of 0.067 ft^3 per minute.)

Using this effective gas generation rate for a room of containers that has the ventilation barrier in place, the closed room emission rate for each VOC is calculated as:

where

$ACRE_{VOC}$	=	average closed room VOC emission rate, mole/room/year
GR	=	effective gas generation rate, mole/drum/year
N_{drums}	=	number of drums in a room
MF_{VOC}	=	VOC mole fraction, mole/mole

IV. Repository

EMISSIONS FROM OPEN PANELS

The open panel emission rate for each VOC is based on the number of full rooms, the number of drums in the open room, and the emission rates from each type of room. This can be calculated as follows:

where

$AOPE_{VOC}$	=	average open panel VOC emission rate, mole/panel/year
$AORE_{VOC}$	=	average open room VOC emission rate, mole/room/year
$ACRE_{VOC}$	=	average closed room VOC emission rate, mole/room/year
R_o	=	number of open rooms in the open panel, 1 room/panel
R_c	=	number of closed rooms in the open panel, room/panel

EMISSIONS FROM CLOSED PANELS Volatile organic compounds will diffuse from the drums at a rate dependent on the concentration gradient across the filters. As the concentration gradient decreases, the diffusion rate of each VOC decreases. After a panel is closed, fresh air will no longer flow across the waste drums, and VOC concentrations in the air space above the filter will begin to build up and approach the concentrations in the drum headspace. Therefore, the concentration of VOCs that would be present in the panel atmosphere would be equivalent to the average drum headspace concentration.

For a closed panel of N drums, the closed panel emission rate for each VOC is calculated as:

where

$ACPE_{VOC}$ = average closed panel VOC emission rate, mole/panel/year
GR = effective gas generation rate, mole/drum/year
N_{drums} = number of drums in a panel
MF_{VOC} = VOC mole fraction, mole/mole

The emission rate from the repository can then be calculated as the sum of the open panel and closed panel rates:

where

EC_{VOC} = the emission rate for VOC in mole/year
P_O = the number of open panels
P_C = the number of closed panels

V. Atmosphere

ATMOSPHERIC DISPERSION This section presents the results of air dispersion modeling performed inside and outside the WIPP site boundary. The modeling was performed to evaluate four specific scenarios: the Boundary Public, Livingston Ridge Rancher (grazing allotment on the north side of the WIPP site), Antelope Ridge Rancher (grazing allotment on the south side of the WIPP site), and Surface Worker. The Long-Term Version of the Industrial Source Complex (ISCLT3) model, (U.S. Environmental Protection Agency, 1995), was used for the original air dispersion modeling. Concentrations were modeled in accordance with (U.S. Environmental Protection Agency, 1992) EPA (1992). Details of the modeling are described in Appendix D10 of the 1996 Permit Application. The modeling produced the air dispersion factors (ADFs) listed in the center column of Table 6. In 2010 the modeling was updated in order to use newer EPA analytical tools (AERMOD) and updated physical conditions (new buildings, three exhaust stacks) (URS Corporation, 2010). The revised ADFs are in the right column in Table 11.

TABLE 6: Air Dispersion Factors for WIPP Site Areas

Area	Original Air Dispersion Factor (ADF)	Revised Air Dispersion Factor (ADF)
WIPP Site Boundary	1.2×10^{-4}	8.78×10^{-5}
Livingston Ridge Allotment	9.8×10^{-5}	1.76×10^{-4}
Antelope Ridge Allotment	6.7×10^{-5}	6.72×10^{-4}
Training Building	1.23×10^{-2}	1.14×10^{-2}

VI. RECEPTOR

LOCATION OF PUBLIC AND WORKERS Three classes of exposed individuals (receptors) were presented in Appendix D9 of the 1996 Permit Application (U. S. Department of Energy, 1996 a); a surface worker, an underground worker, and a member of the public. The compliance point for the surface worker is the Training Building. The compliance point for the underground worker is downwind from the waste during initial emplacement in a room. The compliance point for the member of the public is the nearest point outside the controlled area where ranch hands may be working.

HEALTH BASED LEVELS The environmental performance standard proposed for the workers was the Occupational Safety and Health Administration (OSHA) 8-hour time weighted average (TWA) for each compound. The environmental performance standards proposed for the public were 10^{-6} for Class A and B2 carcinogens and 10^{-5} for Class C carcinogens and a Hazard Quotient of 1 for non-carcinogens. These are summarized in Table 7.

TABLE 7 Risk Levels Proposed in the WIPP RCRA Part B Permit Application in 1996 (Appendix D9, Tables D9-5, -6, -8, and -9)

EXPOSED CLASS	COMPLIANCE POINT	CLASS A and B2 CARCINOGENS	CLASS C CARCINOGENS	NON-CARCINOGENS
Surface Worker	Training Building	OSHA 8-HOUR TWA		
Underground Worker	Exhaust drift adjacent to filled room	OSHA 8-HOUR TWA		
Public	Controlled area fence line	10^{-6}	10^{-5}	1

These risk levels were not used by the New Mexico Environment Department (NMED) to develop the standards that eventually were included in the Hazardous Waste Facility Permit (Permit) that was issued in 1999. The NMED reduced the standards to only two receptors: the Underground Worker and the Surface Worker. These standards which are reflected in the VOC limits in the Permit are listed in Table 8.

TABLE 8 Risk Levels Imposed by the NMED in the Permit in 1999

EXPOSED CLASS	COMPLIANCE POINT	CLASS B2 CARCINOGENS	CLASS C CARCINOGENS	NON-CARCINOGENS
Surface Worker	Training Building	10^{-5}	10^{-5}	1
Underground Worker	Exhaust drift adjacent to filled room	OSHA IDLH or LFL	OSHA IDLH or LFL	OSHA IDLH or LFL
Public	Controlled area fence line	Bounded by Surface Worker Limit		

IDLH = Concentration that is immediately dangerous to life and health
LFL = Lower flammability limit

The NMED translated these risk levels into specific concentrations of concern (Cs of C) for each VOC and published them as repository limits and room-based limits. Action levels associated with these limits were also established in the Permit. The NMED modeled cumulative risk and hazard due to exposure to all compounds simultaneously. This required them to develop a process for translating the total risk into a specific risk associated with each VOC involved. The rationale used is documented in a memorandum to file issued by the NMED in 1998 (Zappe, 1998) and in written testimony submitted at the 1999 Permit Hearing (New Mexico Environment Department, 1999). The NMED accepted the Permittees limited list of analytes (which constituted 99 percent of the risk or hazard) and apportioned risk among the nine compounds. This risk apportionment has been modified over time. The most recent apportionment is shown in Table 8, along with the percentage of the total risk assigned to the compound. Table 9 focuses on repository limits since room-based limits are now monitored separately using a Disposal Room VOC Monitoring System.

TABLE 9 Repository Limits for Specific Compounds and their Related Risk Portions

VOC OF INTEREST	TYPE	LIMIT IN PERMIT (ppbv)	ASSOCIATED RISK	ASSOCIATED HAZARD	PERCENT OF TOTAL RISK	PERCENT OF TOTAL HAZARD
Carbon Tetrachloride	C	960	4.3E-06		44.6	
Chlorobenzene	N	220		2.4E-03		88.5
Chloroform	C	180	2.4E-06		24.9	
1,1-Dichloroethene	N	100		2.3E-04		8.7
1,2-Dichloroethane	C	45	5.6E-07		5.8	
Methylene Chloride	C	1,930	1.9E-08		0.2	
1,1,2,2-Tetrachloroethane	C	50	2.3E-06		24.5	
Toluene	N	190		1.2E-04		4.4
1,1,1-Trichloroethane	N	590		7.6E-05		2.8
		TOTAL	9.6E-6	2.7E-3	100 %	100 %

C = Carcinogen
N = Non-carcinogen

The limit represents a concentration measured in the underground at Station VOC-A.

In the design of the current Panel Closure, performance criteria were established in the form of health based levels (HBLs) that could be applied at any appropriate point of compliance (the Land Withdrawal boundary was used in the Panel Closure design document titled *Conceptual Design for Operational Phase Panel Closure Systems,* Appendix I1 of the 1996 Permit Application (U. S. Department of Energy, 1996 a)). This approach was driven by the no-migration standard found in 40 CFR 268 which applied at the time. The methodology for calculating HBLs that was used was described in the proposed ruling on Subpart S, Corrective Action for Solid Waste Management Units at Hazardous Waste Management Facilities (Federal Register, 1990).

In the proposed 40 CFR 264 Subpart S, the action levels, or HBLs, are calculated given the exposure assumptions for the media of interest and the toxic or carcinogenic effects for each hazardous constituent. The proposed Subpart S recommended that continuous lifetime exposure duration of 70 years be assumed; however, because the operational/closure phase of the facility is 35 years, a 35-year exposure is assumed in determining HBLs for the assessment. The assumed risk levels for carcinogens are 10^{-6} for Class A or B2 carcinogens and 10^{-5} for Class C carcinogens. In determining HBLs for non-carcinogens, the chemical-specific reference concentrations are used, which estimate the daily exposure an individual can experience without appreciable risk of adverse effects during a lifetime. Because the guidelines refer to excess health risks, the calculated HBLs are applied only to potential migration of hazardous constituents from the disposed waste.

The methodology for determining HBLs is derived from the EPA's Risk Assessment Guidance for Superfund (U. S. Environmental Protection Agency, 1989). Although the EPA provides alternate "standard default exposure factors," exposure assumptions outlined in the proposed Subpart S were used.

To calculate the HBLs in air for carcinogens with an absorption factor conservatively assumed to be

equal to 1, the following equation is used:

$$\text{HBL} = \frac{\text{TRL} \times \text{AT} \times \text{EF} \times \text{ED}}{\text{IUR}}$$

where:

HBL = HBL for carcinogen, $\mu g/m^3$
TRL = target risk level (TRL), 10^{-5} (Class C) or 10^{-6} (Class A and B2)
AT = averaging time, 25,550 days for carcinogens (70 years × 365 days/year)
EF = exposure frequency, 365 days/year
ED = exposure duration, 35 years
IUR = inhalation unit risk factor (IUR) for carcinogen, $(\mu g/m^3)^{-1}$

For non-carcinogens, the HBLs in air are calculated as follows:

$$\text{HBL} = \frac{\text{THQ} \times \text{RfC} \times \text{AT}_P \times \text{AT}_w \times \text{EF}_p \times \text{EF}_w \times \text{ED}_p \times \text{ED}_w}{\text{AT}_P \times \text{AT}_w \times \text{EF}_p \times \text{EF}_w \times \text{ED}_p}$$

where:

HBL = HBL for non-carcinogen, $\mu g/m^3$
THQ = target hazard quotient (THQ), assumed to be 1
RfC = reference concentration for the non-carcinogen, mg/m^3
AT_P = averaging time, 12,775 days for non-carcinogenic exposure for public (ED × 365 days/year)
AT_w = averaging time, 87,600 for non-carcinogenic exposure for non-waste surface workers based on exposure duration)
EF_p = exposure frequency for public, 365 days/year
EF_w = exposure frequency for non-waste surface worker, 1,920 hours/year
ED_p = exposure duration for public, 35 years
ED_w = exposure duration, non-waste surface worker, 10 years.

The derivation of both of these equations can be found in DOE/CAO-96-2160, Chapter 5 (U. S. Department of Energy, 1996 b).

The toxicity measures (i.e., IURs and reference concentrations [RfCs]) used in the calculations are presented in Table 10. The main source of these data is the EPA Integrated Risk Information System (IRIS); the data in the IRIS system are updated monthly and are reviewed and approved by the EPA. Values not in the IRIS system are based on EPA recommended sources. This list has been updated from the original study in the Permit Application.

TABLE 10: EPA Risk Factor for Volatile Organic Compounds (as of 4/2/2012)

VOLATILE ORGANIC COMPOUND	Inhalation Unit Risk (IUR) $(ug/m^3)^{-1}$	Reference concentration (RfC) mg/m^3
Acetone	---	3.10E+01
Benzene	7.80E-06	3.00E-02
Bromoform	1.10E-06	---
Butanol	---	6.00E-02
Carbon Disulfide	---	7.00E-01
Carbon Tetrachloride	6.00E-06	1.00E-01
Chlorobenzene	---	5.00E-02
Chloroform	2.30E-05	9.80E-02
Cyclohexane	---	6.00E+00
1,1-Dichloroethane	1.60E-06	---
1,2-Dichloroethane	2.60E-05	7.00E-03
1,1-Dichloroethylene	---	2.00E-01
cis-1,2-Dichloroethylene	---	---
trans-1,2-Dichloroethylene	---	6.00E-02
Ethyl Benzene	2.50E-06	1.00E+00
Ethyl Ether	---	---
Methanol	---	4.00E+00
Methyl Chloride	---	9.00E-02
Methylene Chloride	1.00E-08	6.00E-01
Methyl Ethyl Ketone	---	5.00E+00
Methyl Isobutyl Ketone	---	3.00E+00
1,1,2,2-Tetrachloroethane	5.80E-05	---
Tetrachloroethylene	2.60E-07	4.00E-02
Toluene	---	5.00E+00
1,1,1-Trichloroethane	---	5.00E+00
Trichloroethylene	4.10E-06	2.00E-03
1,1,2-Trichloro-1,2,2-Trifluoroethane	---	3.00E+01
1,2,4-Trimethlybenzene	---	7.00E-03
1,3,5-Trimethylbenzene	---	---
m,p-Xylene	---	1.00E-01
o-Xylene	---	1.00E-01

--- No data/not classifiable/inadequate data

In calculating the HBLs for both carcinogens and non-carcinogens, exposure duration of 35 years was assumed for the public and 10 years for the non-waste surface worker. For non-carcinogens, the averaging time is equivalent to the exposure duration; therefore, this assumption has no effect on the calculated value of the HBL. This assumption is reasonable, because waste emplacement is expected to last 25 years, and a ten-year closure period follows. For the non-waste surface worker, the assumption is based on an employment period of 10-years at 40 hours per week for 48 weeks per year in the Training Building. The averaging time for carcinogens is 70 years, consistent with EPA guidance. The calculated HBL for each indicator VOC in air is listed in Table 11. Values are shown for two risk levels.

The public risk is 10^{-6} and the surface worker risk is 10^{-5}. The original Panel Closure design uses the public risk values.

TABLE 11: Health Based Levels for various Risk Scenarios

VOLATILE ORGANIC COMPOUND	HEALTH BASED LEVELS ($\mu g/m^3$)			
	CARCINOGENIC		NON-CARCINOGENIC	
	10^{-6} RISK LEVEL (Public)	10^{-5} RISK LEVEL (Surface Worker)	Public	Surface Worker
Acetone	---	---	31,000	141,438
Benzene	0.26	41	30	137
Bromoform	1.82	290	---	---
Butanol	---	---	60	274
Carbon Disulfide	---	---	700	3,194
Carbon Tetrachloride	0.33	53	100	456
Chlorobenzene	---	---	50	228
Chloroform	0.09	14	98	447
Cyclohexane	---	---	6,000	27,375
1,1-Dichloroethane	1.25	200	---	---
1,2-Dichloroethane	0.08	12	7	32
1,1-Dichloroethylene	---	---	200	913
cis-1,2-Dichloroethylene	---	---	---	---
trans-1,2-Dichloroethylene	---	---	60	274
Ethyl Benzene	0.80	128	1,000	4,563
Ethyl Ether	---	---	---	---
Methanol	---	---	4,000	18,250
Methyl Chloride	---	---	90	411
Methylene Chloride	200	31,938	600	2,738
Methyl Ethyl Ketone	---	---	5,000	22,813
Methyl Isobutyl Ketone	---	---	3,000	13,688
1,1,2,2-Tetrachloroethane	0.03	6	---	---
Tetrachloroethylene	7.69	1,228	40	183
Toluene	---	---	5,000	22,813
1,1,1-Trichloroethane	---	---	5,000	22,813
Trichloroethylene	0.49	78	2	9
1,1,2-Trichloro-1,2,2-Trifluoroethane	---	---	30,000	136,875
1,2,4-Trimethlybenzene	---	---	7	32
1,3,5-Trimethylbenzene	---	---	---	---
m,p-Xylene	---	---	100	456
o-Xylene	---	---	100	456

VII. SAMPLE CALCULATION

Table 12 provides the expected emission rates for the following:

- Drum
- Open room
- Closed room
- Open panel (with 6 filled rooms and 1 open room)
- Closed panel
- Repository (9 closed panels, one open panel with 6 closed rooms and one open room)

The following assumptions are used:

- Recalculated source term (Table 1)
- Containers have filters with the repository average H_2 diffusion rate of 1.25×10^{-5} mole/s/mole fraction installed (Table 3)
- Effective gas generation rate of 0.5 mole/drum/year (Table 4)
- 4,777 drums containing 6,050 filters per room (Table 5)
- There is no ventilation leakage through closed areas.

The term "average" is used to indicate that the source term is the weighted average concentration. The term "maximum" is used to describe the repository emission rate, since the calculation is for a full repository with one open panel containing a full open room and 6 filled rooms that are isolated from the ventilation.

Concentrations at the receptor points on the surface can be calculated by applying the ADFs in Table 6. The results are shown in Table 13 as a fraction of the HBLs for each compound. The totals show that the HBLs are not exceeded for a repository filled with TRU mixed waste at the weighted average VOC concentrations. The total risk line in Table 13 can be viewed as the compliance margin for each receptor location.

TABLE 12: Annual Emission Rates for Drums, Rooms, Panels, and the Repository

COMPOUND	AVERAGE DRUM EMISSION RATE (mole/drum/ year)	AVERAGE OPEN ROOM EMISSION RATE (mole/room/ year)	AVERAGE CLOSED ROOM EMISSION RATE (mole/room/ year)	AVERAGE OPEN PANEL EMISSION RATE (mole/panel/ year)	AVERAGE CLOSED PANEL EMISSION RATE (mole/panel /year)	MAXIMUM REPOSITORY EMISSION RATE (moles/year)	FULL REPOSITORY CONCENTRATION AT THE EXHAUST SHAFT (ug/m^3)
Acetone	2.58E-03	15.61	0.16	16.57	1.12	26.70	0.40
Benzene	1.89E-04	1.14	0.01	1.22	0.09	2.04	0.04
Bromoform	6.24E-05	0.38	0.01	0.41	0.04	0.75	0.05
Butanol	6.01E-04	3.64	0.04	3.89	0.29	6.52	0.12
Carbon Disulfide	5.54E-04	3.35	0.03	3.55	0.04	3.89	0.08
Carbon Tetrachloride	3.74E-02	226.54	2.79	243.28	19.52	418.95	16.67
Chlorobenzene	1.04E-04	0.63	0.01	0.68	0.06	1.19	0.03
Chloroform	7.25E-04	4.38	0.05	4.68	0.34	7.75	0.24
Cyclohexane	4.50E-04	2.72	0.03	2.92	0.23	4.98	0.11
1,1-Dichloroethane	4.55E-04	2.75	0.03	2.93	0.21	4.82	0.12
1,2-Dichloroethane	1.68E-04	1.02	0.01	1.09	0.08	1.80	0.05
1,1-Dichloroethylene	6.07E-04	3.67	0.04	3.91	0.27	6.37	0.16
cis-1,2-Dichloroethylene	1.84E-04	1.11	0.01	1.18	0.08	1.93	0.05
trans-1,2-	1.93E-04	1.17	0.01	1.24	0.09	2.02	0.05

COMPOUND	AVERAGE DRUM EMISSION RATE (mole/drum/ year)	AVERAGE OPEN ROOM EMISSION RATE (mole/room/ year)	AVERAGE CLOSED ROOM EMISSION RATE (mole/room/ year)	AVERAGE OPEN PANEL EMISSION RATE (mole/panel/ year)	AVERAGE CLOSED PANEL EMISSION RATE (mole/panel /year)	MAXIMUM REPOSITORY EMISSION RATE (moles/year)	FULL REPOSITORY CONCENTRATION AT THE EXHAUST SHAFT (ug/m^3)
Dichloroethylene							
Ethyl Benzene	1.34E-04	0.81	0.01	0.88	0.08	1.56	0.04
Ethyl Ether	2.13E-04	1.29	0.01	1.38	0.10	2.29	0.04
Methanol	4.58E-03	27.70	0.22	28.99	1.51	42.59	0.35
Methyl Chloride	8.39E-04	5.08	0.05	5.36	0.33	8.34	0.11
Methylene Chloride	1.79E-03	10.81	0.11	11.47	0.76	18.33	0.40
Methyl Ethyl Ketone	6.10E-04	3.69	0.04	3.94	0.29	6.57	0.12
Methyl Isobutyl Ketone	4.60E-04	2.79	0.04	3.01	0.26	5.37	0.14
1,1,2,2-Tetrachloroethane	1.12E-04	0.68	0.01	0.73	0.06	1.25	0.05
Tetrachloroethylene	2.51E-04	1.52	0.02	1.61	0.11	2.59	0.11
Toluene	4.90E-04	2.96	0.04	3.19	0.26	5.52	0.13
1,1,1-Trichloroethane	3.01E-02	182.32	2.24	195.76	15.67	336.79	11.62
Trichloroethylene	2.14E-03	12.95	0.15	13.88	1.08	23.64	0.80
1,1,2-Trichloro-1,2,2-Trifluoroethane	9.46E-03	57.23	0.63	61.02	4.42	100.84	6.59
1,2,4-Trimethlybenzene	9.00E-05	0.54	0.01	0.59	0.06	1.09	0.03
1,3,5-Trimethylbenzene	1.11E-04	0.67	0.01	0.73	0.07	1.34	0.04
o-Xylene	1.39E-04	0.84	0.01	0.91	0.08	1.63	0.04
m,p-Xylene	2.38E-04	1.44	0.02	1.56	0.14	2.80	0.08

Table 13: Risk as a Fraction of the Health-Based Levels for Four Exposure Scenarios

COMPOUND	RISK AS A FRACTION OF THE HEALTH BASED LEVEL							
	WORKER TRAINING BUILDING		PUBLIC LIVINGSTON RIDGE		PUBLIC ANTELOPE RIDGE		PUBLIC WIPP SITE BOUNDARY	
	CARCINOGENIC	NON-CARCINOGENIC	CARCINOGENIC	NON-CARCINOGENIC	CARCINOGENIC	NON-CARCINOGENIC	CARCINOGENIC	NON-CARCINOGENIC
Acetone	---	3.23E-08	---	2.28E-09	---	8.69E-09	---	1.14E-09
Benzene	1.15E-05	3.44E-06	2.79E-05	2.42E-07	1.07E-04	9.24E-07	1.39E-05	1.21E-07
Bromoform	1.93E-06	---	4.76E-06	---	1.82E-05	---	2.38E-06	---
Butanol	---	5.20E-06	---	3.67E-07	---	1.40E-06	---	1.83E-07
Carbon Disulfide	---	2.73E-07	---	1.92E-08	---	7.35E-08	---	9.60E-09
Carbon Tetrachloride	3.57E-03	4.17E-04	8.89E-03	2.93E-05	3.39E-02	1.12E-04	4.44E-03	1.46E-05
Chlorobenzene	---	1.73E-06	---	1.22E-07	---	4.65E-07	---	6.07E-08
Chloroform	1.96E-04	6.10E-06	4.68E-04	4.30E-07	1.79E-03	1.64E-06	2.33E-04	2.14E-07
Cyclohexane	---	4.51E-08	---	3.18E-09	---	1.21E-08	---	1.59E-09
1,1-Dichloroethane	7.05E-06	---	1.74E-05	---	6.63E-05	---	8.67E-06	---
1,2-Dichloroethane	4.29E-05	1.65E-05	1.02E-04	1.16E-06	3.88E-04	4.43E-06	5.07E-05	5.79E-07
1,1-Dichloroethylene	---	2.00E-06	---	1.41E-07	---	5.37E-07	---	7.01E-08
cis-1,2-Dichloroethylene	---	---	---	---	---	---	---	---
trans-1,2-Dichloroethylene	---	2.11E-06	---	1.49E-07	---	5.69E-07	---	7.43E-08
Ethyl Benzene	3.68E-06	1.03E-07	9.08E-06	7.26E-09	3.47E-05	2.77E-08	4.53E-06	3.62E-09
Ethyl Ether	---	---	---	---	---	---	---	---
Methanol	---	2.20E-07	---	1.55E-08	---	5.93E-08	---	7.75E-09
Methyl Chloride	---	3.02E-06	---	2.13E-07	---	8.13E-07	---	1.06E-07
Methylene Chloride	1.44E-07	1.68E-06	3.54E-07	1.18E-07	1.35E-06	4.51E-07	1.77E-07	5.89E-08
Methyl Ethyl Ketone	---	6.13E-08	---	4.32E-09	---	1.65E-08	---	2.15E-09
Methyl Isobutyl Ketone	---	1.16E-07	---	8.17E-09	---	3.12E-08	---	4.08E-09
1,1,2,2-Tetrachloroethane	1.12E-04	---	3.19E-04	---	1.22E-03	---	1.59E-04	---
Tetrachloroethylene	1.03E-06	6.93E-06	2.54E-06	4.88E-07	9.69E-06	1.86E-06	1.27E-06	2.43E-07

COMPOUND	RISK AS A FRACTION OF THE HEALTH BASED LEVEL							
	WORKER TRAINING BUILDING		PUBLIC LIVINGSTON RIDGE		PUBLIC ANTELOPE RIDGE		PUBLIC WIPP SITE BOUNDARY	
	CARCINOGENIC	NON-CARCINOGENIC	CARCINOGENIC	NON-CARCINOGENIC	CARCINOGENIC	NON-CARCINOGENIC	CARCINOGENIC	NON-CARCINOGENIC
Toluene	---	6.57E-08	---	4.63E-09	---	1.77E-08	---	2.31E-09
1,1,1-Trichloroethane	---	5.81E-06	---	4.09E-07	---	1.56E-06	---	2.04E-07
Trichloroethylene	1.18E-04	1.00E-03	2.89E-04	7.07E-05	1.10E-03	2.70E-04	1.44E-04	3.53E-05
1,1,2-Trichloro-1,2,2-Trifluoroethane	---	5.49E-07	---	3.87E-08	---	1.48E-07	---	1.93E-08
1,2,4-Trimethlybenzene	---	1.21E-05	---	8.50E-07	---	3.25E-06	---	4.24E-07
1,3,5-Trimethylbenzene	---	---	---	---	---	---	---	---
m,p-Xylene	---	1.62E-04	---	1.14E-05	---	4.37E-05	---	5.71E-06
o-Xylene	---	1.12E-06	---	7.90E-08	---	3.02E-07	---	3.94E-08
Total	4.07E-03	1.65E-03	1.01E-02	1.16E-04	3.87E-02	4.44E-04	5.05E-03	5.81E-05

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ATTACHMENT 2

RECALCULATION OF THE VOLATILE ORGANIC COMPOUND SOURCE TERM

by

Robert F Kehrman

RECALCULATION OF THE VOLATILE ORGANIC COMPOUND SOURCE TERM

The volatile organic compound (VOC) source term that was used in the Resource Conservation and Recovery Act (RCRA) no- migration variance petition (NMVP)[1] and the Part B Permit Application[2] was based on the headspace gas samples taken from 930 drums of waste stored at the Idaho National Laboratory and the Rocky Flats Plant. These containers represented the entire spectrum of transuranic (TRU) waste that was expected to be shipped to the Waste Isolation Plant (WIPP) with the exception of the soils waste form. The measured concentrations were accumulated by "Waste Matrix Code Group" (WMCG), which is nomenclature used to express the physical form of the waste. The following WMCGs were used: Combustible waste, Filter waste, Graphite waste, Heterogeneous waste, Inorganic non-metal waste, Lead/cadmium metal waste, Salt waste, Soils, Solidified inorganic waste, Solidified organic waste, Uncategorized metal waste, and Unknown waste. In order to extend the data from the 930 containers to the entire inventory of WIPP-bound waste, a weighting scheme was developed. The TRU Waste Baseline Inventory Report (TWBIR) was used to determine the then current and projected inventory of TRU waste in each of the WMCGs. This information was tabulated (Table C2-2 in the NMVP Appendix WAP). Since the total volume of stored and projected waste did not add up to the approved inventory limit for the WIPP facility, the quantities were scaled up so that the total added up to the approved limit. A weighting factor was then calculated which represented the percentage of each of the WMCGs in the total (scaled inventory).

In order to calculate the source term, the average concentration of each VOC had to be weighted for each WMCG and then summed. This is represented by the following equation:

$$\bar{X} = \sum_{j=1}^{t} w_j * \bar{x}_j$$

where,

$\bar{X} = weighted\ average$
$\bar{x}_j = average\ concentration\ for\ WMCG\ j$
$w_j = weighting\ factor\ for\ WMCG\ j$
$t = number\ of\ WMCG\ s$

and $\bar{x}_j$ is calcualted by:

$$\bar{x}_j = \frac{1}{n_j} * \sum_{j=1}^{n_j} x_{jk}$$

where,

[1] DOE/CAO-96-2160 (Appendix WAP, Appendix VOC)
[2] DOE/WIPP 91-005, Rev. 6 (Appendix C2, Appendix D13)

n_j = number of samples in $WMCG\ j$
x_{jk} = analysis *k* for $WMCG\ j$.

The new calculations use over 136,000 sample results collected from TRU waste prior to shipment to the WIPP facility. These analyses were conducted in accordance with the WIPP Permit. Prior to October 2006, analyses were required on 100 percent of the containers. After this time, only representative sampling was required resulting in fewer sampled per waste stream.

The process for developing the new source term is as follows:

Step 1—a data dump of all headspace gas measurements was obtained from the WIPP Waste Information System beginning with the first shipment in 1999 through October 6, 2010. The data were provided as concentrations in parts per million by volume (ppmv) for each VOC plus hydrogen and methane for each container.

Step 2—the data were separated by year in order to provide manageable record sizes.

Step 3—measurements that were shown with a "U" flag were undetected. The values shown represent the method detection limit. These values were divided by 2 prior to including them in the total.

Step 4—each container was assigned to a WMCG based on the TRUCON code. During this process, 71 RH waste containers included in the database were removed (TRUCON codes beginning with a "3").

Step 5—the data were sorted by WMCG.

Step 6—the number of measurements for each VOC was determined for each WMCG using the "COUNT" function in Excel.

Step 7—the concentrations were summed

Step 8—the sum was divided by the number of samples to determine the average concentration for each VOC for each WMCG. Because there is a spreadsheet for each year, the yearly totals and counts were rolled up to a single table and then re-averaged for each WMCG and each VOC. Attachment A contains the averages for each year for each WMCG. The rollup is on the last page.

Step 9—the average concentrations for each compound and each WMCG was multiplied by the weighting factor to simulate the average concentration for each VOC in a full repository. This is shown in Attachment B. The following is an explanation of the different sets of concentrations in Attachment B.

Three sets of calculations are provided in Attachment B. All three use the measured repository headspace data from Attachment A. The first set of calculations uses the 2004 Compliance Recertification Application inventory projections for determining the weighting factors.[3] The results of

[3] Title 40 CFR Part 191 Subparts B and C Compliance Recertification Application 2004 March 2004 DOE/WIPP 2004-3231, Appendix DATA, Attachment F

this evaluation should be used in the Risk Screening exercise to determine the VOCs that make up 99 percent of the risk. The second set uses the same weighting factors that were used in the Permit Application and the NMVP. However, the results of the 930 drum sampling campaign is replaced with the new sampling results. This provides a comparison of the original assumptions regarding the VOC source term and the actual results. The third set of calculations modifies the Permit Application and NMVP weighting factors in two ways. The total volume of waste to be disposed is set by the Land Withdrawal Act (LWA) (which was not considered in the original scaling), so the total waste was adjusted to the LWA limits. Second, the original scaling appears to contain some unspecified factor for each WMCG that affected the scaled result. This was changed to a linear scaling of the total stored and projected waste. This resulted in slightly different weighting factors.

Note that the last page in Attachment B compares the various calculations of weighted VOC concentrations to the original source term.

Prepared by: Bob Kehrman
575 234 7210

Revision 3 dated 11.21.11

ATTACHMENT A

ALL WASTE TYPES

		HYDROGEN	METHANE	BENZENE	BROMOFORM	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLOROFORM	CYCLOHEXANE	1,1-DICHLOROETHANE	1,2-DICHLOROETHANE	1,1-DICHLOROETHYLENE	CIS-1,2-DICHLOROETHYLENE	TRANS-1,2-DICHLOROETHYLENE	ETHYL BENZENE	ETHYL ETHER	METHYLENE CHLORIDE	1,1,2,2-TETRACHLOROETHANE	TETRACHLOROETHYLENE
1999	COUNT	253	253	253	253	253	253	253	253	253	253	253	253	0	253	253	253	253	253
	TOTAL (ppmv)	231835.00	71806.00	125.99	145.19	147.61	129.04	118.94	138.01	127.77	136.33	64.44	133.76	0.00	135.22	152.85	177.80	139.17	104.48
	AVERAGE (ppmv)	916.34	283.82	0.50	0.57	0.58	0.51	0.47	0.55	0.51	0.54	0.25	0.53	0.00	0.53	0.60	0.70	0.55	0.41
2000	COUNT	2830	2055	2737	2737	2737	2737	2737	2459	2737	2737	2737	2737	0	2737	2737	2737	2737	2737
	TOTAL (ppmv)	105442.00	12356.00	740.25	379.17	830.74	388.53	686.37	781.58	411.04	389.98	547.90	375.42	0.00	451.02	441.51	1285.65	415.57	416.77
	AVERAGE (ppmv)	37.26	6.01	0.27	0.14	0.30	0.14	0.25	0.32	0.15	0.14	0.20	0.14	0.00	0.16	0.16	0.47	0.15	0.15
2001	COUNT	5128	1191	10421	10421	10421	10421	10421	10209	10421	10421	10421	10421	0	10421	10421	10421	10421	10421
	TOTAL (ppmv)	765049.00	19205.00	6151.14	2242.58	13505.38	2315.60	6744.41	10312.98	5297.09	2317.35	7055.94	2422.48	0.00	3431.28	4555.26	22863.38	2376.15	3795.42
	AVERAGE (ppmv)	149.19	16.13	0.59	0.22	1.30	0.22	0.65	1.01	0.51	0.22	0.68	0.23	0.00	0.33	0.44	2.19	0.23	0.36
2002	COUNT	12678	9200	23450	23450	23450	23450	23450	21889	23450	23450	23450	23450	13222	23450	23450	23450	23450	23450
	TOTAL (ppmv)	1819063.50	336611.50	18677.29	6325.26	56568.34	7474.35	16189.83	37210.52	15468.41	7141.14	16002.83	7828.33	4964.57	12161.16	12680.07	39675.02	6937.45	20152.67
	AVERAGE (ppmv)	143.48	36.59	0.80	0.27	2.41	0.32	0.69	1.70	0.66	0.30	0.68	0.33	0.38	0.52	0.54	1.69	0.30	0.86
2003	COUNT	14595	14579	18374	18375	18374	18374	18375	10300	18375	18373	18375	18374	16758	18375	18375	18374	18375	18375
	TOTAL (ppmv)	1886285.00	819813.50	29629.80	16533.29	242060.93	22060.71	30412.84	10278.79	25232.00	20553.99	23394.42	21061.53	18504.00	26194.61	24248.35	69175.21	21846.22	24718.54
	AVERAGE (ppmv)	129.24	56.23	1.61	0.90	13.17	1.20	1.66	1.00	1.37	1.12	1.27	1.15	1.10	1.43	1.32	3.76	1.19	1.35
2004	COUNT	17032	17032	20100	20098	20100	20100	20100	10913	20100	20100	20099	20100	19433	20100	20099	20100	20099	20100
	TOTAL (ppmv)	3363889.00	1755870.50	44805.37	23191.41	357635.63	32173.63	73317.69	23896.51	34723.77	32416.76	35003.04	29142.78	29300.56	38503.11	33659.56	121035.91	38188.52	38488.45
	AVERAGE (ppmv)	197.50	103.09	2.23	1.15	17.79	1.60	3.65	2.19	1.73	1.61	1.74	1.45	1.51	1.92	1.67	6.02	1.90	1.91
2005	COUNT	20861	20861	20863	20863	20863	20863	20863	14120	20863	20863	20863	20862	20750	20863	20863	20863	20862	20863
	TOTAL (ppmv)	11268765.50	1895636.50	40518.47	27712.05	19733760.60	30681.81	180482.74	142319.43	203042.71	42237.49	305579.24	33953.99	32932.97	43912.18	34371.16	424144.52	33221.58	76465.15
	AVERAGE (ppmv)	540.18	90.87	1.94	1.33	945.87	1.47	8.65	10.08	9.73	2.02	14.65	1.63	1.59	2.10	1.65	20.33	1.59	3.67
2006	COUNT	25638	25638	25876	25876	25876	25876	25876	20181	25876	25876	25876	25876	25876	25876	25876	25876	25876	25876
	TOTAL (ppmv)	19622674.50	2448359.50	183817.42	70797.39	14753266.80	103038.10	486144.16	473663.18	822143.16	145403.45	888073.52	165872.04	160762.63	201140.15	185373.49	5501788.79	105907.54	236865.96
	AVERAGE (ppmv)	765.37	95.50	7.10	2.74	570.15	3.98	18.79	23.47	31.77	5.62	34.32	6.41	6.21	7.77	7.16	212.62	4.09	9.15
2007	COUNT	10742	10742	10750	10727	10727	10750	10727	9271	10749	10749	10749	10750	10749	10750	10750	10727	10727	10727
	TOTAL (ppmv)	11482140.50	919975.00	28650.00	15804.41	1992316.45	19118.07	89759.37	128876.40	125028.78	23739.73	200794.73	26256.43	27977.16	32363.56	29580.94	544321.12	17805.47	77545.36
	AVERAGE (ppmv)	1068.90	85.64	2.67	1.47	185.73	1.78	8.37	13.90	11.63	2.21	18.68	2.44	2.60	3.01	2.75	50.74	1.66	7.23
2008	COUNT	2715	2715	2742	2742	2742	2742	2742	2473	2742	2742	2742	2742	2742	2742	2742	2742	2742	2741
	TOTAL (ppmv)	2003300.00	168958.88	3909.57	2506.53	39647.49	2438.26	6693.61	11014.18	42745.60	3333.33	17259.39	3020.07	3213.82	4379.06	2805.32	188222.40	2947.37	10982.16
	AVERAGE (ppmv)	737.86	62.23	1.43	0.91	14.46	0.89	2.44	4.45	15.59	1.22	6.29	1.10	1.17	1.60	1.02	68.64	1.07	4.01
2009	COUNT	90	90	113	113	113	113	113	112	112	113	113	112	113	113	112	113	113	113
	TOTAL (ppmv)	33031.13	7648.63	148.12	143.86	748.71	176.03	218.30	323.05	1944.19	968.69	2173.45	178.70	182.01	452.95	202.43	3672.61	189.70	340.32
	AVERAGE (ppmv)	367.01	84.98	1.31	1.27	6.63	1.56	1.93	2.88	17.36	8.57	19.23	1.60	1.61	4.01	1.81	32.50	1.68	3.01
2010	COUNT	461	461	536	531	531	536	531	245	536	536	536	536	531	536	536	531	531	531
	TOTAL (ppmv)	161911.92	18879.31	1292.02	639.50	1759.00	633.75	702.46	3234.54	7265.52	657.50	2860.26	908.99	1492.57	1496.70	655.93	10775.43	692.38	7026.82
	AVERAGE (ppmv)	351.22	40.95	2.41	1.20	3.31	1.18	1.32	13.20	13.56	1.23	5.34	1.70	2.81	2.79	1.22	20.29	1.30	13.23
TOTAL	COUNT	113023	104817	136215	136186	136187	136215	136188	102425	136214	136213	136214	136213	110174	136216	136214	136187	136186	136187
	TOTAL (ppmv)	52743387.05	8475120.31	358465.43	166420.63	37192247.67	220627.88	891470.73	842049.16	1283430.06	279295.73	1498809.15	291154.52	279330.28	364621.01	328726.87	6927137.84	230667.13	496902.10
	AVERAGE (ppmv)	466.66	80.86	2.63	1.22	273.10	1.62	6.55	8.22	9.42	2.05	11.00	2.14	2.54	2.68	2.41	50.86	1.69	3.65

ALL WASTE TYPES

		TOLUENE	1,1,1-TRICHLOROETHANE	TRICHLOROETHYLENE	1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE	1,2,4-TRIMETHYLBENZENE	1,3,5-TRIMETHYLBENZENE	M,P-XYLENE	O-XYLENE	ACETONE	BUTANOL	METHANOL	METHYL ETHYL KETONE	METHYL ISOBUTYL KETONE	METHYL CHLORIDE	CARBON DISULFIDE
1999	COUNT	253	253	253	253	127	253	253	253	253	253	253	253	253	0	0
	TOTAL (ppmv)	223.77	3171.19	118.31	106.97	176.64	197.41	263.41	140.22	5961.67	1201.43	3317.70	1716.37	1340.84	0.00	0.00
	AVERAGE (ppmv)	0.88	12.53	0.47	0.42	1.39	0.78	1.04	0.55	23.56	4.75	13.11	6.78	5.30	0.00	0.00
2000	COUNT	2737	2737	2737	2737	2459	2459	2737	2737	2737	2737	2737	2737	2737	0	1791
	TOTAL (ppmv)	7893.90	24718.24	1972.02	662.61	374.58	337.15	597.82	449.07	13169.50	5813.05	16058.50	3786.47	2946.44	0.00	868.06
	AVERAGE (ppmv)	2.88	9.03	0.72	0.24	0.15	0.14	0.22	0.16	4.81	2.12	5.87	1.38	1.08	0.00	0.48
2001	COUNT	10421	10421	10421	10421	9928	10209	10421	10421	10421	10421	10421	10421	10421	85	5997
	TOTAL (ppmv)	37784.43	247049.29	44930.26	12022.98	2418.46	2263.63	6103.96	2875.18	58282.48	44853.77	113820.53	21316.99	16390.76	28.80	4354.37
	AVERAGE (ppmv)	3.63	23.71	4.31	1.15	0.24	0.22	0.59	0.28	5.59	4.30	10.92	2.05	1.57	0.34	0.73
2002	COUNT	23450	23450	23450	23450	21889	21889	23450	23450	23450	23450	23450	23450	23450	1618	11858
	TOTAL (ppmv)	98774.05	378815.80	59074.68	100483.22	5069.20	4738.93	25481.04	10115.79	143426.15	122447.30	266409.54	63483.53	52453.73	2262.78	6060.93
	AVERAGE (ppmv)	4.21	16.15	2.52	4.28	0.23	0.22	1.09	0.43	6.12	5.22	11.36	2.71	2.24	1.40	0.51
2003	COUNT	18375	18374	18375	18374	10680	10680	18367	18374	18375	18374	18375	18375	18374	2075	9809
	TOTAL (ppmv)	110051.35	253019.57	31543.97	69592.02	7894.41	7476.50	45118.52	24950.16	311734.48	153503.43	337931.64	148243.69	135609.89	6826.50	12710.00
	AVERAGE (ppmv)	5.99	13.77	1.72	3.79	0.74	0.70	2.46	1.36	16.97	8.35	18.39	8.07	7.38	3.29	1.30
2004	COUNT	20100	20100	20099	20100	10965	10966	20099	20100	20100	20100	20100	20100	20100	1928	12076
	TOTAL (ppmv)	113736.25	428128.39	59282.70	231410.92	14611.69	14153.76	67592.54	41033.03	345042.00	205387.33	273231.82	210319.08	235227.64	2957.91	18586.93
	AVERAGE (ppmv)	5.66	21.30	2.95	11.51	1.33	1.29	3.36	2.04	17.17	10.22	13.59	10.46	11.70	1.53	1.54
2005	COUNT	20863	20863	20863	20863	14109	14120	20863	20863	20863	20863	20863	20863	20863	11484	11309
	TOTAL (ppmv)	104773.25	16473601.26	1355794.96	3760207.65	22954.19	22254.73	74360.73	41643.42	601901.66	284601.73	1029352.97	240562.09	257553.21	58702.82	21836.15
	AVERAGE (ppmv)	5.02	789.61	64.99	180.23	1.63	1.58	3.56	2.00	28.85	13.64	49.34	11.53	12.34	5.11	1.93
2006	COUNT	25876	25876	25876	25876	20180	20181	25876	25876	25876	25876	25876	25876	25876	22200	19860
	TOTAL (ppmv)	1233323.29	18032738.19	3852478.65	4579212.17	98941.73	121305.14	492018.22	181423.67	4659199.33	584846.27	3295637.71	792919.19	703322.97	464501.27	1299056.89
	AVERAGE (ppmv)	47.66	696.89	148.88	176.97	4.90	6.01	19.01	7.01	180.06	22.60	127.36	30.64	27.18	20.92	65.41
2007	COUNT	10750	10727	10727	10727	9270	9270	10750	10750	10750	10750	10750	10750	10750	10603	10523
	TOTAL (ppmv)	117817.22	4555537.36	1198984.78	873524.73	18306.05	18731.96	64379.83	27927.13	624731.08	175606.36	479158.65	142861.54	175502.56	60210.39	118124.54
	AVERAGE (ppmv)	10.96	424.68	111.77	81.43	1.97	2.02	5.99	2.60	58.11	16.34	44.57	13.29	16.33	5.68	11.23
2008	COUNT	2742	2742	2742	2742	2473	2473	2742	2742	2742	2742	2742	2742	2742	2727	2710
	TOTAL (ppmv)	24454.11	317712.72	417446.22	10517.26	2414.76	2444.18	8992.71	4142.91	69660.12	39341.76	127238.57	26309.88	31878.35	4262.31	7424.62
	AVERAGE (ppmv)	8.92	115.87	152.24	3.84	0.98	0.99	3.28	1.51	25.40	14.35	46.40	9.60	11.63	1.56	2.74
2009	COUNT	113	113.00	113.00	113.00	112.00	112.00	113.00	113.00	112.00	112.00	112.00	112.00	112.00	112.00	83.00
	TOTAL (ppmv)	1323.27	31183.55	22761.84	315.77	199.48	176.42	984.13	427.51	1436.75	1173.89	2036.65	764.30	1033.19	223.90	113.20
	AVERAGE (ppmv)	11.71	275.96	201.43	2.79	1.78	1.58	8.71	3.78	12.83	10.48	18.18	6.82	9.22	2.00	1.36
2010	COUNT	531	531.00	531.00	531.00	245.00	245.00	536.00	536.00	536.00	536.00	536.00	536.00	536.00	529.00	464.00
	TOTAL (ppmv)	3392.31	43729.96	43758.78	3122.14	389.46	365.71	3002.63	1141.72	15451.54	5835.04	20019.71	3993.83	5059.62	1098.92	449.07
	AVERAGE (ppmv)	6.39	82.35	82.41	5.88	1.59	1.49	5.60	2.13	28.83	10.89	37.35	7.45	9.44	2.08	0.97
TOTAL	COUNT	136211	136187.00	136187.00	136187.00	102437.00	102857.00	136207.00	136215.00	136215.00	136214.00	136215.00	136215.00	136214.00	53361.00	86480.00
	TOTAL (ppmv)	1853547.19	40789405.53	7088147.19	9641178.45	173750.64	194445.54	788895.55	336269.81	6849996.75	1624611.36	5964213.98	1656276.95	1618319.22	601075.59	1489584.76
	AVERAGE (ppmv)	13.61	299.51	52.05	70.79	1.70	1.89	5.79	2.47	50.29	11.93	43.79	12.16	11.88	11.26	17.22

ATTACHMENT B

MOST RECENT CRA INVENTORY (cubic meters)

Final Waste Forms	Stored Waste	Projected Waste	Emplaced Waste	Total Waste	SCALED	Weighting Factor	
Combustible Material	4300	1900	610	6800	8149	0.05	
Filter Material	990	590	340	1900	2277	0.01	
Graphite	120	1.3	0	130	156	0.00	
Heterogeneous Debris	49000	9700	570	59000	70706	0.42	
Inorganic Non-Metal	11000	68	970	12000	14381	0.09	
Lead/Cadmium Metal	140	32	81	260	312	0.00	
Salt	150	190	1500	1800	2157	0.01	
Soil	300	6000	0	6300	7550	0.04	
Solidified Inorganic Material	35000	730	3300	39000	46738	0.28	
Solidified Organic Material	5200	380	0	5500	6591	0.04	
Uncategorized Metal	2400	5100	360	7900	9467	0.06	
Unknown							

	HYDROGEN	METHANE	BENZENE	BROMOFORM	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLOROFORM	CYCLOHEXANE	1,1-DICHLOROETHANE	1,2-DICHLOROETHANE	1,1-DICHLOROETHYLENE	CIS-1,2-DICHLOROETHYLENE	TRANS-1,2-DICHLOROETHYLENE	ETHYL BENZENE	ETHYL ETHER	METHYLENE CHLORIDE	1,1,2,2-TETRACHLOROETHANE	TETRACHLOROETHYLENE
WEIGHTED CONCENTRATION FOR EACH WASTE FORM (ppmv)																		
Combustible Material	16.41	1.93	0.21	0.06	2.14	0.10	0.52	1.43	1.75	0.14	0.99	0.19	0.23	0.39	0.16	22.29	0.08	0.34
Filter Material	8.09	1.59	0.02	0.01	0.30	0.01	0.04	0.01	0.09	0.01	0.16	0.01	0.01	0.01	0.01	0.08	0.01	0.01
Graphite	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heterogeneous Debris	231.75	35.79	0.94	0.47	3.51	0.61	0.91	2.44	2.14	0.67	1.73	0.59	0.60	0.73	0.66	9.28	0.66	0.92
Inorganic Non-Metal	9.69	3.62	0.04	0.04	0.22	0.04	0.11	0.36	0.05	0.04	0.04	0.04	0.05	0.04	0.04	0.08	0.04	0.03
Lead/Cadmium Metal	2.36	0.16	0.00	0.00	0.38	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Salt	5.65	0.52	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
Soil	4.83	4.70	0.04	0.05	0.37	0.04	0.05	0.08	0.07	0.05	0.09	0.04	0.05	0.04	0.05	0.06	0.06	0.06
Solidified Inorganic Material	115.70	26.36	0.34	0.28	3.18	0.27	0.32	0.75	2.67	0.26	4.64	0.31	0.43	0.62	0.31	0.63	0.31	1.24
Solidified Organic Material	10.07	2.15	2.63	0.89	911.03	1.57	14.07	5.64	2.99	2.55	5.14	2.64	2.63	1.67	3.46	3.44	1.54	2.42
Uncategorized Metal	10.14	3.40	0.10	0.04	0.38	0.04	0.07	0.04	0.12	0.04	0.09	0.04	0.05	0.07	0.04	0.13	0.04	0.04
TOTAL WEIGHTED CONCENTRATIONS (ppmv)																		
	414.76	80.25	4.32	1.84	921.52	2.67	16.12	10.76	9.89	3.77	12.91	3.87	4.07	3.57	4.76	36.01	2.75	5.07

	TOLUENE	1,1,1-TRICHLOROETHANE	TRICHLOROETHYLENE	1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE	1,2,4-TRIMETHYLBENZENE	1,3,5-TRIMETHYLBENZENE	M,P-XYLENE	O-XYLENE	ACETONE	BUTANOL	METHANOL	METHYL ETHYL KETONE	METHYL ISOBUTYL KETONE	METHYL CHLORIDE	CARBON DISULFIDE
WEIGHTED CONCENTRATION FOR EACH WASTE FORM (ppmv)															
Combustible Material	4.49	5.01	3.29	1.93	0.10	0.10	1.24	0.27	14.62	0.76	1.72	1.91	1.70	0.84	6.39
Filter Material	0.09	1.59	0.28	0.19	0.01	0.01	0.01	0.01	0.43	0.12	0.34	0.12	0.12	0.17	0.02
Graphite	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.05	0.00
Heterogeneous Debris	2.77	20.13	3.76	2.28	0.51	0.50	1.39	0.75	12.63	4.76	8.30	4.14	4.34	4.10	0.68
Inorganic Non-Metal	0.50	0.71	0.09	0.04	0.04	0.04	0.07	0.04	0.73	0.48	1.61	0.41	0.37	1.91	0.06
Lead/Cadmium Metal	0.01	0.13	0.01	0.01	0.00	0.00	0.00	0.00	0.07	0.02	0.03	0.02	0.02	0.05	0.00
Salt	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.04	0.09	0.17	0.03	0.03	0.00	0.01
Soil	0.06	0.19	0.05	0.05	0.05	0.05	0.09	0.06	0.47	0.33	0.51	0.41	0.30	0.00	0.07
Solidified Inorganic Material	1.29	81.52	38.55	8.33	0.33	0.31	1.30	0.46	3.00	3.21	17.08	2.30	2.60	0.49	0.33
Solidified Organic Material	2.51	629.34	4.98	196.00	1.48	2.09	2.20	2.13	20.34	3.58	40.89	4.04	2.35	7.74	2.90
Uncategorized Metal	0.49	1.16	0.17	0.10	0.04	0.04	0.17	0.07	0.76	0.42	0.62	0.42	0.57	0.25	0.04
TOTAL WEIGHTED CONCENTRATIONS (ppmv)															
	12.23	739.815	51.184	208.93	2.57	3.15	6.461	3.8005	53.096	13.775	71.28	13.788	12.393	15.578	10.49

ORIGINAL NMVP AND PART B (cubic meters)

Final Waste Forms	Stored volume	Projected volumes		Total Waste	Scaled Volumes	Weighting Factor		
Combustible	7100	27000		34100	62000	0.35		
Filter	430	1100		1530	2600	0.01		
Graphite	670	43		713	760	0.00		
Heterogeneous	30000	4600		34600	39000	0.22		
Inorganic non-metal	1200	320		1520	1800	0.01		
Lead/cadmium metal	56	130		186	310	0.00		
Salt waste	33	60		93	150	0.00		
Soils	370	450		820	1300	0.01		
Solidified inorganics	17000	8000		25000	34000	0.19		
Solidified organics	1500	300		1800	2100	0.01		
Uncategorized metal	12000	8600		20600	30000	0.17		
Unknown	1700	0		1700	1700	0.01		

	HYDROGEN	METHANE	BENZENE	BROMOFORM	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLOROFORM	CYCLOHEXANE	1,1-DICHLOROETHANE	1,2-DICHLOROETHANE	1,1-DICHLOROETHYLENE	CIS-1,2-DICHLOROETHYLENE	TRANS-1,2-DICHLOROETHYLENE	ETHYL BENZENE	ETHYL ETHER	METHYLENE CHLORIDE	1,1,2,2-TETRACHLOROETHANE	TETRACHLOROETHYLENE
WEIGHTED CONCENTRATION FOR EACH WASTE FORM (ppmv)																		
Combustible	119.78	14.08	1.51	0.40	15.63	0.71	3.77	10.46	12.75	1.00	7.23	1.42	1.67	2.82	1.17	162.66	0.59	2.51
Filter	8.86	1.74	0.03	0.01	0.32	0.01	0.04	0.01	0.10	0.01	0.17	0.01	0.01	0.01	0.01	0.09	0.01	0.01
Graphite	0.31	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heterogeneous	122.60	18.93	0.49	0.25	1.86	0.32	0.48	1.29	1.13	0.36	0.91	0.31	0.32	0.39	0.35	4.91	0.35	0.48
Inorganic non-metal	1.16	0.43	0.01	0.00	0.03	0.00	0.01	0.04	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00
Lead/cadmium metal	2.30	0.15	0.00	0.00	0.37	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Salt waste	0.38	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soils	0.80	0.77	0.01	0.01	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Solidified inorganics	80.91	18.44	0.23	0.20	2.23	0.19	0.22	0.52	1.86	0.18	3.24	0.22	0.30	0.43	0.21	0.44	0.22	0.87
Solidified organics	3.09	0.66	0.81	0.27	279.45	0.48	4.32	1.73	0.92	0.78	1.58	0.81	0.81	0.51	1.06	1.05	0.47	0.74
Uncategorized metal	30.85	10.34	0.30	0.11	1.16	0.11	0.20	0.13	0.36	0.11	0.28	0.12	0.15	0.20	0.13	0.39	0.13	0.13
Unknown																		
TOTAL WEIGHTED CONCENTRATIONS (ppmv)																		
	371.02	65.74	3.39	1.26	301.11	1.83	9.09	14.21	17.18	2.46	13.58	2.90	3.28	4.38	2.96	169.59	1.79	4.77

	TOLUENE	1,1,1-TRICHLOROETHANE	TRICHLOROETHYLENE	1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE	1,2,4-TRIMETHYLBENZENE	1,3,5-TRIMETHYLBENZENE	M,P-XYLENE	O-XYLENE	ACETONE	BUTANOL	METHANOL	METHYL ETHYL KETONE	METHYL ISOBUTYL KETONE	METHYL CHLORIDE	CARBON DISULFIDE
WEIGHTED CONCENTRATION FOR EACH WASTE FORM (ppmv)															
Combustible	32.79	36.55	23.98	14.12	0.76	0.75	9.03	2.01	106.72	5.53	12.57	13.96	12.38	6.15	46.65
Filter	0.10	1.74	0.31	0.21	0.01	0.01	0.02	0.01	0.47	0.13	0.37	0.13	0.13	0.18	0.02
Graphite	0.01	0.14	0.04	0.00	0.00	0.00	0.00	0.00	0.06	0.01	0.04	0.01	0.01	0.25	0.00
Heterogeneous	1.47	10.65	1.99	1.21	0.27	0.27	0.73	0.40	6.68	2.52	4.39	2.19	2.30	2.17	0.36
Inorganic non-metal	0.06	0.09	0.01	0.00	0.00	0.00	0.01	0.00	0.09	0.06	0.19	0.05	0.04	0.23	0.01
Lead/cadmium metal	0.01	0.13	0.01	0.01	0.00	0.00	0.00	0.00	0.07	0.02	0.03	0.02	0.01	0.04	0.00
Salt waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
Soils	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.08	0.05	0.08	0.07	0.05	0.00	0.01
Solidified inorganics	0.90	57.01	26.96	5.83	0.23	0.22	0.91	0.32	2.10	2.25	11.94	1.61	1.82	0.34	0.23
Solidified organics	0.77	193.04	1.53	60.12	0.45	0.64	0.67	0.65	6.24	1.10	12.54	1.24	0.72	2.37	0.89
Uncategorized metal	1.49	3.53	0.52	0.29	0.12	0.12	0.52	0.23	2.31	1.28	1.90	1.27	1.74	0.75	0.11
Unknown															
TOTAL WEIGHTED CONCENTRATIONS (ppmv)															
	37.61	302.91	55.35	81.79	1.86	2.02	11.91	3.63	124.81	12.95	44.07	20.54	19.20	12.48	48.28

REVISED FOR LWA LIMITS (cubic meters)

Final Waste Forms	Stored volume	Projected volumes		Total Waste	Scaled Volumes	Weighting Factor		
Combustible	7100	27000		34100	46839	0.28		
Filter	430	1100		1530	2102	0.01		
Graphite	670	43		713	979	0.01		
Heterogeneous	30000	4600		34600	47526	0.28		
Inorganic non-metal	1200	320		1520	2088	0.01		
Lead/cadmium metal	56	130		186	255	0.00		
Salt waste	33	60		93	128	0.00		
Soils	370	450		820	1126	0.01		
Solidified inorganics	17000	8000		25000	34339	0.20		
Solidified organics	1500	300		1800	2472	0.01		
Uncategorized metal	12000	8600		20600	28296	0.17		
Unknown	1700	0		1700	2335	0.01		

	HYDROGEN	METHANE	BENZENE	BROMOFORM	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLOROFORM	CYCLOHEXANE	1,1-DICHLOROETHANE	1,2-DICHLOROETHANE	1,1-DICHLOROETHYLENE	CIS-1,2-DICHLOROETHYLENE	TRANS-1,2-DICHLOROETHYLENE	ETHYL BENZENE	ETHYL ETHER	METHYLENE CHLORIDE	1,1,2,2-TETRACHLOROETHANE	TETRACHLOROETHYLENE
WEIGHTED CONCENTRATION FOR EACH WASTE FORM (ppmv)																		
Combustible	94.33	11.09	1.19	0.32	12.31	0.56	2.97	8.24	10.04	0.79	5.70	1.12	1.32	2.22	0.93	128.10	0.47	1.98
Filter	7.47	1.47	0.02	0.01	0.27	0.01	0.03	0.01	0.08	0.01	0.15	0.01	0.01	0.01	0.01	0.08	0.01	0.01
Graphite	0.41	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.18	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Heterogeneous	155.77	24.06	0.63	0.31	2.36	0.41	0.61	1.64	1.44	0.45	1.16	0.40	0.40	0.49	0.45	6.24	0.44	0.62
Inorganic non-metal	1.41	0.53	0.01	0.01	0.03	0.01	0.02	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Lead/cadmium metal	1.94	0.13	0.00	0.00	0.31	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Salt waste	0.33	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soils	0.72	0.70	0.01	0.01	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Solidified inorganics	85.00	19.37	0.25	0.21	2.34	0.20	0.23	0.55	1.96	0.19	3.41	0.23	0.32	0.46	0.22	0.46	0.23	0.91
Solidified organics	3.78	0.80	0.99	0.34	341.73	0.59	5.28	2.12	1.12	0.96	1.93	0.99	0.99	0.63	1.30	1.29	0.58	0.91
Uncategorized metal	30.30	10.16	0.29	0.11	1.14	0.11	0.20	0.13	0.35	0.11	0.28	0.12	0.15	0.20	0.13	0.38	0.13	0.13
Unknown																		
TOTAL WEIGHTED CONCENTRATIONS (ppmv)																		
	381.46	68.54	3.38	1.31	360.56	1.88	9.38	12.75	15.06	2.53	12.81	2.88	3.21	4.02	3.05	136.59	1.88	4.57

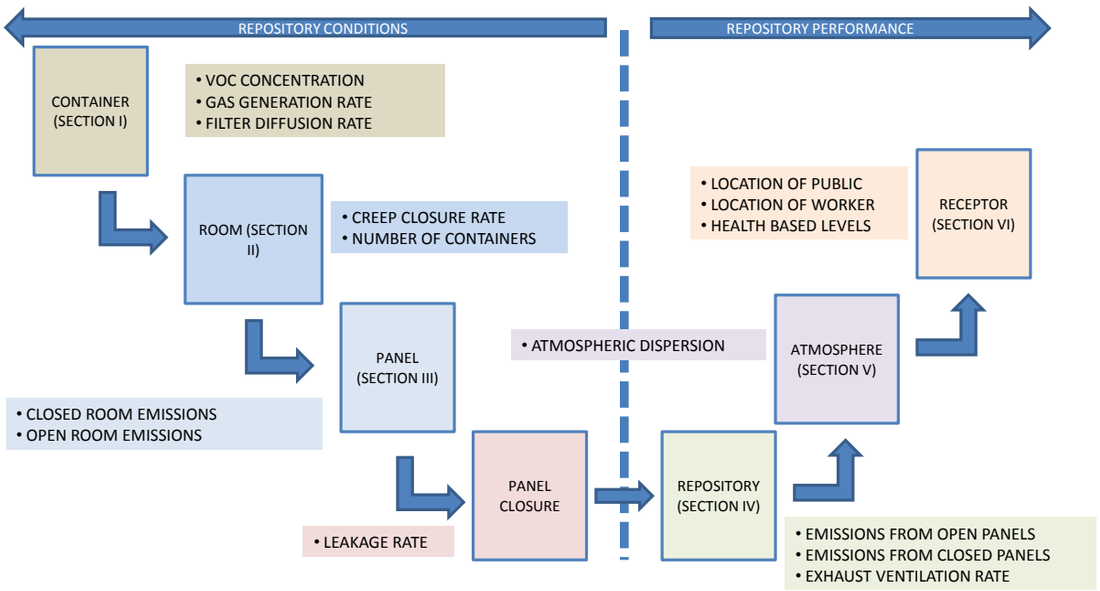
	TOLUENE	1,1,1-TRICHLOROETHANE	TRICHLOROETHYLENE	1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE	1,2,4-TRIMETHYLBENZENE	1,3,5-TRIMETHYLBENZENE	M,P-XYLENE	O-XYLENE	ACETONE	BUTANOL	METHANOL	METHYL ETHYL KETONE	METHYL ISOBUTYL KETONE	METHYL CHLORIDE	CARBON DISULFIDE
WEIGHTED CONCENTRATION FOR EACH WASTE FORM (ppmv)															
Combustible	25.82	28.79	18.88	11.12	0.60	0.59	7.11	1.58	84.05	4.36	9.90	10.99	9.75	4.84	36.74
Filter	0.08	1.47	0.26	0.18	0.01	0.01	0.01	0.01	0.40	0.11	0.31	0.11	0.11	0.15	0.01
Graphite	0.01	0.19	0.05	0.00	0.00	0.00	0.00	0.00	0.08	0.02	0.06	0.01	0.01	0.34	0.00
Heterogeneous	1.86	13.53	2.53	1.53	0.34	0.34	0.93	0.50	8.49	3.20	5.58	2.78	2.92	2.75	0.45
Inorganic non-metal	0.07	0.10	0.01	0.01	0.01	0.01	0.01	0.01	0.11	0.07	0.23	0.06	0.05	0.28	0.01
Lead/cadmium metal	0.01	0.11	0.01	0.01	0.00	0.00	0.00	0.00	0.06	0.02	0.02	0.01	0.01	0.04	0.00
Salt waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
Soils	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.07	0.05	0.08	0.06	0.04	0.00	0.01
Solidified inorganics	0.95	59.89	28.32	6.12	0.24	0.23	0.95	0.34	2.20	2.36	12.55	1.69	1.91	0.36	0.24
Solidified organics	0.94	236.07	1.87	73.52	0.55	0.78	0.82	0.80	7.63	1.34	15.34	1.51	0.88	2.90	1.09
Uncategorized metal	1.47	3.47	0.51	0.29	0.11	0.11	0.52	0.22	2.26	1.25	1.87	1.25	1.71	0.73	0.11
Unknown															
TOTAL WEIGHTED CONCENTRATIONS (ppmv)															
	31.22	343.64	52.45	92.78	1.88	2.08	10.37	3.47	105.35	12.78	45.94	18.48	17.40	12.40	38.67

	MW	930 DRUMS	RECALC WITH HSG DATA		
		APP13	APP13	LWA	CRA
Carbon tetrachloride	153.8	375.5	301.1	360.6	921.5
1,1,2,2-Tetrachloroethane	167.9	9.4	1.8	1.9	4.8
Chloroform	119.4	25.3	9.1	9.4	16.1
1,2-Dichloroethane	99.0	9.1	17.2	2.5	3.8
Methylene chloride	84.9	368.5	169.6	136.6	36.0
Benzene	78.1	9.3	3.4	3.4	4.3
Trichloroethylene	131.4	25.1	55.3	52.5	51.2
Bromoform	252.8	9.4	1.3	1.3	1.8
Tetrachloroethylene	165.9	9.4	4.8	4.6	5.1
Vinyl chloride	62.5	0.2			
1 , 1 ,2-Trichloroethane	133.4	0.1			
Chlorobenzene	112.6	12.5	1.8	1.9	2.7
1,1,1 -Trichloroethane	133.4	317.1	302.9	343.6	739.8
1 ,1-Dichloroethylene	97.0	11.5	13.6	12.8	12.9
Methyl ethyl ketone	72.1	63.7	20.5	18.5	13.8
Toluene	92.1	19.4	37.6	31.2	12.2
Carbon disulfide	76.1	0.1	48.3	38.7	10.5
Trichlorofluoromethane	137.4	0.1			
(cis)-1, 2-Dichloroethylene	97.0	9.0	2.9	2.9	3.9
Isobutanol	74.1	0.1			

ATTACHMENT 3
CALCULATIONS TO SUPPORT PANEL CLOSURE DESIGN PAPER 8 29 12

Figure 1 is a block diagram of the elements that go into preparing a risk model to demonstrate operational impacts due to emissions from the Waste Isolation Pilot Plant repository. The goal of this discussion is to provide information needed to specify the design of the Panel Closure which will serve to assure the performance standards to the right on the diagram are met for the conditions in the repository shown on the left in Figure 1. When the original Part B Permit Application for the Waste Isolation Pilot Plant (WIPP) (U. S. Department of Energy, 1996 a) facility was submitted in 1996, one of the design parameters for Panel Closure was that "the panel closure system shall limit the migration of [volatile organic compounds] VOCs to the compliance point so that compliance is achieved by at least one order of magnitude." This criterion has been changed for the current design to only require compliance without an additional compliance margin. The following discusses each element in the order indicated by the Roman Numerals on the Figure.

FIGURE 1: Elements of the Waste Isolation Pilot Plant Air Exposure Pathway



VOC CONCENTRATION	is in Sheet *Weighted HS Conc*
GAS GENERATION RATE	is in Sheet *Inputs and Outputs*
FILTER DIFFUSION RATE	is in Sheet *Filter Information and Inputs and*
CREEP CLOUSRE RATE	is in Sheet *Inputs and Outputs*
NUMBER OF CONTAINERS	is in Sheet *Containers*
LEAKAGE RATE	is in Sheet *Leakage* , however it is not considered in the Panel Closure Paper.
EMISSIONS FROM OPEN PANELS	is in Sheet *Inputs and Outputs*
EMISSIONS FROM CLOSED PANELS	is in Sheet *Inputs and Outputs*
EXHAUST VENTILATION RATE	is in Sheet *Inputs and Outputs*
ATMOSPHERIC DISPERSION	is in Sheet *Risk Factors, ADFs and HBLs*
LOCATION OF THE WORKER	is in Sheet *Risk Factors, ADFs and HBLs*
LOCATION OF THE PUBLIC	is in Sheet *Risk Factors, ADFs and HBLs*
HEALTH BASED LEVELS	is in Sheet *Risk Factors, ADFs and HBLs*

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The following is from Section 1 of the paper: "ESTABLISHING VOLATILE ORGANIC COMPOUND LIMITS FOR THE PANEL CLOSURE DESIGN". VOC CONCENTRATION Information needed on the container scale for air dispersion modeling is the average concentration of VOCs in the headspace of the container which defines the release source term and the gas generation rate which is a driving force to move VOCs from closed rooms and panels into the repository ventilation system. The VOC source term used for the original Panel Closure design effort was developed based on a limited sampling program conducted in Idaho and at Rocky Flats. Subsequent to that time, a weighted average source term was developed using the same data, however, a weighting process was developed to accommodate the wide variety of waste forms and to weight them in accordance with their prevalence. The process for developing the weighted average source term is described in Appendix C2 of the 1996 Permit Application (U. S. Department of Energy, 1996 a). The results are summarized in Table 1. In 2010, the source term was revised using the same methodology; however, over 130,000 headspace gas measurements were available (Kehrman, 2011). The revised source term is shown in Table 1. The values in Table 1 represent the average concentration that would be expected in a filled, closed room.

THESE VALUES COME FROM A SHEET TITLED "HSGD ROLLUP 11- 21 2011 CORRECTED FILE"

MOST RECENT CRA INVENTORY (cubic meters)									HYDROGEN	METHANE	BENZENE	BROMOFORM	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLOROFORM	CYCLOHEXANE	1,1-DICHLOROETHANE	1,2-DICHLOROETHANE	1,1-DICHLOROETHYLENE	CIS-1,2-DICHLOROETHYLENE	TRANS-1,2-DICHLOROETHYLENE	ETHYL BENZENE	ETHYL ETHER	METHYLENE CHLORIDE	1,1,2,2-TETRACHLOROETHANE	TETRACHLOROETHYLENE	TOLUENE	1,1,1-TRICHLOROETHANE	TRICHLOROETHYLENE	1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE	1,2,4-TRIMETHYLBENZENE	1,3,5-TRIMETHYLBENZENE	M,P-XYLENE	O-XYLENE	ACETONE	BUTANOL	METHANOL	METHYL ETHYL KETONE	METHYL ISOBUTYL KETONE	METHYL CHLORIDE	CARBON DISULFIDE
Final Waste Forms	Stored Waste	Projected Waste	Emplaced Waste	Total Waste	SCALED	Weighting Factor			WEIGHTED CONCENTRATION FOR EACH WASTE FORM (ppmv)																			WEIGHTED CONCENTRATION FOR EACH WASTE FORM (ppmv)																		
Combustible Material	4300.00	1900.00	610.00	6810.00	8136.18	0.05			Combustible Material	16.41	1.93	0.21	0.06	2.14	0.10	0.52	1.43	1.75	0.14	0.99	0.19	0.23	0.39	0.16	22.29	0.08	0.34	Combustible Material	4.49	5.01	3.29	1.93	0.10	0.10	1.24	0.27	14.62	0.76	1.72	1.91	1.70	0.84	6.39
Filter Material	990.00	590.00	340.00	1920.00	2293.90	0.01			Filter Material	8.09	1.59	0.02	0.01	0.30	0.01	0.04	0.01	0.09	0.01	0.16	0.01	0.01	0.01	0.01	0.08	0.01	0.01	Filter Material	0.09	1.59	0.28	0.19	0.01	0.01	0.01	0.01	0.43	0.12	0.34	0.12	0.12	0.17	0.02
Graphite	120.00	1.30	0.00	121.30	144.92	0.00			Graphite	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Graphite	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.05	0.00
Heterogeneous Debris	49000.00	9700.00	570.00	59270.00	70812.25	0.42			Heterogeneous Debris	231.75	35.79	0.94	0.47	3.51	0.61	0.91	2.44	2.14	0.67	1.73	0.59	0.60	0.73	0.66	9.28	0.66	0.92	Heterogeneous Debris	2.77	20.13	3.76	2.28	0.51	0.50	1.39	0.75	12.63	4.76	8.30	4.14	4.34	4.10	0.68
Inorganic Non-Metal	11000.00	68.00	970.00	12038.00	14382.28	0.09			Inorganic Non-Metal	9.69	3.62	0.04	0.04	0.22	0.04	0.11	0.36	0.05	0.04	0.04	0.04	0.05	0.04	0.04	0.08	0.04	0.03	Inorganic Non-Metal	0.50	0.71	0.09	0.04	0.04	0.04	0.07	0.04	0.73	0.48	1.61	0.41	0.37	1.91	0.06
Lead/Cadmium Metal	140.00	32.00	81.00	253.00	302.27	0.00			Lead/Cadmium Metal	2.36	0.16	0.00	0.00	0.38	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	Lead/Cadmium Metal	0.01	0.13	0.01	0.01	0.00	0.00	0.00	0.00	0.07	0.02	0.03	0.02	0.02	0.05	0.00
Salt	150.00	190.00	1500.00	1840.00	2198.32	0.01			Salt	5.65	0.52	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	Salt	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.04	0.09	0.17	0.03	0.03	0.00	0.01
Soil	300.00	6000.00	0.00	6300.00	7526.86	0.04			Soil	4.83	4.70	0.04	0.05	0.37	0.04	0.05	0.08	0.07	0.05	0.09	0.04	0.05	0.04	0.05	0.06	0.06	0.06	Soil	0.06	0.19	0.05	0.05	0.05	0.05	0.09	0.06	0.47	0.33	0.51	0.41	0.30	0.00	0.07
Solidified Inorganic Material	35000.00	730.00	3300.00	39030.00	46630.71	0.28			Solidified Inorganic Material	115.70	26.36	0.34	0.28	3.18	0.27	0.32	0.75	2.67	0.26	4.64	0.31	0.43	0.62	0.31	0.63	0.31	1.24	Solidified Inorganic Material	1.29	81.52	38.55	8.33	0.33	0.31	1.30	0.46	3.00	3.21	17.08	2.30	2.60	0.49	0.33
Solidified Organic Material	5200.00	380.00	0.00	5580.00	6666.65	0.04			Solidified Organic Material	10.07	2.15	2.63	0.89	911.03	1.57	14.07	5.64	2.99	2.55	5.14	2.64	2.63	1.67	3.46	3.44	1.54	2.42	Solidified Organic Material	2.51	629.34	4.98	196.00	1.48	2.09	2.20	2.13	20.34	3.58	40.89	4.04	2.35	7.74	2.90
Uncategorized Metal	2400.00	5100.00	360.00	7860.00	9390.66	0.06			Uncategorized Metal	10.14	3.40	0.10	0.04	0.38	0.04	0.07	0.04	0.12	0.04	0.09	0.04	0.05	0.07	0.04	0.13	0.04	0.04	Uncategorized Metal	0.49	1.16	0.17	0.10	0.04	0.04	0.17	0.07	0.76	0.42	0.62	0.42	0.57	0.25	0.04
Unknown																													Unknown																		
									TOTAL WEIGHTED CONCENTRATIONS (ppmv)																			TOTAL WEIGHTED CONCENTRATIONS (ppmv)																		
										414.76	80.25	4.32	1.84	921.52	2.67	16.12	10.76	9.89	3.77	12.91	3.87	4.07	3.57	4.76	36.01	2.75	5.07		12.23	739.81	51.18	208.93	2.57	3.15	6.46	3.80	53.10	13.77	71.28	13.79	12.39	15.58	10.49

ORIGINAL NMVP AND PART B (cubic meters)									HYDROGEN	METHANE	BENZENE	BROMOFORM	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLOROFORM	CYCLOHEXANE	1,1-DICHLOROETHANE	1,2-DICHLOROETHANE	1,1-DICHLOROETHYLENE	CIS-1,2-DICHLOROETHYLENE	TRANS-1,2-DICHLOROETHYLENE	ETHYL BENZENE	ETHYL ETHER	METHYLENE CHLORIDE	1,1,2,2-TETRACHLOROETHANE	TETRACHLOROETHYLENE	TOLUENE	1,1,1-TRICHLOROETHANE	TRICHLOROETHYLENE	1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE	1,2,4-TRIMETHYLBENZENE	1,3,5-TRIMETHYLBENZENE	M,P-XYLENE	O-XYLENE	ACETONE	BUTANOL	METHANOL	METHYL ETHYL KETONE	METHYL ISOBUTYL KETONE	METHYL CHLORIDE	CARBON DISULFIDE
Final Waste Forms	Stored volume	Projected volumes		Total Waste	Scaled Volumes	Weighting Factor			WEIGHTED CONCENTRATION FOR EACH WASTE FORM (ppmv)																			WEIGHTED CONCENTRATION FOR EACH WASTE FORM (ppmv)																		
Combustible	7100.00	27000.00		34100.00	62000.00	0.35			Combustible	119.78	14.08	1.51	0.40	15.63	0.71	3.77	10.46	12.75	1.00	7.23	1.42	1.67	2.82	1.17	162.66	0.59	2.51	Combustible	32.79	36.55	23.98	14.12	0.76	0.75	9.03	2.01	106.72	5.53	12.57	13.96	12.38	6.15	46.65
Filter	430.00	1100.00		1530.00	2600.00	0.01			Filter	8.86	1.74	0.03	0.01	0.32	0.01	0.04	0.01	0.10	0.01	0.17	0.01	0.01	0.01	0.01	0.09	0.01	0.01	Filter	0.10	1.74	0.31	0.21	0.01	0.01	0.02	0.01	0.47	0.13	0.37	0.13	0.13	0.18	0.02
Graphite	670.00	43.00		713.00	760.00	0.00			Graphite	0.31	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Graphite	0.01	0.14	0.04	0.00	0.00	0.00	0.00	0.00	0.06	0.01	0.04	0.01	0.01	0.25	0.00
Heterogeneous	30000.00	4600.00		34600.00	39000.00	0.22			Heterogeneous	122.60	18.93	0.49	0.25	1.86	0.32	0.48	1.29	1.13	0.36	0.91	0.31	0.32	0.39	0.35	4.91	0.35	0.48	Heterogeneous	1.47	10.65	1.99	1.21	0.27	0.27	0.73	0.40	6.68	2.52	4.39	2.19	2.30	2.17	0.36
Inorganic non-metal	1200.00	320.00		1520.00	1800.00	0.01			Inorganic non-metal	1.16	0.43	0.01	0.00	0.03	0.00	0.01	0.04	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	Inorganic non-metal	0.06	0.09	0.01	0.00	0.00	0.00	0.01	0.00	0.09	0.06	0.19	0.05	0.04	0.23	0.01
Lead/cadmium metal	56.00	130.00		186.00	310.00	0.00			Lead/cadmium metal	2.30	0.15	0.00	0.00	0.37	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	Lead/cadmium metal	0.01	0.13	0.01	0.01	0.00	0.00	0.00	0.00	0.07	0.02	0.03	0.02	0.01	0.04	0.00
Salt waste	33.00	60.00		93.00	150.00	0.00			Salt waste	0.38	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Salt waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
Soils	370.00	450.00		820.00	1300.00	0.01			Soils	0.80	0.77	0.01	0.01	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	Soils	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.08	0.05	0.08	0.07	0.05	0.00	0.01
Solidified inorganics	17000.00	8000.00		25000.00	34000.00	0.19			Solidified inorganics	80.91	18.44	0.23	0.20	2.23	0.19	0.22	0.52	1.86	0.18	3.24	0.22	0.30	0.43	0.21	0.44	0.22	0.87	Solidified inorganics	0.90	57.01	26.96	5.83	0.23	0.22	0.91	0.32	2.10	2.25	11.94	1.61	1.82	0.34	0.23
Solidified organics	1500.00	300.00		1800.00	2100.00	0.01			Solidified organics	3.09	0.66	0.81	0.27	279.45	0.48	4.32	1.73	0.92	0.78	1.58	0.81	0.81	0.51	1.06	1.05	0.47	0.74	Solidified organics	0.77	193.04	1.53	60.12	0.45	0.64	0.67	0.65	6.24	1.10	12.54	1.24	0.72	2.37	0.89
Uncategorized metal	12000.00	8600.00		20600.00	30000.00	0.17			Uncategorized metal	30.85	10.34	0.30	0.11	1.16	0.11	0.20	0.13	0.36	0.11	0.28	0.12	0.15	0.20	0.13	0.39	0.13	0.13	Uncategorized metal	1.49	3.53	0.52	0.29	0.12	0.12	0.52	0.23	2.31	1.28	1.90	1.27	1.74	0.75	0.11
Unknown	1700.00	0.00		1700.00	1700.00	0.01			Unknown																			Unknown																		
									TOTAL WEIGHTED CONCENTRATIONS (ppmv)																			TOTAL WEIGHTED CONCENTRATIONS (ppmv)																		
										371.02	65.74	3.39	1.26	301.11	1.83	9.09	14.21	17.18	2.46	13.58	2.90	3.28	4.38	2.96	169.59	1.79	4.77		37.61	302.91	55.35	81.79	1.86	2.02	11.91	3.63	124.81	12.95	44.07	20.54	19.20	12.48	48.28

REVISED FOR LWA LIMITS (cubic meters)									HYDROGEN	METHANE	BENZENE	BROMOFORM	CARBON TETRACHLORIDE	CHLOROBENZENE	CHLOROFORM	CYCLOHEXANE	1,1-DICHLOROETHANE	1,2-DICHLOROETHANE	1,1-DICHLOROETHYLENE	CIS-1,2-DICHLOROETHYLENE	TRANS-1,2-DICHLOROETHYLENE	ETHYL BENZENE	ETHYL ETHER	METHYLENE CHLORIDE	1,1,2,2-TETRACHLOROETHANE	TETRACHLOROETHYLENE	TOLUENE	1,1,1-TRICHLOROETHANE	TRICHLOROETHYLENE	1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE	1,2,4-TRIMETHYLBENZENE	1,3,5-TRIMETHYLBENZENE	M,P-XYLENE	O-XYLENE	ACETONE	BUTANOL	METHANOL	METHYL ETHYL KETONE	METHYL ISOBUTYL KETONE	METHYL CHLORIDE	CARBON DISULFIDE
Final Waste Forms	Stored volume	Projected volumes		Total Waste	Scaled Volumes	Weighting Factor			WEIGHTED CONCENTRATION FOR EACH WASTE FORM (ppmv)																			WEIGHTED CONCENTRATION FOR EACH WASTE FORM (ppmv)																		
Combustible	7100.00	27000.00		34100.00	46838.78	0.28			Combustible	94.33	11.09	1.19	0.32	12.31	0.56	2.97	8.24	10.04	0.79	5.70	1.12	1.32	2.22	0.93	128.10	0.47	1.98	Combustible	25.82	28.79	18.88	11.12	0.60	0.59	7.11	1.58	84.05	4.36	9.90	10.99	9.75	4.84	36.74
Filter	430.00	1100.00		1530.00	2101.56	0.01			Filter	7.47	1.47	0.02	0.01	0.27	0.01	0.03	0.01	0.08	0.01	0.15	0.01	0.01	0.01	0.01	0.08	0.01	0.01	Filter	0.08	1.47	0.26	0.18	0.01	0.01	0.01	0.01	0.40	0.11	0.31	0.11	0.11	0.15	0.01
Graphite	670.00	43.00		713.00	979.36	0.01			Graphite	0.41	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Graphite	0.01	0.19	0.05	0.00	0.00	0.00	0.00	0.00	0.08	0.02	0.06	0.01	0.01	0.34	0.00
Heterogeneous	30000.00	4600.00		34600.00	47525.57	0.28			Heterogeneous	155.77	24.06	0.63	0.31	2.36	0.41	0.61	1.64	1.44	0.45	1.16	0.40	0.40	0.49	0.45	6.24	0.44	0.62	Heterogeneous	1.86	13.53	2.53	1.53	0.34	0.34	0.93	0.50	8.49	3.20	5.58	2.78	2.92	2.75	0.45
Inorganic non-metal	1200.00	320.00		1520.00	2087.83	0.01			Inorganic non-metal	1.41	0.53	0.01	0.01	0.03	0.01	0.02	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	Inorganic non-metal	0.07	0.10	0.01	0.01	0.01	0.01	0.01	0.01	0.11	0.07	0.23	0.06	0.05	0.28	0.01
Lead/cadmium metal	56.00	130.00		186.00	255.48	0.00			Lead/cadmium metal	1.94	0.13	0.00	0.00	0.31	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	Lead/cadmium metal	0.01	0.11	0.01	0.01	0.00	0.00	0.00	0.00	0.06	0.02	0.02	0.01	0.01	0.04	0.00
Salt waste	33.00	60.00		93.00	127.74	0.00			Salt waste	0.33	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Salt waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soils	370.00	450.00		820.00	1126.33	0.01			Soils	0.72	0.70	0.01	0.01	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	Soils	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.07	0.05	0.08	0.06	0.04	0.00	0.01
Solidified inorganics	17000.00	8000.00		25000.00	34339.28	0.20			Solidified inorganics	85.00	19.37	0.25	0.21	2.34	0.20	0.23	0.55	1.96	0.19	3.41	0.23	0.32	0.46	0.22	0.46	0.23	0.91	Solidified inorganics	0.95	59.89	28.32	6.12	0.24	0.23	0.95	0.34	2.20	2.36	12.55	1.69	1.91	0.36	0.24
Solidified organics	1500.00	300.00		1800.00	2472.43	0.01			Solidified organics	3.78	0.80	0.99	0.34	341.73	0.59	5.28	2.12	1.12	0.96	1.93	0.99	0.99	0.63	1.30	1.29	0.58	0.91	Solidified organics	5.94	236.07	1.87	73.52	0.55	0.78	0.82	0.80	7.63	1.34	15.34	1.51	0.88	2.90	1.09
Uncategorized metal	12000.00	8600.00		20600.00	28295.57	0.17			Uncategorized metal	30.30	10.16	0.29	0.11	1.14	0.11	0.20	0.13	0.35	0.11	0.28	0.12	0.15	0.20	0.13	0.38	0.13	0.13	Uncategorized metal	1.47	3.47	0.51	0.29	0.11	0.11	0.52	0.22	2.26	1.25	1.87	1.25	1.71	0.73	0.11
Unknown	1700.00	0.00		1700.00	2335.07	0.01			Unknown																			Unknown																		
									TOTAL WEIGHTED CONCENTRATIONS (ppmv)																			TOTAL WEIGHTED CONCENTRATIONS (ppmv)																		
										381.46	68.54	3.38	1.31	360.56	1.88	9.38	12.75	15.06	2.53	12.81	2.88	3.21	4.02	3.05	136.59	1.88	4.57		31.22	343.64	52.45	92.78	1.88	2.08	10.37	3.47	105.35	12.78	45.94	18.48	17.40	12.40	38.67

			MW	930 DRUMS	RECALC WITH HSG DATA APP13	LWA	CRA																																					
Carbon tetrachloride			153.84	375.50	301.11	360.56	921.52																																				
1,1,2,2-Tetrachloroethane			167.86	9.35	1.79	1.88	4.76																																				
Chloroform			119.39	25.33	9.09	9.38	16.12																																				
1,2-Dichloroethane			98.96	9.07	17.18	2.53	3.77																																				
Methylene chloride			84.94	368.50	169.59	136.59	36.01																																				
Benzene			78.11	9.25	3.39	3.38	4.32																																				
Trichloroethylene			131.40	25.10	55.35	52.45	51.18																																				
Bromoform			252.77	9.38	1.26	1.31	1.84																																				
Tetrachloroethylene			165.85	9.40	4.77	4.57	5.07																																				
Vinyl chloride			62.50	0.16																																						
1, 1 ,2-Trichloroethane			133.42	0.07																																						
Chlorobenzene			112.56	12.52	1.83	1.88	2.67																																				
1,1,1 -Trichloroethane			133.40	317.10	302.91	343.64	739.81																																				
1, 1-Dichloroethylene			96.95	11.46	13.58	12.81	12.91																																				
Methyl ethyl ketone			72.10	63.66	20.54	18.48	13.79																																				
Toluene			92.13	19.40	37.61	31.22	12.23																																				
Carbon disulfide			76.14	0.13	48.28	38.67	10.49																																				
Trichlorofluoromethane			137.38	0.07																																						
(cis)-1, 2-Dichloroethylene			96.95	8.97	2.90	2.88	3.87																																				
Isobutanol			74.12	0.13																																						
1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE				33.00			208.93																																				
1,1-DICHLOROETHANE				10.20			9.89																																				
1,2,4-TRIMETHYLBENZENE				12.20			2.57																																				
1,3,5-TRIMETHYLBENZENE				8.60			3.15																																				
BUTANOL				78.10			13.77																																				
METHYL ISOBUTYL KETONE				79.00			12.39																																				
ACETONE				79.80			53.10																																				
CYCLOHEXANE				27.50			10.76																																				
ETHYL BENZENE				11.60			3.57																																				
ETHYL ETHER				13.30			4.76																																				
METHANOL				213.00			71.28																																				
O-XYLENE				16.00			3.80																																				
M,P-XYLENE				19.30			6.46																																				
METHYL CHLORIDE							15.58																																				
CARBON DISULFIDE							10.49																																				
TRANS-1,2-DICHLOROETHYLENE							4.07																																				

FILTER DIFFUSION RATE The rate at which VOCs will be emitted from containers is a function of the diffusion rate for the individual filter on the containers. These filters are placed on every container to prevent the buildup of hydrogen as the result of radiolysis. Diffusion is relevant for open rooms only. Closed rooms are assumed to be in equilibrium with the average VOC concentration in the containers. Container filters are specified with a hydrogen diffusion rate. The methodology for calculating the VOC diffusion rate based on the hydrogen rate is given in Chapter 5 of the 1996 No-Migration Variance Petition (U. S. Department of Energy, 1996 b).

This sheet contains input values taken for the analytes of interest. (Rows 15 to 50) The headspace concentration value are the revised weighted average which is an update to the values in the Permit Application in 1995. The diffusivity numbers are copied from column H and were calculated using the following formula from the Permit Application. Critical values were taken from compound specific searches of the Internet.

$$\frac{D_{VOC-air}}{D_{H_2-air}} = \left(\frac{P_{c,VOC}}{P_{c,H_2}}\right)^{1/3} \times \left(\frac{T_{c,VOC}}{T_{c,H_2}}\right)^{5/12} \times \left[\frac{\left(\frac{1}{MW_{air}} + \frac{1}{MW_{VOC}}\right)}{\left(\frac{1}{MW_{air}} + \frac{1}{MW_{H_2}}\right)}\right]^{1/2}$$

Compound	Mol Wt	Headspace Concentration (ppmv)	Diffusivity VOC-air (298.15 K, 1 atm)	Tc (K)	Pc (bar)	Pc (atm)	Diffusivity for specific compound (Use Permit Formula)
Hydrogen	2.02		0.758078	33.30	12.97	12.80	
Air	29.00			132.00	36.88	36.40	
Carbon Tetrachloride	153.82	921.5	0.078381	556.40	45.60	45.00	0.078381
Methylene Chloride	84.90	36.0	0.095732	510.00	60.80	60.00	0.095732
Chlorobenzene	112.56	2.7	0.075401	632.40	45.19	44.60	0.075401
Chloroform	119.39	16.1	0.086747	536.40	54.72	54.00	0.086747
1,1-Dichloroethylene	96.95	12.9	0.090757	495.00	51.98	51.30	0.090757
1,2-Dichloroethane	98.97	3.8	0.085942	561.50	53.70	53.00	0.085942
1,1,2,2-Tetrachloroethane	167.86	2.7	0.078545	644.50	58.36	57.60	0.078545
Toluene	92.13	12.2	0.077245	591.70	41.14	40.60	0.077245
1,1,1-Trichloroethane	133.42	739.8	0.078575	545.00	42.96	42.40	0.078575
Acetone	58.08	53.10	0.093721	508.00	48.00	47.37	0.093721
Benzene	78.11	4.30	0.084859	562.00	47.40	46.78	0.084859
Bromoform	252.73	1.8	0.066869	698.00	43.80	43.23	0.066869
Butanol	74.12	13.8	0.084007	562.00	45.00	44.41	0.084007
Carbon Disulfide	76.13	10.5	0.101875	552.00	79.00	77.97	0.101875
Cyclohexane	84.16	10.8	0.080441	554.00	40.70	40.17	0.080441
1,1-Dichloroethane	98.96	9.9	0.088633	502.70	49.90	49.25	0.088633
cis-1,2-Dichloroethylene	96.94	3.9	0.090883	545.00	60.30	59.51	0.090883
trans-1,2-Dichloroethylene	96.94	4.1	0.090883	545.00	60.30	59.51	0.090883
Ethyl Benzene	106.17	3.6	0.071910	616.00	37.00	36.52	0.071910
Ethyl Ether	74.12	4.8	0.085550	467.00	36.00	35.53	0.085550
Methanol	32.04	71.3	0.123861	513.00	78.50	77.47	0.123861
Methyl Chloride	50.49	15.6	0.103822	510.00	61.00	60.20	0.103822
Methyl Ethyl Ketone	72.11	13.8	0.085297	533.00	43.00	42.44	0.085297
Methyl Isobutyl Ketone	100.16	12.4	0.071618	571.00	32.00	31.58	0.071618
Tetrachloroethylene	165.83	5.1	0.095074	620.00	97.40	96.12	0.095074
Trichloroethylene	131.39	51.2	0.080663	573.00	49.90	49.25	0.080663
1,1,2-Trichloro-1,2,2-Trifluoroethane	102	208.9	0.087344	487.00	46.00	45.40	0.087344
1,2,4-Trimethlybenzene	120.2	2.6	0.066788	664.50	34.50	34.05	0.066788
1,3,5-Trimethylbenzene	120.2	3.2	0.066788	664.50	34.50	34.05	0.066788
m,p-Xylene	106.17	6.5	0.070533	617.00	35.00	34.54	0.070533
o-Xylene	106.17	3.8	0.070533	617.00	35.00	34.54	0.070533

INPUT PARAMETERS			VARIABLE
DRUMS PER ROOM	6050	DRUMS	nD
EFFECTIVE GAS GENERATION RATE	0.5	MOLES/DRUM/YEAR	GR
REPOSITORY VENTILATION RATE	425000	CUBIC FEET PER MINUTE	V_O
VENTILATION RATE AT VOC A	260000	CUBIC FEET PER MINUTE	$V_{E\text{-}300}$
PANEL VENTILATION RATE	130000	CUBIC FEET PER MINUTE	V_{PANEL}
PERMIT APPLICATION FILTER RATE	0.0000117	MOLE/S/MOLE FRACTION	D_{H2}
OPEN ROOMS IN A PANEL	1	ROOMS/PANEL	R_O
CLOSED ROOMS IN A PANEL	6	ROOMS/PANEL	R_C
CLOSED PANELS	9	PANELS	P_C
OPEN PANELS	1	PANELS	P_O
EXPOSURE FREQUENCY CARCINOGENS	8760	hours/year	EF_c
EXPOSURE FREQUENCY NON CARCINOGENS WORKER	1920	hours/year	EF_{nc}
EXPOSURE FREQUENCY NON CARCINOGENS PUBLIC	8760	hours/year	EF_{nc}
EXPOSURE DURATION CARCINOGENS	35	years	ED_c
EXPOSURE DURATION NON CARCINOGENS WORKER	10	years	ED_{nc}
EXPOSURE DURATION NON CARCINOGENS PUBLIC	35	years	ED_{nc}
AVERAGING TIME CARCINOGENS	613200	hours	AT_c
AVERAGING TIME NON CARCINOGENS WORKER	87600	hours	AT_{nc}
AVERAGING TIME NON CARCINOGENS PUBLIC	306600	hours	AT_{nc}

GAS GENERATION Appendix D11 of the 1996 Permit Application (U. S. Department of Energy, 1996 a) includes information on gas generation by WIPP waste. Of the gas-generating mechanisms described in Appendix D11, microbial degradation will contribute the most to the generation rate during the time periods of interest. The best estimate for gas generation from microbial degradation under humid conditions is 0.1 moles of gas per drum per year. Although Appendix D11 states that the maximum expected value for any one drum of waste is 0.4 moles per drum per year, the lowest expected value for any one drum is 0 moles per drum per year. A discussion of the relationship between gas generation, brine inflow, and creep closure can be found in Section I-1e(4). In reality, under the conditions that will initially exist in a closed panel, the predominant degradation mechanisms may consume gas at a rate faster than it is produced. This outcome is a function of the availability of nutrients to sustain microbial activities. Indications of gas consumption activities are in Francis and Gillow (Francis, A.J. and J.B. Gillow, 1994), where they reported 200-day experiments (see Appendix D11).

CREEP CLOSURE RATE The average creep closure rate will result in a reduction of the panel void volume of 812 m^3 per year for each panel. Calculations in Appendix D9 of the 1996 Permit Application (U. S. Department of Energy, 1996 a) convert this rate at which air is "squeezed" out of the room to an equivalent gas generation rate of 0.4 moles/drum/year.

EFFECTIVE GAS GENERATION RATE: The Effectve Gas Generation Rate is the Gas generation rate plus the Creep closure Rate converted to moles/drum/year.

These factor are as follows: For exposure to cancer causing compounds, the receptor is a member of the public. The exposure is 24 hours per day for 35 years. The exposure is averaged over 70 year lifetime. For exposure to non cancer causing compounds, the public receptor is exposed for 24 hours per day for 35 years and the exposure is averaged of the the duration of the exposure (35 years); for the worker inthe training building, the exposure is for 40 hours per week for 48 weeks per year for ten years and the exposure is averaged of the the duration of ten years.

THESE ARE THE FORMULAE USED IN THE CALCULATIONS. SEE THE NARRATIVE FOR FURTHER EXPLANATION.

HS_{VOC}

$MF_{VOC} = (HS_{VOC}) \times (10^{-6} \text{ mole fraction/ppmv})$

$D_{VOC} = \left(\frac{D_{VOC-air}}{D_{H_2-air}}\right) \times D_{H_2}$

$ADE = D_{VOC} \times MF_{VOC} \times 31{,}536{,}000 \text{ s/year}$

OPEN ROOM EMISSIONS The open room emission rate is dependent on the number of drums that have been emplaced in the room and the diffusion of VOCs across the drum vent filters. Assuming a continuous fresh air flow across the filters, VOCs will diffuse from the drums at a rate that is dependent on the concentration gradient across the filters and the diffusion properties of the VOCs. The open room emission rate is calculated using the equation below:

$AORE_{VOC} = ADE_{VOC} \times nD$

EMISSIONS FROM CLOSED ROOMS Using this effective gas generation rate for a room of containers that has the ventilation barrier in place, the closed room emission rate for each VOC is calculated as shown below:

$ACRE_{VOC} = (GR) \times (11{,}571 \text{ drum/roompanel}) \times MF_{VOC}$

EMISSIONS FROM OPEN PANELS The open panel emission rate for each VOC is based on the number of full rooms, the number of drums in the open room, and the emission rates from each type of room. This can be calculated as shown below:

$AOPE_{VOC} = (R_o \times AORE_{VOC}) + (R_{cr} \times ACRE_{VOC})$

EMISSIONS FROM CLOSED PANELS Volatile organic compounds will diffuse from the drums at a rate dependent on the concentration gradient across the filters. As the concentration gradient decreases, the diffusion rate of each VOC decreases. After a panel is closed, fresh air will no longer flow across the waste drums, and VOC concentrations in the air space above the filter will begin to build up and approach the concentrations in the drum headspace. Therefore, the concentration of VOCs that would be present in the panel atmosphere would be equivalent to the average drum headspace concentration. For a closed panel of N drums, the closed panel emission rate for each VOC is calculated as shown below:

$ACPE = (GR) \times (81{,}000 \text{ drums/panel}) \times MF_{VOC}$

The emission rate from the repository can then be calculated as the sum of the open panel and closed panel rates as folllows:

$EC_{VOC} = P_O \times AORE_{VOC} + P_C \times ACPE_{VOC}$

MW_{VOC}

$ER_{VOC} = EC_{VOC} \times MW_{VOC}/(454 \times 2{,}000)$

$ER_{VOC} = ER_{VOC} \times 2{,}000/(365 \times 24)$

This value (SXPE) is calculated by multiplying AOPE times the molecular weight times 1,000,000 micrograms per gram and dividing by the E-300 ventilation rate (260,000 scfm) times 525,600 minutes per year times 0.0283 cubic meters per cubic foot

This value (SCPE) is calculated by multiplying AOPE times the molecular weight times 1,000,000 micrograms per gram and dividing by the E-300 ventilation rate (260,000 scfm) times 525,600 minutes per year times 0.0283 cubic meters per cubic foot

This value is the concentration at VOC A and is SXPE plus 9 times SCPE

This value is the concentration at VOC A and is SXPE plus 9 times SCPE in ppbv

This is the concentration at VOC A for a full repository normalized to the ventilation rates assumed when the concentrations of concern were calculated (425,000 and 130,000).

SCENARIO: OBSERVED FILTER, WEIGHTED AVERAGE HEADSPACE CONCENTRATION EXCEPT FOR CARBON TETRACHLORIDE HAS MAXIMUM AVERAGE FOR ANY ROOM, ACTUAL AVERAGE NUMBER OF CONTAINERS

COMPOUND	AVERAGE CONCENTRATION (ppmv)	MOLE FRACTION	D_{VOC}[1] (mole/s/mole fraction/drum)	AVERAGE DRUM EMISSION RATE (mole/drum/year)	AVERAGE OPEN ROOM EMISSION RATE (mole/room/year)	AVERAGE CLOSED ROOM EMISSION RATE (mole/room/year)	AVERAGE OPEN PANEL EMISSION RATE (mole/panel/year)	AVERAGE CLOSED PANEL EMISSION RATE (mole/panel/year)	REPOSITORY EMISSION RATE (moles/year)	MOLECULAR WEIGHT (g/mole)	REPOSITORY EMISSION RATE (tons/year)	REPOSITORY EMISSION RATE (pounds/hour)	OPEN PANEL CONCENTRATION AT VOC A (ug/m^3)	SINGLE CLOSED PANEL CONCENTRATION AT VOC A (ug/m^3)	FULL REPOSITORY CONCENTRATION AT VOC A (ug/m^3)	FULL REPOSITORY CONCENTRATION AT VOC A (ppbv)	FULL REPOSITORY CONCENTRATION REALTIVE TO THE COMPLIANCE LIMIT (ppbv)
Carbon Tetrachloride	921.5	9.22E-04	1.29E-06	3.74E-02	226.47	2.79	243.20	19.51	4.19E+02	153.82	7.10E-02	1.62E-02	9.67	0.78	16.67	2.65	4.33
Methylene Chloride	36.0	3.60E-05	1.57E-06	1.79E-03	1.08E+01	1.09E-01	1.15E+01	7.63E-01	1.83E+01	84.94	1.72E-03	3.92E-04	0.25	0.02	0.40	0.12	0.38
Chlorobenzene	2.7	2.67E-06	1.24E-06	1.04E-04	6.31E-01	8.07E-03	6.79E-01	5.65E-02	1.19E+00	112.56	1.47E-04	3.36E-05	0.02	0.00	0.03	0.01	0.02
Chloroform	16.1	1.61E-05	1.43E-06	7.25E-04	4.38E+00	4.87E-02	4.68E+00	3.41E-01	7.75E+00	119.39	1.02E-03	2.33E-04	0.14	0.01	0.24	0.05	0.16
1,1-Dichloroethylene	12.9	1.29E-05	1.49E-06	6.07E-04	3.67E+00	3.90E-02	3.91E+00	2.73E-01	6.37E+00	96.95	6.80E-04	1.55E-04	0.10	0.01	0.16	0.04	0.13
1,2-Dichloroethane	3.8	3.77E-06	1.41E-06	1.68E-04	1.02E+00	1.14E-02	1.08E+00	7.99E-02	1.80E+00	98.97	1.97E-04	4.49E-05	0.03	0.00	0.05	0.01	0.04
1,1,2,2-Tetrachloroethane	2.7	2.75E-06	1.29E-06	1.12E-04	6.77E-01	8.31E-03	7.27E-01	5.82E-02	1.25E+00	167.86	2.31E-04	5.28E-05	0.03	0.00	0.05	0.01	0.03
Toluene	12.2	1.22E-05	1.27E-06	4.90E-04	2.96E+00	3.70E-02	3.18E+00	2.59E-01	5.51E+00	92.13	5.60E-04	1.28E-04	0.08	0.01	0.13	0.03	0.11
1,1,1-Trichloroethane	739.8	7.40E-04	1.29E-06	3.01E-02	1.82E+02	2.24E+00	1.96E+02	1.57E+01	3.37E+02	133.42	4.95E-02	1.13E-02	6.75	0.54	11.62	2.13	6.96
Acetone	53.1	5.31E-05	1.54E-06	2.58E-03	1.56E+01	1.61E-01	1.66E+01	1.12E+00	2.67E+01	58.08	1.71E-03	3.90E-04	0.25	0.02	0.40	0.17	0.55
Benzene	4.3	4.30E-06	1.39E-06	1.89E-04	1.14E+00	1.30E-02	1.22E+00	9.11E-02	2.04E+00	78.11	1.76E-04	4.01E-05	0.02	0.00	0.04	0.01	0.04
Bromoform	1.8	1.80E-06	1.10E-06	6.24E-05	3.77E-01	5.45E-03	4.10E-01	3.81E-02	7.53E-01	252.73	2.10E-04	4.79E-05	0.03	0.00	0.05	0.00	0.02
Butanol	13.8	1.38E-05	1.38E-06	6.01E-04	3.63E+00	4.17E-02	3.89E+00	2.92E-01	6.52E+00	74.12	5.32E-04	1.22E-04	0.07	0.01	0.12	0.04	0.13
Carbon Disulfide	10.5	1.05E+01	1.67E-06	5.54E-04	3.35E+00	3.18E-02	3.54E+00	3.81E-02	3.89E+00	76.13	3.26E-04	7.45E-05	0.07	0.00	0.08	0.02	0.08
Cyclohexane	10.8	1.08E-05	1.32E-06	4.50E-04	2.72E+00	3.27E-02	2.92E+00	2.29E-01	4.98E+00	84.16	4.62E-04	1.05E-04	0.06	0.00	0.11	0.03	0.10
1,1-Dichloroethane	9.9	9.90E-06	1.46E-06	4.55E-04	2.75E+00	2.99E-02	2.93E+00	2.10E-01	4.82E+00	98.96	5.26E-04	1.20E-04	0.07	0.01	0.12	0.03	0.10
cis-1,2-Dichloroethylene	3.9	3.90E-06	1.49E-06	1.84E-04	1.11E+00	1.18E-02	1.18E+00	8.26E-02	1.93E+00	96.94	2.06E-04	4.70E-05	0.03	0.00	0.05	0.01	0.04
trans-1,2-Dichloroethylene	4.1	4.10E-06	1.49E-06	1.93E-04	1.17E+00	1.24E-02	1.24E+00	8.68E-02	2.02E+00	96.94	2.16E-04	4.94E-05	0.03	0.00	0.05	0.01	0.04
Ethyl Benzene	3.6	3.60E-06	1.18E-06	1.34E-04	8.12E-01	1.09E-02	8.77E-01	7.62E-02	1.56E+00	106.17	1.83E-04	4.18E-05	0.02	0.00	0.04	0.01	0.03
Ethyl Ether	4.8	4.80E-06	1.41E-06	2.13E-04	1.29E+00	1.45E-02	1.37E+00	1.02E-01	2.29E+00	74.12	1.87E-04	4.27E-05	0.03	0.00	0.04	0.01	0.05
Methanol	71.3	7.13E-05	2.04E-06	4.58E-03	2.77E+01	2.16E-01	2.90E+01	1.51E+00	4.26E+01	32.04	1.50E-03	3.43E-04	0.24	0.01	0.35	0.27	0.88
Methyl Chloride	15.6	1.56E-05	1.71E-06	8.39E-04	5.08E+00	4.72E-02	5.36E+00	3.30E-01	8.33E+00	50.49	4.64E-04	1.06E-04	0.07	0.00	0.11	0.05	0.17
Methyl Ethyl Ketone	13.8	1.38E-05	1.40E-06	6.10E-04	3.69E+00	4.17E-02	3.94E+00	2.92E-01	6.57E+00	72.11	5.22E-04	1.19E-04	0.07	0.01	0.12	0.04	0.14
Methyl Isobutyl Ketone	12.4	1.24E-05	1.18E-06	4.60E-04	2.78E+00	3.75E-02	3.01E+00	2.63E-01	5.37E+00	100.16	5.93E-04	1.35E-04	0.08	0.01	0.14	0.03	0.11
Tetrachloroethylene	5.1	5.10E-06	1.56E-06	2.51E-04	1.52E+00	1.54E-02	1.61E+00	1.08E-01	2.58E+00	165.83	4.72E-04	1.08E-04	0.07	0.00	0.11	0.02	0.05
Trichloroethylene	51.2	5.12E-05	1.33E-06	2.14E-03	1.29E+01	1.55E-01	1.39E+01	1.08E+00	2.36E+01	131.39	3.42E-03	7.82E-04	0.47	0.04	0.80	0.15	0.49
1,1,2-Trichloro-1,2,2-Trifluoroethane	208.9	2.09E-04	1.44E-06	9.46E-03	5.72E+01	6.32E-01	6.10E+01	4.42E+00	1.01E+02	252.73	2.81E-02	6.41E-03	3.99	0.29	6.59	0.64	2.08
1,2,4-Trimethlybenzene	2.6	2.60E-06	1.10E-06	9.00E-05	5.44E-01	7.87E-03	5.92E-01	5.51E-02	1.09E+00	120.20	1.44E-04	3.29E-05	0.02	0.00	0.03	0.01	0.02
1,3,5-Trimethylbenzene	3.2	3.20E-06	1.10E-06	1.11E-04	6.70E-01	9.68E-03	7.28E-01	6.78E-02	1.34E+00	120.20	1.77E-04	4.05E-05	0.02	0.00	0.04	0.01	0.03
m,p-Xylene	6.5	6.50E-06	1.16E-06	2.38E-04	1.44E+00	1.97E-02	1.56E+00	1.38E-01	2.79E+00	106.17	3.27E-04	7.47E-05	0.04	0.00	0.08	0.02	0.06
o-Xylene	3.8	3.80E-06	1.16E-06	1.39E-04	8.40E-01	1.15E-02	9.09E-01	8.05E-02	1.63E+00	106.17	1.91E-04	4.36E-05	0.02	0.00	0.04	0.01	0.03
											1.66E-01	3.78E-02					

FILTER DIFFUSION RATE The rate at which VOCs will be emitted from containers is a function of the diffusion rate for the individual filter on the containers. These filters are placed on every container to prevent the buildup of hydrogen as the result of radiolysis. Diffusion is relevant for open rooms only. Closed rooms are assumed to be in equilibrium with the average VOC concentration in the containers. Container filters are specified with a hydrogen diffusion rate. The methodology for calculating the VOC diffusion rate based on the hydrogen rate is given in Chapter 5 of the 1996 No-Migration Variance Petition (U. S. Department of Energy, 1996 b).

Panel	Room	Inner Container Count	Outer Container Count	Outer Container Filter Count	Summation of Filter Diffusivity	Diffusivity/Filter	Diffusivity/Outer Container	
								0.078 0.758078
1	7	9,953	9,953	10,187	3.12E-02	3.06E-06	3.14E-06	
1	6	2,392	2,393	2,441	7.72E-03	3.16E-06	3.23E-06	
1	5	2,403	2,404	2,427	7.09E-03	2.92E-06	2.95E-06	
1	4	2,484	2,484	2,523	7.97E-03	3.16E-06	3.21E-06	
1	3	10,691	10,691	10,911	3.31E-02	3.03E-06	3.09E-06	
1	2	8,368	8,368	9,115	2.61E-02	2.86E-06	3.12E-06	
1	1	3,737	3,121	3,975	1.47E-02	3.70E-06	4.71E-06	
		40,028	39,414	41,579	1.28E-01	3.08E-06	3.24E-06	3.3544E-07
2	7	7,111	5,158	7,455	2.85E-02	3.82E-06	5.53E-06	
2	6	6,807	4,393	6,981	3.05E-02	4.37E-06	6.94E-06	
2	5	6,965	4,219	7,115	3.18E-02	4.47E-06	7.55E-06	
2	4	6,432	4,173	6,762	3.45E-02	5.10E-06	8.26E-06	
2	3	6,610	5,061	7,102	3.26E-02	4.58E-06	6.43E-06	
2	2	6,727	4,981	6,967	3.93E-02	5.64E-06	7.88E-06	
2	1	2,179	1,785	2,214	3.18E-02	1.43E-05	1.78E-05	
		42,831	29,770	44,596	2.29E-01	5.13E-06	7.69E-06	7.9495E-07
3	7	6,022	1,599	5,657	4.91E-02	8.67E-06	3.07E-05	
3	6	6,678	2,399	3,713	4.37E-02	1.18E-05	1.82E-05	
3	5	5,431	2,575	2,957	4.37E-02	1.48E-05	1.70E-05	
3	4	6,693	3,336	4,548	5.33E-02	1.17E-05	1.60E-05	
3	3	6,476	2,857	4,501	5.06E-02	1.12E-05	1.77E-05	
3	2	6,588	2,734	4,300	5.23E-02	1.22E-05	1.91E-05	
3	1	4,112	2,260	3,256	3.82E-02	1.17E-05	1.69E-05	
		42,000	17,760	28,932	3.31E-01	1.14E-05	1.86E-05	1.9261E-06
4	7	6,063	2,890	4,574	5.09E-02	1.11E-05	1.76E-05	
4	6	6,073	3,604	4,802	6.40E-02	1.33E-05	1.78E-05	
4	5	6,621	4,137	5,728	7.21E-02	1.26E-05	1.74E-05	
4	4	5,870	3,945	4,928	7.61E-02	1.54E-05	1.93E-05	
4	3	5,673	4,264	4,784	8.16E-02	1.70E-05	1.91E-05	
4	2	5,535	4,687	5,236	8.93E-02	1.71E-05	1.91E-05	
4	1	3,545	3,035	3,280	5.72E-02	1.74E-05	1.89E-05	
		39,380	26,562	33,332	4.91E-01	1.47E-05	1.85E-05	1.9121E-06
5	7	6,512	5,576	6,169	1.07E-01	1.74E-05	1.92E-05	
5	6	6,568	5,945	6,442	1.19E-01	1.85E-05	2.00E-05	
5	5	6,332	5,442	6,023	1.03E-01	1.71E-05	1.89E-05	
5	4	6,524	3,972	4,423	6.85E-02	1.55E-05	1.73E-05	
5	3	7,223	4,331	5,120	8.31E-02	1.62E-05	1.92E-05	
5	2	7,088	5,195	6,370	1.05E-01	1.66E-05	2.03E-05	
5	1	5,007	3,997	4,449	7.81E-02	1.76E-05	1.96E-05	
		45,254	34,458	38,996	6.65E-01	1.70E-05	1.93E-05	1.994E-06
			147964	187435	1.8433428	9.83457E-06	1.2458E-05	1.2881E-06
	Filters per container			1.26676083				

NUMBER OF CONTAINERS The original assumption was that each Panel would contain 81,000 containers. This number is important because emissions are related to the filter diffusivity associated with each container; therefore the number of filters emitting VOCs to a room that is being filled is part of the calculation of releases. Closed rooms are unventilated and are conservatively assumed to be at the average concentration of the containers that were disposed and emissions are only related to the gas generation rate and creep closure rate (i.e., equivalent gas generation rate). The following is a compilation of the number of containers disposed by Panel, inlcuding Room 7 of Panel 6. A room is considered to have 567 linear feet of disposal space. Since Room 1 only has 367 feet (i.e., no waste is placed in the intake or exhaust drifts, a full panel is considered to have 6.7 Rooms

WIPP DISPOSAL VOLUMES (cubic meters)
(as of January 14, 2012)

Container Type	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6	Panel 7	Panel 8	Panel 9	Panel 10	Totals
55-gal. Drums	38,139	23,865	8,394	12,858	21,255	6,339					110,850
Volume	8,009.19	5,011.65	1,762.74	2,700.18	4,463.55	1,331.19					23,278.50
SWB	1,239	3,176	1,730	1,405	2,200	741					10,491
Volume	2,329.32	5,970.88	3,252.40	2,641.40	4,136.00	1,393.08					19,723.08
TDOPS	35	1,451	2,227	1,048	788	131					5,680
Volume	157.50	6,529.50	10,021.50	4,716.00	3,546.00	589.50					25,560.00
85-gal drums	2	0	0	3	0	0					5
Volume	0.64	0.00	0.00	0.96	0.00	0.00					1.60
100-gal. Drums	0	1,278	5,409	11,050	9,951	1,218					28,906
Volume	0.00	485.64	2,055.42	4,199.00	3,781.38	462.84					10,984.28
SLB2s	0	0	0	0	0	5					5
Volume	0.00	0.00	0.00	0.00	0.00	36.95					36.95

	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6	Container Total	55-gallon Eq
55-Gallon Drum	38,139	23,865	8,394	12,858	21,255	6,339	110,850	110,850
Standard Waste Boxes	1,239	3,176	1,730	1,405	2,200	741	10,491	41,964
10-Drum Overpack	35	1,451	2,227	1,048	788	131	5,680	56,800
85-Gallon Drum	2	0	0	3	0	0	5	9
100-Gallon Drum	0	1,278	5,409	11,050	9,951	1,218	28,906	67,447
Standard Large Box 2	0	0	0	0	0	5	5	100
Panel Total	39,415	29,770	17,760	26,364	34,194	5,376	152,879	277,170
Rooms per Panel	4.8	6.5	6.6	6.6	6.6	1.0	32.0	32
Containers per Room	8211	4580	2691	3995	5181	5376	4777	8635
Filters per rRoom	10402	5802	3409	5060	6563	6810	6052	

VOC	Mol Wt (g/mole)	Drum Headspace Concentration (ppmv)	Drum Headspace Concentration (mole fraction)	Diffusivity VOC-air (298.15 K, 1 atm Slattery & Bird)	Diffusivity H2-air (298.15 K, 1 atm Slattery & Bird)	Filter Model on Container	Filter Diffusivity for Hydrogen	VOC Filter Diffusivity Coefficient (mole/sec/mf)	VOC Emission Rate per Drum (mole/sec)	Drums per Room	VOC Emission Rate per Room (mole/sec)	Open Room Emission (mole/room/year)	Effective Gas Generation Rate (mole/drum/year)	Closed Room Emission (mole/room/year)	Open Panel Emission (mole/panel/year)	VOC Emission Rate per Open Panel (g/panel/year)	VOC Emission Rate per Open Panel (tons/panel/year)	Closed Panel Emission Rate (moles/panel/year)	Closed Panel Emission Rate (tons/panel/year)	Maximum Repository Emission Rate (tons/year)
BASE CASE--WEIGHTED AVERAGE HEADSPACE CONCENTRATION																				
Carbon Tetrachloride	153.82	921.5209517	0.00092	0.07838	0.75808	1/2 X	1.90E-06	1.96E-07	1.81E-10	6,050	1.095E-06	3.454E+01	0.5	2.79E+00	5.127E+01	7886	0.009	19.513	##################	3.84E-02
Carbon Tetrachloride	153.82	921.5209517	0.00092	0.07838	0.75808	1 X	3.70E-06	3.83E-07	3.53E-10	6,050	2.133E-06	6.726E+01	0.5	2.79E+00	8.399E+01	12919	0.014	19.513	##################	4.40E-02
Carbon Tetrachloride	153.82	921.5209517	0.00092	0.07838	0.75808	2X	7.40E-06	7.65E-07	7.05E-10	6,050	4.266E-06	1.345E+02	0.5	2.79E+00	1.512E+02	23265	0.026	19.513	##################	5.54E-02
Carbon Tetrachloride	153.82	921.5209517	0.00092	0.07838	0.75808	5X	1.85E-05	1.91E-06	1.76E-09	6,050	1.066E-05	3.363E+02	0.5	2.79E+00	3.530E+02	54304	0.060	19.513	##################	8.96E-02
Carbon Tetrachloride	153.82	375.5	0.00038	0.07838	0.75808	APPLICATION	1.17E-05	1.21E-06	4.54E-10	6,050	2.748E-06	8.667E+01	0.5	1.14E+00	9.348E+01	14380	0.016	7.951	##################	2.80E-02
Carbon Tetrachloride	153.82	921.52	0.00092	0.07838	0.75808	N/A	1.2458E-05	1.29E-06	1.19E-09	6,050	7.181E-06	2.265E+02	0.5	2.79E+00	2.432E+02	37409	0.041	19.513	##################	7.09E-02
Methylene Chloride	84.90	36.01012462	0.00004	0.09573	0.75808	1/2 X	1.90E-06	2.40E-07	8.64E-12	6,050	5.227E-08	1.648E+00	0.5	1.09E-01	2.302E+00	195	0.000	0.763	##################	8.57E-04
Methylene Chloride	84.90	36.01012462	0.00004	0.09573	0.75808	1 X	3.70E-06	4.67E-07	1.68E-11	6,050	1.018E-07	3.210E+00	0.5	1.09E-01	3.864E+00	328	0.000	0.763	##################	1.00E-03
Methylene Chloride	84.90	36.01012462	0.00004	0.09573	0.75808	2X	7.40E-06	9.34E-07	3.37E-11	6,050	2.036E-07	6.420E+00	0.5	1.09E-01	7.074E+00	601	0.001	0.763	##################	1.30E-03
Methylene Chloride	84.90	36.01012462	0.00004	0.09573	0.75808	5X	1.85E-05	2.34E-06	8.41E-11	6,050	5.090E-07	1.605E+01	0.5	1.09E-01	1.670E+01	1418	0.002	0.763	##################	2.20E-03
Methylene Chloride	84.90	369	0.00037	0.09573	0.75808	APPLICATION	1.17E-05	1.48E-06	5.45E-10	6,050	3.298E-06	1.040E+02	0.5	1.12E+00	1.107E+02	9400	0.010	7.814	##################	1.69E-02
Methylene Chloride	84.90	36.01012462	0.00004	0.09573	0.75808	N/A	1.2458E-05	1.57E-06	5.67E-11	6,050	3.427E-07	1.081E+01	0.5	1.09E-01	1.146E+01	973	0.001	0.763	##################	1.71E-03
Chlorobenzene	112.56	2.667728853	0.00000	0.07540	0.75808	1/2 X	1.90E-06	1.89E-07	5.04E-13	6,050	3.050E-09	9.619E-02	0.5	8.07E-03	1.446E-01	16	0.000	0.056	##################	0.0
Chlorobenzene	112.56	2.667728853	0.00000	0.07540	0.75808	1 X	3.70E-06	3.68E-07	9.82E-13	6,050	5.940E-09	1.873E-01	0.5	8.07E-03	2.357E-01	27	0.000	0.056	##################	0.0
Chlorobenzene	112.56	2.667728853	0.00000	0.07540	0.75808	2X	7.40E-06	7.36E-07	1.96E-12	6,050	1.188E-08	3.746E-01	0.5	8.07E-03	4.230E-01	48	0.000	0.056	##################	0.0
Chlorobenzene	112.56	2.667728853	0.00000	0.07540	0.75808	5X	1.85E-05	1.84E-06	4.91E-12	6,050	2.970E-08	9.366E-01	0.5	8.07E-03	9.850E-01	111	0.000	0.056	##################	0.0
Chlorobenzene	112.56	12.5	0.00001	0.07540	0.75808	APPLICATION	1.17E-05	1.16E-06	1.45E-11	6,050	8.801E-08	2.775E+00	0.5	3.78E-02	3.002E+00	338	0.000	0.265	##################	0.0
Chlorobenzene	112.56	2.667728853	0.00000	0.07540	0.75808	N/A	1.2458E-05	1.24E-06	3.31E-12	6,050	2.000E-08	6.307E-01	0.5	8.07E-03	6.791E-01	76	0.000	0.056	##################	1.47E-04
Chloroform	119.39	16.11566606	0.00002	0.08675	0.75808	1/2 X	1.90E-06	2.17E-07	3.50E-12	6,050	2.120E-08	6.685E-01	0.5	4.87E-02	9.610E-01	115	0.000	0.341	##################	0.0
Chloroform	119.39	16.11566606	0.00002	0.08675	0.75808	1 X	3.70E-06	4.23E-07	6.82E-12	6,050	4.128E-08	1.302E+00	0.5	4.87E-02	1.594E+00	190	0.000	0.341	##################	0.0
Chloroform	119.39	16.11566606	0.00002	0.08675	0.75808	2X	7.40E-06	8.47E-07	1.36E-11	6,050	8.256E-08	2.604E+00	0.5	4.87E-02	2.896E+00	346	0.000	0.341	##################	0.0
Chloroform	119.39	16.11566606	0.00002	0.08675	0.75808	5X	1.85E-05	2.12E-06	3.41E-11	6,050	2.064E-07	6.509E+00	0.5	4.87E-02	6.802E+00	812	0.001	0.341	##################	0.0
Chloroform	119.39	25.3	0.00003	0.08675	0.75808	APPLICATION	1.17E-05	1.34E-06	3.39E-11	6,050	2.049E-07	6.463E+00	0.5	7.65E-02	6.922E+00	826	0.001	0.536	##################	0.0
Chloroform	119.39	16.11566606	0.00002	0.08675	0.75808	N/A	1.2458E-05	1.43E-06	2.30E-11	6,050	1.390E-07	4.383E+00	0.5	4.87E-02	4.676E+00	558	0.001	0.341	##################	1.02E-03
1,1-Dichloroethylene	96.95	12.90707145	0.00001	0.09076	0.75808	1/2 X	1.90E-06	2.27E-07	2.94E-12	6,050	1.776E-08	5.602E-01	0.5	3.90E-02	7.944E-01	77	0.000	0.273	##################	0.0
1,1-Dichloroethylene	96.95	12.90707145	0.00001	0.09076	0.75808	1 X	3.70E-06	4.43E-07	5.72E-12	6,050	3.459E-08	1.091E+00	0.5	3.90E-02	1.325E+00	128	0.000	0.273	##################	0.0
1,1-Dichloroethylene	96.95	12.90707145	0.00001	0.09076	0.75808	5X	1.85E-05	2.21E-06	2.86E-11	6,050	1.730E-07	5.454E+00	0.5	3.90E-02	5.688E+00	551	0.001	0.273	##################	0.0
1,1-Dichloroethylene	96.95	11.5	0.00001	0.09076	0.75808	APPLICATION	1.17E-05	1.40E-06	1.61E-11	6,050	9.746E-08	3.073E+00	0.5	3.48E-02	3.282E+00	318	0.000	0.244	##################	0.0
1,1-Dichloroethylene	96.95	12.90707145	0.00001	0.09076	0.75808	N/A	1.2458E-05	1.49E-06	1.93E-11	6,050	1.165E-07	3.673E+00	0.5	3.90E-02	3.907E+00	379	0.000	0.273	##################	6.80E-04
1,2-Dichloroethane	98.97	3.771454853	0.00000	0.08594	0.75808	1/2 X	1.90E-06	2.15E-07	8.12E-13	6,050	4.915E-09	1.550E-01	0.5	1.14E-02	2.234E-01	22	0.000	0.080	##################	0.0
1,2-Dichloroethane	98.97	3.771454853	0.00000	0.08594	0.75808	1 X	3.70E-06	4.19E-07	1.58E-12	6,050	9.571E-09	3.018E-01	0.5	1.14E-02	3.703E-01	37	0.000	0.080	##################	0.0
1,2-Dichloroethane	98.97	3.771454853	0.00000	0.08594	0.75808	2X	7.40E-06	8.39E-07	3.16E-12	6,050	1.914E-08	6.037E-01	0.5	1.14E-02	6.721E-01	67	0.000	0.080	##################	0.0
1,2-Dichloroethane	98.97	3.771454853	0.00000	0.08594	0.75808	5X	1.85E-05	2.10E-06	7.91E-12	6,050	4.785E-08	1.509E+00	0.5	1.14E-02	1.578E+00	156	0.000	0.080	##################	0.0
1,2-Dichloroethane	98.97	9.1	0.00001	0.08594	0.75808	APPLICATION	1.17E-05	1.33E-06	1.21E-11	6,050	7.303E-08	2.303E+00	0.5	2.75E-02	2.468E+00	244	0.000	0.193	##################	0.0
1,2-Dichloroethane	98.97	3.771454853	0.00000	0.08594	0.75808	N/A	1.2458E-05	1.41E-06	5.33E-12	6,050	3.223E-08	1.016E+00	0.5	1.14E-02	1.085E+00	107	0.000	0.080	##################	1.97E-04
1,1,2,2-Tetrachloroethane	167.86	2.748672093	0.00000	0.07855	0.75808	1/2 X	1.90E-06	1.97E-07	5.41E-13	6,050	3.274E-09	1.032E-01	0.5	8.31E-03	1.531E-01	26	0.000	0.058	##################	0.0
1,1,2,2-Tetrachloroethane	167.86	2.748672093	0.00000	0.07855	0.75808	1 X	3.70E-06	3.83E-07	1.05E-12	6,050	6.375E-09	2.010E-01	0.5	8.31E-03	2.509E-01	42	0.000	0.058	##################	0.0
1,1,2,2-Tetrachloroethane	167.86	2.748672093	0.00000	0.07855	0.75808	2X	7.40E-06	7.67E-07	2.11E-12	6,050	1.275E-08	4.021E-01	0.5	8.31E-03	4.520E-01	76	0.000	0.058	##################	0.0
1,1,2,2-Tetrachloroethane	167.86	2.748672093	0.00000	0.07855	0.75808	5X	1.85E-05	1.92E-06	5.27E-12	6,050	3.188E-08	1.005E+00	0.5	8.31E-03	1.055E+00	177	0.000	0.058	##################	0.0
1,1,2,2-Tetrachloroethane	167.86	9.4	0.00001	0.07855	0.75808	APPLICATION	1.17E-05	1.21E-06	1.14E-11	6,050	6.894E-08	2.174E+00	0.5	2.84E-02	2.345E+00	394	0.000	0.199	##################	0.0
1,1,2,2-Tetrachloroethane	167.86	2.748672093	0.00000	0.07855	0.75808	N/A	1.2458E-05	1.29E-06	3.55E-12	6,050	2.147E-08	6.769E-01	0.5	8.31E-03	7.268E-01	122	0.000	0.058	##################	2.31E-04
Toluene	92.13	12.23011667	0.00001	0.07724	0.75808	1/2 X	1.90E-06	1.94E-07	2.37E-12	6,050	1.432E-08	4.518E-01	0.5	3.70E-02	6.737E-01	62	0.000	0.259	##################	0.0
Toluene	92.13	12.23011667	0.00001	0.07724	0.75808	1 X	3.70E-06	3.77E-07	4.61E-12	6,050	2.790E-08	8.797E-01	0.5	3.70E-02	1.102E+00	102	0.000	0.259	##################	0.0
Toluene	92.13	12.23011667	0.00001	0.07724	0.75808	2X	7.40E-06	7.54E-07	9.22E-12	6,050	5.579E-08	1.759E+00	0.5	3.70E-02	1.981E+00	183	0.000	0.259	##################	0.0
Toluene	92.13	12.23011667	0.00001	0.07724	0.75808	5X	1.85E-05	1.89E-06	2.31E-11	6,050	1.395E-07	4.399E+00	0.5	3.70E-02	4.621E+00	426	0.000	0.259	##################	0.0
Toluene	92.13	19.4	0.00002	0.07724	0.75808	APPLICATION	1.17E-05	1.19E-06	2.31E-11	6,050	1.399E-07	4.413E+00	0.5	5.87E-02	4.765E+00	439	0.000	0.411	##################	0.0
Toluene	92.13	12.23011667	0.00001	0.07724	0.75808	N/A	1.2458E-05	1.27E-06	1.55E-11	6,050	9.393E-08	2.962E+00	0.5	3.70E-02	3.184E+00	293	0.000	0.259	##################	5.60E-04
1,1,1-Trichloroethane	133.42	739.815	0.00074	0.07858	0.75808	1/2 X	1.90E-06	1.97E-07	1.46E-10	6,050	8.815E-07	2.780E+01	0.5	2.24E+00	4.123E+01	5500	0.006	15.666	##################	0.0
1,1,1-Trichloroethane	133.42	739.815	0.00074	0.07858	0.75808	1 X	3.70E-06	3.84E-07	2.84E-10	6,050	1.717E-06	5.413E+01	0.5	2.24E+00	6.756E+01	9014	0.010	15.666	##################	0.0
1,1,1-Trichloroethane	133.42	739.815	0.00074	0.07858	0.75808	2X	7.40E-06	7.67E-07	5.67E-10	6,050	3.433E-06	1.083E+02	0.5	2.24E+00	1.217E+02	16236	0.018	15.666	##################	0.0
1,1,1-Trichloroethane	133.42	739.815	0.00074	0.07858	0.75808	5X	1.85E-05	1.92E-06	1.42E-09	6,050	8.583E-06	2.707E+02	0.5	2.24E+00	2.841E+02	37903	0.042	15.666	##################	0.1
1,1,1-Trichloroethane	133.42	317	0.00032	0.07858	0.75808	APPLICATION	1.17E-05	1.21E-06	3.84E-10	6,050	2.326E-06	7.335E+01	0.5	9.59E-01	7.910E+01	10553	0.012	6.712	##################	0.0
1,1,1-Trichloroethane	133.42	739.815	0.00074	0.07858	0.75808	N/A	1.2458E-05	1.29E-06	9.55E-10	6,050	5.780E-06	1.823E+02	0.5	2.24E+00	1.957E+02	26109	0.029	15.666	##################	4.95E-02
Acetone	58.08	53.1	0.00005	0.09372	0.75808	1/2 X	1.90E-06	2.35E-07	1.25E-11	6,050	7.546E-08	2.380E+00	0.5	1.61E-01	3.344E+00	194	0.000	1.124	##################	0.0
Acetone	58.08	53.1	0.00005	0.09372	0.75808	1 X	3.70E-06	4.57E-07	2.43E-11	6,050	1.470E-07	4.634E+00	0.5	1.61E-01	5.598E+00	325	0.000	1.124	##################	0.0
Acetone	58.08	53.1	0.00005	0.09372	0.75808	2X	7.40E-06	9.15E-07	4.86E-11	6,050	2.939E-07	9.269E+00	0.5	1.61E-01	1.023E+01	594	0.001	1.124	##################	0.0
Acetone	58.08	53.1	0.00005	0.09372	0.75808	5X	1.85E-05	2.29E-06	1.21E-10	6,050	7.348E-07	2.317E+01	0.5	1.61E-01	2.414E+01	1402	0.002	1.124	##################	0.0

VOC	Mol Wt (g/mole)	Drum Headspace Concentration (ppmv)	Drum Headspace Concentration (mole fraction)	Diffusivity VOC-air (298.15 K, 1 atm Slattery & Bird)	Diffusivity H2-air (298.15 K, 1 atm Slattery & Bird)	Filter Model on Container	Filter Diffusivity for Hydrogen	VOC Filter Diffusivity Coefficient (mole/sec/mf)	VOC Emission Rate per Drum (mole/sec)	Drums per Room	VOC Emission Rate per Room (mole/sec)	Open Room Emission (mole/room/year)	Effective Gas Generation Rate (mole/drum/year)	Closed Room Emission (mole/room/year)	Open Panel Emission (mole/panel/year)	VOC Emission Rate per Open Panel (g/panel/year)	VOC Emission Rate per Open Panel (tons/panel/year)	Closed Panel Emission Rate (moles/panel/year)	Closed Panel Emission Rate (tons/panel/year)	Maximum Repository Emission Rate (tons/year)
Acetone	58.08	79.8	0.00008	0.09372	0.75808	APPLICATION	1.17E-05	1.45E-06	1.15E-10	6,050	6.983E-07	2.202E+01	0.5	2.41E-01	2.347E+01	1363	0.002	1.690	##################	0.0
Acetone	58.08	53.1	0.00005	0.09372	0.75808	N/A	1.2458E-05	1.54E-06	8.18E-11	6,050	4.948E-07	1.560E+01	0.5	1.61E-01	1.657E+01	962	0.001	1.124	##################	1.71E-03
Benzene	78.11	4.30	0.00000	0.08486	0.75808	1/2 X	1.90E-06	2.13E-07	9.15E-13	6,050	5.533E-09	1.745E-01	0.5	1.30E-02	2.525E-01	20	0.000	0.091	##################	0.0
Benzene	78.11	4.3	0.00000	0.08486	0.75808	1 X	3.70E-06	4.14E-07	1.78E-12	6,050	1.077E-08	3.398E-01	0.5	1.30E-02	4.178E-01	33	0.000	0.091	##################	0.0
Benzene	78.11	4.3	0.00000	0.08486	0.75808	2X	7.40E-06	8.28E-07	3.56E-12	6,050	2.155E-08	6.796E-01	0.5	1.30E-02	7.576E-01	59	0.000	0.091	##################	0.0
Benzene	78.11	4.3	0.00000	0.08486	0.75808	5X	1.85E-05	2.07E-06	8.90E-12	6,050	5.387E-08	1.699E+00	0.5	1.30E-02	1.777E+00	139	0.000	0.091	##################	0.0
Benzene	78.11	9.3	0.00001	0.08486	0.75808	APPLICATION	1.17E-05	1.31E-06	1.22E-11	6,050	7.369E-08	2.324E+00	0.5	2.81E-02	2.493E+00	195	0.000	0.197	##################	0.0
Benzene	78.11	4.3	0.00000	0.08486	0.75808	N/A	1.2458E-05	1.39E-06	6.00E-12	6,050	3.628E-08	1.144E+00	0.5	1.30E-02	1.222E+00	95	0.000	0.091	##################	1.76E-04
Bromoform	252.73	1.8	0.00000	0.06687	0.75808	1/2 X	1.90E-06	1.68E-07	3.02E-13	6,050	1.825E-09	5.756E-02	0.5	5.45E-03	9.023E-02	23	0.000	0.038	##################	0.0
Bromoform	252.73	1.8	0.00000	0.06687	0.75808	1 X	3.70E-06	3.26E-07	5.87E-13	6,050	3.554E-09	1.121E-01	0.5	5.45E-03	1.448E-01	37	0.000	0.038	##################	0.0
Bromoform	252.73	1.8	0.00000	0.06687	0.75808	2X	7.40E-06	6.53E-07	1.17E-12	6,050	7.108E-09	2.242E-01	0.5	5.45E-03	2.568E-01	65	0.000	0.038	##################	0.0
Bromoform	252.73	1.8	0.00000	0.06687	0.75808	5X	1.85E-05	1.63E-06	2.94E-12	6,050	1.777E-08	5.604E-01	0.5	5.45E-03	5.931E-01	150	0.000	0.038	##################	0.0
Bromoform	252.73	9.4	0.00001	0.06687	0.75808	APPLICATION	1.17E-05	1.03E-06	9.70E-12	6,050	5.869E-08	1.851E+00	0.5	2.84E-02	2.022E+00	511	0.001	0.199	##################	0.0
Bromoform	252.73	1.8	0.00000	0.06687	0.75808	N/A	1.2458E-05	1.10E-06	1.98E-12	6,050	1.197E-08	3.774E-01	0.5	5.45E-03	4.101E-01	104	0.000	0.038	##################	2.10E-04
Butanol	74.12	13.8	0.00001	0.08401	0.75808	1/2 X	1.90E-06	2.11E-07	2.91E-12	6,050	1.758E-08	5.544E-01	0.5	4.17E-02	8.048E-01	60	0.000	0.292	##################	0.0
Butanol	74.12	13.8	0.00001	0.08401	0.75808	1 X	3.70E-06	4.10E-07	5.66E-12	6,050	3.423E-08	1.080E+00	0.5	4.17E-02	1.330E+00	99	0.000	0.292	##################	0.0
Butanol	74.12	13.8	0.00001	0.08401	0.75808	2X	7.40E-06	8.20E-07	1.13E-11	6,050	6.846E-08	2.159E+00	0.5	4.17E-02	2.410E+00	179	0.000	0.292	##################	0.0
Butanol	74.12	13.8	0.00001	0.08401	0.75808	5X	1.85E-05	2.05E-06	2.83E-11	6,050	1.712E-07	5.398E+00	0.5	4.17E-02	5.648E+00	419	0.000	0.292	##################	0.0
Butanol	74.12	78.1	0.00008	0.08401	0.75808	APPLICATION	1.17E-05	1.30E-06	1.01E-10	6,050	6.126E-07	1.932E+01	0.5	2.36E-01	2.074E+01	1537	0.002	1.654	##################	0.0
Butanol	74.12	13.8	0.00001	0.08401	0.75808	N/A	1.2458E-05	1.38E-06	1.91E-11	6,050	1.153E-07	3.635E+00	0.5	4.17E-02	3.885E+00	288	0.000	0.292	##################	5.32E-04
Carbon Disulfide	76.13	10.5	0.00001	0.10187	0.75808	1/2 X	1.90E-06	2.55E-07	2.68E-12	6,050	1.622E-08	5.115E-01	0.5	3.18E-02	7.021E-01	53	0.000	0.222	##################	0.0
Carbon Disulfide	76.13	10.5	0.00001	0.10187	0.75808	1 X	3.70E-06	4.97E-07	5.22E-12	6,050	3.159E-08	9.961E-01	0.5	3.18E-02	1.187E+00	90	0.000	0.222	##################	0.0
Carbon Disulfide	76.13	10.5	0.00001	0.10187	0.75808	2X	7.40E-06	9.94E-07	1.04E-11	6,050	6.317E-08	1.992E+00	0.5	3.18E-02	2.183E+00	166	0.000	0.222	##################	0.0
Carbon Disulfide	76.13	10.5	0.00001	0.10187	0.75808	5X	1.85E-05	2.49E-06	2.61E-11	6,050	1.579E-07	4.981E+00	0.5	3.18E-02	5.171E+00	394	0.000	0.222	##################	0.0
Carbon Disulfide	76.13	0	0.00000	0.10187	0.75808	APPLICATION	1.17E-05	1.57E-06	0.00E+00	6,050	0.000E+00	0.000E+00	0.5	0.00E+00	0.000E+00	0	0.000	0.000	##################	0.0
Carbon Disulfide	76.13	10.5	0.00001	0.10187	0.75808	N/A	1.2458E-05	1.67E-06	1.76E-11	6,050	1.064E-07	3.354E+00	0.5	3.18E-02	3.545E+00	270	0.000	0.222	##################	4.65E-04
Cyclohexane	84.16	10.8	0.00001	0.08044	0.75808	1/2 X	1.90E-06	2.02E-07	2.18E-12	6,050	1.317E-08	4.154E-01	0.5	3.27E-02	6.115E-01	51	0.000	0.229	##################	0.0
Cyclohexane	84.16	10.8	0.00001	0.08044	0.75808	1 X	3.70E-06	3.93E-07	4.24E-12	6,050	2.565E-08	8.090E-01	0.5	3.27E-02	1.005E+00	85	0.000	0.229	##################	0.0
Cyclohexane	84.16	10.8	0.00001	0.08044	0.75808	2X	7.40E-06	7.85E-07	8.48E-12	6,050	5.131E-08	1.618E+00	0.5	3.27E-02	1.814E+00	153	0.000	0.229	##################	0.0
Cyclohexane	84.16	10.8	0.00001	0.08044	0.75808	5X	1.85E-05	1.96E-06	2.12E-11	6,050	1.283E-07	4.045E+00	0.5	3.27E-02	4.241E+00	357	0.000	0.229	##################	0.0
Cyclohexane	84.16	27.5	0.00003	0.08044	0.75808	APPLICATION	1.17E-05	1.24E-06	3.41E-11	6,050	2.066E-07	6.514E+00	0.5	8.32E-02	7.013E+00	590	0.001	0.582	##################	0.0
Cyclohexane	84.16	10.8	0.00001	0.08044	0.75808	N/A	1.2458E-05	1.32E-06	1.43E-11	6,050	8.638E-08	2.724E+00	0.5	3.27E-02	2.920E+00	246	0.000	0.229	##################	4.61E-04
1,1-Dichloroethane	98.96	9.9	0.00001	0.08863	0.75808	1/2 X	1.90E-06	2.22E-07	2.20E-12	6,050	1.331E-08	4.196E-01	0.5	2.99E-02	5.993E-01	59	0.000	0.210	##################	0.0
1,1-Dichloroethane	98.96	9.9	0.00001	0.08863	0.75808	1 X	3.70E-06	4.33E-07	4.28E-12	6,050	2.591E-08	8.171E-01	0.5	2.99E-02	9.968E-01	99	0.000	0.210	##################	0.0
1,1-Dichloroethane	98.96	9.9	0.00001	0.08863	0.75808	2X	7.40E-06	8.65E-07	8.57E-12	6,050	5.182E-08	1.634E+00	0.5	2.99E-02	1.814E+00	180	0.000	0.210	##################	0.0
1,1-Dichloroethane	98.96	9.9	0.00001	0.08863	0.75808	5X	1.85E-05	2.16E-06	2.14E-11	6,050	1.296E-07	4.086E+00	0.5	2.99E-02	4.265E+00	422	0.000	0.210	##################	0.0
1,1-Dichloroethane	98.96	10.2	0.00001	0.08863	0.75808	APPLICATION	1.17E-05	1.37E-06	1.40E-11	6,050	8.442E-08	2.662E+00	0.5	3.09E-02	2.847E+00	282	0.000	0.216	##################	0.0
1,1-Dichloroethane	98.96	9.9	0.00001	0.08863	0.75808	N/A	1.2458E-05	1.46E-06	1.44E-11	6,050	8.724E-08	2.751E+00	0.5	2.99E-02	2.931E+00	290	0.000	0.210	##################	5.25E-04
cis-1,2-Dichloroethylene	96.94	3.9	0.00000	0.09088	0.75808	1/2 X	1.90E-06	2.28E-07	8.88E-13	6,050	5.375E-09	1.695E-01	0.5	1.18E-02	2.403E-01	23	0.000	0.083	##################	0.0
cis-1,2-Dichloroethylene	96.94	3.9	0.00000	0.09088	0.75808	1 X	3.70E-06	4.44E-07	1.73E-12	6,050	1.047E-08	3.301E-01	0.5	1.18E-02	4.008E-01	39	0.000	0.083	##################	0.0
cis-1,2-Dichloroethylene	96.94	3.9	0.00000	0.09088	0.75808	2X	7.40E-06	8.87E-07	3.46E-12	6,050	2.093E-08	6.601E-01	0.5	1.18E-02	7.309E-01	71	0.000	0.083	##################	0.0
cis-1,2-Dichloroethylene	96.94	3.9	0.00000	0.09088	0.75808	5X	1.85E-05	2.22E-06	8.65E-12	6,050	5.233E-08	1.650E+00	0.5	1.18E-02	1.721E+00	167	0.000	0.083	##################	0.0
cis-1,2-Dichloroethylene	96.94	9	0.00001	0.09088	0.75808	APPLICATION	1.17E-05	1.40E-06	1.26E-11	6,050	7.637E-08	2.409E+00	0.5	2.72E-02	2.572E+00	249	0.000	0.191	##################	0.0
cis-1,2-Dichloroethylene	96.94	3.9	0.00000	0.09088	0.75808	N/A	1.2458E-05	1.49E-06	5.82E-12	6,050	3.524E-08	1.111E+00	0.5	1.18E-02	1.182E+00	115	0.000	0.083	##################	2.06E-04
rans-1,2-Dichloroethylen	96.94	4.1	0.00000	0.09088	0.75808	1/2 X	1.90E-06	2.28E-07	9.34E-13	6,050	5.650E-09	1.782E-01	0.5	1.24E-02	2.526E-01	24	0.000	0.087	##################	0.0
rans-1,2-Dichloroethylen	96.94	4.1	0.00000	0.09088	0.75808	1 X	3.70E-06	4.44E-07	1.82E-12	6,050	1.100E-08	3.470E-01	0.5	1.24E-02	4.214E-01	41	0.000	0.087	##################	0.0
rans-1,2-Dichloroethylen	96.94	4.1	0.00000	0.09088	0.75808	2X	7.40E-06	8.87E-07	3.64E-12	6,050	2.201E-08	6.940E-01	0.5	1.24E-02	7.684E-01	74	0.000	0.087	##################	0.0
rans-1,2-Dichloroethylen	96.94	4.1	0.00000	0.09088	0.75808	5X	1.85E-05	2.22E-06	9.09E-12	6,050	5.501E-08	1.735E+00	0.5	1.24E-02	1.809E+00	175	0.000	0.087	##################	0.0
rans-1,2-Dichloroethylen	96.94	0	0.00000	0.09088	0.75808	APPLICATION	1.17E-05	1.40E-06	0.00E+00	6,050	0.000E+00	0.000E+00	0.5	0.00E+00	0.000E+00	0	0.000	0.000	##################	0.0
rans-1,2-Dichloroethylen	96.94	4.1	4.10E-06	0.09088	0.75808	N/A	1.2458E-05	1.49E-06	6.12E-12	6,050	3.705E-08	1.168E+00	0.5	1.24E-02	1.243E+00	120	0.000	0.087	##################	2.16E-04
Ethyl Benzene	106.17	3.6	0.00000	0.07191	0.75808	1/2 X	1.90E-06	1.80E-07	6.49E-13	6,050	3.925E-09	1.238E-01	0.5	1.09E-02	1.891E-01	20	0.000	0.076	##################	0.0
Ethyl Benzene	106.17	3.6	0.00000	0.07191	0.75808	1 X	3.70E-06	3.51E-07	1.26E-12	6,050	7.644E-09	2.411E-01	0.5	1.09E-02	3.064E-01	33	0.000	0.076	##################	0.0

VOC	Mol Wt (g/mole)	Drum Headspace Concentration (ppmv)	Drum Headspace Concentration (mole fraction)	Diffusivity VOC-air (298.15 K, 1 atm Slattery & Bird)	Diffusivity H2-air (298.15 K, 1 atm Slattery & Bird)	Filter Model on Container	Filter Diffusivity for Hydrogen	VOC Filter Diffusivity Coefficient (mole/sec/mf)	VOC Emission Rate per Drum (mole/sec)	Drums per Room	VOC Emission Rate per Room (mole/sec)	Open Room Emission (mole/room/year)	Effective Gas Generation Rate (mole/drum/year)	Closed Room Emission (mole/room/year)	Open Panel Emission (mole/panel/year)	VOC Emission Rate per Open Panel (g/panel/year)	VOC Emission Rate per Open Panel (tons/panel/year)	Closed Panel Emission Rate (moles/panel/year)	Closed Panel Emission Rate (tons/panel/year)	Maximum Repository Emission Rate (tons/year)
Ethyl Benzene	106.17	3.6	0.00000	0.07191	0.75808	2X	7.40E-06	7.02E-07	2.53E-12	6,050	1.529E-08	4.821E-01	0.5	1.09E-02	5.475E-01	58	0.000	0.076	##################	0.0
Ethyl Benzene	106.17	3.6	0.00000	0.07191	0.75808	5X	1.85E-05	1.75E-06	6.32E-12	6,050	3.822E-08	1.205E+00	0.5	1.09E-02	1.271E+00	135	0.000	0.076	##################	0.0
Ethyl Benzene	106.17	11.6	0.00001	0.07191	0.75808	APPLICATION	1.17E-05	1.11E-06	1.29E-11	6,050	7.789E-08	2.456E+00	0.5	3.51E-02	2.667E+00	283	0.000	0.246	##################	0.0
Ethyl Benzene	106.17	3.6	0.00000	0.07191	0.75808	N/A	1.2458E-05	1.18E-06	4.25E-12	6,050	2.574E-08	8.117E-01	0.5	1.09E-02	8.770E-01	93	0.000	0.076	##################	1.83E-04
Ethyl Ether	74.12	4.8	0.00000	0.08555	0.75808	1/2 X	1.90E-06	2.14E-07	1.03E-12	6,050	6.227E-09	1.964E-01	0.5	1.45E-02	2.835E-01	21	0.000	0.102	##################	0.0
Ethyl Ether	74.12	4.8	0.00000	0.08555	0.75808	1 X	3.70E-06	4.18E-07	2.00E-12	6,050	1.213E-08	3.824E-01	0.5	1.45E-02	4.695E-01	35	0.000	0.102	##################	0.0
Ethyl Ether	74.12	4.8	0.00000	0.08555	0.75808	2X	7.40E-06	8.35E-07	4.01E-12	6,050	2.425E-08	7.648E-01	0.5	1.45E-02	8.519E-01	63	0.000	0.102	##################	0.0
Ethyl Ether	74.12	4.8	0.00000	0.08555	0.75808	5X	1.85E-05	2.09E-06	1.00E-11	6,050	6.063E-08	1.912E+00	0.5	1.45E-02	1.999E+00	148	0.000	0.102	##################	0.0
Ethyl Ether	74.12	13.3	0.00001	0.08555	0.75808	APPLICATION	1.17E-05	1.32E-06	1.76E-11	6,050	1.062E-07	3.350E+00	0.5	4.02E-02	3.592E+00	266	0.000	0.282	##################	0.0
Ethyl Ether	74.12	4.8	0.00000	0.08555	0.75808	N/A	1.2458E-05	1.41E-06	6.75E-12	6,050	4.083E-08	1.288E+00	0.5	1.45E-02	1.375E+00	102	0.000	0.102	##################	1.87E-04
Methanol	32.04	71.3	0.00007	0.12386	0.75808	1/2 X	1.90E-06	3.10E-07	2.21E-11	6,050	1.339E-07	4.223E+00	0.5	2.16E-01	5.517E+00	177	0.000	1.510	##################	0.0
Methanol	32.04	71.3	0.00007	0.12386	0.75808	1 X	3.70E-06	6.05E-07	4.31E-11	6,050	2.608E-07	8.224E+00	0.5	2.16E-01	9.518E+00	305	0.000	1.510	##################	0.0
Methanol	32.04	71.3	0.00007	0.12386	0.75808	2X	7.40E-06	1.21E-06	8.62E-11	6,050	5.216E-07	1.645E+01	0.5	2.16E-01	1.774E+01	568	0.001	1.510	##################	0.0
Methanol	32.04	71.3	0.00007	0.12386	0.75808	5X	1.85E-05	3.02E-06	2.16E-10	6,050	1.304E-06	4.112E+01	0.5	2.16E-01	4.241E+01	1359	0.001	1.510	##################	0.0
Methanol	32.04	213	0.00021	0.12386	0.75808	APPLICATION	1.17E-05	1.91E-06	4.07E-10	6,050	2.463E-06	7.769E+01	0.5	6.44E-01	8.155E+01	2613	0.003	4.510	##################	0.0
Methanol	32.04	71.3	0.00007	0.12386	0.75808	N/A	1.2458E-05	2.04E-06	1.45E-10	6,050	8.780E-07	2.769E+01	0.5	2.16E-01	2.898E+01	929	0.001	1.510	##################	1.50E-03
Methyl Chloride	50.49	15.6	0.00002	0.10382	0.75808	1/2 X	1.90E-06	2.60E-07	4.06E-12	6,050	2.456E-08	7.745E-01	0.5	4.72E-02	1.058E+00	53	0.000	0.330	##################	0.0
Methyl Chloride	50.49	15.6	0.00002	0.10382	0.75808	1 X	3.70E-06	5.07E-07	7.90E-12	6,050	4.783E-08	1.508E+00	0.5	4.72E-02	1.791E+00	90	0.000	0.330	##################	0.0
Methyl Chloride	50.49	15.6	0.00002	0.10382	0.75808	2X	7.40E-06	1.01E-06	1.58E-11	6,050	9.565E-08	3.016E+00	0.5	4.72E-02	3.300E+00	167	0.000	0.330	##################	0.0
Methyl Chloride	50.49	15.6	0.00002	0.10382	0.75808	5X	1.85E-05	2.53E-06	3.95E-11	6,050	2.391E-07	7.541E+00	0.5	4.72E-02	7.824E+00	395	0.000	0.330	##################	0.0
Methyl Chloride	50.49	0	0.00000	0.10382	0.75808	APPLICATION	1.17E-05	1.60E-06	0.00E+00	6,050	0.000E+00	0.000E+00	0.5	0.00E+00	0.000E+00	0	0.000	0.000	##################	0.0
Methyl Chloride	50.49	15.6	0.00002	0.10382	0.75808	N/A	1.2458E-05	1.71E-06	2.66E-11	6,050	1.610E-07	5.078E+00	0.5	4.72E-02	5.361E+00	271	0.000	0.330	##################	4.63E-04
Methyl Ethyl Ketone	72.11	13.8	0.00001	0.08530	0.75808	1/2 X	1.90E-06	2.14E-07	2.95E-12	6,050	1.785E-08	5.629E-01	0.5	4.17E-02	8.133E-01	59	0.000	0.292	##################	0.0
Methyl Ethyl Ketone	72.11	13.8	0.00001	0.08530	0.75808	1 X	3.70E-06	4.16E-07	5.75E-12	6,050	3.476E-08	1.096E+00	0.5	4.17E-02	1.347E+00	97	0.000	0.292	##################	0.0
Methyl Ethyl Ketone	72.11	13.8	0.00001	0.08530	0.75808	2X	7.40E-06	8.33E-07	1.15E-11	6,050	6.952E-08	2.192E+00	0.5	4.17E-02	2.443E+00	176	0.000	0.292	##################	0.0
Methyl Ethyl Ketone	72.11	13.8	0.00001	0.08530	0.75808	5X	1.85E-05	2.08E-06	2.87E-11	6,050	1.738E-07	5.481E+00	0.5	4.17E-02	5.731E+00	413	0.000	0.292	##################	0.0
Methyl Ethyl Ketone	72.11	63.7	0.00006	0.08530	0.75808	APPLICATION	1.17E-05	1.32E-06	8.39E-11	6,050	5.073E-07	1.600E+01	0.5	1.93E-01	1.716E+01	1237	0.001	1.349	##################	0.0
Methyl Ethyl Ketone	72.11	13.8	0.00001	0.08530	0.75808	N/A	1.2458E-05	1.40E-06	1.93E-11	6,050	1.170E-07	3.691E+00	0.5	4.17E-02	3.941E+00	284	0.000	0.292	##################	5.22E-04
Methyl Isobutyl Ketone	100.16	12.4	0.00001	0.07162	0.75808	1/2 X	1.90E-06	1.80E-07	2.23E-12	6,050	1.347E-08	4.247E-01	0.5	3.75E-02	6.497E-01	65	0.000	0.263	##################	0.0
Methyl Isobutyl Ketone	100.16	12.4	0.00001	0.07162	0.75808	1 X	3.70E-06	3.50E-07	4.33E-12	6,050	2.622E-08	8.270E-01	0.5	3.75E-02	1.052E+00	105	0.000	0.263	##################	0.0
Methyl Isobutyl Ketone	100.16	12.4	0.00001	0.07162	0.75808	2X	7.40E-06	6.99E-07	8.67E-12	6,050	5.245E-08	1.654E+00	0.5	3.75E-02	1.879E+00	188	0.000	0.263	##################	0.0
Methyl Isobutyl Ketone	100.16	12.4	0.00001	0.07162	0.75808	5X	1.85E-05	1.75E-06	2.17E-11	6,050	1.311E-07	4.135E+00	0.5	3.75E-02	4.360E+00	437	0.000	0.263	##################	0.0
Methyl Isobutyl Ketone	100.16	79	0.00008	0.07162	0.75808	APPLICATION	1.17E-05	1.11E-06	8.73E-11	6,050	5.283E-07	1.666E+01	0.5	2.39E-01	1.809E+01	1812	0.002	1.673	##################	0.0
Methyl Isobutyl Ketone	100.16	12.4	0.00001	0.07162	0.75808	N/A	1.2458E-05	1.18E-06	1.46E-11	6,050	8.830E-08	2.784E+00	0.5	3.75E-02	3.010E+00	301	0.000	0.263	##################	5.93E-04
Tetrachloroethylene	165.83	5.1	0.00001	0.09507	0.75808	1/2 X	1.90E-06	2.38E-07	1.22E-12	6,050	7.352E-09	2.319E-01	0.5	1.54E-02	3.244E-01	54	0.000	0.108	##################	0.0
Tetrachloroethylene	165.83	5.1	0.00001	0.09507	0.75808	1 X	3.70E-06	4.64E-07	2.37E-12	6,050	1.432E-08	4.515E-01	0.5	1.54E-02	5.441E-01	90	0.000	0.108	##################	0.0
Tetrachloroethylene	165.83	5.1	0.00001	0.09507	0.75808	2X	7.40E-06	9.28E-07	4.73E-12	6,050	2.864E-08	9.031E-01	0.5	1.54E-02	9.956E-01	165	0.000	0.108	##################	0.0
Tetrachloroethylene	165.83	5.1	0.00001	0.09507	0.75808	5X	1.85E-05	2.32E-06	1.18E-11	6,050	7.159E-08	2.258E+00	0.5	1.54E-02	2.350E+00	390	0.000	0.108	##################	0.0
Tetrachloroethylene	165.83	9.4	0.00001	0.09507	0.75808	APPLICATION	1.17E-05	1.47E-06	1.38E-11	6,050	8.345E-08	2.632E+00	0.5	2.84E-02	2.802E+00	465	0.001	0.199	##################	0.0
Tetrachloroethylene	165.83	5.1	0.00001	0.09507	0.75808	N/A	1.2458E-05	1.56E-06	7.97E-12	6,050	4.821E-08	1.520E+00	0.5	1.54E-02	1.613E+00	267	0.000	0.108	##################	4.72E-04
Trichloroethylene	131.39	51.2	0.00005	0.08066	0.75808	1/2 X	1.90E-06	2.02E-07	1.04E-11	6,050	6.262E-08	1.975E+00	0.5	1.55E-01	2.904E+00	382	0.000	1.084	##################	0.0
Trichloroethylene	131.39	51.2	0.00005	0.08066	0.75808	1 X	3.70E-06	3.94E-07	2.02E-11	6,050	1.220E-07	3.846E+00	0.5	1.55E-01	4.775E+00	627	0.001	1.084	##################	0.0
Trichloroethylene	131.39	51.2	0.00005	0.08066	0.75808	2X	7.40E-06	7.87E-07	4.03E-11	6,050	2.439E-07	7.692E+00	0.5	1.55E-01	8.621E+00	1133	0.001	1.084	##################	0.0
Trichloroethylene	131.39	51.2	0.00005	0.08066	0.75808	5X	1.85E-05	1.97E-06	1.01E-10	6,050	6.098E-07	1.923E+01	0.5	1.55E-01	2.016E+01	2649	0.003	1.084	##################	0.0
Trichloroethylene	131.39	25.1	0.00003	0.08066	0.75808	APPLICATION	1.17E-05	1.24E-06	3.12E-11	6,050	1.890E-07	5.962E+00	0.5	7.59E-02	6.417E+00	843	0.001	0.531	##################	0.0
Trichloroethylene	131.39	51.2	0.00005	0.08066	0.75808	N/A	1.2458E-05	1.33E-06	6.79E-11	6,050	4.106E-07	1.295E+01	0.5	1.55E-01	1.388E+01	1823	0.002	1.084	##################	3.42E-03
Trichloro-1,2,2-Trifluoroe	102	208.9	0.00021	0.08734	0.75808	1/2 X	1.90E-06	2.19E-07	4.57E-11	6,050	2.767E-07	8.725E+00	0.5	6.32E-01	1.252E+01	1277	0.001	4.423	##################	0.0
Trichloro-1,2,2-Trifluoroe	102	208.9	0.00021	0.08734	0.75808	1 X	3.70E-06	4.26E-07	8.91E-11	6,050	5.388E-07	1.699E+01	0.5	6.32E-01	2.078E+01	2120	0.002	4.423	##################	0.0
Trichloro-1,2,2-Trifluoroe	102	208.9	0.00021	0.08734	0.75808	2X	7.40E-06	8.53E-07	1.78E-10	6,050	1.078E-06	3.398E+01	0.5	6.32E-01	3.777E+01	3853	0.004	4.423	##################	0.0
Trichloro-1,2,2-Trifluoroe	102	208.9	0.00021	0.08734	0.75808	5X	1.85E-05	2.13E-06	4.45E-10	6,050	2.694E-06	8.496E+01	0.5	6.32E-01	8.875E+01	9052	0.010	4.423	##################	0.0
Trichloro-1,2,2-Trifluoroe	102	33	0.00003	0.08734	0.75808	APPLICATION	1.17E-05	1.35E-06	4.45E-11	6,050	2.691E-07	8.488E+00	0.5	9.98E-02	9.086E+00	927	0.001	0.699	##################	0.0
Trichloro-1,2,2-Trifluoroe	102	208.9	0.00021	0.08734	0.75808	N/A	1.2458E-05	1.44E-06	3.00E-10	6,050	1.814E-06	5.721E+01	0.5	6.32E-01	6.100E+01	6222	0.007	4.423	##################	1.13E-02

VOC	Mol Wt (g/mole)	Drum Headspace Concentration (ppmv)	Drum Headspace Concentration (mole fraction)	Diffusivity VOC-air (298.15 K, 1 atm Slattery & Bird)	Diffusivity H2-air (298.15 K, 1 atm Slattery & Bird)	Filter Model on Container	Filter Diffusivity for Hydrogen	VOC Filter Diffusivity Coefficient (mole/sec/mf)	VOC Emission Rate per Drum (mole/sec)	Drums per Room	VOC Emission Rate per Room (mole/sec)	Open Room Emission (mole/room/year)	Effective Gas Generation Rate (mole/drum/year)	Closed Room Emission (mole/room/year)	Open Panel Emission (mole/panel/year)	VOC Emission Rate per Open Panel (g/panel/year)	VOC Emission Rate per Open Panel (tons/panel/year)	Closed Panel Emission Rate (moles/panel/year)	Closed Panel Emission Rate (tons/panel/year)	Maximum Repository Emission Rate (tons/year)
1,2,4-Trimethlybenzene	120.2	2.6	0.00000	0.06679	0.75808	1/2 X	1.90E-06	1.67E-07	4.35E-13	6,050	2.633E-09	8.304E-02	0.5	7.87E-03	1.302E-01	16	0.000	0.055	##################	0.0
1,2,4-Trimethlybenzene	120.2	2.6	0.00000	0.06679	0.75808	1 X	3.70E-06	3.26E-07	8.48E-13	6,050	5.128E-09	1.617E-01	0.5	7.87E-03	2.089E-01	25	0.000	0.055	##################	0.0
1,2,4-Trimethlybenzene	120.2	2.6	0.00000	0.06679	0.75808	2X	7.40E-06	6.52E-07	1.70E-12	6,050	1.026E-08	3.234E-01	0.5	7.87E-03	3.706E-01	45	0.000	0.055	##################	0.0
1,2,4-Trimethlybenzene	120.2	2.6	0.00000	0.06679	0.75808	5X	1.85E-05	1.63E-06	4.24E-12	6,050	2.564E-08	8.085E-01	0.5	7.87E-03	8.557E-01	103	0.000	0.055	##################	0.0
1,2,4-Trimethlybenzene	120.2	12.2	0.00001	0.06679	0.75808	APPLICATION	1.17E-05	1.03E-06	1.26E-11	6,050	7.608E-08	2.399E+00	0.5	3.69E-02	2.621E+00	315	0.000	0.258	##################	0.0
1,2,4-Trimethlybenzene	120.2	2.6	0.00000	0.06679	0.75808	N/A	1.2458E-05	1.10E-06	2.85E-12	6,050	1.726E-08	5.445E-01	0.5	7.87E-03	5.917E-01	71	0.000	0.055	##################	1.44E-04
1,3,5-Trimethylbenzene	120.2	3.2	0.00000	0.06679	0.75808	1/2 X	1.90E-06	1.67E-07	5.36E-13	6,050	3.241E-09	1.022E-01	0.5	9.68E-03	1.603E-01	19	0.000	0.068	##################	0.0
1,3,5-Trimethylbenzene	120.2	3.2	0.00000	0.06679	0.75808	1 X	3.70E-06	3.26E-07	1.04E-12	6,050	6.311E-09	1.990E-01	0.5	9.68E-03	2.571E-01	31	0.000	0.068	##################	0.0
1,3,5-Trimethylbenzene	120.2	3.2	0.00000	0.06679	0.75808	2X	7.40E-06	6.52E-07	2.09E-12	6,050	1.262E-08	3.980E-01	0.5	9.68E-03	4.561E-01	55	0.000	0.068	##################	0.0
1,3,5-Trimethylbenzene	120.2	3.2	0.00000	0.06679	0.75808	5X	1.85E-05	1.63E-06	5.22E-12	6,050	3.155E-08	9.951E-01	0.5	9.68E-03	1.053E+00	127	0.000	0.068	##################	0.0
1,3,5-Trimethylbenzene	120.2	8.6	0.00001	0.06679	0.75808	APPLICATION	1.17E-05	1.03E-06	8.86E-12	6,050	5.363E-08	1.691E+00	0.5	2.60E-02	1.847E+00	222	0.000	0.182	##################	0.0
1,3,5-Trimethylbenzene	120.2	3.2	0.00000	0.06679	0.75808	N/A	1.2458E-05	1.10E-06	3.51E-12	6,050	2.125E-08	6.701E-01	0.5	9.68E-03	7.282E-01	88	0.000	0.068	##################	1.77E-04
m,p-Xylene	106.17	6.5	0.00001	0.07053	0.75808	1/2 X	1.90E-06	1.77E-07	1.15E-12	6,050	6.952E-09	2.192E-01	0.5	1.97E-02	3.372E-01	36	0.000	0.138	##################	0.0
m,p-Xylene	106.17	6.5	0.00001	0.07053	0.75808	1 X	3.70E-06	3.44E-07	2.24E-12	6,050	1.354E-08	4.269E-01	0.5	1.97E-02	5.449E-01	58	0.000	0.138	##################	0.0
m,p-Xylene	106.17	6.5	0.00001	0.07053	0.75808	2X	7.40E-06	6.89E-07	4.48E-12	6,050	2.708E-08	8.539E-01	0.5	1.97E-02	9.718E-01	103	0.000	0.138	##################	0.0
m,p-Xylene	106.17	6.5	0.00001	0.07053	0.75808	5X	1.85E-05	1.72E-06	1.12E-11	6,050	6.769E-08	2.135E+00	0.5	1.97E-02	2.253E+00	239	0.000	0.138	##################	0.0
m,p-Xylene	106.17	19.3	0.00002	0.07053	0.75808	APPLICATION	1.17E-05	1.09E-06	2.10E-11	6,050	1.271E-07	4.009E+00	0.5	5.84E-02	4.359E+00	463	0.001	0.409	##################	0.0
m,p-Xylene	106.17	6.5	0.00001	0.07053	0.75808	N/A	1.2458E-05	1.16E-06	7.53E-12	6,050	4.558E-08	1.437E+00	0.5	1.97E-02	1.555E+00	165	0.000	0.138	##################	3.27E-04
o-Xylene	106.17	3.8	0.00000	0.07053	0.75808	1/2 X	1.90E-06	1.77E-07	6.72E-13	6,050	4.064E-09	1.282E-01	0.5	1.15E-02	1.971E-01	21	0.000	0.080	##################	0.0
o-Xylene	106.17	3.8	0.00000	0.07053	0.75808	1 X	3.70E-06	3.44E-07	1.31E-12	6,050	7.914E-09	2.496E-01	0.5	1.15E-02	3.186E-01	34	0.000	0.080	##################	0.0
o-Xylene	106.17	3.8	0.00000	0.07053	0.75808	2X	7.40E-06	6.89E-07	2.62E-12	6,050	1.583E-08	4.992E-01	0.5	1.15E-02	5.682E-01	60	0.000	0.080	##################	0.0
o-Xylene	106.17	3.8	0.00000	0.07053	0.75808	5X	1.85E-05	1.72E-06	6.54E-12	6,050	3.957E-08	1.248E+00	0.5	1.15E-02	1.317E+00	140	0.000	0.080	##################	0.0
o-Xylene	16.00	79.8	0.00008	0.07053	0.75808	APPLICATION	1.17E-05	1.09E-06	8.69E-11	6,050	5.256E-07	1.657E+01	0.5	2.41E-01	1.802E+01	288	0.000	1.690	##################	0.0
o-Xylene	106.17	3.8	0.00000	0.07053	0.75808	N/A	1.2458E-05	1.16E-06	4.40E-12	6,050	2.665E-08	8.404E-01	0.5	1.15E-02	9.094E-01	97	0.000	0.080	##################	1.91E-04

ATMOSPHERIC DISPERSION This section presents the results of air dispersion modeling performed inside and outside the WIPP site boundary. The modeling was performed to evaluate four specific scenarios: the Boundary Public, Livingston Ridge Rancher (grazing allotment on the north side of the WIPP site), Antelope Ridge Rancher (grazing allotment on the south side of the WIPP site), and Surface Worker. The Long-Term Version of the Industrial Source Complex (ISCLT3) model, (U.S. Environmental Protection Agency, 1995), was used for the original air dispersion modeling. Concentrations were modeled in accordance with (U.S. Environmental Protection Agency, 1992) EPA (1992). Details of the modeling are described in Appendix D10 of the 1996 Permit Application. The modeling produced the air dispersion factors (ADFs) listed in the center column of Table 6. In 2010 the modeling was updated in order to use newer EPA analytical tools (AERMOD) and updated physical conditions (new buildings, three exhaust stacks) (URS Corporation, 2010).

Area	Original Air Dispersion Factor (ADF)	Revised Air Dispersion Factor (ADF)
Training Building	1.23E-02	1.14E-02
Livingston Ridge Allotment	9.80E-05	1.76E-04
Antelope Ridge Allotment	6.70E-05	6.72E-04
WIPP Site Boundary	1.20E-04	8.78E-05

LOCATION OF PUBLIC AND WORKERS Three classes of exposed individuals (receptors) were presented in Appendix D9 of the 1996 Permit Application (U. S. Department of Energy, 1996 a); a surface worker, an underground worker, and a member of the public. The compliance point for the surface worker is the Training Building. The compliance point for the underground worker is downwind from the waste during initial emplacement in a room. The compliance point for the member of the public is the nearest point outside the controlled area where ranch hands may be working.

HEALTH BASED LEVELS The environmental performance standard proposed for the workers was the Occupational Safety and Health Administration (OSHA) 8-hour time weighted average (TWA) for each compound. The environmental performance standards proposed for the public were 10^{-6} for Class A and B2 carcinogens and 10^{-5} for Class C carcinogens and a Hazard Quotient of 1 for non-carcinogens. These are summarized in Table 7. These risk levels were not used by the New Mexico Environment Department (NMED) to develop the standards that eventually were included in the Hazardous Waste Facility Permit (Permit) that was issued in 1999. The NMED reduced the standards to only two receptors: the Underground Worker and the Surface Worker. These standards which are reflected in the VOC limits in the Permit are listed in Table 8. The NMED translated these risk levels into specific concentrations of concern (Cs of C) for each VOC and published them as repository limits and room-based limits. Action levels associated with these limits were also established in the Permit. The NMED modeled cumulative risk and hazard due to exposure to all compounds simultaneously. This required them to develop a process for translating the total risk into a specific risk associated with each VOC involved. The rationale used is documented in a memorandum to file issued by the NMED in 1998 (Zappe, 1998) and in written testimony submitted at the 1999 Permit Hearing (New Mexico Environment Department, 1999). The NMED accepted the Permittees limited list of analytes (which constituted 99 percent of the risk or hazard) and apportioned risk among the nine compounds. This risk apportionment has been modified over time. The most recent apportionment is shown in Table 8, along with the percentage of the total risk assigned to the compound. Table 9 focuses on repository limits since room-based limits are now monitored separately using a Disposal Room VOC Monitoring System. In the design of the current Panel Closure, performance criteria were established in the form of health based levels (HBLs) that could be applied at any appropriate point of compliance (the Land Withdrawal boundary was used in the Panel Closure design document titled Conceptual Design for Operational Phase Panel Closure Systems, Appendix I1 of the 1996 Permit Application (U. S. Department of Energy, 1996 a)). This approach was driven by the no-migration standard found in 40 CFR 268 which applied at the time. The methodology for calculating HBLs that was used was described in the proposed ruling on Subpart S, Corrective Action for Solid Waste Management Units at Hazardous Waste Management Facilities (Federal Register, 1990). In the proposed 40 CFR 264 Subpart S, the action levels, or HBLs, are calculated given the exposure assumptions for the media of interest and the toxic or carcinogenic effects for each hazardous constituent. The proposed Subpart S recommended that continuous lifetime exposure duration of 70 years be assumed; however, because the operational/closure phase of the facility is 35 years, a 35-year exposure is assumed in determining HBLs for the assessment. The assumed risk levels for carcinogens are 10^{-6} for Class A or B2 carcinogens and 10^{-5} for Class C carcinogens. In determining HBLs for non-carcinogens, the chemical-specific reference concentrations are used, which estimate the daily exposure an individual can experience without appreciable risk of adverse effects during a lifetime. Because the guidelines refer to excess health risks, the calculated HBLs are applied only to potential migration of hazardous constituents from the disposed waste. The methodology for determining HBLs is derived from the EPA's Risk Assessment Guidance for Superfund (U. S. Environmental Protection Agency, 1989). Although the EPA provides alternate "standard default exposure factors," exposure assumptions outlined in the proposed Subpart S were used. To calculate the HBLs in air for carcinogens with an absorption factor conservatively assumed to be equal to 1, the following equation is used:

and reference concentrations (RfCs)) used in the
ble 10. The main source of these data is the EPA
tem (IRIS); the data in the IRIS system are updated
approved by the EPA. Values not in the IRIS system are
urces. This list has been updated from the original study

$$HBL = \frac{TRL \times AT}{EF \times ED \times IUR}$$

where:

HBL	=	HBL for carcinogen, $\mu g/m^3$
TRL	=	target risk level (TRL), 10^{-5} (Class C) or 10^{-6} (Class A and B2)
AT	=	averaging time, 25,550 days for carcinogens (70 years × 365 days/year)
EF	=	exposure frequency, 365 days/year
ED	=	exposure duration, 35 years
IUR	=	inhalation unit risk factor (IUR) for carcinogen, $(\mu g/m^3)^{-1}$

For non-carcinogens, the HBLs in air are calculated as follows:

$$HBL = \frac{THQ \times RfC \times AT_{p\,or\,w} \times (1{,}000\,\frac{\mu g}{mg})}{EF_{p\,or\,w} \times ED_{p\,or\,w}}$$

where:

HBL	=	HBL for non-carcinogen, $\mu g/m^3$
THQ	=	target hazard quotient (THQ), assumed to be 1
RfC	=	reference concentration for the non-carcinogen, mg/m^3
AT_p	=	averaging time, 12,775 days for non-carcinogenic exposure for public (ED × 365 days/year)
AT_w	=	averaging time, 87,600 for non-carcinogenic exposure for non-waste surface workers based on exposure duration)
EF_p	=	exposure frequency for public, 365 days/year
EF_w	=	exposure frequency for non-waste surface worker, 1,920 hours/year
ED_p	=	exposure duration for public, 35 years
ED_w	=	exposure duration, non-waste surface worker, 10 years.

cinogens and non-carcinogens, exposure duration of 35 years
years for the non-waste surface worker. For non-carcinogens,
the exposure duration; therefore, this assumption has no effect
This assumption is reasonable, because waste emplacement is
-year closure period follows. For the non-waste surface
an employment period of 10 years in the training building.
or VOC in air is listed in Table 11. Values are shown for two
d the surface worker risk is 10^{-5}. The original Panel Closure

IUR = Inhalation unit risk factor (IUR) for carcinogen, $(\mu g/m^3)^{-1}$

For non-carcinogens, the HBLs in air are calculated as follows:

$$HBL = \frac{THQ \times RfC \times AT_{p\,or\,w} \times (1{,}000\ \frac{\mu g}{mg})}{EF_{p\,or\,w} \times ED_{p\,or\,w}}$$

where:

HBL = HBL for non-carcinogen, $\mu g/m^3$
THQ = target hazard quotient (THQ), assumed to be 1
RfC = reference concentration for the non-carcinogen, mg/m^3
AT_p = averaging time, 12,775 days for non-carcinogenic exposure for public (ED x 365 days/year)
AT_w = averaging time, 87,600 for non-carcinogenic exposure for non-waste surface workers based on exposure duration)
EF_p = exposure frequency for public, 365 days/year
EF_w = exposure frequency for non-waste surface worker, 1,920 hours/year
ED_p = exposure duration for public, 35 years
ED_w = exposure duration, non-waste surface worker, 10 years.

The toxicity measures (i.e., IURs calculations are presented in Ta Integrated Risk Information Syst monthly and are reviewed and u based on EPA recommended so in the Permit Application.

In calculating the HBLs for both car was assumed for the public and 10 the averaging time is equivalent to on the calculated value of the HBL. expected to last 25 years, and a ter worker, the assumption is based or The calculated HBL for each indicat risk levels. The public risk is 10^{-6} an design uses the public risk values.

	VOLATILE ORGANIC COMPOUND	MOLECULAR WEIGHT (g/mole)	Exhaust Shaft Concentration ug/m^3	Inhalation Unit Risk (IUR) $(ug/m^3)^{-1}$	Reference concentration (RfC) mg/m^3	Health Based Levels for Reduced Exposure ug/cubic meter: 10^{-6} RISK LEVEL	10^{-5} RISK LEVEL	NON-CARCINOGENIC	RECEPTOR CONCENTRATION: conc times old ADF	conc times new ADF
RISK AT THE TRAINING BUILDING	Acetone	58.08	0.40	---	3.10E+01	---	---	141,438	4.93E-03	4.57E-03
	Benzene	78.11	0.04	7.80E-06	3.00E-02	4.094551282	41	137	5.07E-04	4.70E-04
	Bromoform	252.73	0.05	1.10E-06	---	29.03409091	290	---	6.06E-04	5.61E-04
	Butanol	74.12	0.12	---	6.00E-02	---	---	274	1.54E-03	1.42E-03
	Carbon Disulfide	76.13	0.08	---	7.00E-01	---	---	3,194	9.41E-04	8.72E-04
	Carbon Tetrachloride	153.84	16.67	6.00E-06	1.00E-01	5.322916667	53	456	2.05E-01	1.90E-01
	Chlorobenzene	112.56	0.03	---	5.00E-02	---	---	228	4.25E-04	3.94E-04
	Chloroform	119.39	0.24	2.30E-05	9.80E-02	1.388586957	14	447	2.94E-03	2.73E-03
	Cyclohexane	84.16	0.11	---	6	---	---	27,375	1.33E-03	1.24E-03
	1,1-Dichloroethane	98.96	0.12	1.60E-06	---	19.9609375	200	---	1.52E-03	1.41E-03
	1,2-Dichloroethane	98.97	0.05	2.60E-05	7.00E-03	1.228365385	12	32	5.68E-04	5.26E-04
	1,1-Dichloroethylene	96.95	0.16	---	2.00E-01	---	---	913	1.96E-03	1.82E-03
	cis-1,2-Dichloroethylene	96.94	0.05	---	---	---	---	---	5.94E-04	5.50E-04
	trans-1,2-Dichloroethylene	96.94	0.05	---	6.00E-02	---	---	274	6.24E-04	5.79E-04
	Ethyl Benzene	106.17	0.04	2.50E-06	1	12.775	128	4,563	5.07E-04	4.70E-04
	Ethyl Ether	74.12	0.04	---	---	---	---	---	5.40E-04	5.00E-04
	Methanol	32.04	0.35	---	4	---	---	18,250	4.34E-03	4.02E-03
	Methyl Chloride	50.49	0.11	---	9.00E-02	---	---	411	1.34E-03	1.24E-03
	Methylene Chloride	84.94	0.40	1.00E-08	6.00E-01	3193.75	31,938	2,738	4.95E-03	4.59E-03
	Methyl Ethyl Ketone	72.11	0.12	---	5	---	---	22,813	1.51E-03	1.40E-03
	Methyl Isobutyl Ketone	100.16	0.14	---	3	---	---	13,688	1.71E-03	1.59E-03
	1,1,2,2-Tetrachloroethane	167.86	0.05	5.80E-05	---	0.550646552	6	---	6.68E-04	6.19E-04
	Tetrachloroethylene	165.83	0.11	2.60E-07	4.00E-02	122.8365385	1,228	183	1.36E-03	1.26E-03
	Toluene	92.13	0.13	---	5	---	---	22,813	1.62E-03	1.50E-03
	1,1,1-Trichloroethane	133.42	11.62	---	5	---	---	22,813	1.43E-01	1.32E-01
	Trichloroethylene	131.39	0.80	4.10E-06	2.00E-03	7.789634146	78	9	9.88E-03	9.16E-03
	1,1,2-Trichloro-1,2,2-Trifluoroethane	252.73	6.59	---	3.00E+01	---	---	136,875	8.11E-02	7.51E-02
	1,2,4-Trimethylbenzene	120.2	0.03	---	7.00E-03	---	---	32	4.16E-04	3.85E-04
	1,3,5-Trimethylbenzene	120.2	0.04	---	---	---	---	---	5.12E-04	4.74E-04
	m,p-Xylene	106.17	6.50	---	1.00E-01	---	---	456	8.00E-02	7.41E-02
	o-Xylene	106.17	0.04	---	1.00E-01	---	---	456	5.52E-04	5.11E-04

These HBLs are based on 10 years exposure in Training Building (87,600 hours)

Concentration as percent of Health Based Level

1 in 1000000		1 in 100000		HI		RISK = (FULL REPOSITORY CONCENTRATION X ADF X EF X IUR X ED)/(AT)	RISK = FULL REPOSITORY CONCENTRATION X ADF X EF X (AT X RfC X 1000)
conc times old ADF	conc times new ADF	conc times old ADF	conc times new ADF	conc times old ADF	conc times new ADF		
---	---	---	---	0.00%	0.00%	---	3.23177E-08
0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	1.14858E-10	3.43593E-06
0.00%	0.00%	0.00%	0.00%	---	---	1.93338E-11	---
---	---	---	---	0.00%	0.00%	---	5.20243E-06
---	---	---	---	0.00%	0.00%	---	2.7319E-07
3.85%	3.57%	0.39%	0.36%	0.04%	0.04%	3.56932E-08	0.00041642
---	---	---	---	0.00%	0.00%	---	1.72804E-06
0.21%	0.20%	0.02%	0.02%	0.00%	0.00%	1.96435E-09	6.10046E-06
---	---	---	---	0.00%	0.00%	---	4.51355E-08
0.01%	0.01%	0.00%	0.00%	---	---	7.04361E-11	---
0.05%	0.04%	0.00%	0.00%	0.00%	0.00%	4.28522E-10	1.64816E-05
---	---	---	---	0.00%	0.00%	---	1.99492E-06
---	---	---	---	---	---	---	---
---	---	---	---	0.00%	0.00%	---	2.11379E-06
0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.68136E-11	1.03078E-07
---	---	---	---	---	---	---	---
---	---	---	---	0.00%	0.00%	---	2.20395E-07
---	---	---	---	0.00%	0.00%	---	3.02202E-06
0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.43725E-12	1.6768E-06
---	---	---	---	0.00%	0.00%	---	6.12563E-08
---	---	---	---	0.00%	0.00%	---	1.15949E-07
0.12%	0.11%	0.01%	0.01%	---	---	1.12436E-09	---
0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.02906E-11	6.92635E-06
---	---	---	---	0.00%	0.00%	---	6.56838E-08
---	---	---	---	0.00%	0.00%	---	5.80722E-06
0.13%	0.12%	0.01%	0.01%	0.11%	0.10%	1.17574E-09	0.001003681
---	---	---	---	0.00%	0.00%	---	5.48949E-07
---	---	---	---	0.00%	0.00%	---	1.20673E-05
---	---	---	---	---	---	---	---
---	---	---	---	0.02%	0.02%	---	0.000162411
---	---	---	---	0.00%	0.00%	---	1.12108E-06
4.38%	4.06%	0.44%	0.41%	0.18%	0.17%		
						4.06393E-08	0.001651656

		MOLECULAR WEIGHT (g/mole)	Exhaust Shaft Concentration ug/m3	Inhalation Unit Risk (IUR) $(ug/m^3)^{-1}$	Reference concentration (RfC) mg/m^3	10^{-6} RISK LEVEL	10^{-5} RISK LEVEL	NON-CARCINOGENIC	conc times old ADF	conc times new ADF
	Acetone	58.08	0.40	---	3.10E+01	---	---	31000	3.93E-05	7.06E-05
	Benzene	78.11	0.04	7.80E-06	3.00E-02	0.26	2.56	30	4.04E-06	7.26E-06
	Bromoform	252.73	0.05	1.10E-06	---	1.82	18.18	---	4.83E-06	8.67E-06
	Butanol	74.12	0.12	---	6.00E-02	---	---	60	1.22E-05	2.20E-05

Concentration as percent of Health Based Level

1 in 1000000		1 in 100000		HI		RISK = (FULL REPOSITORY CONCENTRATION X ADF X EF X IUR X ED)/(AT)	RISK = FULL REPOSITORY CONCENTRATION X ADF X EF X ED)/(AT X RfC X 1000)
conc times old ADF	conc times new ADF	conc times old ADF	conc times new ADF	conc times old ADF	conc times new ADF		
---	---	---	---	0.00%	0.00%	---	2.27642E-09
0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	2.8362E-11	2.42022E-07
0.00%	0.00%	0.00%	0.00%	---	---	4.76695E-12	---
---	---	---	---	0.00%	0.00%	---	3.66452E-07

RISK AT LIVINGSTON RIDGE WORKER

Carbon Disulfide	76.13	0.08	---	7.00E-01		---	---	700	7.50E-06	1.35E-05	---	---	---	---	0.00%	0.00%	---		1.92431E-08
Carbon Tetrachloride	153.84	16.67	6.00E-06	1.00E-01		0.33	3.33	100	1.63E-03	2.93E-03	0.49%	0.89%	0.05%	0.09%	0.00%	0.00%		8.80843E-09	2.93321E-05
Chlorobenzene	112.56	0.03	---	5.00E-02		---	---	50	3.39E-06	6.09E-06	---	---	---	---	0.00%	0.00%	---		1.2172E-07
Chloroform	119.39	0.24	2.30E-05	9.80E-02		0.09	0.87	98	2.34E-05	4.21E-05	0.03%	0.05%	0.00%	0.00%	0.00%	0.00%		4.84039E-10	4.29708E-07
Cyclohexane	84.16	0.11	---	6		---	---	6000	1.06E-05	1.91E-05	---	---	---	---	0.00%	0.00%	---		3.17928E-09
1,1-Dichloroethane	98.96	0.12	1.60E-06	---		1.25	12.5	---	1.21E-05	2.17E-05	0.00%	0.00%	0.00%	0.00%	---	---		1.7365E-11	---
1,2-Dichloroethane	98.97	0.05	2.60E-05	7.00E-03		0.08	0.77	7	4.53E-06	8.13E-06	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%		1.0554E-10	1.16094E-06
1,1-Dichloroethylene	96.95	0.16	---	2.00E-01		---	---	200	1.56E-05	2.81E-05	---	---	---	---	0.00%	0.00%	---		1.40519E-07
cis-1,2-Dichloroethylene	96.94	0.05	---	---		---	---	---	4.73E-06	8.50E-06	---	---	---	---	---	---	---		---
trans-1,2-Dichloroethylene	96.94	0.05	---	6.00E-02		---	---	60	4.97E-06	8.93E-06	---	---	---	---	0.00%	0.00%	---		1.48892E-07
Ethyl Benzene	106.17	0.04	2.50E-06	1		0.8	8	1000	4.04E-06	7.26E-06	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		9.07584E-12	7.26067E-09
Ethyl Ether	74.12	0.04	---	---		---	---	---	4.30E-06	7.73E-06	---	---	---	---	---	---	---		---
Methanol	32.04	0.35	---	4		---	---	4000	3.46E-05	6.21E-05	---	---	---	---	0.00%	0.00%	---		1.55243E-08
Methyl Chloride	50.49	0.11	---	9.00E-02		---	---	90	1.07E-05	1.92E-05	---	---	---	---	0.00%	0.00%	---		2.12867E-07
Methylene Chloride	84.94	0.40	1.00E-08	6.00E-01		200	2000	600	3.95E-05	7.09E-05	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		3.54333E-13	1.18111E-07
Methyl Ethyl Ketone	72.11	0.12	---	5		---	---	5000	1.20E-05	2.16E-05	---	---	---	---	0.00%	0.00%	---		4.31481E-09
Methyl Isobutyl Ketone	100.16	0.14	---	3		---	---	3000	1.36E-05	2.45E-05	---	---	---	---	0.00%	0.00%	---		8.16732E-09
1,1,2,2-Tetrachloroethane	167.86	0.05	5.80E-05	---		0.03	0.34	---	5.32E-06	9.56E-06	0.02%	0.03%	0.00%	0.00%	---	---		2.8113E-10	---
Tetrachloroethylene	165.83	0.11	2.60E-07	4.00E-02		7.69	76.92	40	1.09E-05	1.95E-05	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		2.53709E-12	4.87882E-07
Toluene	92.13	0.13	---	5		---	---	5000	1.29E-05	2.31E-05	---	---	---	---	0.00%	0.00%	---		4.62668E-09
1,1,1-Trichloroethane	133.42	11.62	---	5		---	---	5000	1.14E-03	2.05E-03	---	---	---	---	0.00%	0.00%	---		4.09052E-07
Trichloroethylene	131.39	0.80	4.10E-06	2.00E-03		0.49	4.88	2	7.87E-05	1.41E-04	0.02%	0.03%	0.00%	0.00%	0.00%	0.01%		2.89745E-10	7.06979E-05
1,1,2-Trichloro-1,2,2-Trifluoroethane	252.73	6.59	---	3.00E+01		---	---	30000	6.46E-04	1.16E-03	---	---	---	---	0.00%	0.00%	---		3.86672E-08
1,2,4-Trimethylbenzene	120.2	0.03	---	7.00E-03		---	---	7	3.31E-06	5.95E-06	---	---	---	---	0.00%	0.00%	---		8.50003E-07
1,3,5-Trimethylbenzene	120.2	0.04	---	---		---	---	---	4.08E-06	7.32E-06	---	---	---	---	---	---	---		---
m,p-Xylene	106.17	6.50	---	1.00E-01		---	---	100	6.37E-04	1.14E-03	---	---	---	---	0.00%	0.00%	---		0.00001144
o-Xylene	106.17	0.04	---	1.00E-01		---	---	100	4.40E-06	7.90E-06	---	---	---	---	0.00%	0.00%	---		7.89675E-08
											0.56%	1.01%	0.06%	0.10%	0.01%	0.01%		1.00313E-08	0.00011634

RISK AT ANTELOPE RIDGE WORKER

	MOLECULAR WEIGHT (g/mole)	Exhaust Shaft Concentration ug/m^3	Inhalation Unit Risk (IUR) (ug/m^3)$^{-1}$	Reference concentration (RfC) mg/m^3		10^{-6} RISK LEVEL	10^{-5} RISK LEVEL	NON-CARCINOGE NIC	conc times old ADF	conc times new ADF	1 in 1000000 conc times old ADF	1 in 1000000 conc times new ADF	1 in 100000 conc times old ADF	1 in 100000 conc times new ADF	HI conc times old ADF	HI conc times new ADF	RISK = (FULL REPOSITORY CONCENTRATION X ADF X EF X IUR X ED)/(AT)	RISK = FULL REPOSITORY CONCENTRATION X ADF X EF X ED)/(AT X RfC X 1000)
Acetone	58.08	0.40	---	3.10E+01		---	---	31000	2.69E-05	2.69E-04	---	---	---	---	0.00%	0.00%	---	8.69177E-09
Benzene	78.11	0.04	7.80E-06	3.00E-02		0.26	2.56	30	2.76E-06	2.77E-05	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%		1.08291E-10	9.24085E-07
Bromoform	252.73	0.05	1.10E-06	---		1.82	18.18	---	3.30E-06	3.31E-05	0.00%	0.00%	0.00%	0.00%	---	---		1.82011E-11	---
Butanol	74.12	0.12	---	6.00E-02		---	---	60	8.37E-06	8.40E-05	---	---	---	---	0.00%	0.00%	---		1.39918E-06
Carbon Disulfide	76.13	0.08	---	7.00E-01		---	---	700	5.13E-06	5.14E-05	---	---	---	---	0.00%	0.00%	---		7.34736E-08
Carbon Tetrachloride	153.84	16.67	6.00E-06	1.00E-01		0.33	3.33	100	1.12E-03	1.12E-02	0.34%	3.39%	0.03%	0.34%	0.00%	0.01%		3.36322E-08	0.000111995
Chlorobenzene	112.56	0.03	---	5.00E-02		---	---	50	2.32E-06	2.32E-05	---	---	---	---	0.00%	0.00%	---		4.64751E-07
Chloroform	119.39	0.24	2.30E-05	9.80E-02		0.09	0.87	98	1.60E-05	1.61E-04	0.02%	0.18%	0.00%	0.02%	0.00%	0.00%		1.84815E-09	1.6407E-06
Cyclohexane	84.16	0.11	---	6		---	---	6000	7.26E-06	7.28E-05	---	---	---	---	0.00%	0.00%	---		1.21391E-08
1,1-Dichloroethane	98.96	0.12	1.60E-06	---		1.25	12.5	---	8.26E-06	8.29E-05	0.00%	0.01%	0.00%	0.00%	---	---		6.63026E-11	---
1,2-Dichloroethane	98.97	0.05	2.60E-05	7.00E-03		0.08	0.77	7	3.09E-06	3.10E-05	0.00%	0.04%	0.00%	0.00%	0.00%	0.00%		4.02971E-10	4.43269E-06
1,1-Dichloroethylene	96.95	0.16	---	2.00E-01		---	---	200	1.07E-05	1.07E-04	---	---	---	---	0.00%	0.00%	---		5.36527E-07
cis-1,2-Dichloroethylene	96.94	0.05	---	---		---	---	---	3.23E-06	3.24E-05	---	---	---	---	---	---	---		---
trans-1,2-Dichloroethylene	96.94	0.05	---	6.00E-02		---	---	60	3.40E-06	3.41E-05	---	---	---	---	0.00%	0.00%	---		5.68497E-07
Ethyl Benzene	106.17	0.04	2.50E-06	1		0.8	8	1000	2.76E-06	2.77E-05	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		3.46532E-11	2.77226E-08
Ethyl Ether	74.12	0.04	---	---		---	---	---	2.94E-06	2.95E-05	---	---	---	---	---	---	---		---
Methanol	32.04	0.35	---	4		---	---	4000	2.36E-05	2.37E-04	---	---	---	---	0.00%	0.00%	---		5.92748E-08
Methyl Chloride	50.49	0.11	---	9.00E-02		---	---	90	7.29E-06	7.31E-05	---	---	---	---	0.00%	0.00%	---		8.12763E-07
Methylene Chloride	84.94	0.40	1.00E-08	6.00E-01		200	2000	600	2.70E-05	2.71E-04	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		1.35291E-12	4.5097E-07
Methyl Ethyl Ketone	72.11	0.12	---	5		---	---	5000	8.21E-06	8.24E-05	---	---	---	---	0.00%	0.00%	---		1.64747E-08
Methyl Isobutyl Ketone	100.16	0.14	---	3		---	---	3000	9.33E-06	9.36E-05	---	---	---	---	0.00%	0.00%	---		3.11843E-08
1,1,2,2-Tetrachloroethane	167.86	0.05	5.80E-05	---		0.03	0.34	---	3.64E-06	3.65E-05	0.01%	0.12%	0.00%	0.01%	---	---		1.0734E-09	---

	Tetrachloroethylene	165.83	0.11	2.60E-07	4.00E-02		7.69	76.92	40	7.43E-06	7.45E-05	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		9.68707E-12	1.86282E-06
	Toluene	92.13	0.13	---	5		---	---	5000	8.81E-06	8.83E-05	---	---	---	---	0.00%	0.00%	---		1.76655E-08
	1,1,1-Trichloroethane	133.42	11.62	---	5		---	---	5000	7.79E-04	7.81E-03	---	---	---	---	0.00%	0.00%	---		1.56184E-06
	Trichloroethylene	131.39	0.80	4.10E-06	2.00E-03		0.49	4.88	2	5.38E-05	5.40E-04	0.01%	0.11%	0.00%	0.01%	0.00%	0.03%		1.1063E-09	0.000269937
	1,1,2-Trichloro-1,2,2-Trifluoroethane	252.73	6.59	---	3.00E+01		---	---	30000	4.42E-04	4.43E-03	---	---	---	---	0.00%	0.00%	---		1.47638E-07
	1,2,4-Trimethylbenzene	120.2	0.03	---	7.00E-03		---	---	7	2.27E-06	2.27E-05	---	---	---	---	0.00%	0.00%	---		3.24547E-06
	1,3,5-Trimethylbenzene	120.2	0.04	---	---		---	---	---	2.79E-06	2.80E-05	---	---	---	---	---	---	---	---	---
	m,p-Xylene	106.17	6.50	---	1.00E-01		---	---	100	4.36E-04	4.37E-03	---	---	---	---	0.00%	0.00%	---		0.00004368
	o-Xylene	106.17	0.04	---	1.00E-01		---	---	100	3.01E-06	3.02E-05	---	---	---	---	0.00%	0.00%	---		3.01512E-07
												0.39%	3.87%	0.04%	0.38%	0.00%	0.04%			
																			3.83015E-08	0.000444209

Concentration as percent of Health Based Level

		MOLECULAR WEIGHT (g/mole)	Exhaust Shaft Concentration ug/m^3	Inhalation Unit Risk (IUR) (ug/m^3)$^{-1}$	Reference concentration (RfC) mg/m^3		10^{-6} RISK LEVEL	10^{-5} RISK LEVEL	NON-CARCINOGENIC	conc times old ADF	conc times new ADF	1 in 1000000		1 in 100000		HI		RISK = (FULL REPOSITORY CONCENTRATION X ADF X EF X IUR X ED)/(AT)	RISK = FULL REPOSITORY CONCENTRATION X ADF X EF X ED)/(AT X RfC X 1000)
												conc times old ADF	conc times new ADF	conc times old ADF	conc times new ADF	conc times old ADF	conc times new ADF		
RISK AT WIPP SITE BOUNDARY	Acetone	58.08	0.40	---	3.10E+01		---	---	31000	4.81E-05	3.52E-05	---	---	---	---	0.00%	0.00%	---	1.13562E-09
	Benzene	78.11	0.04	7.80E-06	3.00E-02		0.26	2.56	30	4.95E-06	3.62E-06	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		1.41488E-11	1.20736E-07
	Bromoform	252.73	0.05	1.10E-06	---		1.82	18.18	---	5.91E-06	4.32E-06	0.00%	0.00%	0.00%	0.00%	---	---		2.37806E-12	---
	Butanol	74.12	0.12	---	6.00E-02		---	---	60	1.50E-05	1.10E-05	---	---	---	---	0.00%	0.00%	---		1.8281E-07
	Carbon Disulfide	76.13	0.08	---	7.00E-01		---	---	700	9.18E-06	6.72E-06	---	---	---	---	0.00%	0.00%	---		9.59968E-09
	Carbon Tetrachloride	153.84	16.67	6.00E-06	1.00E-01		0.33	3.33	100	2.00E-03	1.46E-03	0.61%	0.44%	0.06%	0.04%	0.00%	0.00%		4.39421E-09	1.46327E-05
	Chlorobenzene	112.56	0.03	---	5.00E-02		---	---	50	4.15E-06	3.04E-06	---	---	---	---	0.00%	0.00%	---		6.07219E-08
	Chloroform	119.39	0.24	2.30E-05	9.80E-02		0.09	0.87	98	2.87E-05	2.10E-05	0.03%	0.02%	0.00%	0.00%	0.00%	0.00%		2.41469E-10	2.14366E-07
	Cyclohexane	84.16	0.11	---	6		---	---	6000	1.30E-05	9.52E-06	---	---	---	---	0.00%	0.00%	---		1.58603E-09
	1,1-Dichloroethane	98.96	0.12	1.60E-06	---		1.25	12.5	---	1.48E-05	1.08E-05	0.00%	0.00%	0.00%	0.00%	---	---		8.66276E-12	---
	1,2-Dichloroethane	98.97	0.05	2.60E-05	7.00E-03		0.08	0.77	7	5.54E-06	4.05E-06	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%		5.26501E-11	5.79151E-07
	1,1-Dichloroethylene	96.95	0.16	---	2.00E-01		---	---	200	1.92E-05	1.40E-05	---	---	---	---	0.00%	0.00%	---		7.00998E-08
	cis-1,2-Dichloroethylene	96.94	0.05	---	---		---	---	---	5.79E-06	4.24E-06	---	---	---	---	---	---	---	---	---
	trans-1,2-Dichloroethylene	96.94	0.05	---	6.00E-02		---	---	60	6.09E-06	4.46E-06	---	---	---	---	0.00%	0.00%	---		7.42769E-08
	Ethyl Benzene	106.17	0.04	2.50E-06	1		0.8	8	1000	4.95E-06	3.62E-06	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		4.52761E-12	3.62209E-09
	Ethyl Ether	74.12	0.04	---	---		---	---	---	5.27E-06	3.85E-06	---	---	---	---	---	---	---	---	---
	Methanol	32.04	0.35	---	4		---	---	4000	4.23E-05	3.10E-05	---	---	---	---	0.00%	0.00%	---		7.74453E-09
	Methyl Chloride	50.49	0.11	---	9.00E-02		---	---	90	1.31E-05	9.56E-06	---	---	---	---	0.00%	0.00%	---		1.06191E-07
	Methylene Chloride	84.94	0.40	1.00E-08	6.00E-01		200	2000	600	4.83E-05	3.54E-05	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		1.76764E-13	5.89213E-08
	Methyl Ethyl Ketone	72.11	0.12	---	5		---	---	5000	1.47E-05	1.08E-05	---	---	---	---	0.00%	0.00%	---		2.1525E-09
	Methyl Isobutyl Ketone	100.16	0.14	---	3		---	---	3000	1.67E-05	1.22E-05	---	---	---	---	0.00%	0.00%	---		4.07438E-09
	1,1,2,2-Tetrachloroethane	167.86	0.05	5.80E-05	---		0.03	0.34	---	6.52E-06	4.77E-06	0.02%	0.02%	0.00%	0.00%	---	---		1.40245E-10	---
	Tetrachloroethylene	165.83	0.11	2.60E-07	4.00E-02		7.69	76.92	40	1.33E-05	9.74E-06	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		1.26566E-12	2.43387E-07
	Toluene	92.13	0.13	---	5		---	---	5000	1.58E-05	1.15E-05	---	---	---	---	0.00%	0.00%	---		2.30808E-09
	1,1,1-Trichloroethane	133.42	11.62	---	5		---	---	5000	1.39E-03	1.02E-03	---	---	---	---	0.00%	0.00%	---		2.04061E-07
	Trichloroethylene	131.39	0.80	4.10E-06	2.00E-03		0.49	4.88	2	9.64E-05	7.05E-05	0.02%	0.01%	0.00%	0.00%	0.00%	0.00%		1.44543E-10	3.52686E-05
	1,1,2-Trichloro-1,2,2-Trifluoroethane	252.73	6.59	---	3.00E+01		---	---	30000	7.91E-04	5.79E-04	---	---	---	---	0.00%	0.00%	---		1.92897E-08
	1,2,4-Trimethylbenzene	120.2	0.03	---	7.00E-03		---	---	7	4.06E-06	2.97E-06	---	---	---	---	0.00%	0.00%	---		4.24036E-07
	1,3,5-Trimethylbenzene	120.2	0.04	---	---		---	---	---	4.99E-06	3.65E-06	---	---	---	---	---	---	---	---	---
	m,p-Xylene	106.17	6.50	---	1.00E-01		---	---	100	7.80E-04	5.71E-04	---	---	---	---	0.00%	0.00%	---		0.000005707
	o-Xylene	106.17	0.04	---	1.00E-01		---	---	100	5.38E-06	3.94E-06	---	---	---	---	0.00%	0.00%	---		3.9394E-08
												0.69%	0.51%	0.07%	0.05%	0.01%	0.01%			
																			5.00427E-09	5.8038E-05

TABLE 1 TRU Waste VOC Source Term

Constituent	Original Weighted Average (ppmv)	Revised Weighted Average (ppmv)
ACETONE	79.8	53.1
BENZENE	9.3	4.3
BROMOFORM	9.4	1.8
BUTANOL	78.1	13.8
CARBON DISULFIDE	---	10.5
CARBON TETRACHLORIDE	375.5	921.5
CHLOROBENZENE	12.5	2.7
CHLOROFORM	25.3	16.1
CYCLOHEXANE	27.5	10.8
1,1-DICHLOROETHANE	10.2	9.9
1,2-DICHLOROETHANE	9.1	3.8
1,1-DICHLOROETHYLENE	11.5	12.9
CIS-1,2-DICHLOROETHYLENE	9.0	3.9
TRANS-1,2-DICHLOROETHYLENE	---	4.1
ETHYL BENZENE	11.6	3.6
ETHYL ETHER	13.3	4.8
METHANOL	213.0	71.3
METHYL CHLORIDE	---	15.6
METHYLENE CHLORIDE	368.5	36.0
METHYL ETHYL KETONE	63.7	13.8
METHYL ISOBUTYL KETONE	79.0	12.4
1,1,2,2-TETRACHLOROETHANE	9.4	4.8
TETRACHLOROETHYLENE	9.4	5.1
TOLUENE	19.4	12.2
1,1,1-TRICHLOROETHANE	317.1	739.8
TRICHLOROETHYLENE	25.1	51.2
1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE	33.0	208.9
1,2,4-TRIMETHYLBENZENE	12.2	2.6
1,3,5-TRIMETHYLBENZENE	8.6	3.2
M,P-XYLENE	19.3	6.5
O-XYLENE	16.0	3.8

Table 1 is derived from the Weighted HS Conc sheet

TABLE 3 Compilation of Filter H_2 Diffusivity for Disposed Waste (Panels 1 through 5) (mole/sec/mole fraction)

Panel	Room	Inner Container Count	Outer Container Count	Outer Container Filter Count	Summation of Filter Diffusivity	Diffusivity/Filter	Diffusivity/Outer Container
1	7	9953	9953	10187	3.12E-02	3.06E-06	3.14E-06
1	6	2392	2393	2441	7.72E-03	3.16E-06	3.23E-06
1	5	2403	2404	2427	7.09E-03	2.92E-06	2.95E-06
1	4	2484	2484	2523	7.97E-03	3.16E-06	3.21E-06
1	3	10691	10691	10911	3.31E-02	3.03E-06	3.09E-06
1	2	8368	8368	9115	2.61E-02	2.86E-06	3.12E-06
PANEL TOTAL		**3737**	**3121**	**3975**	**1.47E-02**	**3.70E-06**	**4.71E-06**
2	7	7111	5158	7455	2.85E-02	3.82E-06	5.53E-06
2	5	6965	4219	7115	3.18E-02	4.47E-06	7.55E-06
2	3	6610	5061	7102	3.26E-02	4.58E-06	6.43E-06
2	2	6727	4981	6967	3.93E-02	5.64E-06	7.88E-06
2	1	2179	1785	2214	3.18E-02	1.43E-05	1.78E-05
PANEL TOTAL		**42831**	**29770**	**44596**	**2.29E-01**	**5.13E-06**	**7.69E-06**
3	7	6022	1599	5657	4.91E-02	8.67E-06	3.07E-05
3	6	6678	2399	3713	4.37E-02	1.18E-05	1.82E-05
3	4	6693	3336	4548	5.33E-02	1.17E-05	1.60E-05
3	3	6476	2857	4501	5.06E-02	1.12E-05	1.77E-05
3	2	6588	2734	4300	5.23E-02	1.22E-05	1.91E-05
3	1	4112	2260	3256	3.82E-02	1.17E-05	1.69E-05
PANEL TOTAL		**42000**	**17760**	**28932**	**3.31E-01**	**1.14E-05**	**1.86E-05**
4	7	6063	2890	4574	5.09E-02	1.11E-05	1.76E-05
4	6	6073	3604	4802	6.40E-02	1.33E-05	1.78E-05
4	5	6621	4137	5728	7.21E-02	1.26E-05	1.74E-05
4	4	5870	3945	4928	7.61E-02	1.54E-05	1.93E-05
4	3	5673	4264	4784	8.16E-02	1.70E-05	1.91E-05
4	2	5535	4687	5236	8.93E-02	1.71E-05	1.91E-05
4	1	3545	3035	3280	5.72E-02	1.74E-05	1.89E-05
PANEL TOTAL		**39380**	**26562**	**33332**	**4.91E-01**	**1.47E-05**	**1.85E-05**
5	7	6512	5576	6169	1.07E-01	1.74E-05	1.92E-05
5	6	6568	5945	6442	1.19E-01	1.85E-05	2.00E-05
5	5	6332	5442	6023	1.03E-01	1.71E-05	1.89E-05
5	4	6524	3972	4423	6.85E-02	1.55E-05	1.73E-05
5	3	7223	4331	5120	8.31E-02	1.62E-05	1.92E-05
5	2	7088	5195	6370	1.05E-01	1.66E-05	2.03E-05
5	1	5007	3997	4449	7.81E-02	1.76E-05	1.96E-05
PANEL TOTAL		**45254**	**34458**	**38996**	**6.65E-01**	**1.70E-05**	**1.93E-05**

Table based on data provided by Eric D'Amico (WDS data)

This Table is manufactured from the Permit and the VOC Carbon Tetrachloride Modification

TABLE 9 Repository Limits for Specific Compounds and their Related Risk Portions

VOC OF INTEREST	TYPE	LIMIT IN PERMIT (ppbv)	ASSOCIATED RISK	ASSOCIATED HAZARD	PERCENT OF TOTAL RISK	PERCENT OF TOTAL HAZARD
Carbon Tetrachloride	C	960	4.30E-06		44.6	
Chlorobenzene	N	220		2.40E-03		88.5
Chloroform	C	180	2.40E-06		24.9	
1,1-Dichloroethene	N	100		2.30E-04		8.7
1,2-Dichloroethane	C	45	5.60E-07		5.8	
Methylene Chloride	C	1,930	1.90E-08		0.2	
1,1,2,2-Tetrachloroethane	C	50	2.30E-06		24.5	
Toluene	N	190		1.20E-04		4.4
1,1,1-Trichloroethane	N	590		7.60E-05		2.8
		TOTAL	9.60E-06	2.70E-03	100%	100%

C = Carcinogen

N = Non-carcinogen

TABLE 11: Health Based Levels for various Risk Scenarios

VOLATILE ORGANIC COMPOUND	HEALTH BASED LEVELS (ug/m³)			
	10^{-6} RISK LEVEL	10^{-5} RISK LEVEL	NON-CARCINOGENIC	
	Public	Surface Worker	Public	Surface Worker
Acetone	---	---	31,000	141,438
Benzene	0.26	41	30	137
Bromoform	1.82	290	---	---
Butanol	---	---	60	274
Carbon Disulfide	---	---	700	3,194
Carbon Tetrachloride	0.33	53	100	456
Chlorobenzene	---	---	50	228
Chloroform	0.09	14	98	447
Cyclohexane	---	---	6,000	27,375
1,1-Dichloroethane	1.25	200	---	---
1,2-Dichloroethane	0.08	12	7	32
1,1-Dichloroethylene	---	---	200	913
cis-1,2-Dichloroethylene	---	---	---	---
trans-1,2-Dichloroethylene	---	---	60	274
Ethyl Benzene	0.80	128	1,000	4,563
Ethyl Ether	---	---	---	---
Methanol	---	---	4,000	18,250
Methyl Chloride	---	---	90	411
Methylene Chloride	200	31,938	600	2,738
Methyl Ethyl Ketone	---	---	5,000	22,813
Methyl Isobutyl Ketone	---	---	3,000	13,688
1,1,2,2-Tetrachloroethane	0.03	6	---	---
Tetrachloroethylene	7.69	1,228	40	183
Toluene	---	---	5,000	22,813
1,1,1-Trichloroethane	---	---	5,000	22,813
Trichloroethylene	0.49	78	2	9
1,1,2-Trichloro-1,2,2-Trifluoroethane	---	---	30,000	136,875
1,2,4-Trimethlybenzene	---	---	7	32
1,3,5-Trimethylbenzene	---	---	---	---
m,p-Xylene	---	---	100	456
o-Xylene	---	---	100	456

TABLE 5: Number of Containers Disposed in Each Panel

Container Type	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6	Container Total
55-Gallon Drum	38,139	23,865	8,394	12,858	21,255	6,339	110,850
Standard Waste Boxes	1,239	3,176	1,730	1,405	2,200	741	10,491
10-Drum Overpack	35	1,451	2,227	1,048	788	131	5,680
85-Gallon Drum	2	-	-	3	-	-	5
100-Gallon Drum	-	1,278	5,409	11,050	9,951	1,218	28,906
Standard Large Box 2	-	-	-	-	-	5	5
Panel Total	39,415	29,770	17,760	26,364	34,194	5,376	152,879
Rooms per Panel	5	7	7	7	7	1	32
Containers per Room	8,211	4,580	2,691	3,995	5,181	5,376	4,777

This information was taken from a compilation provided by Don Hancock as of January 14, 2012

TABLE 6: Air Dispersion Factors for WIPP Site Areas

Area	Original Air Dispersion Factor (ADF)	Revised Air Dispersion Factor (ADF)
WIPP Site Boundary	1.2E-04	8.8E-05
Livingston Ridge Allotment	9.8E-05	1.8E-04
Antelope Ridge Allotment	6.7E-05	6.7E-04
Training Building	1.2E-02	1.1E-02

Calculated by URS Austin

TABLE 2: TRU Waste Container Gas Generation Rates Due to Microbial Degradation

	High	Low	Expected
Gas-Generation Rate moles/drum/year	0.4	0	0.1

From Permit Application and NMVP

TABLE 4: Effective Gas Generation Rate

Gas-Generation Rate	moles/drum/year
Microbial Degradation	0.1
Creep Closure	0.4
Total Effective Gas Generation Rate	0.5

From Permit Application and NMVP

TABLE 12: Annual Emission Rates for Drums, Rooms, Panels, and the Repository

COMPOUND	AVERAGE DRUM EMISSION RATE (mole/drum/year)	AVERAGE OPEN ROOM EMISSION RATE (mole/room/year)	AVERAGE CLOSED ROOM EMISSION RATE (mole/room/year)	AVERAGE OPEN PANEL EMISSION RATE (mole/panel/year)	AVERAGE CLOSED PANEL EMISSION RATE (mole/panel/year)	MAXIMUM REPOSITORY EMISSION RATE (moles/year)	FULL REPOSITORY CONCENTRATION AT THE EXHAUST SHAFT (ug/m³)
Acetone	2.58E-03	15.60	0.16	16.57	1.12	26.69	0.40
Benzene	1.89E-04	1.14	0.01	1.22	0.09	2.04	0.04
Bromoform	6.24E-05	0.38	0.01	0.41	0.04	0.75	0.05
Butanol	6.01E-04	3.63	0.04	3.89	0.29	6.52	0.12
Carbon Disulfide	5.54E-04	3.35	0.03	3.54	0.04	3.89	0.08
Carbon Tetrachloride	3.74E-02	226.47	2.79	243.20	19.51	418.82	16.67
Chlorobenzene	1.04E-04	0.63	0.01	0.68	0.06	1.19	0.03
Chloroform	7.25E-04	4.38	0.05	4.68	0.34	7.75	0.24
Cyclohexane	4.50E-04	2.72	0.03	2.92	0.23	4.98	0.11
1,1-Dichloroethane	4.55E-04	2.75	0.03	2.93	0.21	4.82	0.12
1,2-Dichloroethane	1.68E-04	1.02	0.01	1.08	0.08	1.80	0.05
1,1-Dichloroethylene	6.07E-04	3.67	0.04	3.91	0.27	6.37	0.16
cis-1,2-Dichloroethylene	1.84E-04	1.11	0.01	1.18	0.08	1.93	0.05
trans-1,2-Dichloroethylene	1.93E-04	1.17	0.01	1.24	0.09	2.02	0.05
Ethyl Benzene	1.34E-04	0.81	0.01	0.88	0.08	1.56	0.04
Ethyl Ether	2.13E-04	1.29	0.01	1.37	0.10	2.29	0.04
Methanol	4.58E-03	27.69	0.22	28.98	1.51	42.57	0.35
Methyl Chloride	8.39E-04	5.08	0.05	5.36	0.33	8.33	0.11
Methylene Chloride	1.79E-03	10.81	0.11	11.46	0.76	18.33	0.40
Methyl Ethyl Ketone	6.10E-04	3.69	0.04	3.94	0.29	6.57	0.12
Methyl Isobutyl Ketone	4.60E-04	2.78	0.04	3.01	0.26	5.37	0.14
1,1,2,2-Tetrachloroethane	1.12E-04	0.68	0.01	0.73	0.06	1.25	0.05
Tetrachloroethylene	2.51E-04	1.52	0.02	1.61	0.11	2.58	0.11
Toluene	4.90E-04	2.96	0.04	3.18	0.26	5.51	0.13
1,1,1-Trichloroethane	3.01E-02	182.27	2.24	195.69	15.67	336.68	11.62
Trichloroethylene	2.14E-03	12.95	0.15	13.88	1.08	23.64	0.80
1,1,2-Trichloro-1,2,2-Trifluoroethane	9.46E-03	57.21	0.63	61.00	4.42	100.81	6.59
1,2,4-Trimethlybenzene	9.00E-05	0.54	0.01	0.59	0.06	1.09	0.03
1,3,5-Trimethylbenzene	1.11E-04	0.67	0.01	0.73	0.07	1.34	0.04
o-Xylene	1.39E-04	0.84	0.01	0.91	0.08	1.63	0.04
m,p-Xylene	2.38E-04	1.44	0.02	1.56	0.14	2.79	0.08

TABLE 10: EPA Risk Factor for Volatile Organic Compounds (as of 4/2/2012)

VOLATILE ORGANIC COMPOUND	Inhalation Unit Risk (IUR) (ug/m3)-1	Reference concentration (RfC) mg/m3
Acetone	---	3.10E+01
Benzene	7.80E-06	3.00E-02
Bromoform	1.10E-06	---
Butanol	---	6.00E-02
Carbon Disulfide	---	7.00E-01
Carbon Tetrachloride	6.00E-06	1.00E-01
Chlorobenzene	---	5.00E-02
Chloroform	2.30E-05	9.80E-02
Cyclohexane	---	6.00E+00
1,1-Dichloroethane	1.60E-06	---
1,2-Dichloroethane	2.60E-05	7.00E-03
1,1-Dichloroethylene	---	2.00E-01
cis-1,2-Dichloroethylene	---	---
trans-1,2-Dichloroethylene	---	6.00E-02
Ethyl Benzene	2.50E-06	1.00E+00
Ethyl Ether	---	---
Methanol	---	4.00E+00
Methyl Chloride	---	9.00E-02
Methylene Chloride	1.00E-08	6.00E-01
Methyl Ethyl Ketone	---	5.00E+00
Methyl Isobutyl Ketone	---	3.00E+00
1,1,2,2-Tetrachloroethane	5.80E-05	---
Tetrachloroethylene	2.60E-07	4.00E-02
Toluene	---	5.00E+00
1,1,1-Trichloroethane	---	5.00E+00
Trichloroethylene	4.10E-06	2.00E-03
1,1,2-Trichloro-1,2,2-Trifluoroethane	---	3.00E+01
1,2,4-Trimethlybenzene	---	7.00E-03
1,3,5-Trimethylbenzene	---	---
m,p-Xylene	---	1.00E-01
o-Xylene	---	1.00E-01

Updated by URS comment--IRIS and related databases

TABLE 7 Risk Levels Proposed in the WIPP RCRA Part B Permit Application in 1996 (Appendix D9, Tables D9-5, -6, -8, and -9)

EXPOSED CLASS	COMPLIANCE POINT	CARCINOGENS		NON-CARCINOGENS
		CLASS A and B2 CARCINOGENS	CLASS C	
Surface Worker	Training Building	OSHA 8-HOUR TWA		
Underground Worker	Exhaust drift adjacent to filled room	OSHA 8-HOUR TWA		
Public	Controlled area fence line	1.00E-06	1.00E-05	1

From Permit Application and NMVP

TABLE 8 Risk Levels Imposed by the NMED in the Permit in 1999

EXPOSED CLASS	COMPLIANCE POINT	CLASS B2 CARCINOGENS	CLASS C CARCINOGENS	NON-CARCINOGENS
Surface Worker	Training Building	1.00E-05	1.00E-05	1
Underground Worker	Exhaust drift adjacent to filled room	OSHA IDLH or LFL	OSHA IDLH or LFL	OSHA IDLH or LFL
Public	Controlled area fence line	Bounded by Surface Worker Limit		

IDLH = Concentration that is immediately dangerous to life and health

LFL = Lower flammability limit

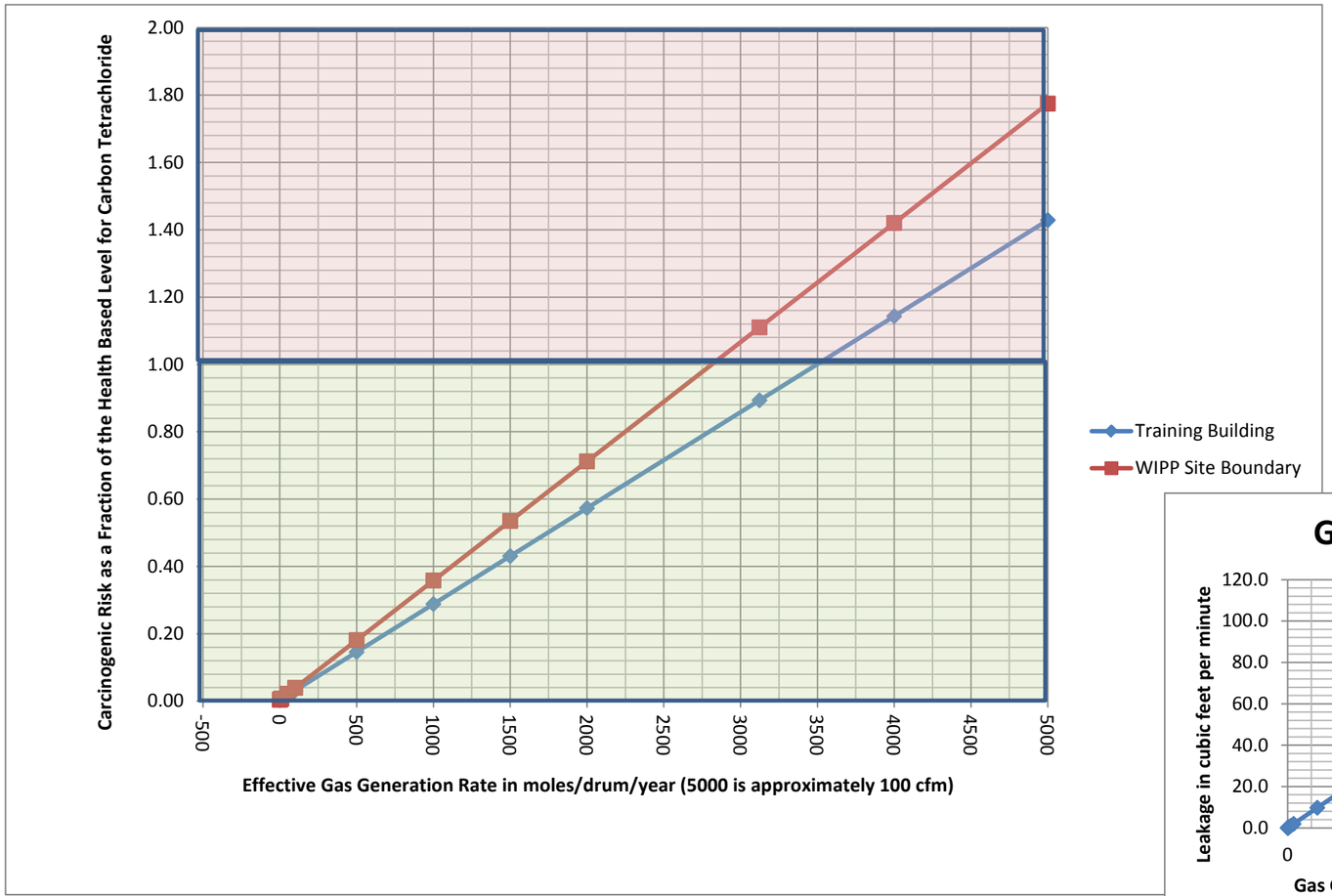
From Zappe Memo

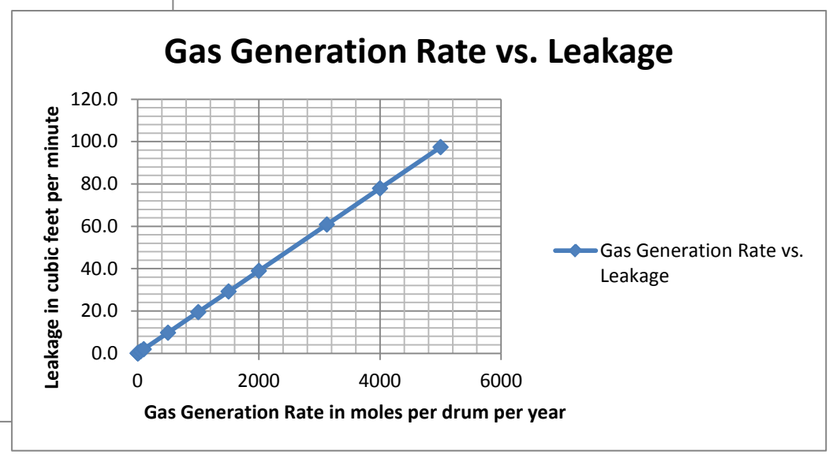
Table 13: Risk as a Fraction of the Health-Based Levels for Four Exposure Scenarios

COMPOUND	RISK AS A FRACTION OF THE HEALTH BASED LEVEL							
	WORKER		PUBLIC		PUBLIC		PUBLIC	
	TRAINING BUILDING		LIVINGSTON RIDGE		ANTELOPE RIDGE		WIPP SITE BOUNDARY	
	CARCINOGENIC	NON-CARCINOGENIC	CARCINOGENIC	NON-CARCINOGENIC	CARCINOGENIC	NON-CARCINOGENIC	CARCINOGENIC	NON-CARCINOGENIC
Acetone	---	3.23E-08	---	2.28E-09	---	8.69E-09	---	1.14E-09
Benzene	1.15E-05	3.44E-06	2.79E-05	2.42E-07	1.07E-04	9.24E-07	1.39E-05	1.21E-07
Bromoform	1.93E-06	---	4.76E-06	---	1.82E-05	---	2.38E-06	---
Butanol	---	5.20E-06	---	3.66E-07	---	1.40E-06	---	1.83E-07
Carbon Disulfide	---	2.73E-07	---	1.92E-08	---	7.35E-08	---	9.60E-09
Carbon Tetrachloride	3.57E-03	4.16E-04	8.89E-03	2.93E-05	3.39E-02	1.12E-04	4.43E-03	1.46E-05
Chlorobenzene	---	1.73E-06	---	1.22E-07	---	4.65E-07	---	6.07E-08
Chloroform	1.96E-04	6.10E-06	4.68E-04	4.30E-07	1.79E-03	1.64E-06	2.33E-04	2.14E-07
Cyclohexane	---	4.51E-08	---	3.18E-09	---	1.21E-08	---	1.59E-09
1,1-Dichloroethane	7.04E-06	---	1.74E-05	---	6.63E-05	---	8.66E-06	---
1,2-Dichloroethane	4.29E-05	1.65E-05	1.02E-04	1.16E-06	3.88E-04	4.43E-06	5.07E-05	5.79E-07
1,1-Dichloroethylene	---	1.99E-06	---	1.41E-07	---	5.37E-07	---	7.01E-08
cis-1,2-Dichloroethylene	---	---	---	---	---	---	---	---
trans-1,2-Dichloroethylene	---	2.11E-06	---	1.49E-07	---	5.68E-07	---	7.43E-08
Ethyl Benzene	3.68E-06	1.03E-07	9.08E-06	7.26E-09	3.47E-05	2.77E-08	4.53E-06	3.62E-09
Ethyl Ether	---	---	---	---	---	---	---	---
Methanol	---	2.20E-07	---	1.55E-08	---	5.93E-08	---	7.74E-09
Methyl Chloride	---	3.02E-06	---	2.13E-07	---	8.13E-07	---	1.06E-07
Methylene Chloride	1.44E-07	1.68E-06	3.54E-07	1.18E-07	1.35E-06	4.51E-07	1.77E-07	5.89E-08
Methyl Ethyl Ketone	---	6.13E-08	---	4.31E-09	---	1.65E-08	---	2.15E-09
Methyl Isobutyl Ketone	---	1.16E-07	---	8.17E-09	---	3.12E-08	---	4.07E-09
1,1,2,2-Tetrachloroethane	1.12E-04	---	3.19E-04	---	1.22E-03	---	1.59E-04	---
Tetrachloroethylene	1.03E-06	6.93E-06	2.54E-06	4.88E-07	9.69E-06	1.86E-06	1.27E-06	2.43E-07
Toluene	---	6.57E-08	---	4.63E-09	---	1.77E-08	---	2.31E-09
1,1,1-Trichloroethane	---	5.81E-06	---	4.09E-07	---	1.56E-06	---	2.04E-07
Trichloroethylene	1.18E-04	1.00E-03	2.89E-04	7.07E-05	1.10E-03	2.70E-04	1.44E-04	3.53E-05
1,1,2-Trichloro-1,2,2-Trifluoroethane	---	5.49E-07	---	3.87E-08	---	1.48E-07	---	1.93E-08
1,2,4-Trimethlybenzene	---	1.21E-05	---	8.50E-07	---	3.25E-06	---	4.24E-07
1,3,5-Trimethylbenzene	---	---	---	---	---	---	---	---
m,p-Xylene	---	1.62E-04	---	1.14E-05	---	4.37E-05	---	5.71E-06
o-Xylene	---	1.12E-06	---	7.90E-08	---	3.02E-07	---	3.94E-08
Total	4.06E-03	1.65E-03	1.01E-02	1.16E-04	3.87E-02	4.44E-04	5.05E-03	5.80E-05

GAS GENERATION RATE	WIPP TRAINING BUILDING		LIVINGSTON RIDGE WORKER		ANTELOPE RIDGE WORKER		WIPP SITE BOUNDARY RESIDENT		Equivalent flow rate in cfm
	Carcinogenic	Non Carcinogenic	Carcinogenic	Non Carcinogenic	Carcinogenic	Non Carcinogenic	Carcinogenic	Non Carcinogenic	
	FRACTION OF THE HEALTH BASED LIMIT (CCl4)								
0.5	3.57E-03	4.16E-04	8.89E-03	2.93E-05	3.39E-02	1.12E-04	4.43E-03	1.46E-05	0.00974
1	3.71E-03	4.33E-04	9.25E-03	3.05E-05	3.53E-02	1.17E-04	4.61E-03	1.52E-05	0.01948
5	4.85E-03	5.66E-04	1.21E-02	3.99E-05	4.61E-02	1.52E-04	6.03E-03	1.99E-05	0.0974
10	6.28E-03	7.32E-04	1.56E-02	5.16E-05	5.97E-02	1.97E-04	7.80E-03	2.57E-05	0.1948
50	1.77E-02	2.06E-03	4.40E-02	1.45E-04	1.68E-01	5.55E-04	2.20E-02	7.25E-05	0.974
100	3.19E-02	3.73E-03	7.95E-02	2.62E-04	3.04E-01	1.00E-03	3.97E-02	1.31E-04	1.948
500	1.46E-01	1.70E-02	3.63E-01	1.20E-03	1.39E+00	4.58E-03	1.81E-01	5.98E-04	9.74
1000	2.88E-01	3.37E-02	7.18E-01	2.37E-03	2.74E+00	9.05E-03	3.58E-01	1.18E-03	19.48
1500	4.31E-01	5.03E-02	1.07E+00	3.54E-03	4.10E+00	1.35E-02	5.35E-01	1.77E-03	29.22
2000	5.73E-01	6.69E-02	1.43E+00	4.71E-03	5.45E+00	1.80E-02	7.12E-01	2.35E-03	38.96
3123	8.94E-01	1.04E-01	2.23E+00	7.34E-03	8.50E+00	2.80E-02	1.11E+00	3.66E-03	60.83604
4000	1.14E+00	1.33E-01	2.85E+00	9.39E-03	1.09E+01	3.59E-02	1.42E+00	4.69E-03	77.92
5000	1.43E+00	1.67E-01	3.56E+00	1.17E-02	1.36E+01	4.48E-02	1.77E+00	5.86E-03	97.4

These calculations are performed by changing the gas generation rate in Sheet "Inputs and Outputs" and pasting the values into the correct line in the table.





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Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project

R. D. Krieg

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Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project

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ABSTRACT

A stratigraphic description of the country rock near the working horizon at the Waste Isolation Pilot Plant (WIPP) is presented along with a set of mechanical and thermal properties of materials involved. Data from 41 cores and shafts are examined. The entire stratigraphic section is found to vary in elevation in a regular manner, but individual layer thicknesses and relative separation between layers are found to have no statistically significant variation over the one mile north to south extent of the working horizon. The stratigraphic description is taken to be relative to the local elevation of Anhydrite b. The material properties have been updated slightly from those in the July '81 Reference Stratigraphy. This reference stratigraphy/properties document is intended primarily for use in thermal/structural analyses. This document supercedes the July '81 stratigraphy/properties document.

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I. INTRODUCTION

There are many structural analysts in several organizations who have been and presently are performing thermal/structural analyses of shafts, drifts, and rooms at the WIPP site. The details of the stratigraphy and materials have been found to be important in these analyses. Rather than have each analyst build a model of his/her own, it was decided in mid 1979 to study the available data and collectively decide on an appropriate reference model of the stratigraphy and a set of materials properties. The initial reference set was particularly valuable since only cores and core-hole logs were available at that time to define the stratigraphy and the interpretation of these was subjective so that choice of a set required some judgement. Analysts, geologists, geophysicists, and mining engineers all had useful inputs to interpretation of the data and definition of a reference stratigraphy/properties. It was recognized from the outset that this reference set must be updated as new data became available. These updates could hopefully be made in a controlled manner so that analysts could always use a reference set without having to use ad hoc modifications to the reference with a different set of modifications used by each organization or analyst.

Early work on a reference stratigraphy was documented in internal memos [1,2] at Sandia National Laboratories. There were probably similar memos written by structural analysts in other companies associated with the WIPP. A meeting was held on November 15, 1979, with attendees from WPO/DOE, Bechtel, the TSC/D'Appolonia, and Sandia, and the first reference stratigraphy and properties were set down [3,4,5]. This was then declared by the project office to be used for all structural calculations[6]. It was called the "November '79 Reference Stratigraphy" and was used for some time [7].

The November '79 Reference Stratigraphy was updated in July, 1981, when more data became available [8]. The material properties in particular were revised at that time. Since this was prior to construction of the shafts, no attempt was made to revise the stratigraphy. This document was used [9,10] as the reference until the present time.

When the shafts were constructed and logged, it became apparent that the July '81 Reference Stratigraphy should be updated. Analysts began using updates to the stratigraphy which accounted for new observational data [11]. A meeting was held between analysts, project geologists, and geological properties scientists at Sandia to consider updates to the reference stratigraphy [12]. Because other analysts are involved, it was obvious that a consensus of everyone, not just Sandia, was needed to define a useful reference.

On July 7, 1983, a meeting was held with attendees from Bechtel National, the TSC/D'Appolonia, Sandia National Laboratories, and the DOE/WIPP Project Office. The meeting notice, meeting schedule, and minutes are included in Appendix A. Action items resulting from the meeting and recorded there include clearing up some questions about correlation between the core, core logs, and tests on insolubles content. Another was a bringing together of suggested reference stratigraphies submitted by Bechtel [13] and the TSC/D'Appolonia [14] and Sandia into a documented reference stratigraphy/properties that would be accepted by everyone. This is the resulting reference stratigraphy/properties document.

A suggestion was made at the meeting documented in Appendix A that three stratigraphic descriptions would be useful as noted on page 43. The present document is a combination of two of the suggested models. The third model would cover a 900m (3000 ft) depth and would be used for regional studies. Due to time constraints, this is not covered here.

The present document is not intended to be a final report on this topic. It is expected that as more data become available, then this document will be revised or superceded.

II. INTENT OF REFERENCE STRATIGRAPHY/PROPERTIES

The intent of this report is to set down a consensus stratigraphy and set of material properties which are suitable for structural analyses of the underground WIPP site. The first part is a presentation of the model which is local to the underground WIPP horizon (near a depth of 655 m (2150 ft)), and is to be used for drift and room calculations. Next, the properties of the rocks listed in the stratigraphy are presented which are generally those presented in the July '81 Reference Stratigraphy. The report concludes with a short summary.

III. STRATIGRAPHY

A. Shift in Reference Depth

The stratigraphy near the underground WIPP horizon has been characterized by examining 41 cores and core logs [10(App C,D,E),15]. These cores were taken throughout the site as it existed in the summer of 1983. The locations of the various coreholes [15] are shown in Figure 1. The layers are fairly planar but dip to the south somewhat. This is shown in Figure 2 taken from reference [15]. Stein, Sandia organization 6331, made quantitative tests on the insolubles at various layers in the core from DH 52,53. It was found that visual estimates of the percentages of impurities listed in the core logs were in error. As an action item from the stratigraphic meeting on June 15, 1983, a group of geologists reexamined the core from four boreholes including DH 52,53. With the measured insolubles as a point of reference for visual estimates, the estimates of impurities listed on the core logs were revised. These four revised core logs were then used by Bechtel National [13] and the TSC/D'Appolonia [14] to identify what they felt were the stratigraphic features which are important to structural analyses. The Sandia National Laboratories input was not documented. All three inputs had generally the same features. These features were then identified on all the 41 logs available. The logs were then shifted to a zero level at anhydrite b above the drifts. Anhydrite b was chosen because of its proximity to the drift and its lack of waviness. The height of the various layers above anhydrite b as well as their thicknesses were then listed as shown in Table I.

B. Layer Thicknesses

Average thickness of the anhydrite layers and their standard deviations are listed as entries in Table I. Note the considerable variation in the thicknesses of the anhydrite layers. Fortunately, these variations are not very important in a structural analysis because most of the layers are thin.

Table I. Heights and Thicknesses of Distinct Layers Measured with Respect to the Base of Anhydrite b. All Entries are in Meters

Core Number	Location of Corehole	Elevation of Anhydrite b	Anhydrite c		Anhydrite MB 139		Unit 4		Anhydrite b	Anhydrite a		Anhydrite MB 138	
			Btm	Thk	Btm	Thk	Btm	Thk	Thk	Btm	Thk	Btm	Thk
DH 227,228	S3656 E147	382.25	-16.09	.06	-8.47	.64	-3.69	.55	tr	1.77	.24	8.78	.15
DH 223,224	S3079 E154	385.05	-15.97	.09	-8.35	.94	-3.96	.82	tr	1.83	.30	9.05	.21
DH 219,220	S2422 E162	388.41	-16.28	.06	-8.50	.67	-3.66	.79	.01	1.98	.18	9.17	.24
DH 215,216	S1960 E153	389.96	-16.82	.06	-8.93	1.01	-3.60	.64	.06	2.01	.15	9.27	.18
DH 211,212	S1320 E163	389.63	-16.92	.09	-8.90	.58	-3.72	.91	.03	2.04	.18	9.20	.15
DH 207,208	S697 E155	386.65	-17.16	.06	-9.02	1.07	-3.61	.82	.05	2.13	.21	9.27	.24
MB 139-2, DO-229	S410 E150	386.58	---	---	-9.14	.98	-3.81	.88	.03	2.26	.21	9.57	.15
Vent Shaft	S410 E25	386.91	---	---	-8.87	1.06	-3.93	.76	.06	2.10	.24	9.40	.18
DO 201,202	S406 W19	387.07	-17.16	.12	-8.81	.85	-4.15	.94	.06	2.16	.21	9.33	.18
MB 139-3	S101 E157	---	---	---	---	.70	---	.70	---	---	---	---	--
MB 139-4	S99 W17	---	---	---	---	1.04	---	.94	---	---	---	---	--
Expl. Shaft	N0 E0	390.37	-17.28	.11	-8.99	.85	-3.88	.91	.08	2.16	.23	9.39	~ .15
MB 139-1	N79 W6	---	---	---	---	.67	---	.94	---	---	---	---	--
DO 52,53	N146 W4	391.88	-16.70	.06	-8.44	1.13	-3.66	1.01	.06	2.04	.15	9.51	.12
DO 45,46	N254 E147	393.92	-16.70	.06	-8.81	1.25	---	---	.03	2.77	.18	9.91	.18
DO 203,204	N624 E140	398.13	-16.18	.06	-8.29	.79	---	---	.06	1.89	.24	8.81	.21
DO 56,57	N621 E0	397.64	-16.64	.09	-8.75	.64	-3.90	1.01	.06	2.10	.18	9.05	.15
DO 63,64	N1110 E0	401.45	-15.79	.18	-8.66	.67	-3.53	.98	.06	2.16	.37	9.02	.21
DO 67,69	N1265 W231.5	401.45	-15.91	.09	-8.26	.94	-3.29	.64	.08	2.13	.27	8.93	.12
DH 77,79	N1270 W364.5	400.75	-16.00	.06	-8.38	.98	-3.41	.76	.08	2.04	.09	8.90	.30
DO 88,90	N1265 W497.5	400.23	-16.22	.05	-8.17	.93*	-3.62	.76	.07	2.13	.15	8.84	.26
DO 91,93	N1275 W630.5	399.91	-15.88	.09	-8.29	1.04*	-3.52	.79	.05	2.16	.21	8.90	.21
DO 205,206	N1410 E0	403.13	-15.76	.06	-8.84	.40	-3.63	.85	.06	2.04	.21	8.93	.24
Average			-16.41	.08	-8.63	.86	-3.70	.83	.06	2.10	.21	9.16	.19
Std. Deviation			.51	.03	.30	.21	.21	.13	.02	.20	.06	.30	.05

*This includes an adjacent polyhalite layer

The thickness of MB139 is important because of its proximity to the drift and its considerable stiffening effect. It is known to be very non-uniform in thickness as shown in Figure 3 for the variation around the shaft [10(App C)]. Note from the figure that if a small diameter core were to have been taken from the areas shown, the thickness might have been measured as 0.61 m to 1.06 m (2.0 to 3.5 ft) in the exploratory shaft [10(App C, Fig. 4] and from 0.53 m to 1.08 m (1.7 to 3.5 ft) in the ventilation shaft [10(App D)]. The local variation in thickness of MB139 must be averaged out over a considerable bedding area in order to make plane strain drift calculations. The layer thicknesses found from the core are essentially values found at a point in the plan view of the site. In Table II, the average thickness of MB139 and its standard deviation have been determined for the data taken on the two shafts, for the data in Table I, and for two subsets of the Table I data. Note that the average value is not a strong function of north/south position. Note also that as data from larger areas are used, then the standard deviation becomes larger. The relation between standard deviation of the thickness of MB139 S and averaging area A is roughly

$$S = 0.1\ A^{0.06} \qquad (1)$$

where S is in meters and A in square meters. This seems to indicate a long range variation in thickness as well as the short range variation shown in Figure 3. For a 10 m room width, it would not be unreasonable to average the bed thickness over a $400 m^2$ area centered on the drift at the station of interest. The standard deviation expected over this area would be given from Eqn (1) as 0.14 m so that the variation would be roughly that seen in Figure 3. A careful study of the statistics could probably produce an expected average thickness as a function of position over the site. At this point in time, it does not seem reasonable to pursue this approach for three reasons: (i) the confidence in the results would be low because of the small sample size, (ii) it is presently necessary to assume that the thickness variation is isotropic[1] and homogeneous[2], (iii) it appears from Table II that the variation over the site would not be large enough to significantly affect structural behavior of the drifts in any case.

The thickness of MB139 as averaged over a $10\ m^2$ area or larger is a reasonable characterization of the layer in that region. It also appears that layer thicknesses averaged over the entire site are the best values to use at every location on the site. This conclusion is based on the study included as Appendix B. In that study, the thicknesses and relative depths of the anhydrite layers were assumed to vary in a linear manner from north to south. The least square fits to the data, however, showed very little regular variation from north to south. Furthermore, it was found that the variations in the variables were not statistically significant. More concisely, based on the data in Table I, one cannot even determine whether

1. If the shape of the thick and thin places are not generally directional like a plowed field, then the variations are said to be isotropic.

2. If the variation is the same everywhere, i.e., there are no areas which are smoother than others, then it is said to be homogeneous.

TABLE II. VARIATION IN THICKNESS OF ANHYDRITE MB139

Location	Average Thickness (m)	Standard Deviation (m)	Averaged Area (m^2)
Ventilation Shaft	1.06	.15	1.8 m dia = 10.5 m^2
Exploratory Shaft	.85	.11	3.6 m dia = 42. m^2
Entries, Table I	.86	.21	240 x 1540 = 370,000 m^2
S Entries, Tbl. I	.90	.21	55. x 1190 m = 66,000 m^2
N Entries, Tbl. I*	.80	.22	235. x 240 m = 56,000 m^2

*Last eight entries in Table I.

any layer thickens or whether it thins from north to south, much less quantify the variation. Thus, averages of layer thicknesses over the entire site are used here to determine the reference stratigraphy.

The mixed layers are more difficult to identify and abstract for the reference stratigraphy. Some of these layers are present in one core but not the other or they have shifted position with respect to the anhydrite layers. Fortunately, the mixed layers are not adjacent to the drift and it is estimated in the next section that the properties are not drastically different from pure rock salt. Several argillaceous layers are identified near MB138 on the logs from the southern end of the site which have 3-4% clay. Only one smaller thickness layer of this type is seen in the log of D079 taken from the north end. The logs of eight coreholes from the northern end of the site (the last eight entries in Table I) were then compared in the region between anhydrite a and MB138. All the clay seams, breaks, and partings from the logs are identified in Figure 4. Clusters of clay discontinuities and/or argillaceous halite layers are noted in all the logs. Their general locations are not significantly different from those found at the southern end of the site. For this reason, it seems that although D079 has fewer impurities than are found at the southern end of the site, it is far from pure and it would not be unreasonable to include clay discontinuities or argillaceous layers in a model at the clustered regions shown in Figure 4. The thicknesses of the argillaceous layers in this region were taken as a subjective average of that seen in DH227, DH215, D052, and from Figure 4.

Unit 4 in Table I has been mapped in all the drifts at the site. For consistency, these maps were used at locations nearest each of the corehole locations in Table I and the resulting values entered in the table.

C. Locations and Identification of Layers

The locations and identifications of each of the layers for the September '83 Reference Stratigraphy are shown in Figure 5. Averages over the entire site which are listed in Table I have been used for most of the layers.

The layers above clay L were taken from the logs of the ventilation shaft and exploratory shaft. The average height of the layers above mid-height of MB138 was taken from the shaft logs and this same elevation difference was used to construct Figure 5.

The layers below anhydrite c were taken from the logs of ERDA 9. In Table III, the significant layers from the geologic log of ERDA 9 are compared to the position of layers from Table I. We note that the two stratigraphic columns are very similar. This is used to justify the use of the ERDA 9 log to append MB140 and MB141 to the data in Table I. The distance between anhydrite c, MB140 and MB141 are taken for the Reference Stratigraphy to be the same as for ERDA 9. The values are shown in parentheses in Table III.

The thicknesses and locations of the combined layers on the ERDA 9 log denoted as MB136, MB140, and MB141 in Table III were found as follows. Adjacent layer thicknesses were added to obtain the thickness of the idealized layer. (This included three thin polyhalite layers in MB136 and one thin one in MB140 as well as a thin claystone layer in MB141. The properties are similar enough to make this a reasonable approximation). The location of the idealized layer was found by requiring the average height (first moment) to be identical to the actual layers. This averaging was necessary since the several layers in each case were interspersed with halite layers.

Anhydrite b is shown in Figure 5 but should not be included in a structural model since it is too thin to be structurally sound. Its presence as an elastic layer in a model could introduce a local stiffness that is not physically realizable.

The clay layers are designated with letters from A through M and are taken to be of zero thickness. A clay layer C was originally defined in the rough draft of this report but was subsequently removed after discussions with various participants. The remaining layers retained their original designations.

Table III.
Midheights of Significant Layers Taken from the Geologic Log of ERDA 9 as Compared with Table I.

Layer I.D.	Height Above the Datum (m)	
	ERDA 9	Table I
MB136	30.79	30.61
MB137	23.47	---
MB138	9.39	9.26
Anhydrite	5.19	---
Anhydrite a	2.20	2.20
Anhydrite b	---	.03
MB139	-8.29	-8.20
Anhydrite c	-16.76	-16.37
MB140	-28.56	(-28.17)
MB141	-52.82	(-52.43)

Note: MB136 includes 7 layers here, MB140 includes 5, and MB141 includes 4.

D. Comparison with Input from Bechtel and TSC/D'Appolonia

Bechtel, TSC/D'Appolonia, and Sandia each proposed an idealized or reference stratigraphy as outlined in Appendix A. The stratigraphies from Bechtel and TSC/D'Appolonia are compared in Figure 6 with the compromise reference described above. The principal difference is that the reference includes several clay seams not present in the others and is a single stratigraphy whereas Bechtel proposed two references, one for the southern end and another for the northern end. The justification for the single stratigraphy is given in Appendix B and discussed above in connection with layer thicknesses and will not be repeated here. The clay seams were included primarily to signal caution to a designer or stress analyst that trouble is possible if mining occurs in these horizons. These are planes (or at least zones) where slip is possible. With the coefficient of friction of 0.4 specified for these seams, most of them will not actually demonstrate slip in most calculations. Since slip planes can increase the cost of an analysis, even if they are not active, it is generally best to omit them from a model if they are not active. This depends upon their location relative to a drift or other disturbance, the coefficient of friction of the clay seam, and the time for which the analysis is to be run. Auxiliary studies can be made to identify active seams in any particular case.

IV. MECHANICAL PROPERTIES

A. Lithostatic Stress and Density

The idealized stratigraphy of the previous section does not extend up to the surface. It is necessary to apply pressure at the top (and bottom) of a structural model of this stratigraphic interval. The value of pressure to be used here is based on the weight of overburden rock above the site. An average density of 2320 kg/m^3 has been calculated [16] by integration of the mass density measured in the well log on ERDA 9 for the interval from the surface to the room horizon. The depth of anhydrite b is given from the geologic logs of the exploratory and vent shafts as 648.24 m and 652.67 m, respectively. Using an average of 650.45 m and the height of 52.87 m to the top of MB 134 (from Figure 5) we find 597.58 m of overburden at the top of the defined stratigraphy. A value of the elevation adjusted acceleration of gravity of 9.790 m/sec^2 is used then to obtain

$$p = (9.790)(597.58)(2320.)$$

$$= 13.57 \text{ MPa } (1968. \text{ psi})$$

This is to be used as the isotropic lithostatic stress state at the top of the stratigraphic section idealized here.

A constant average density over the interval of depth used in the September '83 Reference Stratigraphy can be used for convenience. The value to be used was found by adding all the layers of halite and argillaceous halite to obtain a thickness of 90.02 m. If 99% of this is pure halite, then over the 107.06 m interval studied, we have 89.12 m of halite (2163. kg/m^3) and 17.94 m of other material for which we assume the density of anhydrite (2960. kg/m^3). This mixture gives a weighted average of

$$\rho = \frac{(89.12)(2163.)+(17.94)(2960.)}{107.06}$$

$$= 2300. \text{ kg/m}^3$$

This gives a lithostatic stress at the clay seam F of 14.83 MPa (2150.psi).

B. Thermal and Mechanical Properties

Only five materials are identified in the stratigraphy and listed here. The properties of these layers are given in this section. They are generally the same properties as were identified in the July '81 Reference Stratigraphy [8] and used elsewhere [7,9,10]. This section is organized as follows. Two tables of properties are presented, one with thermal properties and the second with mechanical properties with terms defined in the text. The source of each quantity is then identified or explained.

B1. Thermal Properties

The thermal properties are listed in Table IV. Note that clay is missing from the table. Since the clay seams are generally less than 0.02m (1. in) thick, they are ignored thermally.

The density is taken to be the same value for all materials as discussed in the previous section.

Values of specific heat are also taken to be the same for all materials. The Debye temperature for salt is near room temperature so that the variation of the specific heat with temperature is small at temperatures of interest here.

TABLE IV. Thermal Properties for the WIPP Materials

Material	Density* ρ (Kg/m^3)	Specific* Heat, C_p (J/kg-K)	Coefficient of Linear Thermal Expansion, α (K^{-1})	Thermal Conductivity Parameters	
				λ_{300} (w/mK)	γ
Halite	2300.	860.	45.0 E-6	5.0	1.14
Argillaceous Salt	2300.	860.	40.0 E-6	4.0	1.14
Anhydrite	2300.	860.	20.0 E-6	4.7	1.15
Polyhalite	2300.	860.	24.0 E-6	1.4	0.35

*These values are taken to be the same for convenience in analysis. Actual values differ somewhat.

The coefficients of linear thermal expansion are measured quantities [17]. Core specimens were used for these tests with samples taken at various depths.

Thermal conductivity for the materials [17,18,19] were fitted to the equation

$$\lambda = \lambda_{300} \, (300/T)^{\gamma}$$

where T is temperature in kelvin. The thermal conductivity expression given here has been compared by Torres [20] to data for salt from West Germany where it was found that the values were within roughly ± 3% from room temperature to 200°C.

B2. Elastic Constants

Suggested values for the elastic constants of halite, anhydrite, and polyhalite [18,19,21] are listed in Table V for 25°C and 100°C. Both anhydrite and polyhalite properties show some change with temperature; however, for reference calculations the values for 25°C should be used. Argillaceous halite is considered to be similar to the "clean" halite units and, therefore, should be assigned the same elastic constants. For the present, the elastic constants for the halite and argillaceous halite units are considered to be independent of temperature, and the values indicated for 25°C should be used.

TABLE V. Elastic Constants

	Halite*	Anhydrite **		Polyhalite**	
	25°C	25°C	100°C	25°C	100°C
Young's Modulus (E)	31.0 GPa	75.1 GPa	51 GPa	55.3 GPa	46.1 GPa
Poisson's Ratio, ν	0.25	0.35	0.26	0.36	0.30
Bulk Modulus (K)	20.7 GPa	83.4 GPa	35.4 GPa	65.8 GPa	38.4 GPa
Shear Modulus (μ)	12.4 GPa	27.8 GPa	20.2 GPa	20.3 GPa	17.7 GPa

*Similar constants for Argillaceous Halite are to be used

**As determined from tests [22,23] at a strain rate of 2.1×10^{-4} sec^{-1}

3. Creep Constitutive Properties

The constitutive models for the materials exhibiting creep behavior are described as follows [21].

The strain rate is characterized by the equation:

$$\dot{\varepsilon}_{ij} = -\frac{\nu}{E}\dot{\sigma}_{kk}\,\delta_{ij} + \frac{1+\nu}{E}\,\dot{\sigma}_{ij} + \dot{\varepsilon}^{c}_{ij} + 3\alpha\,\dot{T}\,\delta_{ij} \qquad (2)$$

where

σ_{ij} are the components of the stress tensor.

ν is the Poisson's ratio.

E is Young's modulus.

T is temperature, degrees kelvin.

α is coefficient of linear thermal expansion.

δ_{ij} is the Kronecker Delta,

and the creep strain rate, $\dot{\varepsilon}^{c}_{ij}$, is given by:

$$\dot{\varepsilon}^{c}_{ij} = \left|\dot{\varepsilon}^{c}_{kl}\right| \frac{\sigma'_{ij}}{|\sigma'_{mn}|} \qquad (3)$$

where σ'_{ij} are the components of the deviatoric stress tensor. Standard summation convention is implied.

For the case in which only secondary creep (steady state) is considered, the magnitude of the creep strain rate can be expressed in terms of the effective creep strain rate, $\dot{\bar{\varepsilon}}$, or the effective stress, $\bar{\sigma}$, as follows [24]:

$$\left|\dot{\varepsilon}^{c}_{ij}\right| = \sqrt{1.5}\;\dot{\bar{\varepsilon}} \qquad (4a)$$

$$\dot{\bar{\varepsilon}} = D\,\bar{\sigma}^{n}\,\exp(-Q/RT) \quad . \qquad (4b)$$

where $\dot{\bar{\varepsilon}}$ is defined as:

$$\dot{\bar{\varepsilon}} = \left(\frac{2}{3}\ \dot{\varepsilon}^{c}_{ij}\ \dot{\varepsilon}^{c}_{ij}\right)^{1/2} \qquad (5)$$

while $\bar{\sigma}$ is

$$\bar{\sigma} = \left(\frac{3}{2}\ \sigma'_{ij}\ \sigma'_{ij}\right)^{1/2} \qquad (6)$$

D, n are constants determined from data analysis.

T is temperature, degrees kelvin.

Q is the effective activation energy, cal/mole.

R is the universal gas constant, 1.987 cal/mole-K.

Values for the parameters are given in Table VI.

Table VI. Constants for Reference Creep Law
(Repository Level, Nominal Elevation 390 m)

Material	Primary Constants			Secondary Constants		
	A	B	$\dot{\varepsilon}^*$ (sec^{-1})	D ($Pa^{-4.9}/sec$)	n	Q (Kcal/mole)
Halite	4.56	127	5.39 E-8	5.79 E-36	4.9	12.0
Argillaceous Halite	4 56	127	5.39 E-8	1.74 E-35	4.9	12.0

In many cases, clay seams can be modeled by a slip line, which allows compressive but no tensile normal stresses. Transverse forces can be transmitted with the frictional coefficient given in Section B5 for clay seam mechanical response.

The creep constants are based on the analysis of data presented in References 24, 25, and 26. The expressions used here are equivalent to those in Reference 24 but have been expressed in terms of effective strain rate.

A factor of 2/3 must be used to convert the steady state shear creep strain rate ($\dot{\gamma}_s$) in a triaxial test to effective creep strain rate $\dot{\bar{\varepsilon}}$ as:

$$\dot{\bar{\varepsilon}} = 2/3 \ \dot{\gamma}_s \tag{7}$$

Reference values for secondary creep strain rates from these formulations are given in Table VII:

Table VII Secondary Creep Effective Strain Rate $\dot{\bar{\varepsilon}}$

Temperature	Effective Stress	
	5 MPa	15 MPa
300°K	7.02 E-12	1.53 E-9
350°K	1.25 E-10	2.71 E-8

If primary creep is to be included in the constitutive model, the primary creep rate is derived [26;(Eqs 27, 28, 29; p 19)] in the following manner.

The effective creep strain rate is the sum of the secondary and primary terms as:

$$\dot{\bar{\varepsilon}} = \dot{\varepsilon}_s + \dot{\varepsilon}_p \tag{8}$$

The secondary term $\dot{\varepsilon}_s$ is defined exactly as before (Eq 4b), and the primary term $\dot{\varepsilon}_p$ is obtained from the solution of the following differential equation:

$$\dot{\varepsilon}_p = (A\text{-}B\ \varepsilon_p)\dot{\varepsilon}_s \text{ for } \dot{\varepsilon}_s \geq \dot{\varepsilon}^* \tag{9a}$$

and

$$\dot{\varepsilon}_p = (A\text{-}B\ \frac{\dot{\varepsilon}^*}{\dot{\varepsilon}_s}\ \varepsilon_p)\dot{\varepsilon}_s \text{ for } \dot{\varepsilon}_s < \dot{\varepsilon}^* \tag{9b}$$

where the initial condition of $\varepsilon_p = 0$ at $t = 0$ is assumed.

The primary creep constants A, B, and $\dot{\varepsilon}^*$ are given in Table VI. Equations (3), (4), and (8) are combined to give:

$$\dot{\varepsilon}^c_{ij} = 1.5 \frac{\sigma'_{ij}}{|\sigma'_{mn}|} \left[D\bar{\sigma}^n \exp(-Q/RT) + \dot{\varepsilon}_p \right] \tag{10}$$

where $\dot{\varepsilon}_p$ is given by Eqs (9).

The argillaceous halite is not considered to be significantly different from the "clean" halite. The secondary creep constants indicated in Table VI for argillaceous halite are derived from preliminary test results [27].

The failure of halite can be described using a failure function ϕ such that when ϕ becomes positive, halite no longer supports any deviatoric stress. This function will be assumed to be given by the following:

$$\phi = \bar{\varepsilon} - 0.023 - f(p) \tag{11}$$

where p is the pressure which is positive in compression, $\bar{\varepsilon}$ is the effecive creep strain found from the integration of Eqn (3) using Eqs (4) or (10) and the expression:

$$f(p) = \begin{cases} 0.132 \text{ for } p \geq 6.0 \text{ E6 Pa} \\ p(a-bp) \text{ otherwise} \end{cases} \tag{12}$$

Here $a = 4.43$ E-8 Pa^{-1}, and $b = 3.7$ E-15 Pa^{-2}.

The relation between pressure and effective strain for $\phi = 0$ is shown in Figure 7.

B4. Anhydrite and Polyhalite Failure Criteria

The mechanical response of both anhydrite and polyhalite can be considered as isotropic and linearly elastic up until failure [22,23]. Failure is described in terms of the fracture stress or ultimate strength of the rock, which is the maximum load it can support in a stress-strain test. Ultimate strengths of both rocks can be assumed to be independent of temperature between 25°C and 100°C, and creep can also be ignored.

Fracture of both rocks can be described equally well by two fracture criteria because insufficient information exists to distinguish between the two (the differences are expected to be small) [22]. The Mohr-Coulomb criterion can be stated in terms of resolved principal stresses where $\sigma_1 \leq \sigma_2 \leq \sigma_3$ as

$$\sigma_3 - \sigma_1 = 2\tau_0 \cos\beta - (\sigma_3+\sigma_1)\sin\beta \quad (13)$$

The Drucker-Prager is the other criterion which can be used and is stated as

$$\sqrt{J_2'} = C - aJ_1 \quad (14)$$

where $\sqrt{J_2'}$ is the second deviatoric stress invariant, and is equal to $\bar{\sigma}/\sqrt{3}$ and J_1 is the first stress invariant or the sum of the three normal stress components. Constants for these equations are given in Table VIII [22,23]. For anhydrite, there is a slight decrease in ultimate strength with decrease in strain rate of approximately 5% for every decade of strain rate change, i.e., a 10% decrease in going from 10^{-4} sec^{-1} to 10^{-6} sec^{-1}. Polyhalite ultimate strengths can be assumed independent of strain rate.

Although there is very little deviation of stress-strain curves from elastic response as the fracture stress is approached, a yield point is detectable in both rocks. The yield point is defined as the onset of dilatancy. Since some designs are based on yield rather than ultimate strength, yield stress design parameters are also listed in Table VIII. The yield point of anhydrite is consistently observed to be 75% of the ultimate strength and is 81% of the ultimate strength for polyhalite.

Table VIII. Failure Parameters* for Anhydrite and Polyhalite

Type of Failure	Anhydrite	Polyhalite
Ultimate		
Mohr-Colomb	τ_0 = 30 MPa	τ_0 = 18.9 MPa
	β = 37°	β = 51°
Drucker-Prager	a = 0.279	a = 0.395
	c = 36 MPa	c = 19.8 MPa
Yield		
Mohr-Coulomb	σ_0 = 27 MPa	σ_0 = 17.2 MPa
	β = 29°	β = 46.5°
Drucker-Prager	a = 0.226	a = 0.361
	c = 33 MPa	c = 19.3 MPa

*Data from triaxial compression tests at strain rates of approximately 2.1×10^{-4} sec^{-1} [22,23].

B5. Clay Seam Mechanical Response

Clay seams in the middle to lower part of the Salado formation at the WIPP site are described as [28]:

1. At most a few centimeters thick
2. Having nonplanar bounding surfaces
3. Having evaporite growths of halite, anhydrite, and polyhalite penetrating into them
4. Having a significant component of quartz and illite.

Thus, the clay seams tend to be simply layers of evaporites which contain higher concentrations of silicates than adjacent evaporites. Clay seams D, I and J in Figure 5 actually correspond to clusters of thin clay partings similar to those seen in Figure 4. Their combined behavior is taken to be that of a clay seam. In view of the "grit" interspersed in the clay minerals and the nonplanar bounding surfaces, a coefficient of static and dynamic friction of 0.4 is recommended for all reference calculations. This simple description of clay with a dry friction model may appear to the uninitiated as an ad hoc assumption. This is not the case however. The bulk clay might conventionally be modeled as a Mohr-Coulomb material. For the special case of a thin layer, the relation between these two models can be shown as follows.

The Mohr-Coulomb material is taken to be an elastic-perfectly plastic material with a yield stress, Y, which varies linearly with pressure, p, as given by

$$Y = \tau_0 + p \tan \phi$$

where p is positive in compression. For a set of experimentally observed yield stresses under specified pressures, the constants α and ϕ may be determined. The general yield condition is then written as

$$(a+cp)^2 = \frac{1}{2}\left[(\sigma_{11}-\sigma_{22})^2 + (\sigma_{22}-\sigma_{33})^2 + (\sigma_{33}-\sigma_{11})^2\right] + 3\left[\sigma_{12}^2 + \sigma_{13}^2 + \sigma_{23}^2\right]$$

A thin clay seam is now considered in a geologic setting where the normal stress components are roughly equal to each other, i.e.,

$$p \cong -\sigma_{11} \cong -\sigma_{22} \cong -\sigma_{33}$$

where the normal stresses are positive in tension. The coordinate system is oriented such that the x_1-direction is normal to the plane of the seam and the x_2-direction is in the direction of motion or incipient motion.

Then σ_{12} is the only non-zero term on the right side of Eqn (11) so that it may be rewritten as

$$\sigma_{12} = \frac{\alpha - \sigma_{11} \tan \phi}{\sqrt{3}}$$

If the cohesive strength is small, then Eqn (12) is the form of a dry friction law:

$$\sigma_{12} = \mu \, |\sigma_{11}|$$

Thus, Eqn (12) applies to a Mohr-Coulomb material under clay seam conditions. In spite of this correspondence between the dry friction surface model and Mohr-Coulomb bulk behavior, it is preferable to consider a clay seam as a dry friction surface. This is due to the asperity or roughness of the seam as well as its waviness. The friction factor μ is then increased to account for the seam geometry as well as the basic bulk properties of the clay.

A complete statement of behavior of the clay seam model then is:

if $\sigma_{12} < \mu|\sigma_{11}|$ then no slip occurs and if $\sigma_{12} = \mu|\sigma_{11}|$ then slip takes place and the shear stress is limited to this value. The effect of clay seams on overall behavior of the drifts in the repository has been studied in some detail [29]. Mechanical modeling [30] and numerical behavior of the model has also been of some concern [31]. These studies have shown that the seams near the drift will be active for $\mu = 0.4$, that this is a reasonable value, and that clay seam separation is unlikely unless the seam is very near the drift. The effect of these clay seams is significant in regard to room closure and is discussed in Reference 29.

V. SUMMARY

The September '83 Reference Stratigraphy has been described as shown in Figure 5. The new stratigraphy consists of one polyhalite layer, three argillaceous halite layers, eight anhydrite layers, 12 clay seams, and halite as the remaining constituent. No mixed polyhalite/anhydrite/halite layers are included. The definition of the new stratigraphy is based on Bechtel, the TSC/D'Appolonia, and Sandia interpretations of a detailed re-examination by a selected group of individuals from these concerns of core from four selected coreholes. The location and thicknesses of the various layers were then adjusted by averaging values taken from the 41 core logs listed in Table I. Logs from the vent shaft, exploratory shaft, and ERDA 9 were used for layers remote from the horizon. The uniformity of the logs, the lack of a statistical significance in bed thicknesses and elevation variation, and the expected small influence on structural behavior resulted in a decision to use the same reference stratigraphy everywhere over the site. Anhydrite b was used as the datum layer, and elevations of other layers are specified with respect to it. It is not to be included in the model because of its small thickness.

Properties of materials are listed in Tables IV through VIII and are similar to previously used properties. A change has been made in the lithostatic pressure to be used at the top of the stratigraphic interval. A change in the average density to be used for the stratigraphic section has also been made.

The reader is cautioned that the September '83 Reference Stratigraphy is intended for structural modeling and does not include many stratigraphic details. The core logs are available and should be consulted if details are important. The reader is also reminded that while the Reference Stratigraphy and Material Properties are the basis for structural calculations and by the project participants, parameteric studies and associated analyses are not meant to be precluded by this document. It is expected that this document will be updated as more data beccme available.

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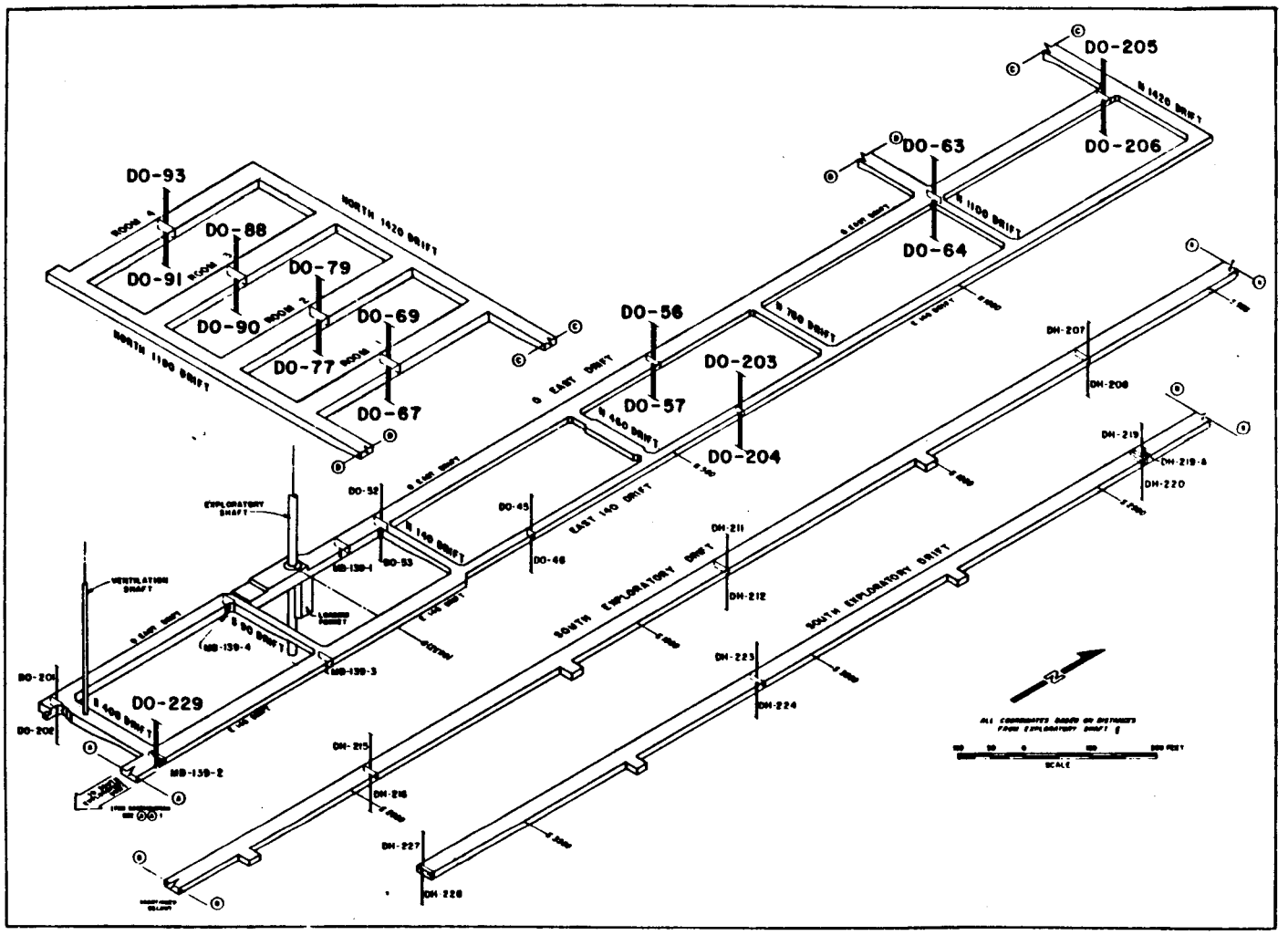

Figure 1. Location of coreholes and shafts whose geologic logs were used in construction of Table I.

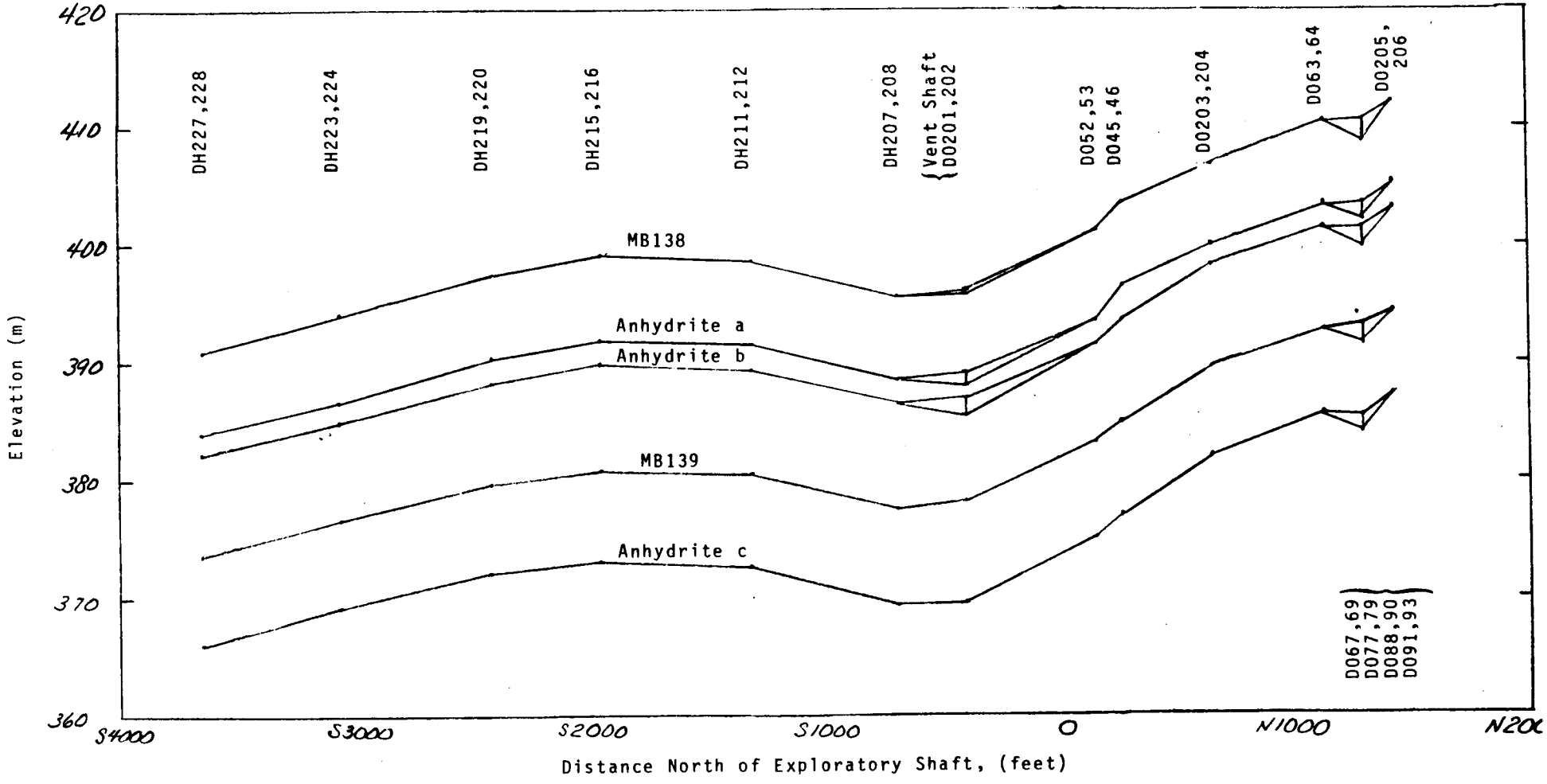

Figure 2. Elevation of the Principal Anhydrite Layers Showing Generally Parallel Layers and Dip Toward the South. Multiple Points Show E-W Spread. See Table I.

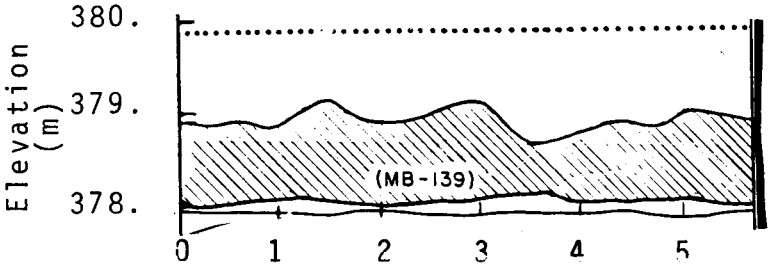

Figure 3a. Mapped shape of MB139 in the ventilation shaft.

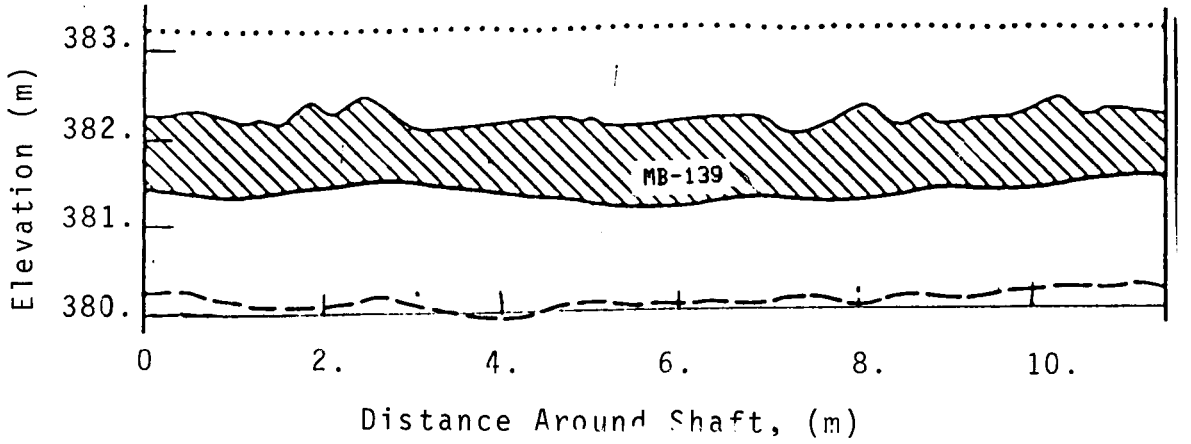

Figure 3b. Mapped shape of MB139 in the exploratory shaft.

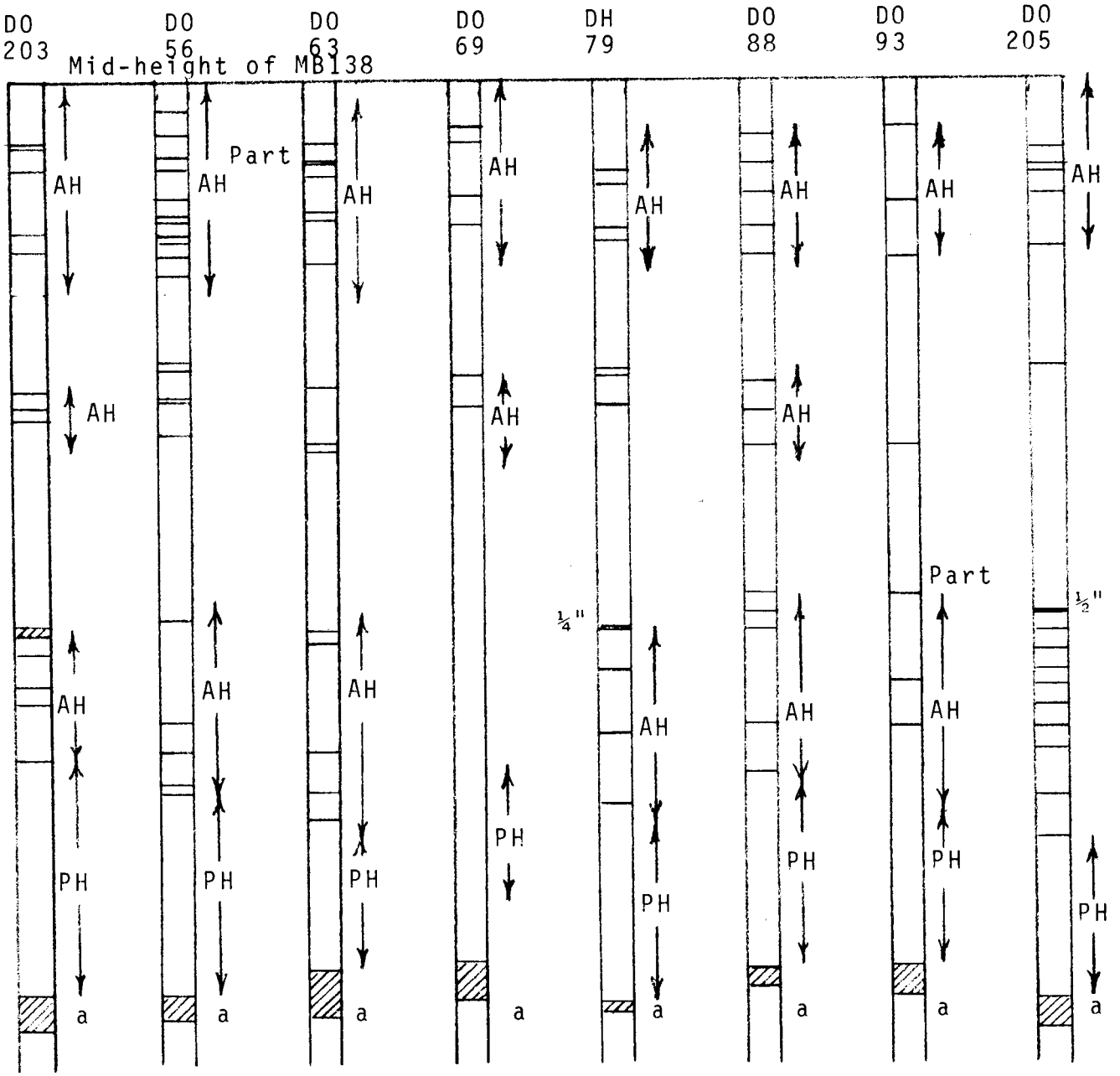

Figure 4. The clay layers are identified in the eight cores taken from the north end of the WIPP site [14]. Argillaceous halite (AH) and polyhalitic halite (PH) layers are identified also. Core logs have been shifted to the mid-height of MB138.

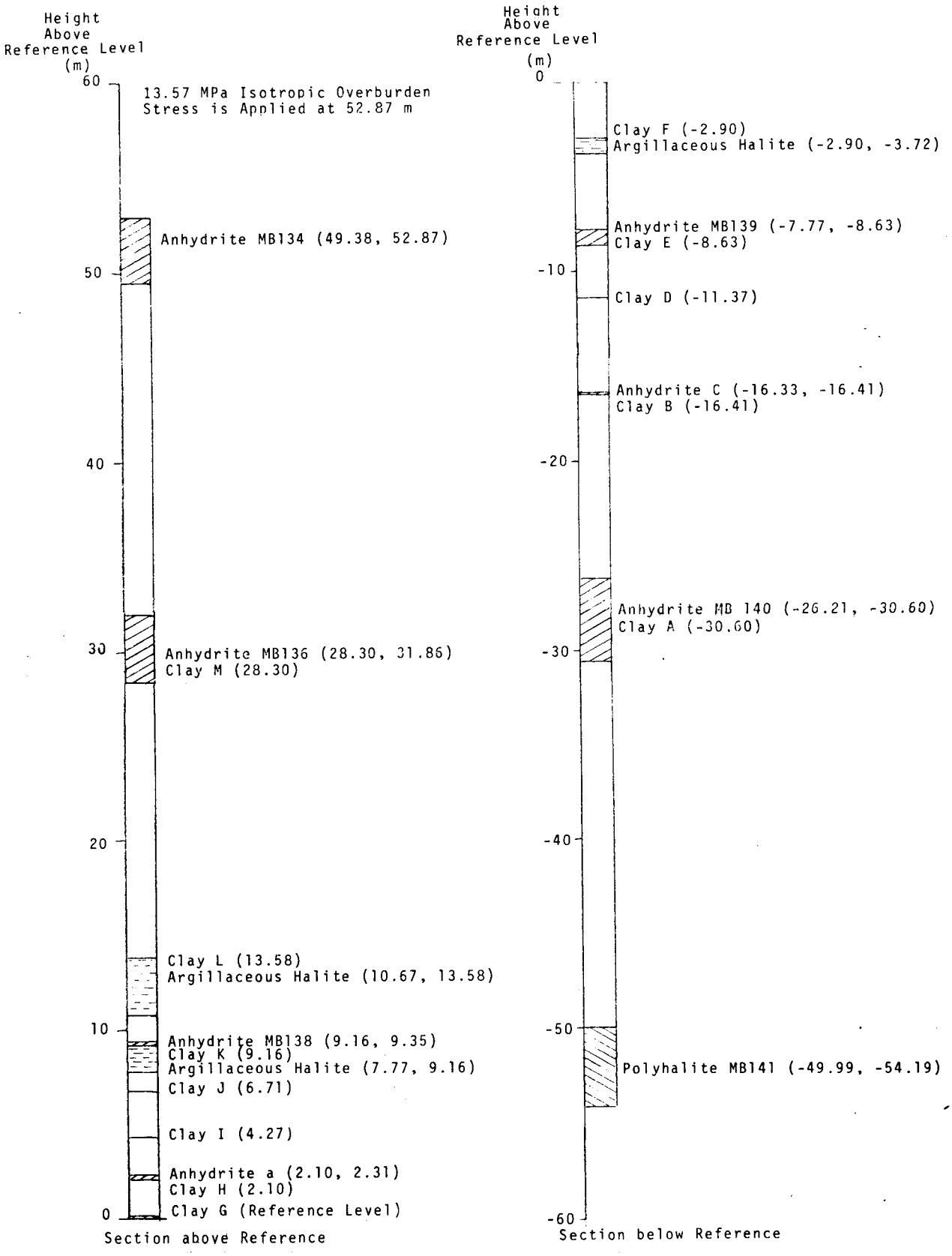

Figure 5. September '83 Reference Stratigraphy. Anhydrite b should not be used in a structural model. It is only included for reference purposes.

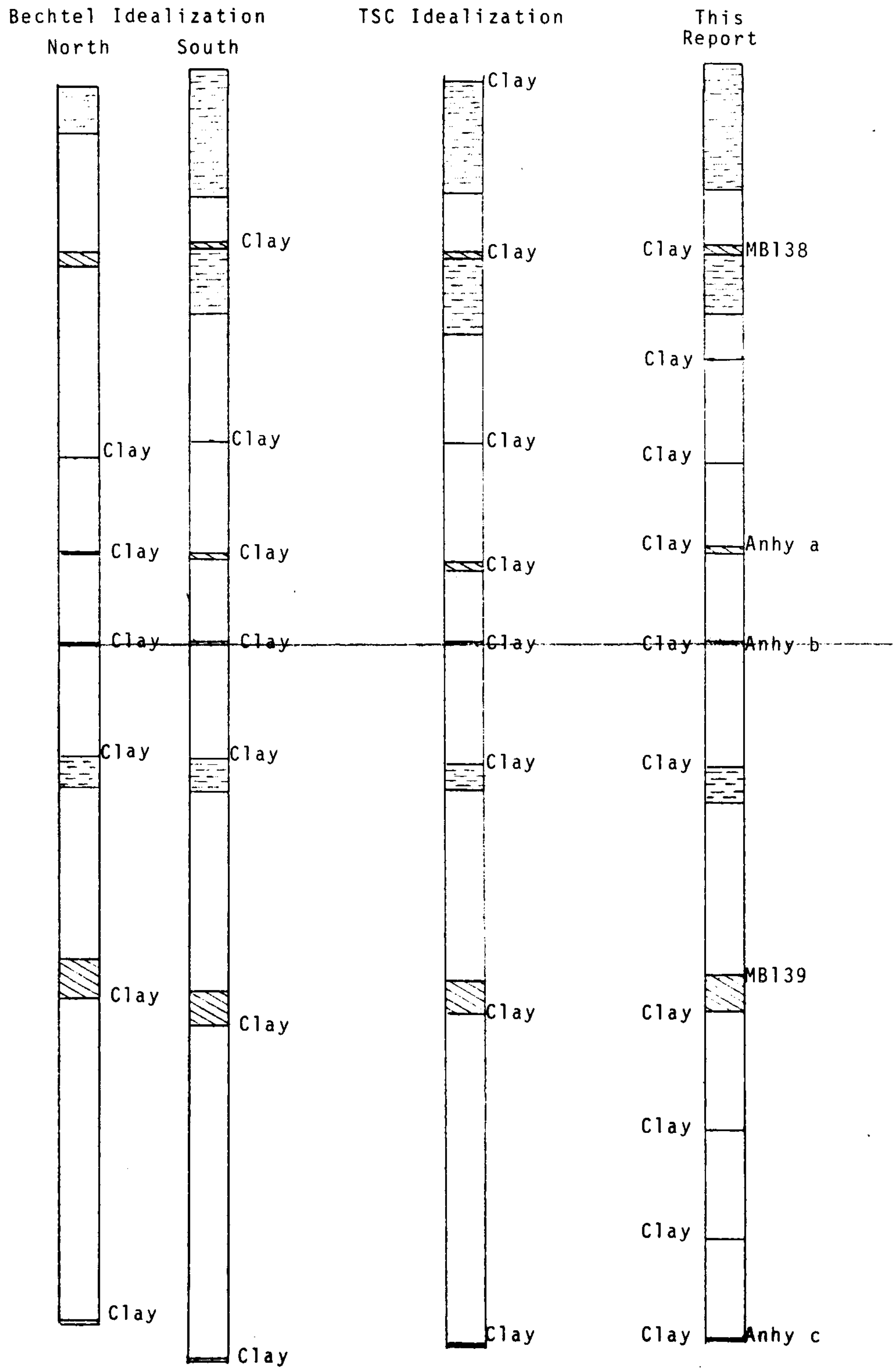

Figure 6. Comparison of idealized stratigraphies of Bechtel and TSC with the idealization of this report.

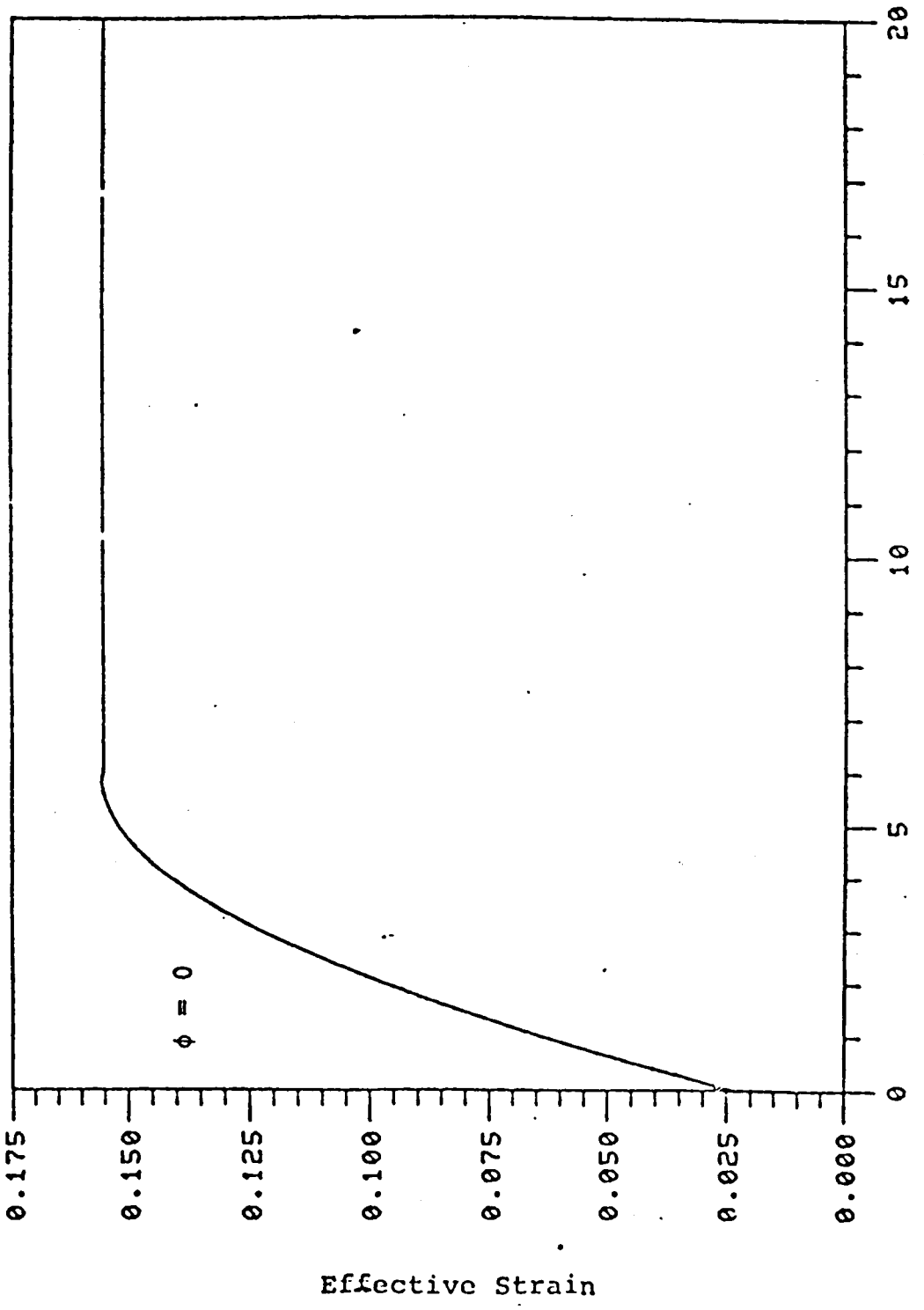

Figure 7. Failure Functions for Halite.

APPENDIX A

REVIEW MEETING ON STRATIGRAPHY AND THERMAL AND MECHANICAL PROPERTIES

Contents

- Meeting Notice
- Agenda
- Attendees
- Notes from Meeting
- Action Items

Progress Review Meeting on Stratigraphy and Thermal and Mechanical Properties Near the Working Horizon at the WIPP

July 7, 1983
8:00am - 4:30pm
Coronado Club, Room B4, Kirtland Base East
Albuquerque, NM

A standard abstracted stratigraphy and set of mechanical and thermal properties was first agreed upon by a group of experimentalists, field geologists, and structural analysts in November 1979. This has been a useful concept both for structural/thermal analyses and for design of experiments at the WIPP. The two shafts have been logged at the WIPP site and about a mile of drifts have been excavated. Some new materials tests have also been performed and some old data reanalyzed. The standard stratigraphy and set of material properties should be updated at this time to include the new information. This data base is not complete since all mechanical tests will not be completed for quite some time. However, many important calculations must be started and experimental detail decisions made prior to test completions. The new standard stratigraphy and set of properties is not meant to be a final set but rather an update.

The progress review meeting is not intended to be a showcase for the latest and greatest tools, techniques, and achievements, but rather intended to be a working meeting. The review meeting participants will collectively reach decisions which will allow an updated standard stratigraphy document to be constructed. Some participants are being asked to prepare presentations on work which directly bears on the decisions to be made by the group. Discussions and decisions on each limited topic will follow the presentation on that particular topic.

As you realize, it is difficult for a diverse group of individuals to reach decisions on anything. The success of this meeting then depends upon:

1. *an attitude of cooperation and unity of purpose, not competition and divisiveness.*
2. *conscientious preparation of "homework assignments" by participants who are asked to make presentations.*
3. *a structured program with limited scope of discussion topics.*

It is felt that these are achievable goals considering the participants who are being invited. Lunch will be served at the Coronado Club to the invitees to relieve the intensity of the meeting without rushing the meal in the time allowed.

This workshop should result in an enjoyable, tiring but satisfying day.

PROGRESS REVIEW MEETING AGENDA

Chairman: T. Hunter

8:00 *SNL, Hunter, Introduction and statement of ground rules*

STRATIGRAPHY INTRODUCTION

8:20 *Bechtel - Roberts - Concerns, needs, and uses by Bechtel for the standard stratigraphy definition and other recommendations*

8:30 *SNL, Branstetter - Sensitivity of closure in the South Drift to the initial stress state and concerns, needs, and uses by Sandia for the standard stratigraphy definition*

8:40 *TSC - Sources of data base for definition of stratigraphy*

8:50 *Directed discussion on stratigraphy, necessity for horizontal variations in the standard but no decisions on the details until properties are defined*

PROPERTIES ON ROCK SALT

9:25 *SNL, Krieg - Sensitivity of closure to variations in low stress creep behavior and other secondary creep properties, homogeneity of properties, variations in elastic moduli*

9:40 *SNL, Wawersik - Update on secondary creep description*

9:55 *Discussion on rock salt properties*

10:25 *Break*

10:40 *Decision on a standard set of properties - for rock salt*

PROPERTIES OF CLAY SEAMS

11:10 *SNL, Stone - Sensitivity of closure to clay seam friction coefficient*

11:20 *TSC - Clay seam studies*

11:30 *SNL, Butcher - Update on clay seam mechanical property studies*

11:40 *Discussion on clay seam description and decision on standard properties for seams present*

12:00 *Lunch*

PROPERTIES OF OTHER LAYERS

1:00 *SNL, Stein - Status of tests on constituents in the mixed layers*

1:10 *SNL, Wawersik - Interpretation and consequences of tests on mixed layers*

1:20 *Discussion on anhydrite, polyhalite, and mixed layers and decisions on a standard set of properties*

STRATIGRAPHY DECISION

2:00 *Bechtel - A proposed standard stratigraphy*

2:10 *TSC - A proposed standard stratigraphy*

2:20 *SNL, Krieg - A proposed standard stratigraphy*

2:30 *Discussion on stratigraphy and proposed models*

2:45 *Break*

3:00 *Decision on standard stratigraphy*

3:30 *Break*

ACTION ITEMS

4:00 *SNL, Krieg - Summary of standard stratigraphy and properties*

4:15 *Assignment of action items and conclusions*

4:30 *Closure*

Attendees

Arlen Hunt	DOE
Randy Robinson	"
Howard Taylor	Bechtel Nat'l Co.
Dale Roberts	"
Ching Wu	"
Da Lee Wu	"
William T. Li	"
Ray Krieg	1521, Sandia National Labs
Linda Branstetter	"
Hal Morgan	"
Mike Stone	"
David Webb	"
B. M. Butcher	1542, Sandia National Labs
W. R. Wawersik	"
Wendell Weart	6330, Sandia National Labs
Al Lappin	6331, Sandia National Labs
Tom Hunter	6332, Sandia National Labs
C. L. Christensen	"
Rudy Matalucci	"
Darrell Munson	"
John Stormont	"
T. M. Torres	"
Joseph Franzoni	TSC/D'Appolonia
Lubor Jarolimek	"
Roy McKinney	"
Art Moss	"
Dev Shukla	"
Dale Stephenson	

Notes from Progress Review Meeting on
Stratigraphy and Mechanical Properties Near the Working Horizon at the WIPP
July 7, 1983
Albuquerque, New Mexico

The meeting consisted of participants from Sandia, Bechtel and the TSC/D'Appolonia in the WIPP project to establish and update the reference properties to describe the rocks in the underground in the WIPP. The introduction to the meeting by T. O. Hunter consisted of a discussion of the overall purpose of the modeling and calculational effort in its relation to design. Two aspects are important in terms of this activity. One is the establishment of the technical basis for the design, and a development of the associated technology and technology demonstration as regard to WIPP's role as an R&D facility. The project is operating with a structure such that Bechtel will develop the design validation including the conclusions about the validity of the design relative to the original design assumptions. These conclusions and activities will be supported by other project participants who provide data and information supportive to that goal. Sandia will provide modeling studies and laboratory property determinations of materials which support the Bechtel design calculations. The TSC/D'Appolonia will provide interpretations of the sight geology and their impact on the development of reference, stratigraphy and properties.

The design process consists of many elements. These include the design objectives and the design basis in the actual engineering design itself. Within the engineering design are included the calculations which are necessary to form the basis for that design, as well as other empirical techniques and engineering design practices which are used to establish design of an underground facility. Two other key elements include the stratigraphy of the rocks near the working level and the assumptions about rock properties in the different geologic units. Thes two subjects, the stratigraphy and the rock properties are the subject of today's meeting. Other meetings have discussed the basis for the calculations and the basis for the design. Tomorrow's meeting will address measurement techniques and field observations that are used to correlate the design assumptions with the actual data. Finally the process consists of conclusions about the design process itself which will be part of both the design validation report by Bechtel and the conclusions regarding the R&D repository development in rock salt. The format of the meeting consists of presentations on selected subjects and focus discussions about how to develop or establish agreement on the items addressed.

The first series of presentations consisted of establishing the need in basis for development of a stratigraphy in the WIPP. The first presentation was by Dale Roberts of Bechtel.

The basis for reference stratigraphies in Bechtel's use is as a model for calculations. They are concerned about spacial variations in the stratigraphy and how it impacts design calculations. Particularly, Howard Taylor from Bechtel described how they will concentrate on calculations in the storage rooms and then associated calculations in the south drift for the design validation calculations.

Linda Branstetter, Sandia, presented a discussion of the sensitivity of the calculations to various parameters. The parameters included the density and hence the original lithostatic stress and its variation on room closure. She pointed out that it is important to establish the uncertainties in the material data and their influence on rock response. Further it was pointed out that the stratigraphic assumption should be as simple as possible, but should include the relevant mechanisms which are operative.

Dev Shukla, D'Appolonia, pointed out the basic difference between the models and assumptions about stratigraphy. He described that models and stratigraphic assumptions can be based on different views. The operational view in which one looks carefully at intervals near the drift, perhaps plus or minus 50 feet, the view of room closure or longer term room response in which one looks one looks at rock and rock performance at greater depth, perhaps plus or minus 150 feet, and finally when one looks at regional or overlying formation response, it is necessary to have general stratigraphies to depths of about 3000 feet. One conclusion that was made from the discussion by the TSC/D'Appolonia was that everyone agrees that there is good lateral continuity of the beds, the south drift variations are ranged from approximately 27 to 24 feet for the facility horizon. Hence, the uncertainty in material properties appears to be the most important parameter at the present, not the lateral continuity or variability of the beds.

An assessment of the session on introduction to stratigraphy was that we should establish what is important in terms of needs for stratigraphy. It was clear that important primers include bed thicknesses, placing location and properties, and the identification and modeling of mixed layers. Further, it appears to be important to resolve what is a special variation in the stratigraphic assumptions. Also discussed was the importance of applying this stratigraphy to the modeling in determining which primers are really important ones for the intent of the modeling. An additional discussion took place regarding the need for correlation of geophysical techniques to determine in situ rock properties from boreholes within the drift in order to simplify the assumptions about characterizing stratigraphy as well as to allow development of priorities for the testing of laboratory samples.

The second session was devoted to the properties of rock salt. Ray Krieg of Sandia described the series of parameters or assumptions which can be important in terms of the overall modeling. He described the early studies which were done with analytical formulations to decide whether or not the elastic terms were important. It was concluded that these were important in these studies and have since been incorporated in the computer modeling. Second, he described the studies on elastic properties that have been done with the finite element codes, and shows that the lowering of the sheer moduli can result in a significant impact on room closure, and, in fact, may provide a better agreement with the field data. Third, he described the effect of random properties in the studies that were done to try to look at the variation in laboratory properties on the overall impact on room closure. Fourth, he described the effect of low stress or stress cutoff on the

deformation of the rooms. It was concluded that depending on the spacial variation of stress, the existence of a low cutoff stress can be important and affect the room closure. Further, it was discussed that a correlation can be made between the existence of a cutoff stress and the long-term deformation process studies that are being done by David Borns of Sandia, and this correlation should be made. Fifth, he discussed the effect of primary creep and indicated that from Sandia's view, primary creep calculations appear to be expensive, but may be necessary if it is important to model the early time behavior. Finally, he indicated that the need and accuracy of comparing data with calculations is probably better in the long term than in the short term, and discouraged the use of equivalent parameters or factors to try to model the data, but rather emphasized a more fundamental understanding of what parameters are important and how they affect the rock response.

In the same session Wolfgang Wawersik discussed the status of secondary creep modeling in data that we have. He showed new data which indicate that Q values for example, and stress exponents may change from the reference creep law. He indicated that the new data is much higher quality and would tend to change the numbers that have been used in the past. However, from a discussion from a practical point of view, he concluded that the current model is reasonably accurate to represent a good approximation at this time. He indicated, though, that the new samples may show that two types of rocks should be considered. One is basic rock salt, primarily anhydrite, which he concluded from what he had seen in the underground at WIPP, was very similar to the assumptions of the upper level WIPP salt in the original investigations. In addition, though, there may be areas which are truly argillaceous rock salt which could exhibit a higher creep property, perhaps a factor of 2 to 5, and this should be examined further. Finally, he discussed the potential for the uniqueness of secondary creep as a equilibrium state under deformation. It is not clear if, in fact, this is exhibited by the laboratory tests and subsequent microscopic examinations. However, practically speaking, this may not be significant, but could, in fact, alter the assumptions about the reference creep law. He did indicate that there are extremely good results from strategic petroleum reserve calculations about cavern response and fluid volumes which corroborate the data correlations made for WIPP. Barry Butcher pointed out that it is important to establish a threshold about which we are not longer concerned about the impact on the predicted response. Some number like creep response within plus or minus 30% was noted as being insignificant in terms of concern about material properties.

In the same section Mr. Ching Wu from Bechtel, discussed the material concepts which he felt were needed to satisfy design validation. These included: 1) the definition of the materials, 2) the elastic constants, 3) the coefficient of friction of clay seams, 4) the unconfined compressive strength of the rocks, 5) the tensile constants, 6) appropriate failure criteria, and 7) primary creep characteristics. Mr. Li from Bechtel indicated some questions about the use of the primary creep law which may indicate typographical errors in the Sandia reference creep law. Further, he sought clarification on the use of the failure criteria for halite described in the reference creep law.

The next section consisted of discussion of the properties of clay seams. Mike Stone, Sandia, presented a result of defective clay seams on room response, and indicated that previous studies showed that for certain stratigraphies that is not necessary to incorporate all of the clay seams in a particular calculation. However, it appeared that the clay seams have a significant effect on not only room closure, but also on the closure rates, which may be strongly affected. He pointed out that the determination of which clay seams are active should be decided upon by the analysis based on the reference stratigraphy.

Franzoni of TSC/D'Appolonia reviewed the data from clay seam performance obtained in supporting document 12 in the SPDV experiment document. He discussed the Atterberg limits test, the tensile test and the direct shear test, the latter of which indicated that the coefficient of frictions ranged from 0.2 to 0.7 and significant cohesion around 100 psi was observed in the test from the data fitting. Finally, he indicated that tensile strengths of greater than 100 psi
were observed in some of the clay samples taken.

Barry Butcher discussed the prior data in assumptions about clay seam characterization and indicated that a reasonable categorization should be established for what kind of clay seams are actually present, whether they are uniform flat slipping, clay seams which have significant undulations, or in fact consist of mixed layers with intergranular clay which exhibit a similar response.

The discussions of properties of other layers indicated that we should in fact deal with four major rock types. The rock salt, the clay seams, major anhydrite ore, stiff elastic members and finally a mixed unit which is principally argillaceous rock. Carol Stein reviewed the mineralogical investigations which had been performed on drill holes near the WIPP drifts which show that the maximum impurity content for all of the samples throughout the sequence within 50 feet of the drift is about 5% water insoluble impurities, hence the clay content or the anhydrite polyhalite content is limited to just a few percent. It was concluded that more samples need to be taken and a better correlation of the mineralogical analysis with the SPDV data logging should be undertaken. Finally, it was observed that there is no evidence for either mixed polyhalite or mixed anhydrite units which would be significant. Wolfgang Wawersik pointed out that based on his qualitative interpretation he had not observed any mixed layers except perhaps the argillaceous units which would provide any different material response than we had observed in the upper level layers assumed in the original statistical study of creep properties.

The next discussion revolved around the stratigraphy which should be adopted as a reference for the WIPP project. Bechtel, TSC/D'Appolonia and Sandia presented proposed stratigraphies. Bechtel's Howard Taylor indicated that they were concerned about clay seams very near the room including the definition of argillaceous units as perhaps clay partings. The TSC/D'Appolonia Dale Stephenson, indicated that they had adopted three proposed stratigraphies, one about 3,000 ft in extent, one about 300 ft. in extent, and one about 100 ft. in extent.

They based their referencing on the anhydrite units which are very near the rooms and indicated that those, in fact, are continuous in most cases, although reasonably thin and can be used as a basis for the stratigraphy. Ray Krieg, Sandia, compared the original 1979 stratigraphy which was adopted in 9/82 and discussed the possible variations which should be considered.

At that point a general discussion followed on the importance of various layers to the reference stratigraphy. It was pointed out that all of the argillaceous layers may contain clay seams and hence should be considered as possible slip planes or points of extreme weakness. Consequently, further consideration should be given to examining those cores. Some discussion took place on the halite-halite contacts observed above the rooms. It was concluded that these were local details and not sufficiently wide-spread to be considered in the reference stratigraphy. Further discussion on materials properties was that at this point we can concentrate on intergranular impurities, principally those associated with the argillaceous material to establish a difference in creep response for the various materials.

At that point Ray Krieg presented the underlying assumptions for a reference stratigraphy, and indicated that he would take the three proposed stratigraphies, match them up and provide a common reference stratigraphy for all participants to review.

A summary of the modifications to the reference stratigraphy and material properties is as follows:

> In terms of the material description it was concluded that the primary creep assumptions will remain unchanged at this point. The secondary creep assumptions will remain unchanged, the elastic moduli based on unloading will remain the base case, but the analyst will be allowed to determine whether or not these moduli or moduli based on the secant modulus will be used in conjunction with the secondary creep models. It was suggested that a model which seems reasonable would be to leave the bulk modulus constant and to lower the shear modulus by a factor of four. It was further concluded that the failure models for rock salt will remain the original formulation of the reference creep law based on pressure and total strain.

The polyhalitic halite will be modeled as rock salt and no distinction will be made for polyhalite in conjunction with halite as a different material.

The anhydrite will be modeled with the same elastic properties and the same failure criteria if used as was developed by Sandia and available literature on the subject, and this will be presented in the new reference creep law. The argillaceous halite will require separate action but should be considered as a different material. Two aspects must be considered: 1) whether or not each argillaceous layer should be considered as a slip plane, and 2) whether or not the argillaceous material is sufficiently different mineralogically to introduce different creep properties. These will be evaluated by the creep testing matrix and mineralogical studies being conducted by Sandia.
Finally a list of action items was developed of items which should be done to support the development of a reference stratigraphy. These are outlined in the following list.

ACTION ITEMS

July 7, 1983

1. Compare and correlate mineralogical analyses results (especially argillaceous halite) with stratigraphic section - C. Stein.

2. Evaluate overburden density to surface from drill hole or geophysical (gravity and uphole velocity) data, perhaps comparing structure contour of anhydrite B with surface topography - A. Lappin.

3. Evaluate geophysical techniques for correlating stratigraphic/physical properties information in drill holes from drifts. - TSC/D'Appolonia.

4. Develop further tests to investigate clay seam properties in drill holes considering drilling techniques, drying out, etc. - TSC/D'Appolonia.

5. Develop a referring or characterizing method for clay seams. B. Butcher, C. Stein.

6. Obtain samples of argillaceous rocks from drifts for creep tests (per original test matrix). - C. Christensen.

7. Obtain samples from MB 139 and other anhydrites for quasistatic tests. - C. Christensen.

8. Reinterpret a north/south drill hole combination for comparison of logging data and mineralogical analysis. - Sandia/TSC/D'Appolonia/-Bechtel.

9. Compare proposed reference stratigraphies and develop a new reference for project review. - R. Krieg.

10. Compile and publish a document with reference constitutive models, stratigraphy, and common data base. - R. Krieg and T. Hunter.

APPENDIX B.

Statistical Proof of the Non-Significance of Spacial Variations

The anhydrite layers in Table I have been characterized by their thicknesses and elevations above anhydrite b. We note a considerable variation in the values of these parameters in any given column. The rows are arranged such that the most southerly core is at the top of the table and the most northerly at the bottom. Looking over the columns, we see a consistent variation from top to bottom in the absolute elevation of anhydrite b but little regularity in other parameters with the possible exception of the thickness of anhydrite b. Variations in the anhydrite layers listed then appear to be due to ripples or short range, rather than to long range variations. A consequence of this would be that a local measurement would not be as indicative of a mean local region thickness or height as an average value from Table I would be. We need not rely on intuition for this decision since we can statistically examine the quantities in the table.

Each column was considered individually. If X is the north-south location of the core as given in the second column of Table I with south considered to be negative, and if Y is thickness or elevation above anhydrite b, as given in one of the columns, then we make the usual statistical assumptions. We assume that a linear north-south variation does exist and the X locations of the core holes are known. The Y values are assumed to be random variables normally distributed around the assumed linear north-south variation.

If (X_i, Y_i) for i = 1, n are the values from the table, then average values $\overline{X}$ and $\overline{Y}$ are computed to be

$$\overline{X} = \sum_{i=1}^{n} X_i$$

$$\overline{Y} = \sum_{i=1}^{n} Y_i$$

A least squares fit to the data gives the curve:

$$Y = a + bX \tag{B1}$$

where a and b are found using the relations:

$$b = \frac{\Sigma(X_i - \overline{X})(Y_i - \overline{Y})}{\Sigma(X_i - \overline{X})^2} \tag{B2}$$

$$a = \overline{Y} - b\,\overline{X} \tag{B3}$$

where the summations are taken to be over the limits from 1 to n.

The values of a and b are listed in Table B-1. The variance of Y and X is denoted as $S^2_{Y,X}$ and is given as

$$S^2_{Y,X} = \frac{1}{n-2}\left[\Sigma(Y_i-\bar{Y})^2 - b\,\Sigma(X_i-\bar{X})(Y_i-\bar{Y})\right] \tag{B4}$$

This is in turn used to find the variance on the regression coefficients a and b. These variances are given by

$$S^2_b = \frac{S^2_{Y,X}}{(X_i-\bar{X})^2} \tag{B5}$$

$$S^2_a = S^2_{Y,X}\left[\frac{1}{n} + \frac{\bar{X}^2}{\Sigma(X_i-\bar{X})^2}\right] \tag{B6}$$

Another informative and useful measure is obtained by considering the fraction of the total variation in Y that is accounted for by the association between X and Y. The ratio of the sum of squares associated with the regression to the total sum of squares for Y is called the coefficient of determination and is given by

$$r^2 = \frac{\Sigma(a+bX_i-\bar{Y})^2}{\Sigma(Y_i-\bar{Y})^2} \tag{B7}$$

The variances and the coefficient of determination are all listed in Table B.

The variances and coefficient of determination are all informative, but the bottom line is simply an answer to the question of whether the north-south changes in variables in Table I are statistically significant. For this, we go to the t-distribution and consider confidence limits.

We want to know whether or not there is a linear association between X and Y, for if there is not, then there is nothing to be gained by using the X's as they will contribute nothing to the analysis of the Y's. For this, we compute

$$t = \frac{b}{S_b} \tag{B8}$$

This is compared to values for the t-distribution for (n-2) points listed in statistical tables for given confidence intervals. Values for computed and tabular values at 95% confidence interval are listed in Table B-1. The tabular values are greater than computed values for all but the thickness of anhydrite b.

The conclusion is that with a confidence of 95%, it can be said that there is no statistically significant north-south variation in any of the parameters except the thickness of anhydrite b. We further note that the most statistically significant value we can use for these variables is an average over the entire site.

Table B-1. Statistical Parameters Associated with a Spatial Variation Over the WIPP Site

Parameter	a	b	n	$S^2_{Y,X}$	S^2_a	S^2_b	r^2	t_{comp}	t_{95}
Elev Anh C	16.4	-6.76E-5	18	.265	.0150	5.96E-9	.0460	.88	2.12
Thk Anh C	.0814	3.32E-6	18	.00106	6.04E-4	2.39E-11	.0280	.68	2.12
Elev MB139	8.64	-3.05E-5	20	.0911	.00469	2.05E-9	.0246	.67	2.10
Thk MB139	.865	1.09E-5	23	.0459	.00205	1.03E-9	.00545	.34	2.08
Elev Unit 4	3.68	-4.97E-5	18	.0404	.00235	9.33E-10	.1419	1.63	2.12
Thk Unit 4	.837	2.88E-6	21	.0152	.753	3.49E-10	.1112	.15	2.09
Thk Anh b	.0528	1.29E-5	20	.000239	1.23E-5	5.38E-12	.6316	5.56	2.10
Elev Anh a	2.11	5.70E-5	20	.0339	.00174	7.61E-10	.1918	2.07	2.10
Thk Anh a	.209	-3.60E-6	20	.00381	1.96E-4	8.57E-11	.0083	.39	2.10
Elev MB139	9.16	-1.91E-5	20	.0920	.00474	2.07E-9	.0097	.42	2.10
Thk MB139	.193	5.98E-6	20	.00237	1.22E-4	5.33E-11	.0360	.82	2.10

Notes:
1. Parameters a and b are determined as in Eqs (B2) and (B3)
2. The number of samples is denoted as n
3. $S^2_{Y,X}$ is computed in Eqn (B4)
4. S^2_a is computed in Eqn (B6)
5. S^2_b is computed in Eqn (B5)
6. r^2 is computed in Eqn (B7)
7. t_{comp} is computed in Eqn (B8)
8. t_{95} is a standard tabulated 95% confidence value

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Laboratory Characterization of Mechanical and Permeability Properties of Dynamically Compacted Crushed Salt

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ABSTRACT

The U.S. Department of Energy (DOE) plans to dispose of transuranic wastes at the Waste Isolation Pilot Plant (WIPP), a geologic repository located at a depth of about 655 meters. The WIPP underground facility is located in the bedded salt of the Salado Formation. Access to the facility is provided through vertical shafts, which will be sealed after decommissioning to limit the release of hazardous waste from the repository and to limit flow into the facility.

Because limited data are available to characterize the properties of dynamically compacted crushed salt, Sandia National Laboratories authorized RE/SPEC to perform additional tests on specimens of dynamically compacted crushed salt. These included shear consolidation creep, permeability, and constant strain-rate triaxial compression tests. A limited number of samples obtained from the large compacted mass produced by Hansen and Ahrens (1996) were available for use in the testing program. Thus, additional tests were performed on samples that were prepared on a smaller scale device in the RE/SPEC laboratory using a dynamic-compaction procedure based on the full-scale construction technique.

The laboratory results were expected to (1) illuminate the phenomenology of crushed-salt deformation behavior and (2) add test results to a small preexisting database for purposes of estimating parameters in a crushed-salt constitutive model. The candidate constitutive model for dynamically compacted crushed salt was refined in parallel with this laboratory testing.

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1.0 INTRODUCTION

1.1 Background

The U.S. Department of Energy (DOE) plans to dispose of transuranic wastes at the Waste Isolation Pilot Plant (WIPP) located in southeastern New Mexico. The WIPP is designed to be a full-scale geologic repository, and its underground facility is located in the bedded salt of the Salado Formation at a depth of about 655 meters below ground surface. Access to the facility is provided through vertical shafts. Because these shafts comprise direct communication between lithologic units and connect the underground facility to the surface, they will be sealed to limit the release of hazardous waste from the repository and to limit flow into the facility.

One of the primary seal components in the Salado Formation is dynamically compacted crushed salt. Crushed salt has been selected because of its chemical compatibility with the host salt rock. In addition, crushed salt is an attractive sealing material because its permeability is expected to decrease as the surrounding host salt rock creeps into the shaft and reduces the volume of sealing material (crushed salt). The initial fractional density of the crushed salt at placement will be 0.9 (Sandia National Laboratories, 1996), where fractional density is defined as the ratio of the current bulk density to the density of intact salt (i.e., 2.16 g/cc (Callahan et al., 1998)). Hansen and Ahrens (1998) demonstrated that initial fractional densities of 0.9 could be achieved in a full-scale construction technology demonstration. Their study produced large blocks from which laboratory-scale specimens were subcored for use in laboratory programs.

Because limited data are available to characterize the properties of dynamically compacted crushed salt; the Sandia National Laboratories (SNL) Repository Isolation Systems Department authorized RE/SPEC to perform additional tests on specimens of dynamically compacted crushed salt. The types of tests to be performed included shear consolidation creep, permeability, and constant strain-rate triaxial compression. A limited number of samples obtained from the large compacted mass produced by Hansen and Ahrens were available for use in the testing program. Thus, additional tests were performed on samples that were prepared on a smaller scale device in the RE/SPEC laboratory using a dynamic-compaction procedure based on the full-scale construction technique.

The purpose of the laboratory work was twofold. The laboratory results were expected to (1) illuminate the phenomenology of crushed-salt deformation behavior and (2) add test results to a small preexisting database for purposes of estimating parameters in a crushed-salt constitutive model. The candidate constitutive model for dynamically compacted crushed salt (Callahan et al., 1998b) was refined in parallel with this laboratory testing and the current model refinements have been published (Callahan et al., 1998a). The work was conducted under RE/SPEC's QA Program

as specified in the document, "Quality Assurance Project Plan: Rock Mechanics Analysis Support for Sandia National Laboratories, AG-4911 (RSI Job 325), RSI QAPP-09.

1.2 Organization

In addition to this introduction, this report is organized into five additional chapters and two appendices. Chapter 2.0 provides a description of the specimens used for the testing and the equipment and procedures used to fabricate the laboratory-scale specimens. Chapter 3.0 describes the test equipment and procedures that were used in the study and is followed by Chapter 4.0, which summarizes the results of the testing. Concluding remarks are in Chapter 5.0 followed by a list of cited references in Chapter 6.0. The two appendices contain technical memoranda that outline specific work conducted on crushed salt.

2.0 SPECIMENS

There were two sources of dynamically compacted crushed-salt specimens. The first was the large-scale, dynamically compacted crushed salt recovered from the dynamic-compaction demonstration study (Hansen and Ahrens, 1998) that produced a compacted mass greater than 40 m^3. The second source of specimens was provided by the laboratory-scale, dynamic-compaction device designed and built at RE/SPEC.

The specimens derived from the large-scale dynamically compacted mass provided by SNL (Hansen and Ahrens, 1998) were prepared by dry-coring them from the large blocks and then finishing the ends to produce cylindrical specimens suitable for testing. Finished specimens had a diameter of 100 millimeters and lengths up to 200 millimeters. Some specimens had lengths less than 200 millimeters because of dimensional limitations imposed by the irregular geometry of the large blocks. Hansen and Ahrens also produced a small amount of dynamically compacted material from initial intermediate technology demonstration trials. A few specimens from the intermediate-scale trials were used for early permeability work by Brodsky (Appendix B).

Some of the dynamically compacted crushed-salt specimens used for this laboratory program were fabricated in a laboratory-scale compaction device. This device approximated the compaction technique envisioned for the shaft sealing design. The laboratory-scale compaction device is shown in Figure 2-1. The system uses a 30-pound cylindrical hammer that can be dropped from a height of 1.52 meters (5 feet) through a rail guide that directs the position where the hammer strikes the crushed salt that is contained in a cylindrical mold. The hammer diameter is 50.8 millimeters (2 inches) which equals the radius of the mold. The hammer guide was constructed such that it could be rotated to strike along any desired radius of the specimen. This feature was included in the design to mimic the compaction technique used in the large-scale compaction device operated by SNL. The mold was fabricated from two standard Proctor split compaction molds. The assembled mold is capable of producing a cylindrical sample with a diameter of 101.6 millimeters (4 inches) that can be machined into a specimen with a nominal length of 200 millimeters.

Brodsky (1994) has characterized the disaggregated crushed salt that was used as the raw material for making the laboratory-scale specimens. The crushed salt was subjected to a sieve analysis, and all particles larger than 9.5 millimeters were crushed to pass a 9.5-millimeter sieve and then added back into the mixture. The particle size limit of 9.5 millimeters was selected to ensure the largest particle was less than a tenth of the specimen diameter, which was about 100 millimeters. The sieve analysis of the material satisfying the 9.5-millimeter limit indicated a particle size of approximately 1.8 millimeters at the 50th percentile.

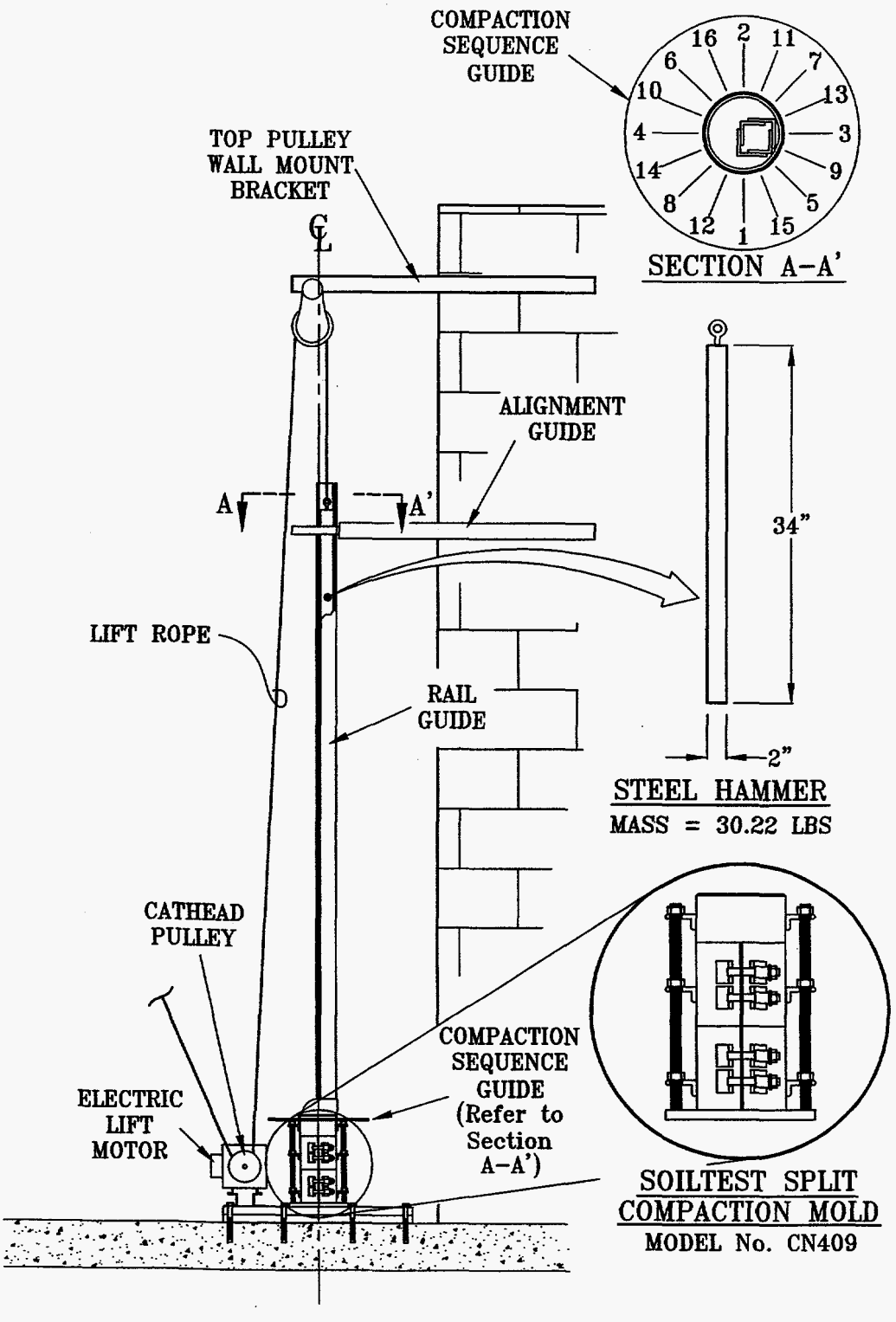

Figure 2-1. Laboratory-scale dynamic-compaction device.

During shakedown testing of the compaction device, the question arose regarding how much friction loss was imparted to the hammer by the rail guide. A simple, comparative method was used to assess the frictional effect by first dropping the hammer from varying heights onto a lead ball target *without* the rail guide in place (free fall) and then repeating the drops *with* the rail guide in place (guided fall). The results of that testing are presented in Figure 2-2, which plots the final deformed thickness of the lead ball versus the drop height. There is one curve for the free-fall tests and one curve for the guided-fall tests. The deformed thickness of the lead balls were compared to determine what the equivalent free-fall drop height was for a given guided-fall drop height. That comparison gave an equivalent free-fall height for each guided-fall height, and the relationship is shown in Figure 2-3. For a guided-fall drop height of 1.52 meters (5 feet), the equivalent free-fall drop height was approximately 1.34 meters (4.4 feet). The equivalent free-fall drop height is the value that was used to calculate the three times, modified-Proctor energy level that was imparted to the specimen during the compaction process.

The specimens fabricated with the laboratory-scale device were identified as RS/DCCS/n, where n took on values of 1, 2, 3, etc. to designate individual specimens. After machining the end of the compacted cylindrical sample, the specimens had final nominal dimensions of 100-millimeter diameter and 200-millimeter length. The starting material was wetted with a WIPP brine that had previously been manufactured at RE/SPEC using distilled water and the same crushed salt used to fabricate the specimens, so the specimen moisture content was nominally 1.6 percent by weight. The initial dry fractional density of the specimens was about 0.9 (assuming intact salt has a density of 2.16 g/cc).

The moisture content of the laboratory-scale specimens was determined using standard laboratory procedures, as described below. Samples of the disaggregated crushed salt were placed in metal containers of known mass. Each sample and container was weighed using a balance having a resolution of 0.01 gram and placed in an oven regulated to a temperature of 110°C. Periodically, the samples and containers were removed from the oven and weighed to monitor the loss of water during drying. When the mass of each sample/container changed by less than 0.01 gram over a 24-hour period, it was assumed that all of the moisture in the sample had been removed. The mass of water contained in the specimen was calculated as the difference between the initial and final masses of the sample/container. Using the data from the drying procedure, values were calculated for moisture content of the samples and density of the test specimens using the following expressions:

$$w = 100\frac{M_w}{M_{ds}} \tag{2-1}$$

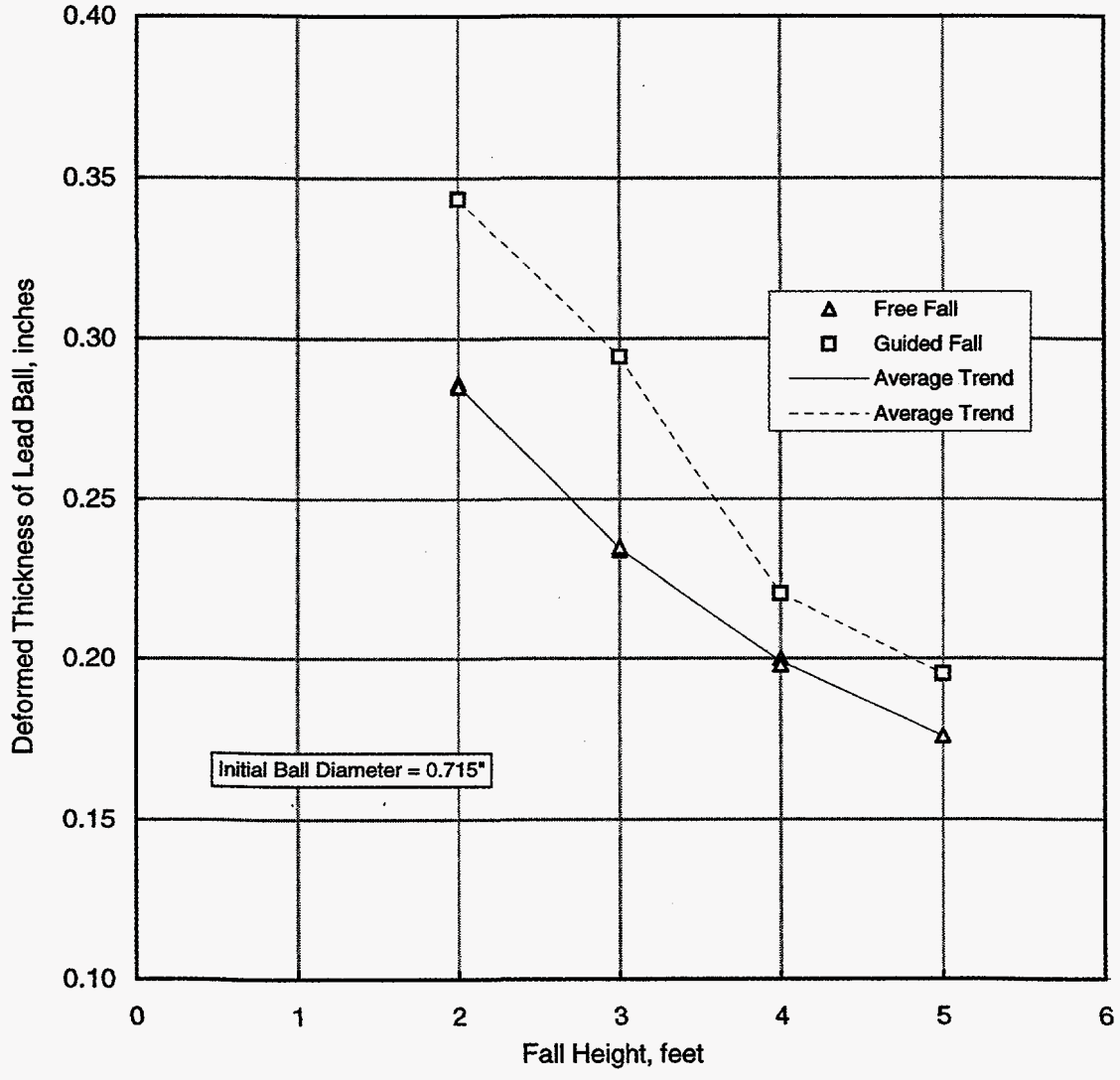

Figure 2-2. Lead ball deformation as a function of drop height.

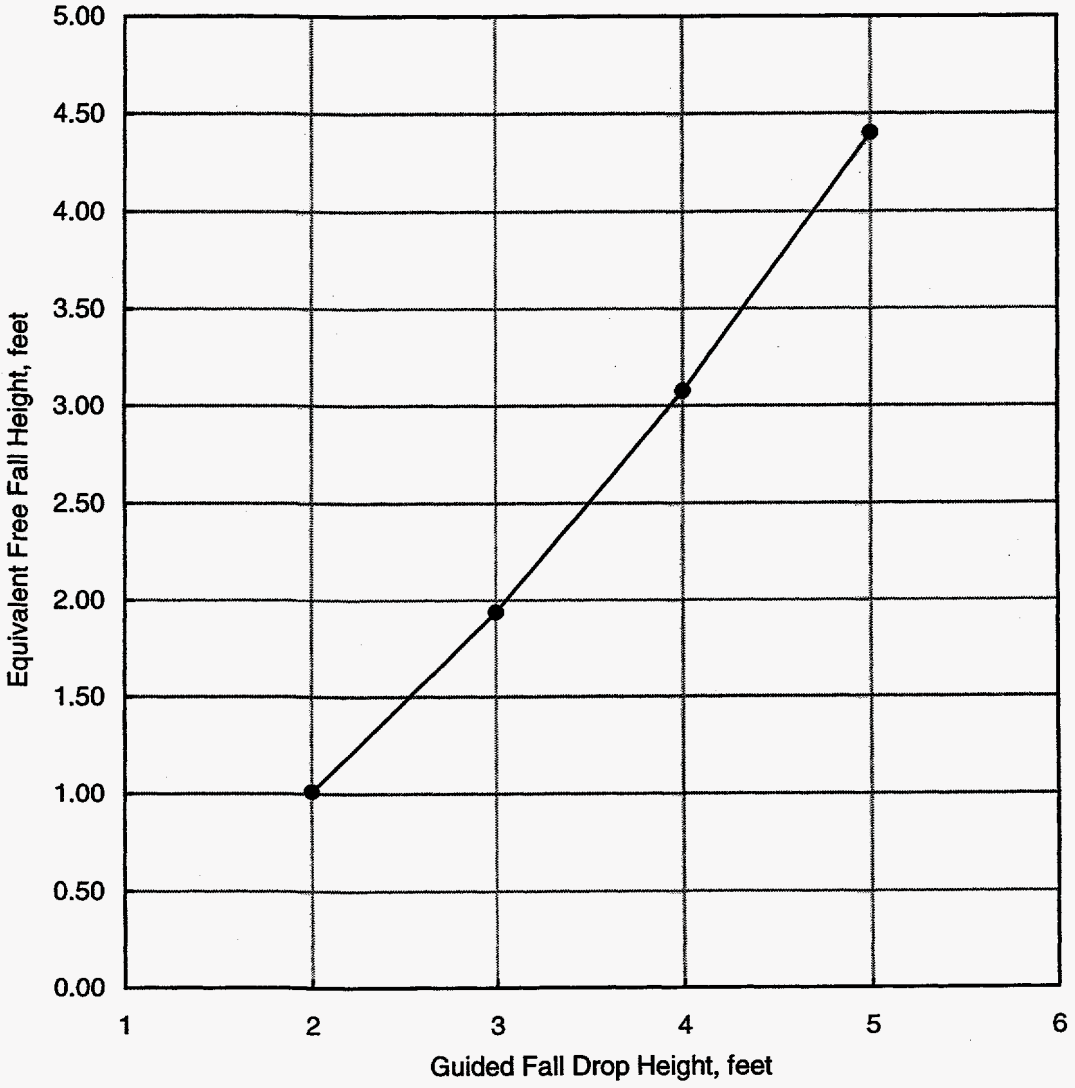

Figure 2-3. Equivalent free-fall drop height as a function of guided-fall drop height.

$$\rho = \frac{M_{ws}}{V_s\left(1+\frac{w}{100}\right)} \tag{2-2}$$

where:

w = percent moisture content
ρ = dry density
M_{ds} = mass of the dry sample
M_{ws} = mass of the wet sample
M_w = mass of water contained in the sample
V_s = volume of specimen.

Volume was determined for finished specimens having regular solid geometries (e.g., solid cylinders) using direct measurements of the specimen dimensions (i.e., length and diameter).

A summary of the moisture contents and densities of the laboratory-scale specimens fabricated at RE/SPEC and used in this study is presented in Table 2-1. The first column is the specimen identification label, and the second column indicates the type of testing applied to that specimen. The third column gives the moisture content for each specimen, and the fourth column lists the dry fractional density for each specimen before it was tested. These dry fractional densities were calculated assuming the density of intact salt is 2.16 g/cc.

A summary of the moisture contents and densities of the large-scale specimens made available by the Hansen and Ahrens experiment and used in this study is presented in Table 2-2. This table is similar to the previous table presented for laboratory-scale specimens produced by RE/SPEC. The fractional densities were calculated assuming the density of intact salt is 2.16 g/cc.

Table 2-1. Laboratory-Scale, Dynamically Compacted Crushed-Salt Specimen

Specimen Identification	Test Type	Moisture Content (%)	Initial Dry Fractional Density
RS/DCCS/1	Shear Consolidation	1.66	0.904
RS/DCCS/3	Shear Consolidation	1.63	0.905
RS/DCCS/4	Shear Consolidation	1.59	0.904
RS/DCCS/5	Shear Consolidation	1.55	0.898
RS/DCCS/6	Constant Strain Rate	1.47	0.901
RS/DCCS/10	Shear Consolidation	1.49	0.907
RS/DCCS/11	Constant Strain Rate	1.68	0.912
RS/DCCS/15	Shear Consolidation	1.77	0.901
RS/DCCS/21	Constant Strain Rate	1.62	0.907

Table 2-2. Large-Scale, Dynamically Compacted Crushed-Salt Specimens

Specimen Identification	Test Type	Moisture Content (%)	Initial Dry Fractional Density
DCCS/3/3/3-1	Brine Permeability	Saturated	0.889
CS/DC2/T2S-1/1[(a)]	Brine Permeability	Saturated	0.863
CS/DC1/8-3[(a)]	Brine Permeability	Saturated	0.864
DCCS/3/2/3-1	Shear Consolidation	1.53	0.889
DCCS/3/1/2-1	Shear Consolidation	1.52	0.889
DCCS/3/3/3-1	Gas Permeability	0.44	0.889
DCCS/3/2/1-1	Gas Permeability	0.44	0.901
DCCS/3/1/1-4	Gas Permeability	0.44	0.889
DCCS/3/3/1-4	Gas Permeability	0.44	0.901
DCCS/3/2/2-1	Gas Permeability	1.27	0.899

(a) These specimens were initially tested using a gas permeant (Appendix B).

3.0 TEST EQUIPMENT AND PROCEDURES

The laboratory program encompassed three different types of experiments: shear consolidation creep, constant strain-rate triaxial compression, and permeability. Petrographic studies of test specimens are contained in this chapter, following test descriptions. The equipment and procedures are discussed in the separate sections.

3.1 Shear Consolidation

The shear consolidation tests were effectively standard creep tests. The specimens were initially loaded hydrostatically to the level of specified confining pressure (radial stress). Following the hydrostatic loading, the axial stress was increased by 4 MPa while the confining pressure was held constant. Each of the tests was the same in this regard, in that each was subjected to a 4 MPa axial stress difference. Only the specified level of the confining pressure varied among tests. Following the application of the axial stress difference, the axial stress difference was held constant at 4 MPa while data were acquired during the creep consolidation phase. At the termination of the test, an unload/reload cycle was performed by reducing the applied axial force to drop the stress difference to near zero and then reapplying the axial force to reload the specimen to a stress difference of 4 MPa before totally unloading the specimen. The ascending loading data from the reloading portion of the cycle were used for estimating elastic constants. The following sections present additional details on the equipment and procedures used for the shear consolidation testing.

3.1.1 Load Frame

Figure 3-1 presents a cross section of a typical consolidation frame with prominent components labeled for reference. The frames used single-ended, triaxial pressure vessels. A linear actuator (hydraulic cylinder) bolted to the base of the load frame advanced the loading piston, which in turn, applied axial compressive force to the specimen. Confining pressure was applied to the jacketed specimens by pressurizing the sealed vessel chamber with silicone oil. A dilatometer system maintained constant confining pressure and provided the volumetric measurement. The testing machines could apply compressive axial loads up to 1.5 MN and confining pressures up to 70 MPa. The heating system, including seals on the pressure vessel, could maintain specimen temperatures up to 200°C, although all the current testing was performed at 25°C. A control panel located near the load frames housed accumulators, hydraulic pumps, pressure intensifiers, transducer signal conditioners, temperature controllers, and confining pressure controllers for two adjacent test frames.

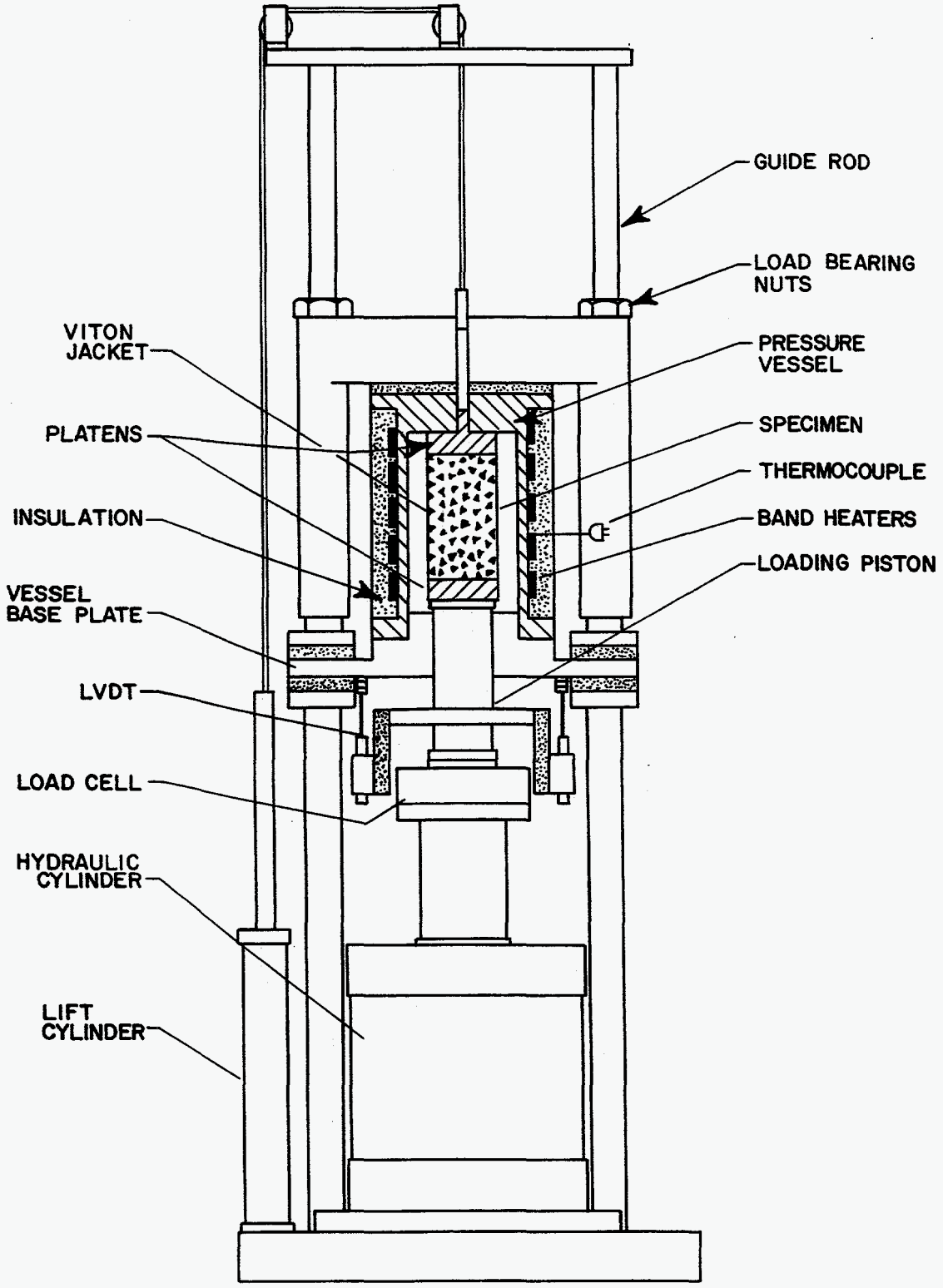

Figure 3-1. Schematic of static triaxial test system.

3.1.2 Instrumentation

Axial force was measured by a load cell located in the load train outside the pressure vessel, while confining pressure was measured by a pressure transducer located in the line between the intensifier and the pressure vessel. Temperature was measured by a thermocouple embedded in the wall of the pressure vessel. The relationship between the actual specimen temperature and the thermocouple measurement has been determined by calibration at several temperatures spanning the operating range. Two linear variable differential transformers (LVDTs) mounted outside the pressure vessel monitored displacement of the loading piston relative to the bottom of the pressure vessel. Volumetric deformation was measured using a dilatometer. With this technique, volumetric deformation was determined at fixed pressure by first measuring the volume of oil that the dilatometer supplied to the pressure vessel, and then compensating for the axial deformation measured by the LVDTs. A stroke transducer was mounted on the dilatometer shaft to provide a signal proportional to the volume of oil, either supplied to or extracted from the pressure vessel.

The transducers used to collect force, pressure, deformation, and temperature data were calibrated under documented RE/SPEC procedures using standards traceable to the National Institute of Standards and Technology (NIST). Each transducer was calibrated in its normal operating position on the test system so that the signal conditioners, filters, and analog-to-digital converters were included within the end-to-end calibration. Calibration constants were determined for each transducer from a linear, least-squares regression of indicated reading versus standard input. Readings were collected at 20 standard inputs equally spaced over the range of the transducer. These constants were verified immediately before testing began by comparing the predicted response of the transducer using these constants, with the standard input applied in ten equally spaced steps over the calibrated range. Acceptance criteria developed for the verification process were based on the following accuracy criteria: 1 percent of reading for force and pressure transducers, 2 percent of reading for deformation transducers, and ±1°C for thermocouples. The accuracy specifications included both linearity and repeatability.

3.1.3 Control

Test system variables were controlled by a personal computer running data acquisition and control software programmed for loading and maintaining creep tests. Temperature was maintained by a software routine that regulated power to the band heaters on the vessel based on a feedback signal provided by a thermocouple in the pressure vessel wall. Confining pressure was controlled by inputting the pressure transducer signal to another routine that maintained the confining pressure within a 20 kPa deadband around the desired pressure. Through the use of digital I/O signals, the pressure control software instructed the dilatometer to advance or retreat,

depending upon whether the lower or upper edge of the deadband had been reached. Axial load was adjusted by a similar software routine to maintain a constant axial stress on the specimen. The program determined the current cross-sectional area of the specimen from the outputs of the deformation transducers and then adjusted the load to maintain constant stress. The deadband on load under this control was 0.4 kN. A standby diesel generator provided electrical power to the test systems during periods of commercial electrical power outages.

3.2 Constant Strain Rate

Three constant strain-rate tests were performed on the laboratory-scale, dynamically compacted crushed salt. All three tests were performed at the same confining pressure (1 MPa), but three different axial strain rates were imposed (0.5×10^{-7}, 1.0×10^{-7}, and 2.0×10^{-7} s^{-1}). The following sections present additional information on the equipment and procedure used to perform the constant strain-rate testing.

3.2.1 Load Frame

A computerized, servohydraulic test frame manufactured by MTS Systems was used to perform the constant strain-rate tests. The test frame is equipped with two reaction posts that provide a total axial force capacity of 0.5 MN. A custom pressure vessel designed by RE/SPEC was mounted in the test frame to provide triaxial compression capability.

The load frame configuration is shown in Figure 3-2 where prominent components have been labeled for reference. The pressure vessel is designed for confining pressure of up to 70 MPa and is fitted with resistance heaters and insulation blankets allowing operation at temperatures of 200°C. However, for this work, the confining pressure was limited to 1 MPa and the tests were all performed at a temperature of 20°C.

3.2.2 Instrumentation

The test system instrumentation was typical of most triaxial compression experiments. The load cell attached to the test frame crosshead recorded total axial force and confining pressure was measured by a pressure transducer located in the line leading from a hydraulic intensifier to the vessel. For specimen deformation measurements, the specimen was encased in a protective jacket and instrumented with deformation transducers, as shown in Figure 3-3. The extensometers shown in Figure 3-3 directly recorded the axial and radial deformations of the specimen over their respective gage lengths. The axial extensometer was an MTS Model 632.90C unit with deformation sensors in both arms. The sensor outputs are combined and scaled into a single analog output voltage, which gets measured by an analog-to-digital converter

(ADC). Simultaneous ADC measurements are made of the output signal provided by the radial deformation extensometer. The radial deformation extensometer is a strain-gaged ring (i.e., lateral disk gage) rigidly connected to two vertical mounting posts that contact the specimen at opposite ends of a diameter located at specimen midheight.

All data were logged with respect to time by using the clock provided by the Digital Equipment Corporation (DEC) 11/73 microprocessor which was the platform running the data acquisition and control software program. The software was written in MTS MultiUser BASIC which is the programming language provided with the system by MTS Systems. The acquired data were archived onto the computer disk and then transferred over a local area network to make them available for postprocessing using standard spreadsheets; e.g., EXCEL 97.

The original specimen dimensions were those measured on the bench before the specimen was encased in its protective jacket. The current specimen dimensions were determined from the deformation measurements made during the test. The change in diameter was measured directly by the lateral disk gage (LDG) mounted across a diameter at the midheight of the specimen. The change in specimen length was calculated by assuming the axial strain measured over the axial extensometer gage length represented the average strain in the specimen. The area of the loading ram was always larger than the area of the specimen.

3.2.3 Control

There were two segments of the load path used to perform a constant strain-rate test. The first segment imposed a hydrostatic load path up to the level of the desired confining pressure, which, for these tests, was 1 MPa. This segment was performed in load control with the servohydraulic control system advancing the axial force and the confining pressure to effect a hydrostatic pressurization rate of 0.02 MPa/second. At this slow pressurization rate, the extensometers were not subjected to thermal drift that could be caused by adiabatic heating of the confining fluid (Mellegard et al., 1993). At the end of the hydrostatic pressurization ramp, the stresses were held constant and the consolidation rates were monitored. If the axial strain rate during hydrostatic consolidation was larger than the axial strain rate specified for the next segment of loading, the load path was held at the hydrostatic state until the consolidation rate fell below the specified axial strain rate. The reason for this delay follows from the constraints imposed by the test machine loading system. If the consolidation rate were higher than the axial strain rate specified for the constant strain-rate segment, the control system would sense a feedback signal that is too high and would attempt to reduce the axial strain rate by removing axial load. Since a test is initiated at a hydrostatic state, the removal of axial load would cause the axial stress to fall below the hydrostatic stress state and a state of triaxial extension would be imposed. The test system

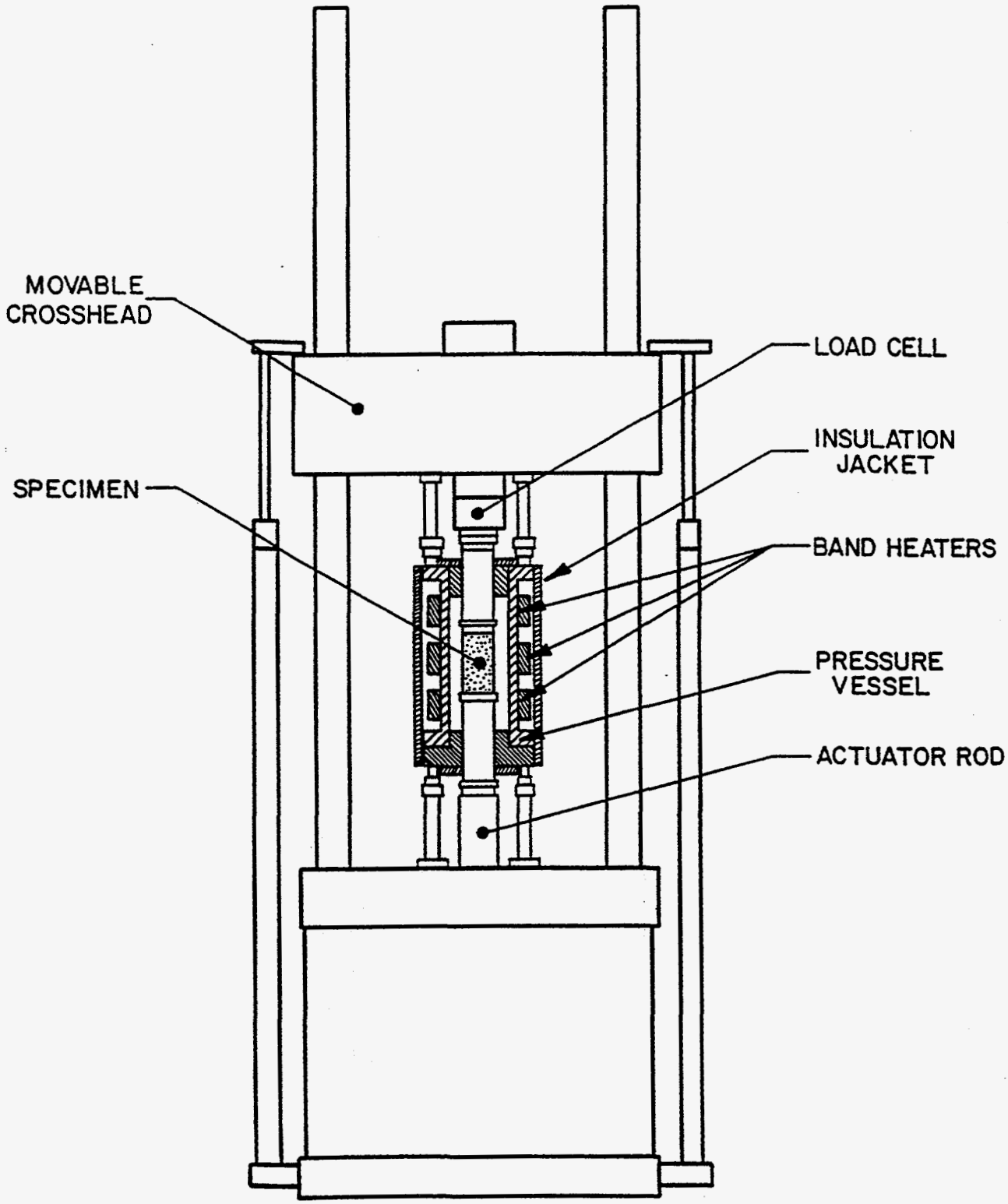

Figure 3-2. Schematic of dynamic triaxial test system.

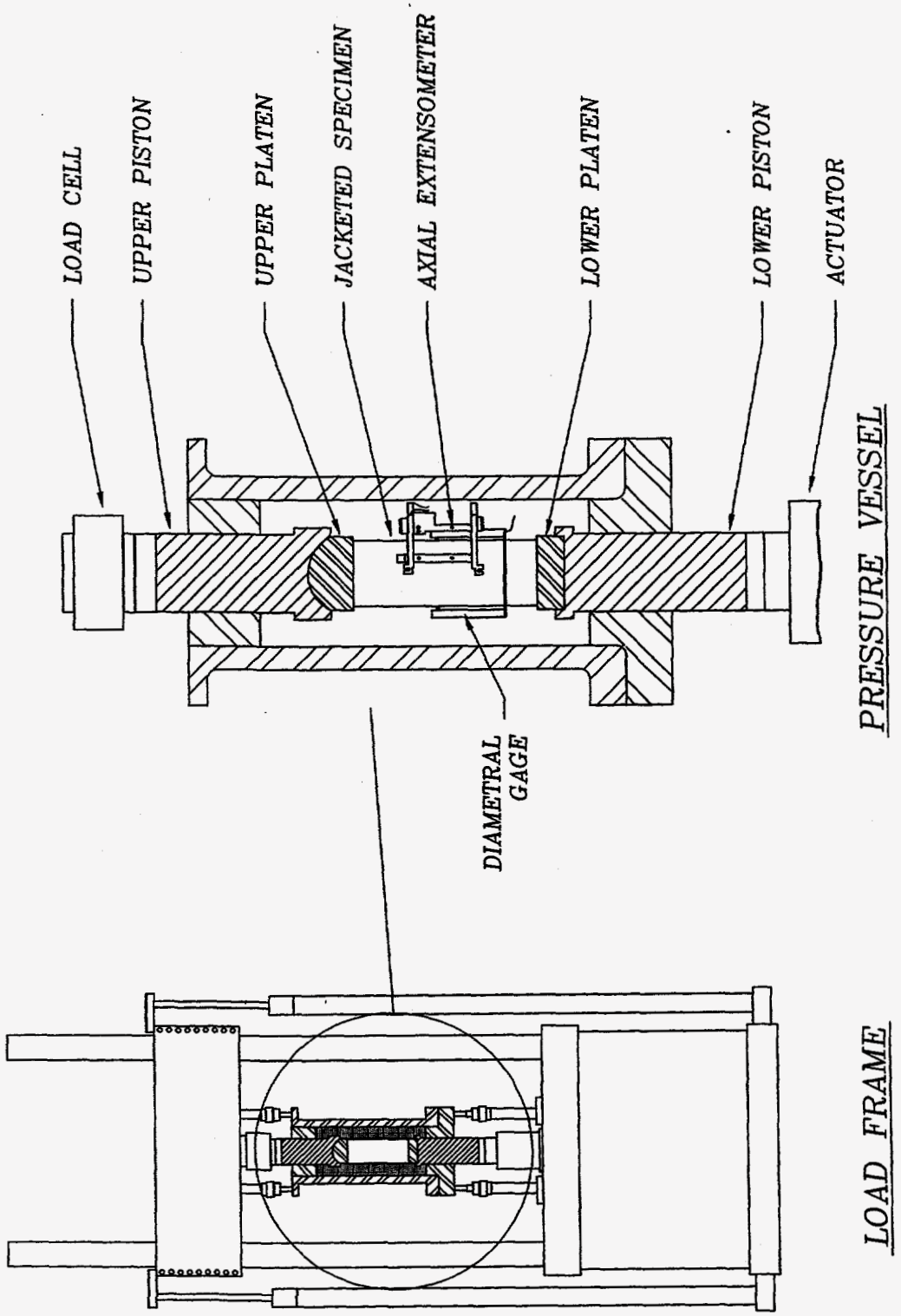

Figure 3-3. Constant strain-rate test setup.

used here will not support triaxial extension because the vessel is a single-ended apparatus. Thus, if the system attempted to impose triaxial extension, the axial loading column would simply decouple and all of the axial load would be removed, effectively terminating the test immediately.

After waiting for the consolidation rates to decrease to an appropriate level, the constant strain-rate segment of the test started. Upon entering the constant strain-rate segment, the mode of axial force control was switched from load to axial strain; i.e., the feedback signal for controlling application of axial load was switched from the load cell to the axial extensometer mounted on the specimen. The command signal provided by the computer was ramped linearly to cause the axial extensometer to deform at the specified constant axial strain rate while the confining pressure was held constant. The axial load increased as required, depending upon the specimen response. The loading was terminated when the deformation transducers reached their maximum operating range.

3.3 Permeability

Specimens identified for permeability testing were placed inside protective flexible Viton sleeves or jackets which were secured to two metal platens positioned at either end of the specimen, as shown in Figure 3-4. The jacket served to protect the specimen from the hydraulic fluid (silicone oil) used to apply radial stress during permeability measurements. Each platen was equipped with a 3.2-millimeter-diameter vent drilled along the central axis of the platen to provide access to porous felt metal disks placed in the specimen/platen interfaces. These disks were used to ensure one-dimensional flow parallel to the central axis of the specimen by inducing uniform permeant pressure across the specimen ends. The specimen assembly shown in Figure 3-4 was placed inside the pressure vessel of the testing frame depicted schematically in Figure 3-1, which is the same test system that was used for the shear consolidation tests.

For those specimens tested with a brine permeant, the specimen exit was connected to the buret measurement system shown in Figure 3-5. Brine permeant was supplied to the specimen inlet by a pressurized accumulator. The charge pressure to the accumulator was controlled manually with a valve located on a nitrogen gas bottle and measured by a pressure transducer located in the hydraulic line at the inlet to the specimen. A hydrostatic stress of 1 MPa was applied to the external surfaces of the specimen by pressurizing the annulus between the specimen and the pressure vessel wall. The valve located at the specimen inlet was then opened to permit the flow of brine through the test specimen. The flow rate at the specimen exit and brine pressure at the specimen inlet were then recorded by reading the buret level and the pressure transducer, respectively. The pressure at the inlet was limited to 0.34 MPa (about one-third the confining pressure) to ensure that the flow paths were through the specimen and not

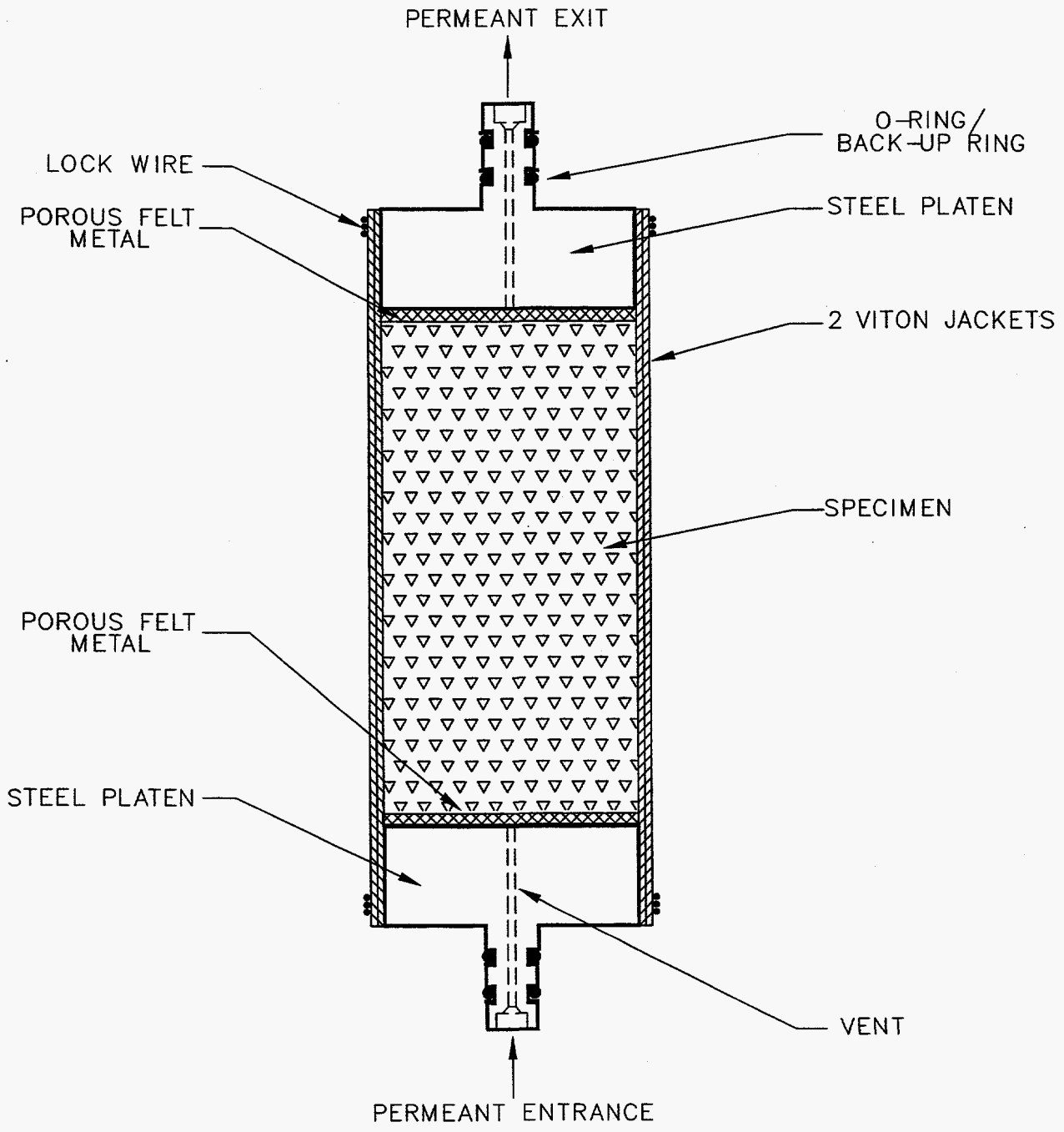

Figure 3-4. Jacketed specimen test assembly.

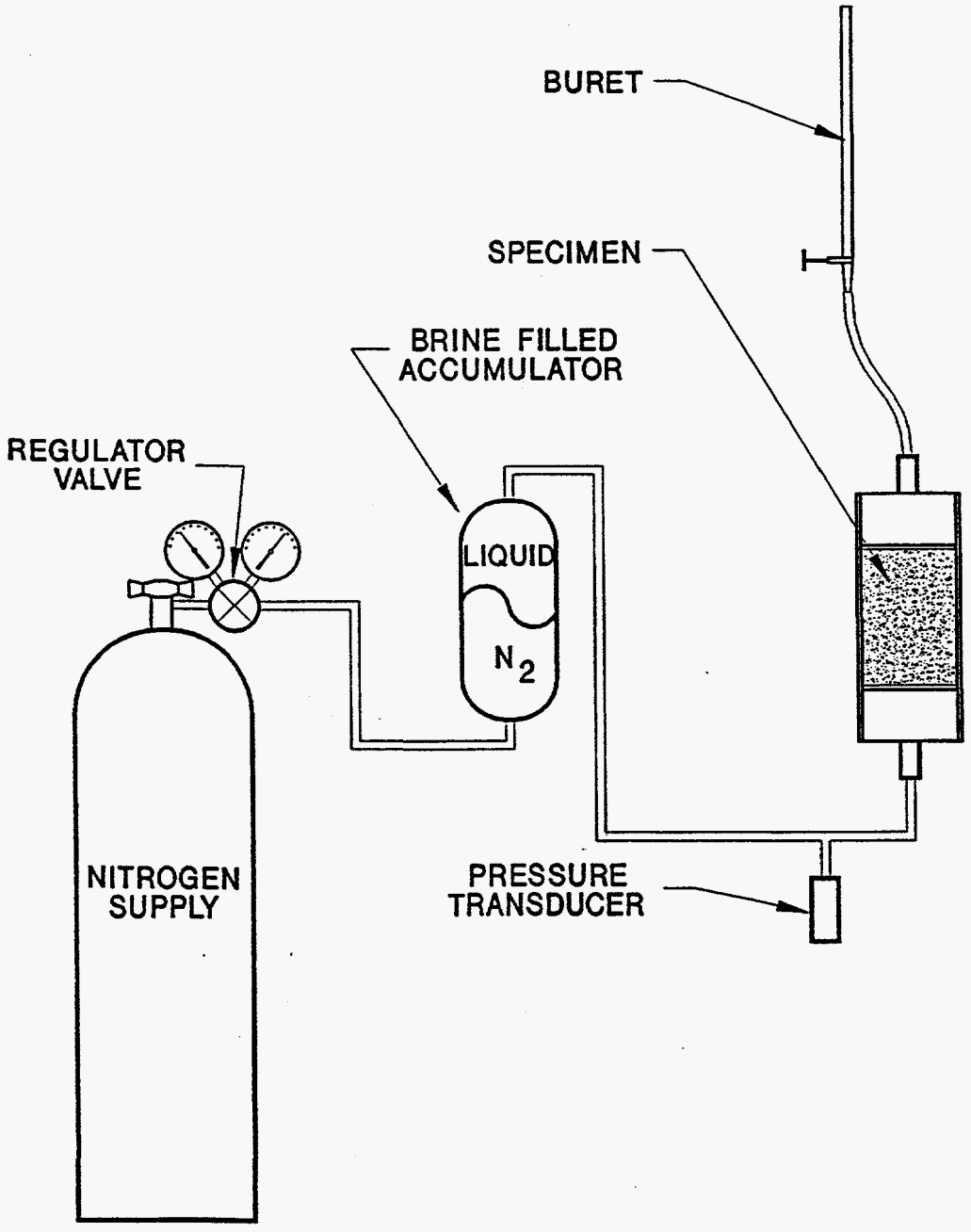

Figure 3-5. Brine permeability test setup.

along the jacket-specimen interface. In some cases where the flow rate was very high, the buret was periodically emptied during the test, and the amount emptied was recorded to calculate the accumulated flow quantity. In extremely high flow tests, the buret was removed entirely and replaced with a balance. The accumulated mass flow rate was then converted to a volume flow rate using the known density of brine (1.208g/cc [Brodsky, 1994]).

For those specimens tested with a gas permeant, the specimen assembly was connected to a rotameter flow meter system, as shown in Figure 3-6. Nitrogen gas was supplied to the flow meter by a pressurized bottle. The charge pressure to the flow meter was manually controlled with a valve located on the gas bottle, and measured by a pressure transducer located in the hydraulic line at the inlet to the flow meter. The flow meter consists of two components: an interchangeable flow tube and a tube holder. The design of the flow meter permits the removal of a tube with a specified maximum flow capacity and the replacement of the tube with another having either a larger or smaller flow capacity so that different flow rates can be accommodated with the same apparatus. The flow meter was hydraulically connected to the specimen using 3/16-inch i.d. stainless steel tubing. A second pressure transducer located in the hydraulic line near the inlet to the specimen provided the measurement for the specimen inlet gas pressure. Gas exiting the specimen was vented to atmosphere. Similar to the brine permeant tests, a hydrostatic stress of 1 MPa was applied to the external surface of the specimen. Then, the valve located on the pressurized nitrogen gas bottle was opened to permit the flow of nitrogen through the flow meter system and test specimen. The pressure at the inlet to the flow meter was adjusted to a value of 0.345 MPa (50 psi), which was the flow meter calibration pressure. The flow rate and gas pressure at the specimen inlet were then recorded by reading the flow meter and pressure transducer outputs, respectively.

Two of the specimens from the large-scale, dynamic-compaction blocks were subjected to a combination of hydrostatic compaction and hydrostatic creep consolidation loading. This loading caused the specimen fractional densities to increase from their initial value of about 0.9. As the specimens were deformed, nitrogen gas permeability measurements were conducted at incrementally higher levels of fractional density. The test system used for these tests was the same as the one described for the constant strain-rate tests, although a particular loading path was applied to the specimens. The loading history for a typical hydrostatic consolidation test can be summarized as follows:

1. A jacketed specimen was placed inside the pressure vessel of the testing machine and hydrostatically loaded to a stress of 1 MPa. A nitrogen gas permeability measurement was performed at this point.

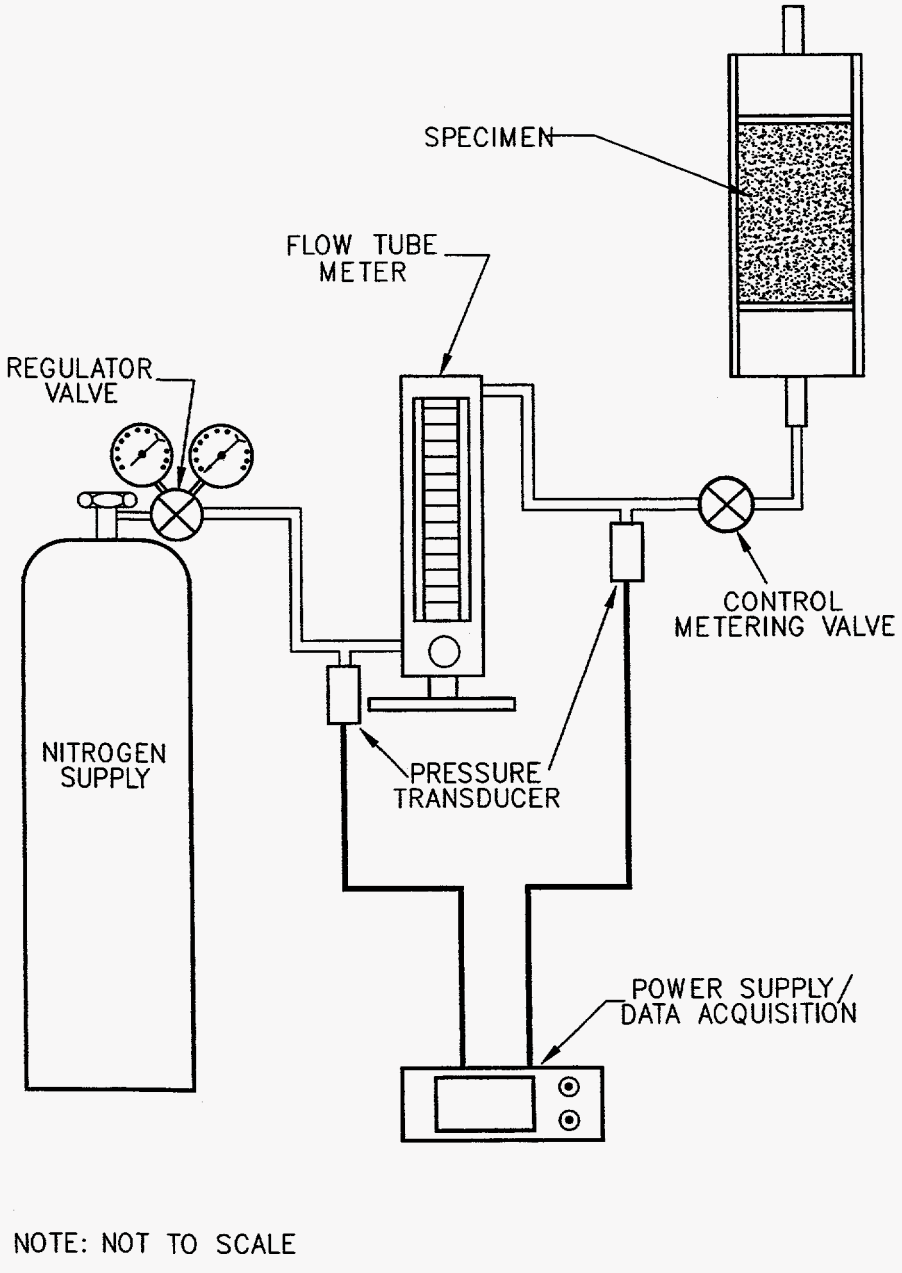

Figure 3-6. Gas permeability test setup.

2. The specimen was then hydrostatically loaded at a rate of 0.02 MPa/s. Loading continued until either of two criteria was met: (1) the fractional density had changed by a prescribed amount or (2) the hydrostatic stress had reached a prescribed level. If the first criterion was met, the specimen was unloaded to 1 MPa, reloaded to the highest stress it had attained during the hydrostatic loading stage, and then unloaded again to 1 MPa, at which time, another gas permeability measurement was performed. If the second criterion was met, the hydrostatic stress was held at its prescribed level until creep consolidation produced the desired change in fractional density. The specimen was then unloaded to 1 MPa, at which time another gas permeability measurement was performed. The hydrostatic unload-reload-unload cycle was performed to acquire data for calculating bulk modulus at the prescribed levels of fractional density.

3. Following the hydrostatic unload-reload-unload cycle and the gas permeability measurement, the specimen was subjected to a small, shear stress by increasing the axial stress to 6 MPa while maintaining the radial stress (i.e., confining pressure) at 1 MPa. The shear stress was then removed by lowering the axial stress to 1 MPa. Data collected during the shear loading/unloading were used to calculate values for Young's modulus and Poisson's ratio. Again, a gas permeability measurement was performed after the shear load cycle was completed.

4. Steps 2 and 3 were repeated until sufficient data were obtained to characterize the relationships between fractional density and gas permeability and elastic constants.

A typical load history for one specimen is shown in Figure 3-7. The load/unload cycles for both the hydrostatic and shear loading stages were of short duration (less than 1 hour), while the consolidation stages were often quite long (>5–6 days). Because the consolidation process was slow (particularly for dry specimens), hydrostatic stress levels were increased at later stages in the test so that density changes would occur more rapidly. The maximum hydrostatic stress level used to induce creep consolidation deformations was 15 MPa.

During the hydrostatic compaction/consolidation stages of the tests, current specimen density was determined from initial specimen dimensions and measurements of axial and radial strain taken during the test. Axial and radial deformations were measured using direct-contact extensometers as described previously for the constant strain-rate tests.

3.4 Petrographic Studies

Great care was taken to ensure consistency of test specimens. Specimens used in these laboratory experiments were derived from the large, dynamic-compaction demonstration initially and prepared in the laboratory later on. This section describes the microstructure of variously prepared specimens. Further descriptions are included in a memorandum included as Appendix A. In the end, consistency of grain size, moisture content, and starting density was obtained for all tested specimens. Because experimental results are controlled by these first-order specimen characteristics, features of the physical substructure are summarized here. Later in Section 4.4, petrofabrics of reconsolidated salt will be demonstrated via Scanning Electron Microscopy (SEM) and optical microscopy.

As noted earlier, several of these experiments were conducted on specimens prepared from the very large-scale, dynamic-compaction field demonstration conducted by Hansen and Ahrens. Only a few finished specimens were actually obtained from the blocks extracted from the large compacted mass. In addition to the limited number of test specimens, it was determined during the course of experimentation that the compacted mass had dehydrated from the original 1-percent water content. Therefore, it became necessary to produce alternative, similarly compacted samples in the laboratory to complete requisite experimental work.

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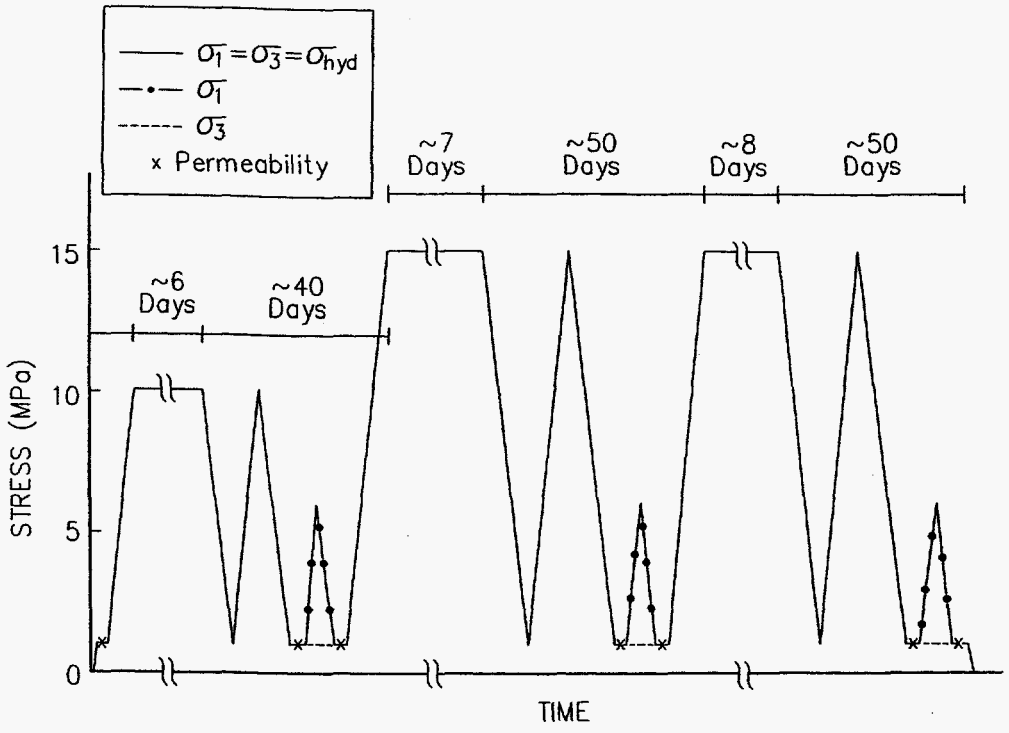

Figure 3-7. Typical load history for hydrostatic compaction and consolidation.

Specimens for SEM observations were all prepared by cutting down larger pieces into parallelepipeds having two dimensions approximately 20×20 millimeters. The sawn beam was then broken by finger pressure to produce a fresh face. This sample preparation technique was necessary because any other preparation technique, such as sawing or polishing, produces additional textures, obscuring the original. Comparisons here are made only for the substructure of the specimens before they are tested. Resultant microstructures of tested specimens are given in Section 4.4.

The characteristics of the compacted salt prepared by large-scale, dynamic compaction are examined first. Figure 3-8 (SEM numeric 0003) represents the mass of compacted grains magnified 1,100 times. Dynamically compacted salt aggregate structure has been examined and previously published (Hansen, 1997), and the heterogeneous gradation of fine particulate shown here is identical to those independent studies. Grain boundaries are open, and the relatively larger grains are abraded and blocky, rather more rounded than cleaved. Rounded abraded larger grains coupled with a significant population of fine grains indicate severe mechanical abrasion imparted by large-scale, dynamic compaction. Figure 3-9 (SEM numeric 0004) is the same material as above, shown at a magnification of only 110 times. One can observe a dense substructure comprising sorted grain sizes, with fine grains occupying available interstices.

Equivalent photomicrographs for laboratory-prepared test specimens are shown in Figures 3-10 and 3-11. At a magnification of 1,100, the ground mass comprises a well-cleaved, uniform grain size between 20 and 30 μm. Grain boundaries are open and the broken surface indicates a lack of intergranular cohesion, a feature very similar to the large-scale, dynamically compacted substructure. At 110 magnification, fine powder fills space between larger grains (up to 1 millimeter). At the lower magnification, little difference in size composition between the specimen preparation techniques can be seen.

These photomicrographs are representative of a larger population taken of several samples from the large-scale, dynamic-compaction demonstration and from laboratory-prepared samples. While laboratory-prepared samples are tailored to replicate the large-scale test fractional density (0.9) and can be prepared at an ideal water content, the texture of laboratory-prepared samples is different than that produced by large-scale, dynamic compaction. Both sample preparation processes produce a similar percentage of grains between 20 and 30 μm; however, the large-scale dynamic process produces a greater proportion of fines. Grains of laboratory-prepared specimens are cubic, as compared to more rounded, abraded grains produced by the full-scale demonstration. Based on knowledge of consolidation processes (that densification results from pressure solution/redeposition) the finer grain size produced by large-scale, dynamic compaction would be expected to increase consolidation rate relative to laboratory-prepared samples.

Other attempts to match laboratory-prepared samples to field-compacted samples were made. For example, one assembly used ten separate lifts. When the substructures of the three-lift samples, the ten-lift samples, and large-scale, dynamic compaction are compared, it is evident that the three-lift construction of test specimens is adequate for laboratory investigations (see Appendix A). Laboratory-prepared specimens are tailored to a desired moisture content, appropriate density, and a similar grain size, not withstanding the lack of fine grains. Further evidence on the adequacy of laboratory-prepared specimens is presented later when consolidated substructures are discussed.

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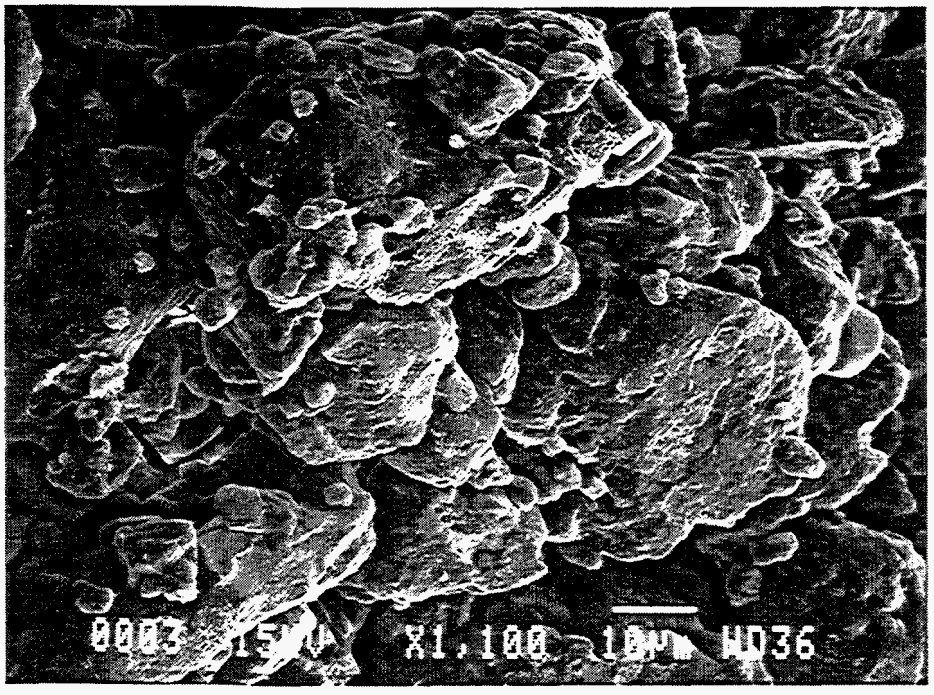

Figure 3-8. Compacted salt matrix from large-scale, dynamic-compaction demonstration (SEM 1,10X).

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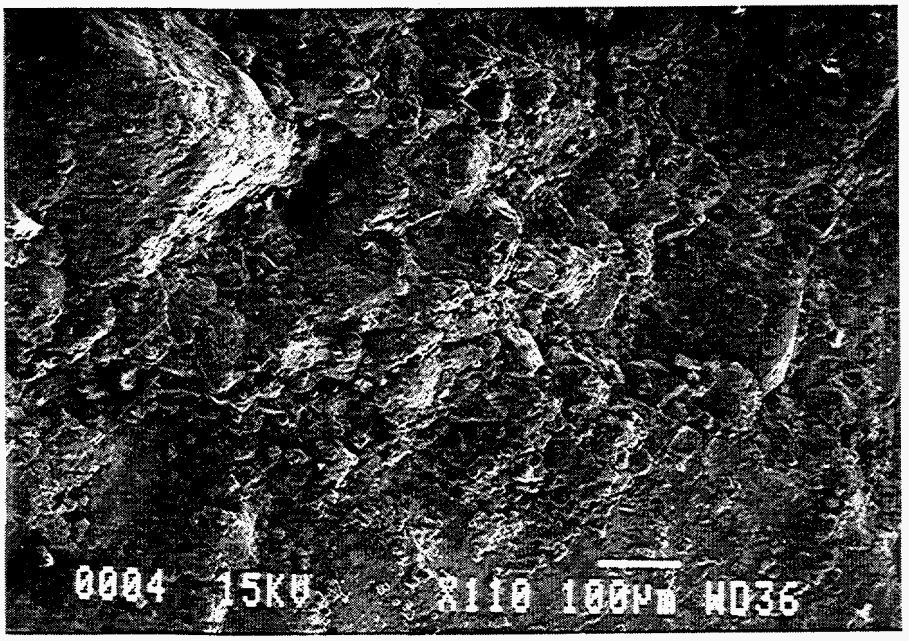

Figure 3-9. Compacted salt matrix from large-scale, dynamic-compaction demonstration (SEM 110X).

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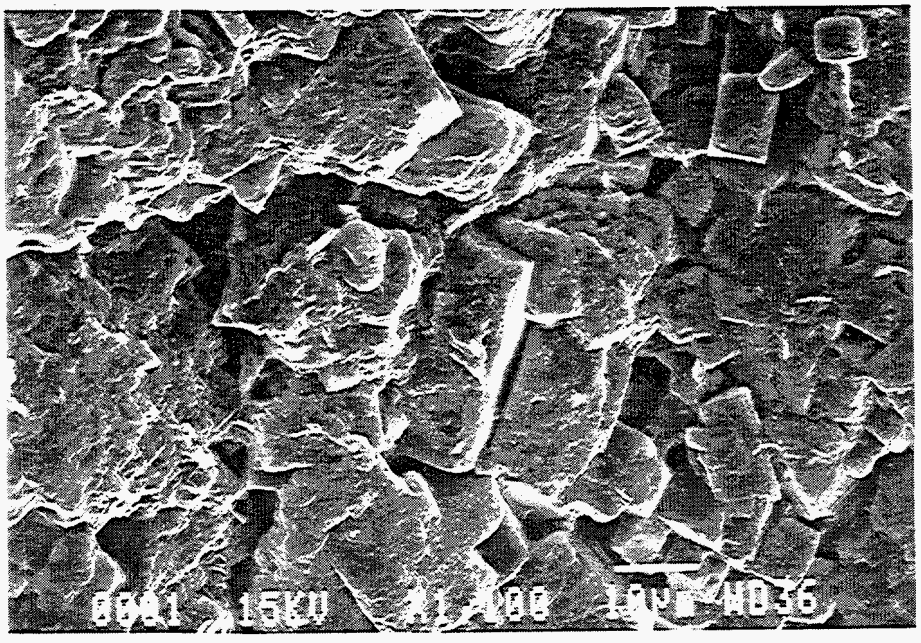

Figure 3-10. Compacted salt matrix from laboratory-prepared three-lift specimen. (SEM 1,100 X).

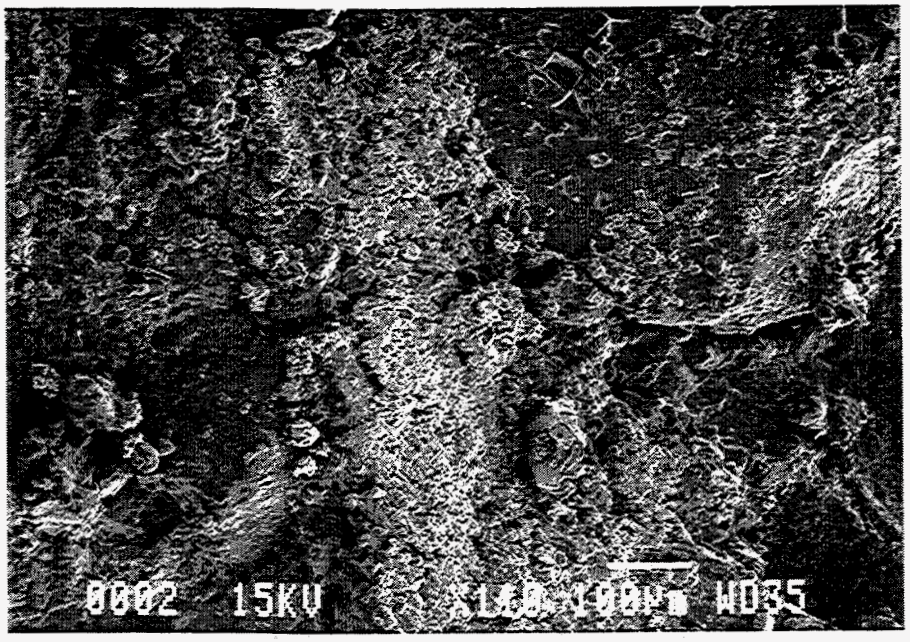

Figure 3-11. Compacted salt matrix from laboratory-prepared three-lift specimen (SEM 110X).

4.0 TEST RESULTS

The experiments conducted as part of this work comprised shear consolidation testing, constant strain-rate testing, and permeability testing. The results from each of these types of testing are reported in the individual sections that follow. One additional section presents the results of the petrographic studies carried out to provide a physical description of the densification mechanisms.

4.1 Shear Consolidation

A total of eight shear consolidation tests was performed; six were performed on laboratory-scale specimens manufactured at RE/SPEC, and two were performed on specimens cored from the large-scale samples provided by Hansen and Ahrens (1998). All tests were performed at a temperature of 25°C and an axial stress difference (axial stress minus radial stress) of 4 MPa. The only controlled variable that changed among the tests was the level of radial stress (confining pressure). The test matrix for the shear consolidation tests is shown in Table 4-1. The first column in the table contains the specimen identification. The following three columns give the axial stress, radial stress, and temperature, respectively. All tests were performed in a drained condition; i.e., the ends of the specimens were vented.

Table 4-1. Shear Consolidation Test Matrix

Specimen Identification	Test Conditions		
	Axial Stress (MPa)	Radial Stress (MPa)	Temperature (°C)
RS/DCCS/1	5	1	25
RS/DCCS/3	6	2	25
RS/DCCS/4	7	3	25
RS/DCCS/5	8	4	25
RS/DCCS/10	9	5	25
RS/DCCS/15	5	1	25
DCCS/3/2/3-1	8	4	25
DCCS/3/1/2-1	8	4	25

The data acquired during the test were used to calculate principal stresses and strains according to formulas that provided true stress and true strain measures. The sign convention was that positive values indicate compression. The data reduction formulas for axial and radial strain at each data point were:

$$\varepsilon_1 = -\ln\left(\frac{L_i}{L_o}\right) \tag{4-1}$$

$$\varepsilon_3 = -\ln\left(\frac{D_i}{D_o}\right) \tag{4-2}$$

where L_o and D_o are the original length and diameter of the specimen and L_i and D_i are the current length and diameter of the specimen at any data point.

The original specimen dimensions were those measured on the bench before the specimen was encased in its protective jacket. The current specimen dimensions were determined from the deformation measurements made during the test. The change in specimen length was calculated by correcting the LVDT measurements for nonspecimen deformation; the remainder represented the axial shortening of the specimen. The change in specimen diameter was calculated from the dilatometer data after correcting for movement of the axial force ram.

The data reduction formulas for calculating true stresses used the measurements provided by the load cell and pressure transducer, and accounted for the change in specimen area. The formulas for axial and radial stresses were:

$$\sigma_1 = \frac{F - P(A_r - A_s)}{A_s} \tag{4-3}$$

$$\sigma_3 = P \tag{4-4}$$

The variables F and P represent the measured values of total axial force and confining pressure, respectively. The current area of the specimen, A_s, was calculated using the previously determined radial strain values. The area of the loading ram, A_r, was constant.

The first five tests listed in Table 4-1 were designed to investigate the effect of changes in mean stress by testing at different confining pressures while holding the axial stress difference constant. The hypothesis was that a stress state would be encountered where the radial strain rate would initially be positive (consolidation) and then reverse direction and become negative as the specimen density increased. The creep strain results for these first five tests are compared in Figures 4-1 and 4-2, which plot axial creep strain and radial creep strain, respectively, as a

function of time. In Figure 4-1, the three axial strain curves for tests performed at confining pressure above 2 MPa exhibit an inflection where the axial strain rate begins to increase. This behavior appears to be repeatable and different from the three tests performed at confining pressure of 1 and 2 MPa. No explanation is offered for this apparent pressure-sensitive behavior, but the phenomenon is being noted as a point of interest.

A significant observation is apparent in Figure 4-2 where a trend appeared in the radial strain response; that is, the radial strain rate decreases as the confining pressure increases. A very significant phenomenon was observed in the tests performed at confining pressures of 4 MPa and 5 MPa. The radial strain rate in those two tests was initially positive (specimen diameter decreasing), and after some densification of the specimen, the radial strain rate decreased and ultimately changed sign (specimen diameter increasing). This observation supports the original hypothesis that the direction of the radial strain response depends upon both the state of stress being applied and the fractional density of the specimen.

The sixth test listed in Table 4-1 was performed to replicate the radial stress test condition imposed on the first test; i.e., a confining pressure of 1 MPa. The first test seemed to exhibit very large strains as compared to the strains measured for the tests performed at higher radial stresses, so a replicate test was conducted. The two tests performed at a radial stress of 1 MPa are compared in Figures 4-1 and 4-2. As seen in the figures, the results are very comparable. The strain response at 1 MPa may result from a different mechanism, such as translation/rotation of relatively loosely packed crystals. At the higher confining pressures, the grains would be more tightly packed and densification would be dominated by pressure solution/redeposition.

The last two tests listed in Table 4-1 were performed using specimens obtained from the large compacted mass provided by the Hansen and Ahrens demonstration. These two tests were conducted to estimate the specimen-to-specimen variability in the large-scale specimens and also to compare large-scale results with laboratory-scale results. The two tests from the large-scale blocks and the single test result from the laboratory-scale specimen are given in Figure 4-3. The same test conditions were applied to all three specimens; i.e., an axial stress difference of 4 MPa and a confining pressure of 4 MPa.

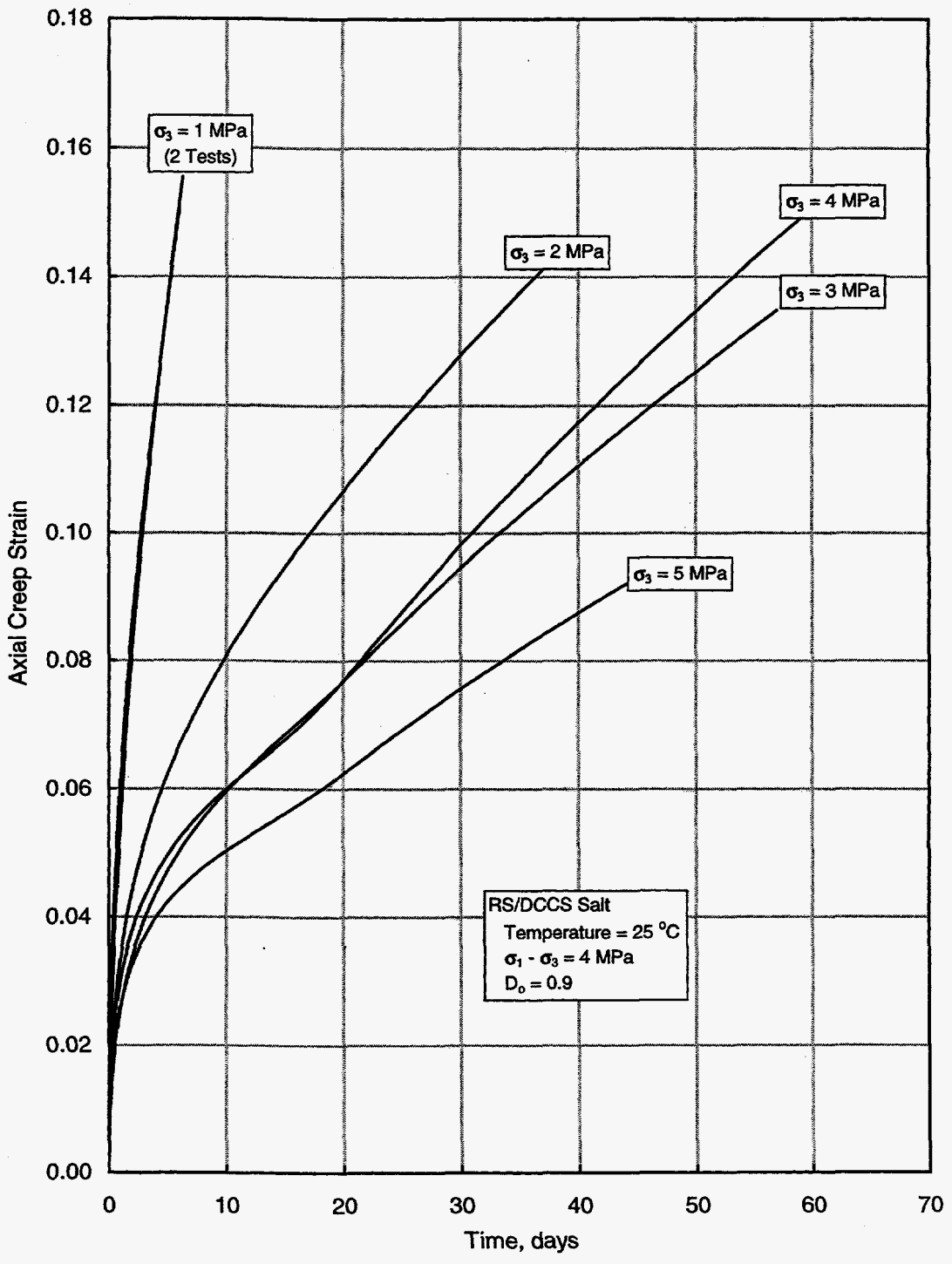

Figure 4-1. Axial creep strain as a function of time for laboratory-scale, dynamically compacted salt.

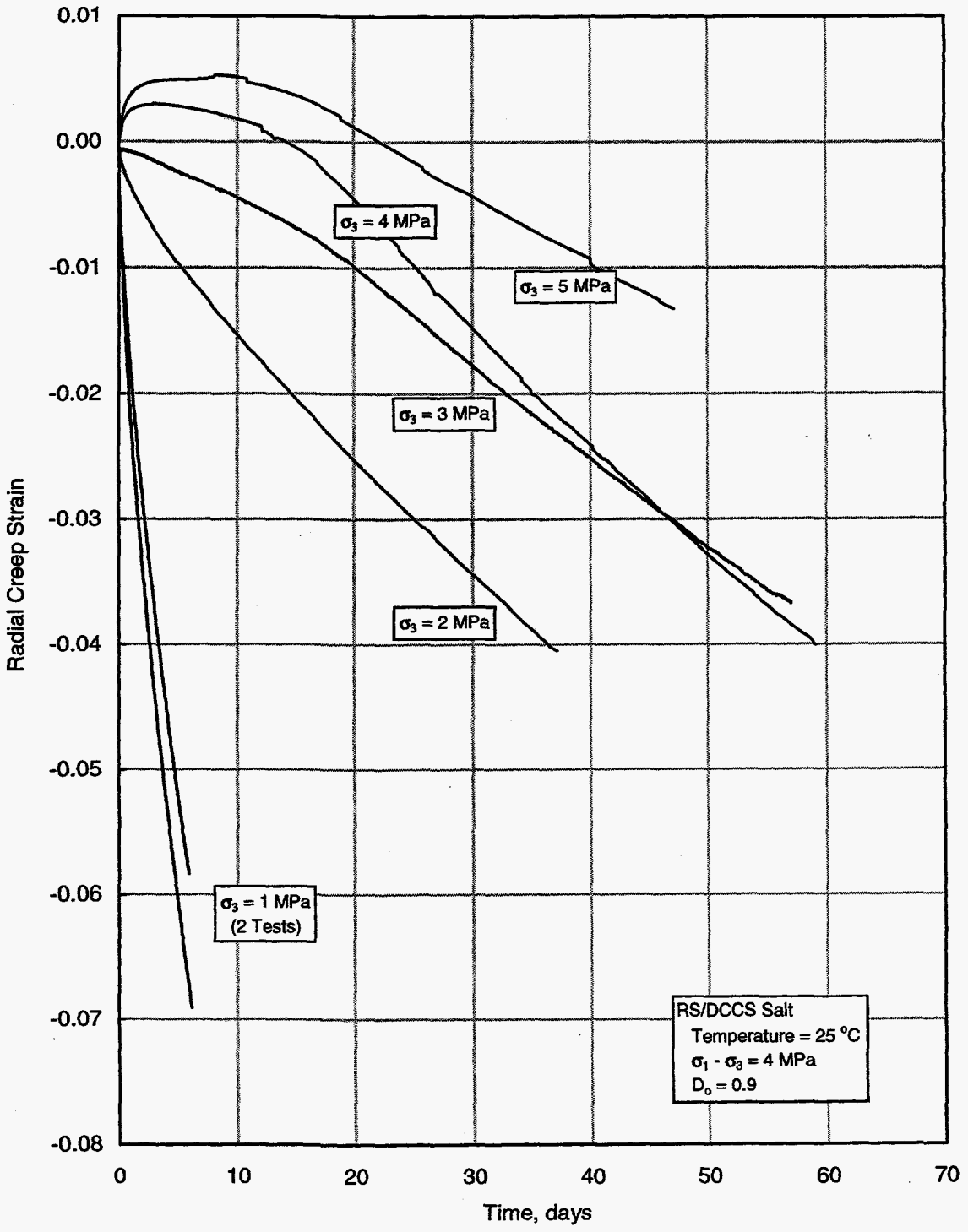

Figure 4-2. Radial creep strain as a function of time for laboratory-scale, dynamically compacted salt.

As seen in Figure 4-3, all three specimens displayed the same radial strain phenomenon; that is, the radial strain rate was initially compressive and then became extensile after some densification of the specimen. The difference between the laboratory-scale and large-scale results is likely caused by the difference in which the specimens were made. The large-scale specimens were cored from very large blocks, which were dynamically compacted as a single unit. Using that technique, it is expected that the particle size distribution of a specimen taken from the dynamically compacted mass is fairly homogeneous throughout the specimen volume. To the contrary, the laboratory-scale specimen was fabricated by dynamically compacting the crushed salt in three separate sections or lifts. This technique involved placing a third of the loose crushed salt in a mold and then compacting it by repetitive drops of a steel hammer. This process was repeated a second and third time to create a specimen of the proper length. The final product was a specimen that had two distinct zones (about ¼-inch thick) of fine crystals where the hammering took place that separated the specimen into three relatively homogeneous sections. During shear consolidation testing, the thin, fine-grain zones deformed differently than the three larger zones of coarser-grain crystals. This was apparent in post-test examination of the specimens where the fine-grain interface zones appeared as bulges. An example of the post-test profile of a typical specimen is given in Figure 4-4. The difference in deformation between the fine-grain and coarse-grain portions of the specimen was attributed to their probable difference in grain size. It is also possible that the fine-grain zones had a slightly higher fractional density at the outset. It is important to note that while the fine-grain zones may account for some difference between the laboratory-scale and large-scale results, the radial strain reversal phenomenon was observed in both types of specimens, as seen in Figure 4-3. This means that the radial-strain reversal should be seen in all types of crushed salt (assuming the proper stress state and fractional density) and is not just an experimental artifact.

Because of the post-test bulges seen in the laboratory-scale specimens, there was some concern that nonuniform deformation might have caused significant errors in the strain measurements made during the test. This concern was addressed by comparing the total inelastic strain measured during the test (the sum of stress application strains and constant stress consolidation strains) to the strain calculated as the logarithm of the ratio of post-test dimension to pre-test dimension. Those comparisons are outlined in Table 4-2 and indicate that the test system measurements were accurate. The axial strain values compare extremely favorably. The radial strain values do not compare as well as the axial strain values. This difference may be caused by the technique used to measure the specimen diameter. Two orthogonal measurements of diameter were made at 13 points along the length of the specimen. These values were then averaged to give an average specimen diameter that was used for the bench measure strain calculation. The bulges in the specimen could have a disproportionate effect on the average diameter determination, depending upon the exact locations where the measurements were made.

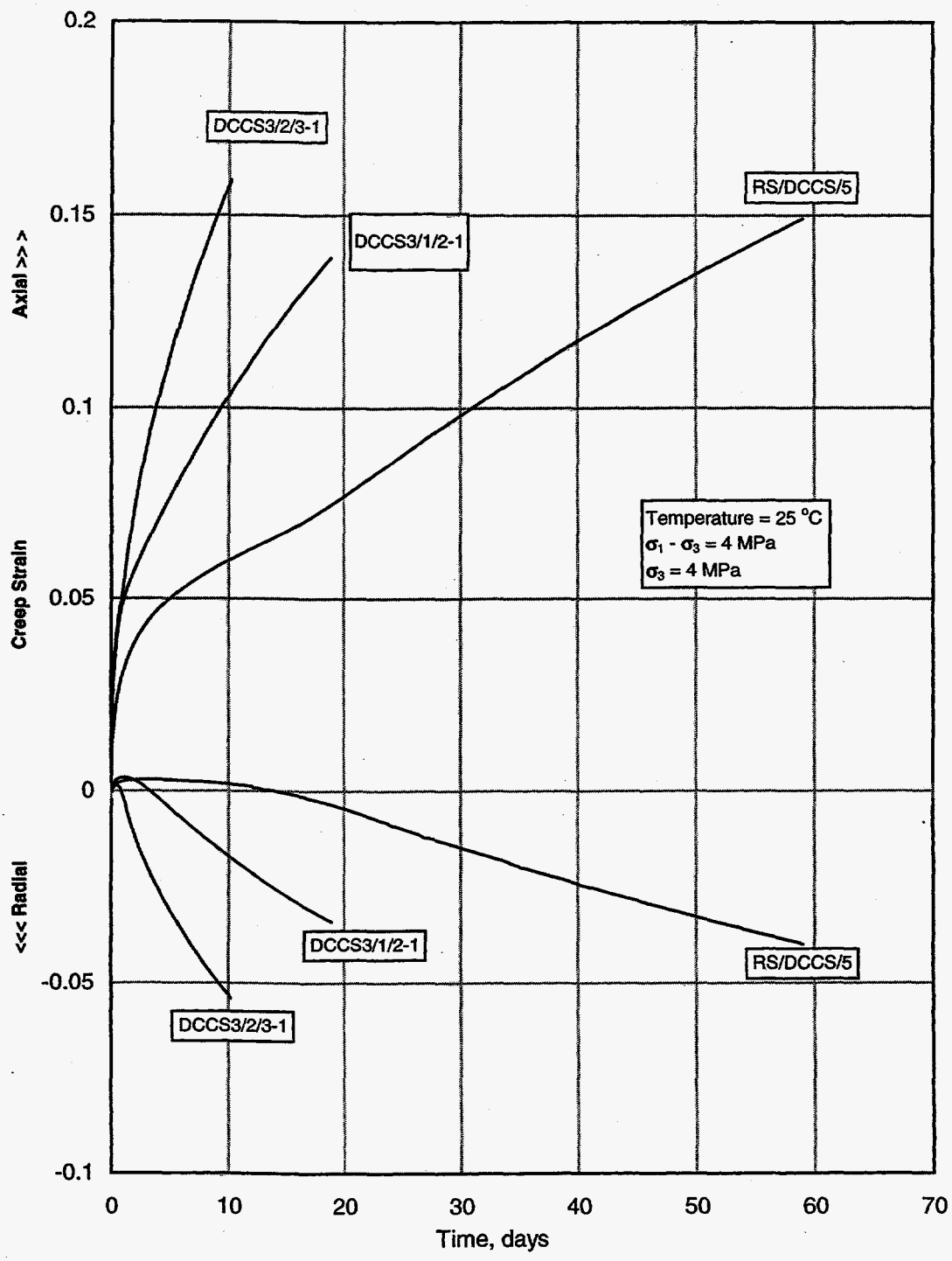

Figure 4-3. Comparison of test results from large-scale and laboratory-scale dynamically compacted salt specimens.

The effect of the bulges would be to introduce a bias in the diameter measurement, such that the post-test diameter would be overestimated, leading to an overestimation of radial strain in the bench measure calculations. Another possible explanation for the difference in radial strain measures is the existence of a leak in the test system dilatometer. A leak would cause the test measurements to underestimate the radial strain during the test. No gross leaks were detected during testing, but a small dilatometer leak could cause the relatively small differences in radial strain noted in Table 4-2.

Table 4-2. Comparison of Test System and Bench Strain Measurements

Specimen I.D.	Principal Strain Direction	Load Path Segments			Test System Total	Bench Measure Total
		Hydrostatic Pressurization	Shear Stress Application	Creep Consolidation		
RS/DCCS/1	ε_1	(a)	0.00192	0.15550	0.15742+	0.16763
	ε_3	(a)	–0.00084	–0.06905	–0.06989+	–0.06335
RS/DCCS/3	ε_1	0.00153	0.00187	0.16541	0.16882	0.16981
	ε_3	0.00153	–0.00069	–0.04976	–0.04891	–0.05294
RS/DCCS/4	ε_1	0.00967	0.00181	0.14565	0.15712	0.15238
	ε_3	0.00967	–0.00062	–0.04342	–0.03437	–0.04442
RS/DCCS/5	ε_1	0.00349	0.00166	0.14917	0.15432	0.15507
	ε_3	0.00349	–0.00234	–0.04005	–0.03890	–0.04102
RS/DCCS/10	ε_1	0.00362	0.00109	0.09518	0.09989	0.09544
	ε_3	0.00362	–0.00026	–0.01324	–0.00989	–0.01467
RS/DCCS/15	ε_1	0.00214	0.00152	0.15064	0.15431	0.15290
	ε_3	0.00214	–0.00046	–0.05835	–0.05666	–0.06260

(a) No deformation data collected. The total system strain should have some small compressive strain added. Note that the effect would make the test system measurement lie closer to the bench measurement values.

At the termination of seven of the eight tests on dynamically compacted crushed salt, an unload/reload cycle was conducted. The data collected during the reload portion of the cycle were used to calculate estimates of the elastic constants. The data analysis was relatively simple. The slope of the axial stress difference versus axial strain curve represented Young's modulus, E. Poisson's ratio, ν, was estimated by calculating the ratio of Young's modulus to the slope of the axial stress difference versus radial strain curve. Using the estimates of E and ν, an estimate of bulk modulus, K, was then calculated from the relation $K = E / [3(1-2\nu)]$. The suite of elastic constants determined in this fashion is shown in Table 4-3. The first column contains the specimen identification and the next three columns list the elastic constant estimates. The final column lists the fractional density of the specimen at the time the unload/reload cycle was conducted.

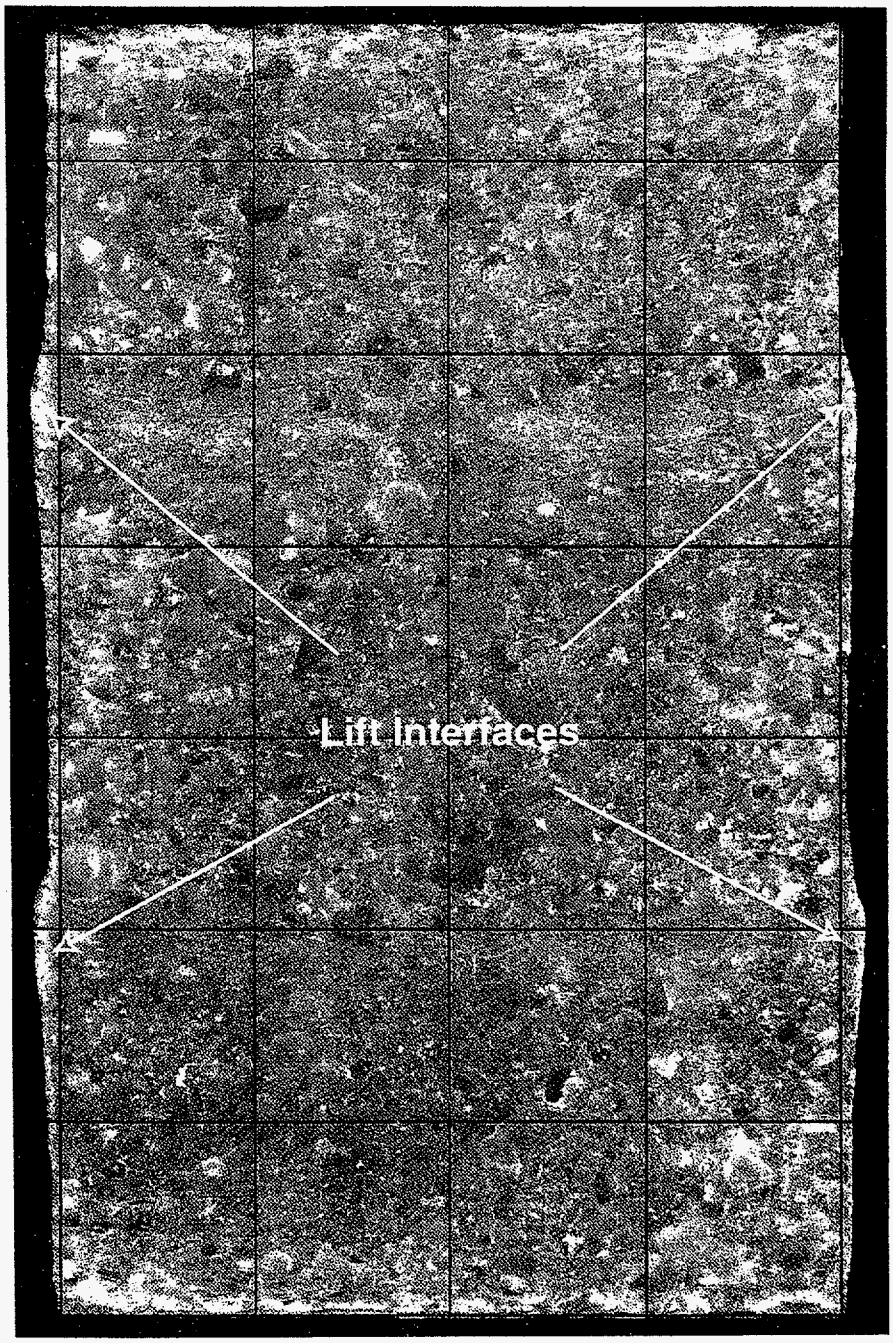

Figure 4-4. Polished half cylinder of consolidated three-lift specimen.

An inspection of the values given in Table 4-3 indicates that the elastic constants display a dependence upon the value of the fractional density of the specimen. This dependence is analyzed later at the end of Section 4.3 on permeability because additional elastic constant results were obtained during that testing.

Table 4-3. Elastic Constants for Dynamically Compacted Crushed Salt

Specimen I.D.	Young's Modulus, E (GPa)	Poisson's Ratio, ν	Bulk Modulus, K (GPa)	Fractional Density
RS/DCCS/1	N/A	N/A	N/A	N/A
RS/DCCS/3	11.7	0.303	9.9	0.971
RS/DCCS/4	13.0	0.480[(a)]	108.0	0.988
RS/DCCS/5	11.7	0.339	12.1	0.969
RS/DCCS/10	12.6	0.386	18.4	0.982
RS/DCCS/15	6.3	0.330	6.1	0.939
DCCS3/2/3-1	9.5	0.368	12.0	0.971
DCCS3/1/2-1	12.1	0.291	9.6	0.994

(a) Apparent outlier. Causes a gross increase in bulk modulus value.

4.2 Constant Strain Rate

Three constant strain-rate tests were performed on laboratory-scale specimens. The specimens were dynamically compacted using the same technique and raw crushed-salt materials that were employed for fabrication of the shear consolidation specimens. Thus, the constant strain-rate specimens had a nominal length of 200 millimeters, a nominal diameter of 100 millimeters, and a nominal fractional density of 0.9. All three tests were performed at a confining pressure of 1 MPa, a temperature of 20°C, and a constant axial strain rate. The constant axial strain rate was different for each test, as shown in Table 4-4, which is the completed test matrix. The data acquired during the tests were used to calculate principal stresses and strains according to formulas that provided true stress and true strain measures, as described for the shear consolidation tests. The sign convention was also the same; positive values indicate compression.

Table 4-4. Test Matrix for Constant Strain-Rate Experiment

Specimen I.D.	Axial Strain Rate (10^{-7} s^{-1})	Confining Pressure (MPa)	Temperature (°C)
RS/DCCS/11	0.5	1	20
RS/DCCS/6	1.0	1	20
RS/DCCS/21	2.0	1	20

Specimen RS/DCCS/6 was used to perform the first constant strain-rate test on crushed salt, and this first test served to refine the procedure outlined previously in Section 3.2.3. The first two attempts at performing this test were aborted, but the third attempt was successful and is being reported here. The first attempt was aborted because the constant strain-rate phase of the test was entered before the consolidation rates in the preceding hydrostatic phase had slowed to a value less than 1×10^{-7} s^{-1}. This caused the system to unload, as described in Section 3.2.3. The second attempt was aborted by failure of an electronic power supply in the test system shortly after the constant strain-rate phase had begun.

After determining new specimen dimensions (there was some deformation induced during the first two aborted attempts), a third attempt was successful. At the start of the third attempt, the specimen had a length of 190.3 millimeters, a diameter of 101.6 millimeters, and a fractional density of 0.92. The test duration was about 1 week, and the controlled test variables were maintained at a constant pressure of 1 MPa and a constant axial strain rate of 1×10^{-7} s^{-1} as shown in Figure 4-5 that plots the measured stresses and strains as a function of time. The plot origin represents the first data point acquired before any stresses were applied. Thus, the plot represents the entire loading history of the specimen, including the initial hydrostatic ramp up to the confining pressure of 1 MPa, the hydrostatic consolidation stage, and then the shear loading conducted at a constant axial strain rate. During the hydrostatic loading, axial strain exceeded radial strain. During the shear loading phase of the test, a small increase in compressive radial strain was measured, followed by extensile radial strains as loading continued. This appears to be a different radial strain behavior than was observed during shear consolidation creep testing at a confining pressure of 1 MPa. The fact that a small amount of compaction was observed during the initial constant strain rate shear loading may be attributed to the fact that at early loading times, the stress differences are small; whereas, in the creep tests the stress difference was 4 MPa.

The discontinuities in the axial stress measurement were traced back to a test system control problem. A multirange signal conditioner was used to measure the axial strain and that signal conditioner was adjusted for maximum sensitivity at the start of the test. As the axial strain increased, the system automatically changed to a less sensitive range. During this range switch, the closed-loop feedback circuitry is designed to operate in a "bumpless transfer" fashion; however, the system was not well tuned for these tests and a small error was introduced into the control signal during the range switch. This problem was eventually diagnosed and eliminated, but not until after all three tests in Table 4-4 were conducted, so the discontinuities in axial stress were seen in all three tests.

The other two constant strain-rate tests, RS/DCCS/11 and RS/DCCS/21, were performed without incident at axial strain rates of half and double, respectively, the strain rate used for RS/DCCS/6. The results from these two tests are shown in Figures 4-6 and 4-7, which plot the entire load history of the tests as a function of time.

The results from the three tests are compared in Figure 4-8, which plots the axial stress response from each test as a function of time. As expected, the axial stress rate is highest for the test conducted at the highest strain rate. The entire load history is plotted for each test, so they do not all start at the same point in time near the origin because of the differences in the hydrostatic consolidation duration.

Figure 4-9 plots the axial stress response of each specimen as a function of the specimen fractional density. The fractional density of the specimens was calculated using the volumetric strain data as:

$$D = \frac{\rho}{\rho_{max}} = \frac{\rho_o}{\rho_{max}(1-e_v)} \tag{4-5}$$

D is the fractional density, ρ is the current density, ρ_o is the density at the start of the test, ρ_{max} is the density of intact salt, and e_v is the engineering volumetric strain. For these calculations, the density of intact salt was 2.16 g/cc.

As seen in Figure 4-9, the axial stress response depends primarily on the fractional density of the specimen. The expectation was that a different response would be seen among the different strain-rate conditions. The fact that no large difference is seen may be attributable to the relatively small range of strain rates that was investigated.

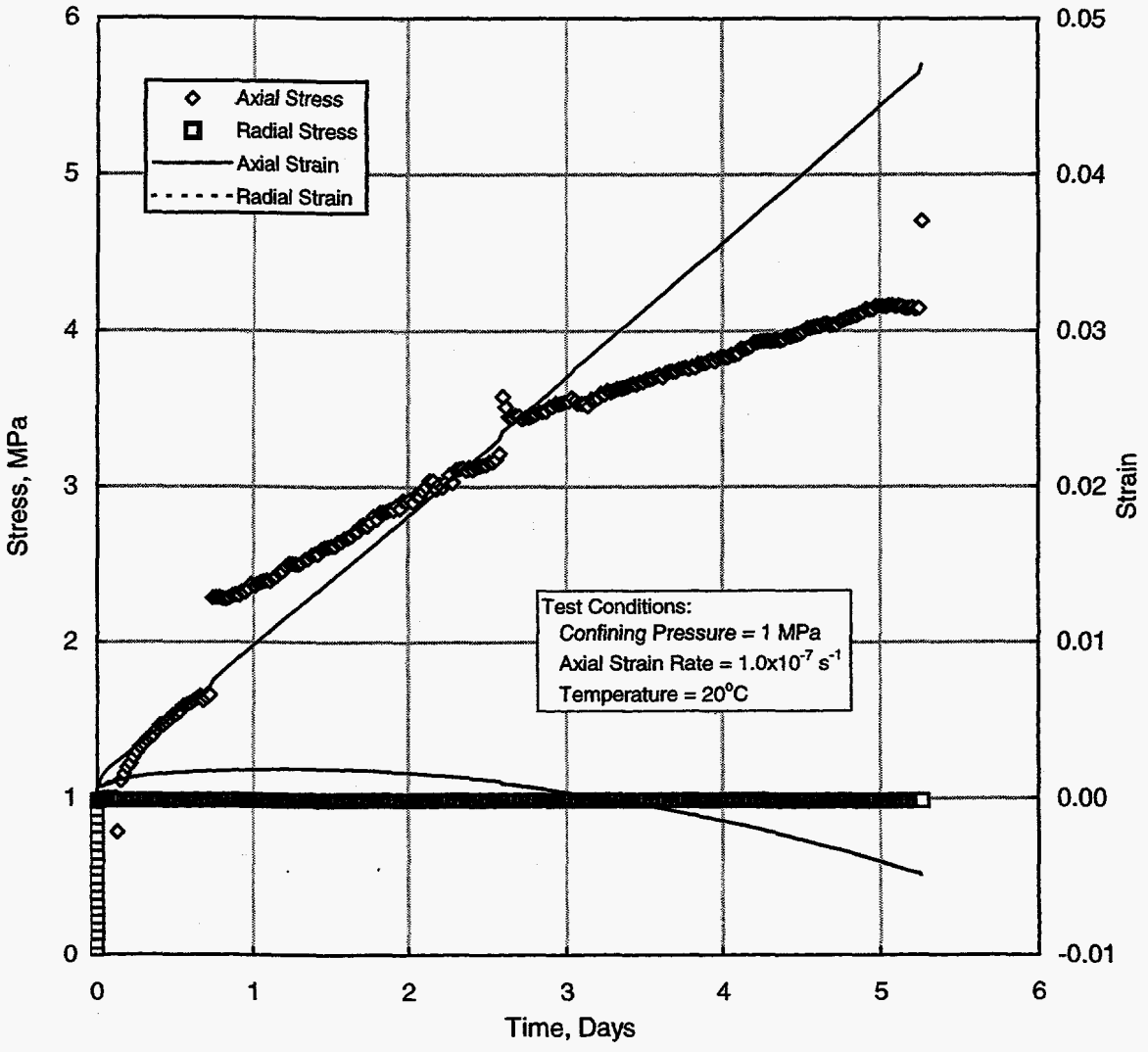

Figure 4-5. Constant strain-rate test on specimen RS/DCCS/6.

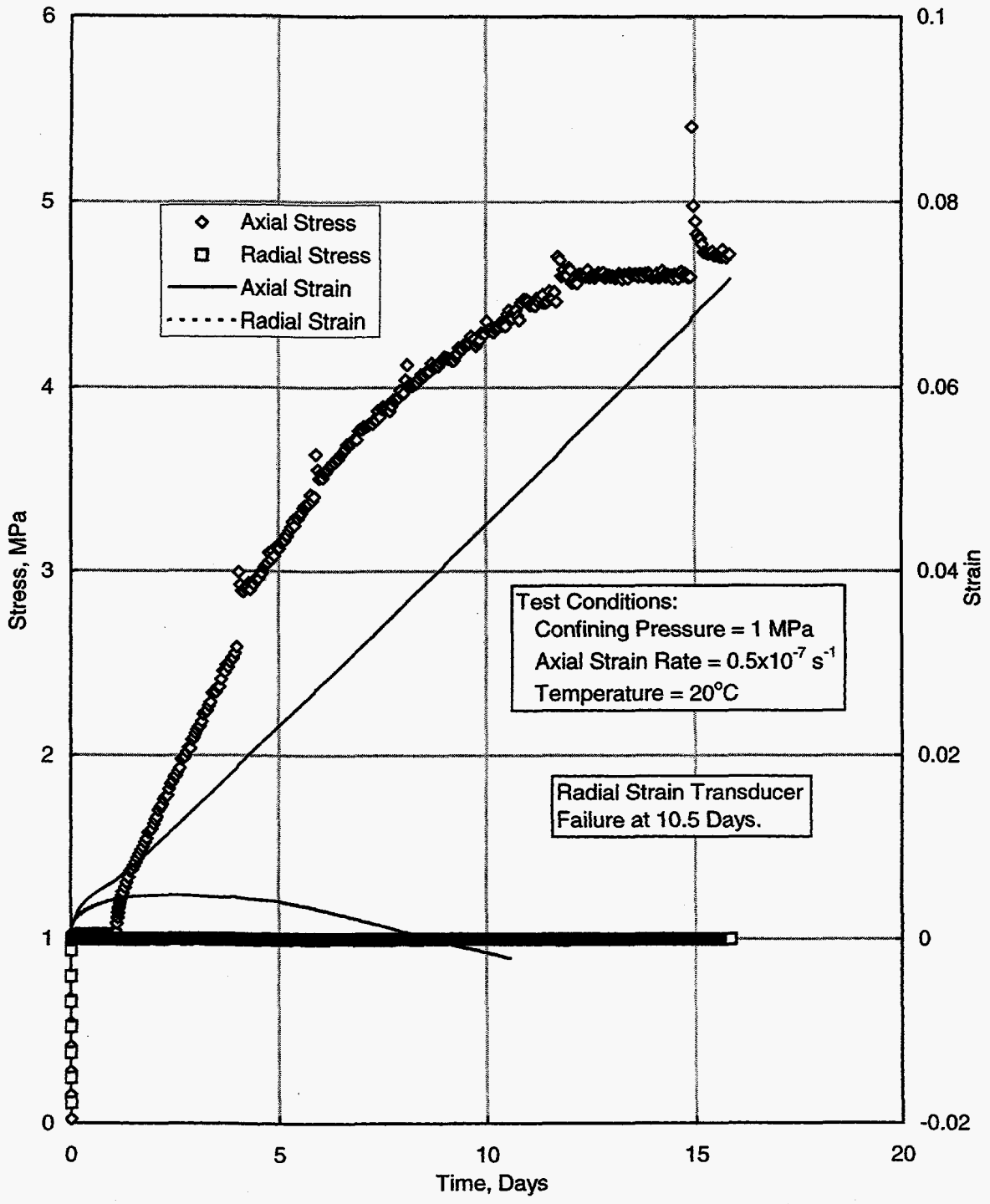

Figure 4-6. Constant strain-rate test on specimen RS/DCCS/11.

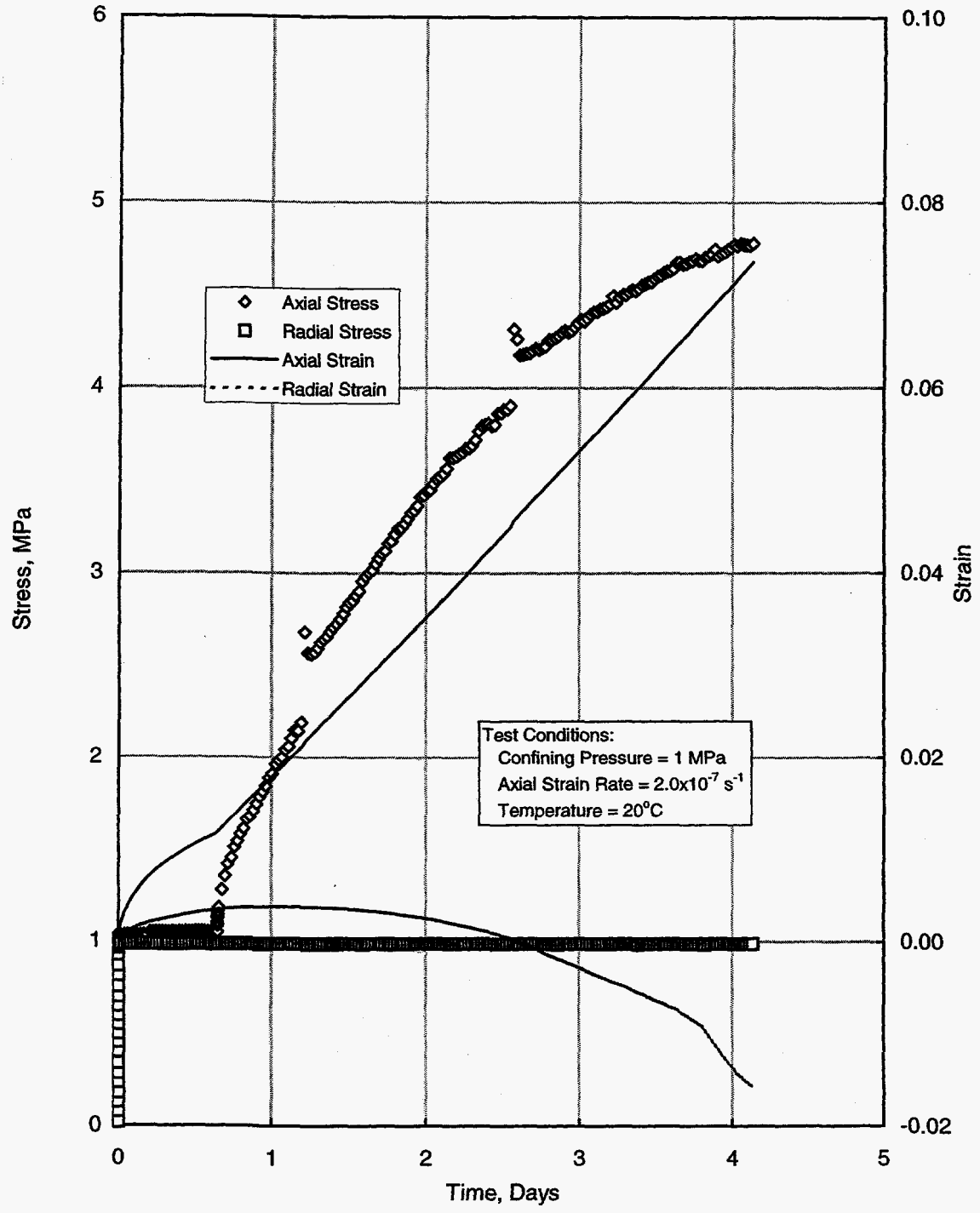

Figure 4-7. Constant strain-rate test on specimen RS/DCCS/21.

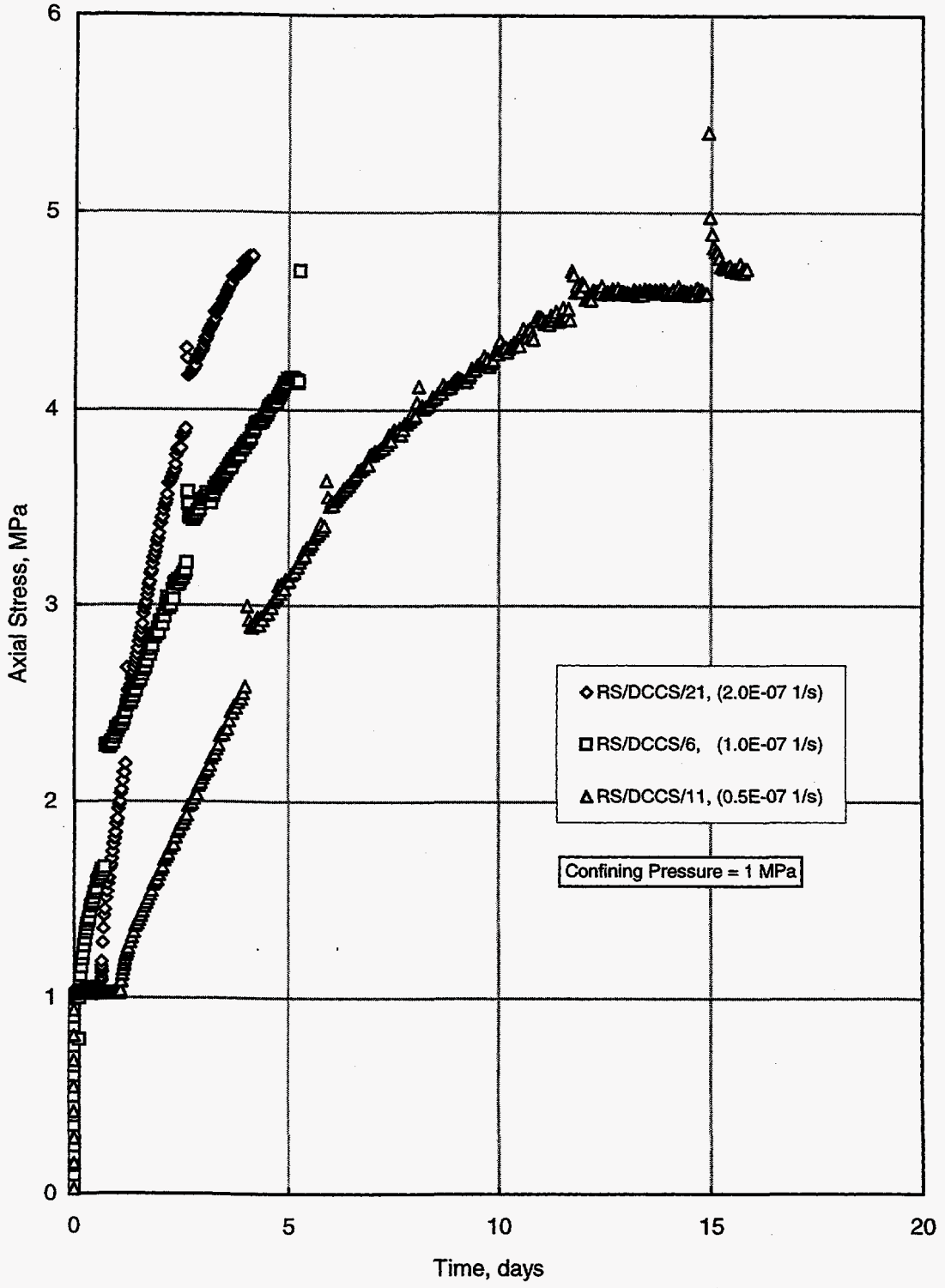

Figure 4-8. Comparison of results from three constant strain-rate tests.

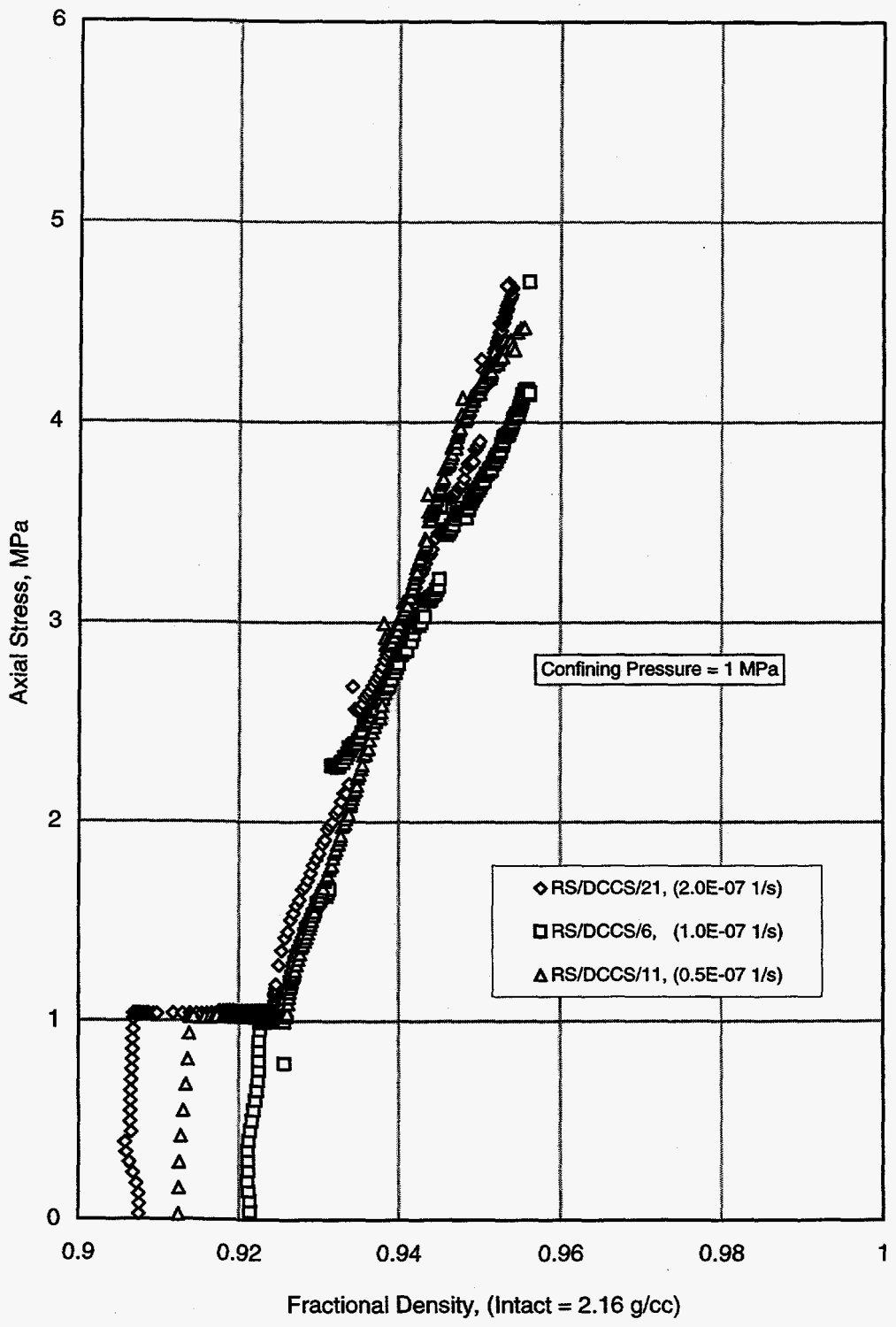

Figure 4-9. Axial stress response as a function of fractional density for three constant strain-rate tests.

4.3 Permeability

Three brine permeability tests were performed on specimens that had been previously tested for permeability using nitrogen gas. The current tests were performed at a temperature of 25°C using a hydrostatic confining stress of 1 MPa and a pore pressure of 0.345 MPa to drive the brine permeant. These test conditions were comparable to those used previously when the specimen permeability was determined using nitrogen gas as the permeant. The data reduction was based on Darcy's law as outlined by Brodsky (1994):

$$k = \frac{Q\mu L}{A\Delta P} \tag{4-6}$$

where:

k = permeability
Q = measured flow rate of brine
A = cross - sectional area of specimen
μ = brine viscosity = 1.26cP (Brodsky, 1994)
L = current specimen length
ΔP = pressure drop across the specimen.

The matrix of tests is presented in Table 4-5. The first column in the table identifies the specimen. The second and third columns contain the test conditions. The fourth column is the fractional density of the specimen at the start of the test, and the fifth column is the permeability value calculated for each specimen.

Table 4-5. Summary of Brine Permeability Experiment

Specimen I.D.	Test Conditions		Initial Fractional Density	Permeability (m^2)
	Confining Pressure (MPa)	Brine Inlet Pressure (MPa)		
DCCS/3/3/3-1	1	0.35	0.90	0[(a)]
CS/DC2/T2S-1/1	1	0.35	0.86	8.2×10^{-14}
CS/DC1/8-3	1	0.35	0.86	1.5×10^{-14}

(a) This test had an initial permeability of about 5×10^{-16} m^2. As the test progressed, the specimen consolidated and the permeability decreased to near zero.

The test on DCCS3/3/3-1 produced the data shown in Figure 4-10 that plots volumetric strain as a function of time on the primary axis and brine permeant flow as a function of time on the secondary axis. Two of the four curves in Figure 4-10 are actual test measurements; the other two are calculated. The curve labeled *Buret Measurement* is the total measured volume of brine collected at the vented end of the specimen, and the curve labeled *Volumetric Strain* is a test system measurement provided by the dilatometer. The data indicate that the saturated specimen was consolidating; thus, some volume of brine was getting expelled at the vented specimen end. This means that the buret measurement had two components. One was the volume of fluid being expelled by the action of consolidating the specimen, and the other was the volume of fluid traveling through the specimen from the pressurized brine inlet at one end of the specimen to the vented specimen end where the buret was located. Figure 4-10 implies that permeability decreases as fractional density increases. Such a relationship is reasonable, but other factors can also affect permeability without a change in fractional density. For example, under constant conditions, Brodsky (1993) reported decreasing brine permeabilities that were probably attributable to localized precipitation.

The curve labeled *Calculated Consolidation Flow* is the volume of fluid expelled from the specimen, which was calculated from the volumetric strain data. This calculation was performed by first using the relationship from Brodsky (1993) describing how the specimen density changes as a function of volumetric strain:

$$\rho_i = \rho_o \times \left(\frac{1}{1-\varepsilon_v} \right) \tag{4-7}$$

where ρ_i is the current density of the specimen, ρ_o is the original (pretest) density of the specimen, and ε_v is the engineering volumetric strain which is signed positive for compression. A second equation relates the pore space volume to the fractional density of the specimen:

$$PV_i = V_o \times \left(1 - \frac{\rho_i}{\rho_{\max}} \right) \tag{4-8}$$

PV_i is the pore space volume, V_o is the original volume of the specimen, and ρ_{max} is the density of intact salt. The ratio of the two densities is known as the fractional density of the specimen. Substituting the first equation into the second gives a relationship for the change in pore space volume as a function of the volumetric strain:

$$PV_i = V_o \times \left(1 - \frac{\frac{\rho_o}{\rho_{\max}}}{1-\varepsilon_v} \right) \tag{4-9}$$

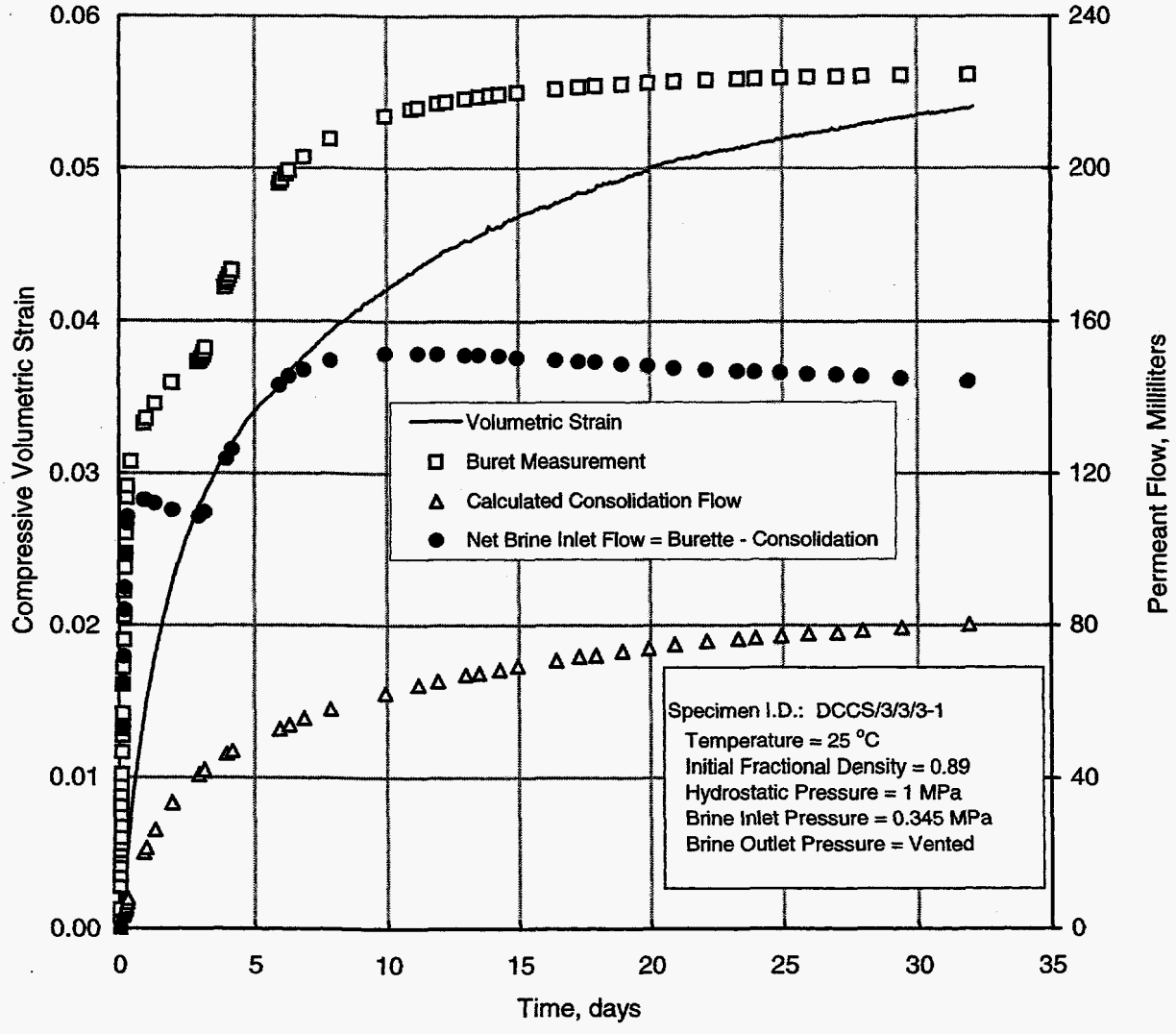

Figure 4-10. Volumetric strain and brine flow as a function of time for specimen DCCS3/3/3-1.

The curve labeled *Calculated Consolidation Flow* is the volume of fluid expelled from the specimen, which was calculated from the volumetric strain data. This calculation was performed by first using the relationship from Brodsky (1994) describing how the specimen density changes as a function of volumetric strain:

$$\rho_i = \rho_o \times \left(\frac{1}{1-\varepsilon_v} \right) \tag{4-10}$$

where ρ_i is the current density of the specimen, ρ_o is the original (pretest) density of the specimen, and ε_v is the engineering volumetric strain which is signed positive for compression. A second equation relates the pore space volume to the fractional density of the specimen:

$$PV_i = V_o \times \left(1 - \frac{\rho_i}{\rho_{\max}} \right) \tag{4-11}$$

PV_i is the pore space volume, V_o is the original volume of the specimen, and ρ_{max} is the density of intact salt. The ratio of the two densities is known as the fractional density of the specimen. Substituting the first equation into the second gives a relationship for the change in pore space volume as a function of the volumetric strain:

$$PV_i = V_o \times \left(1 - \frac{\frac{\rho_o}{\rho_{\max}}}{1-\varepsilon_v} \right) \tag{4-12}$$

Because the specimen was saturated, the volume of expelled pore fluid was calculated as the change in specimen pore volume. The volume of expelled fluid was then subtracted from the buret measurement to get the curve labeled *Net Brine Inlet Flow*. This net brine flow was the value used to calculate permeability. From inspection of the figure, it is apparent that the permeability rapidly decreased to a final value of about zero. Actually, the curve shows a small negative slope that was attributed to a combination of small measurement errors. Another possibility was that a pore pressure built up in excess of the 0.345 MPa pressure used to drive the brine through the specimen; however, such an increase would require that the vented end of the specimen was somehow plugged. The possibility of a plugged vent was checked by slowly lowering the hydrostatic confining pressure from its 1 MPa value to the 0.35 MPa brine inlet pressure value. The pressure was dropped at a rate of 0.1 MPa/minute while the buret was monitored for a change in the level of brine. The brine level remained constant until the confining pressure had decreased to the 0.35 MPa brine inlet pressure, at which time, the brine began flowing along the specimen-to-jacket interface and the buret reading began to increase. Since the brine level in the buret remained constant until the confining pressure was low enough to allow flow along the specimen-to-jacket interface, the conclusion was that the upper pore

pressure vent was not plugged during the test. Therefore, the pore pressure had not increased during the test, and permeability had diminished to zero.

The second brine permeability test was performed using Specimen CS/DC2/T2S-1/1 that had an initial fractional density of 0.86. The flow rates in this test were much higher than were observed in the first test, and the test was completed in about 1 hour. The flow versus time curve for the second test is shown in Figure 4-11, along with the calculated permeability value of 8.2×10^{-14} m^2.

The third and final brine permeability test was performed using the specimen identified as CS/DC1/8-3. The test conditions used were the same as those for the two previous brine permeability tests. The third brine permeability test had an initial fractional density of 0.86. The flow rates in this test were quite high and the accumulator used as a pressurized brine source held only about 4 liters of fluid. As a result, the accumulator was depleted in a short time, so three stages of the test were performed. Between stages, the confining pressure was reduced and the accumulator was refilled with brine. The confining pressure was then reapplied and the next stage of permeant flow was initiated. The data from the three stages were merged in chronological order and are shown in the flow versus time curve plotted in Figure 4-12. The data from the final two stages were used to calculate a permeability value of 1.5×10^{-14} m^2.

Five specimens prepared from the large-scale blocks were tested for permeability using nitrogen gas as the permeant fluid. Three of those specimens were tested at their initial fractional density (nominally 0.9) and two were mechanically deformed in a series of hydrostatic compaction/consolidation load paths so that the effect of density on permeability could be investigated. Although hydrostatic stresses of up to 15 MPa were used to increase the density of these two specimens, all permeability testing was performed at a hydrostatic stress of 1 MPa so that hydrostatic stress could be eliminated as a variable affecting the permeability measurements. Table 4-6 summarizes the permeability measurements recorded from these five specimens.

Specimen DCCS3/3/1-4 was mechanically deformed in its as-received state of moisture content; i.e., 0.44 percent. The stress and density history for this specimen is shown in Figure 4-13. For this specimen, the fractional density increased from 0.901 to 0.934 after approximately 21 days of testing and its permeability decreased from 5×10^{-14} m^2 to 5×10^{-15} m^2 over this range in fractional density.

The small change in fractional density exhibited by Specimen DCCS3/3/1-4 was attributed to the low moisture content of the specimen. Therefore, before starting the second test using Specimen DCCS3/2/2-1, the specimen was humidified to increase its moisture content to approximately the value specified in the large scale dynamic-compaction demonstration study (i.e., 1-percent). The

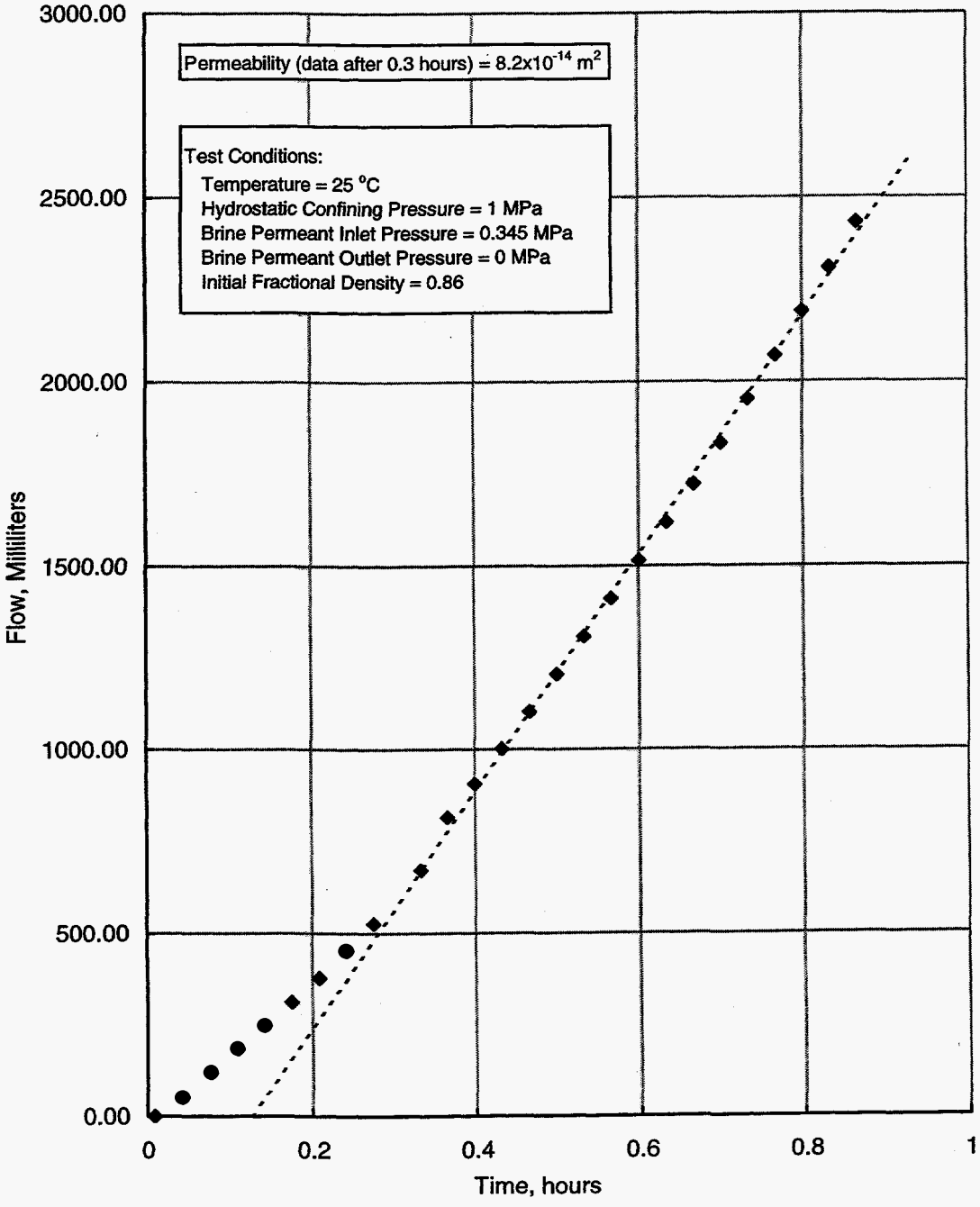

Figure 4-11. Permeability data for specimen CS/DC2/T2S-1/1.

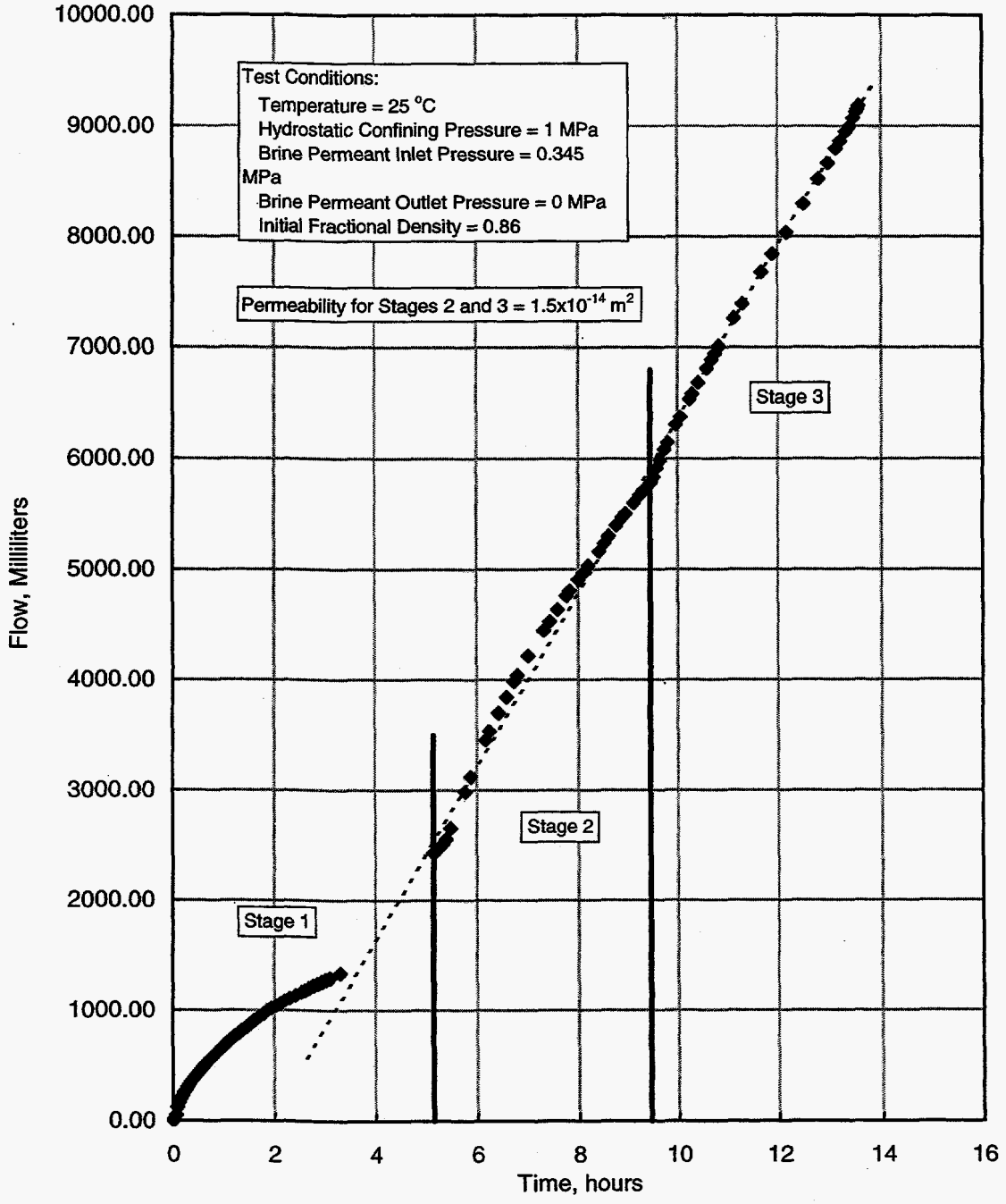

Figure 4-12. Permeability data for specimen CS/DC1/8-3.

Table 4-6. Summary of Gas Permeability Experiment

Specimen I.D.	Fractional Density	Permeability (m^2)
DCCS3/3/3-1	0.889	7.88×10^{-14}
DCCS3/2/1-1	0.901	4.99×10^{-14}
DCCS3/1/1-4	0.889	5.51×10^{-14}
DCCS3/3/1-4	0.901	4.99×10^{-14}
	0.916	2.63×10^{-14}
	0.929	4.58×10^{-15}
	0.934	4.95×10^{-15}
DCCS3/2/2-1	0.899	8.61×10^{-14}
	0.902	6.25×10^{-14}
	0.915	3.50×10^{-14}
	0.922	2.22×10^{-14}
	0.945	5.15×10^{-15}
	0.946	7.06×10^{-16}
	0.949	8.67×10^{-17}
	0.954	2.29×10^{-16}
	0.962	9.88×10^{-17}
	0.965	1.76×10^{-16}
	0.990	6.55×10^{-21}

moisture content of Specimen DCCS3/2/2-1 was 1.27 percent after humidification. Figure 4-14 provides the stress and density history for this specimen. As shown, the fractional density increased to about 0.97 within a time of approximately 3 hours. The rapid increase in density is attributed to the addition of the small amount of moisture. The permeability for this specimen changed from approximately 8.6×10^{-14} m^2 to 6.5×10^{-21} m^2. At the high fractional densities that occurred at the end of the test on Specimen DCCS3/2/2-1, the specimen is expected to have a high brine saturation because of the moisture added before the test began. Therefore, the low gas permeability measured at the end of the test probably represents a relative permeability value rather than the true intrinsic permeability and should be used with caution.

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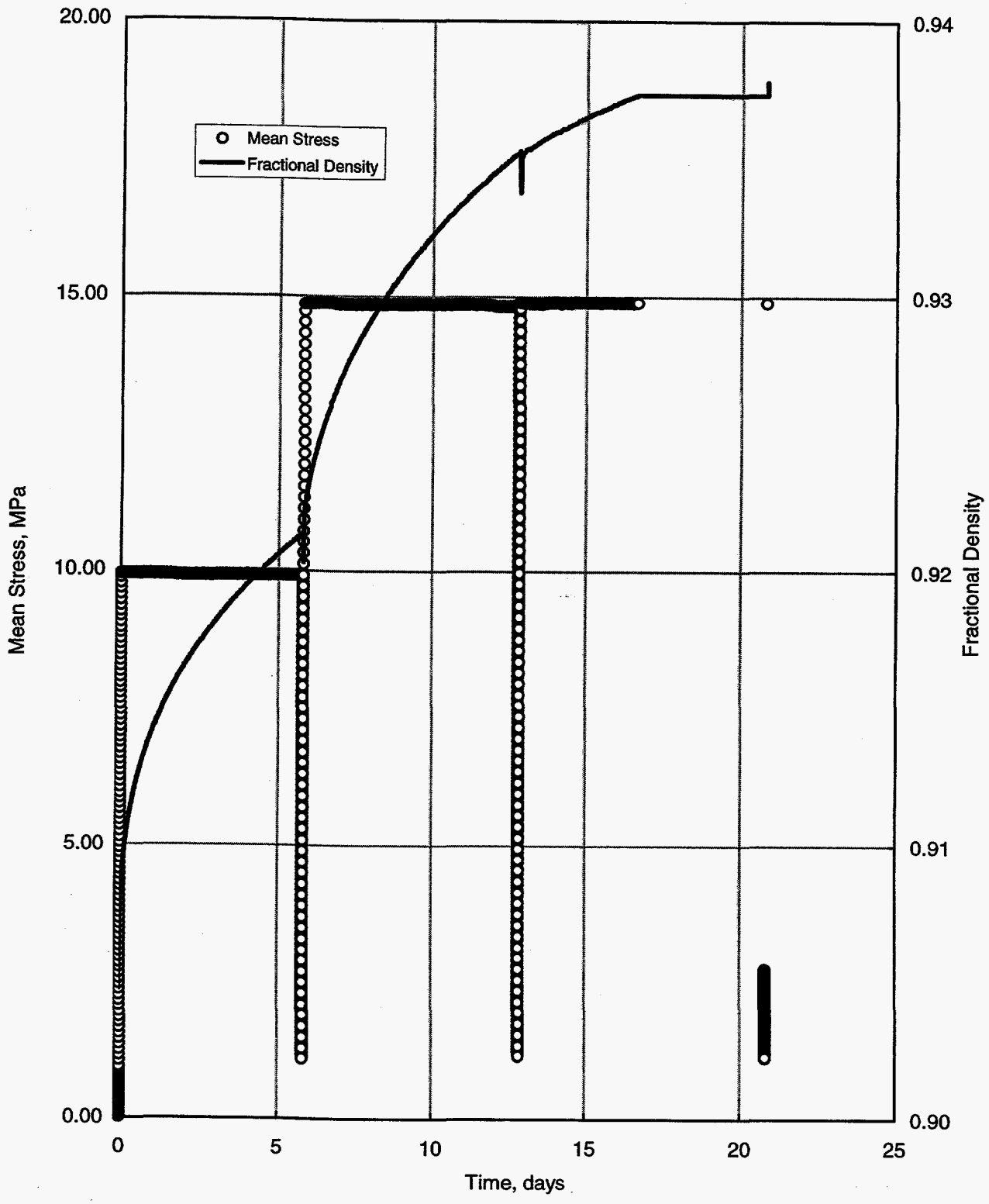

Figure 4-13. Stress and density history for permeability test on specimen DCCS3/3/1-4.

The permeability values from the three brine permeability tests (Table 4-5) and the five gas permeability tests (Table 4-6) were added to a previous database of laboratory permeability results (Appendix B) and field results generated for dynamically compacted crushed salt (Hansen and Ahrens, 1998). In compiling the combined database of permeability results, the values of fractional density reported in Appendix B were modified to account for differences in calculational methods. The fractional densities in Appendix B were calculated using the wet mass of the specimens and assuming the density of intact salt was 2.14 g/cc. The current calculations of fractional density use the dry mass of the specimen and a value of 2.16 g/cc for the density of intact salt. Thus, the fractional densities ($\overline{\rho}$) in Appendix B were corrected for water content, w, and higher density of intact salt using the expression:

$$\overline{\rho}_{2.16} = \frac{2.14}{2.16}\left(\frac{\overline{\rho}_{2.14}}{1+\frac{w}{100}}\right) \tag{4-13}$$

The moisture content for the two specimens listed as CS/DC1-4-1/3/1 and CS/DC1-8-3 in Appendix B was 0.26 percent. The moisture content for the other four specimens listed in Appendix B was 1.27 percent.

A significant difference among the permeability results was thought to be the difference in the type of permeant used. Some of the tests were performed using nitrogen gas as the permeant while the remainder of the tests used saturated brine as the permeant. The results from the two types of testing are compared in Figure 4-15, which plots permeability as a function of fractional density. As seen in the figure, the type of permeant used apparently has no major effect on the permeability determination, although the brine-based values do indicate a somewhat lower permeability than the permeability determined using gas. From only a few brine tests, statistically significant conclusions are not warranted. However, it is possible the effect results from salt precipitation at interstitial sites. A continuous decrease in brine permeability, while under constant conditions, was reported by Brodsky (1994).

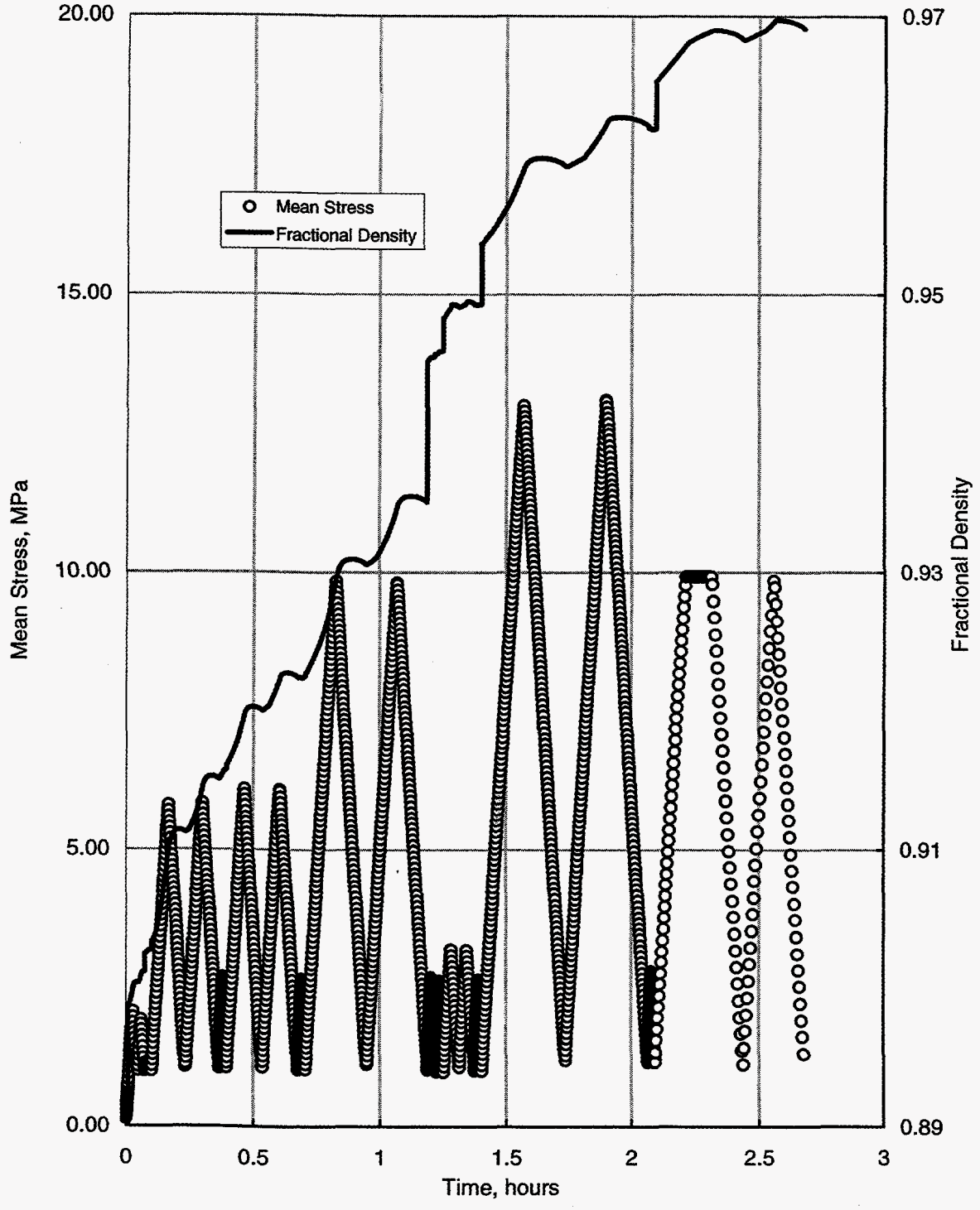

Figure 4-14. Stress and density history for permeability test on specimen DCCS3/2/2-1.

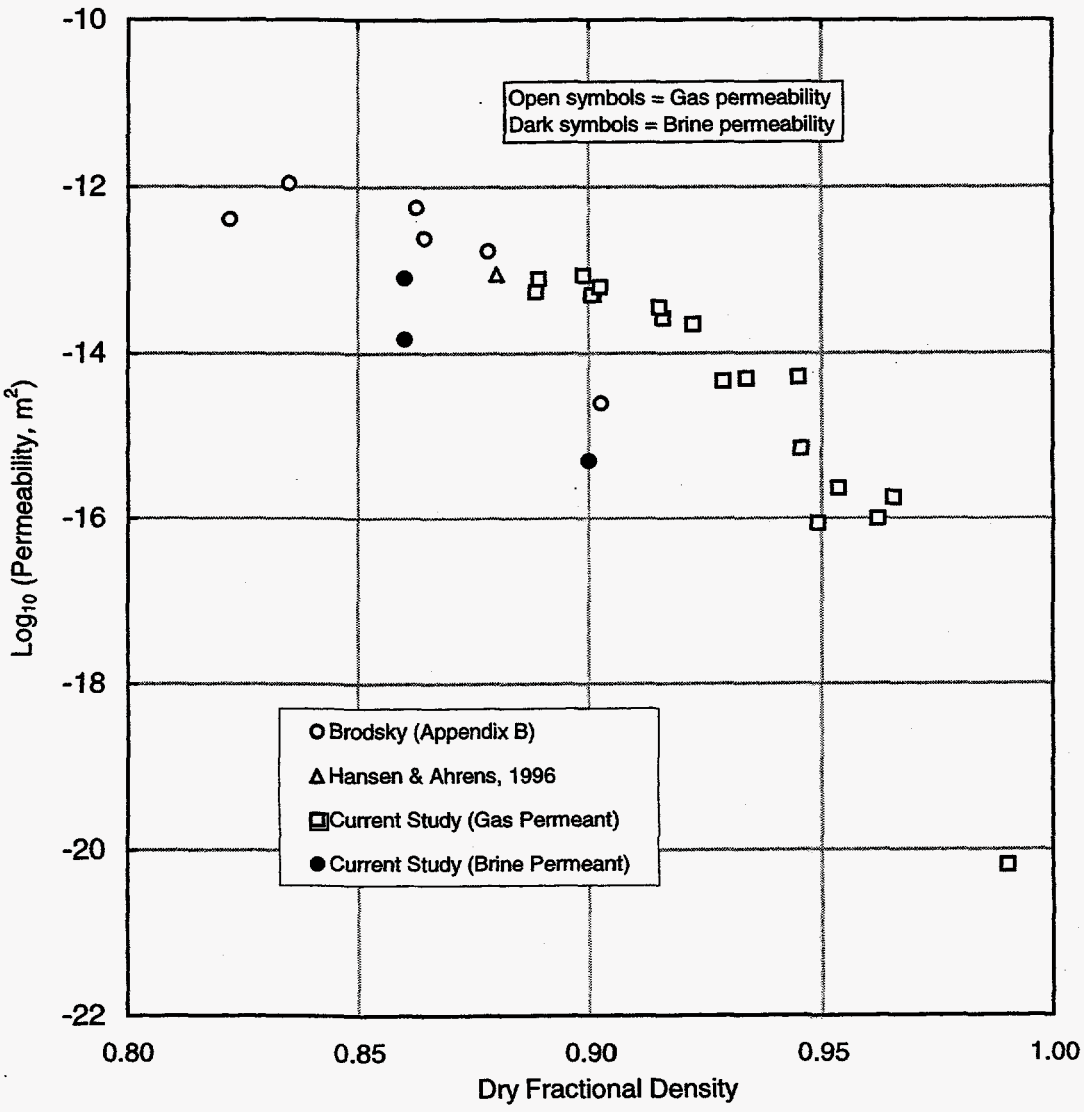

Figure 4-15. Permeability as a function of fractional density for dynamically compacted crushed salt.

Deformation data were collected from the gas permeability test on Specimen DCCS3/3/1-4 for estimating the bulk modulus, K, of the large-scale material. This provided additional information on a topic that has been investigated previously (Holcomb and Hannum, 1982); i.e., the dependence of the bulk modulus, K, on changes in fractional density. The results of the Holcomb and Hannum investigations, the test on the large-scale specimen, and the results tabulated in Table 4-3 are shown in Figure 4-16. Also shown on the figure is the value for intact salt (Munson et al., 1989). Even though the Holcomb and Hannum data were obtained using mine-run salt instead of dynamically compacted salt, the data clearly indicate that the bulk modulus of crushed salt increases nonlinearly toward the value for intact salt as the density increases. No current model was fit to describe this relationship, but a model fit by Holcomb and Hannum is shown on the figure and the current data appear to be in reasonable agreement with that model.

4.4 Substructures of Reconsolidated Crushed Salt

It has been postulated and confirmed that consolidation of granular rock salt occurs by two primary mechanisms: grain boundary pressure solution, and dislocation creep. Further, a minor amount of added moisture greatly enhances densification (Spiers and Brzesowsky, 1993). Consideration of the fundamental deformational processes guided formulation of the constitutive model for reconsolidating crushed salt (Callahan et al., 1998a). As crushed salt is loaded, the principal densification mechanism of fluid-phase grain boundary solution/redeposition is rampant. As consolidation proceeds, the material attains sufficient density that its response assumes the constitutive response of intact salt. Thus, the proper material law for reconsolidating crushed salt incorporates pressure solution and dislocation creep.

Photomicrographs of tamped and reconsolidated crushed salt, which display essential features, have been published by Brodsky et al. (1998). In this section, particular attention is given to microstructures of the reconsolidated laboratory-prepared specimens because of a unique phenomenon observed. Recall that laboratory-prepared specimens were fabricated in three lifts. Dynamic compaction, whether at the Proctor scale in the laboratory or at the full scale of construction, naturally creates more fine grain sizes at the surface than at depth in each lift. Scanning electron microscopy showed the grain size at the lift interfaces to be nearly the same as those created in the full-scale, dynamic-compaction construction demonstration (Hansen and Ahrens, 1998). Based on a considerable body of observational evidence, reconsolidation is governed by very effective pressure solution/redeposition processes occurring on the fine grains.

Figure 4-4 shows a complete cross-section of a consolidated three-lift specimen. After consolidation, the three-lift specimen actually bulged in a girdle at the lift interfaces. The reason for this behavior lies with the relatively finer grain size at the interface. The finer grain size (relative to the remainder of each lift) gives rise to more rapid grain boundary processes because

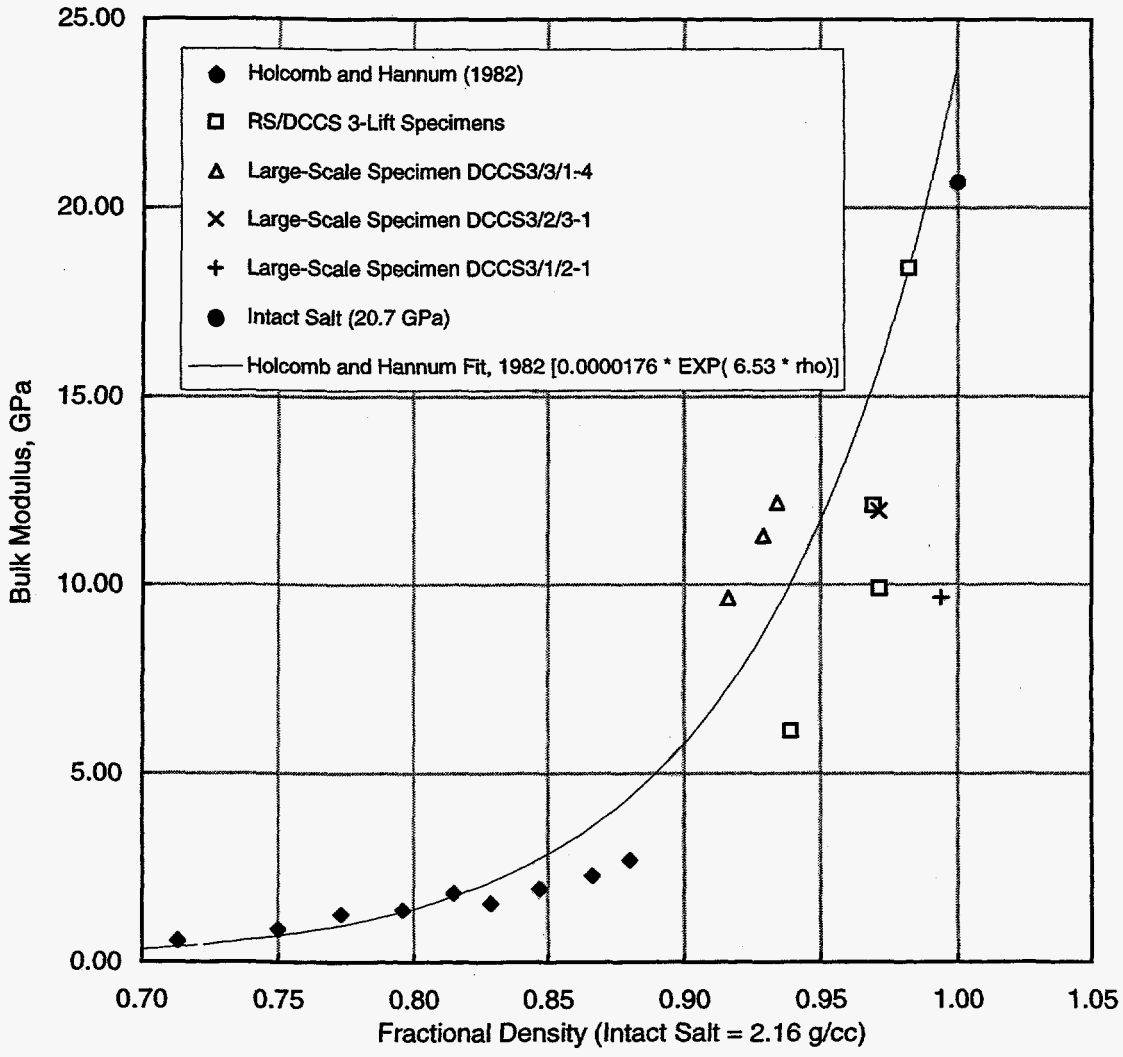

Figure 4-16. Bulk modulus as a function of fractional density.

of greater surface area available. The initial local density may also be higher than the initial average specimen density, which would also enhance the local change in consolidation mode. As the lift interface consolidates more rapidly than the rest of the specimen, the local density increases toward that of intact salt and the constitutive response changes from a consolidating mode to an intact mode. Hence, the bulges reflect locales where lateral deformation has reversed more readily from an inward direction (consolidation) to an outward direction, consistent with intact material response.

Two photomicrographs of the consolidation processes are provided in Figures 4-17 and 4-18. These examinations were made on the interface material. The first is an SEM micrograph shot at a magnification of 1,100. Note the grain size is approximately 20-30 um and almost no fine grains remain. Pressure solution is recognized by the triple junction of grains in the lower right field of view. The glossy nature of the surface is caused by cleavage fracture when the specimen surface was broken. No voids are evident, with an observation consistent with permeability diminishing to zero as consolidation approaches a fractional density of 0.95 and greater. The second is an optical micrograph with the scale bar shown on the figure. Healed grain boundaries can be discerned by the outline of fluid inclusions. Upon complete healing, these last inclusions will disappear and no optical evidence will remain of the former grain boundary. As grain boundaries heal, the very thin fluid films become isolated. These occluded fluid inclusions are displayed as the black, irregular spots in Figure 4-18. This optical photomicrograph shows the late stage of complete grain boundary healing.

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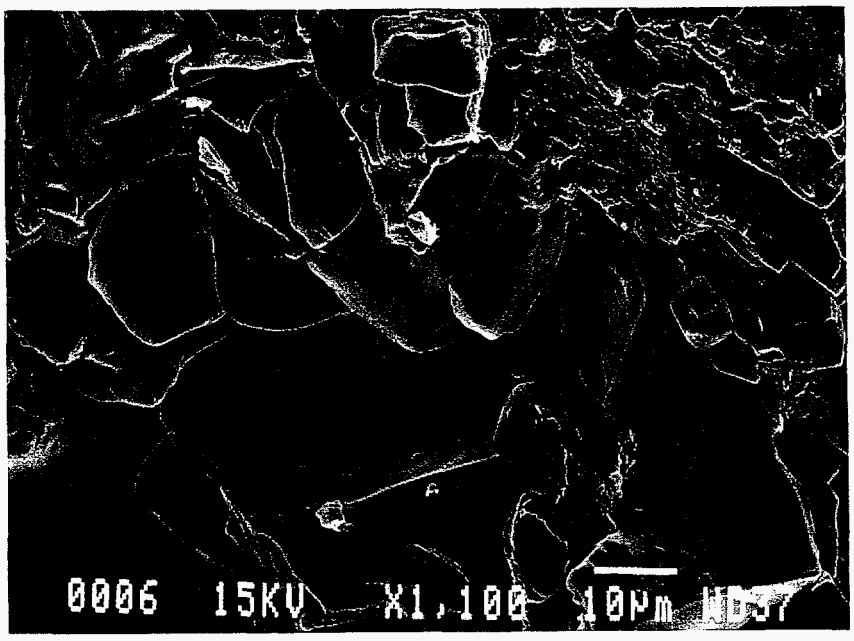

Figure 4-17. Reconsolidated three-lift sample on the fine-grained interface (SEM 1,100X).

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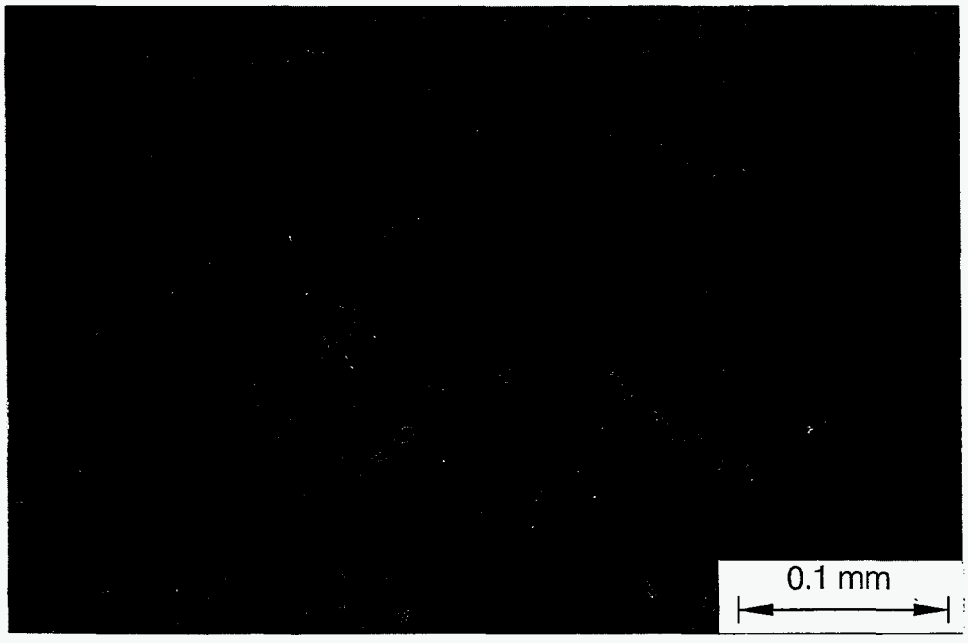

Figure 4-18. Healed grain boundaries of reconsolidating salt.

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5.0 CONCLUSIONS

The work documented in this report demonstrated that dynamically compacted crushed-salt specimens could be fabricated on a laboratory scale using a relatively simple device. The dynamic-compaction procedure resulted in specimens that were very similar in fractional density (0.9), water content (1.6 percent), and fabric. The similarity among specimens helped reduce the specimen-to-specimen variability in the test results.

The permeability testing of the dynamically compacted crushed salt provided further evidence that the permeability decreases as the fractional density of the salt increases. This conclusion agrees with previous results. The current test results were added to the previous database of permeability results to reinforce that conclusion.

A suite of shear consolidation creep test results were added to a database of similar results for the purpose of estimating parameters in a constitutive model that represents the behavior of crushed salt (Callahan et al., 1998a). The current testing was performed at higher initial fractional densities (0.9) and stresses (1 to 5 MPa) than were used in previous programs to give better coverage of the range of conditions likely to be encountered during sealing operations at the WIPP. The current testing provided new observations on specimen deformation that confirmed constitutive model predictions. The constitutive model predicted that stress states existed where the radial strain rate would initially be positive (consolidation) and then reverse direction and become negative as the specimen density increased. This phenomenon was clearly observed in multiple tests.

Three constant axial strain-rate tests were performed. These three tests were not to be included in the database used for estimating the parameters in the constitutive model. The purpose of these tests was to provide results from a unique load path that could be used to evaluate the predictive capability of the constitutive model.

All of the observational microscopy supports the fundamental theory of densification behavior of wet granular salt. The constitutive model developed by Callahan and coworkers embodies the governing mechanisms as documented by the enclosed micrographs. The experimental behavior is found to be consistent with theory both in the mesoscopic scale of laboratory experiments as well as the microscopic scale where the processes occur. It is the complete understanding of reconsolidation processes, verified by laboratory experiments, parameterized in one database and predicted accurately in independent experiments, comprehensively embodied in the mathematical formulation of the constitutive equations that provide the scientific basis and confidence for performance predictions of compacted-salt seal performance.

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6.0 REFERENCES

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APPENDIX A
MEMORANDUM TO L.D. HURTADO
RE: OBSERVATIONS AND RECOMMENDATIONS REGARDING DYNAMICALLY COMPACTED SAMPLES

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November 17, 1997

L. D. Hurtado MS 1322
Sandia National Laboratories
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Albuquerque, NM 87185

Subject: Observations and recommendations regarding dynamically compacted samples

Dear L. D.:

Introduction

On Friday November 14 I examined a compacted sample of WIPP crushed salt that had been prepared by RE/SPEC, Inc. The Scanning Electron Microscope at SDSM&T, Rapid City SD was used, as in previous observations discussed here. Because of its depth of field and very high magnification, SEM is used to characterize the minute fabric on surfaces of compacted crushed salt samples. The fabric comprising size, shape and arrangement of grains is important to reconsolidation processes. Because large-scale dynamic compaction is the specified construction technique for placing crushed salt in WIPP shafts, laboratory samples prepared for experiments should closely match the fabric of that produced by large-scale dynamic compaction. At this point, only 4 samples remain from the large-scale demonstration itself. The microscopic study summarized in this letter is primarily to assess how closely lab-prepared compaction samples match those created by large-scale dynamic compaction.

This letter characterizes the original fabric of three dynamically compacted samples. The original fabric is that which is created by the dynamic compaction process, before any further consolidation is imparted by laboratory experiments. The three compacted samples include one from the large-scale dynamic compaction demonstration, one from a well compacted 3-lift lab sample, and one from a new 10-lift lab sample, prepared by reduction of drop height. A fourth photograph shows the consolidated fabric of the fine-grained interface of the 3-lift sample. Multiple photomicrographs were shot of several distinct surfaces representing these three preparation techniques, but only one photomicrograph of each is shown here.

Descriptions of Substructures

Large-Scale Dynamic Compaction. (Photograph #0003). A heterogeneous gradation of fine particulate is seen . Grain boundaries are open. Grains produced during the large-scale dynamic compaction demonstration are abraded and rounded, rather than cleaved. Rounded, abraded larger (20-30 μm) grains and a significant population of fine grains (<10 μm) as seen in Photograph #0003 indicate physical abrasion occurs in large-scale dynamic compaction.

Three-Lift Lab-Prepared Sample. (Photograph #0001). Relatively uniformly sized (20-30 μm) cubic cleaved crystals comprise the ground mass. Grain boundaries are tighter than those produced by large-scale dynamic compaction, as can be seen by comparison to Photograph #0003. The density represented by the 3-lift sample is similar to that of the large-scale dynamically compacted sample, but the cubic cleaved grains indicate less abrasion than experienced by the large-scale sample. Fewer fine grains possessing diameters less than 10 μm are present in the 3-lift sample than found in the large-scale dynamic compaction sample.

Ten-Lift Lab-Prepared Sample. (Photograph #0014). Greater void space is apparent here than in the other two samples. Cubic shape is consistent with the 3-lift sample, indicating less abrasion for both lab techniques than experienced in large dynamic compaction. Fine grain size is about 10 μm, with "larger" grains about 20-30 μm (microns). More 10 μm grains are present and bonded, which perhaps results from the addition of 2 wt % water. Grains appear slightly "washed".

Three-Lift After Reconsolidation. (Photograph #0006). This particular photograph is taken from the "bulged" zone. That is, consolidation of the three lift sample was nonuniform and accentuated at the lift interface where grain size was visibly finer than the remainder of the sample volume. As can be seen, the grain size at the bulged interface is uniformly 20 μm. This is evidence that grain size of the original 3-lift sample as shown in Photograph #0001 is preserved. The microprocess of pressure solution/redeposition operates effectively on points of stress concentration, filling interstitial voids rapidly without greatly changing the original grain diameter. In addition, the consolidated fabric shown in Photograph #0006 is indistinguishable from the consolidated large-scale dynamic compaction substructure. The size and density of grains occupying the 3-lift interfaces are quite representative of the large scale dynamic compaction sample.

Discussion and Recommendations.

I recommend using the 3-lift, well compacted lab-prepared samples for further testing.

Reasons for this conclusion include the following:

1. The grain size in the fine grained interface zone is very similar to that of large-scale dynamic compaction. (about 20 μm), although the 3-lift sample lacks a population of grains from 1-3 μm.
2. Density of the 3-lift lab-prepared sample equals that of the large-scale dynamic compaction.
3. Consolidated substructures for the 3-lift samples and consolidated substructures of the large-scale dynamic compaction samples are similar (20 μm).

The bulged zones in the 3-lift samples represent accentuated deformation relative to the remainder of the sample. It was felt that the evident finer grains at the lift interface may influence results and representativeness of these experiments. Based on SEM observations, it appears that interface fines on the 3-lift samples are a close approximation to the large-scale dynamic samples because the density is the same and the grain size similar, although lacking some of the finer distributions.

Care should be exercised during addition of water to the 3-lift samples. Based on SEM observations, it appears that the lab samples, particularly the 10-lift sample, contain more water than the large-scale dynamically compacted sample. That is, the grains in the 10-lift sample are "washed" by the moisture. The water content should be monitored to be about 1.5 wt %.

If you have any problem interpreting these conclusions, please call me at 505-234-0066.

Sincerely,

F. D. Hansen

Copy to:
Mr. T. W. Pfeifle, RE/SPEC

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SWCF-C:1.1.03.2.1: DPRP1:SE:DES:QA:AG-4911,RE/SPEC, Task 17

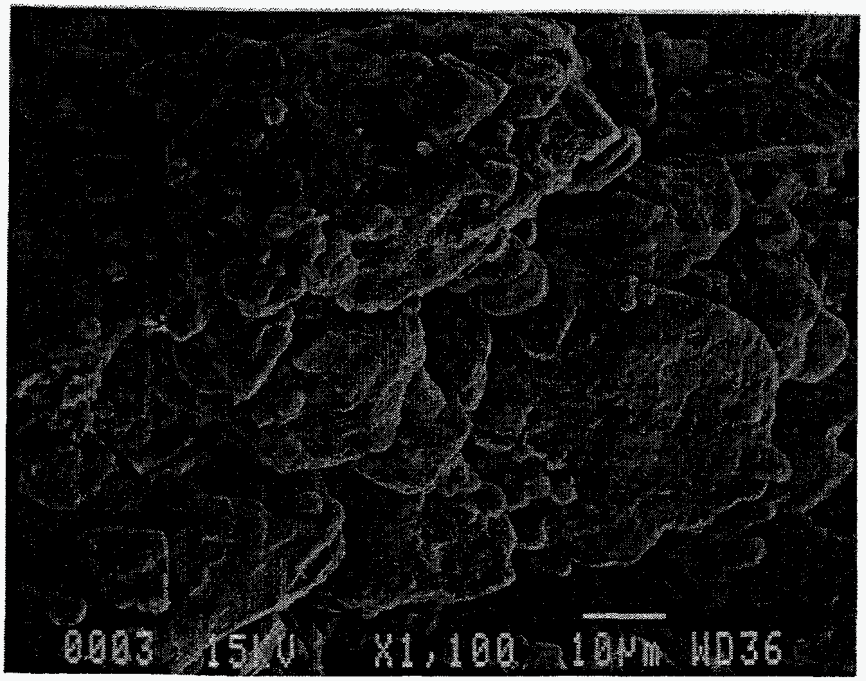

Figure A-1. Photograph #0003: Original fabric of large-scale dynamically compacted crushed salt.

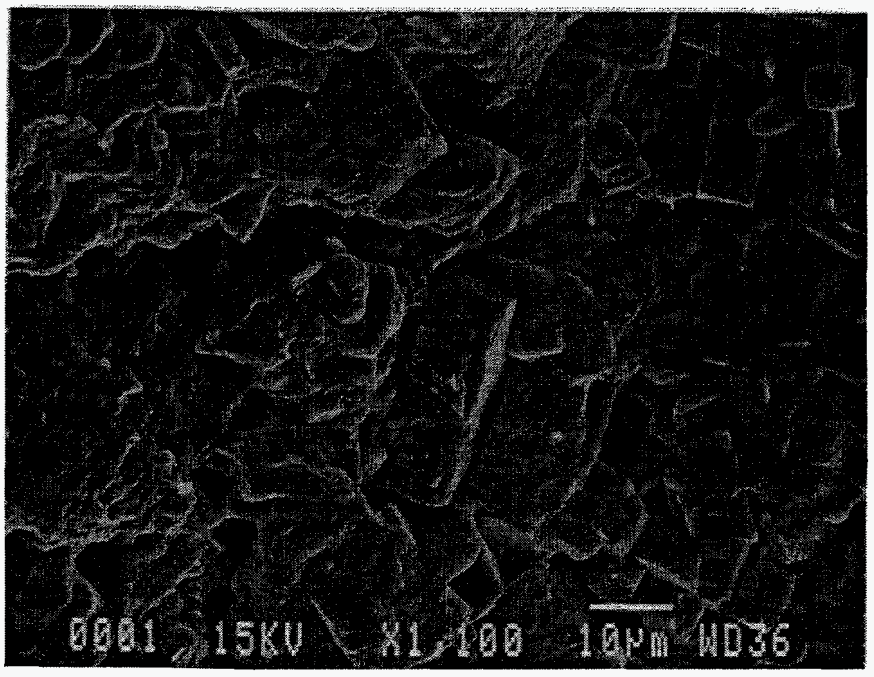

Figure A-2. Photograph #0001: Original fabric of three-lift, laboratory-prepared sample of crushed salt.

Figure A-3. Photograph #0014: Original fabric of ten-lift laboratory-prepared sample of crushed salt.

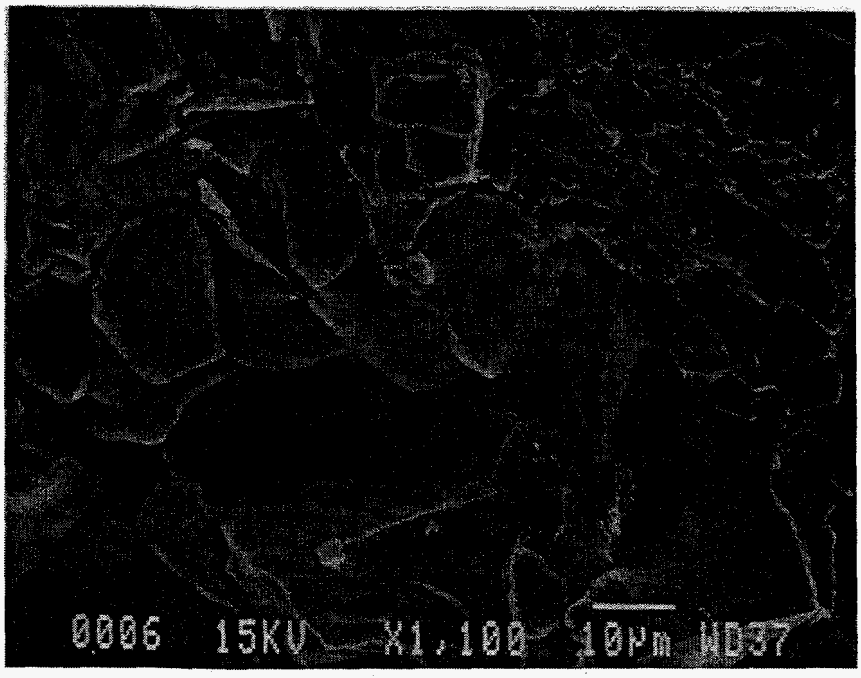

Figure A-4. Photograph #0006: Reconsolated three-lift sample on the fine grained interface.

APPENDIX B
MEMORANDUM TO F.D. HANSEN RE: PROGRESS REPORT FOR SANDIA NATIONAL LABORATORIES CONTRACT AA-2020 COVERING THE PERIOD SEPTEMBER 1, 1994 TO SEPTEMBER 30, 1994

RE/SPEC INC.
RESEARCH/SPECIALISTS

Rapid City, South Dakota • Albuquerque, New Mexico
Pierre, South Dakota • Minneapolis, Minnesota

External Memorandum

To: Sandia National Laboratories
Attn: Dr. Frank D. Hansen (6121)
P.O. Box 5800
Albuquerque, NM 87185-5800

cc: Mr. Gary Romero (10233)
Dr. Arlo F. Fossum (RE/SPEC Inc.)
Mr. Darrell K. Svalstad (RE/SPEC Inc.)
Mr. Tom W. Pfeifle (RE/SPEC Inc.)
Mr. Leo Van Sambeek (RE/SPEC Inc.)
Laboratory Staff
248C GR6.1

From: Dr. Nancy S. Brodsky NSB
RE/SPEC Inc.
P.O. Box 725
Rapid City, SD 57709

Date: October 12, 1994

Subject: Progress Report for Sandia National Laboratories Contract AA-2020 Covering the Period September 1, 1994 to September 30, 1994.

Project Administration and QA. Routine administrative and quality assurance activities were performed.

Permeability Tests. The previous progress report suggested that we had reached the upper detection limit for the manometer system that was used for gas permeability measurements. The gas flow rates measured for Specimens CS/DC1-4-1/3/1 and CS/DC2MM-2/1 were both near the maximum flow rate limit. Although the equivalent liquid permeability as determined using a Klinkenberg correction was reasonable for Specimen CS/DC1-4-1/3/1 (2.5×10^{-15} m^2), a negative value was obtained for Specimen CS/DC2MM-2/1. (The Klinkenberg correction is determined by performing a straight line fit to the permeability-versus-inverse mean gas pressure data. The permeability value determined at an inverse mean pressure of zero, i.e., at infinite pressure, is the equivalent liquid permeability or Klinkenberg-corrected permeability. The equivalent liquid permeability should be less than the gas permeability.)

The test system was reconfigured as described in the previous progress report and gas permeability measurements were made using flow meters. The system was checked for gas leaks using "Snoop," a commercially available clear liquid that is placed on all of the connection points to detect gas bubbles. A Klinkenberg correction could not be applied to these measurements because only a single value of gas inflow pressure could be used.

The gas permeabilities measured to date on dynamically compacted crushed salt are summarized in Table 1. Unfortunately, Specimen CS/DC1-4-1/3/1 had been epoxy-impregnated and sectioned and so its permeability could not be remeasured using the flow meter system. The permeability data are plotted in Figure 1 along with data given in Brodsky [1993][1]. There is no systematic difference between the permeabilities measured for the two different sample shipments even though they differed in moisture content (CS/DC2 specimens had 1 percent moisture added whereas CS/DC1 specimens did not). Based on relative permeability effects, the permeabilities of CS/DC2 specimens were expected to be lower than in CS/DC1 specimens. The gas permeabilities are above the projection of the straight-line fit to the brine permeability data by about 2 orders of magnitude. Barring relative permeability effects, one would expect gas permeabilities to be higher than brine permeabilities because of the Klinkenberg effect; however, for Specimen CS/DC1-4-1/3/1, the Klinkenberg correction changed the permeability value by less than a factor of 2.

Table 1. Summary of Permeability Measurements on Dynamically Compacted Crushed Salt Specimens

Specimen ID[(a)]	Fractional Density [(b)]	Permeability (m^2)	Measurement Method
CS/DC1-8-3	0.875	2.43×10^{-13}	Flowmeter
CS/DC1-4-1/3/1	0.913	2.50×10^{-15}	Manometer; Klinkenberg-corrected value
CS/DC2/MM-1/1	0.898	1.71×10^{-13}	Flowmeter
CS/DC2/MM-2/1	0.840	4.11×10^{-13}	Flowmeter
CS/DC2/T2S-1/1	0.882	5.71×10^{-13}	Flowmeter
CS/DC2/T2S-3/2	0.853	1.10×10^{-12}	Flowmeter

(a) CS = Crushed Salt; DC1 = Dynamically Compacted, First Shipment; DC2 = Dynamically Compacted, Second Shipment.

(b) Fractional density is based on an intact density of 2140 kg · m^{-3} and the specimen volume determined before permeability testing was initiated. The permeability tests were conducted at 1 MPa confining pressure and in some cases additional consolidation occurred during the test.

[1]**Brodsky, N. S., 1993.** *Hydrostatic and Shear Consolidation Tests With Permeability Measurements on Waste Isolation Pilot Plant Crushed Salt*, SAND93-7058, prepared by RE/SPEC Inc, Rapid City, SD, for Sandia National Laboratories, Albuquerque, NM.

As an additional check on the testing method, a steel specimen was placed in the pressure vessel after testing was completed and a "permeability test" was run. As expected, there was no detectable gas flow. While this does not ensure that there were no leaks in the system during testing that would have caused erroneously high permeability values, it does lend some reassurance.

Projected Activities for the Next Reporting Period. The Sandia Technical Representative (Dr. Frank Hansen) is planning to visit the RE/SPEC Rapid City facility during the next reporting period. The status of this work and future direction will be discussed at that time.

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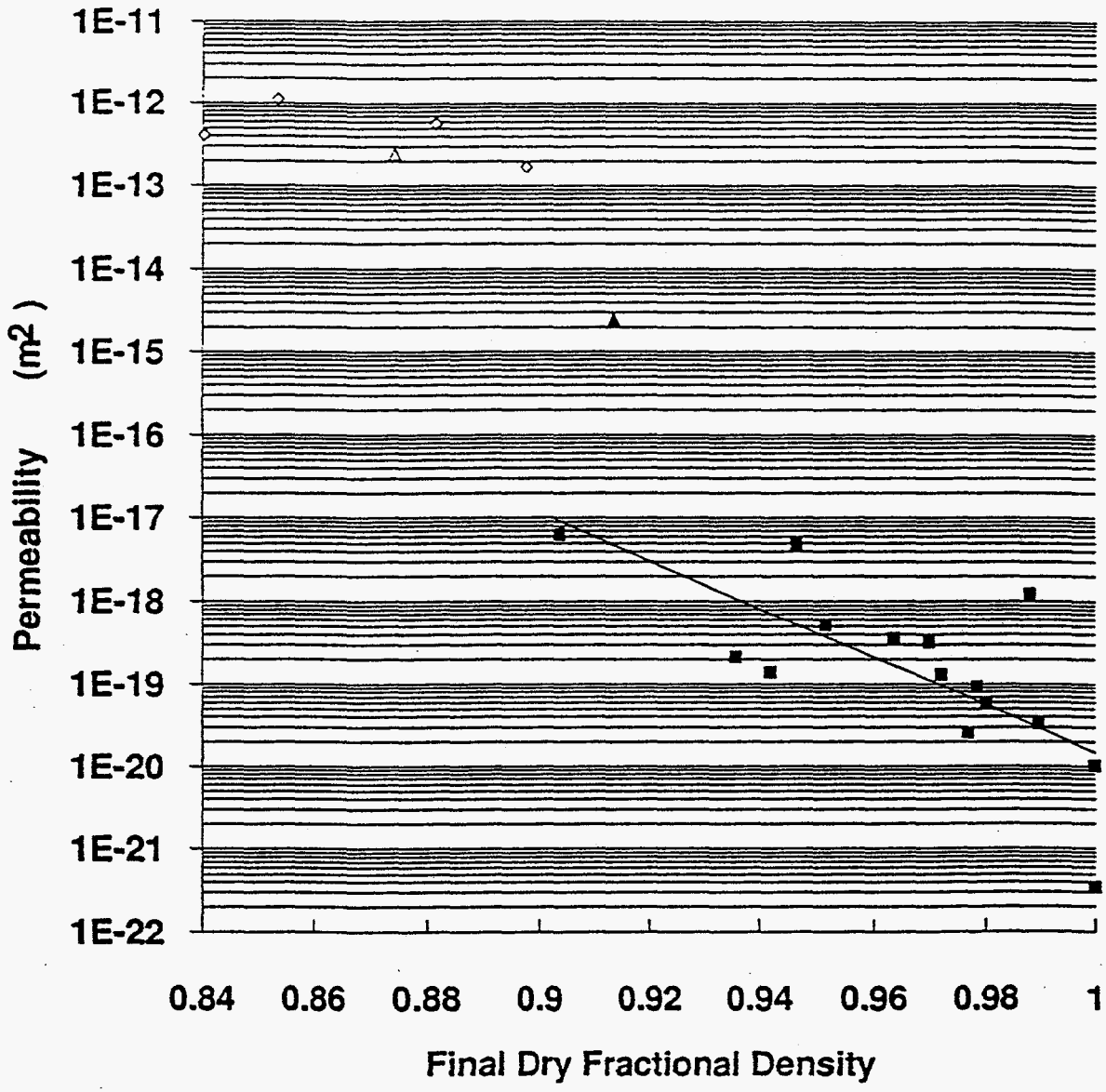

Figure 1. Permeability-versus-fractional density for crushed salt specimens. Solid squares represent brine permeability measurements given in Brodsky [1993] and a linear fit to that data is given. Triangles represent CS/DC1 specimens and diamonds represent CS/DC2 specimens. Unfilled symbols (diamonds and one triangle) indicate use of a flow meter and the solid triangle indicates use of a manometer and the application of a Klinkenberg correction.

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VENTILATION SYSTEM DESIGN FOR PANEL 9A AND PANEL 10A FOR THE UNDERGROUND VENTILATION SYSTEM AT THE WIPP FACILITY

Prepared For:

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Waste Isolation Pilot Plant
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DN-3590-01

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May 2011

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1. EXECUTIVE SUMMARY

Mine Ventilation Services, Inc. (MVS) was contracted by Washington TRU Solutions, LLC (WTS) to evaluate the ventilation system at the Waste Isolation Pilot Plant (WIPP) for various configurations to support the mining of new proposed Panels 9A and 10A. These panels are to be added south of Panels 4 and 5. Several alternatives were also investigated in order to evaluate possible systems should the E-140 drift be impassable because of ground control work. In addition, alternatives were investigated to use the W-30 drift for disposal transporter movement and E-140 for construction equipment movement. Three alternatives were studied when mining is initiated towards Panel 9A and emplacement is occurring in Panel 7 with Panel 8 having been certified. Three more alternatives were investigated when Panel 10A is under construction and emplacement is occurring in Panels 8 and 9A.

The results of the modeling showed that every scenario analyzed could be successfully ventilated to the criteria given in Section 3. A series of doors, regulators and auxiliary duct with fans are required to control the airflow throughout the facility. This infrastructure and airflow distribution values are described in detail in Sections 4 through 9. Section 10 compares the results of each system studied.

MVS engineers also analyzed the shift to filtration capabilities and concluded with the design as presented in this report. All configurations could be successfully shifted to filtration by the closing of strategic doors and regulators and the conversion of the surface 700 fans to a single 860 fan in filtration mode.

A description of ventilation related structures and recommended monitoring systems are also discussed in Section 10.

2. INTRODUCTION

This report describes the ventilation designs generated to investigate methods of providing airflow to mine Panels 9A and 10A. These panels are to be added south of Panels 4 and 5. The models investigate mining strategies developed by WTS engineers. These strategies include concepts to provide air for disposal in Panels 7 and 8 while initiating mining for Panels 9A and 10A and disposal in Panel 8 and 9A while developing Panel 10A. In addition to these goals, a further constraint was given if the main disposal intake, E-140, is not available for equipment movement because of major ground control work (e.g. the installation of additional support resulting in blocking equipment movement, but not airflow).

In most of these scenarios, the transport of TRU waste will travel through an area that is used as an intake for the construction circuit. It is MVS' understanding that a permit change has been granted to allow this to occur. The disposal transporter will either need to cross a construction intake drift, or will be in a common intake to both the disposal and construction air splits, depending on the scenario investigated.

MVS did not include in this design those infrastructure components needed to support the W-30 alternate waste transportation route prior to the inclusion of the 9A and 10A panels (e.g. the proposed doors in W-30 between S-600 and S-700 and the regulator in S-700 between W-170 and W-30).

2.1 DESCRIPTION OF THE VENTILATION SYSTEM

Ventilation of the underground facility at WIPP is accomplished with four main ventilation splits: the north split, the construction split, the waste disposal split, and the waste shaft station split. In order to minimize occupational exposure of underground personnel to radiation and radioactive materials, the facility is designed and constructed based on the "As Low As Reasonably Achievable" (ALARA) concept. This concept resulted in a design where the nuclear waste transportation and disposal areas are separated from the mining and non-radioactive experimental areas. The ventilation system is also designed such that air leakage is from the mining and north areas into the waste disposal areas. Furthermore, radiation detectors are strategically located in the underground, and a contingent exhaust filtration system is installed on surface to minimize the effects of an unlikely release of radioactive material to the environment.

The underground facility is accessed and ventilated through four vertical shafts, three of which supply intake air, with the fourth acting as a common exhaust. Ventilation of the facility is provided by running either one or two of the three 600 hp centrifugal main fans (700A, 700B and 700C).

During concurrent mining and disposal operations, two of the main fans operate in parallel (Normal Ventilation Mode) to provide a minimum of 425,000 scfm (standard cubic feet of air per minute at a density of 0.075 lb/ft^3). In the unlikely event of an underground radioactive material release, the ventilation system is shifted to Filtration Mode. In Filtration Mode, the underground airflow is reduced to approximately 60,000 scfm. This is achieved by de-energizing all 600 hp fan(s) in operation and starting one of three 235 hp centrifugal filtration fans (860A, 860B, or 860C). Isolation dampers open and close to divert the air through the High Efficiency Particulate Air (HEPA) filters.

For normal operation the direction of the pressure differential between the mining and waste disposal systems is from the mining circuit to the waste disposal circuit. A pressure difference less than 2.00 in. w.g. and greater than 0.05 in. w.g. in the correct direction is desired between these systems. The waste shaft is kept as a low flow, downcast shaft. The negative pressure developed across the head frame should not exceed -1.8 in. w.g. during normal operation. However, because of the system-fans in BH 309, the operating pressure-range of the waste tower can be reduced to between -0.3 and -1.6 in. w.g. by opening the AAIT louvers (located in Building 465 on surface). By reducing the tower pressure an increased pressure drop is realized on BH 308.

Figure 1 shows the underground facility infrastructure with shops, bulkheads, shafts, doors and regulators locations. To meet the airflow criteria established for this study, MVS engineers modified some of the infrastructure. These modifications are also shown on this figure. Figure 2 shows the surface fan configuration.

2.2 OBJECTIVE

The objective of this study is to develop a series of models to simulate the ventilation of Panel 9A and Panel 10A. This report will include analyses, results and the viability of the six ventilation configurations required.

2.3 SCOPE OF STUDY

- Develop network models representing the B-1, B-2A, B-2B, B-3, B-4A, and B-4B ventilation configurations.
- Compare and contrast the ventilation related benefits and potential issues for each ventilation configuration and determine the system viability.
- Evaluate one scenario during a shift to filtration to validate the concept.
- Ensure that each model and ventilation layout is checked for accuracy and all calculations and reports are developed in accordance with the Project Quality Assurance Manual (PQAM) for Providing Technical Services Related to the Underground Ventilation System at the Waste Isolation Pilot Plant (WIPP) Project.
- Prepare a detailed report on the results of the ventilation modeling.

2.4 PROCEDURES

The procedures and quality assurance requirements for this project are described in detail in the MVS documents; “Project Quality Assurance Manual (PQAM) For Providing Technical Services Related to the Underground Ventilation System at the Waste Isolation Pilot Plant (WIPP) Project” (Rev. 5 dated August 2009), and in the “Quality Assurance Manual for Mine Ventilation Services, Inc.” (Rev. 5 dated August 2009).

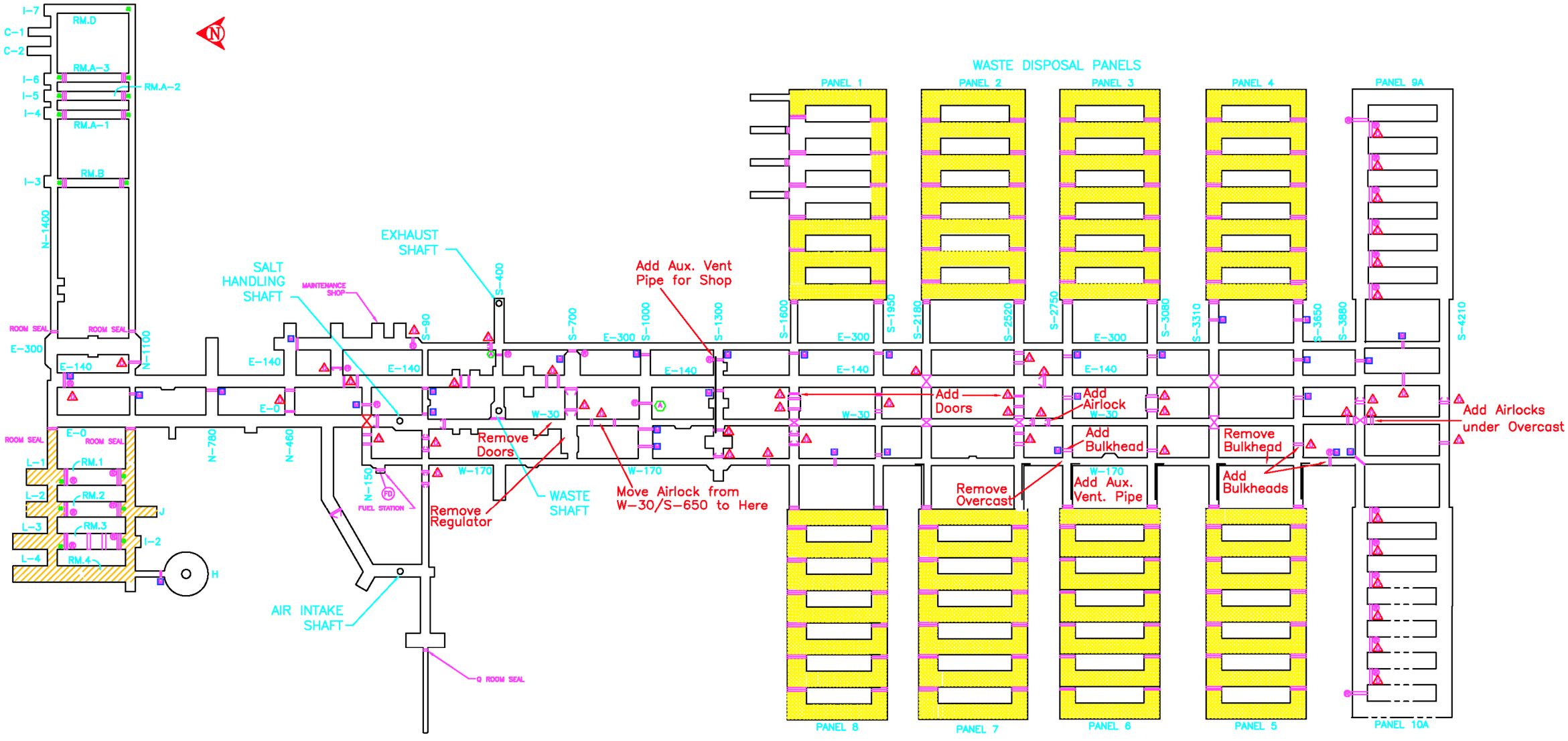

Figure 1: Underground Facility Infrastructure Including Shop Locations, Door and Regulator Locations, and Main Shafts. Modifications to Infrastructure are also shown.

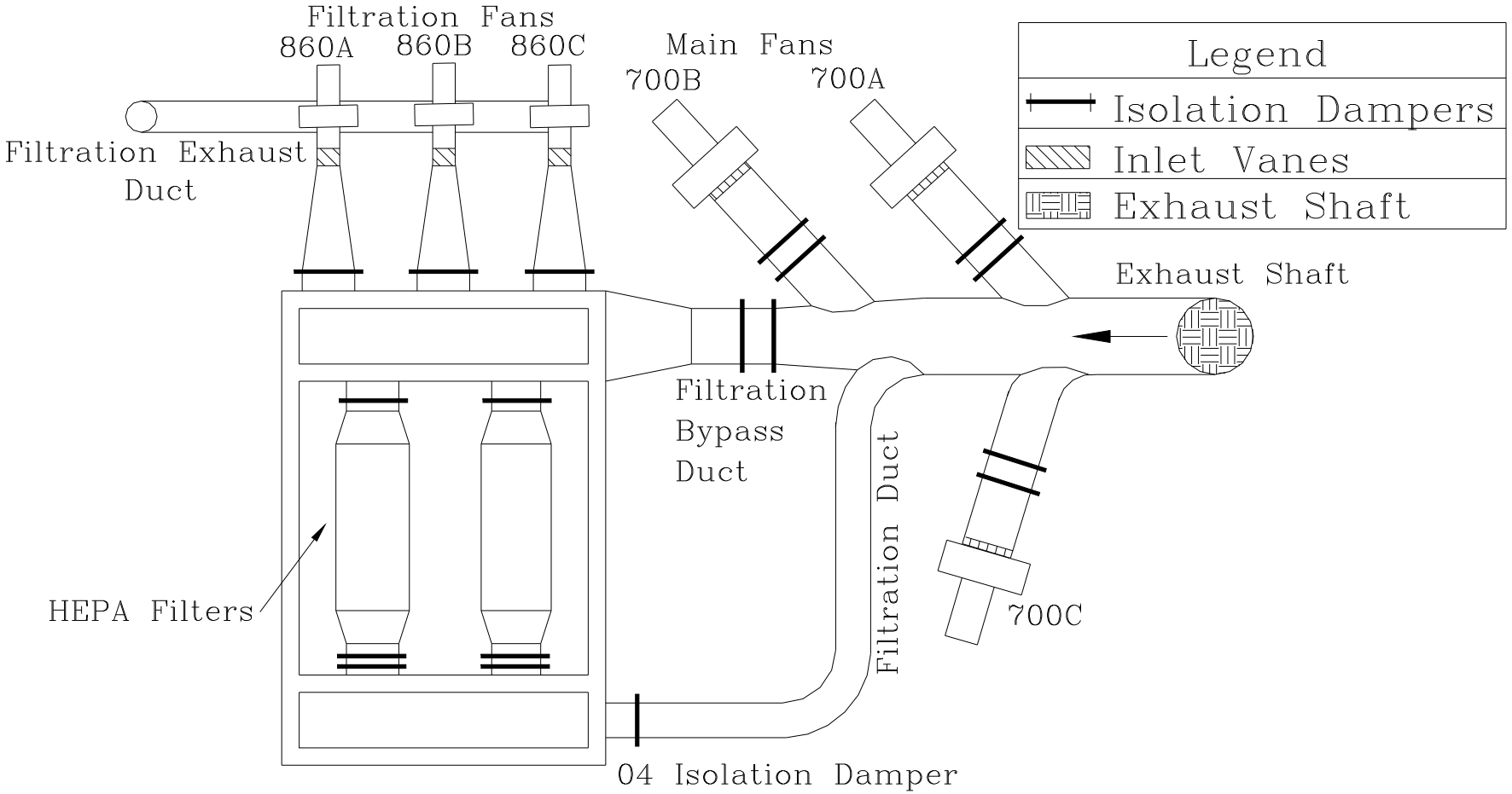

Figure 2: Main Surface Fan Configuration. (Not to Scale)

3. DESIGN CRITERIA

The scenarios described in this report are based on the Normal Mode model developed from the testing and balance conducted in 2010. The basis of the design includes the concept that all air leakage was to be maintained from the construction circuit to the waste handling circuit. In addition, the system must successfully shift to filtration. In this regard, MVS adopted the philosophy that a shift to filtration must include all disposal panels with accessible waste and all air leakage must be from the construction to the waste handling circuits.

Modifications to the E-300, which include the removal of overcast and slashing of the drift, are incorporated in the ventilation base model. This is critical to the success of the system, as the current bulkheads and E-300 are inadequate to control leakage from E-140 to E-300.

Where feasible, MVS worked with the infrastructure currently in the facility. However, because the W-170 drift is not used as a construction air return split, all air from the construction area will be exhausted to E-300. MVS was instructed that the E-300 will be mined to 16 ft x 15 ft from S-2180 to S-3310 and at 16 ft x 13 ft from S-2180 to S-400. In addition, all bulkheads between E-140 and E-300 will be rebuilt with bulkheads with mandoors only (except at S-2520 where an automated drive through airlock will be established). These changes will result in much better leakage control from E-140 to E-300. The modeled systems in this report will only work if these changes are done.

For design scenarios B-1, B-2A, and B-2B Panel 7 has two disposal rooms open while Panel 8 is ready for disposal with room 7 actively ventilated for this purpose. The construction circuit is assumed to have mined the mains towards S-4210 and is preparing to mine the entries to Panel 9A. For scenarios B-3, B-4A and B-4B, active disposal is being completed in one room of Panel 8 with two rooms available in Panel 9A. Panel 10A is under construction with one room mined. The difference in the scenarios for the same layouts deals with the whether the disposal transporter has access to E-140. Most of the scenarios assume the disposal transporter traveling in W-30 while the haulage trucks haul in E-140. Some of the scenarios assume that E-140 will be having major ground support requirements that result in no passing of vehicles, although airflow can pass by this construction area. If E-140 is closed to disposal and/or haulage truck transportation, then W-30 must be available for this purpose.

In the initial information provided to MVS, Washington TRU Solution engineers showed a set of doors in W-30 at S-650 and a regulator in S-700 at W-80. In analyzing all scenarios for this study, MVS concluded that these structures are not required. These structures would have been necessary if Panels 9A and 10A were not to be mined and W-30 was to be used as an alternative disposal route. In addition to these changes, MVS engineers added infrastructure to control airflow to strategic areas in the facility. These additions are described in each scenario. Additional changes to the original infrastructure suggested by MVS engineers includes removing the overcast at S-2750 and W-170, installing a regulator in W-170 at S-2600, removing the bulkhead in W-170 at S-3500 and adding bulkheads at S-3650 and W-140 and in W-170 at S-3700. In addition the S-1300 shop had a 36 inch duct installed to carry air from the shop to E-300 exhaust.

A resistance to airflow is computed for each branch in the ventilation network schematic. Based on previous testing and balance ventilation surveys conducted at the WIPP facility a measure friction factor of 40 lbf min^2/ft^4 x 10^{-10} was determined. Branch resistances are computed using the Atkinson's equation, as given in Equation 1, with Table 1 listing the various resistance values for ventilation controls modeled.

Equation 1: $$R = \frac{k\,(L + L_e)\,P_{er}}{52\,A^3}$$

Where:
- k = friction factor (lbf min^2/ft^4 x 10^{10})
- L = length of airway (ft)
- L_e = equivalent length of shock loss (ft)
- P_{er} = perimeter of airway (ft)
- A = cross-sectional area (ft^2)

Table 2 lists the height, width, area and perimeter for various airway dimensions at the WIPP facility used for the design scenarios projections. For these analyses, WIPP personnel provided new entry dimensions for the E-300. The entry dimensions and locations used in the analyses are listed Table 3. Table 4 lists the Panels 9A and 10A design target airflow quantities for the underground WIPP facility.

Table 1: Ventilation Control Resistances

Description	Resistance (PU)
Single Overcast Installation	0.0112
Future Emplacement Panel Regulator (closed)	100
Brattice/Curtain	2
Bulkhead	500
Vehicle Airlock Doors	25
Sealed Brattice	25
Panel Room Regulators (fully open)	0.0785

Table 2: Airway Drift Dimensions for Various Airways at the WIPP Underground Facility

Location	Height (ft)	Width (ft)	Area (ft^2)	Perimeter (ft)
W-170	11.8	15.5	182.9	54.6
W-30	13.0	15.5	201.5	57.0
E-140	15.4	26.0	400.4	82.8
Panel Rooms	15.6	33.6	524.2	98.4
Panel Access Drifts - Intake	15.0	20.0	300.0	70.0
Panel Access Drifts - Return	12.5	14.5	181.3	54.0

Table 3: E300 Newly Mined Airway Dimensions at the WIPP Underground Facility (WIPP)

Location	Height (ft)	Width (ft)	Area (ft^2)	Perimeter (ft)
E300: S2180 to S3310	16.0	15.0	240.0	62.0
E300: S2180 to S400	16.0	13.0	208.0	58.0

Table 4: Design Target Airflow Quantities for WIPP Panels 9A and 10A

Description	Quantity (kcfm)
Panel Room 1	43
Panel Room 2	43
Panel Room 3	43
Fuel Bay	20
S-1300 Shop	15
Construction Split Regulator	50
North Experimental Regulator	60
North Shop	55
Waste Handling Shaft Station	50 to 65

For bulkheads simulated with vehicle doors open an equivalent length of 50 ft is added to incorporate shock losses attributed to the vehicle doors open. For the simulations, the 700 A and 700 C fans are used for modeling. These fans are used to be conservative because 700 C has a lower operating point. This assumption allows the WIPP facility with the option to utilize any combination of two of the three fans for normal operations. For each of the six configurations specific design assumptions are identified. The design assumptions for each of the six configurations are identified in Sections 4 through 9.

4. VENTILATION CONFIGURATION: B-1

Scenario B-1 shows the alternative where Panel 7 and Panel 8 are available for disposal. Construction is occurring in the mains driving them south to S-4210. The basic layout keeps the ventilation circuits similar to the current system where disposal intake is in E-140 and construction intake is in W-30. For this scenario the transporter crosses the construction intake W-30 at either S-1600 or S-2520.

Figure 3 illustrates the underground facility infrastructure for the B-1 configuration provided to MVS by WTS engineers and the primary disposal and truck haulage routes.

4.1 DESIGN CRITERIA AND ASSUMPTIONS

The following lists assumptions and modifications that were specified for the B-1 configuration to be incorporated into the ventilation system design:

- Waste disposal is taking place in Panel 7 with Panel 8 having been certified.
- Mining/Construction is taking place at the southern end of the mains. The mains are being extended to accommodate two more panels (Panel 9A and Panel 10A).
- The waste disposal transportation route is as follows (E-140 not blocked by repair work):
  - Waste Shaft to S-400/E-140
  - South in E-140 to S-1600 (P8) or S-2520 (P7)
  - West in either S-1600 or S-2520 to the open disposal room
- The mining transportation route is as follows:
  - Empty trucks from Salt Handling Shaft (SHS) south in W-30 to the mining face (southern mains)
  - Loaded trucks north in W-30 from the mining face (southern mains) to the SHS
- The mine has been configured as follows:
  - The 402/403 airlock at S-90/W-200 is open.
  - The 305/306 airlock at S-90/W-140 is open.
  - The 302 regulator is set for 20,000 cfm. This allows ventilation of the diesel fueling station.
  - An overcast with airlocks on the east and west side (under the overcast) is located at S-1600/W-30. This overcast allows the disposal circuit air from E-140 to travel across W-30 without mixing with the construction circuit air. The airlocks allow the waste transporter to cross W-30 and access Panel 8 (transporter is temporarily in the construction circuit when traveling through the W-30/S-1600 intersection).

- An isolation door is located in the S-1600/E-100 cross-cut. This door is open for this scenario. This door is installed in the event the disposal route is moved to W-30.
- An overcast with airlocks on the east and west side (under the overcast) is located at S-2520/W-30. This overcast allows the disposal circuit air from E-140 to travel across W-30 without mixing with the construction circuit air. The airlocks allow the waste transporter to cross W-30 and access Panel 7 (transporter is temporarily in the construction circuit when traveling through the W-30/S-1600 intersection).
- An isolation door is located in the S-2520/E-100 cross-cut. This door is open for this scenario. This door is installed in the event the disposal route is moved to W-30.
- An overcast is installed at S-3310/W-30. This overcast exhausts air from the block walls of Panels 5 and 6 to the exhaust at E-300 without mixing with the construction circuit. This area will be ventilated via a regulator in W-170 at S-2600 to take 15 kcfm from the disposal intake to the overcast. Auxiliary ventilation systems will pass approximately 10,000 cfm per face to the seals in S3310 and S3080. The design assumes series ventilation to each seal. Ventilating the block walls will dilute and VOCs emitting from behind the seals.
- The construction split regulator is located in E-300 between S-3650 and S-3310.
- A bulkhead with vehicle doors is located at E-140/S-2600. For this scenario these doors are closed.
- An airlock with vehicle doors is located at W-30/S-2600. For this scenario these doors are open.
- The bulkhead in S-2750 at E-50 is temporarily removed to allow construction air to enter from W-30 to E-140.
- An airlock is installed in W-30 at S-800. For this scenario, the airlock is kept open, but will be closed in the event the disposal route is moved to W-30.

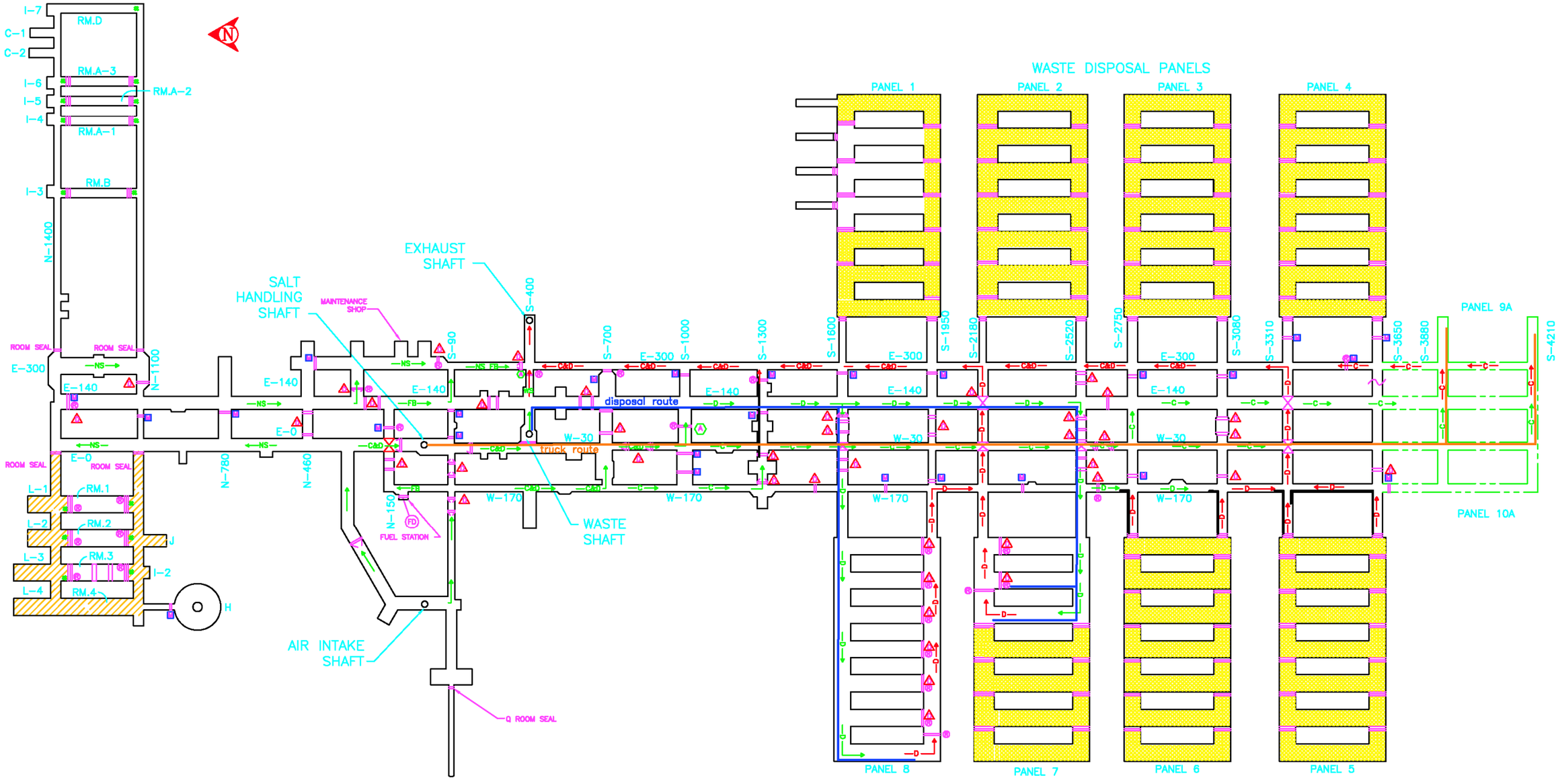

Figure 3: Underground Facility Infrastructure Locations and Primary Disposal and Truck Haulage Routes for the B-1 Ventilation Configuration

4.2 B-1 VENTILATION SCENARIO RESULTS

The results of the B-1 ventilation analyses showed that all airflow criteria could be achieved. The basic flow routes with strategic predicted airflows are shown on Figure 4. This alternative assumed 700C is operating with 700A. Both were set at maximum flow. The natural ventilation pressures were maintained as those calculated during the 2010 Test and Balance.

A total volume of 20,000 cfm is passing through BH-302 to provide air for the diesel fuel bay. A total of 55,000 cfm is exhausting the construction circuit. With leakage, the flow to this zone is closer to 70,000 cfm (the sum of the intake air in W-30 and E-140 south of S-2750). The North zone is ventilated with 55,000 cfm and the Waste Shaft Station at 67,000 cfm. All leakage is from the construction circuit to the disposal circuit. From S-2750 to S-4210, the air can course through both the E-140 and W-30 drifts to the mining area. Localized control of the air can be achieved by opening bulkheads between W-30 and E-140 or use of curtains.

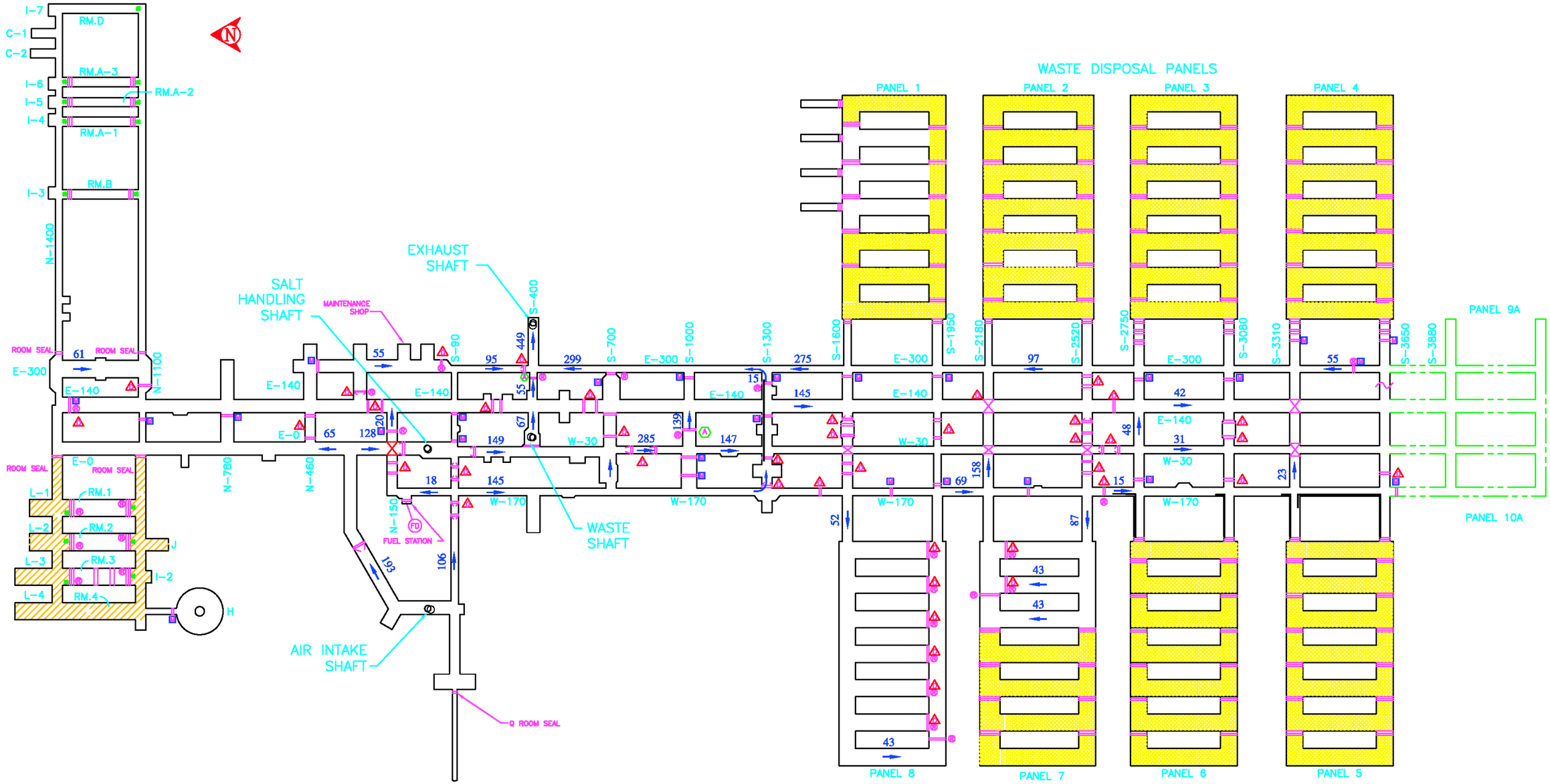

Figure 4: Results of Ventilation Modeling for Scenario B-1 with Predicted Airflow Distribution (kcfm).

5. VENTILATION CONFIGURATION: B-2A

Configuration B-2A is similar to configuration B-1, except the disposal airflow is routed to W-30 instead of E-140. Construction air and vehicles move in E-140 for this scenario (it is not blocked by repair work). For this configuration, the airlock doors in S-700 between W-30 and E-140 are opened and the airlock doors in W-30 between S-700 and S-1000 are closed. The isolation doors in S-1600/E-100 and S-2520/E-100 are closed.

5.1 DESIGN CRITERIA AND ASSUMPTIONS

The design criteria described in Section 4.1 is identical to the B-1 configuration except as follows:

- The waste disposal transportation route is as follows:
  - Waste Shaft to S400/E140
  - South in E140 to S700
  - West in S-700 to W30
  - South in W-30 to either S1600 or S2520
  - West in either S1600 or S2520 to the open disposal room
- The mining transportation route is as follows (E-140 is not blocked by repair work):
  - Empty trucks from SHS south in W-30 to S-700
  - East in S-700 to E-140
  - South in E-140 to the mining face
  - Loaded return along the same route to the SHS
- The mine has been reconfigured to accommodate the W-30 Alternative Waste Disposal Route.
  - Airflow is routed to E-140 then through Bulkhead 313 to supply air to the disposal circuit.
  - The airlock doors in S-700 between W-30 and E0140 are opened.
  - The airlock doors in W-30 between S-700 and S-1000 are closed
  - An isolation door is located in the S-1600/E-100 cross-cut. This door is closed for this scenario.
  - An isolation door is located in the S-2520/E-100 cross-cut. This door is closed in this scenario.
  - An overcast with airlock doors on the east and west side (under the overcast) is located at S-1600/W-30. For this scenario the doors of the west airlock are open.
  - An overcast with airlock doors on the east and west side (under the overcast) is located at S-2520/W-30. For this scenario the doors of the west airlock are open.

- An airlock with vehicle doors is located at W-30/S-2600. For this scenario these doors are closed.
- An airlock with vehicle door is located at E-140/S-2600. For this scenario these doors are open.

5.1 B-2A VENTILATION SCENARIO RESULTS

MVS was successful in achieving all ventilation criteria for this scenario. The basic ventilation design configuration with primary transportation routes is shown on Figure 5. Figure 6 shows the predicted airflow distribution for this scenario.

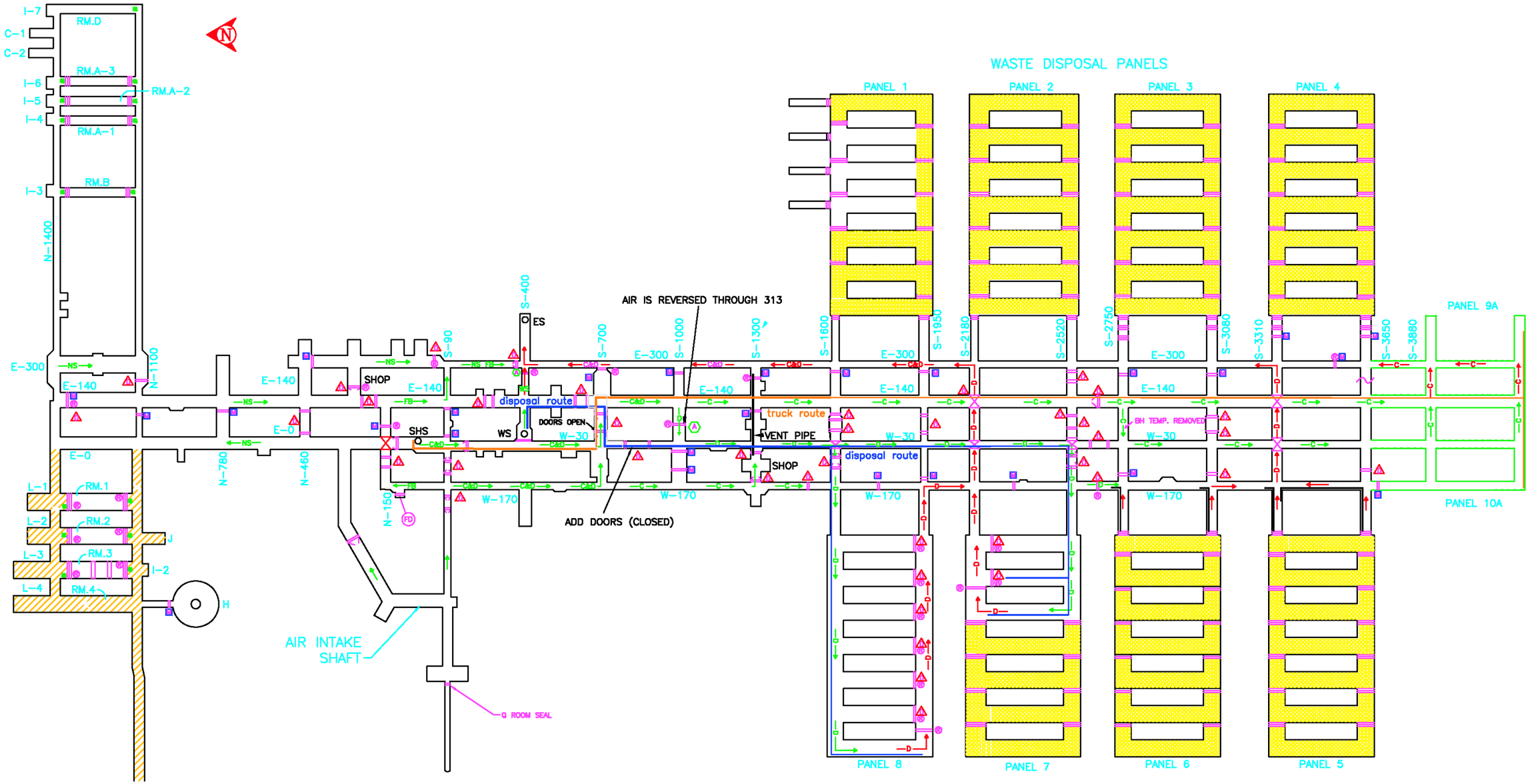

Figure 5: Ventilation Configuration for Option B-2A including Main Transportation Routes.

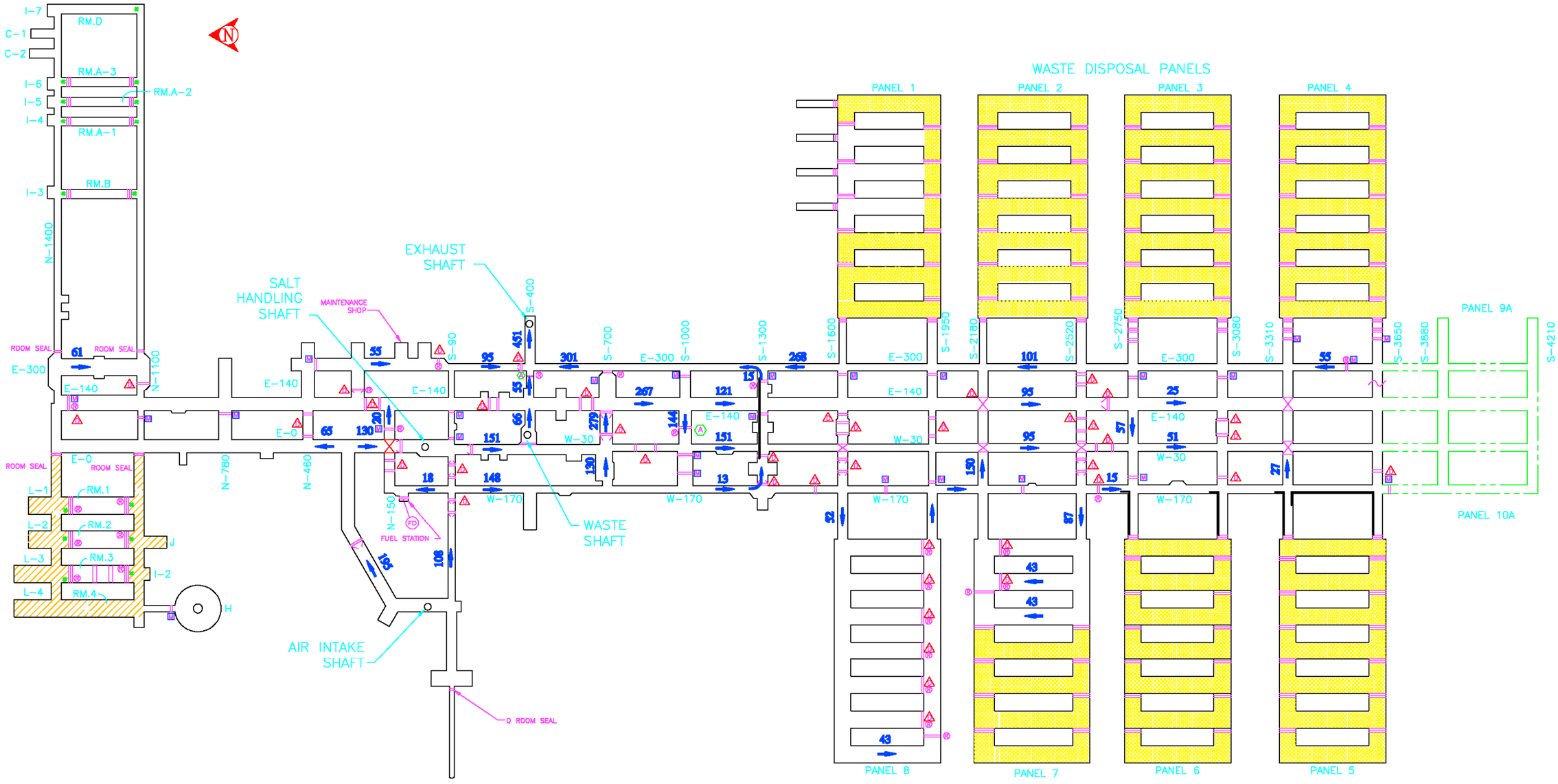

Figure 6: Predicted Airflow Distribution for B-2A Ventilation Configuration (kcfm).

6. VENTILATION CONFIGURATION: B-2B

Configuration B-2B is identical to B-2A except that E-140 is closed to vehicle traffic and all mining vehicles must route through W-30.

6.1 DESIGN CRITERIA AND ASSUMPTIONS

The design criteria are identical to the B-2A configuration except as follows:

- The mining transportation route is as follows (E140 is blocked by repair work):
  - Empty trucks from SHS south in W-30 to the mining face. Optional truck routes can be through the doors located at S-1950 and S-2520 around the repair work area.
  - Loaded return along the same route to the SHS

6.2 B-2B VENTILATION SCENARIO RESULTS

MVS was successful in achieving all ventilation criteria for this scenario. This basic ventilation design configuration and primary transportation routes are shown Figure 7.

The modeling results for the airflow distribution for scenario B-2B are identical to the scenario B-2A. The only difference is the truck haulage routing from the mining area. Figure 6 illustrates the predicted airflow distribution for this scenario. The results show that all criteria are achieved.

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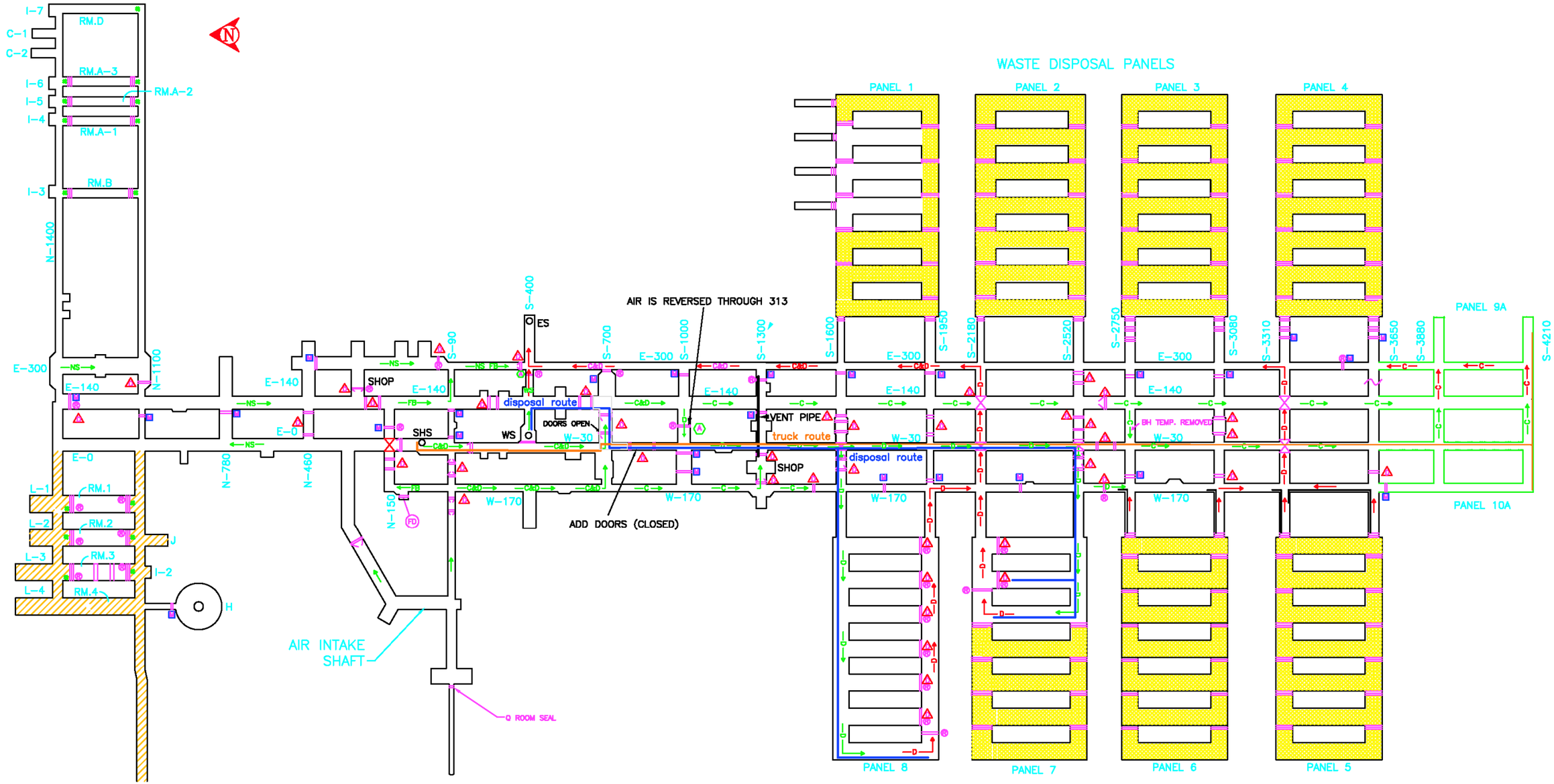

Figure 7: Ventilation Configuration for Option B-2B including Main Transportation Routes.

7. VENTILATION CONFIGURATION: B-3

Configuration B-3 is the base case for mining in Panel 10A while emplacing operations are in Panel 8 and Panel 9A. For this scenario, the transporter will need to cross W-30 at S-1600 in order to reach Panel 8.

This alternative assumed 700C is operating with 700A. Both were set at maximum flow. The natural ventilation pressures were maintained as those calculated during the 2010 Test and Balance.

7.1 DESIGN CRITERIA AND ASSUMPTIONS

The criteria and assumptions used for the B-1 configuration are used for the B-3 configuration with the following exceptions:

- Waste disposal is taking place in Panel 8 and Panel 9A.
- Mining/Construction is taking place in Panel 10A.
- The waste disposal transportation route is as follows (E-140 is not blocked by repair work):
  - Waste Shaft to S-400/E-140
  - South in E-140 to S-1600 or S-4210
  - West in S-1600 to P8 or east in S-4210 to Panel 9A
- The mining transportation route is as follows:
  - Empty trucks from SHS south in W-30 to the mining face (Panel 10A)
  - Loaded return along the same route (W-30) to the SHS.
- Other changes to the system include:
  - Move the construction split regulator to W-170/S-3700.
  - Remove the regulator at W-170/S-2600.
  - The air doors installed at S-2520/E-100 are closed for this scenario.
  - A bulkhead with vehicle doors is located at E-140/S-2600. For this scenario these doors are open (if no other scenarios are considered, then this bulkhead could be removed).
  - Install a diagonal brattice bulkhead at the W-170/S-3880 intersection
  - Install an overcast at W-30/S-3880 with double airlock doors underneath the overcast. For this scenario the double doors are open.
  - Install air door at E-140/S-4000. For this scenario this doors is open.
  - Install air doors at S-3880/E-100 and S-4210/E-100. For this scenario these doors are closed.

- Install air door at S-4210/W-100. For this scenario the doors are closed.
- Install panel room regulators.

Figure 8 illustrates the underground facility infrastructure locations for the B-3 ventilation configuration. This figure also shows the primary vehicle transportation routes.

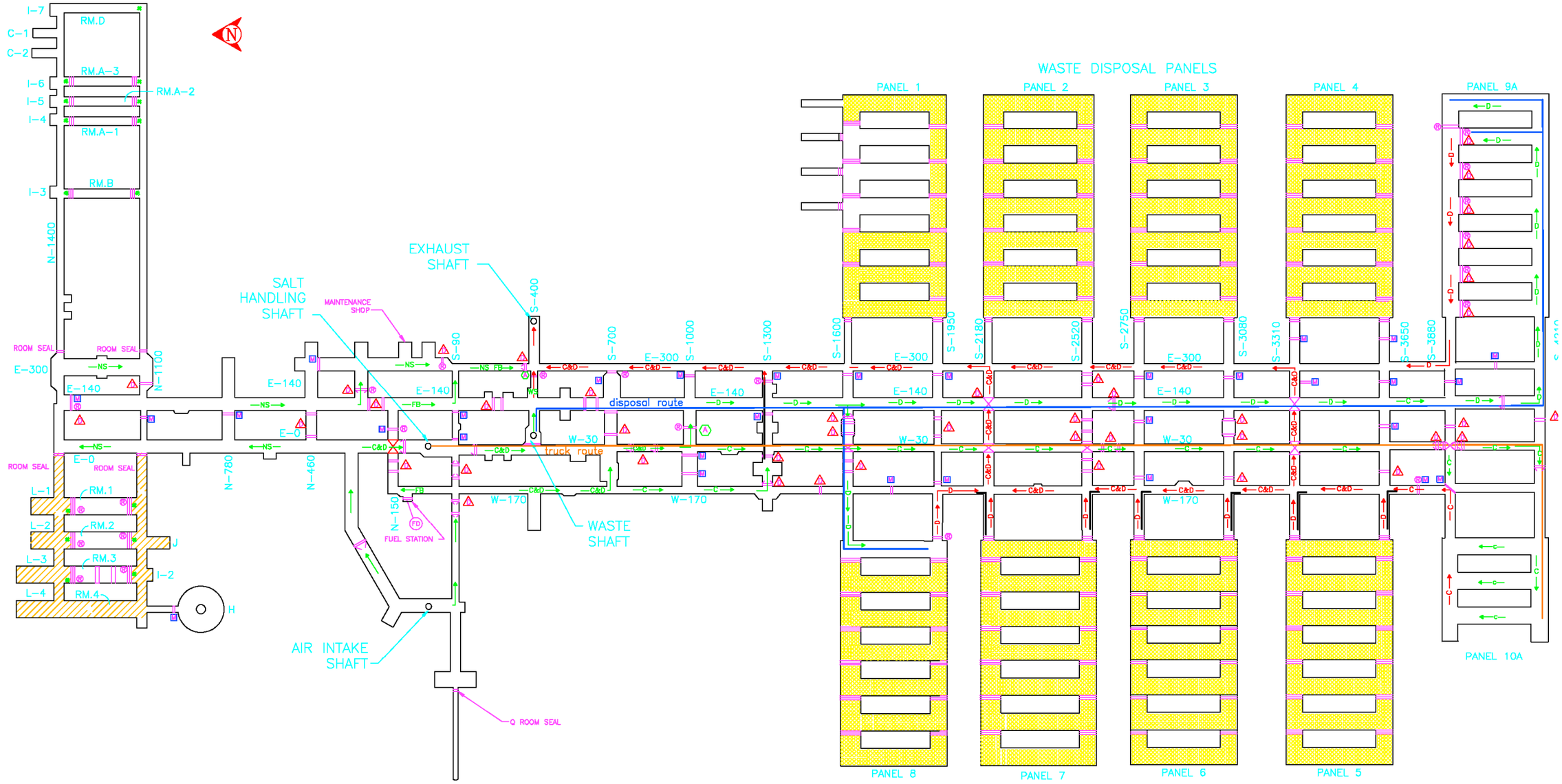

Figure 8: Underground Facility Infrastructure Locations and Primary Disposal and Truck Haulage Routes for the B-3 Ventilation Configuration.

7.2 B-3 VENTILATION SCENARIO RESULTS

The results of the B-3 ventilation analyses showed that all airflow criteria could be achieved. This alternative assumed 700C and 700A are both operating. Both were set at maximum flow. The natural ventilation pressures were maintained as those calculated during the 2010 Test and Balance.

A total volume of 20,000 cfm is passing through BH-302 to provide air for the diesel fuel bay. A total of 80,000 cfm is exhausting the construction circuit. With leakage, the construction flow to this zone is closer to 90,000 cfm. The North Shop is ventilated with 55,000 cfm and the Waste Shaft Station is over 60,000 cfm. All leakage is from the construction circuit to the disposal circuit. Figure 9 shows the predicted airflow distribution for this scenario.

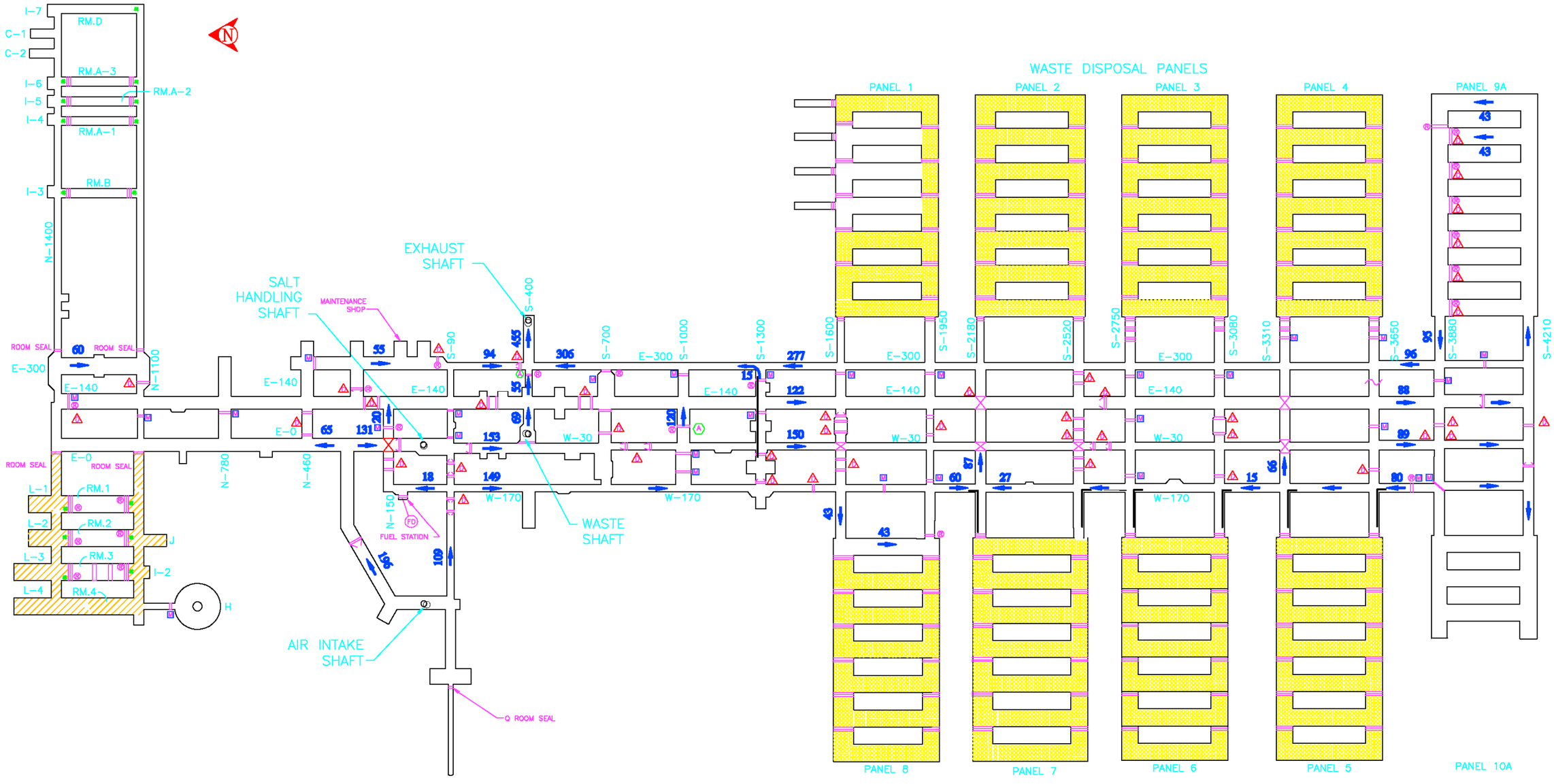

Figure 9: Predicted Airflow Distribution for Configuration B-3 (kcfm).

8. VENTILATION CONFIGURATION: B-4A

Configuration B-4A is similar to configuration B-3, except the disposal airflow is routed to W-30 instead of E-140. Construction air and vehicles move in E-140 for this scenario (it is not blocked by repair work). For this configuration, the doors in S-700 between W-30 and E-140 are opened and the doors in W-30 between S-700 and S-1000 are closed. The isolation doors in S-1600/E-100 are opened. In addition, the airlock doors under the overcast at W-30/S-3880 are closed as well as the door at S-4210/W-100 and E-140/S-4000. Doors are opened at S-3880/E100 and S-4210/E-100.

8.1 DESIGN CRITERIA AND ASSUMPTIONS

The design criteria described in Section 7.14.1 are identical to the B-3 configuration except as follows:

- The waste disposal transportation route is as follows:
  - Waste Shaft to S-400/E-140
  - South in E-140 to S-700
  - West in S-700 to W-30
  - South in W-30 to S-1600 (for P8 waste emplacement) or to S-4210 (for P9A waste emplacement). At S-3880 the disposal transporter must cross the truck haulage route.
- The mining transportation route is as follows (E-140 is not blocked by repair work):
  - Empty trucks from SHS south in W-30 to S-700
  - East in S-700 to E-140
  - South in E-140 to S-3880
  - West in S-3880 to W-170
  - South in W-170 to S-4210 and Panel 10A
  - Loaded return along the same route listed above to the SHS
- Other infrastructure requirements include:
  - West airlock doors under the overcast at W-30/S-1600 are open
  - Airlock doors under the overcast at W-30/S-3880 are closed
  - Doors are closed at S-4210/W-100 and E-140/S-3900
  - Doors are opened at S-3880/E-100 and S-4210/E-100
  - Install a diagonal brattice bulkhead at the W-170/S-3880 intersection.

Figure 10 illustrates the underground facility infrastructure locations and primary haulage routes for the B-4A ventilation configuration.

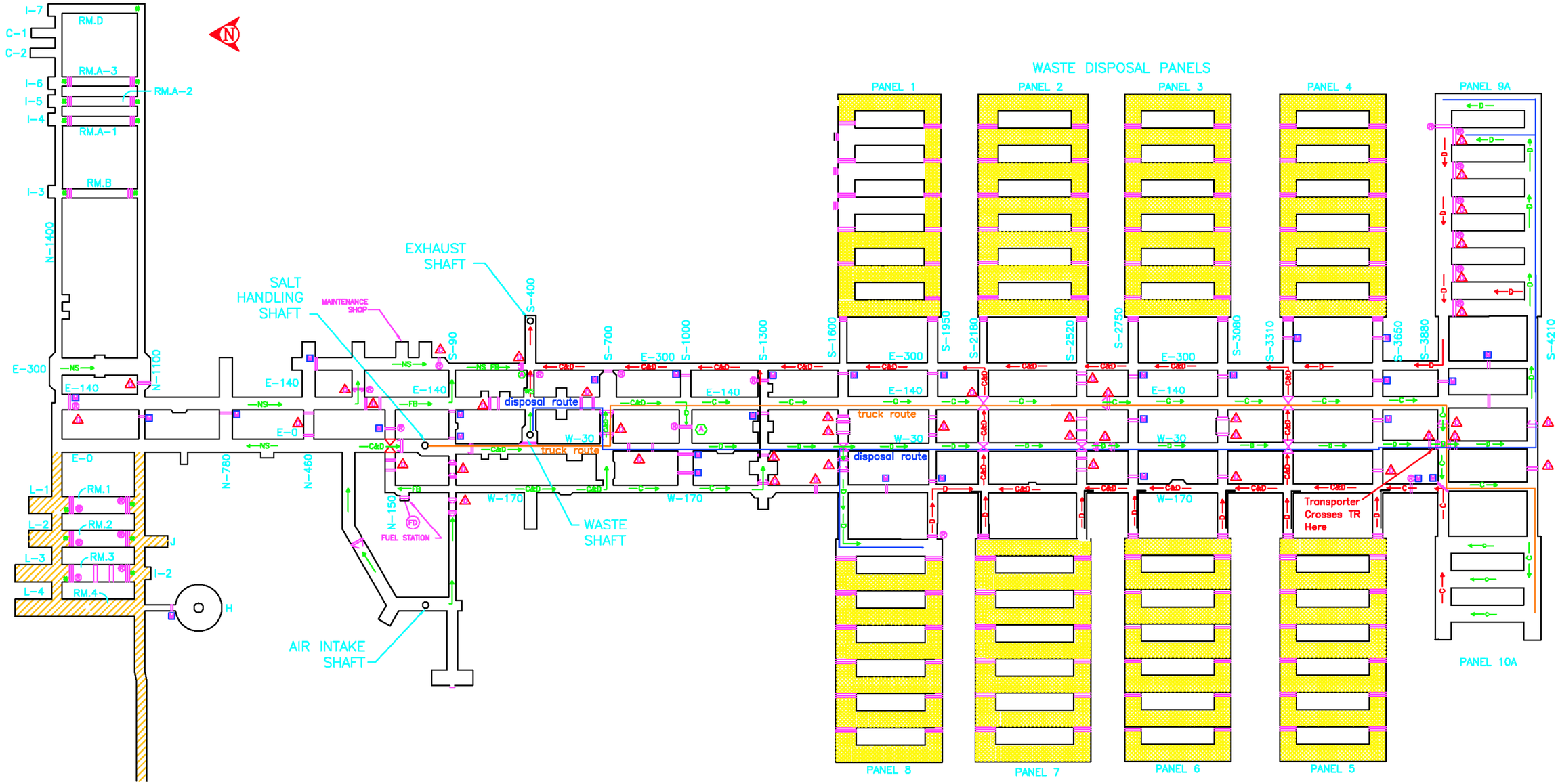

Figure 10: Ventilation Configuration for Option B-4A including Main Transportation Routes.

8.1 B-4A VENTILATION RESULTS

The results of the B-4A ventilation analyses showed that all airflow criteria could be achieved. This alternative assumed 700C is operating with 700A. Both were set at maximum flow. The natural ventilation pressures were maintained as those calculated during the 2010 Test and Balance.

A total volume of 20,000 cfm is passing through BH-302 to provide air for the diesel fuel bay. A total of 85,000 cfm is exhausting the construction circuit. The North Shop is ventilated with 55,000 cfm and the Waste Shaft Station is over 60,000 cfm. All leakage is from the construction circuit to the disposal circuit. Figure 11 shows the predicted airflow distribution for this scenario.

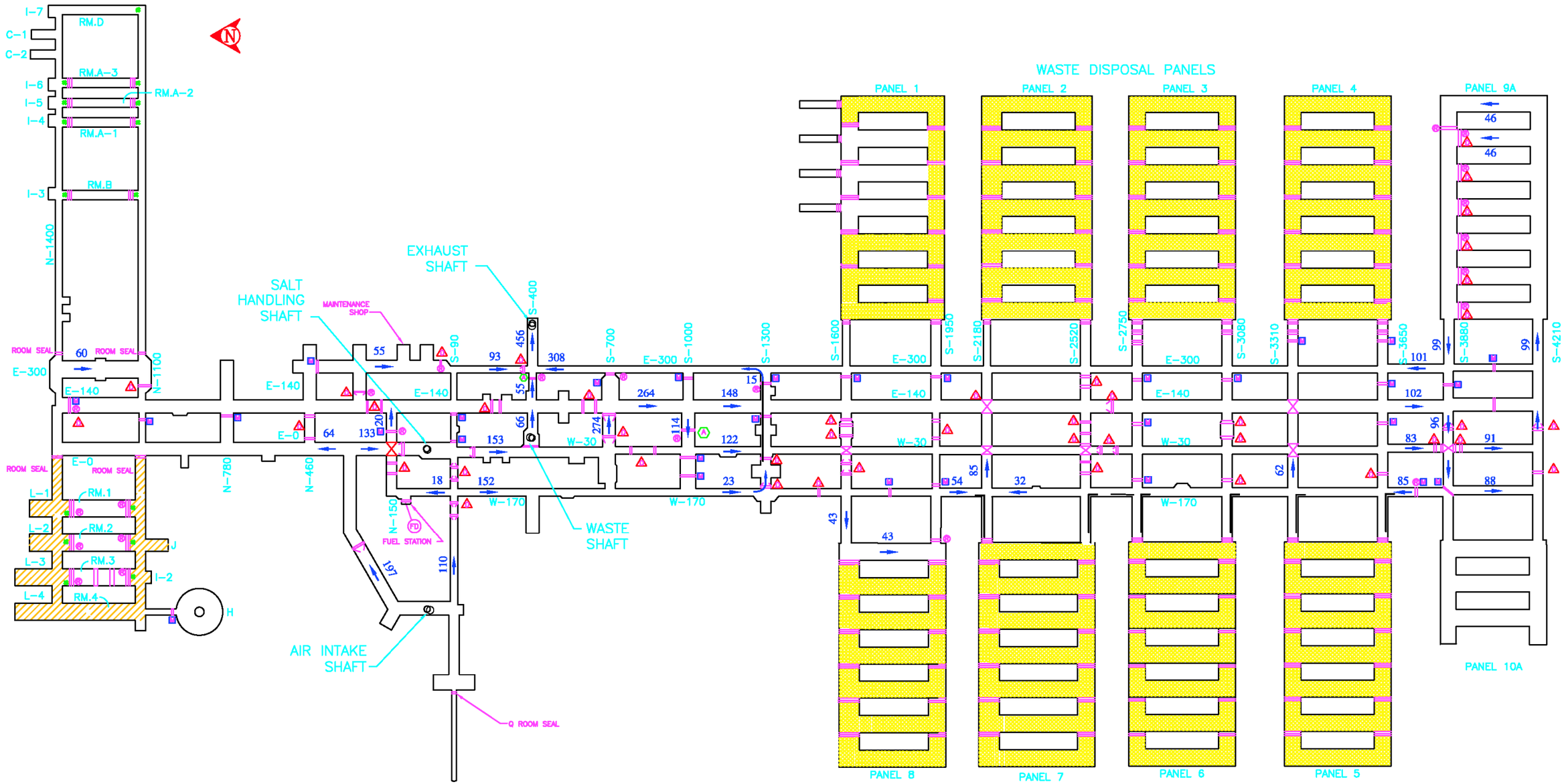

Figure 11: Predicted Airflow Distribution for Configuration for B-4A (kcfm).

9. VENTILATION CONFIGURATION: B-4B

Configuration B-4B is identical to B-4A except that E-140 is closed to vehicle traffic and all mining vehicles must travel through W-30.

9.1 DESIGN CRITERIA AND ASSUMPTIONS

The design criteria are identical to the B-4A configuration except as follows:

- The mining transportation route is as follows (E-140 is blocked by repair work):
  - Empty trucks from SHS south in W-30 to the mining faces at Panel 10A. The mining vehicles will exit W-30 via the airlock under the overcast at the S-3880 intersection. Optional truck routes can be through the doors located at S-1950, S-2520 and S-3810 around the E-140 repair work area.
  - Loaded return along the same route to the SHS

9.2 B-4B VENTILATION SCENARIO RESULTS

MVS was successful in achieving all ventilation criteria for this scenario. This basic ventilation design configuration and primary transportation routes are shown on Figure 12.

The modeling results for the airflow distribution for scenario B-4B are identical to the scenario B-4A. The only difference is the truck haulage routing from the mining area. Figure 11 illustrates the predicted airflow distribution for this scenario. The results show that all criteria are achieved.

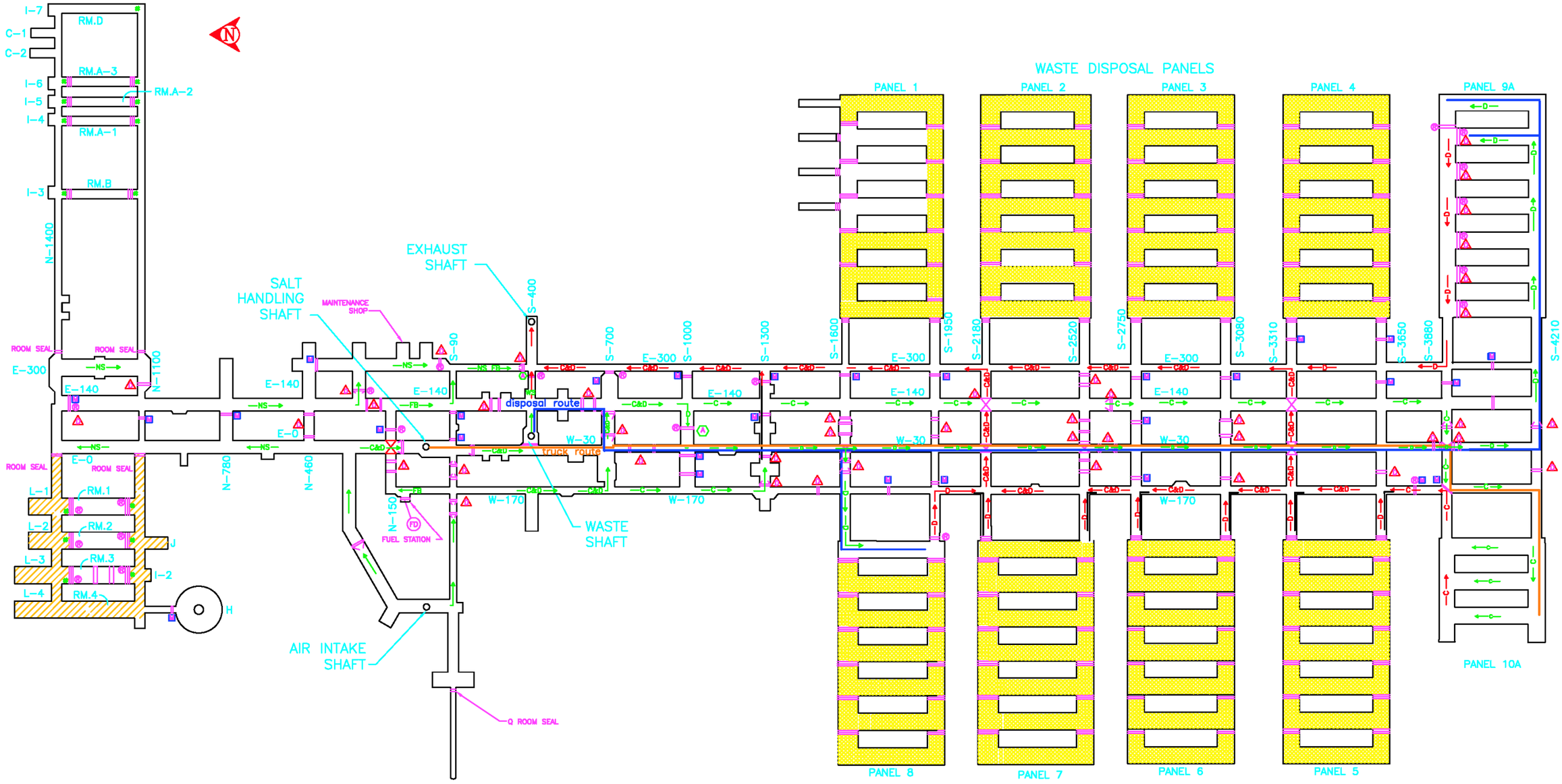

Figure 12: Ventilation Configuration for Option B-4B including Main Transportation Routes.

10.SUMMARY OF RESULTS

In summary, all scenarios investigated were modeled successfully. This means that all airflow criteria were successfully achieved. The predicted airflows for each configuration as compared with the design value on Table 5, with Table 6 showing the primary fan operating points for each model.

Table 5: Airflow Summary for the Ventilation Configurations Studied

Location	Design Flow (kcfm)	Scenario B-1 Model Predicted Flow (kcfm)	Scenario B-2A Scenario B-2B Model Predicted Flow (kcfm)	Scenario B-3 Model Predicted Flow (kcfm)	Scenario B-4A Scenario B-4B Model Predicted Flow (kcfm)
North Experimental Area	60	61	61	60	60
North Maintenance Shop	50	55	55	55	55
Waste Shaft Station	50	67	66	69	66
Waste Shaft Exhaust (BH 308)	none	55	55	55	55
Fuel Bay (BH 302)	20	20	20	20	20
S-1300 Shop	15	15	15	15	15
Panel Airflow					
Panel 7 Room 2	43	43	43	n/a	n/a
Panel 7 Room 3	43	43	43	n/a	n/a
Panel 8 Room 7	43	43	43	n/a	n/a
Panel 9A Room 7	43	n/a	n/a	43	46
Panel 9A Room 6	43	n/a	n/a	43	46
Panel 8 Room 1	43	n/a	n/a	43	43
Mining Consplit Regulator	50	55	55	80	85
Panel 5 and 6 Regulator (W-170)	15	15	15	n/a	n/a
Intake Disposal Circuit (BH 313)	none	139	144	120	114
Air Intake Shaft S-90	none	106	108	109	110
Air Intake Shaft North	none	193	195	196	197
Salt Handling Shaft	none	89	90	90	90
Exhaust at S-400	none	449	451	455	456

Note: n/a – not available (not in models). Red indicates flow from E-140 to W-30 through BH 313.

Table 6: Summary of Primary Fan Operating Duties for the Ventilation Configurations Studied

	Scenario B-1		Scenario B-2A and Scenario B-2B		Scenario B-3		Scenario B-4A and Scenario B-4B	
Location	Predicted Flow (kcfm)	Predicted Fan Pressure (in. w.g.)	Predicted Flow (kcfm)	Predicted Fan Pressure (in. w.g.)	Predicted Flow (kcfm)	Predicted Fan Pressure (in. w.g.)	Predicted Flow (kcfm)	Predicted Fan Pressure (in. w.g.)
700 A Fan	255	7.7	255	7.7	254	7.8	258	7.5
700 C Fan	230	7.7	230	7.7	229	7.7	233	7.4

From the above tables it is noted that all design criteria are met. In addition, the primary operating fans do not differ significantly for the various ventilation configurations. The results show each scenario to be viable. The decision as to which option works best is not so much a ventilation question, as an operational question. If work is ongoing in E-140 for ground support, then moving the disposal equipment to W-30 is a viable alternative. Conversely, maintaining E-140 for disposal is also practical.

To make the system operate successfully, an auxiliary ventilation duct/fan system was assumed for the S-1300 Shop and into each drift connecting to room 1 of Panels 5, 6 and 7. The later auxiliary systems were for controlling potential VOC releases from these panels.

In each configuration the waste handling transporter will need to either cross a construction air split, or will need to be upstream in a common split of air to both construction and disposal operations. MVS understands that WTS has a permit change to allow this to occur. This permit needs to ensure that this “crossing over” of the disposal transporter in construction air (or mixed with construction equipment) is allowed to the S-3880 intersection. The only real viable way for the transporter to effectively operate is to cross the construction air split.

Of concern to MVS engineers in the design of this ventilation system was the ability to successfully shift to filtration (STF) in all configurations analyzed. MVS conducted several STF models for the scenario B-4B configuration and noted that the basic requirements of a STF are met. These requirements are a) maintain the Waste Shaft tower at a negative pressure and b) maintain the differential pressure from the disposal circuit to the construction circuit. These requirements can be met by:

1. Closing BH 336 (E-300/S-350).
2. Closing BH 313 (regardless of airflow direction through the regulator).
3. Closing the Consplit regulator.

4. If open, depending on the configuration, close the doors in S-700/E-100 (although not necessarily required, closing these doors applies a greater negative pressure on the Waste Shaft tower).

In addition, after a STF, an airflow route can be established, if needed, to ventilate a single panel in filtration mode. This would allow WTS radiological staff to re-enter an area for any required work. If W-30 is used as the disposal circuit, the configuration is as follows:

1. Close the doors in S-700/E-100
2. Ensure doors at W-30/S-800 are closed
3. Open the doors south of the Waste Shaft in E-140/S-650
4. Open BH 313
5. Close BH 308
6. Control the airflow in the panel of interest by closing the room regulators in the panels where ventilation is not required.

If E-140 is used as the disposal route, the following actions are required:

1. Open the doors south of the Waste Shaft in E-140/S650
2. Close BH 308
3. Control the airflow in the panel of interest by closing the room regulators in those panels with no need for ventilation.

From the modeling, MVS concludes that each configuration analyzed can be effectively ventilated and have a successful shift to filtration. However, there are several features of the WIPP ventilation system that will need consideration. First, at present a differential pressure device is located at the S-1300 bulkhead separating W-30 from E-140. This device is used to alarm should the differential pressure drops below a set point. Obviously if configurations B-2A, B-2B, B-4A or B-4B are implemented, the pressure drop across this sensor will be reversed. A logic system needs to be installed to allow for the differential pressure to be monitored depending on the configuration.

In addition, because the differential pressure will be reversed (over the present configuration), all doors, both drive through and mandoors) will require latches and be monitored, since the doors will be opening with the pressure in some configurations. No self-closing doors should be used between W-30 and E-140. In addition, some configurations will have doors opening with the pressure which will make for a less tight seal.

The ventilation to the S-1300 Shop (between W-170 and W-30) was simplified in every model such that access to the shop was always from the W-170 side. This allowed for the duct system to be installed to the W-30 side of the shop with air sweeping across the shop from W-170. Doors can still be opened to W-30 for temporary movement of equipment, but should be closed on a regular basis.

The ventilation system as designed has the advantage of being very flexible between the configurations. By opening and closing strategic doors throughout the facility, the system can be readily adjusted to move the disposal route from E-140 to W-30 and vice versa. The time required to open and close doors could be a matter of an hour or so. This is advantageous if ground control is limited or completed in the E-140 airway.

In order to ensure the system is operating successfully, WTS should consider adding additional airflow and differential pressure devices in the underground. Additional units to monitor airflow should be considered at:

1. S-90 from the AIS shaft
2. W-170 for the flow to Panels 5, 6 and 7 (at the regulator providing airflow to the W-170 drift when panel 9A is being constructed and at the Consplit regulator in later scenarios sending air to W-170 from panel 10A).

Differential pressure should considered at:

1. The air door located at E-140/S-2600
2. Airlock at W-30/S-800

Door open/closed position devices are required on all doors in the facility. A logic diagram needs to be developed to show those doors that are required to be open or closed for the various configurations. In addition, a control system needs to be implemented that ensures the facility is configured correctly for the scenarios. The sequence of converting the scenarios is also required since it is possible to close doors and block the primary airflow routes from the intake shafts to the exhaust shaft (e.g. closing the doors in W-30/S-800 and S-700/E-100 at the same time). The procedure to convert the scenarios may consider reducing the primary fan system to Alternate Mode (a single 700 fan in operation) to minimize the risk during a changeover of inadvertently closing doors out of sequence. Finally, one of the doors in S-90 at W-200 should be designated a “fire door” for the AIS shaft. This is required to be in compliance with current WIPP standards.

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VnetPC Pro

USER'S MANUAL &

TUTORIAL

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1. Introduction

Welcome to VnetPC Pro. This latest upgrade of the popular ventilation simulation program combines the input of ventilation and mining engineers from around the world to provide an unparalleled engineering tool. This program continues to be designed by practicing ventilation engineers. Credit for many of the new features goes to the hundreds of users in the mining and tunneling industries throughout the world.

The applicability of VnetPC to subsurface ventilation system design ranges from the initial concept through to the system operations phase of a project. Given information that describes the geometry of a ventilation network, airway resistances or dimensions, and the locations and characteristic curves of fans, the code will produce listings and visual graphics of many parameters. The output includes predicted airflows, frictional pressure drops, air power losses in airways, contaminant flows and concentrations, and fan operating points.

VnetPC has been developed specifically for computers operating under the Windows environment. The system is supplied on one CD-ROM. Data files and fan databases prepared using the previous version of VnetPC 2007 and VnetPC 2003 can be imported and converted for use with the latest program.

Prior to installing the software, it is recommended that the user become familiar with this User's Manual. This manual provides an overview of the VnetPC package and software encryption routine that is recommended for both new users, and for users of previous versions. Comprehensive Help Menus are included with the program to further assist users in understanding how the program works. To access the Help Menu, click on the Help Menu above the tool bar. A tutorial section is included with this manual, which provides a quick-start to developing ventilation networks.

If you have any questions or comments regarding VnetPC please do not hesitate to contact us. Mine Ventilation Services, Inc. (MVS) maintains a comprehensive web site, which includes up-to-date information on VnetPC. We also offer free technical support to all users of the latest version of the VnetPC Program. Thank you for choosing the VnetPC software program, and for supporting the continued development of the code.

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Website**:** www.mvsengineering.com

2. Overview of VnetPC

The VnetPC program is designed to assist the mine ventilation practitioner in the planning and monitoring of underground ventilation layouts. Given data that describes the geometry of the mine network, airway resistances or dimensions, and the location and characteristic curves of fans, the program will provide graphical and tabular representations of various predicted ventilation parameters.

2.1 VnetPC: Its Applications and Uses

VnetPC can simulate existing ventilation networks such that fan operating points, airflow quantities, and frictional pressure drops approximate those of the actual system. This is accomplished using data from ventilation surveys together with information determined from known airway dimensions and characteristics. Proposed subsurface facilities may also be designed using VnetPC. Such simulations are conducted by incorporating physical input data from conceptual plans with documented design parameters used to determine estimated resistances for airways in the network. The range of fan duties required, airflows, pressure drops, operating costs, and the location of ventilation controls may be ascertained for the entire life of a project by conducting time-phase exercises. Options within VnetPC allow for the display and manipulation of three-dimensional networks, production of listings and output files, and plots of input and output data.

2.2 Background Theory of VnetPC

The VnetPC Program has been developed with the assumption of incompressible flow and is based on Kirchhoff's Laws. The code utilizes an accelerated form of the Hardy Cross iterative technique to converge to a solution.

2.3 List of Main Program Features

- Full-color, interactive 3D network schematic
- Enhanced, expandable coordinate system
- Data input and output via the Schematic or tabular views
- Color coding of branches for airway type (user defined)
- Import DXF files from CAD and mine planning programs
- Ability to enter series and parallel arrangements for fans
- Imperial and SI units with full data conversion
- Automatic allocation of surface branches to close meshes around surface nodes
- Notepad to enter detailed description of simulation
- Full annotation capabilities in all schematic views - allows angled text
- Automatic calculation of branch length from coordinate values
- Regulator orifice sizing tool
- Default network size limit is 10,000 branches, 4,000 junctions, and 600 fans

- Extensive Help Tools and Tutorials
- Full online support at www.mvsengineering.com
- Direct graphic printing and multi-colored plotting
- Export DXF files to CAD and mine planning programs – attribute exported specifically chosen
- Four input data types for branch resistance
- Steady state contaminant distribution analyses
- Fixed quantity tool
- Color coding of branches for range of parameter (airflow, pressure, etc.)
- Dual parameters display in schematic view
- Cut/copy/paste features for data exchange within Windows
- Variable frequency drives – fan curve adjustments for density and frequency (RPM)
- Edit branches in multiple views
- Fan curve graphics with current operating point displayed
- Transient time calculator based on user-selected path
- Branch templates
- Multiple branch selection and editing
- Editing single or multiple branch properties with templates
- Scroll wheel zooming
- Pan with center mouse wheel
- Fan stall warnings
- Shock loss calculator with reference material
- Isometric (3D) editing capabilities

2.4 Minimum System Requirements of VnetPC

- IBM Compatible Computer running Windows XP, Vista or Windows 7
- Intel Pentium class processor or above
- 512 MB RAM Memory
- 100 MB Hard Disk Space for the VnetPC Program (additional for Adobe Acrobat Reader™)
- CD/DVD Drive
- USB Slot (HASP Key)
- VGA Display

2.5 Setup Procedure

The VnetPC Program is shipped as a single installation file on a CD-ROM (VnetPC Pro Setup.EXE). The following installation instructions will assist you in achieving a trouble-free installation, regardless of what operation system you are running, or whether or not you already have a version of VnetPC installed on your machine. Please note that there is an additional setup file for installing the network version on a server.

1. Insert VnetPC Pro distribution disk into the CD/DVD Drive and execute the self-installing utility program from VnetPC Pro Setup.exe.

The default install directory is C:\Program Files\VnetPC Pro\ or other as specified by the user. The installation process creates the directory and inserts the associated program and ancillary files. When the installation is complete, a shortcut for VnetPC Pro will appear on the desktop.

2. Plug the HASP key tag into a USB port. Windows should automatically install the latest device drivers for the HASP key if your computer has an active internet connection. If Windows does not install the HASP device drivers automatically, the device drivers can be found on the installation disc, or at our website: www.mvsengineering.com

   Once the installation of the HASP device drivers is complete, a red light will activate in the HASP key tag. The red light will remain on as long as the HASP key tag is plugged into the machine and is functionally properly.

3. Click on the shortcut to start VnetPC Pro program.

   a. The program should open.
   b. Use the File→New→VnetPC Pro File sequence to open a new model illustrated in Figure 1.

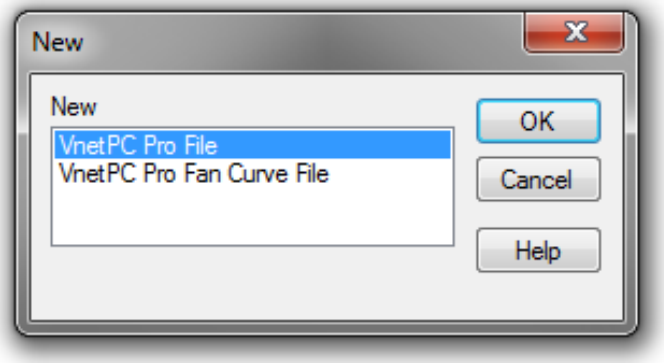


Figure 1: New Model

   c. Next a dialog box should appear, as shown below in Figure 2, requesting you to select the system of units for this model. Select units desired for your model and press “OK”.

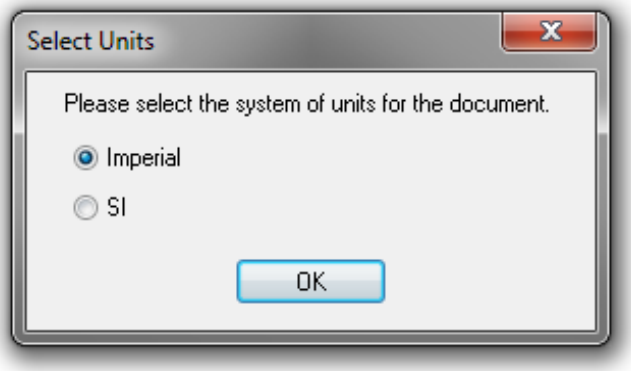


Figure 2: Unit Selection Dialog Box

d. If you get an Untitled – Model Information dialog box, the program and the associated support programs are installed correctly.

Congratulations!! You can now begin using VnetPC Pro ventilation simulation program.

If the VnetPC Pro program window does not open, but you get a HASP not found (x) error please verify:

HASP not found (0) – that the HASP device is properly attached to the computer (on a USB HASP the red light in the device should be on).

Now, that the program is functioning, check the version number:
Help→About Vnetwin

Then check for updates and patches: www.mvsengineering.com/download.htm

If the patch has a higher version alpha-numeric than shows up in the help about information panel, then you may download the patch.

Simply "Save Target" to your program directory and then extract the replacement *.exe and *.dll files to over-write the existing version in the installation directory. Note that if you retain the current program files as a backup, you will need to make sure that you manually verify any shortcut associations. Windows may retain the shortcuts targeted to the original program files rather than the installation directory.

If you have any further questions with regard to the installation process, or the operation of this or other MVS software, please feel free to contact us by telephone: 1-559-452-0182 or email: support@mvsengineering.com.

2.6 Software Encryption

The VnetPC Program is protected by a software hardlock (HASP). The hardlock device is installed on a USB port of the computer or server (Net-HASP). After the VnetPC Program is installed, the hardlock device drivers must be installed. If your PC has an active internet connection, Windows may download and install the necessary drivers automatically. For the single user version of VnetPC Pro, the driver installation routine will be located on the installation disc, for the multi-user version of the program the driver installation routine will be located in a separate "Net-HASP License Manager" directory.

If any problems are encountered please contact MVS. MVS can be reached at; phone (559) 452-0182, fax (559) 452-0184, or e-mail at MVS at support@mvsengineering.com.

3. Data Preparation and Input

VnetPC is structured such that the user moves between views, or windows, where input and output data are located. A single file is used for the network input, schematic coordinates, and contaminant data. A separate archive file is used to store multiple fan curves. Creating, importing, editing, or viewing fan curves are performed within the VnetPC Program. The VnetPC Program comprises ten screens for the input and display of program data. The screens are listed on the Menu Bar under the "Go To" Menu. These views are:

- Model Information
- Branch Input
- Branch Results
- Branch Templates
- Fixed Quantities
- Fan Input
- Fan Results
- Junction Data
- Schematic
- Contaminants

This section details the content and form of the input data required for the VnetPC Program. The data requirements are presented in six categories:

1. Ventilation Network (page 7)
2. Descriptive Data (page 8)
3. Branch Data (page 10)
4. Fan Data (page 29)
5. Fixed Quantity Tool (page 35)
6. Contaminant Distribution Data (page 36)

3.1 Ventilation Network (Schematic)

A ventilation network is a graphical representation of a ventilation system and consists of a set of junctions and interconnecting lines (branches) which denote major or significant airflow routes. The following subsections describe the schematic requirements.

3.1.1 Closed Circuit

The network schematic must consist of interconnected branches that form closed circuits. Each branch should represent a single airway, a group of airways, or leakage paths. VnetPC will automatically close those branches connected to the surface, as long as the user specifies them as being either "Surface Intake" or "Surface Exhaust" branches. There are options to select the surface state of the various network branches in both the Schematic and Branch Input Views (refer to Section 3.3.3.5).

3.1.2 Junction Numbers

Junction numbers must be assigned to each junction in the schematic. Valid numbers are whole integers from 1 to 10000. VnetPC is capable of selective viewing and printing of branches interconnected to any specified range of junction numbers. VnetPC will automatically allocate junction numbers for new branches drawn in the Schematic View or for imported data from a DXF file.

3.1.3 Schematic Layout

Three techniques can be used to enter the schematic into VnetPC:

1. Draw the schematic in a CAD or mine planning program (established as a unique layer, perhaps called VnetPC) and import to VnetPC. This method is typically adopted when the user wants to drape/overlay the ventilation network on a mine plan (within a CAD program).
2. Directly plot the network on the screen using the Vnet drawing tools (acceptable for smaller networks and where precise geometry is not necessary).
3. Numerically enter the coordinate data in tabular form, or copy the coordinate data from a spreadsheet and paste into the Junction Data View.

Note: Scaling and Offset of Coordinates during DXF import

VnetPC supports real-world coordinates, and will generally import exact coordinates from CAD programs. The exception is when the program has to apply an offset to the imported data, and/or scale the network because the coordinate range is too great for the VnetPC views (coordinate values greater than 1 billion). Any scaling or offset is identified to the user during the importing process. For importing multiple layers or DXF files into the same network, the initial offset and scaling information (used for the first layer) will automatically be applied to all subsequently layers.

3.1.4 Parallel Branches

Users experienced with previous versions of VnetPC have indicated that confusion can arise if two or more branches are entered with identical From and To junction numbers. VnetPC checks for this condition during data entry and will not allow duplicate branches. However the user can effectively connect any two junctions with parallel branches by either reversing the junction numbers or inserting intermediate nodes.

Note: Parallel Branch Tool

A tool is available to allow the user to rapidly adjust the resistance of a branch according to parallel network theory. This tool is accessible in both the Branch Input View (Parallel Factor column) and the Schematic View (Branch Data dialog box). The user may enter a number, with the default being 1. If the user selects a 2, then the code will adjust the input branch resistance to double the number of airways represented by the branch. If the user were to enter 0.5, then the resistance would be adjusted to give half the number of airways represented in the branch. If the user enters 1, then the resistance is reset to the original value. During ventilation surveys, resistances are determined for parallel entries and are input directly to the model. Although only one branch is modeled it will sometime actually represent two or more parallel entries. Care should be taken to identify exactly how many entries are incorporated into the original resistance value.

3.2 Descriptive Data

Descriptive data consists of both required and optional information for documentation and program initiation. This information is modified in the Model Information View. The Model Information View allows data to be directly entered into fields as shown in Figure 3.

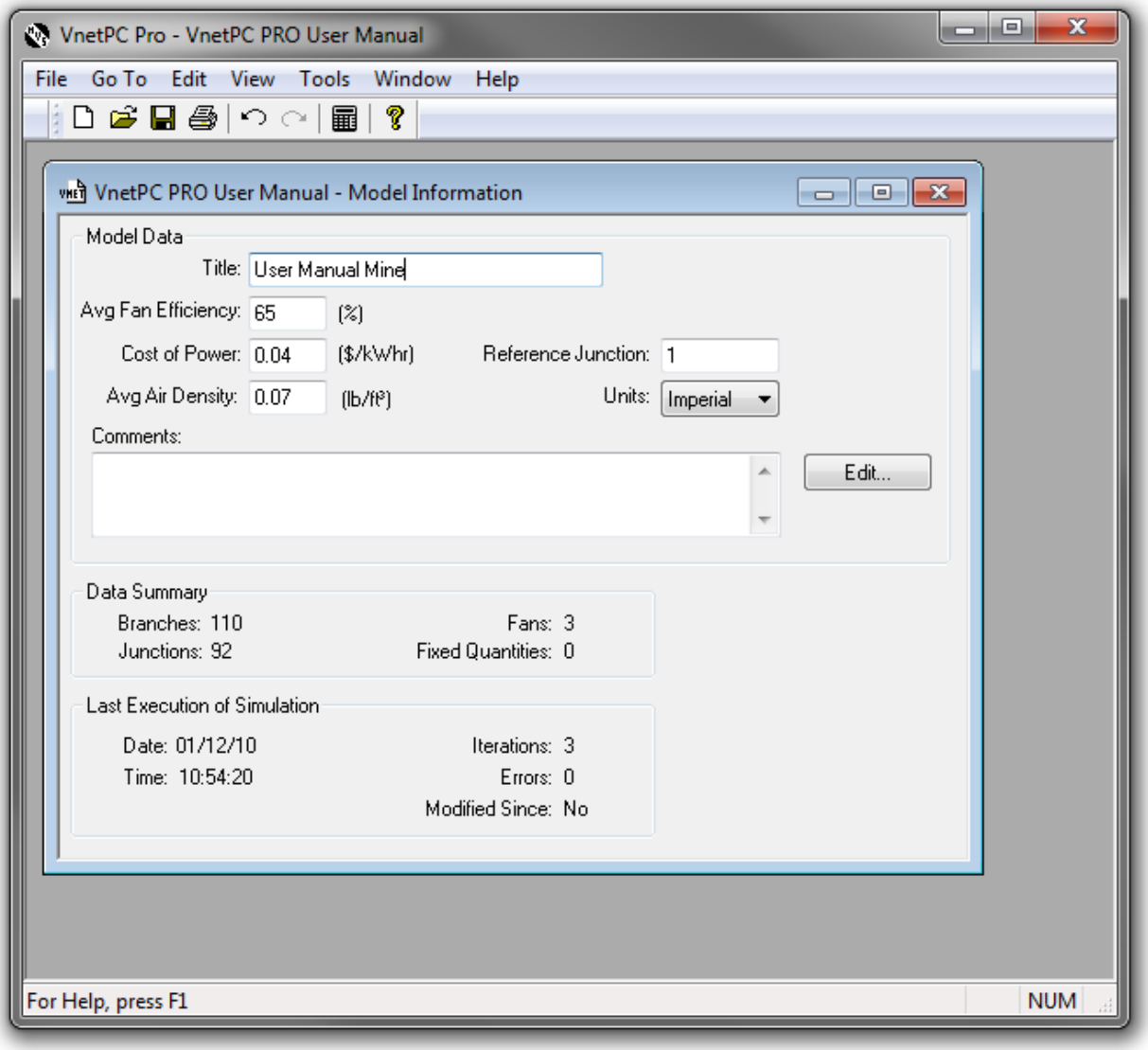


Figure 3: Model Information View

The following subsections describe the input and required format for the data in the Model Information View.

3.2.1 File Name

A file name must be assigned when saving the file for the first time, or when utilizing the "Save As" command under the File Menu. When a file is saved, the program automatically prompts for the extension .vdb. VnetPC supports extended file names.

3.2.2 Units and Conversion Utility

VnetPC supports both Imperial and SI units. The user must initially specify one type of engineering unit; however, should the user decide to change units, an automatic conversion feature is available. This conversion feature is available from the Tools Menu in any view. The

conversion utility converts all the input data including the fan curves. It is important that the user executes the program following unit conversion. In rare cases during conversion, one or more data values may become out of range, and the program will truncate the values. However, this will only occur if the original network contains extremely high input parameters, and the truncated values should still be sufficiently large so that the network accuracy is not impacted.

3.2.3 Power Cost

The user should enter an electrical power cost to determine the operating cost for the system fans. Power costs are provided in units/kWh, where the unit may be any currency.

3.2.4 Air Density and Regulator Sizing and Shock Loss Calculator

The user is required to input an average air density for the underground. This value is needed to compute the orifice area for any regulators listed in the Fixed Quantity View. The average air density parameter is used to calculate shock losses added to branches.

3.2.5 Notepad (Comments)

There is a large text field available to enter a detailed description of the particular file. Information may include a title, summary of results, and the specific details associated with that model. This Notepad is seen in the Model Information View. Text may be entered directly in the reduced window or the Notepad may be maximized by pressing the Edit key. Users need to deactivate a modified field by choosing a new active field before attempting to save the file. Changes made to an active field will not be retained when the file is saved.

3.3 Branch Data

3.3.1 Branch Data Formats

Each branch is defined by two junctions and by numerical data that indicate the characteristics of the airway. Data may be entered in any of four formats. The mouse can be used to copy and paste ranges of data between branches in the Branch Input View or from other Windows applications (such as spreadsheets or other ventilation simulators). Once data is entered into the program, the data will remain until deleted or overwritten by new data of the same format. If the resistance type is changed to a different data format, original data entered for other formats will be retained and available though inactive.

VnetPC recognizes four branch data formats: Fixed Resistance (R), Pressure Loss and Airflow Quantity (p/Q), Atkinson Friction Factor (k-factor), and Resistance Per Branch Length (R/L). A branch data format is chosen for each branch depending on information available about the airway to be represented. The format for each branch is independent of the other branches in the model and can be changed at any time. The available branch types may be accessed in the Branch Input View from a drop-down list under the appropriate column for each branch as shown in Figure 4. These types can also be set or modified in the Branch Data Dialog from the Schematic View as shown in Figure 5.

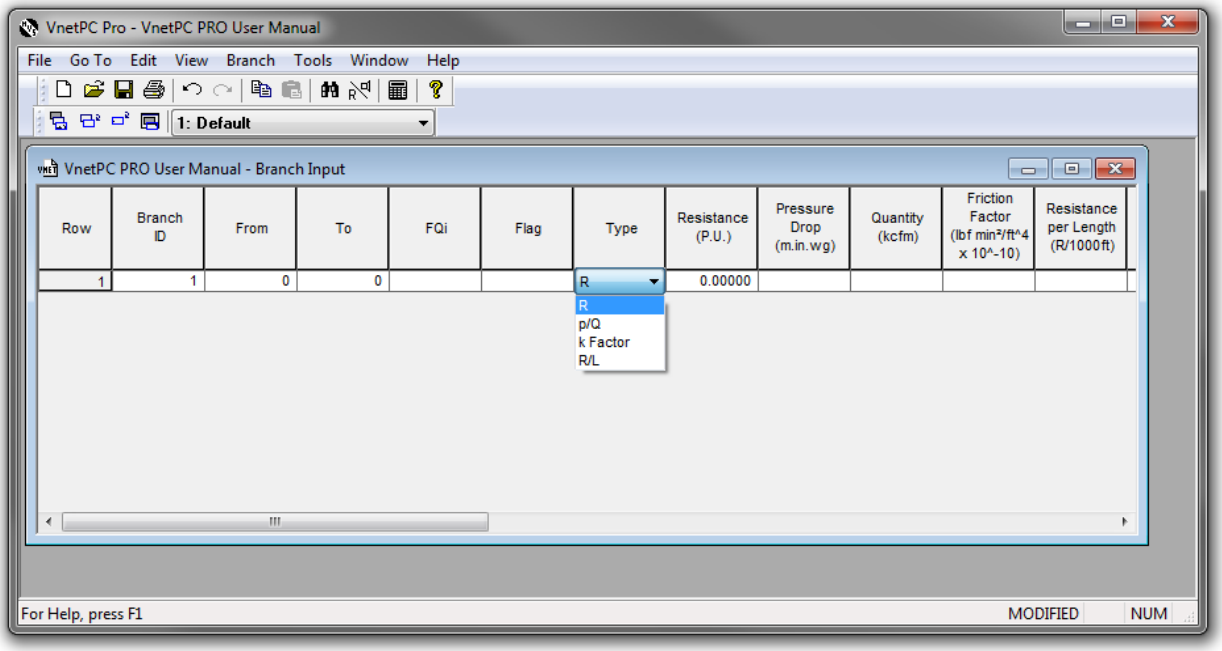


Figure 4: Branch Input View

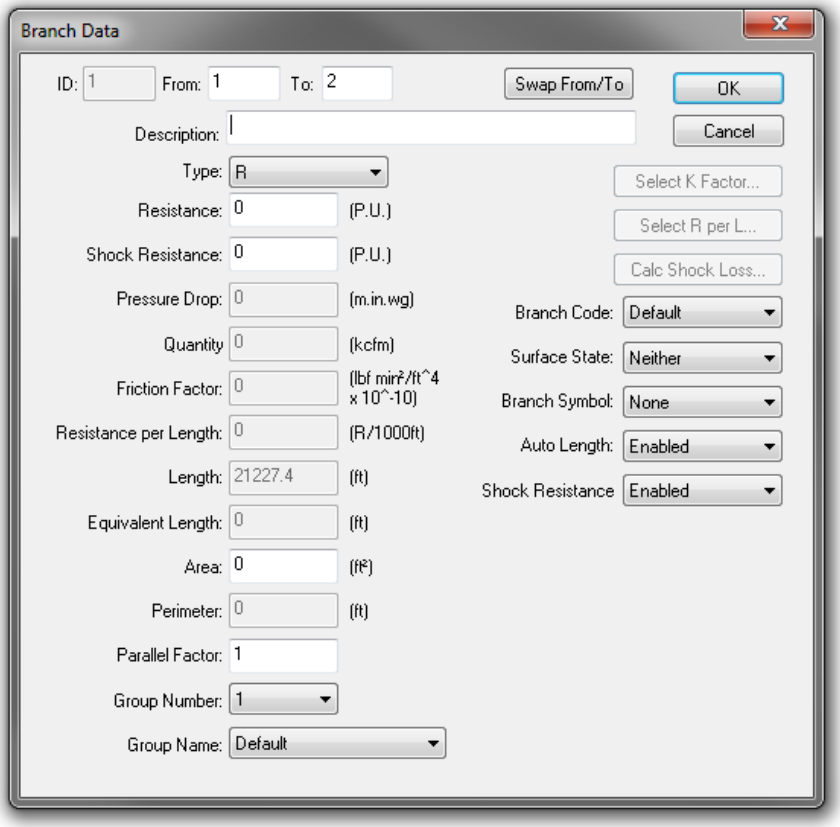


Figure 5: Branch Information Dialog Box

The Branch Data Dialog box can be accessed from the Schematic view using the Edit tool or the Selection Pointer. The Edit tool can be selected in the Tools drop down menu or by selecting the Edit tool icon located on the Drawing toolbar and pressing the left mouse button while hovering the cursor over a branch. The Selection Pointer is available under the Tools drop down menu or by selecting the Selection Pointer icon on the Drawing toolbar. By pressing the right mouse button when hovering the cursor over a branch, the user can select the Branch Data option from the list. Using either of these methods will call up the Branch Data dialog box, illustrated in Figure 5. Branch types and other branch data can be changed in this view.

VnetPC has a feature that links a numerical code to the branch data format options to assist the user when entering data into the Branch Input View using the number pad on a keyboard. A code of 1, 2, 3 or 4 can be entered in the branch type field to call up the respective branch type rapidly. The number and type associations are given in Table 1.

Table 1 - Branch Data Types

Data Type	Entry Form	Comments
1	R (airway resistance)	Fixed resistance
2	p, Q (frictional pressure drop and quantity)	Pressure drop - volume data
3	k, L, L_{eq}, A, Per (friction factor, length, equivalent length, area and perimeter)	Required input for Atkinson's Equation
4	R/Length, L, L_{eq} (resistance per unit length, airway length and equivalent length)	Allows direct calculation of resistance from previously measured resistance

A detailed description of the four data entry formats is described in the following sections.

3.3.1.1 Resistance Data

The Resistance data type (R) requires that a resistance value be input for the branch. This data type is useful for branches with a known or previously computed resistance. A common example would be adding a stopping or door using an average resistance value calculated from survey data. When a new branch is created in either the Branch Input or Schematic views, the default branch data type is R.

3.3.1.2 Pressure and Quantity Data

The p/Q data type requires pressure loss and volume flow (quantity, Q) values to be input. These values are typically obtained from a pressure-quantity survey using the gauge and tube method for pressure loss and vane anemometers for airflow quantity. Vnet PC Pro calculates the resistance, R, on the basis of the Square Law, as given in Equation 1. Directly entering survey data allows the user to bypass a calculation step when preparing data and helps facilitate correlation between measured airflow values and those resulting from the model simulation.

Equation 1: $$R = \frac{p}{Q^2}$$

Where: R = airway resistance (Practical Unit *[P.U.]* or Ns^2/m^8)
p = pressure drop (milli inch w.g. or Pa)
Q = flow rate (kcfm *[× 1000 cfm]* or m^3/s)

3.3.1.3 Atkinson Friction Factor (k-factor)

The k-factor data type requires the physical characteristics of the airway to be input, including: Atkinson Friction Factor (k-factor), length (L), equivalent length of shock loss (L_{eq}, if desired), perimeter (P_{er}), and cross-sectional area (A). This data type computes branch resistance using an empirical formula known as Atkinson's equation, expressed below in Equation 2:

Equation 2: $$R = \frac{k(L + L_{eq})P_{er}}{cA^3}$$

Where: R = airway resistance (Practical Unit or Ns^2/m^8)
k = friction factor (lbf $min^2/ft^4 \times 10^{-10}$ or kg/m^3)
L = length of airway (ft or m)
L_{eq} = equivalent length of shock loss (ft or m)
A = area (ft^2 or m^2)
P_{er} = perimeter of airway (ft or m)
c = constant (Imperial = 52 and SI = 1)

VnetPC verifies each entry as it is input and, if invalid, requests re-entry. It should be noted when inputting a value for k-factor in Imperial Units into the Branch Data: the 10^{-10} factor must not be included in the entry. Hence, for a typical airway with a k-factor of 65×10^{-10} lbf min^2/ft^4, the user would enter only 65. **Note that VnetPC uses a constant of 52 not 5.2 in the Atkinson Equation. This allows the Atkinson friction factor to be entered directly without including the 10^{-10} factor. The resulting unit is termed the Practical Unit (PU).** This same unit is obtained from the Square Law by using milli inch w.g. (thousandths of an inch w.g.) and kcfm (thousand cubic feet of air per minute).

To facilitate input of friction factors, a user-defined list of k-factors may be accessed by clicking the 'Select K-factor' button on the Branch Data dialog box. The Select Friction Factor dialog box will appear as shown in Figure 6. Use the selection pointer and left mouse click on a cell in the row of the desired k-factor and press 'OK' to apply the k-factor to the branch.

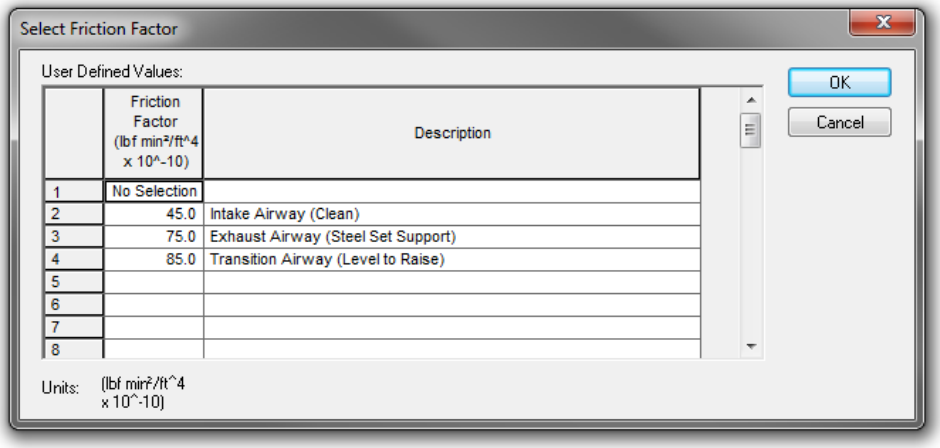


Figure 6: Friction Factor Dialog Box

The 'Select Friction Factor' feature allows the user to enter a k-factor value and description for each variety of airways to be modeled with the k-factor data type. These stored values can then be recalled rapidly to populate resistance data for future branches. The Select Friction Factor dialog box can also be accessed in the Branch Input view from the 'Branch' drop-down when a k-factor field is selected. An additional way to access the stored friction factors from the Branch Input view is to double click on the edge of the spreadsheet cell for the friction factor of a desired branch.

3.3.1.4 Resistance per Length Data Format

The resistance per unit length (R/L) data type allows the user to input an empirical resistance per length value for the airway and requires branch length. Equivalent length of shock losses may also be entered if desired. Resistance per unit length values for the airways being modeled are typically obtained from survey results or empirically computed using suitable friction factors and airway geometry.

It is most common to use this data type for extending existing airways without requiring the calculation of k-factors. This is only effective if characteristics such as the dimensions of the opening, roof control methods, and airflow obstructions are consistent along the length of the airway. Resistance per length values are typically calculated as the average of the values of several similar airways. This will eliminate anomalies that commonly occur during ventilation surveys and yield more realistic results than values from a single branch or estimated using a table of k-factors.

The process for entering R/L values is identical to that for entering k-factors in both the Schematic view and the Branch Input view. To facilitate input of R/L values, a user-defined list of R/L values may be accessed by clicking the 'Select R per L' button on the Branch Data dialog box. The Select Resistance Per Length dialog box will appear as shown in Figure 7. Use the selection pointer and left mouse click on a cell in the row of the desired R/L value and press 'OK' to apply the R/L value to the branch. Note: Resistance per length values are input per 1,000 units (ft or m).

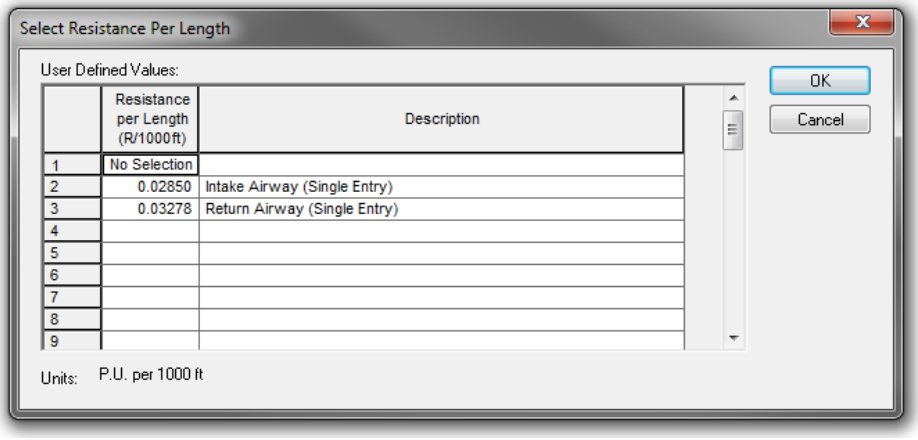


Figure 7: Resistance per Length Values Dialog Box

The 'Select R per L' feature allows the user to enter an R/L value and description for each variety of airways to be modeled with the R/L data type. These stored values can then be recalled rapidly to populate resistance data for future branches. The Select Resistance Per Length dialog box can also be accessed in the Branch Input view from the 'Branch' drop-down when an R/L field is selected. An additional way to access the stored R/L values from the Branch Input view is to double click on the edge of the spreadsheet cell for the R/L value of a desired branch.

3.3.1.5 Automatic Length Tool

The VnetPC Program incorporates an automatic length tool to provide a length value based on junction coordinates. This feature can be activated for each branch through the appropriate column in the Branch Input view and through the Branch Data dialog in Schematic view. Universal settings for this feature can be adjusted by selecting 'Auto Length' in the Tools drop down menu in most views. This displays the Automatic Branch Length Calculation dialog box as shown in Figure 8.

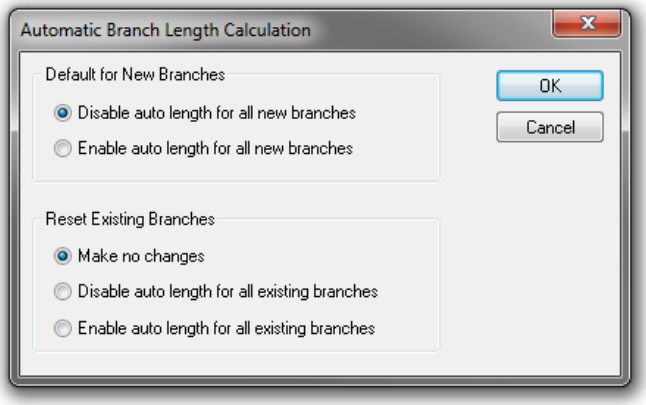


Figure 8: Automatic Branch Length Dialog Box

The top section of the dialog box sets the default for any new branches added to the network. If the automatic length feature is enabled, the program will calculate the branch length based on the x, y and z coordinate data of the two junctions that define the branch. This feature is commonly activated when the model is created to scale from a dxf. It is important to note that VnetPC assumes that each division (coordinate) in Imperial units is 1 foot and in SI Units is 1 meter. The units of a source dxf must be identified correctly when imported as this cannot be adjusted afterward.

When Autolength is enabled, the length field will become “read only” or “grayed out” in both the Branch input and Branch Data dialog views. This is indicated by changing the color of the text and fill of the field. The user will not be able to edit this inactive field while Autolength is enabled.

Modifying junction locations or creating a not-to-scale model can make viewing and manipulating the model easier. The automatic length tool will update the branch length when there has been a change in the location of one of the junctions or if the branch junction numbers have been reassigned. When modifying junction locations care should be taken to enter correct airway lengths by hand in order to achieve realistic branch resistance values when using the k-factor and R/L data formats are used. This is especially important for branches used to represent shafts and raises. Length values are also required for calculating airflow velocity. Airflow velocity values can be displayed in the Schematic view and are required for contaminant flow and transient time calculations.

The lower section of the Automatic Branch Length Calculation dialog box allows changes to be made to existing branches. The default is set to "Make no changes." If the user selects to enable the automatic length feature for all existing branches, the length of all existing branches will be updated to the respective computed values. Any existing length data will be overwritten and is not retained.

During unit conversion, the length of branches is converted automatically regardless of Autolength status. The coordinates in the Schematic View are also converted, resulting in updated length data from the automatic length feature.

3.3.1.6 Shock Loss Calculator

The VnetPC Program incorporates a tool to calculate and apply shock loss resistances to branches. This feature can be activated for each branch through the Branch Data dialog box in Schematic View or the appropriate column in Branch Input.

A shock loss resistance may be added to any branch in the ventilation model. This feature can be enabled or disabled at anytime in the ventilation model and when disabled will retain the shock resistance value but will not apply it to the system.

To add a shock loss resistance to the model with the Branch Data dialog box the user must “Enable” the Shock Resistance using the drop-down menu located on the right of the dialog box.

Users then may manually add a value to the Shock Resistance text box or select “Calc Shock Loss” to calculate a shock loss resistance.

In order for VnetPC Pro to calculate the shock loss resistance, users must define three parameters; airway cross-sectional area, average mine air density, and shock loss factor. The cross-sectional area is user defined for each branch in the Branch Data dialog box or Branch Input screen. The average mine air density is user defined on Model Information view. After the user selects “Calc Shock Loss” the Shock Loss Factor dialog box will be displayed (see Figure 9). Shock loss (X) factors may be defined as the number of velocity head that give the frictional pressure loss due to turbulence at any bend, variation in cross-sectional area, or any other configuration that causes a change in the general direction of airflow. Users may select Reference for additional information for selecting a Shock Loss Factor. After users enter a shock loss factor and press “OK”, the calculated shock loss resistance will appear in the Branch Data dialog box.

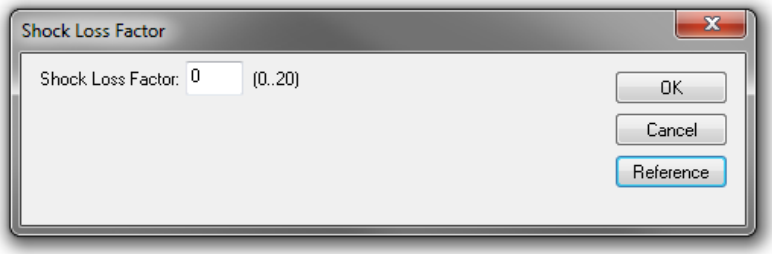


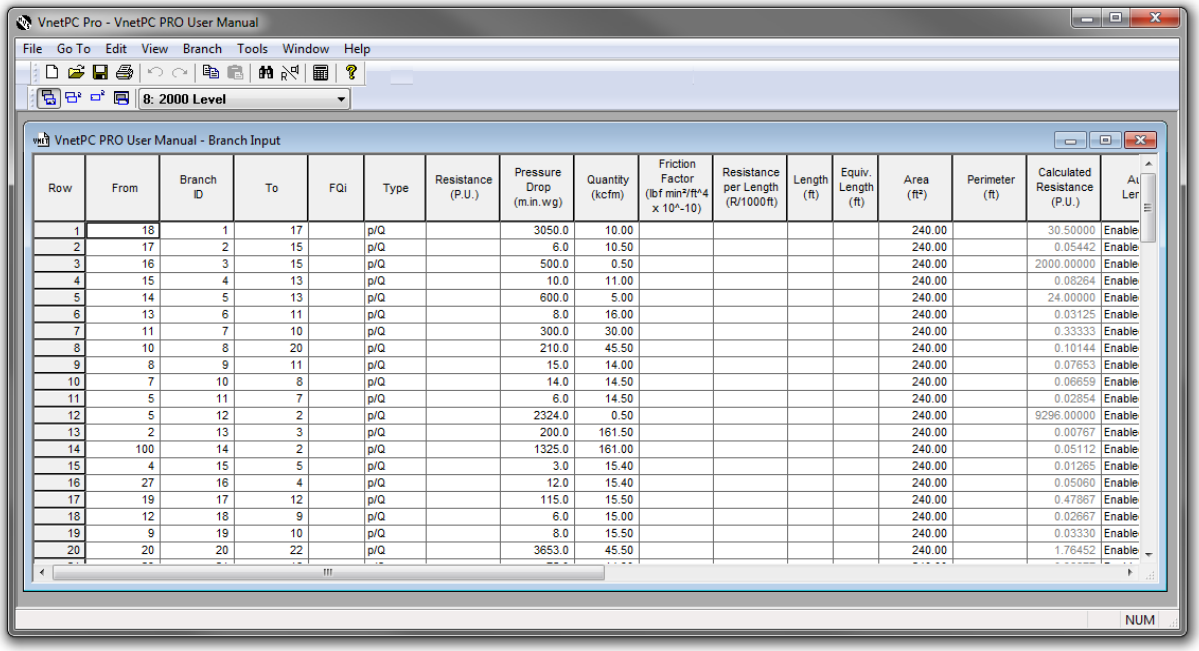
Figure 9: Shock Loss Factor Dialog Box

3.3.2 Branch Input View

Branch characteristic data can be entered and modified in a manner typical of Windows-based spreadsheets in the Branch Input view. A branch can be added, deleted, or inserted by selecting the respective command under the Branch menu.

If a new model is being developed or branches are being added from this view, the user can select ‘Add Branch’ under the Branch menu. When the first branch in a network has been entered, additional branches are added automatically by typing Enter at the end of the last row in the Branch Input View. Additional branches may also be added by typing Shift-Enter at any point in the Branch Input View.

Once data has been entered in a particular cell the user can press either the Enter key or the Tab key to progress to the next cell. This section allows the user to enter a description about each branch, allocate one of six ventilation symbols to the branch, enter a branch code for the type of branch, and specify surface status. The columns in all tabular views may be frozen, hidden or shown using tools under the View menu. Figure 10 shows an example Branch Input View.



Row	From	Branch ID	To	FQi	Type	Resistance (P.U.)	Pressure Drop (m.in.wg)	Quantity (kcfm)	Friction Factor (lbf min²/ft^4 x 10^-10)	Resistance per Length (R/1000ft)	Length (ft)	Equiv. Length (ft)	Area (ft²)	Perimeter (ft)	Calculated Resistance (P.U.)	Au Ler
1	18	1	17		p/Q		3050.0	10.00					240.00		30.50000	Enable
2	17	2	15		p/Q		6.0	10.50					240.00		0.05442	Enable
3	16	3	15		p/Q		500.0	0.50					240.00		2000.00000	Enable
4	15	4	13		p/Q		10.0	11.00					240.00		0.08264	Enable
5	14	5	13		p/Q		600.0	5.00					240.00		24.00000	Enable
6	13	6	11		p/Q		8.0	16.00					240.00		0.03125	Enable
7	11	7	10		p/Q		300.0	30.00					240.00		0.33333	Enable
8	10	8	20		p/Q		210.0	45.50					240.00		0.10144	Enable
9	8	9	11		p/Q		15.0	14.00					240.00		0.07653	Enable
10	7	10	8		p/Q		14.0	14.50					240.00		0.06659	Enable
11	5	11	7		p/Q		6.0	14.50					240.00		0.02854	Enable
12	5	12	2		p/Q		2324.0	0.50					240.00		9296.00000	Enable
13	2	13	3		p/Q		200.0	161.50					240.00		0.00767	Enable
14	100	14	2		p/Q		1325.0	161.00					240.00		0.05112	Enable
15	4	15	5		p/Q		3.0	15.40					240.00		0.01265	Enable
16	27	16	4		p/Q		12.0	15.40					240.00		0.05060	Enable
17	19	17	12		p/Q		115.0	15.50					240.00		0.47867	Enable
18	12	18	9		p/Q		6.0	15.00					240.00		0.02667	Enable
19	9	19	10		p/Q		8.0	15.50					240.00		0.03330	Enable
20	20	20	22		p/Q		3653.0	45.50					240.00		1.76452	Enable

Figure 10: Branch Input View

In the Branch Input view the Find option may be used under the Edit menu or via the Find Branch icon (binoculars) on the tool bar. These tools are different. The Find option seeks up or down a selected column for an input text string. The Find Branch option allows branches to be located either by entering from and to junction numbers or by finding the next occurrence of a particular junction number. The Replace option allows the user to make global changes to the input data.

3.3.3 Schematic View

VnetPC Pro features a reversal function, which signals when airflow in a particular airway has changed direction from that which was intended. In order for this function to work properly, the user must define each branch with junctions set up in the proper order (similar to fans and fixed quantities). Once a simulation is executed, reversed airways will be tagged, as shown in Figure 11.

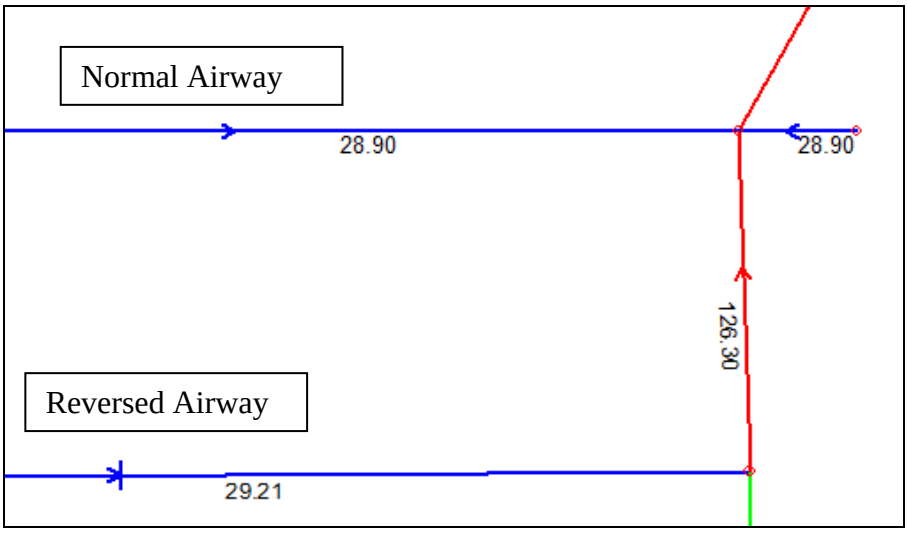


Figure 11: Example Airways

If desired, the ventilation network may be developed entirely within the Schematic View. Networks are established using functions obtained from the Tools menu or Tools Bar. This menu allocates different functions to the selection pointer. The following list of functions is available:

Selection Pointer

Create Junction

Create Branch

Plot Existing Junction

Create Fan

Create Contaminant

Create Label

Zoom Tool

Eraser Tool

Edit Tool

3D Spin Tool

The ***Selection Pointer*** is the default option. This allows the user to highlight branches and by pressing the right mouse button change the attributes of those branches and access Template features. The network may also be resized or adjusted by dragging nodes around the screen using this pointer.

The ***Create Junction*** option allows new junctions to be created prior to branch entry. The branches may then be inserted between the junctions using the Create Branch option. The creation of junctions is normally not necessary, because branches drawn in blank areas of the screen (using Create Branch) will automatically be assigned From and To nodes and numbers. These default numbers can be changed as required. Use of the Create Junction tool is generally

restricted to the addition of nodes to identify shafts, raises and ramps. The user cannot create nodes in the section views. Nodes can only be input in the plan views. A branch may then be created between these existing nodes in a section view. Note that the user can select Junction Creation under the Tools Menu to change the starting node number (refer to Section 3.3.3.3).

The ***Create Branch*** tool allows new branches to be drawn. The program automatically allocates junctions at the start and end of these branches, unless the user clicks on an existing node or intersects an existing branch. If an existing airway is used for a starting or termination point, then the branch will be divided and a new node will be added. The divided airway will be represented by one branch with the original branch data details, and a second new branch set at zero resistance.

The ***Plot Existing Junction*** tool allows the user to plot the locations for junctions entered in the Branch Input View. This tool will not allow new junctions to be added, and just allows existing junctions to be plotted.

The ***Create Fan*** tool allows fans or fixed quantity values to be allocated to existing branches. If a fan or fixed quantity already exists in the selected branch, then the fan or fixed quantity attributes for that branch are displayed. The direction of flow is based on the From/To node input data. By selecting a branch with the Create Fan tool the following dialog box appears, shown in Figure 12. The user is then allowed to select a fan or fixed quantity for the assigned branch.

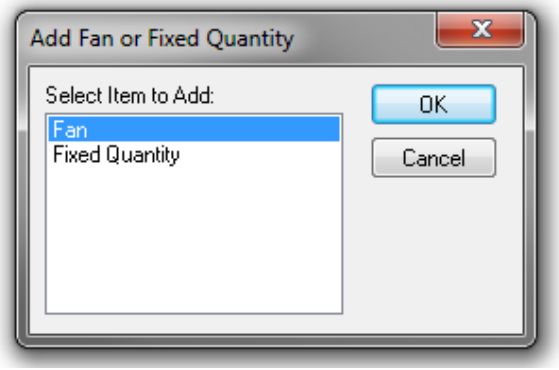


Figure 12: Create Fan Dialog Box

The ***Create Contaminant*** feature is handled in a similar fashion as the fan tool. In this case a dialog box will appear, illustrated in Figure 13, which requires the user to input either a contaminant volume flow or a concentration. The input concentration represents the concentration of the emission at that point in the airway. The user should not enter the total contaminant concentration, which will include any upstream sources. The output contaminant flow and concentration (evaluated by the program) will integrate all of the sources to determine actual concentration and volume based on a steady state condition.

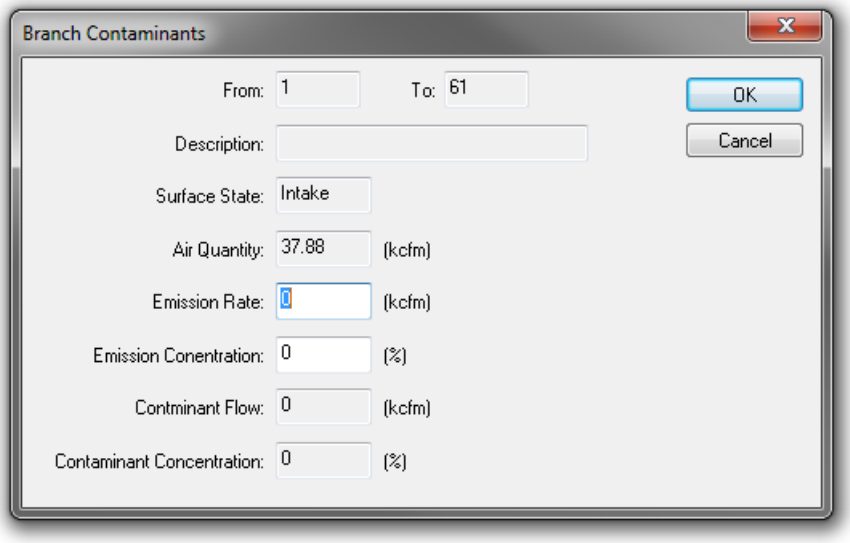


Figure 13: Branch Contaminants Dialog Box

The ***Create Label*** option allows labels to be entered for specific views or groups (layers). Attributes for these labels may then be changed using the Selection Pointer and the right mouse button or the Edit Tool. All the common Windows fonts are supported, and the text size may be adjusted over a large range for individual labels (see Figure 14). The orientation of the label can also be rotated through 360°. The user is allowed to specify a default text font and size (under the Preferences Menu/Default Font).

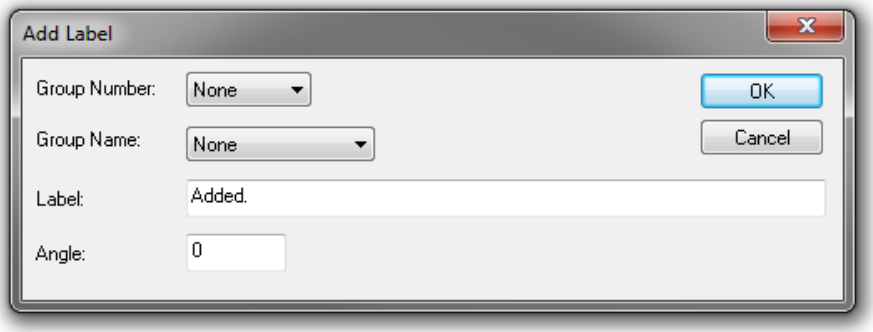


Figure 14: Edit Label Dialog Box

The ***Zoom Tool*** allows the user to resize the view rapidly. A section of the network may be expanded by dragging the mouse over the selected area while holding down the left mouse button. The user can also press the left mouse button to zoom-in, or the right mouse button to zoom-out. Tool buttons in the Schematic View also enable the user to zoom-in/out and zoom all. These buttons are typically required to allow zooming when using a different tool for the mouse (such as Add Branch tool or similar). The zoom –in/out tool is also enabled by scrolling the center wheel on the mouse.

The ***Eraser Tool*** allows the user to rapidly remove unwanted objects from the schematic. The tool will work with branches, nodes and text. A detailed Undo/Redo option ensures that erased data may be recalled in the event of a mistake.

The ***Edit Tool*** allows the attributes of existing objects to be amended. The user must select the required node, branch or text to obtain the properties of the object.

3.3.3.1 Levels and Perspective

VnetPC has been developed to allow networks to be constructed in both the Schematic and Branch Input Views. The Schematic View allows the user to develop 3D models using a level scheme. A level in VnetPC is defined as a group of branches falling within a user-specified range of z coordinates (may be thought of as a "Group" of branches that span a defined z range). It is recommended that the user initially specify a series of levels to cover the entire vertical extent of the network. The levels can be established with overlapping z ranges, such that a shaft or ramp level would represent a group of branches spread across the entire vertical extent of the mine.

By selecting Groups under the Tools drop down menu the user can add, edit, or delete groups from the network in the Branch Groups dialog box as shown in Figure 15.

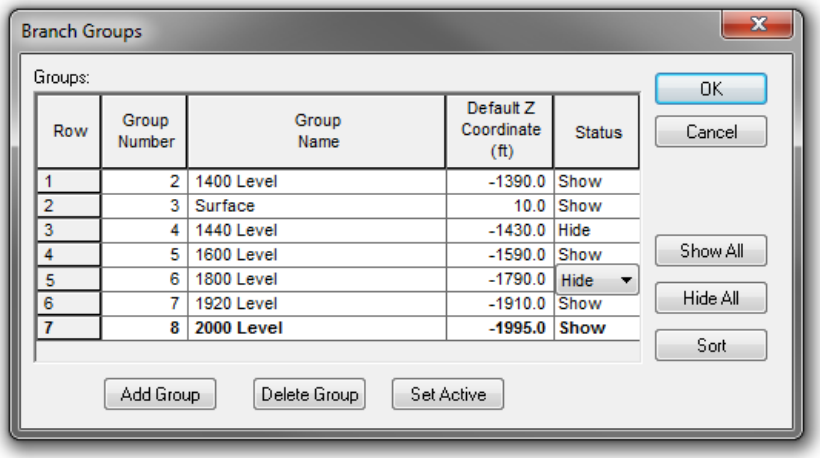


Figure 15: Branch Groups Dialog Box

From this view the names and default z-coordinates of any group can also be modified. Within the Branch Groups dialog box the user can also select which levels to "Show" or "Hide," and which group is Active. The Active group is in bold text and is on which new branches or text can be added.

The level system allows the user to digitize the network in plan view on a level by level basis, which simplifies the construction of a complex 3D mine. VnetPC incorporates multiple choices in viewing perspective for the network.

Plan View

Long Section View

Cross Section View

Isometric (3D View)

Active Group (Level)

Selected Groups (Levels)

All Groups (Levels)

Edit Groups (Levels) Dialog Box

Two of the views are illustrated in Figure 16 (3D) and Figure 17 (Cross Section). The active perspectives may be selected in the Schematic View from the View drop down menu or by selecting an icon on the toolbar.

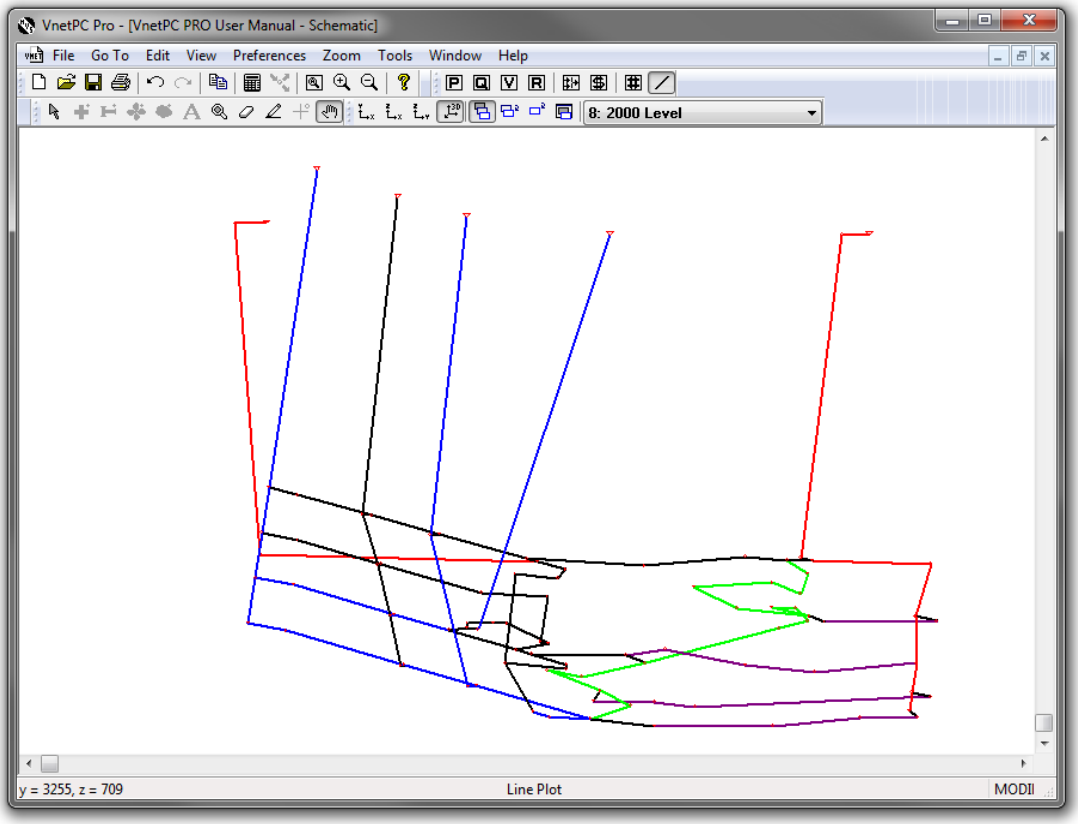


Figure 16: 3D View of a Metal Mine with 3D Spin Tool Active

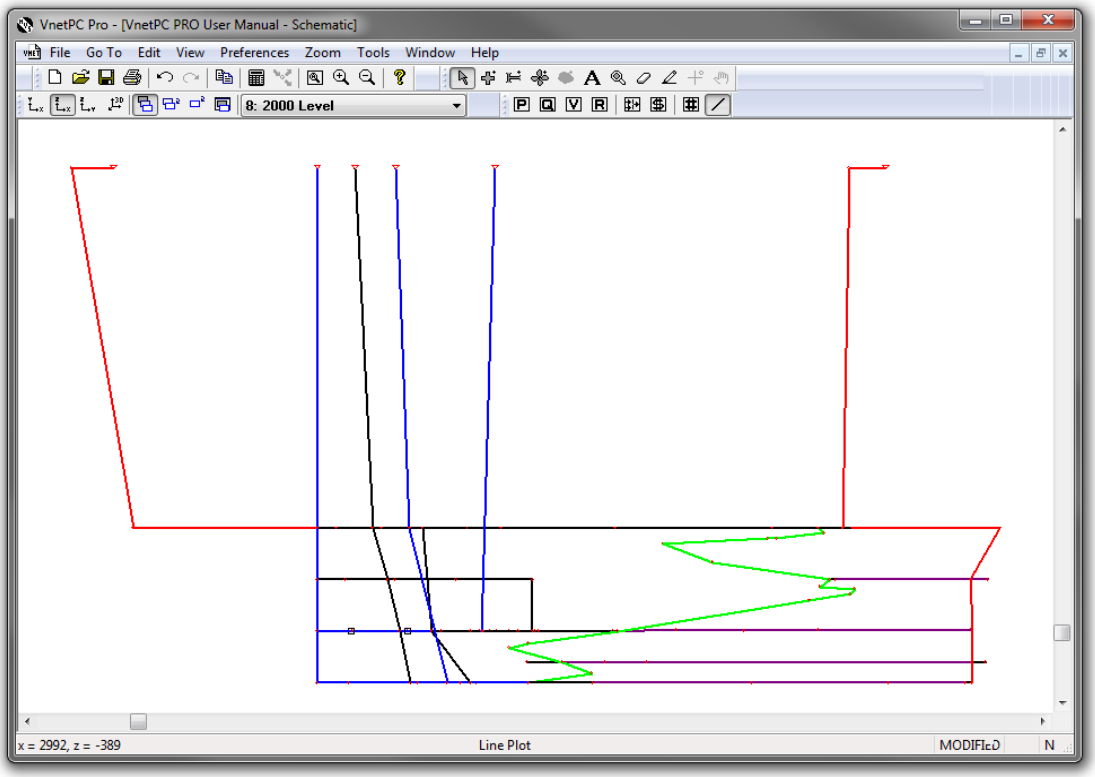


Figure 17: Cross Section View of a Metal Mine

The Plan View, Long Section View, Cross Section View and Isometric (3D) can illustrate all of the groups, selected groups, or only the active group. The groups are designated in the Branch Groups dialog box illustrated previously in Figure 15. The network can be manipulated in each of these views.

The user can select the background color for the Schematic View. The background colors are white, light gray, gray, dark gray, and black with the foreground in black or white. The Background Colors dialog box is shown in Figure 15. The selected background color will be retained for the saved current model. If the user creates and new model, the background color will be the defaulted color of white with the foreground of black.

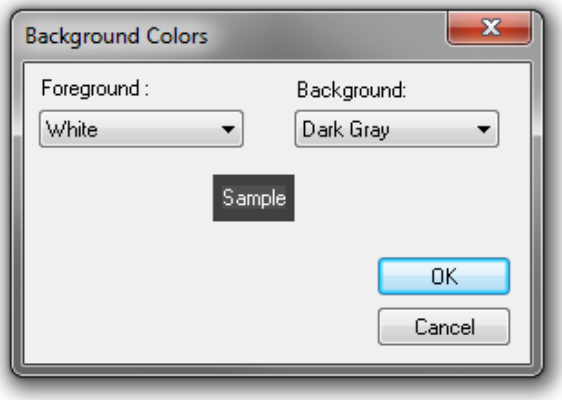


Figure 18: Background Colors Dialog Box

The user can select which group is active using the Branch Groups dialog box or the drop down menu located on the toolbar in the Schematic view. The user can see which group is active because it will be shown in the drop down box on the toolbar. The option of viewing a single group allows the user to work with just that level in Plan, Long Section, or Cross Section View. When using the Plan view, Long Section View, Cross Section View, or Isometric (3D) the user may rapidly change the active group using the drop down menu as illustrated in Figure 19.

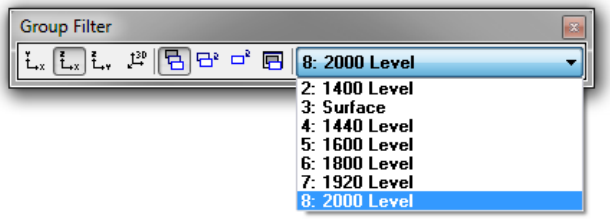


Figure 19: Active Group Drop Down Menu

Non-level airways, such as ramps and shafts may be entered in plan view or in a section view. The nodes should already exist when working in a section view (the start and end nodes), however, this is not necessary. A branch can be drawn from an existing start node to a new node that is not attached to an existing branch. In this case the coordinates of the "new" node will be established by taking the two coordinates shown on the graphical view for that point, and transferring the coordinate perpendicular to the graphical view from the start node to the "new" node.

For example; if a branch is drawn form an existing junction in the cross-section view (Z-X) to a new node then the "Z" and "X" coordinates will be determined by the placement of the junction, and the "Y" coordinate will be taken from the start node.

Once the junctions have been added, they may be moved across the entire vertical extent specified for that level by dragging the nodes within the sectional views.

When entering nodes for a level the "x" value will default to the "z" coordinate that the user specified in the Branch Groups dialog box shown in Figure 14. These default "z" coordinates may be adjusted in the Schematic View using the Selection Pointer to highlight a junction and the right mouse button to change attributes or by using the Edit Tool. Another approach is to drag and drop the node when viewing the network in a section. The "z" coordinate or the group number may be changed directly in the Junction Data View and the Schematic will be automatically updated.

When using in the Isometric view (3D), the tools are limited to Edit Tool, Easer, Zoom and the 3D Spin Tool. The Selection Pointer may also be used to select branches or edit data but the user cannot draw or move branches in the Isometric view. The Zoom tool allows the user to zoom in and out of the network. The 3D Spin tool is used to interact with the model by "grabbing" and "pulling" the network in order to rotate it on the screen. The network can be rotated through 360° in order to find the ideal viewing perspective. During the actual rotation using the 3D Spin Tool (while the user is holding down the left mouse button) the data on the

network will disappear for faster redraw. When the user releases the mouse, the data will reappear onto the network in the new perspective.

3.3.3.2 Grids and Snap to Grid

VnetPC features gridlines that may be plotted on the x, y, and z axes. Under the Preferences menu in the Schematic view select Grid Settings, the Grid Spacing dialog box will appear as shown in Figure 20. This box allows the user to enter the spacing and origin for the gridlines. If the user selects a spacing that is too dense to display, a message box will appear and the user must input new data. A tag at the bottom of the dialog box allows a snap feature to be enabled or disabled. If enabled, then any new or moved nodes will be snapped to the grid.

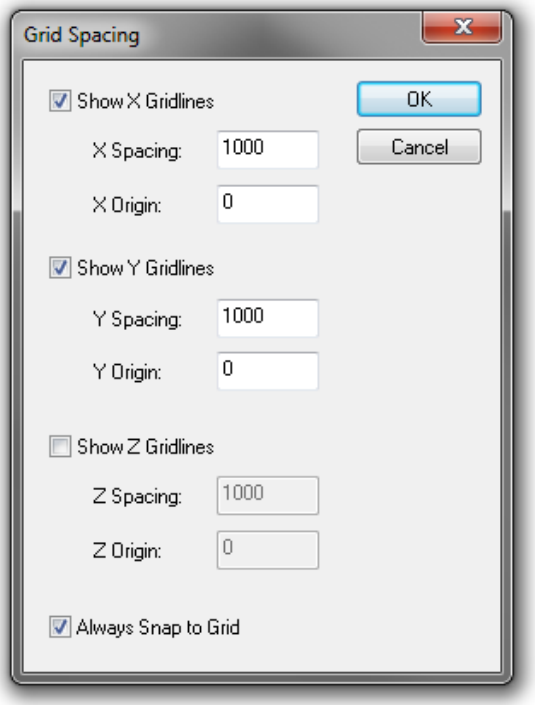


Figure 20: Grid Spacing Dialog Box

3.3.3.3 Junction Creation

When branches are added in the Schematic View, VnetPC will normally add node numbers in an ascending sequence starting from the lowest available number. By selecting Junction Creation under the Preferences Menu the user may disable the feature of using the lowest available number, and input a number to commence the node sequence. Figure 21 illustrates where a user may define the next junction value. The program internally checks node numbers to ensure that a node is only used once.

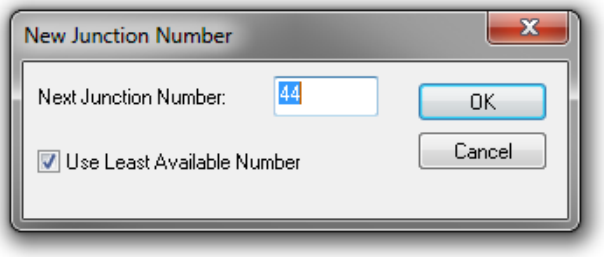


Figure 21: New Junction Number Dialog Box

3.3.3.4 Importing DXF Files from CAD and Mine Planning Programs

VnetPC allows the user to import a network or level from a CAD or mine planning program using a DXF file to transfer the data. Selecting File/Open and DXF Files under the Files of Type option allows data to be imported as a new VnetPC file. The user may also import data into an existing network using the Import DXF feature under the Tools drop-down menu of the Schematic View. A Layer Selection dialog box will appear and the user must select the ventilation schematic layer. When the user selects a DXF file, VnetPC will examine the file for available layers and then prompt the user to select a layer to be used as shown below in Figure 22. The imported layer will created a new Branch Groups defaulting to the name the user specified for the imported layer.

The user has the option to select a default branch type. The selected defaulted branch type will be applied to all new imported branches created for the selected layer. Branch type can be altered quickly following DXF import using the branch templates. The units drop down menu is utilized when the DXF file and VnetPC model have different units. For example, if a VnetPC model is developed in Imperial units but the DXF files are in SI units, the user will select SI units on the Layer Selection dialog box. This function will convert the DXF files units to the VnetPC model units.

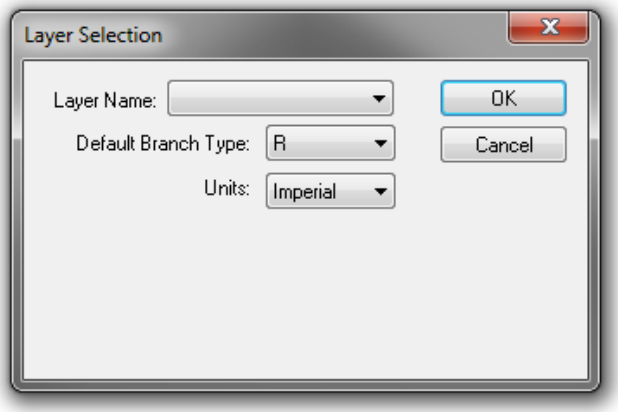


Figure 22: DXF Import - Layer Selection

Establishing a suitable DXF file requires a program that supports layers (such as AutoCAD™). The user should develop the network in the CAD program using only Lines, Polylines, and Text. The network should be developed on a unique (preferably new) layer, with an obvious name,

such as VnetPC. The end point for each line or section of a polyline should represent a node location. Care must be taken to ensure that the end and starting points of connected branches are at exactly the same coordinate (i.e. the nodes do actually connect). This would be done in AutoCAD™ using the snap-to <endpoint of> or <intersection of> options. Failure to do this will result in the data being imported as separate lines rather than a network.

The DXF import feature is not limited to CAD programs and will support DXF data from most mine planning software. Care needs to be taken to ensure that a level is contained in the DXF file, which represents the simplified schematic. If the mine plan is not simplified and centerline coordinates are imported for all the lines and polylines, then an extremely large network will result (for example, a coal mine could import every crosscut in the mine).

3.3.3.5 Surface State

In previous versions of VnetPC the user was required to manually connect all the surface nodes together using zero resistance dummy branches (to ensure full mesh closure). This is not required in VnetPC Pro. The user can now select the surface state of a branch during data entry as Intake, Return, or Neither. It is important that the branch is entered in the correct direction (From and To nodes) such that the airflow will be positive. Failure to do so will result in an error during execution, and a message box stating that one of the surface junctions is allocated in another branch (other than the specified surface branch). This results because the code is attempting to allocate a node as being on surface, when it is actually attached to more than one branch. All surface branches must be specified as either Intake or Return for the program to correctly close meshes and to execute without error.

3.3.3.6 Branch Code

VnetPC Pro allows the network to be color coded according to the type of airway, as well as parameter range. The user may select from a list of airway types; Default, Intake, Return, Neutral, Active and other user defined types. The Branch Codes colors allocated to these types may be changed under the Preferences menu Define Colors as shown in the dialog box in Figure 23. Colors can also be adjusted for the branch parameters in the Define Colors menu. The option to enable the color codes can be selected under the Preferences menu; No Color, Use Color Range, or Use Color Code.

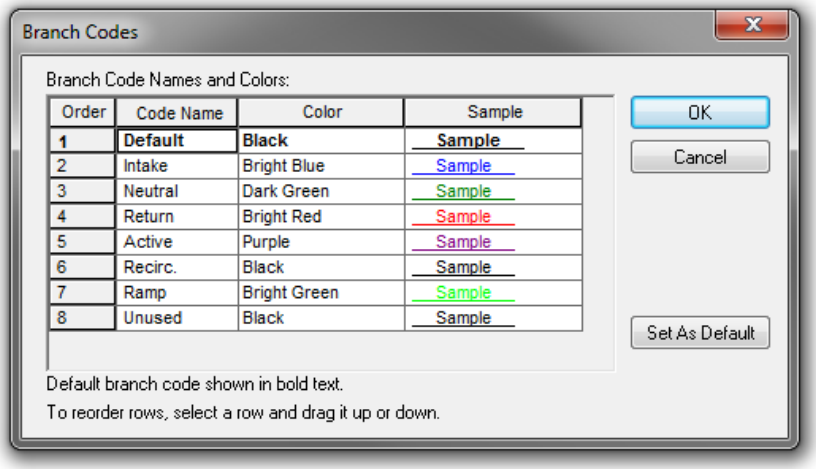


Figure 23: Branch Codes Dialog Box

3.4 Fan Data

The user may add fans in the Branch Input, Fan Input or the Schematic Views. When a fan or fixed quantity of air is added to a branch, an F or a Q will appear in the F/Q/i column. The Fan Input View will be updated to incorporate the new fan details. It is important that the user input the junction numbers in the expected direction of airflow for fixed quantity or fan branches.

In the Branch Input View a fan is added by using the fan input icon or double clicking the cell under the F/Q/i (fan, fixed quantity, inject/reject) column. In the Fan Input View the user may add a fan by selecting Add Fan under the Fan menu or by clicking the add fan icon. In the Schematic View a fan or fixed quantity is added using the Fan Tool, and "dropping" the fan on the desired branch.

3.4.1 Fan Location and Flow Direction

A fan can be located in any branch that does not contain a fixed quantity. The branch junction numbers dictate the fan location. The order in which the junction numbers are entered defines the direction of the fan. To view or edit (or add to) the fans in the model, the user may use the Fan Input View.

3.4.2 Fan Type

Any fan can be entered with either a fixed pressure or with a characteristic curve of pressure against volume flow. The fixed pressure and description of the fan can be entered in the Fan Data dialog box illustrated in Figure 24. This dialog box also allows the user to enter an initial fan pressure if a fan curve is input, then this pressure is used as the starting point on the fan curve. However, if a fan curve is not input, then the fan will be fixed at this pressure (regardless of quantity). Users may turn the operating status for fans in VnetPC models without removing them. When a fan status is turn “Off”, the program will use the entered branch resistance and it will not assume or added resistance to the airway created by the fan dampers closing or by a non-

operating/idle fan. To simulate the resistance of an idle fan or closed dampers, the user must modify the resistance in the branch for the arranged conditions.

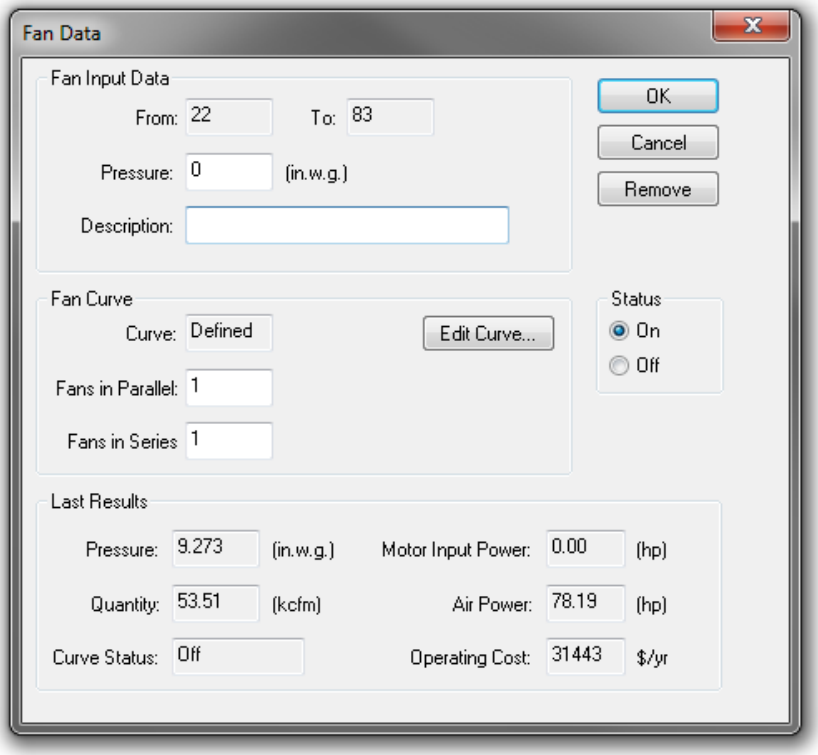


Figure 24: Fan Data Dialog Box

The user may enter a fan curve by selecting Edit Curve from the Fan Data dialog box illustrated in Figure 24, or Edit Fan under the Fan menu in the Fan Input and Fan Results views. Fan characteristic curves are registered by entering between two and twenty sets of pressure/airflow data points (see Figure 25). These points should be chosen such that they adequately represent the full extent of the curve. Users may add efficiencies for each of the fan curve points entered. The program will use the enter airflow, pressure, and efficiency to calculated the Motor Input Power. The program assumes a linear line between any two points on the fan curve. Fans with characteristic curves can be entered under fan data or retrieved from the fan data bank. Once the points of the fan curve are entered into the Fan Data Sheet the user can select "OK" to incorporate the curve into the model or "Save" to export the curve to an external fan curve data base. Note that the fan curves are unit-dependent and that the curves are converted if the unit conversion utility is used.

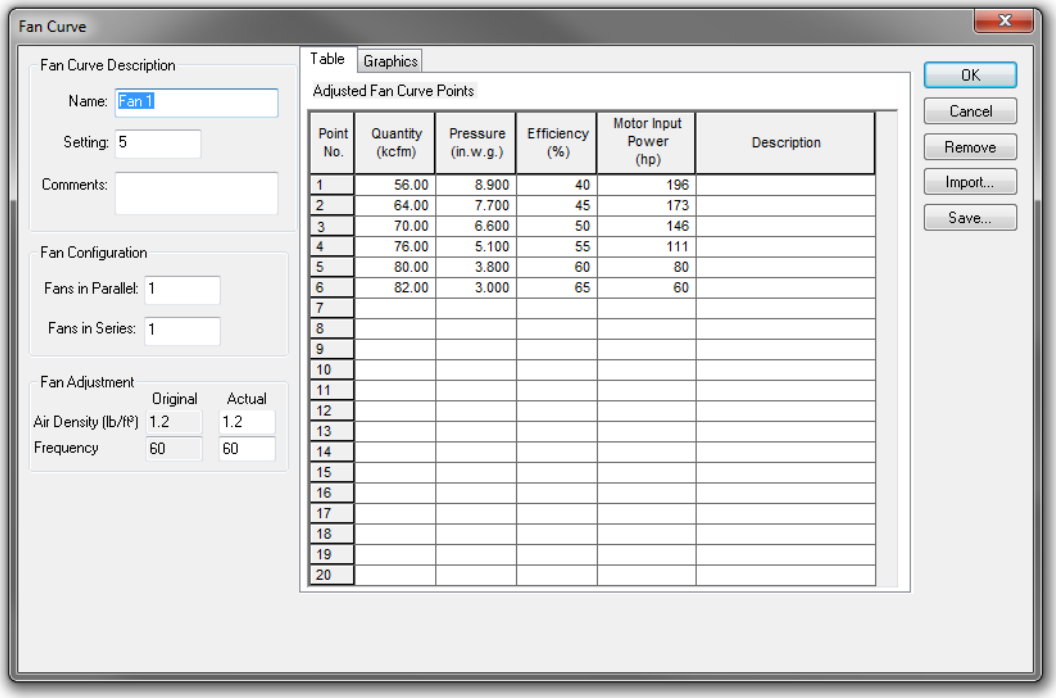


Figure 25: Fan Curve Dialog Box

Using the entered fan characteristic curve, VnetPC Pro will generate a graphical display as shown in Figure 26. After the simulation is executed, the predicted operating point with motor input power is plotted.

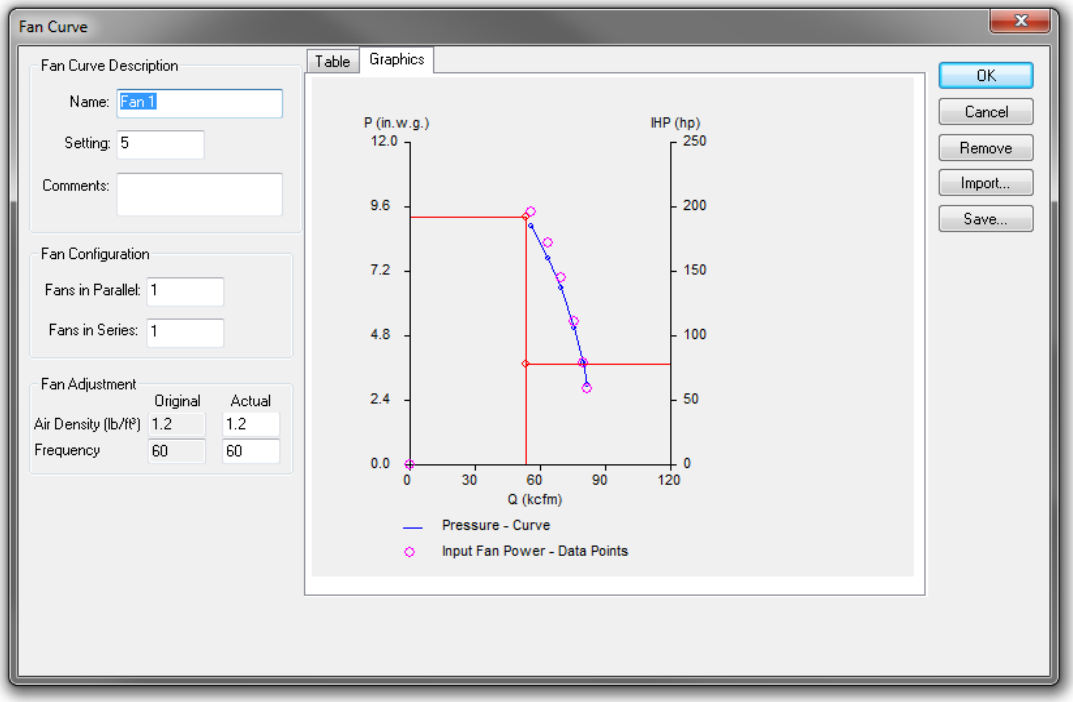
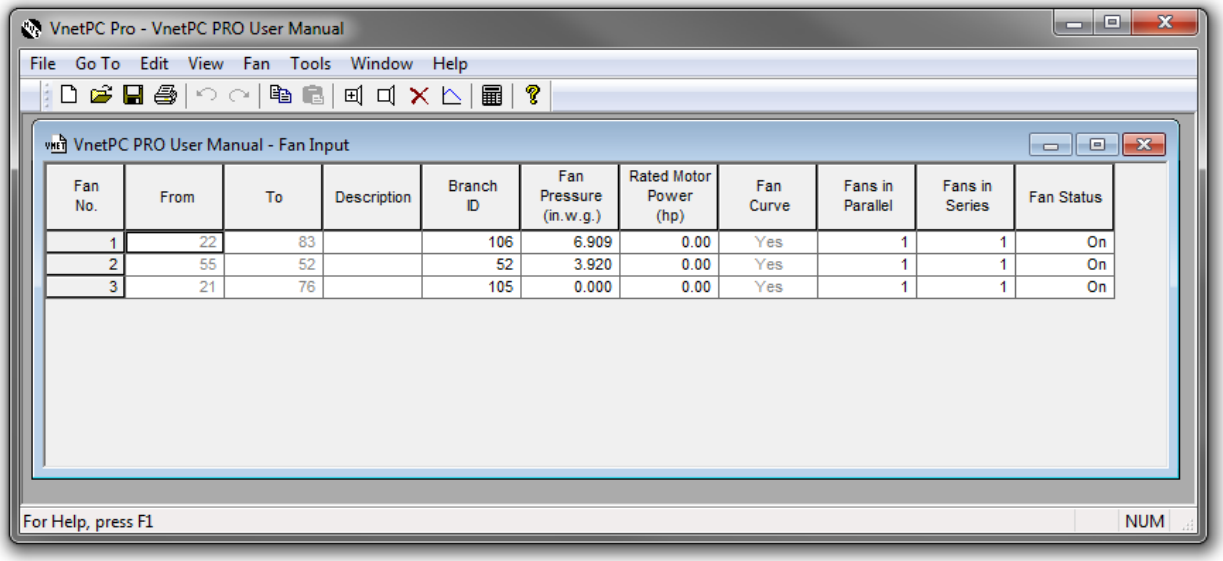


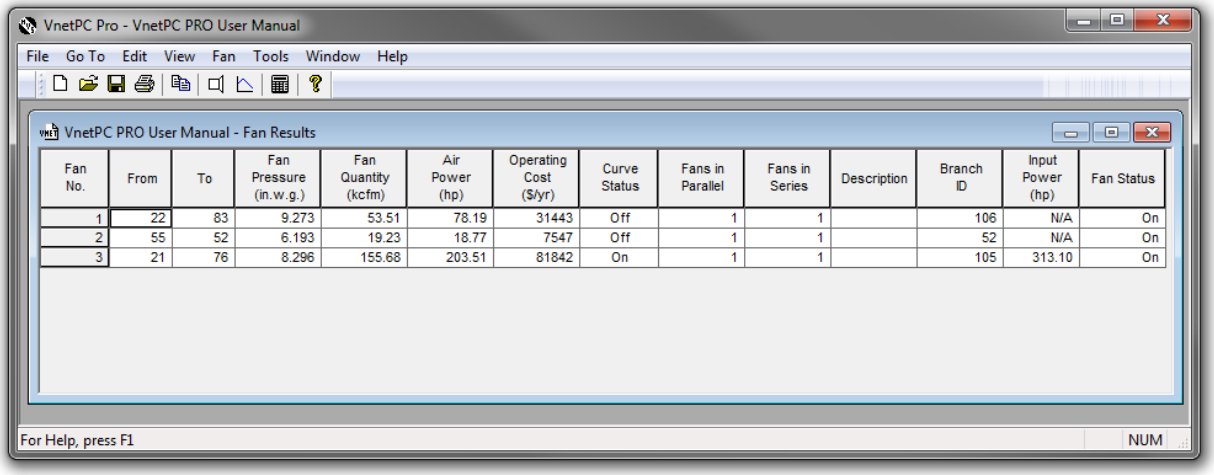
Figure 26: Fan Curve Graphic Dialog Box

The user is also allowed to input data for multiple fans (series or parallel). When multiple fans are selected the program will develop an equivalent fan curve based on series/parallel fan theory. The series and parallel fan data are shown in columns in the Fan Input and Fan Results views (see Figure 27 and Figure 28).



Fan No.	From	To	Description	Branch ID	Fan Pressure (in.w.g.)	Rated Motor Power (hp)	Fan Curve	Fans in Parallel	Fans in Series	Fan Status
1	22	83		106	6.909	0.00	Yes	1	1	On
2	55	52		52	3.920	0.00	Yes	1	1	On
3	21	76		105	0.000	0.00	Yes	1	1	On

Figure 27: Fan Input View



Fan No.	From	To	Fan Pressure (in.w.g.)	Fan Quantity (kcfm)	Air Power (hp)	Operating Cost ($/yr)	Curve Status	Fans in Parallel	Fans in Series	Description	Branch ID	Input Power (hp)	Fan Status
1	22	83	9.273	53.51	78.19	31443	Off	1	1		106	N/A	On
2	55	52	6.193	19.23	18.77	7547	Off	1	1		52	N/A	On
3	21	76	8.296	155.68	203.51	81842	On	1	1		105	313.10	On

Figure 28: Fan Results View

After execution of the ventilation model, a warning message dialog box will appear if one or more fans are operating off their fan curves (see Figure 29). The dialog box is a warning and does not affect the execution of the simulation.

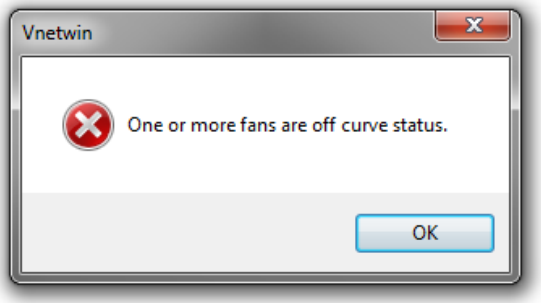


Figure 29: Off Fan Curve Status Warning Dialog Box

Fixed pressure fans are useful when modeling a known fan at a specific operating pressure or when modeling natural ventilation pressure (NVP). In the case of a fixed pressure fan, the fan curve should not be defined in the Fan Curve dialog box, only the fan pressure in the Fan Data dialog box should be input.

3.4.3 Fan File Manager

VnetPC incorporates a data archival program for the development, manipulation and storage of fan curves. This feature is called the Fan File Manager. The Fan File Manager allows the user to generate different fan files, each of which can hold many different curves. Hence, the user may select to have just one fan file for all mine fans, or conversely, have separate fan files for each fan, perhaps with the different curve settings saved for each individual fan.

The Fan File Manager is accessed directly from VnetPC by selecting File/Open and choosing a fan file (*.fdb extension). Application of the Fan File Manager is recommended when a large number of fans must be entered, edited or deleted from the fan database. The user may develop a new fan file by selecting File/New and choosing VnetPC Pro Fan Curve File as the new file type as shown in Figure 30.

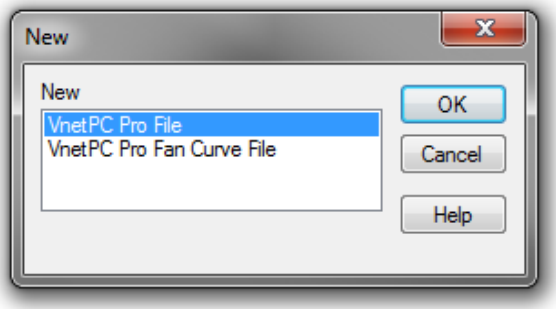


Figure 30: New Fan Curve File

When a new file is opened, a screen will appear which allows the user to input a new curve from the Curve menu. Once the fan points are entered, the file should be saved.

For each fan curve entered into the Fan File Manager a reference density for the curve and a drive frequency need to be entered. When the user brings the fan curve into the ventilation

model, the user can elect to change the reference density of the fan. In this way a fan curve that is supplied from the manufacturer at standard atmospheric density can be saved and then brought into the VnetPC Program at a different density. By shifting the fan operating density, the fan curve will also be shifted according to the ratio of the new density but will retain the original settings from the Fan File Manager. After the fan curve is imported into the VnetPC model, the user may modify the frequency and density using the tool shown in Figure 31.

With the push toward maximizing the efficiency of ventilation systems, MVS has incorporated a tool to modify the fan curve with respect to changes in fan rotational speed based upon the supplied frequency of a variable frequency drive (VFD). When inserting a fan curve into the ventilation model, the user can elect to increase the frequency of the drive or decrease the frequency of the drive – thus changing the rotational speed for the fan and the fan characteristic curve.

The user may save and import fan curves directly from the Fan Curve dialog box (within VnetPC) by clicking the Save and Import buttons. Note that a fan data file must already exist to allow a curve to be saved to it.

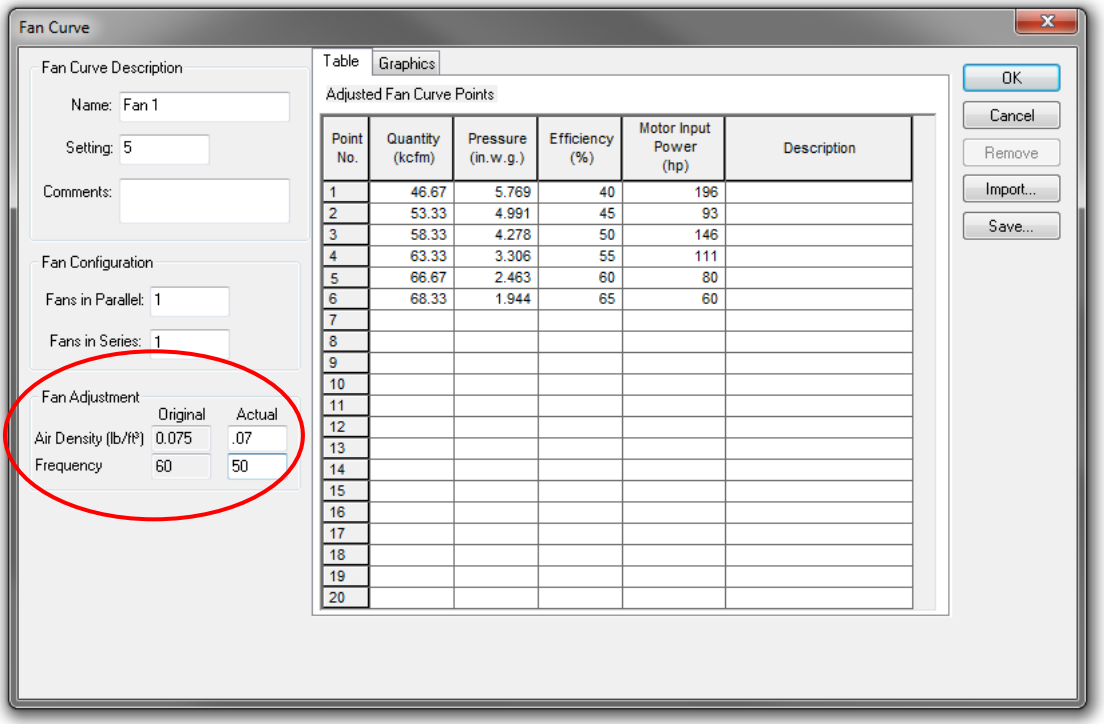


Figure 31: VFD Fan Adjustment

3.4.3.1 Creating a Fan Curve Data Base

a. Under the “File” menu select “New”.
b. Select “VnetPC Pro Fan Curve File”, then select “OK”
c. Select units, then press “OK”
d. Under the “Curve” menu select “Add Curve”

e. Fill out the “Fan Curve Dialog Box”, with the Pressure and Quantity curves points and the Air Density and Frequency for the original curves, then press “OK”
f. Repeat steps a through e to add as many curves as desired
g. Under the “File” menu select “Save As”, then save the file like any Windows application with .fdb file type

3.4.3.2 Importing a fan curve into a model

a. Insert the fan into the model as described above, select the “Edit Curve” button on the “Fan Data” dialog box
b. Select the “Import” button
c. Find the Fan Curve Data Base File in the Windows dialog box
d. Hi-light the desired fan curve and select the “OK” button
e. The fan curve will then be transferred into the Fan Curve dialog box.
f. In the Fan Curve dialog adjust the Air Density and Frequency to actual mine conditions, then press “OK”

3.4.3.3 Saving a fan curve from a model into the Fan Curve Data Base

a. While in the “Fan Data Dialog Box” select the “Save” button
b. Find the Fan Curve Data Base File in the Windows dialog box
c. Select the method to add the fan curve to the data base (replace hi-lighted curve, or add to bottom) and select the “OK” button

3.5 Fixed Quantity Tool

The user may add a fixed quantity to a branch in the Branch Input, Fixed Quantity or Schematic views. In the Branch Input View the Fixed Quantity tool is enabled from the Branch menu, tool button, or by double clicking in the F/Q/i column. This tool is used to simulate control of airflow, and will determine the resistance, pressure drop and orifice area for a regulator or the operating pressure of a booster fan. A fixed quantity can be allocated to any branch that does not contain a fan. The user adds a fixed quantity in the Fixed Quantity View (see Figure 32) by selecting Add Fixed Quantity from the Branch menu, or by clicking the R\Fan tool button. The fixed quantity tool is applied in the Schematic View using the Fan Tool option, and selecting Fixed Quantity rather than Fan when prompted as shown in Figure 33.

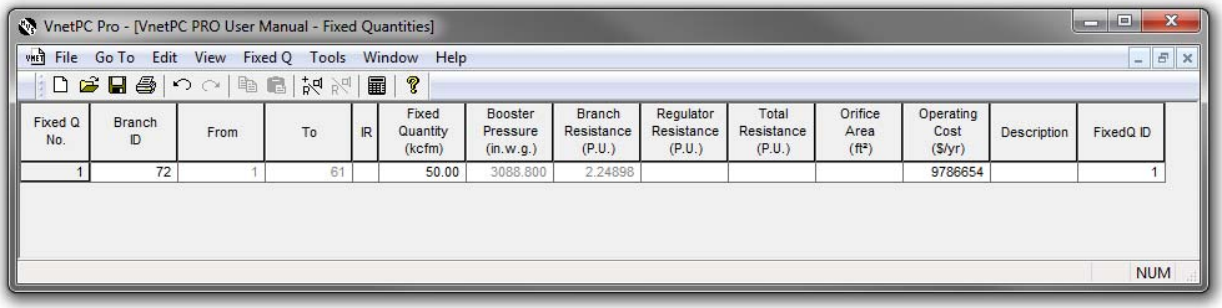


Figure 32: Branch Input Fixed Quantity View

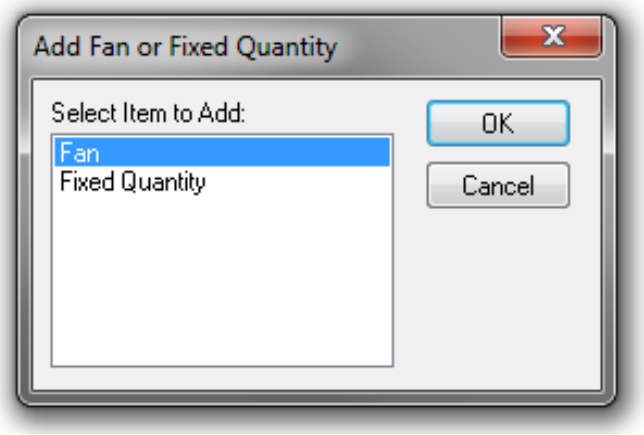


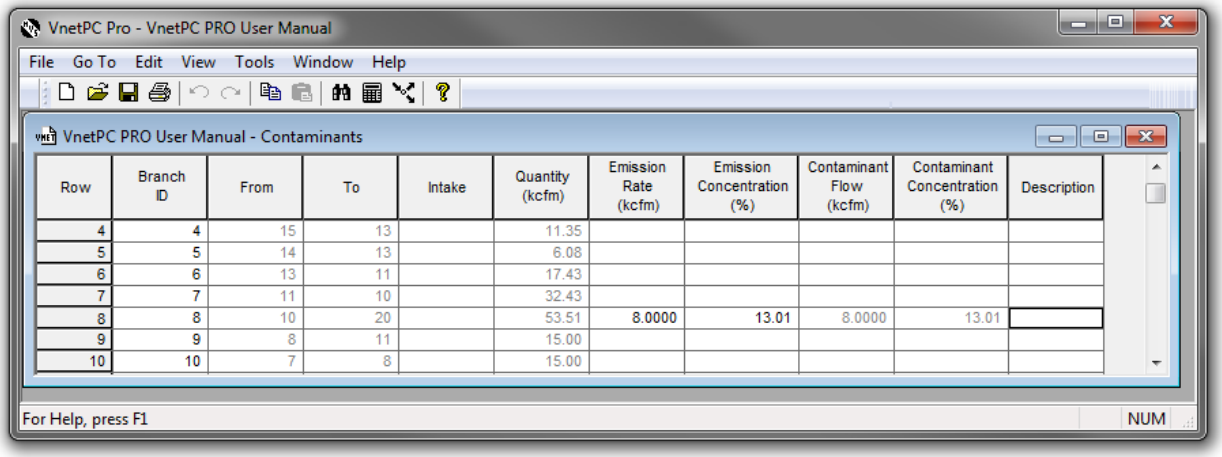
Figure 33: Schematic View Fix Quantity

The Fixed Quantity View will automatically be updated according to the information entered in the Branch Input or Schematic Views. The input data type (1-4) dictates the resistance of the branch. This resistance is usually the natural resistance of the airway without a regulator or booster fan. Upon execution, the program calculates the regulator resistance and orifice area or the pressure of the booster fan required to achieve the specified airflow. Negative integers cannot be entered and it is necessary to change the branch node numbers if airflow is to be reversed.

Within the fixed quantity dialog box there is the option of specifying the branch as an Inject or Reject branch. This tool is used to add or remove air from selected junctions to account for compressibility effects, ducts, compressed air lines, or areas of the facility not otherwise represented in the network. For example, as air passes down a shaft it is compressed due to autocompression. Since VnetPC assumes incompressible flow, this compression may need to be modeled separately by removing air (rejecting) from the model at the base or along the length of the intake shaft. Note that air will probably need to be injected in deep mines to account for the effects of expansion as the air rises.

3.6 Contaminant Distribution Analysis Data

The contaminant distribution utility incorporated in VnetPC utilizes results of the network exercises to evaluate contaminant concentration and gasflow distributions. The user specifies locations and magnitudes of contaminant sources (refer to Figure 34). The program uses airflows from the last execution of the ventilation simulation to calculate contaminant flow assuming steady-state conditions. The program also assumes fully turbulent flows with complete mixing.



Row	Branch ID	From	To	Intake	Quantity (kcfm)	Emission Rate (kcfm)	Emission Concentration (%)	Contaminant Flow (kcfm)	Contaminant Concentration (%)	Description
4	4	15	13		11.35					
5	5	14	13		6.08					
6	6	13	11		17.43					
7	7	11	10		32.43					
8	8	10	20		53.51	8.0000	13.01	8.0000	13.01	
9	9	8	11		15.00					
10	10	7	8		15.00					

Figure 34: Contaminant Data View

Identifying the branches representing the location of the contaminant emissions lets the user specify the sources. Under the Contaminant Data View the branch numbers, junction numbers and branch description will appear the same as in the Branch Input View. These values cannot be changed in the Contaminant Data View. Contaminant sources are entered as quantities or concentrations in the various columns. Valid entries for emission rate must be positive and less than 10.0 kcfm or m^3/s. Data can be entered to four decimal places. Contaminant data is entered in the Schematic View using the Contaminant Tool, and clicking on the branch where the contaminant will be added. The input concentration represents the concentration of the emission at that point in the airway. The user should not enter the total contaminant concentration, which will include any upstream sources (this value is computed by the program).

The contaminant distribution analysis routine requires that branches representing intakes carrying fresh air directly from the surface be identified. VnetPC uses those branches selected as Intake from the Branch Input and Schematic Views (used for mesh closure as well as contaminant analyses). The contaminant execution is conducted by selecting Execute Contaminant from the Tools Menu (in any view), or pressing the Execute Contaminant button, located on the Tool Bar.

3.7 Branch Template

The Branch Template feature equips users with the ability to apply data to individual or multiple branches. Users define individual branch data properties using a Branch Template (see Figure 35). After a branch template is defined, users may apply this to a single branch or multiple selected branched. Users can locate the list of templates using the “Go To” drop-down menu and selecting Branch Template.

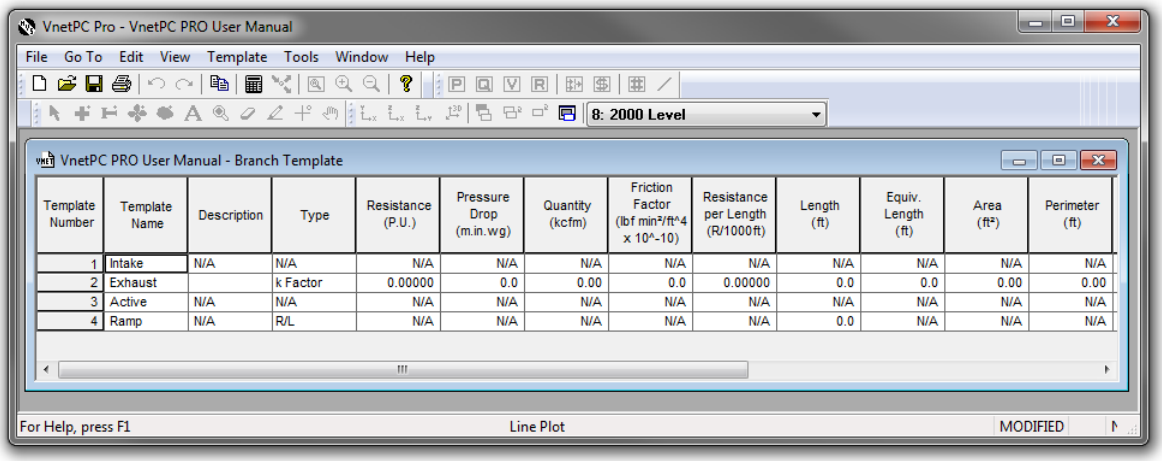


Figure 35: Branch Template View

Branch Templates allows users to rapidly apply either complete branch data or selected branch data. Branch Templates are designed for users to rapidly develop models and have the ability to selectively modify individual fields of data. Using the Template Fields (see Figure 36), users can select which fields of data will be changed when the template is applied. The Template Fields dialog box can be accessed by choosing "Select Fields" from the Template drop-down menu is in the Branch Template view. This feature will only modify the selected fields. For example, a user creates multiple branches with varying resistance data types but would like to modify the Branch Code to all the same. The user will select to apply the Branch Code and ignore the other available fields.

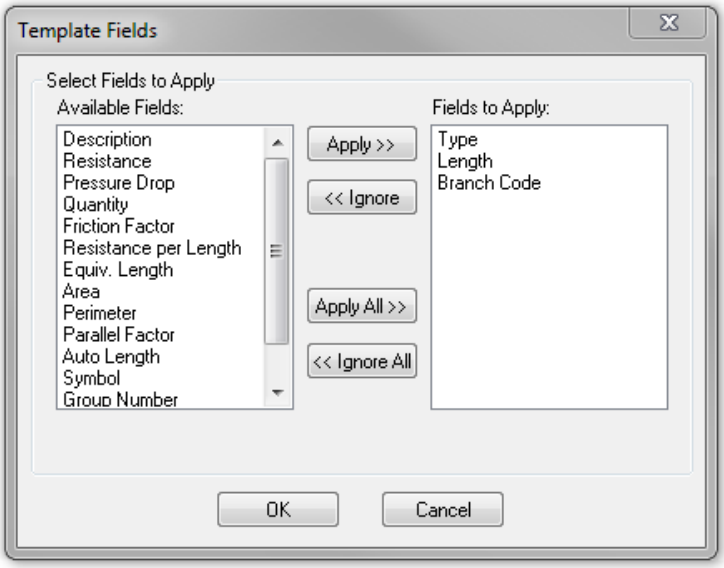


Figure 36: Branch Template Fields Selection Dialog Box

Branch Templates can be added to a ventilation model in the Schematic View and Brach Input View. In Schematic View, a user may select a branch or branches using the Selection Pointer tool. Using the Selection Point right click on a selected branch a selection dialog pop-up will

appear where the user may select “Apply Template”. A Select Template dialog box will appear as shown in Figure 37.

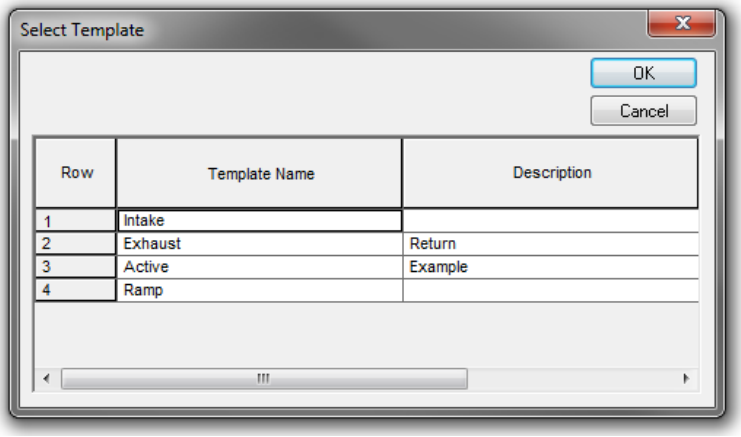


Figure 37: Select Template Dialog Box

3.8 Transient Time Calculator

The transient time calculator is used to calculate how long it will take for a particle to travel through a defined section of the network. This time is determined with the air velocity calculated from the airflow quantity, the area of the openings, and the length of the branches. The calculator is accessed through Tools drop down menu selecting Transient Time. In this dialog box shown in Figure 38 the user must start by entering a series of junctions to create a path, which will be traversed by the particle. After this is done, the user must enter the average cross-sectional area and length of the individual branches in either the Branch Input View or Schematic View. The program will extract the pertinent airflows, lengths, and areas from the branch data. Once the user has input the dimensions of the branches, the total time to traverse the path is computed by pressing the Calculate button on the Air Transient Time Calculator dialog box. The user can store sequences that will be used more than once by using the Sequence List button available on the Transient Time dialog box.

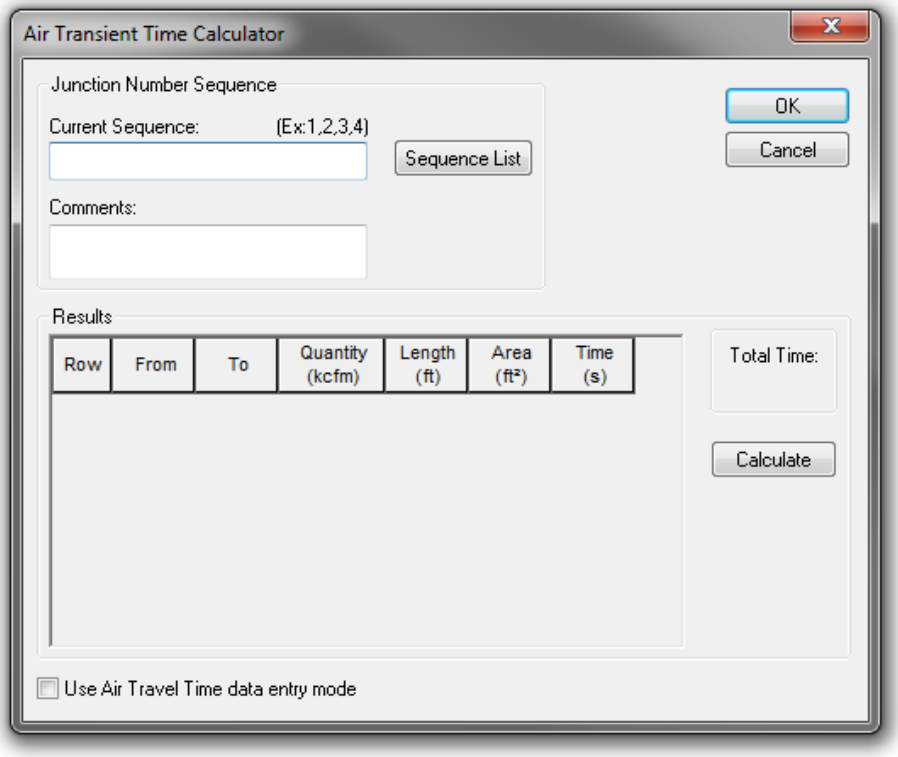


Figure 38: Transient Time Calculator Dialog Box

4. Operating the Program

4.1 Manage Network Files

VnetPC utilizes conventional Windows protocol for managing files. VnetPC files are searched for under the designated .vdb file extension and fan files under the .fdb extension. Files may be accessed from the host computer or through a network system.

4.2 Data Conversion – Previous VnetPC Versions

VnetPC allows import of files from the previous version of VnetPC (VnetPC 2000, VnetPC 2003, and VnetPC 2007). To convert a file, the user opens it normally, executes the simulation, and then saves the file in the new VnetPC Pro format. It is important that the file to be converted (from VnetPC for Windows) has coordinates specified for all the junctions in the network. If the user has not specified coordinates for all the nodes, then errors will appear when the file is opened.

4.3 Execute Ventilation Simulation

Executing the program is accomplished by selecting the Tools Menu on the menu bar and then choosing "Execute Simulation". This should only be done when the branch, fan, and descriptive data for the network have been fully entered. When the program has finished execution, each

view, and any previously accessed windows, will be updated with the current information. Execution may also be initiated by hitting the Execute Simulation tool button (denoted by a calculator symbol) on the toolbar in any view. The contaminant simulation must be executed separately after the airflow simulation has been accomplished.

Unlike the previous versions of VnetPC, relative pressure analyses are conducted during every execution of the code (the user does not have to tag on or off). Relative pressure is the difference in pressure from each node to the user specified reference junction. This reference is often useful to determine relative pressure difference between two unconnected junctions. Output of the relative pressure is viewed on the schematic, in square brackets, or in the Junction Data View. The user can select whether to view or hide the relative pressure data on the Schematic using the Preferences drop down menu and selecting Relative Pressure.

4.4 Viewing the Results of a Simulation

Once the program has been executed, the results of a simulation may be viewed using the Branch Results, Fan Results, Fixed Quantity, Schematic or the Contaminant Data Views. The output data can also be sent to a Plotter or Printer. Any computational errors are automatically listed in the Error dialog box immediately following execution. This dialog box may also be accessed from the Tools Menu in any view.

4.4.1 List Errors

VnetPC identifies four basic execution errors (see Figure 39).

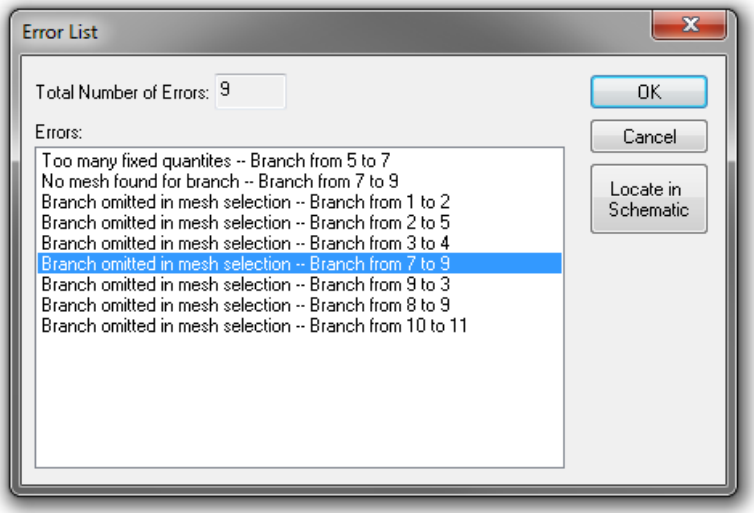


Figure 39: View Errors Dialog Box

Once an error has been identified in a branch, the program does not stop execution but continues operation until it converges on a solution. The following errors may occur:

4.4.1.1 Too Many Fixed Quantities

This error message arises if the input data file contains an excessive number of fixed quantity or inject/reject branches. If fixed quantity branches are used excessively in interconnecting branches, some fixed quantities will be omitted from the mesh selection process. Only one fixed quantity branch is allowed per mesh. In the case of this error the Branch Input View should be modified to decrease the number of fixed quantity or inject/reject branches before the network is re-executed.

4.4.1.2 Branch Omitted in Mesh Selection

The branches that appear under this heading in the error screen were not included in the mesh formation process and were omitted. The truncated network is still evaluated, but without the omitted branches. Junctions connected to only one branch (e.g. dead-end branches) usually cause this error. If this message appears the network should be scrutinized and amended.

4.4.1.3 No Mesh Found for Branch

This message arises from the basic branch and mesh selection processes. The minimum number of basic branches and meshes required for every network is defined as (number of branches - [number of junctions + 1]). If, for any reason, this value is not attained during the basic branch selection process, or the mesh selection process, this error message will occur. The program is designed to continue evaluation of the network based on the number of meshes attained.

4.4.1.4 Iteration Limit Exceeded

The number of iterations for the Hardy Cross process used to solve the network is limited to 1000 iterations. If, after 1000 iterations a balance has not been reached, the program terminates and the values obtained after the 1000th iteration are listed as the results in the output.

This error is most often caused by excessive use of very high resistance branches. The network data should be checked and the schematic viewed to identify any erroneous branches. The iteration limit is set in order that the computer does not spend excessive time performing iterations trying to resolve an unsolvable network.

4.4.1.5 Locate Error in Schematic Tool

In the event an Error List dialog box appears after execution, the user may highlight the error in the list and push “Locate in Schematic”. The selected branch in the error list will become highlighted as shown in Figure 40. The error list will remain on the screen to assist the user with locating the errors in the ventilation model.

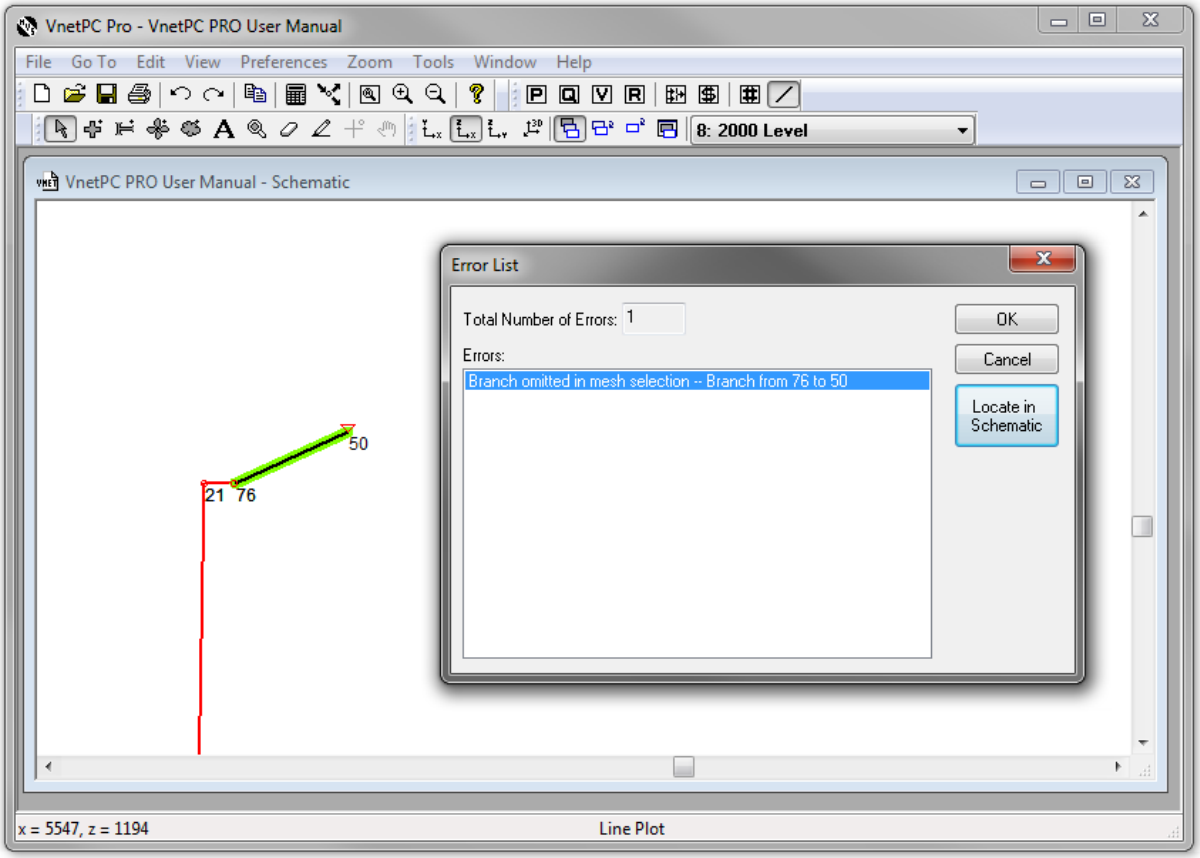


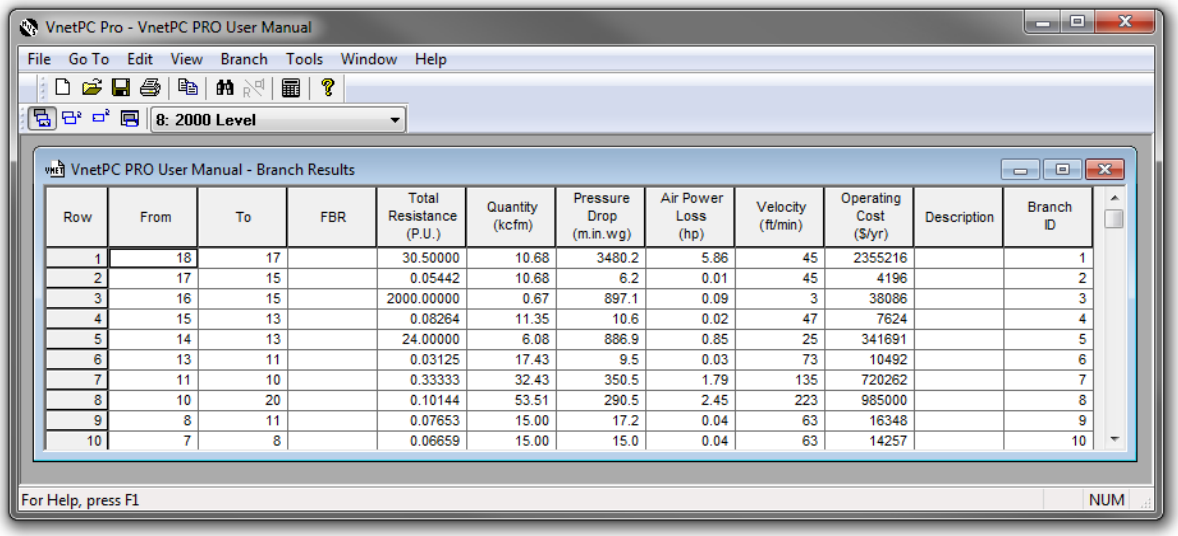
Figure 40: Locate in Schematic Error List

4.4.2 Fan Operating Points

The Fan Results View lists the output operating points for the fan(s) in the model. It gives the operating pressure, airflow, parallel/series configuration, required power, annual operating cost, curve status, fan status, and a description of the fan. If the user supplies a fan curve then the Fan Results View also lists whether or not the fan is operating on the curve. The user cannot modify the Fan Results View.

4.4.3 Branch Results

The Branch Results View lists the output in a spreadsheet format (see Figure 41). Data includes the branch number, junction numbers, airway total resistance, airflow, pressure drop, air power, velocity, branch description, and a symbol indicating whether the branch contains a fan, regulator or booster fan (FRB). The output sheet is designed such that it is easy to read and simple to scroll through. The user cannot modify the data in the Branch Results View. The total resistance column reports the total of the branch input resistance and the resistance of any regulation resulting from fixed quantities. To obtain a breakdown of these two resistance values it is necessary to examine the Fixed Quantity View.



Row	From	To	FBR	Total Resistance (P.U.)	Quantity (kcfm)	Pressure Drop (m.in.wg)	Air Power Loss (hp)	Velocity (ft/min)	Operating Cost ($/yr)	Description	Branch ID
1	18	17		30.50000	10.68	3480.2	5.86	45	2355216		1
2	17	15		0.05442	10.68	6.2	0.01	45	4196		2
3	16	15		2000.00000	0.67	897.1	0.09	3	38086		3
4	15	13		0.08264	11.35	10.6	0.02	47	7624		4
5	14	13		24.00000	6.08	886.9	0.85	25	341691		5
6	13	11		0.03125	17.43	9.5	0.03	73	10492		6
7	11	10		0.33333	32.43	350.5	1.79	135	720262		7
8	10	20		0.10144	53.51	290.5	2.45	223	985000		8
9	8	11		0.07653	15.00	17.2	0.04	63	16348		9
10	7	8		0.06659	15.00	15.0	0.04	63	14257		10

Figure 41: Branch Results View

4.4.4 Fixed Quantity Information

Fixed quantity input and output data are shown under the Fixed Quantity View (refer to Figure 32). This view lists branch number, junction From/To, whether the branch is designated as inject/reject (I/R), booster pressure, regulator resistance, regulator orifice area, input branch resistance, total resistance of the branch (if regulated), and description for the fixed quantity.

4.4.5 Displaying the Results using the Schematic

The on-screen schematic is perhaps the most user-friendly way to input and view data. Ventilation networks can be entirely developed within the Schematic View, and it provides a rapid means of viewing the network results. In the Schematic View different parameters may be plotted onto the network using the Preferences Menu.

4.4.5.1 Preferences Menu

The Preferences Menu allows the user to select which output parameters are to be shown and how to show them. The key features from this menu are listed below;

Parameter

This command allows the user to identify the desired parameter to be displayed on the schematic. The eleven choices are:

- Quantity
- Velocity
- Pressure Drop
- Air Power Loss
- Operating Cost

- Contaminant Flow Results
- Contaminant Concentration
- Resistance
- Branch Number
- Line Plot
- Dual Parameters

Each parameter may be plotted separately for legibility or the user may use the Dual Parameters feature. Dual Parameters allows the user to select two types of parameters to be displayed on the schematic and the user may select the text color for the selected parameters being displayed.

The user may rapidly change the parameters being displayed on the schematic using the quick select tool bar shown in Figure 42.

Figure 42: Parameter Quick Select Tool Bar

Dual Parameters

The Dual Parameters feature enables users with the ability to display two parameter outputs on the schematic simultaneously. Users can access the Dual Parameters through the Preferences drop-down menu, then selecting Parameters (see Figure 43).

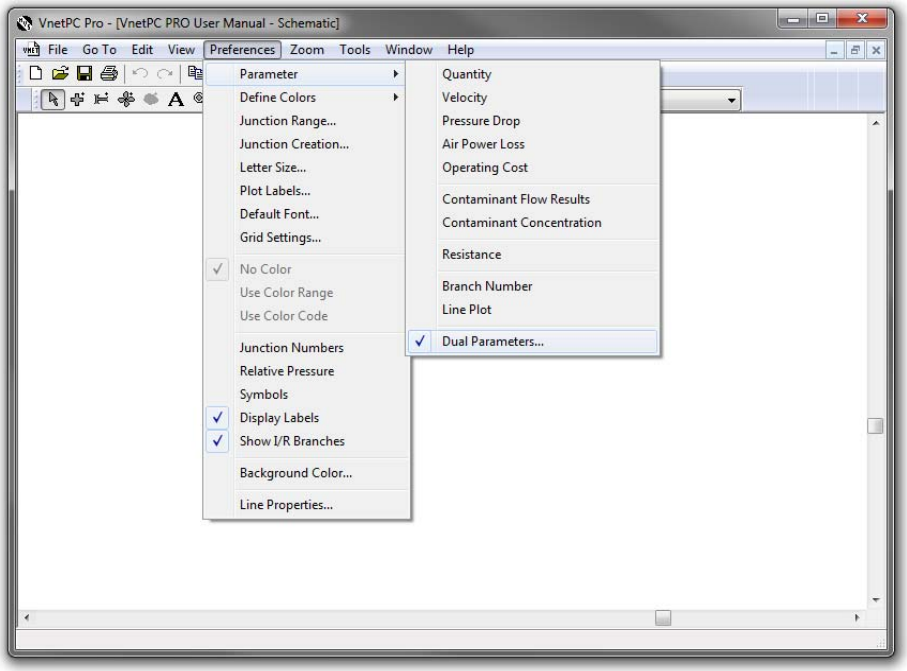


Figure 43: Selecting Dual Parameters in Schematic View

After selecting Dual Parameters from the Preferences drop-down menu a Select Dual Parameters dialog box will appear (see Figure 44). With the drop-down menus for parameter and color, users may select with two parameters will be displayed on the schematic. The text colors displayed on the schematic are user defined. After the user selects the parameters and colors press "OK".

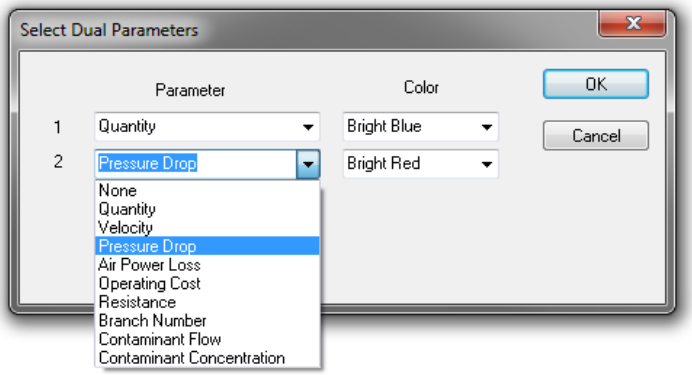


Figure 44: Select Dual Parameters Dialog Box

Figure 45 is an example of Dual Parameters being displayed on the ventilation schematic in VnetPC Pro. For this example, Quantity color coded Bright Blue was selected for Parameter 1 and Pressure Drop color coded Bright Red was selected for Parameter 2.

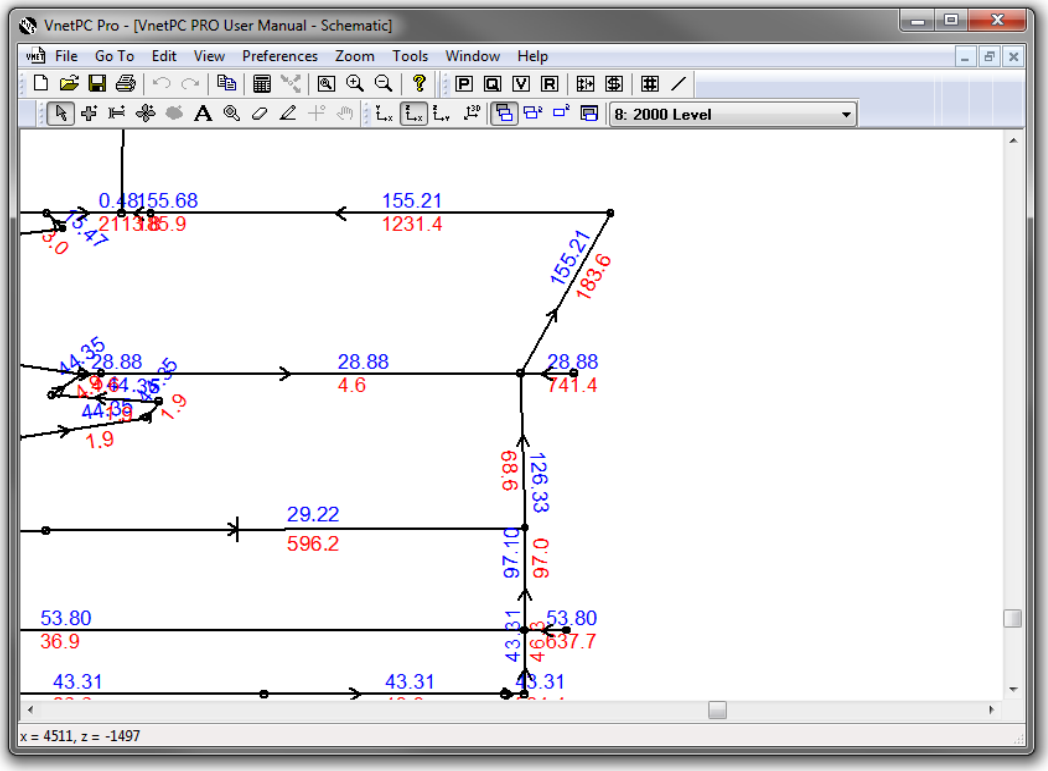


Figure 45: Example of Dual Parameters Displayed on a Ventilation Schematic

Define Colors

This command allows color ranges to be specified for the different parameters. There is a choice between fourteen colors, black, and white. For a specified parameter range, the network branches containing values within that range will appear on the screen and printer/plotter in the specified color. A legend can be printed detailing parameter ranges and color assignments. This option is useful to help identify high pressure drops or excessive operating costs in the branches within the network. If the specified printer does not have color, then the legend will automatically be omitted from the output. Within this group there is also the option of setting a color for junction numbers and relative pressure.

The user may also select to define colors for the Branch Code, as opposed to a parameter range. This allows colors to be assigned for different types of branches, which can be specified from certain categories during entry of the input data. The basic branch types available are Default, Intake, Neutral, Return, Active, and several user defined branch labels. Within the Preferences Menu the user can select whether to use branch colors based on parameter range, branch code, or whether to disable the color option entirely.

Junction Range

This command allows the user to display a selected series of nodes. This is particularly helpful when sections of the schematic are no longer in use, and the user wishes to show only relevant areas. The total junction range is from 1 to 10000.

Letter Size

This command allows the user to adjust the size of the parameters plotted on the schematic. It is often useful to customize the lettering size to fit the schematic so that the labels are easily read. The range of font sizes is as follows; screen 4 to 12 point, printer 4 to 14 point, and DXF 1 to 200. These fonts are actual sizes, and do not vary according to coordinate range.

Junction Numbers

This command toggles the junction numbers on and off in the Schematic View. This is helpful when branch values and node numbers become cluttered. Removing the junction numbers may help to clarify the drawing.

Relative Pressure

The relative pressure is given in square brackets next to each junction. This feature is now available to be toddled on and off in the Schematic View and does not have to be tagged during execution (as with previous versions of VnetPC).

Symbols

This command toggles on and off any symbols the user has specified in the network.

Display Labels

This command toggles on and off the labels created in the Schematic view.

Show Inject/Reject Branches

This command toggles on and off any inject/reject branches that the user has specified in the network. The branches are still included in the calculation, but are not shown in the Schematic View.

Line Properties

This command allows the user to change the thickness of the branches to be displayed in Schematic view and printed with the Line Width as illustrated in Figure 46. The Highlight function allows users to increase the thickness of branches. The Highlight function can be used based on the Selected Branch, Active Group, or Contaminates. An example of the Highlight function is shown in Figure 47.

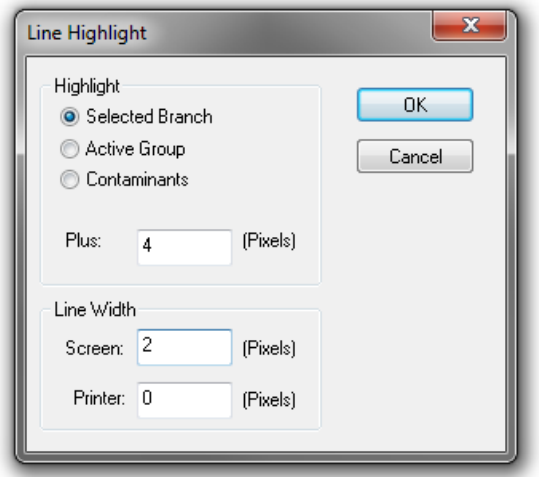


Figure 46: Line Highlight Dialog Box

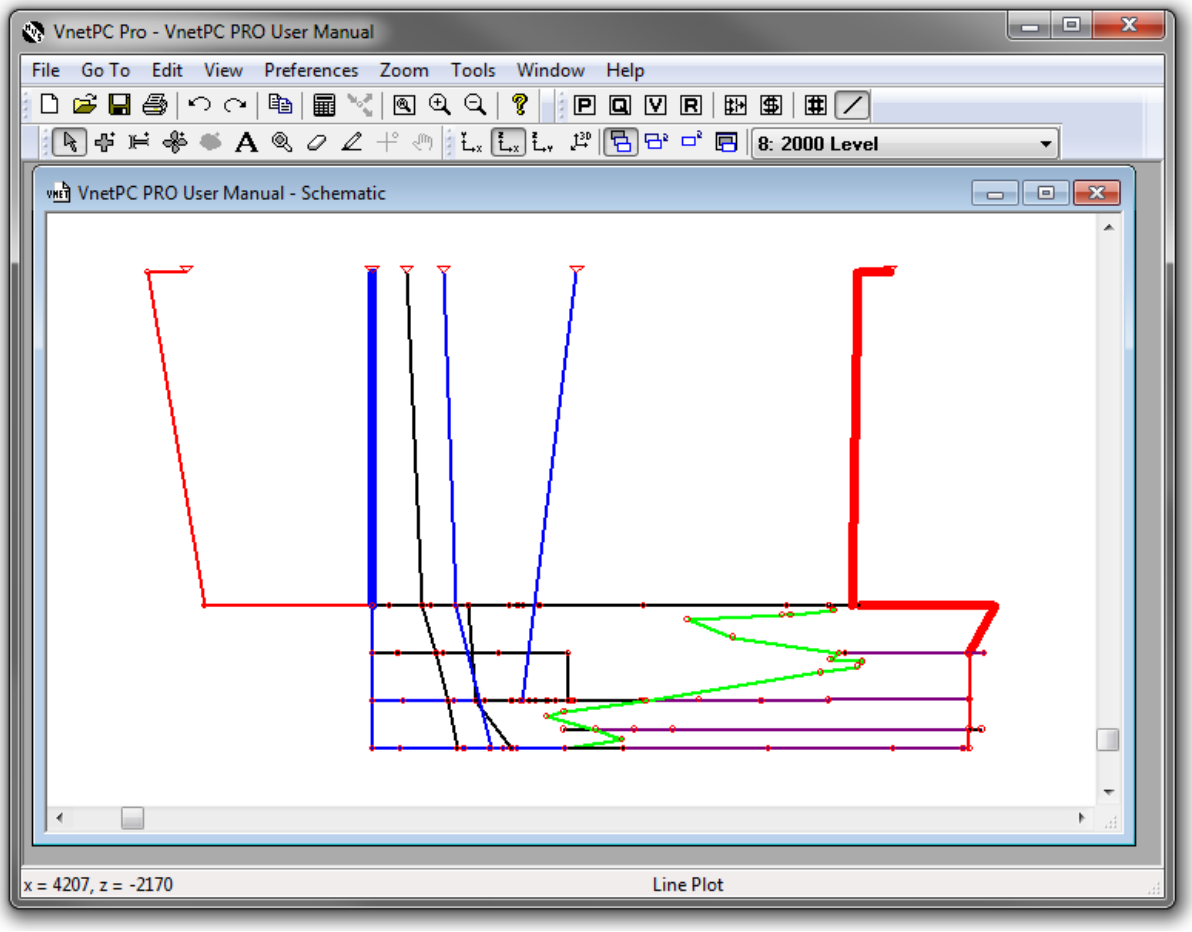


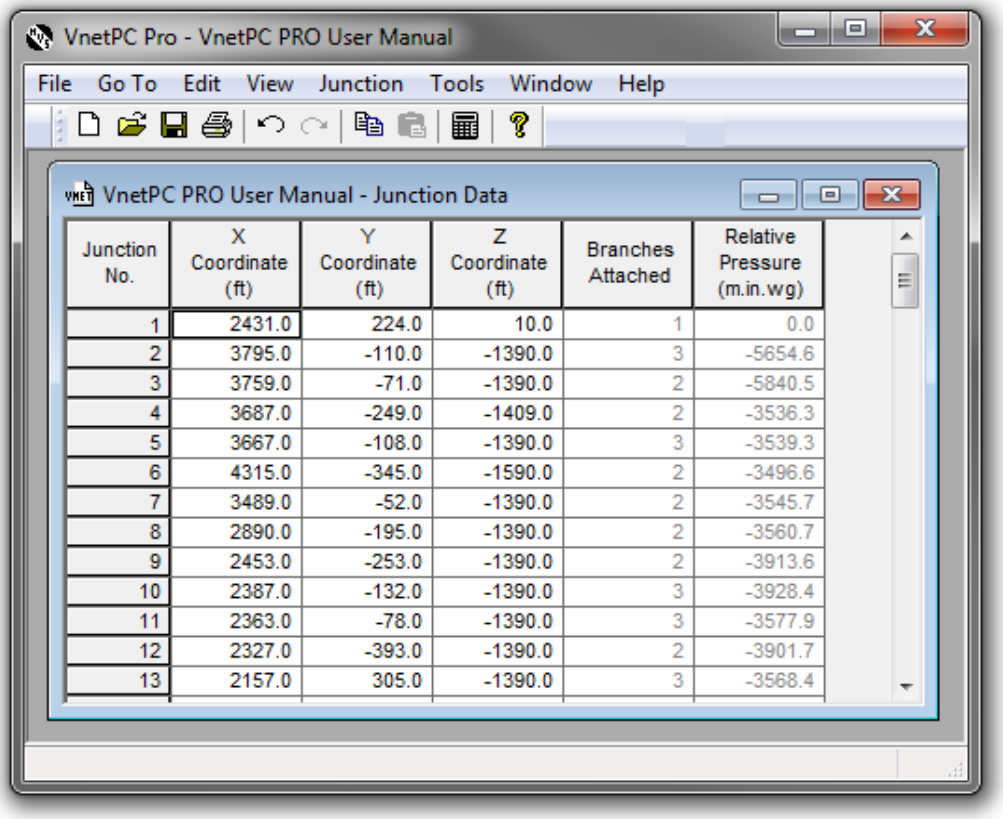
Figure 47: Example of Line Highlight for a Metal Mine

4.4.5.2 Zoom Menu

With the Zoom command the user can either zoom-in or zoom-out within the schematic. The user can also select a window to zoom by engaging the Zoom Tool under the Tools Menu. Once a window has been zoomed it can be reduced by using the "Previous" or All command on the Zoom Menu. The "Previous" command zooms to the previous level. The All command resizes the extents of the network to fit on the screen. There is also a Zoom All tool button present in the Schematic View. Panning from one portion of an enlarged schematic to another can be accomplished by utilizing the scroll bars, arrow keys on the keyboard, or pressing down the center mouse wheel. When panning, the program will redraw the schematic between each pan.

4.4.5.3 Junction Data

In order to display or print the on-screen schematic, coordinates must be assigned to each junction. Coordinates are either entered manually or copied (from a spreadsheet) into the Junction Data View (see Figure 48), imported from a DXF file, or digitized using the system pointer within the Schematic View. In the Junction Data View the junction numbers appear on the left column, and X, Y and Z coordinates are shown in the adjacent three columns. The column marked Branches Attached indicates how many branches are connected to each node.



Junction No.	X Coordinate (ft)	Y Coordinate (ft)	Z Coordinate (ft)	Branches Attached	Relative Pressure (m.in.wg)
1	2431.0	224.0	10.0	1	0.0
2	3795.0	-110.0	-1390.0	3	-5654.6
3	3759.0	-71.0	-1390.0	2	-5840.5
4	3687.0	-249.0	-1409.0	2	-3536.3
5	3667.0	-108.0	-1390.0	3	-3539.3
6	4315.0	-345.0	-1590.0	2	-3496.6
7	3489.0	-52.0	-1390.0	2	-3545.7
8	2890.0	-195.0	-1390.0	2	-3560.7
9	2453.0	-253.0	-1390.0	2	-3913.6
10	2387.0	-132.0	-1390.0	3	-3928.4
11	2363.0	-78.0	-1390.0	3	-3577.9
12	2327.0	-393.0	-1390.0	2	-3901.7
13	2157.0	305.0	-1390.0	3	-3568.4

Figure 48: Junction Data View

4.4.5.4 Ventilation Structure Symbols

Ventilation structure symbols are entered in either the Schematic or Branch Input views. From the Schematic View the user enters a symbol in the Branch Data dialog box. In the Branch Input View the user selects from a list of six symbols in the Symbol column. These symbols can be toggled on/off by tagging Symbols under the Preferences Menu.

4.4.6 Printing Output Data

The output data (tabular views) and the schematic can be directly printed by either clicking the print icon on the tool bar, or by selecting the Print Active View subheading under the File Menu. A dialog box will appear that allows the user to print in draft or final mode. In draft mode lines are placed around the header of each page being printed. In final mode each output cell in the tabular views is bordered which requires additional printing time. The user can also specify a print range in the Print Dialog box. Printing a range of branches is possible by checking the Branch Range box and specifying those branches to be printed.

Prior to printing the output or the schematic, it can be previewed on the screen by selecting the Print Preview subheading under the File menu. The printer can be reconfigured by selecting the Print Setup subheading under the File Menu. This can be particularly helpful when changing the

paper orientation from portrait to landscape. Often the schematics and branch input data are better represented by printing in landscape mode. Different output devices can be specified using the Print Setup option as long as the device driver has been loaded within Windows.

4.4.7 Plotting Output Data

Plotting is managed the same way as printing, except that the device driver selected in the Print Setup will be a system plotter. VnetPC allows plotting to a complete range of plotters supported by Windows. Providing that the plotter device driver has been loaded in the Windows Setup, VnetPC should recognize and communicate with any plotter.

4.4.8 DXF File Generation

The user can export the schematic to a DXF file. This feature is accessed through the Schematic view using the Tools/DXF file menu. A dialog box will appear for the user to Save As in DXF format, then another dialog box will appear prompting the user to select a parameter to export, illustrated on Figure 49. This feature allows the users to define which parameter or no parameters to be exported. The exported DXF file layers will be named (automatically) to allow the user to easily recognize what data is contained on each layer.

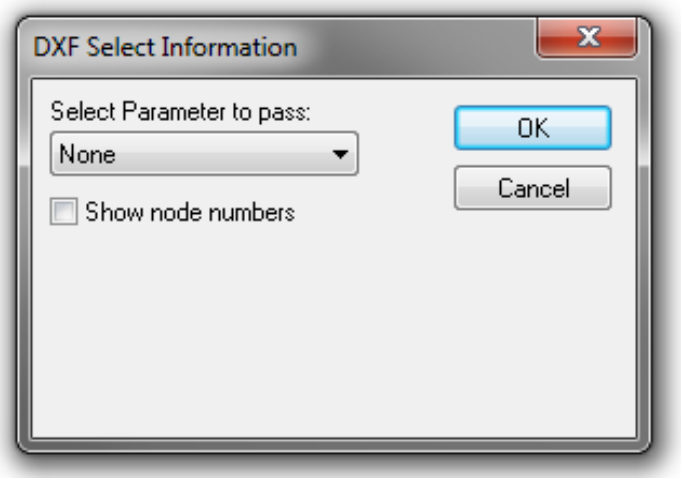


Figure 49: DXF Select Information Dialog Box

4.5 Changing the Appearance of a Table View

All of the columns in the table views can be changed in any number of ways. The columns and rows can be rearranged, widened or narrowed, removed or added. The columns can be easily rearranged by clicking on the column or row header with the left mouse button to hi-light it, then by clicking on it and dragging it to its new position. The column width can be widened or narrowed by clicking on the column separators in the column header and dragging it in one direction or another. The columns can be removed or added by selecting Columns from under the View menu on the tool bar. This is useful so that the items on a view can be limited to only those parameters actually used in the simulation. Figure 50 shows the columns dialog box for the Branch Input View. Users may view all the groups, selected groups, or active group in the

Branch Input and Branch Results views as shown in Figure 51. This function allows the user sort the data by groups for easier viewing.

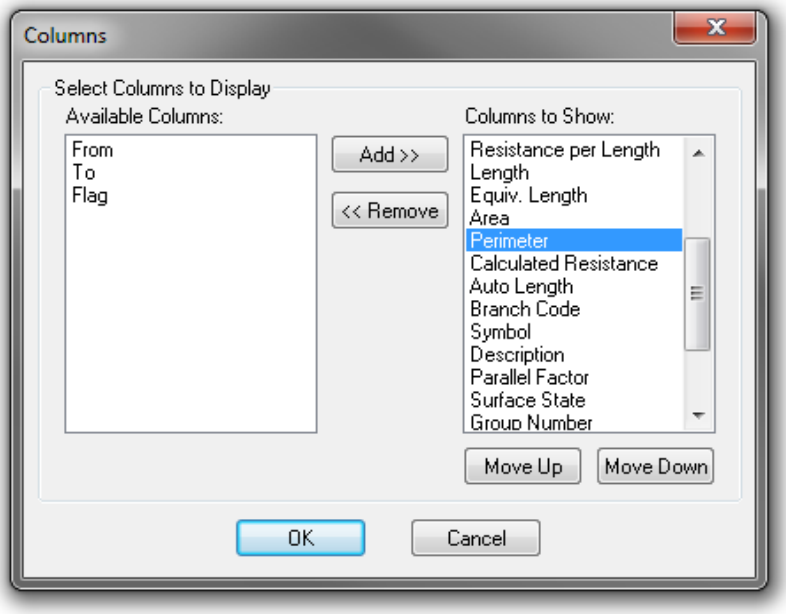
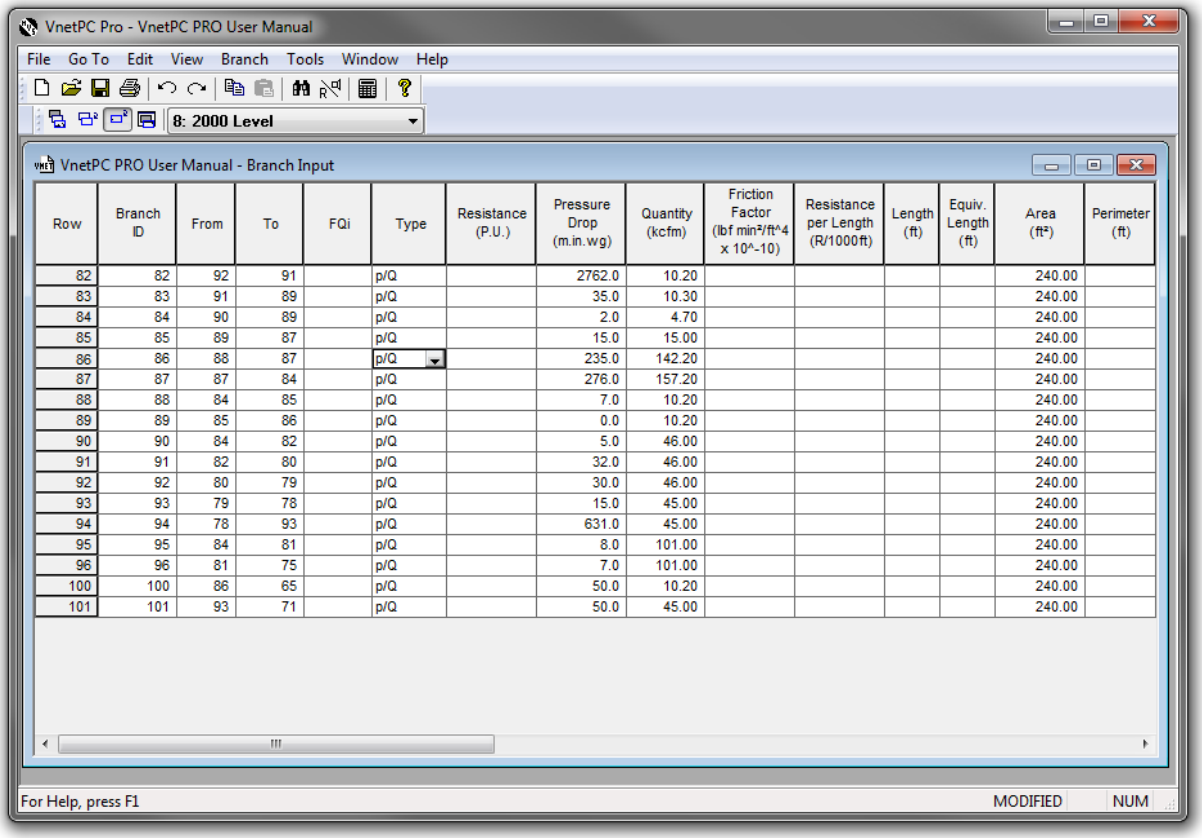


Figure 50: Columns Dialog Box for Branch Input View



Row	Branch ID	From	To	FQi	Type	Resistance (P.U.)	Pressure Drop (m.in.wg)	Quantity (kcfm)	Friction Factor (lbf min²/ft^4 x 10^-10)	Resistance per Length (R/1000ft)	Length (ft)	Equiv. Length (ft)	Area (ft²)	Perimeter (ft)
82	82	92	91		p/Q		2762.0	10.20					240.00	
83	83	91	89		p/Q		35.0	10.30					240.00	
84	84	90	89		p/Q		2.0	4.70					240.00	
85	85	89	87		p/Q		15.0	15.00					240.00	
86	86	88	87		p/Q		235.0	142.20					240.00	
87	87	87	84		p/Q		276.0	157.20					240.00	
88	88	84	85		p/Q		7.0	10.20					240.00	
89	89	85	86		p/Q		0.0	10.20					240.00	
90	90	84	82		p/Q		5.0	46.00					240.00	
91	91	82	80		p/Q		32.0	46.00					240.00	
92	92	80	79		p/Q		30.0	46.00					240.00	
93	93	79	78		p/Q		15.0	45.00					240.00	
94	94	78	93		p/Q		631.0	45.00					240.00	
95	95	84	81		p/Q		8.0	101.00					240.00	
96	96	81	75		p/Q		7.0	101.00					240.00	
100	100	86	65		p/Q		50.0	10.20					240.00	
101	101	93	71		p/Q		50.0	45.00					240.00	

Figure 51: Selected Group being Displayed in Branch Input View

5. Tutorial

For additional information on the many tools and features mentioned in this section, refer to the previous sections in this document and the program "Help Tools".

5.1 Introduction

This tutorial describes how to establish a ventilation model in VnetPC using AutoCAD™ (or a DXF file generated by another mine planning or CAD package) to establish a network schematic. Additional help about other VnetPC features can be found in the Contents selection of the Help menu in the VnetPC Program. The following sections detail how to establish a ventilation schematic in AutoCAD™ and create a new VnetPC file from the data. The step by step process provides the user with an in-depth look at how to get started.

5.2 Setting Up the Model in AutoCAD

5.2.1 Adding the Ventilation Layers

The AutoCAD™ program allows users to create layers. It is suggested that for each section/component of the mine, a new layer be created for the network schematic (e.g. set up new layers for each level, or the ramp, shaft, etc.). An example Layer Properties Manager dialog box has been copied out of AutoCAD™ and is shown in Figure 52 to demonstrate this feature. The original drawing layers are 1400, 1600, 1800, 1920, and 2000. The layers 1400VENT, 1600VENT, 1800VENT, 1920VENT and 2000VENT were created for the purpose of importing a schematic into the VnetPC Program.

Each of the layers denoted with the suffix VENT, will contain a portion of the overall schematic. When transferring the schematic to VnetPC, each level must be individually imported. Because VnetPC uses the digital exchange format (DXF), it can import files from other software applications that utilize a graphical image to present data. An example metal mine is shown below with each layer turned on to show how they overlay. This procedure can be done with multiple files (one for each level instead of a layer); however, it can be more efficient to develop a mine map in one DXF file with multiple layers (as shown on Figure 53). Figure 54 shows a single level of the mine. This level will be used to start a schematic drawing.

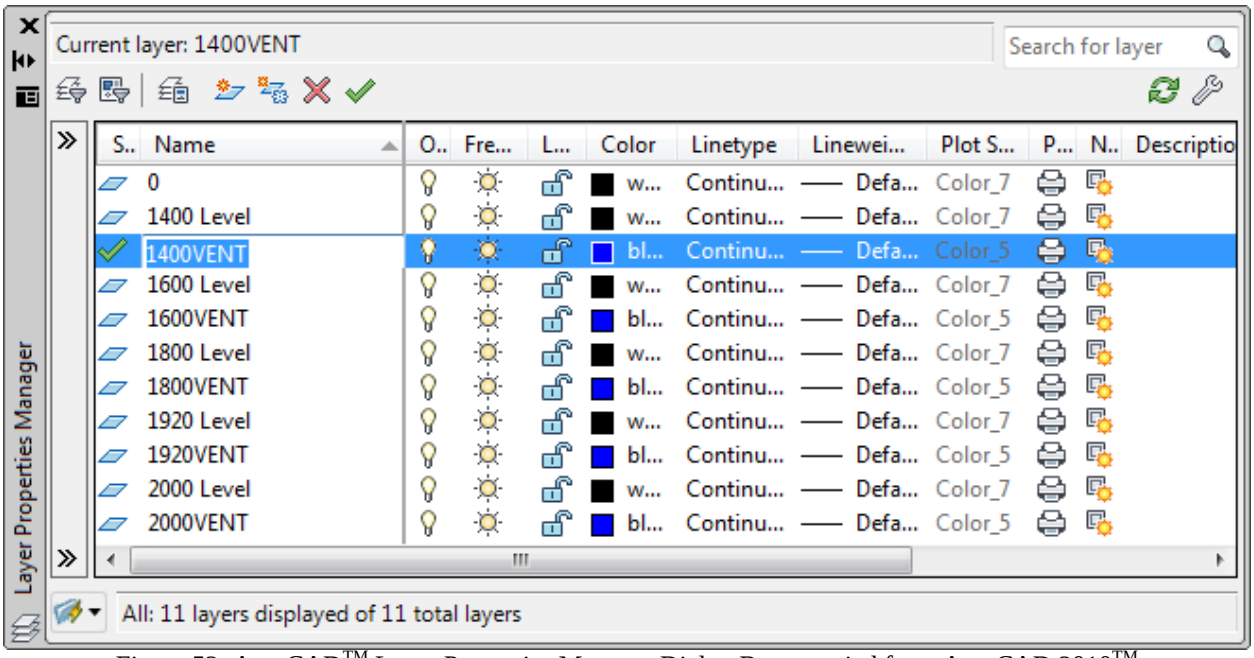


Figure 52: AutoCAD™ Layer Properties Manager Dialog Box - copied from AutoCAD 2010™

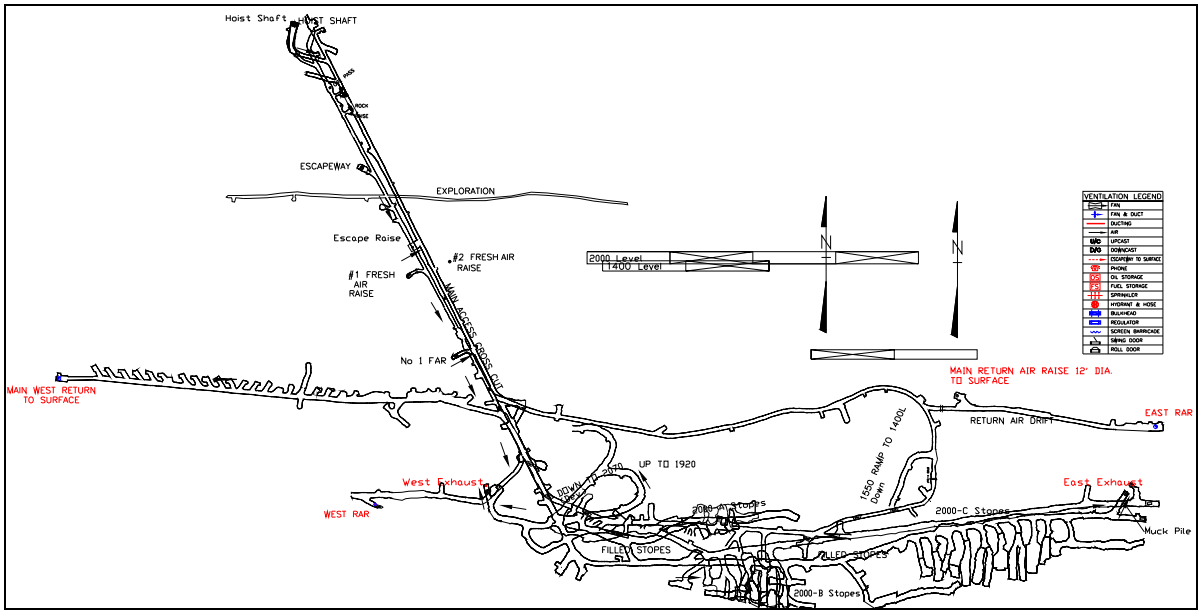


Figure 53: Drawing of Metal Mine Airways (Plan View with multiple levels active)

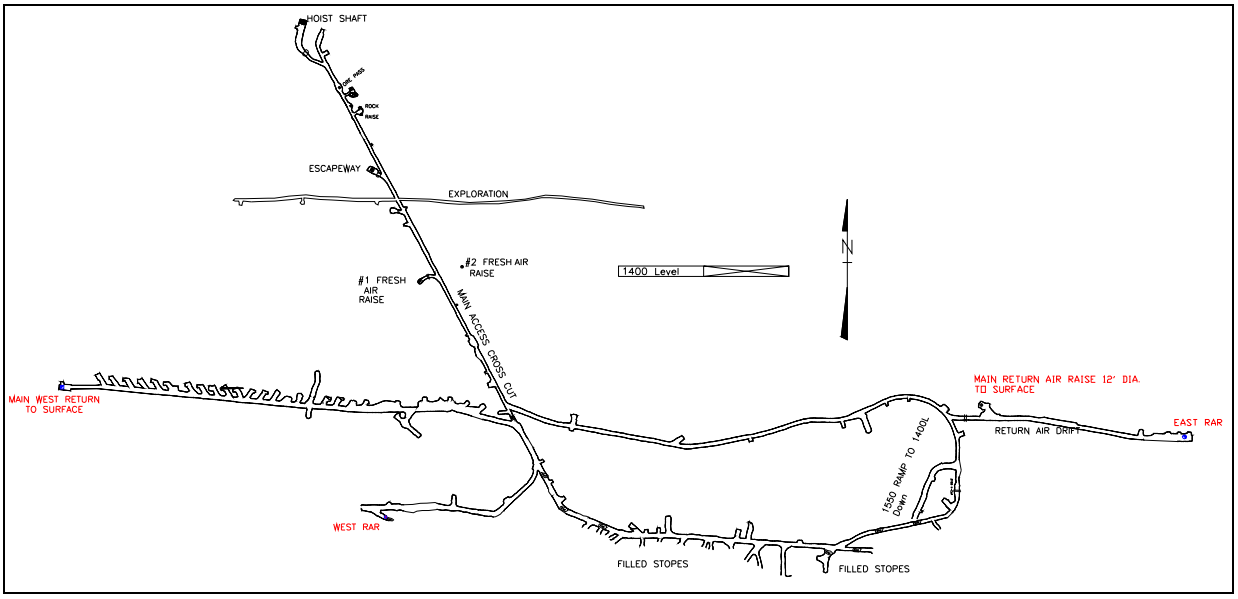


Figure 54: 1400 Level

5.2.2 Drawing the Schematic (Line Diagram)

When drawing the schematic it is important to ensure that each branch is connected. **Do not terminate a branch and then begin the next branch without ensuring that the two are connected**. In AutoCAD™, it is suggested that the user enable a running object snap such as [endpoint] or [intersection] to connect the branches. The user may develop the network using Lines, Polylines and Text. The schematic will be drawn on the VENT layer while displaying both the VENT layer and the corresponding mine level (basically overlaying the mine map). The schematic will be a line diagram, with each line representing an airway. When drawing the schematic, it may be helpful to think of the lines as centerlines. Not all airways need to be drawn. An excessive number of airways can result in model inefficiencies and lead to a greater potential for errors. Large networks require more time to execute and will not necessarily provide increased accuracy. The AutoCAD™ schematic does not have to be exact, since it can be adjusted in the VnetPC Program for evenness, spacing, and alignment. Figure 55 through Figure 59 illustrate the four levels with the network lines drawn on overlying layers.

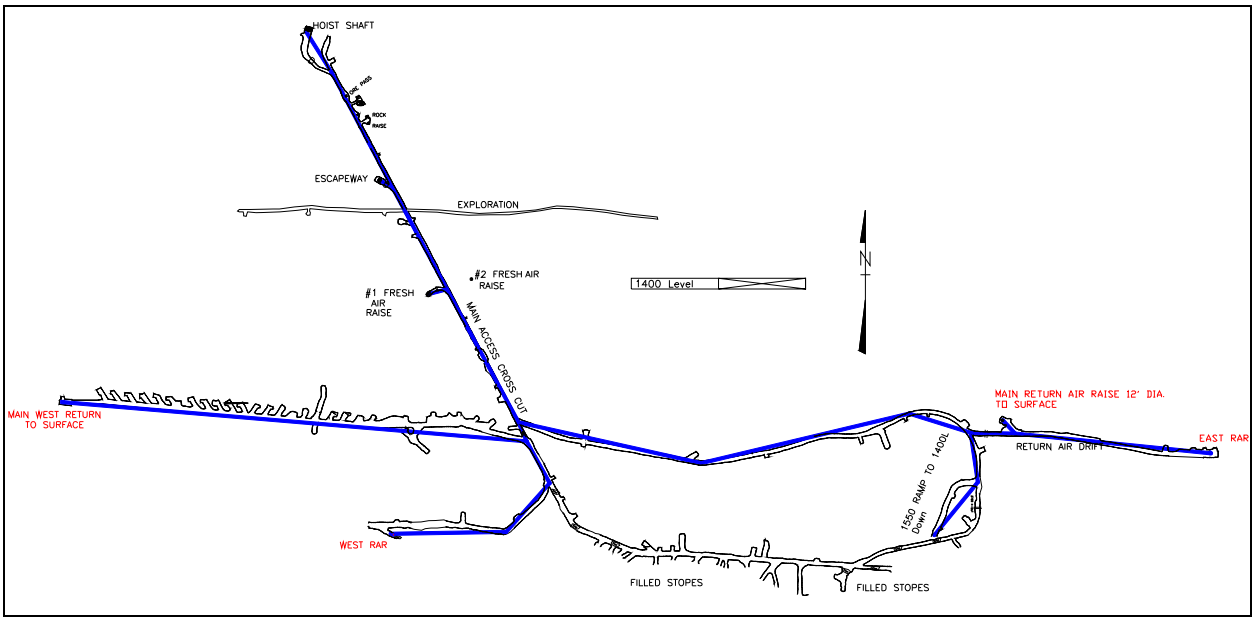


Figure 55: 1400 Level with Wire Frame Drawn

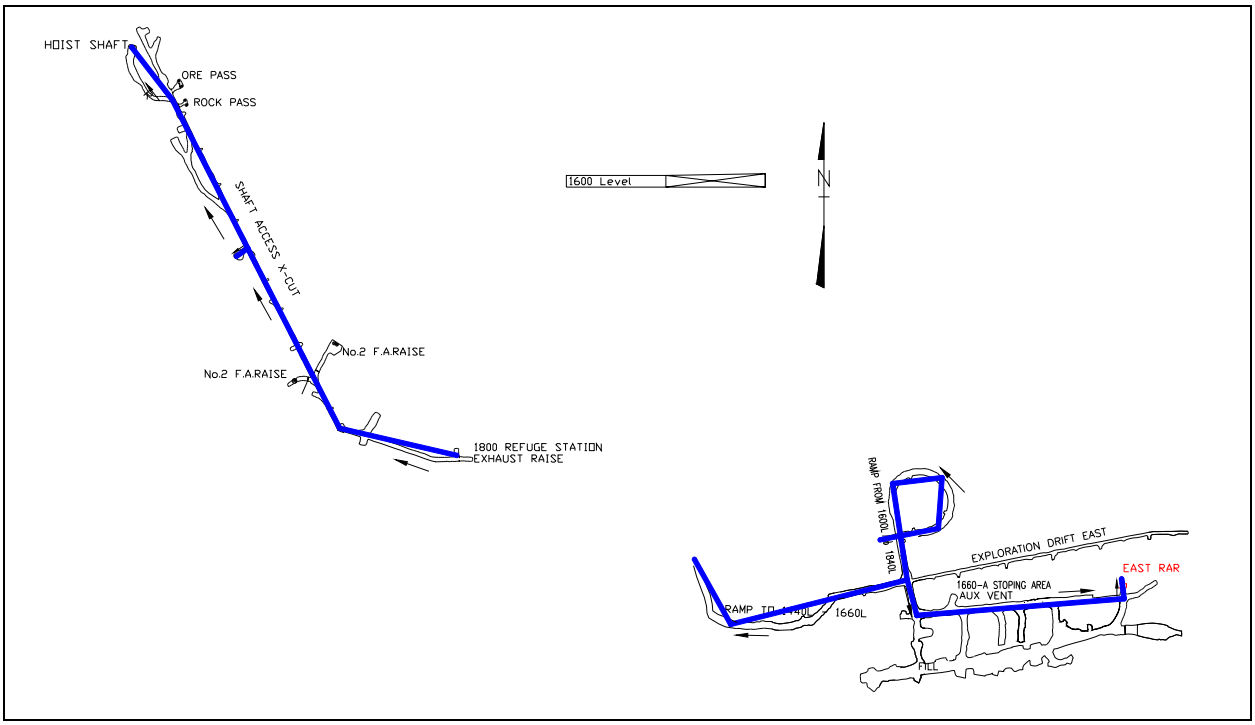


Figure 56: 1600 Level with Wire Frame Drawn

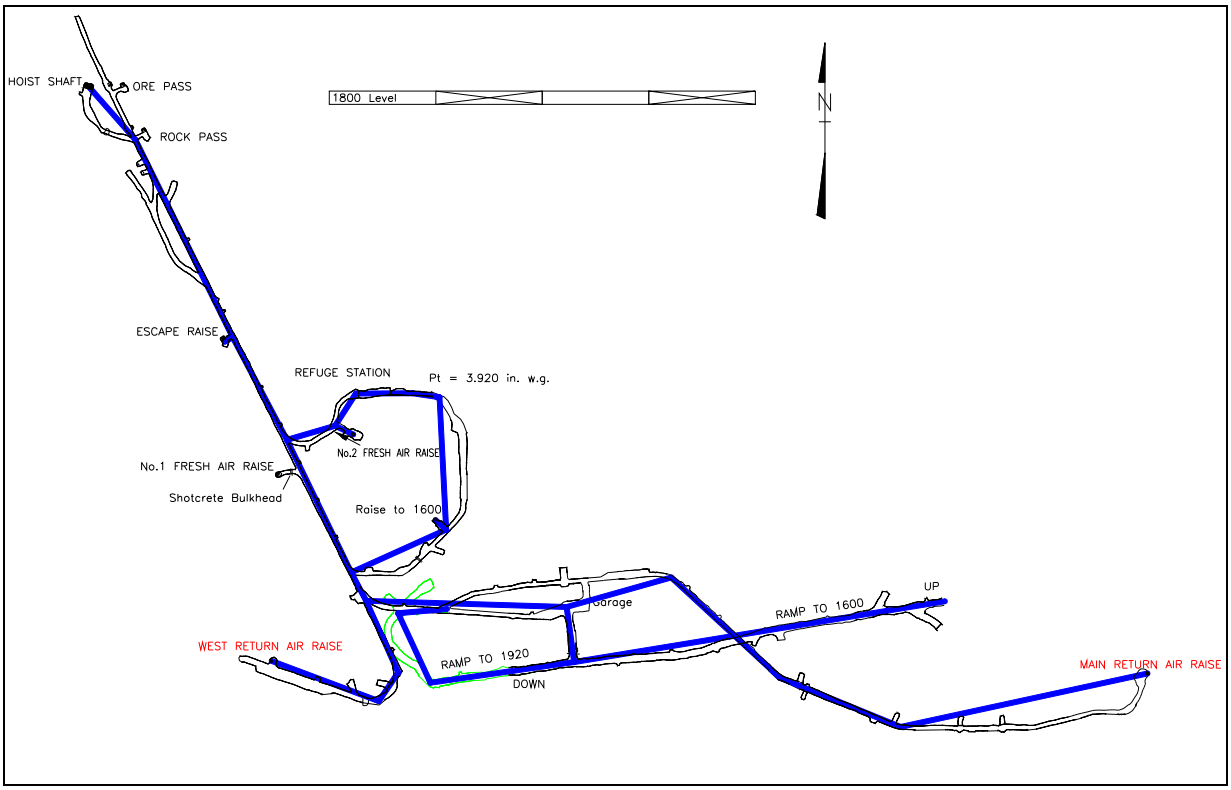


Figure 57: 1800 Level with Wire Frame Drawn

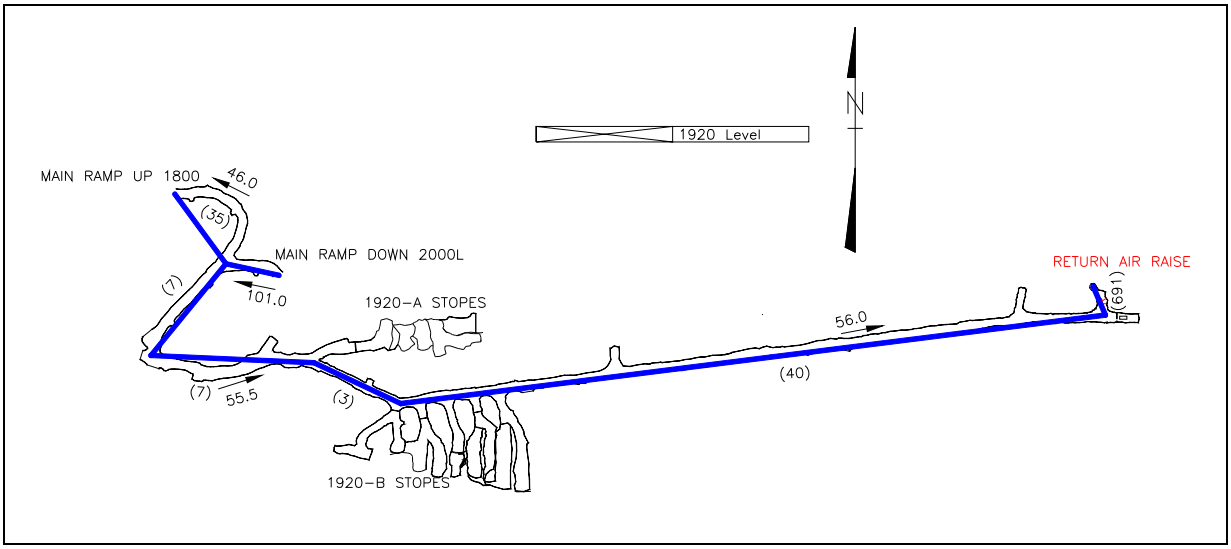


Figure 58: 1920 Level with Wire Frame Drawn

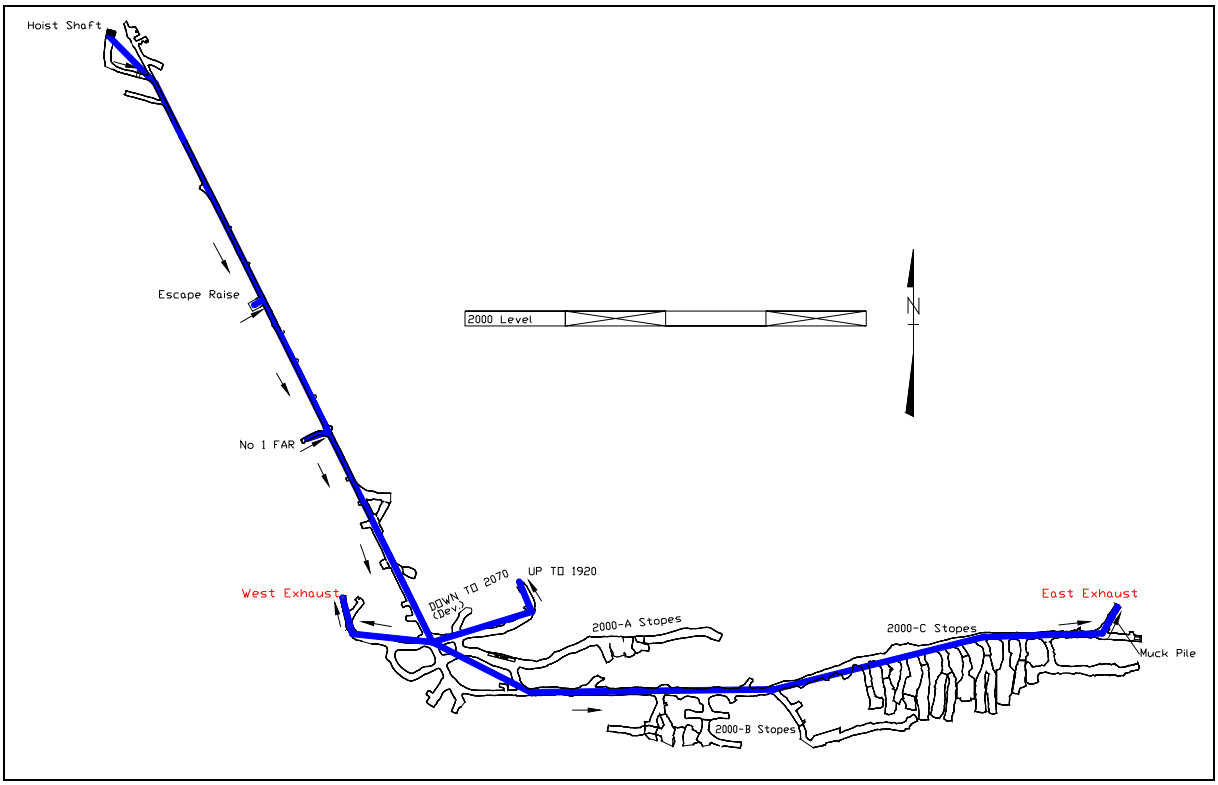


Figure 59: 2000 Level with Wire Frame Drawn

After the line diagrams are established for each level, the ramp is then identified. VnetPC does not treat each of these layers as a distinct “level”, although in some cases it can be thought of in this manner. Instead, each layer imported to VnetPC is identified as a Group of branches with similar general characteristics. When all of the branches have the same general elevation then they can be considered a Level. However, since a ramp will have various elevations for each set of branches, it may be easier to think of them as a Group. The branches drawn for the ramp are shown on Figure 60.

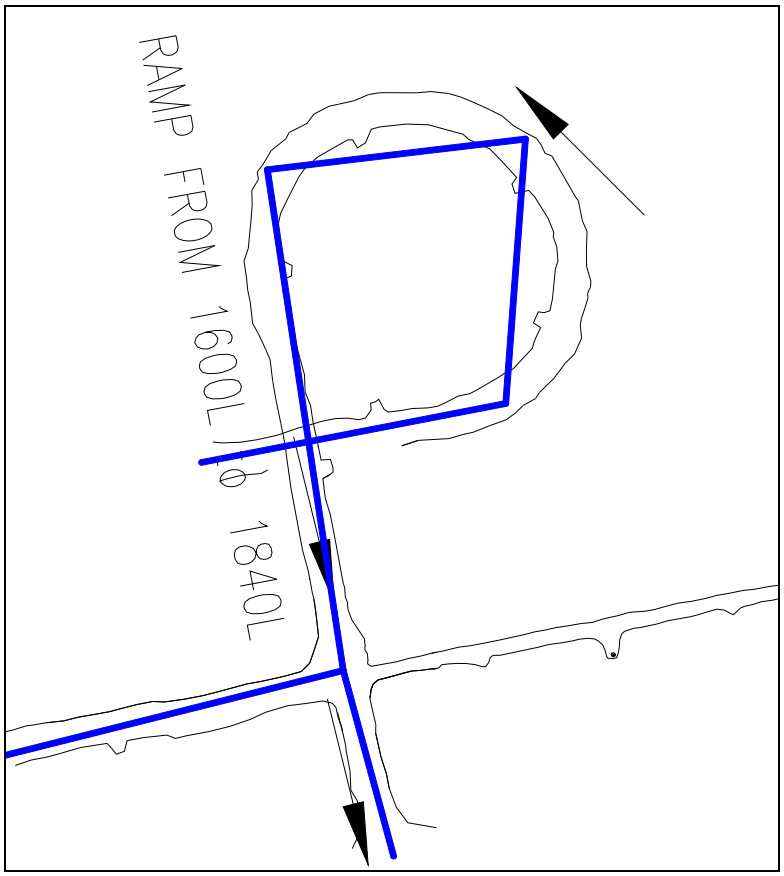


Figure 60: Close-up of Branches Drawn in Ramp

The ramp is traced using large line segments. Wherever the ramp connects to a level, the schematic wire frame is connected to the intersection previously drawn as displayed in Figure 61.

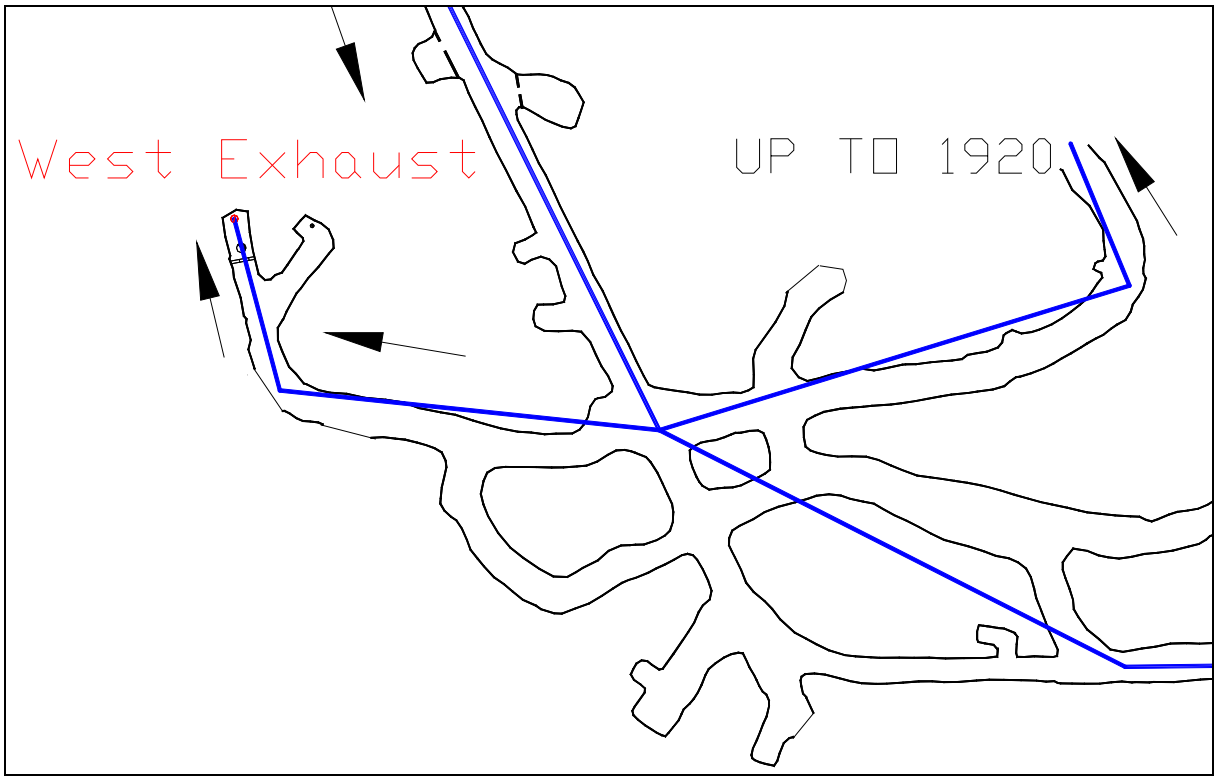


Figure 61: Ensure all Branches are Connected

The [end entity] tool in AutoCAD™ is used to ensure that all of the level connections are in fact terminated at the endpoint of the line segments. Once the wire frame diagrams are drawn they will look like the pictures in Figure 62 through Figure 66 in plan view.

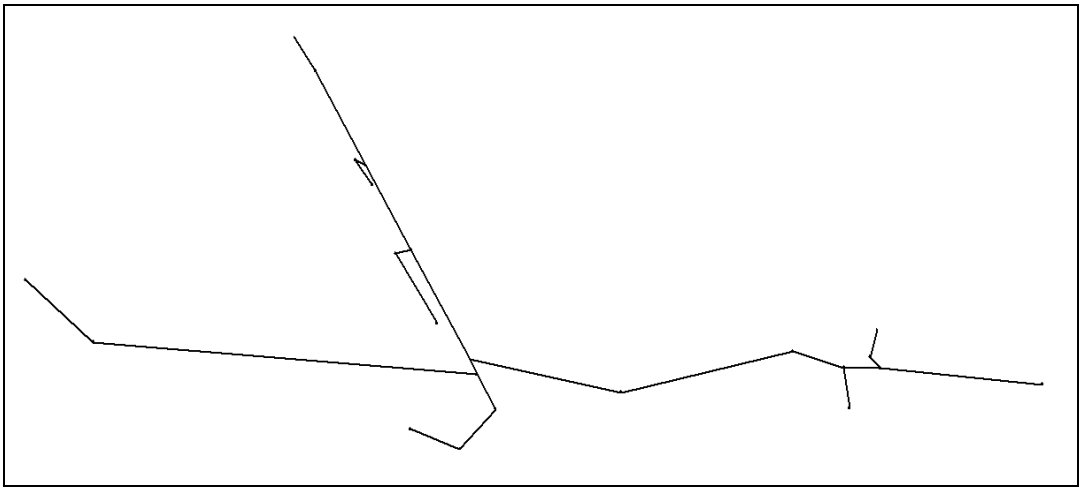


Figure 62: 1400 Level VnetPC Pro Schematic

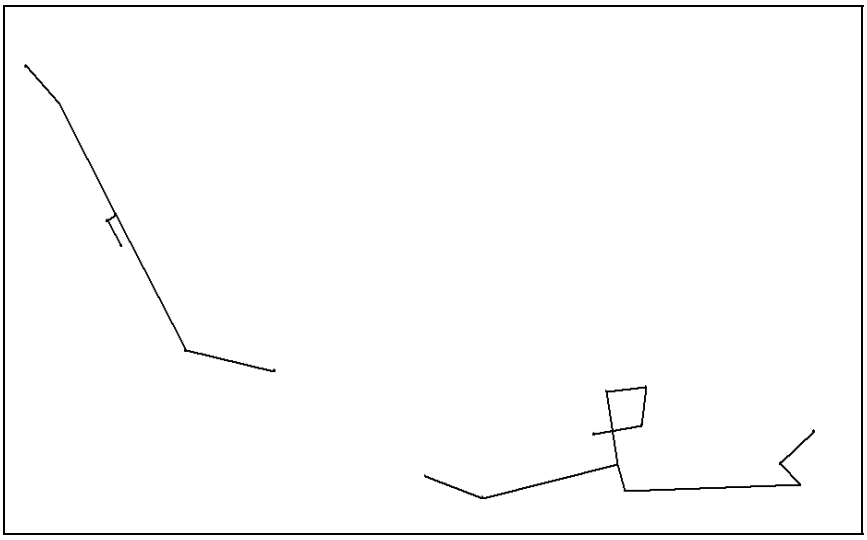


Figure 63: 1600 Level VnetPC Pro Schematic

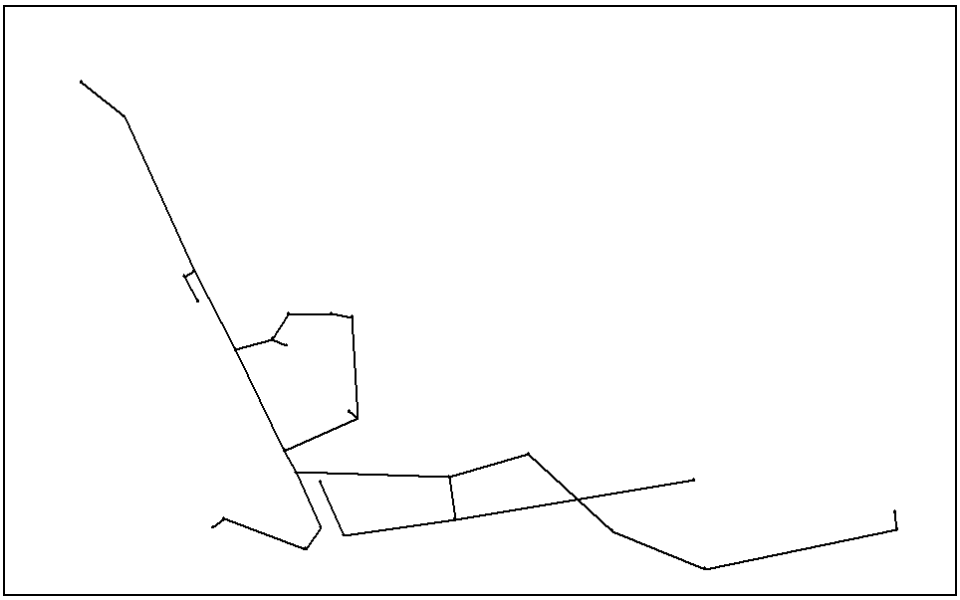


Figure 64: 1800 Level VnetPC Pro Schematic

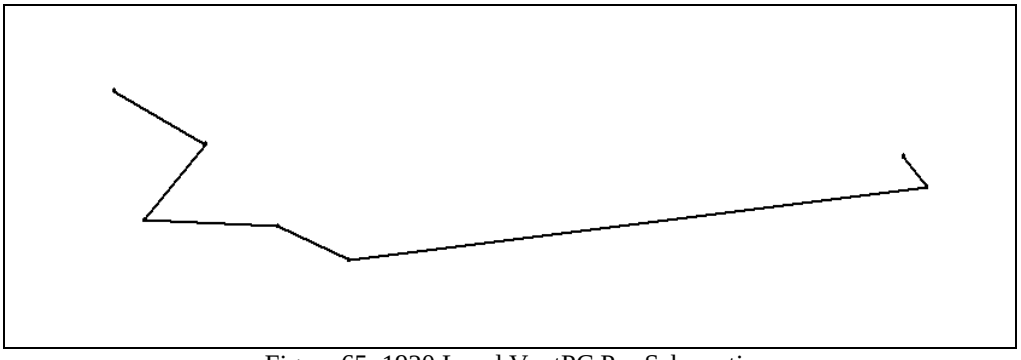


Figure 65: 1920 Level VnetPC Pro Schematic

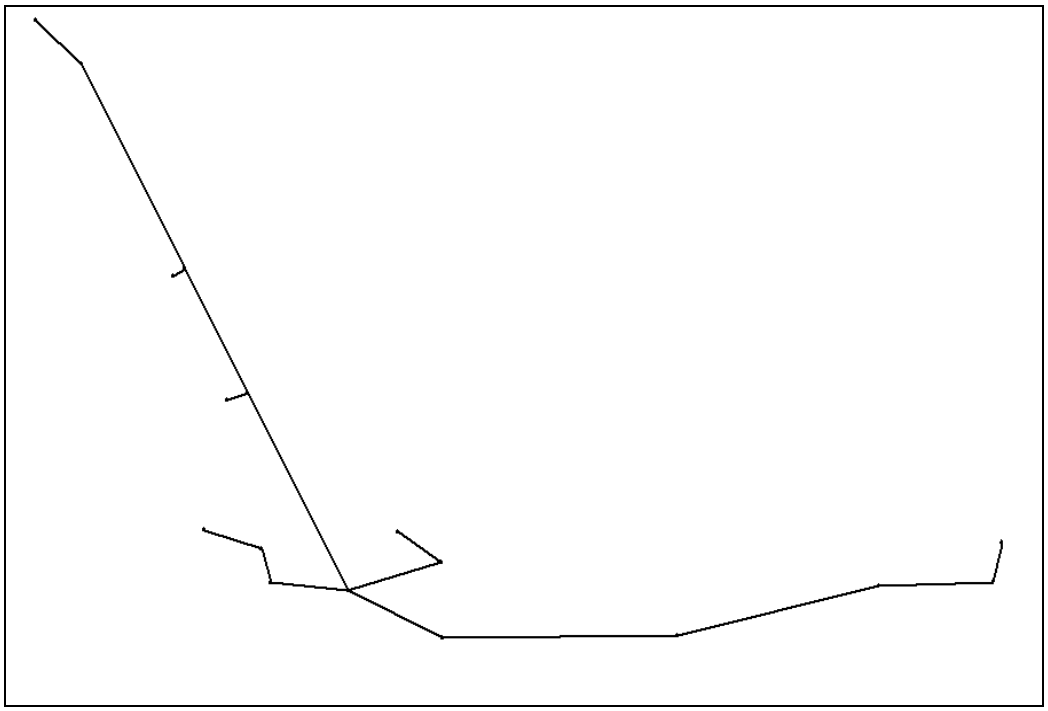


Figure 66: 2000 Level VnetPC Pro Schematic

5.2.3 Exporting the DXF File

Once the line diagrams are completed, a DXF file needs to be generated. This is done in AutoCAD™ by selecting the Save As option listed under the File menu. Be sure to select the DXF option under the File Type drop down menu. The dialog box is shown in Figure 67 for the tutorial example.

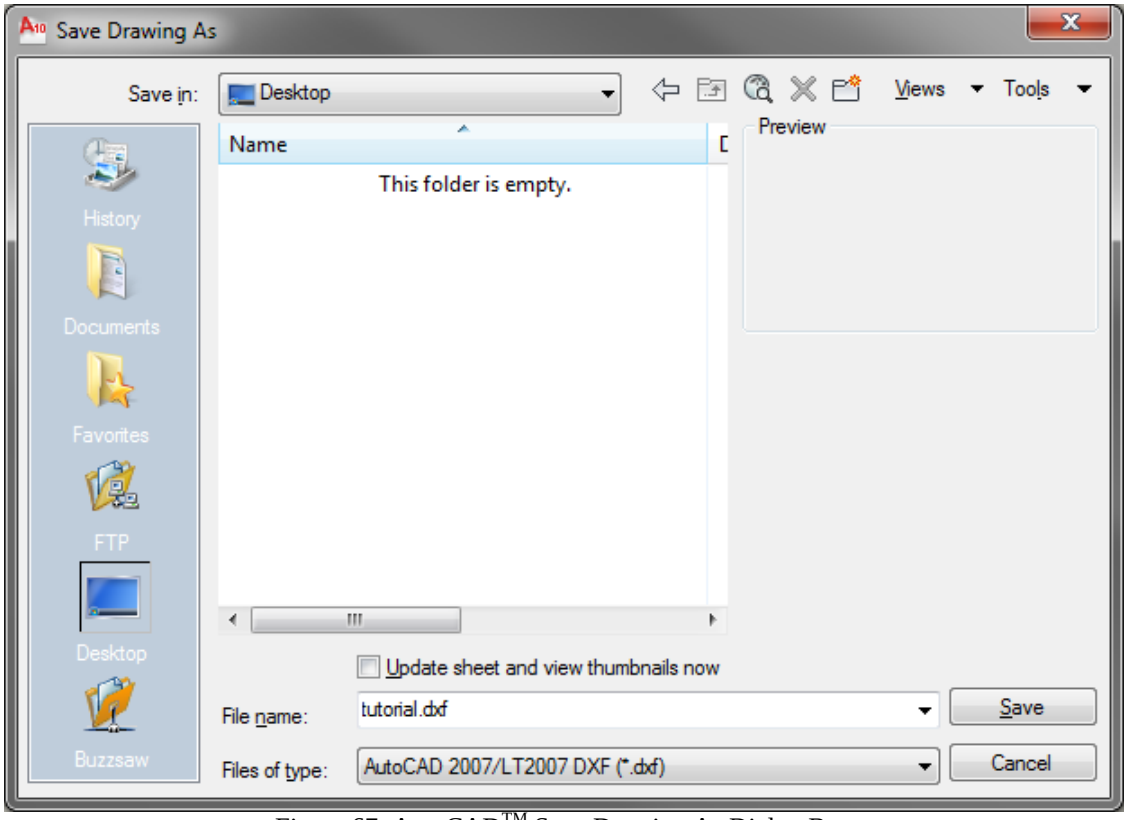


Figure 67: AutoCAD™ Save Drawing As Dialog Box

Once a DXF file has been generated the AutoCAD™ program can be closed.

5.3 Working in the VnetPC Program

5.3.1 Model Information View

The New File View is the first view presented to the user when a model is opened. For a model to be initiated the user selects the New option from under the File Menu which brings up a dialog box illustrated in Figure 68. This dialog box provides the user the choice of generating a fan data base or VnetPC document.

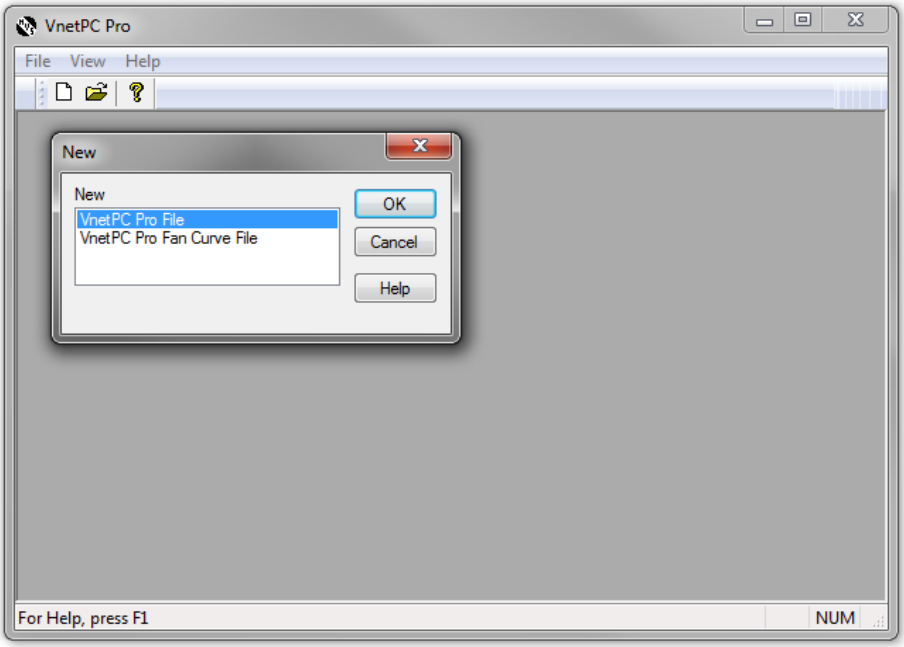


Figure 68: VnetPC New Model Dialog Box

In this case, the user will choose a VnetPC Pro File. Then another dialog box will appear prompting the user to select units as shown in Figure 69.

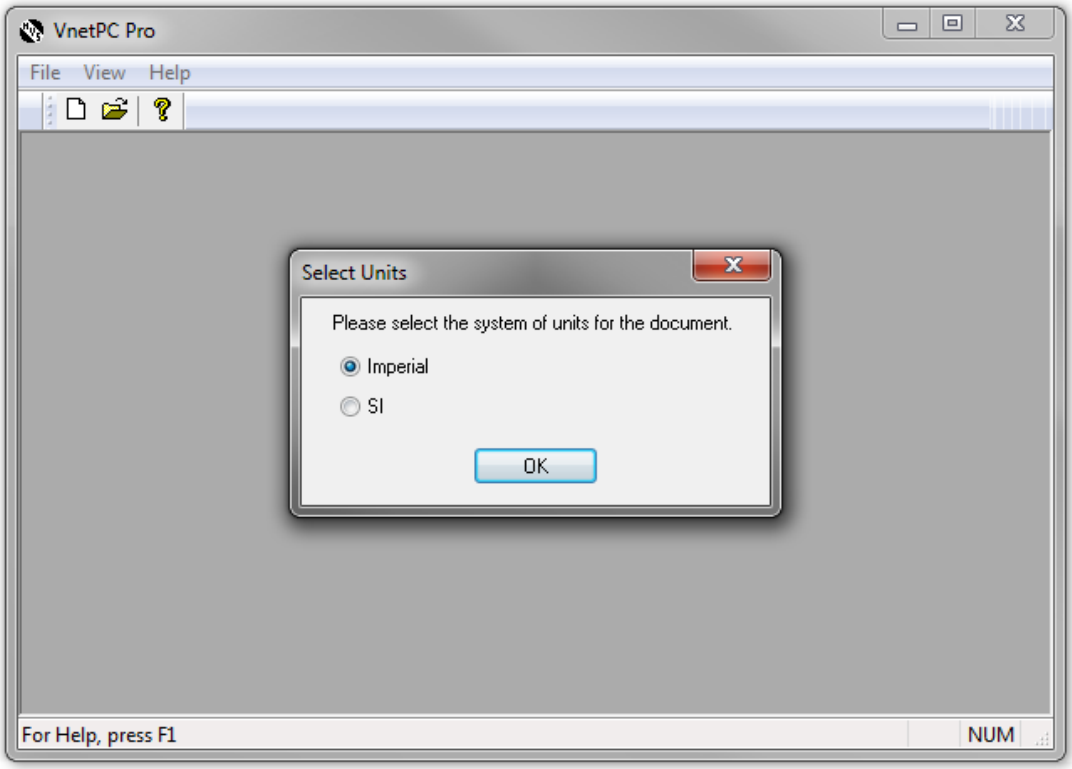


Figure 69: Select Units Dialog Box

A blank model will appear with the Model Information view. In the Model Information View, the user provides general data for the model as shown in Figure 70.

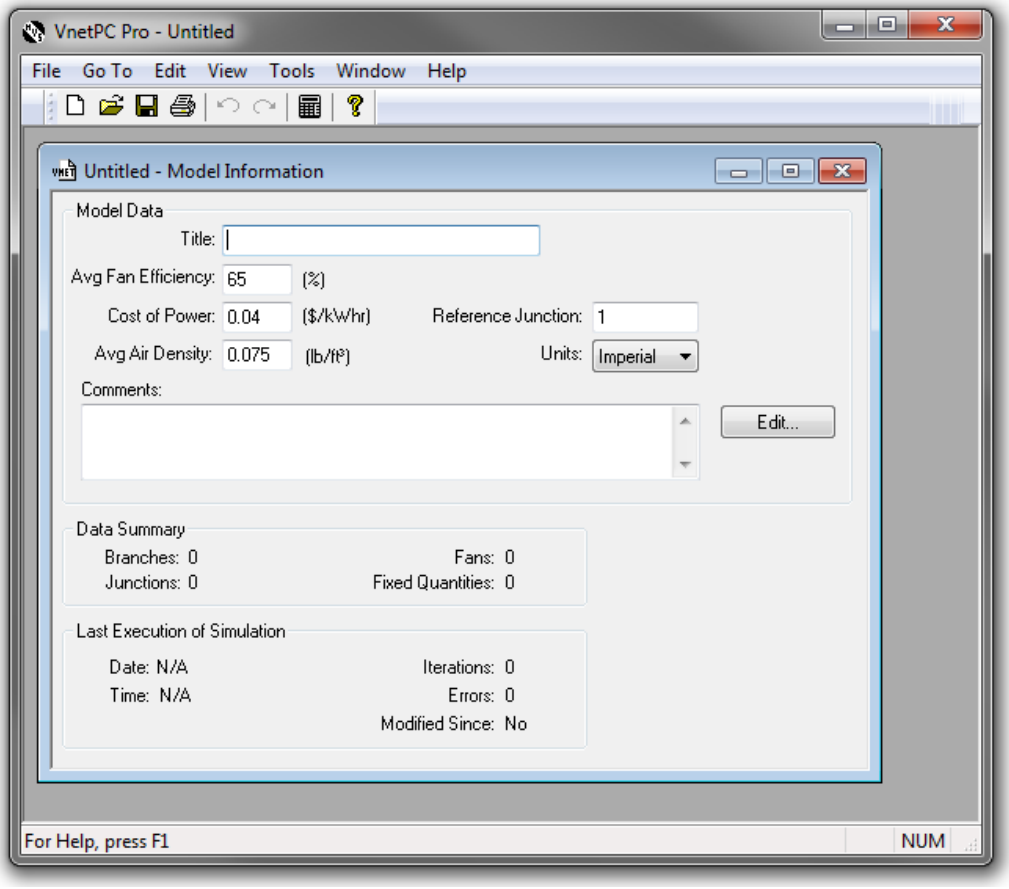


Figure 70: Model Information View

The model title and any particular description can be entered to further identify the purpose of the simulation. The unit basis is selected as either Imperial or SI and can be changed from this view. The user can enter the average power cost and fan efficiency in this view. This data is used to calculate fan power consumption, air power cost of each branch in the network, and shock losses. A reference junction is also selected. This junction is usually associated with a surface condition. A relative pressure table will be calculated relative to this point.

5.3.2 Schematic View

The Schematic View is obtained by selecting Schematic from the Go To menu.

5.3.2.1 Importing the Schematic

The screen will be blank as no schematic or model has yet been input. From under the Tools Menu the user will select Import DXF (see Figure 71) to bring the network into VnetPC.

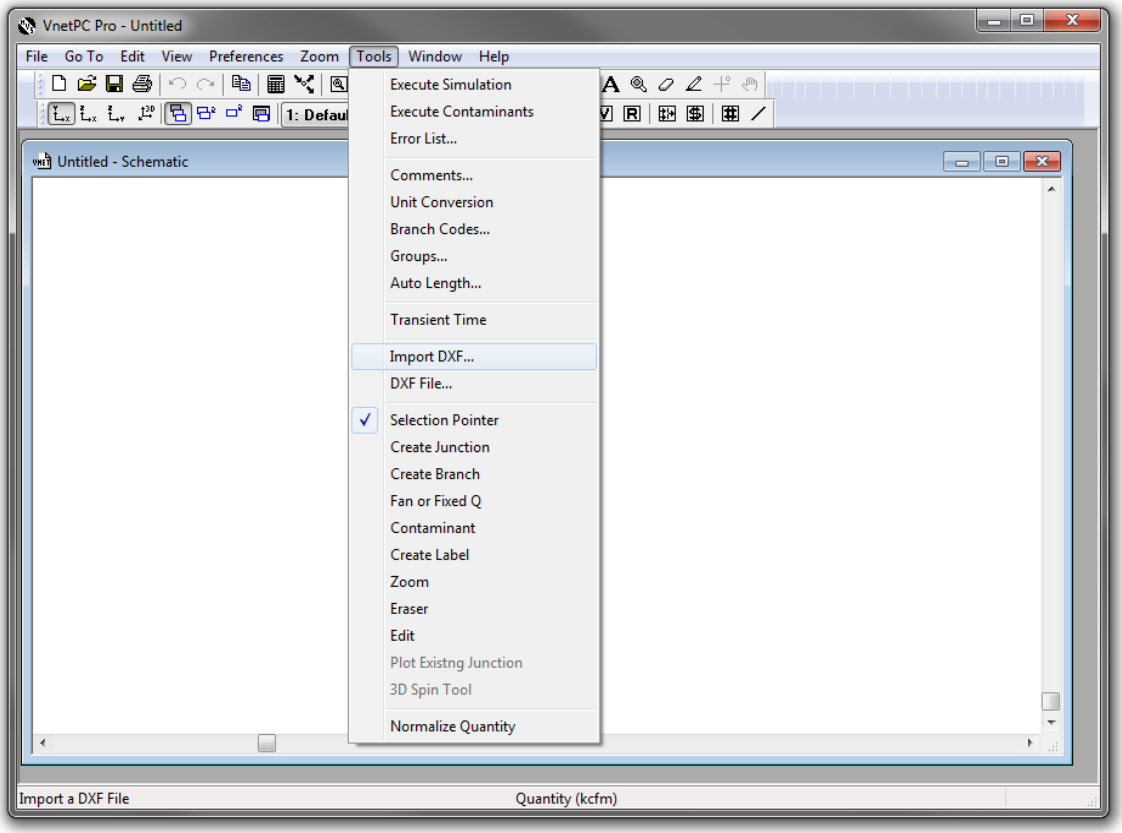


Figure 71: Importing the DXF File into VnetPC

Once the user selects the Import DXF tool, a standard Open file dialog box will appear prompting the user to identify the DXF file to be imported. The user then selects the DXF file. The Layer Selection dialog box shown in Figure 72 will then appear prompting the user to identify the layer to be imported. In this case the VENT and RAMP layers will be imported. The layers can only be imported one at a time. At this point the user may select the default branch type will be imported as either R, P/Q, k Factor, or R/L. The units drop down menu is utilized when the DXF file and VnetPC model have different units. For example, if a VnetPC model is developed in Imperial units but the DXF files are in SI units, the user will select SI units on the Layer Selection dialog box. This function will convert the DXF files units to the VnetPC model units.

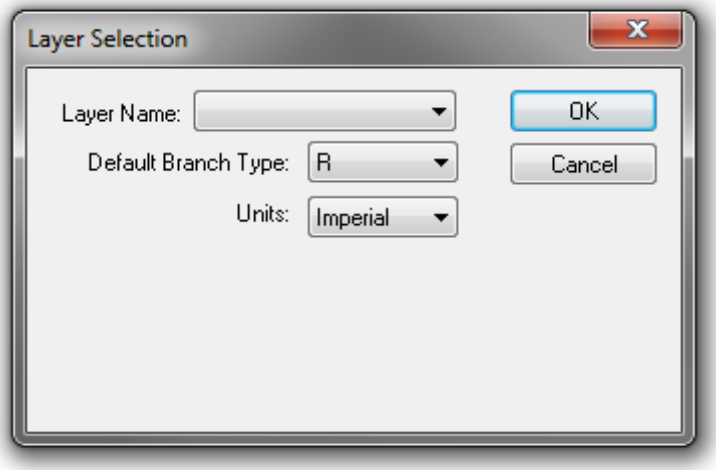


Figure 72: Layer Selection Dialog Box

As the layers are imported, the schematic (Figure 73) will begin to appear on the screen. If the schematic does not begin to appear, select "All" from the Zoom menu or the "Zoom All" button on the Toolbar. This will show the extents of the schematic on the screen. If a junction is connected to more than one branch the junction will be illustrated with a circle, if the junction is connected to a single branch the junction will be represented with a triangle as illustrated in Figure 73.

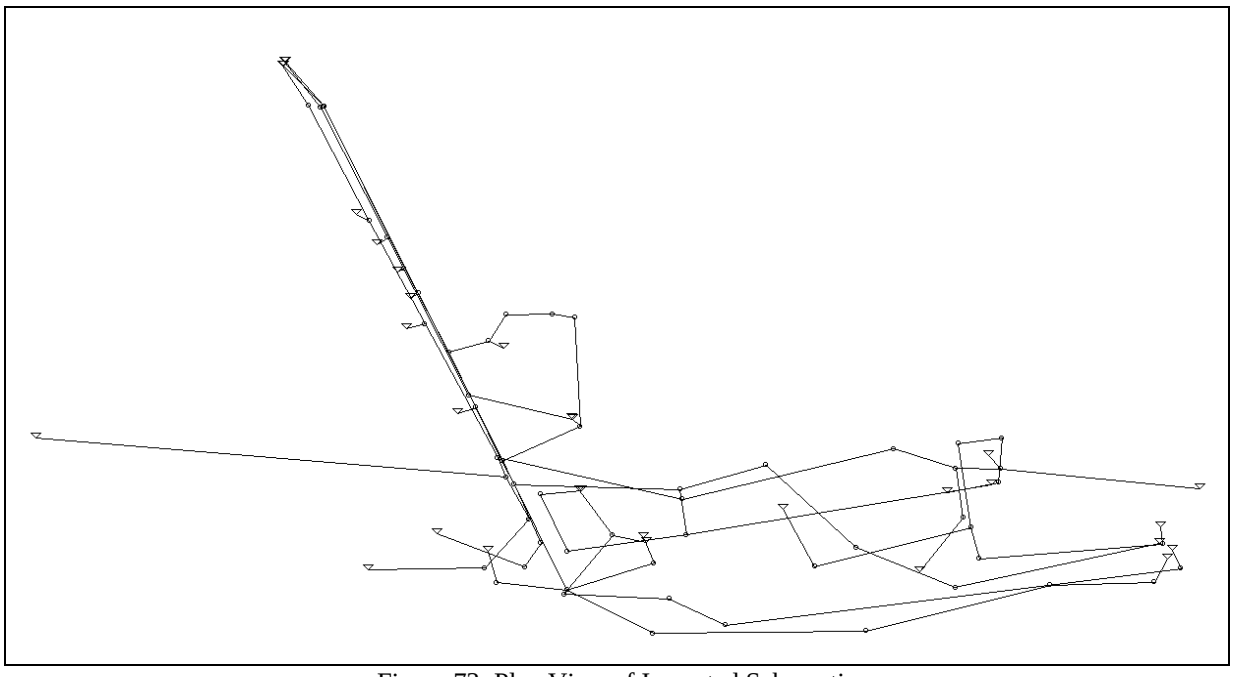


Figure 73: Plan View of Imported Schematic

Initially the schematic may seem complex and hard to understand; however, each node can be easily moved after the import process is complete. Furthermore, the layers or groups can be hidden from view to simplify the screen data. Once all of the layers have been successfully imported into the program, their general group attributes need to be defined. When branches are

imported into the program the junction numbers are automatically defined. This numbering is conducted sequentially and progresses from right to left across the network.

5.3.2.2 Defining Group Attributes

Each layer or group has a set of general attributes, which separate it from the other groups. In this case each group represents an individual level having a discrete range of elevation. For example, the group 3120VENT has a range of elevations from 3115 to 3125 which separates it from the others groups. Any changes to a group's attributes may be made by clicking on the "Groups" item on the Tools Menu (shown on Figure 74).

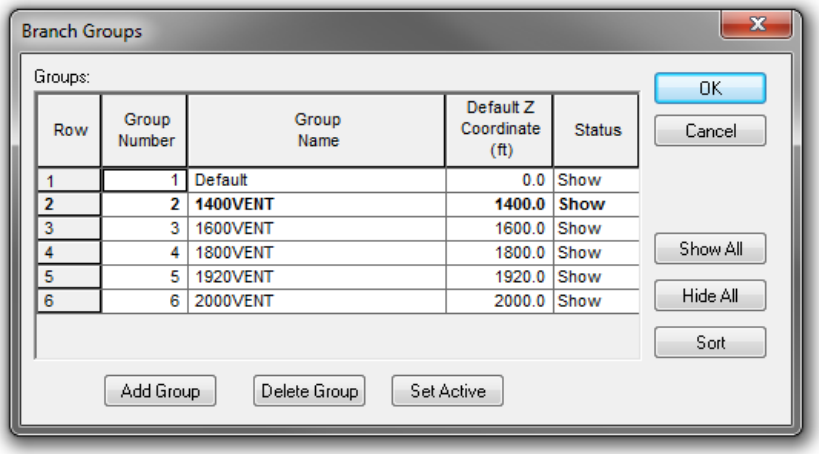


Figure 74: Junction Groups Dialog Box

The Junction Groups dialog box will appear which allows the user to select the group to be modified from the list provided. In this case we will first modify the attributes of the group 2700VENT. To modify this group select any of the group attributes shown and make any wanted changes.

The RAMP group provides a little more challenge in that it is not a level; rather it is a group that spans a wide range of mine levels. For this reason, the ramp is often created within VnetPC by connecting the different levels with a single line representing a section of ramp between two points. If you choose to create your ramp in 3D, the z-coordinate values will be automatically imported with the rest of your model.

If desired, group names can be modified. Initial names are defaulted to the layer names imported from AutoCAD™. Group 1, entitled "Default" is the initial default level. This level can be deleted or re-named to suit the user. **If this level is renamed, then the z coordinates for this level should be modified from 0 to the desired level elevation**. If these z coordinates are not changed, then the zoom-all command will not display the schematic when in the cross-section views (the difference in elevations 0 to 3125 will be too great to show on the screen). It is important to note that only the active group can be modified by the user (the user cannot construct branches in non-active groups). Furthermore, only one group can be active at any one time, although all or multiple groups can be displayed.

5.3.2.3 Viewing the Model Cross-Section

The schematic Cross-Section can be viewed by selecting a button on the tool bar. The following buttons automatically appear on the tool bar and are used to change the view of the schematic.

	Cross-Section View		View all groups
	Long-Section View		View only the selected groups
	Plan View		View the Active Group in Plan View
	Isometric (3D) View		Change the selected groups, turn

When viewing single levels, the drop down menu on the tool bar can be used to select which group to view and edit with the mouse. When viewing all of the groups in plan view, the drop down list can be used to specify which group is active

If the ramp was created in 2D, the elevations for the nodes in the RAMP group can be entered in either one of two ways. In the sectional views, existing nodes can be moved anywhere in the vertical or horizontal planes with the mouse, or each node can be selected individually and an elevation assigned to it. Individual nodes can be selected and an elevation assigned to them in the isometric view. In this case each node will be selected and the elevation modified individually. The junction is edited using the "Edit" icon located on the Toolbar or by selecting the "Edit" option under the Tools menu, and then clicking on the junction. The Edit Junction dialog box will appear allowing the user to change the location of the junction (see Figure 75).

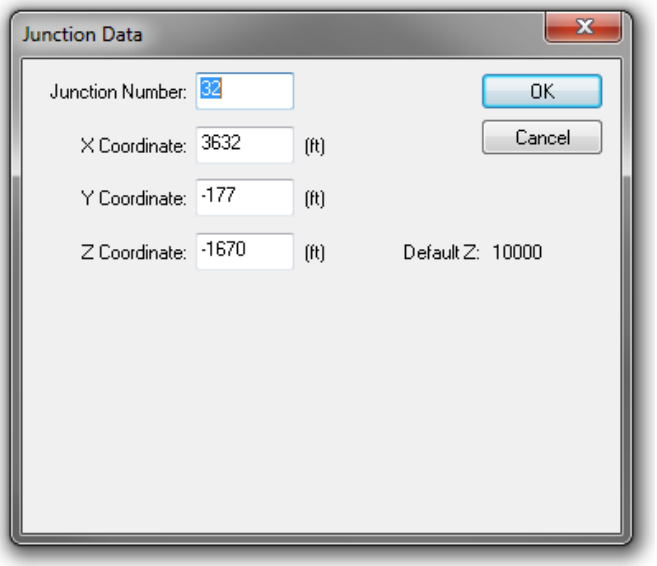


Figure 75: Edit Junction Dialog Box

Figure 76 shows the modification of the elevation of node 32 on the ramp from 1800 Level to 1600 Level. When a group is imported without an elevation defined, then all of the nodes in that group will be defaulted to the mean elevation value. However, the elevation values can be easily modified to allow the ramp to extend from the base of the model to the upper levels (as displayed on Figure 76).

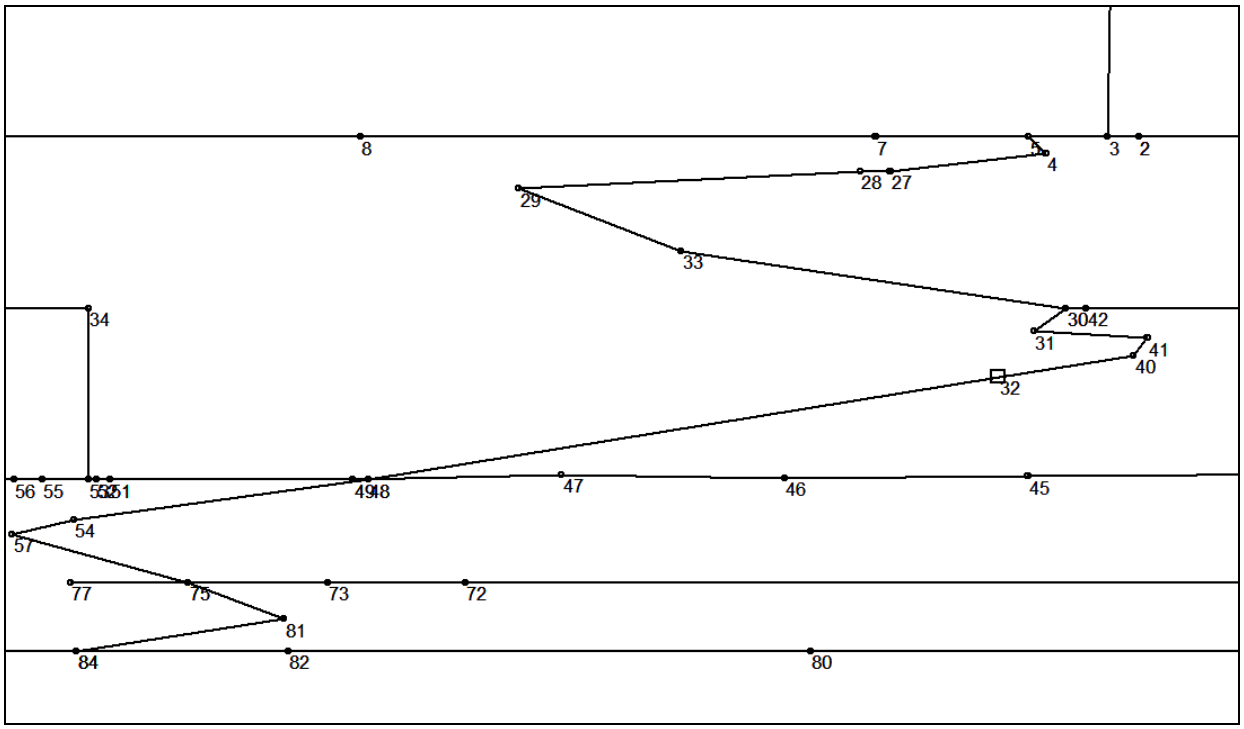


Figure 76: Completed Cross-Sectional View of Schematic

Because this model was developed on a two dimensional plane in AutoCAD™ no elevations were imported into VnetPC. If elevations were used in the AutoCAD™ drawing they would have been imported and the z-coordinates would have been defined. In the AutoCAD™ drawing no branches were given for the intake and exhaust shafts. These can be added directly in VnetPC (the junctions should already exist on the levels).

5.3.2.4 Viewing and Editing the Schematic in 3D

The VnetPC Program incorporates a feature that allows the user to view and edit Branch Data and Junction the schematic in 3D (isometric). The user can actively rotate the schematic and zoom in/out on the schematic. To switch to the 3D perspective, the user selects the button from the tool bar. The schematic can be rotated by using the 3D Spin Tool. The user can "drag and drop" with the mouse to rotate the schematic. If portions of the schematic rotate off the edges of the screen the user can automatically resize the schematic to fit the screen with the Zoom All button located on the tool bar or scrolling the center mouse wheel. Figure 77 shows the schematic rotated to allow the branches to be viewed and edit more clearly.

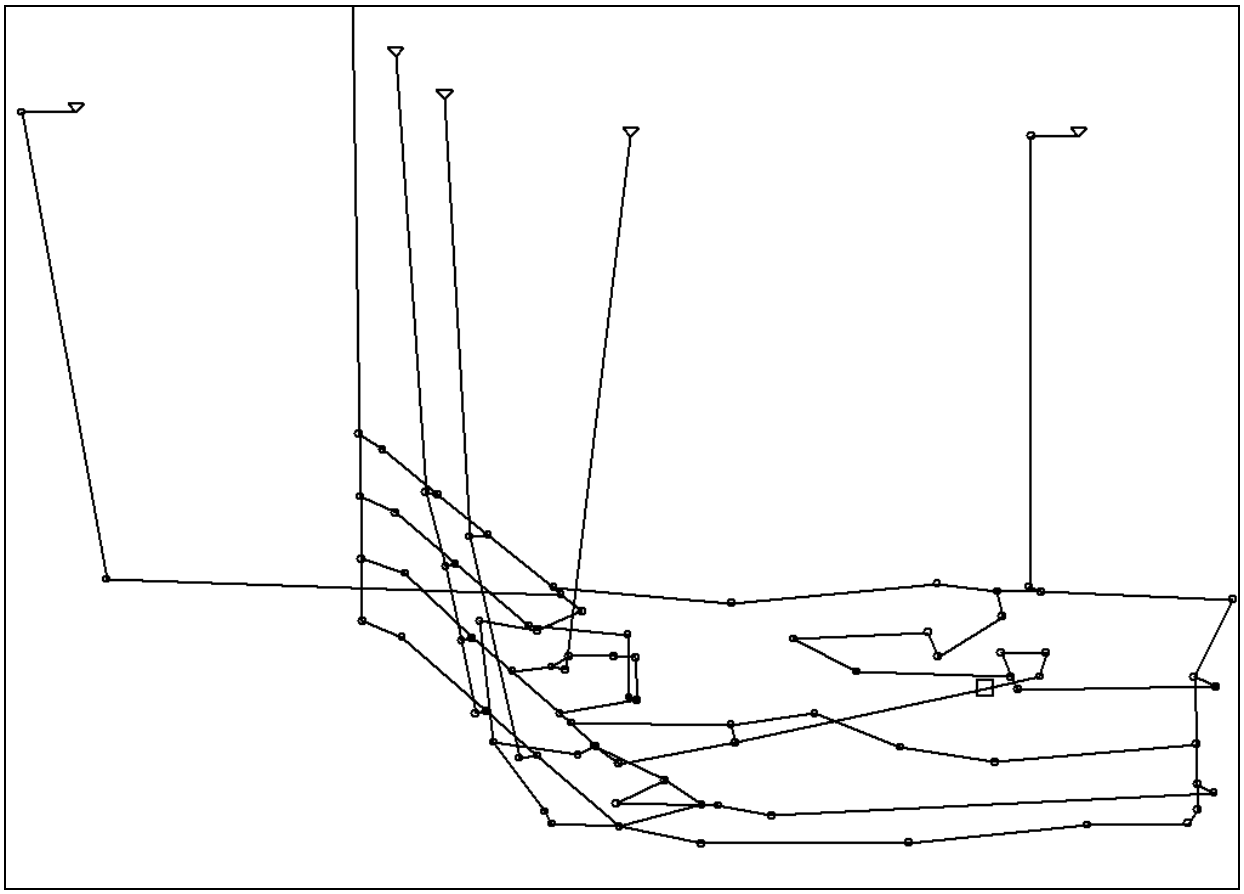


Figure 77: Rotated 3D Schematic

5.4 Adding Branches to the Schematic

Branches can be added to the ventilation model directly in the Schematic View (or in the Branch Input View). Branches that are added through the schematic will automatically show up in the Branch Input View with resistance values defaulted to zero. The user selects the Create Branch option located under the Tools Menu or the Create Branch icon on the Toolbar. To add a branch, click on the branch origin (from node), then holding the left mouse button down, move the mouse to the branch termination point (similar in operation to drag and drop features of other Windows based programs). A segment of the exhaust shaft is being inserted in Figure 78. If there is an existing node in close proximity to either of the two nodes (From/To) then the branch will automatically "snap" to those junctions. If the user chooses to either begin or terminate a branch by intersecting an existing branch, then the existing branch will be split, and a junction inserted. Branches can be added, deleted, or split in Plan, Cross Section, or Long Section views.

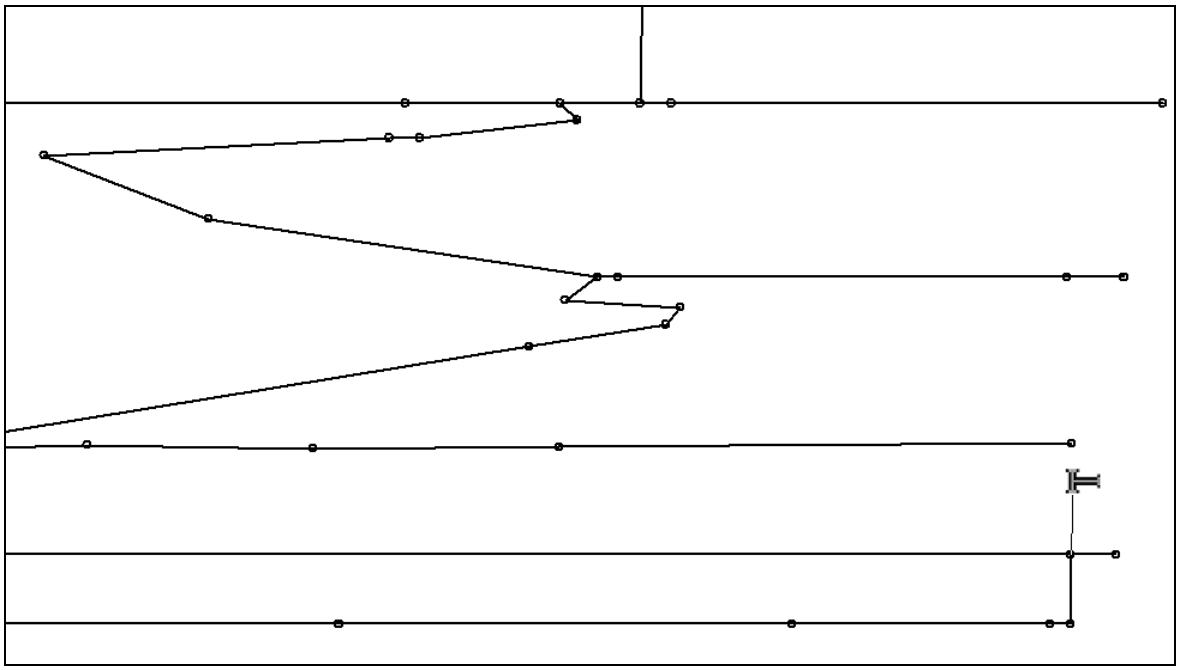


Figure 78: Drawing Branches in Schematic Cross-Section

During the initial schematic development in AutoCAD™, a node was inadvertently left out. On the 1800 level (top level) the location for the regulator at the intersection of the level and the exhaust shaft was omitted. This can be rectified by either adding a branch for the regulator, or by inserting a node in the existing branch to split it to allow for the addition of the regulator. To do this the 3120 level must be displayed on the screen (see Figure 79). To view the 3120 level the user selects the level from the list provided by the drop down dialog box on the Toolbar, and then by pressing the button.

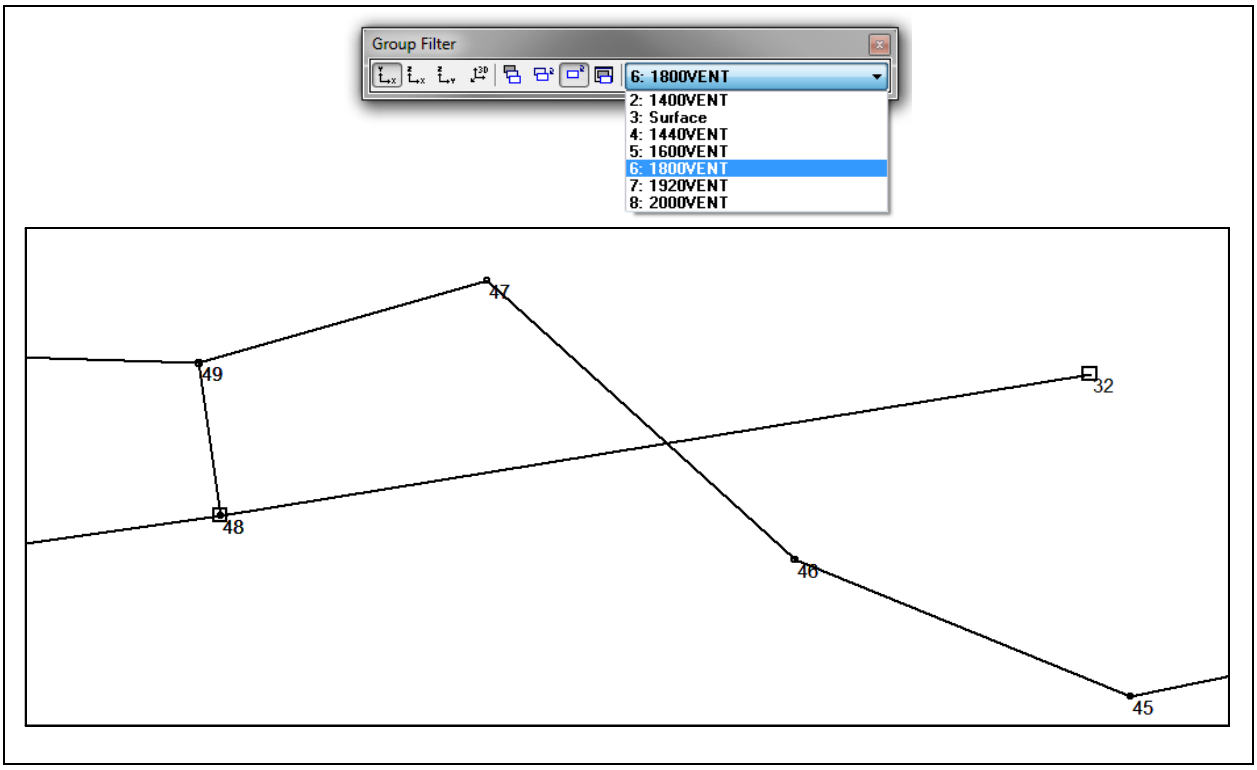


Figure 79: Illustration of a Single Group (Level) and Group Filter

In this case a node will be inserted in branch 48-32. To insert the junction the user selects the "Create Junction" option from the Tools Menu or uses the Create Junction icon located on the Toolbar. The inserted node is displayed on Figure 80.

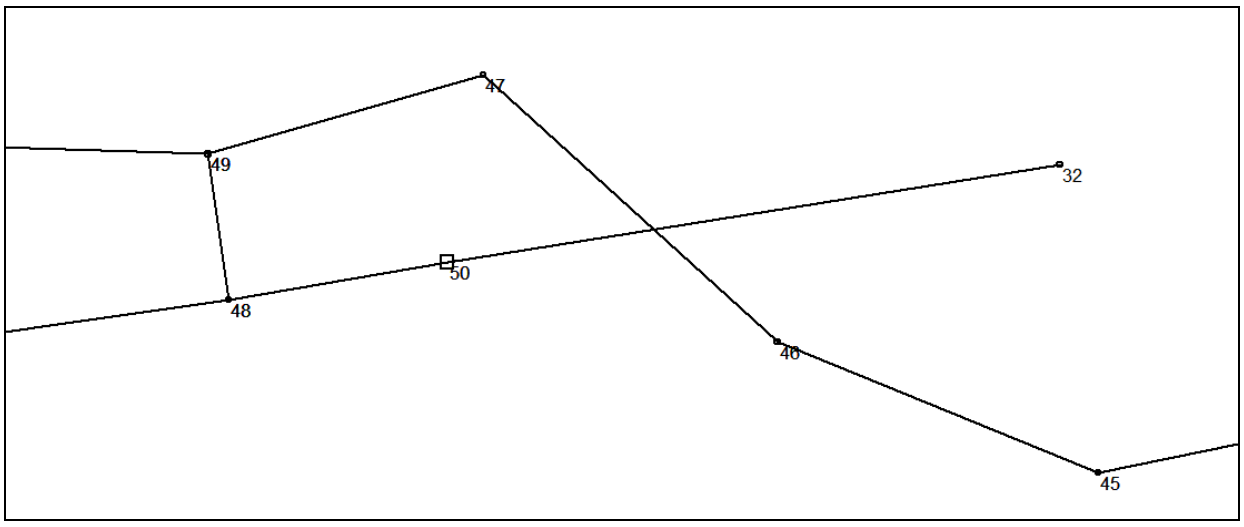


Figure 80: Inserting a Junction

The VnetPC Program will assign the junction the next free junction number and automatically place the newly created branch 50-32 on the 1800VENT group with all of the attributes belonging to that group.

5.5 Defining Branch Attributes (Resistances)

Branch attributes can be defined or modified through either the Schematic View or the Branch Input View. Because al subsurface airways do have some resistance each branch should have a resistance value assigned to it. The exception is if the branch is being used solely for graphical representation. To define the attributes or resistances for each branch, select the "Edit" option from the Tools Menu or use the button located on the Toolbar. Once the Edit tool has been selected, click on a branch, and the Branch Data dialog box (see Figure 81) will open. All data that can be modified in this dialog box can also be modified in the Branch Input View.

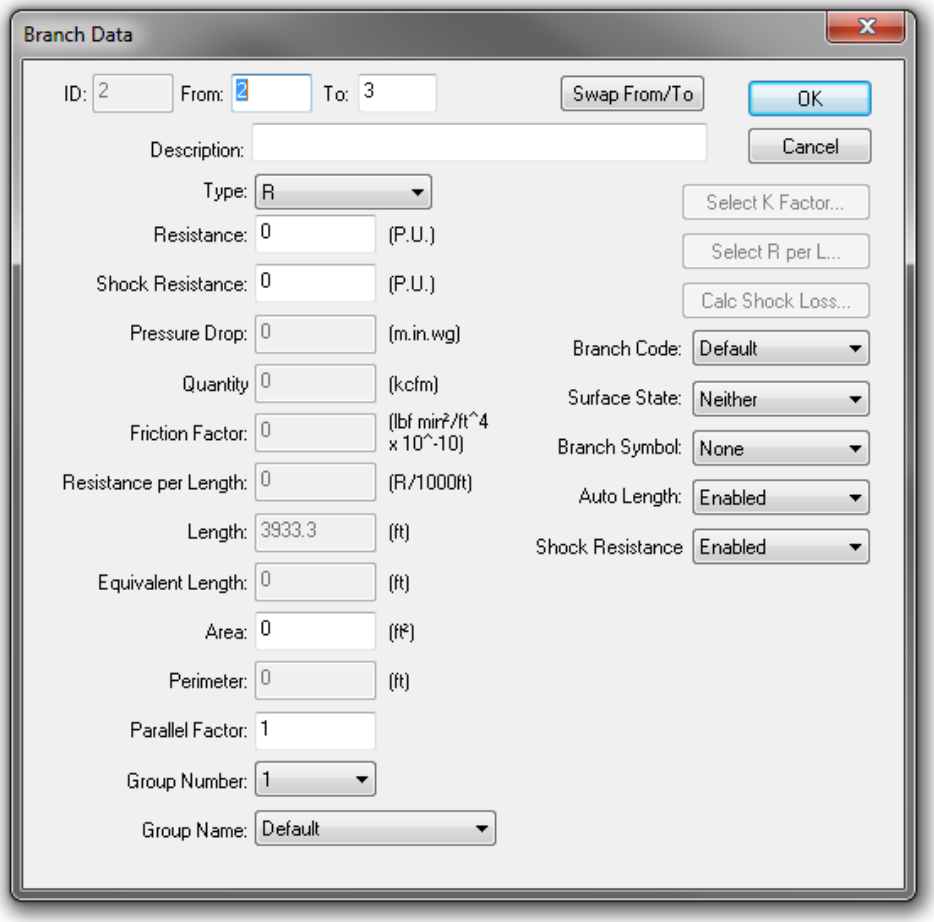


Figure 81: Branch Data Dialog Box

Each branch can be color coded to visually differentiate between airway types. The Branch Code Menu allows the user to color code the schematic. Each airway type can have an individual color assigned to it, or have the color modified by selecting "Define Colors" from the Preferences Menu and then selecting the "Branch Code" option.

Every ventilation network, as with every mine, must have at least one intake and one exhaust airway connected to the surface (atmosphere). The VnetPC Program requires that the intake and

exhaust portals and shaft surface connections be identified. This system takes the place of the old method of creating zero resistance "atmospheric" branches connecting all surface junctions to some arbitrary atmospheric node. It is important to ensure that the surface branch is identified correctly with the direction of airflow. For example, a branch starting at a portal (node 1) and terminating at a airway junction (node 2) would be identified as an intake airway and is required to be written with the nodes ordered From 1 To 2.

Each branch can also be allocated a symbol. Symbols include bulkheads/stoppings, doors, brattices, and regulators. In addition to the descriptive data, each branch can have a resistance assigned to it through this dialog box. One of four methods can be used to assign or calculate the resistance for each branch by selecting from the drop-down list. Additional cells will appear in the dialog box to allow the user to enter the necessary data to calculate branch resistance.

When entering resistance data for k Factor (type 3) and Resistance per Length (R/L) (type 4), a tool (Auto Length) has been incorporated that will calculate the lengths of the branches according to their coordinate positions in the Schematic View. This will only work for schematics that have been drawn to scale. When entering resistance data for which a length is required in only a few branches, the Auto Length Selection box can be set to the Enabled mode. If an entire network is being developed, then the Auto Length can be enabled using the "Auto Length" from the Tools menu in the Schematic View. A dialog box will appear as shown in Figure 82, the user will need to select a default for all new branches created or make changes to all existing branches. The length of each branch will be updated automatically as junctions are moved or added to the schematic.

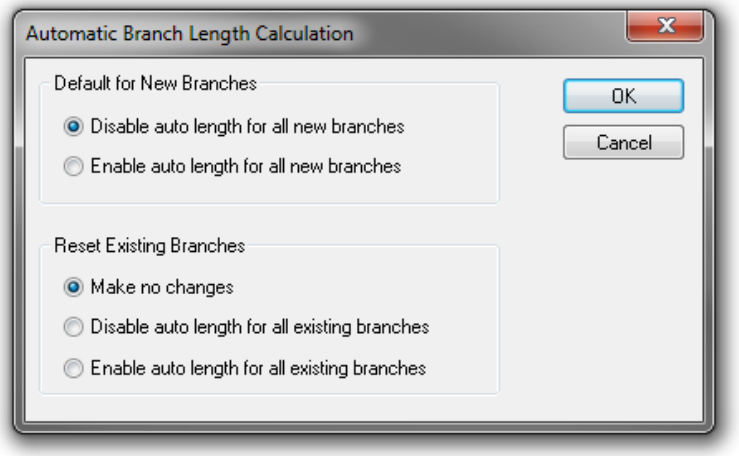


Figure 82: Automatic Branch Length Calculation Dialog Box

5.6 Inserting Fans and Fixed Quantities

Once the attributes for each branch have been entered, the next step is to add fans or fixed quantities in the ventilation model. These can be rapidly input to the model in the Schematic View; however, they may also be added in the Branch Input View, Fan Input View, or Fixed Quantities View. To insert a fan, select "Fan or Fixed Q" from the Tools menu or use the Fan or Fixed Q icon on the Toolbar, then click on the branch where the fan will be located. Once the

branch is selected, the Add Fan or Fixed Quantity dialog box will be displayed as shown in Figure 83. In this dialog box either the fan option or the fixed quantity option can be tagged.

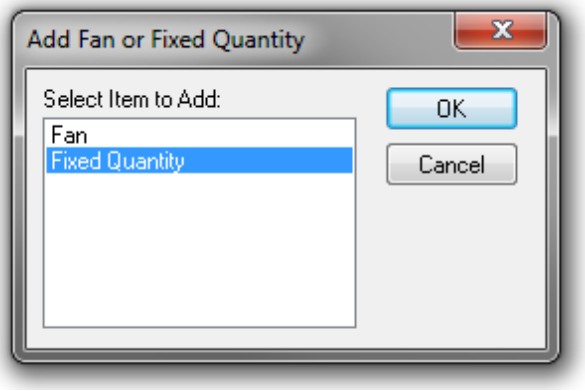


Figure 83: Fan or Fixed Quantity Dialog Box

If the fan option is selected the Fan Data dialog box, Figure 84, will be displayed. This dialog box allows the user to input the fan characteristics to the model. Note that the nodes' From/To order will specify the airflow direction for the fixed quantity or fan.

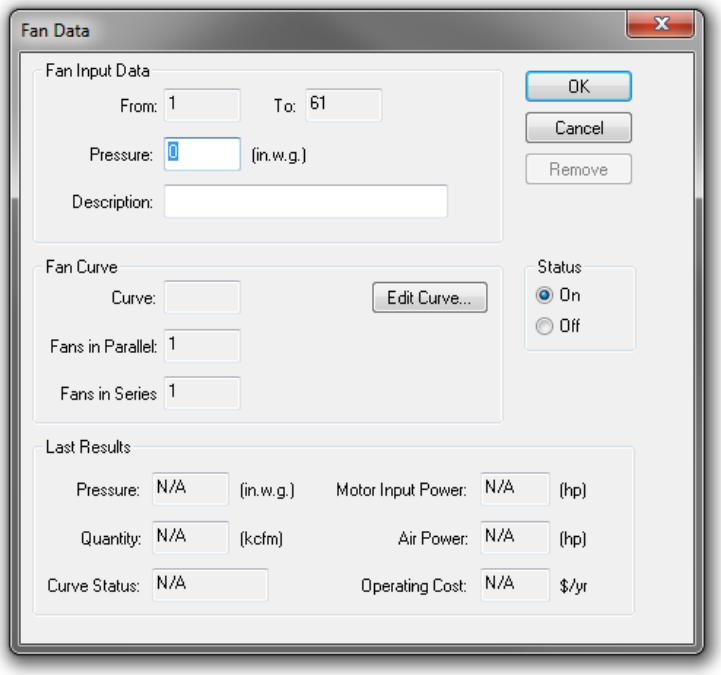


Figure 84: Fan Data Dialog Box

Another tool included in VnetPC allows the user to create a single fan and apply it to the model as a multiple, series or parallel installation. This tool will automatically adjust the fan curves for multi-fan installations with identical fans. If a fan is already defined in the fan database or if a fan characteristic curve is going to be added to the model, then the user selects the Edit Curve

button. This will bring up the Fan Curve dialog box that contains the fan curve data series as illustrated in Figure 85.

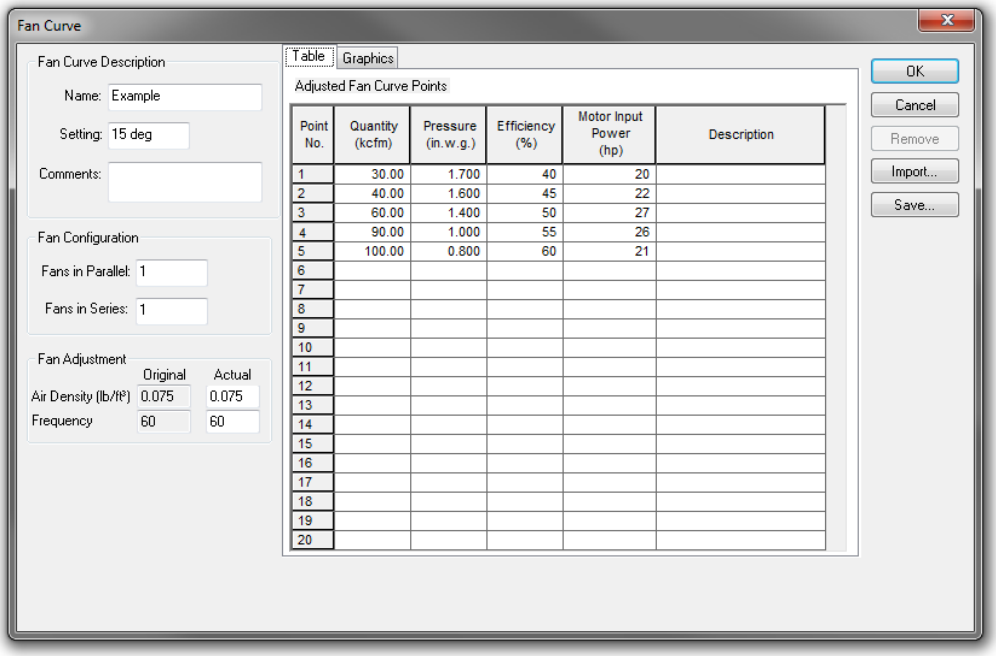


Figure 85: Fan Curve Dialog Box

The individual properties of the fan are entered in the Fan Curve dialog box. A maximum of 20 points are allowed to be input for each curve. It is generally a good idea to cluster the greatest number of points along the operating section of the fan curve. The program will linearly interpolate between each of these points. Once the fan curve is entered, select "OK". The buttons "Save" and "Import" refer to the Fan File Manager. By selecting "Save" the fan curve will be saved to an existing fan database, and can be used in any model in the future by selecting "Import". This removes the task of continuously developing the same fan curve for different models. Once the fan curve is entered in the dialog box, select the "OK" button. The fan curve will then be incorporated into the model, it is not necessary to select "Save".

5.7 Adding a Contaminant

In the VnetPC Program, a contaminant can be traced through the network. This contaminant is added to the network by selecting the button on the Toolbar or selecting "Contaminant" from the Tools menu. A contaminant is inserted by selecting the desired branch with the contaminant curser, the Branch Contaminants dialog box, Figure 86, will be displayed on the screen. In this dialog box the emission rate of the contaminant can be identified or the concentration of the contaminant in that branch can be inserted.

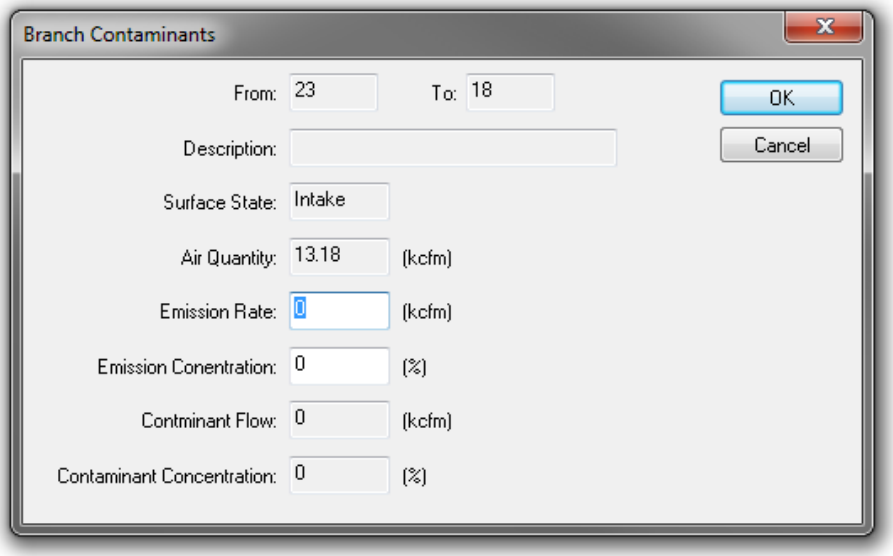


Figure 86: Contaminant Dialog Box

The downstream steady state concentrations and flow rates of the contaminant will be calculated for all affected branches.

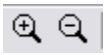
5.8 Program Execution

Once the model is established the user should execute the simulation. After successfully simulating the mine ventilation system the user can export the schematic back into AutoCAD™ through a DXF file to provide an overlay of the projected ventilation values.

During the program execution, any simulation errors detected by the program will be listed in a dialog box on the screen. Information regarding these errors can be found in Section 4.4.1 and the Help program.

6. Appendix: Tools and Tool Buttons

The following list is a description of the buttons and tools available in the Schematic View.

	Selection Pointer	This button selects branches, and is the default mode. The user can drag and drop existing junctions using this tool. It also has right button mouse features for editing objects.
	Zoom In/Out	These two buttons zoom in and out as referenced from the center of the schematic shown on the screen. They are useful to apply when the Zoom Tool is not active, but the user still wishes to zoom the network.
	Zoom All	This tool zooms the extents of the schematic to fit the screen.

	Create Junction	This tool creates/inserts a junction.
	Create Branch	This tool creates a new branch. This tool features a drag and drop approach. Select the initial point, and drag to the second point (keeping the left mouse button depressed).
	Fan or Fixed Q	This tool creates a fan or fixed quantity and inserts it in the selected branch.
	Contaminant	This branch adds a contaminant to the selected branch.
	Create Label	This tool allows the user to annotate or add text to the schematic.
	Zoom	This tool allows the user to "window" or zoom in on a specific area in the schematic. The user may zoom to a window by dragging a rectangle on the screen. The user may also zoom in and out using the left and right mouse buttons respectively (each click will zoom in or out one division).
	Erase	This tool allows the user to rapidly erase selected objects.
	Edit/Information	This tool allows the user to edit the details of an object.
	Plot Junction	This tool will relocate any existing junction/node to another location selected by the user.
	3-D Spin	This tool allows the user to rotate the schematic. The mouse is used to drag the schematic around a central axis to clarify the view of the network.
	Cross-Section	Change the view to the cross-section.
	Long-Section	Change the view to the long-section.
	Plan View	View all groups (layers) in the plan view.
	3D View	View the schematic in three dimensions. The schematic can then be actively dragged. Branch and junction data can be edited in three dimensions.
	Active Groups	View only the active group (layer).
	Edit Groups	Edit the layer attributes.
	All Groups	View all groups (layers) in the current view.
	Selected Groups	View only the selected groups (layers) in the current view.
	Undo/Redo	Allows the users to undo and redo changes in the model. The data will be restored in each branch by using the redo button.

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Title 30: Mineral Resources

PART 57—SAFETY AND HEALTH STANDARDS—UNDERGROUND METAL AND NONMETAL MINES

Authority: 30 U.S.C. 811.

Source: 50 FR 4082, Jan. 29, 1985, unless otherwise noted.

Subpart A—General

§ 57.1 Purpose and scope.

This part 57 sets forth mandatory safety and health standards for each underground metal or nonmetal mine, including related surface operations, subject to the Federal Mine Safety and Health Act of 1977. The purpose of these standards is the protection of life, the promotion of health and safety, and the prevention of accidents.

§ 57.2 Definitions.

The following definitions apply to this part. In addition definitions contained in any subpart of part 57 apply in that subpart. If inconsistent with the general definitions in this section, the definition in the subpart will apply in that subpart:

Abandoned areas means areas in which work has been completed, no further work is planned, and travel is not permitted.

Abandoned mine means all work has stopped on the mine premises and an office with a responsible person in charge is no longer maintained at the mine.

Abandoned workings means deserted mine areas in which further work is not intended.

Active workings means areas at, in, or around a mine or plant where men work or travel.

American Table of Distances means the current edition of “The American Table of Distances for Storage of Explosives” published by the Institute of Makers of Explosives.

Approved means tested and accepted for a specific purpose by a nationally recognized agency.

Attended means presence of an individual or continuous monitoring to prevent unauthorized entry or access. In addition, areas containing explosive material at underground areas of a mine can be considered attended when all access to the underground areas of the mine is secured from unauthorized entry. Vertical shafts shall be considered secure. Inclined shafts or adits shall be considered secure when locked at the surface.

Authorized person means a person approved or assigned by mine management to perform a specific type of duty or duties or to be at a specific location or locations in the mine.

Auxilary fan means a fan used to deliver air to a working place off the main airstream; generally used with ventilation tubing.

Barricaded means obstructed to prevent the passage of persons, vehicles, or flying materials.

Barrier means a material object, or objects that separates, keeps apart, or demarcates in a conspicuous manner such as cones, a warning sign, or tape.

Berm means a pile or mound of material along an elevated roadway capable of moderating or limiting the force of a vehicle in order to impede the vehicle's passage over the bank of the roadway.

Blast area means the area in which concussion (shock wave), flying material, or gases from an explosion may cause injury to persons. In determining the blast area, the following factors, shall be considered:

(1) Geology or material to be blasted.

(2) Blast pattern.

(3) Burden, depth, diameter, and angle of the holes.

(4) Blasting experience of the mine.

(5) Delay system, powder factor, and pounds per delay.

(6) Type and amount of explosive material.

(7) Type and amount of stemming.

Blast site means the area where explosive material is handled during loading, including the perimeter formed by the loaded blastholes and 50 feet (15.2 meters) in all directions from loaded holes. A minimum distance of 30 feet (9.1 meters) may replace the 50-foot (15.2-meter) requirement if the perimeter of loaded holes is demarcated with a barrier. The 50-foot (15.2-meter) and alternative 30-foot (9.1-meter) requirements also apply in all directions along the full depth of the hole. In underground mines, at least 15 feet (4.6 meters) of solid rib, pillar, or broken rock can be substituted for the 50-foot (15.2-meter) distance. In underground mines utilizing a block-caving system or similar system, at least 6 feet (1.8 meters) of solid rib or pillar, including concrete reinforcement of at least 10 inches (254 millimeters), with overall dimensions of not less than 6 feet (1.8 meters) may be substituted for the 50-foot (15.2-meter) distance requirement.

Blasting agent means any substance classified as a blasting agent by the Department of Transportation in 49 CFR 173.114(a) (44 FR 31182, May 31, 1979) which is incorporated by reference. This document is available for inspection at each Metal and Nonmetal Mine Safety and Health District Office of the Mine Safety and Health Administration, and may be obtained from the U.S. Government Printing Office, Washington, DC 20402.

Blasting area means the area near blasting operations in which concussion or flying material can reasonably be expected to cause injury.

Blasting cap means a detonator which is initiated by a safety fuse.

Blasting circuit means the electrical circuit used to fire one or more electric blasting caps.

Blasting switch means a switch used to connect a power source to a blasting circuit.

Blowout means a sudden, violent, release of gas or liquid due to the reservoir pressure in a petroleum mine.

Booster means any unit of explosive or blasting agent used for the purpose of perpetuating or intensifying an initial detonation.

Booster fan means a fan installed in the main airstream or a split of the main airstream to increase airflow through a section or sections of a mine.

Capped fuse means a length of safety fuse to which a blasting cap has been attached.

Capped primer means a package or cartridge of explosives which is specifically designed to transmit detonation to other explosives and which contains a detonator.

Circuit breaker means a device designed to open and close a circuit by nonautomatic means and to open the circuit automatically on a predetermined overcurrent setting without injury to itself when properly applied within its rating.

Combustible means capable of being ignited and consumed by fire.

Combustible material means a material that, in the form in which it is used and under the conditions anticipated, will ignite, burn, support combustion or release flammable vapors when subjected to fire or heat. Wood, paper, rubber, and plastics are examples of combustible materials.

Company official means a member of the company supervisory or technical staff.

Competent person means a person having abilities and experience that fully qualify him to perform the duty to which he is assigned.

Conductor means a material, usually in the form of a wire, cable, or bus bar, capable of carrying an electric current.

Delay connector means a nonelectric short interval delay device for use in delaying blasts which are initiated by detonating cord.

Detonating cord means a flexible cord containing a solid core of high explosives.

Detonator means any device containing a detonating charge that is used to initiate an explosive and includes but is not limited to blasting caps, electric blasting caps and non-electric instantaneous or delay blasting caps.

Distribution box means a portable apparatus with an enclosure through which an electric circuit is carried to one or more cables from a single incoming feed line; each cable circuit being connected through individual overcurrent protective devices.

Electric blasting cap means a detonator designed for and capable of being initiated by means of an electric current.

Electrical grounding means to connect with the ground to make the earth part of the circuit.

Employee means a person who works for wages or salary in the service of an employer.

Employer means a person or organization which hires one or more persons to work for wages or salary.

Emulsion means an explosive material containing substantial amounts of oxidizers dissolved in water droplets, surrounded by an immiscible fuel.

Escapeway means a passageway by which persons may leave a mine.

Explosive means any substance classified as an explosive by the Department of Transportation in 49 CFR 173.53, 173.88 and 173.100 which are incorporated by reference. Title 49 CFR is available for inspection at each Metal and Nonmetal Mine Safety and Health District Office of the Mine Safety and Health Administration, and may be obtained from the U.S. Government Printing Office, Washington, DC 20402.

Face or bank means that part of any mine where excavating is progressing or was last done.

Fire resistance rating means the time, in minutes or hours, that an assembly of materials will retain its protective characteristics or structural integrity upon exposure to fire.

Flame spread rating means the numerical designation that indicates the extent flame will spread over the surface of a material during a specified period of time.

Flammable means capable of being easily ignited and of burning rapidly.

Flammable gas means a gas that will burn in the normal concentrations of oxygen in the air.

Flammable liquid a liquid that has a flash point below 100 °F (37.8 °C), a vapor pressure not exceeding 40 pounds per square inch (absolute) at 100 °F (37.8 °C), and is known as a Class I liquid.

Flash point means the minimum temperature at which sufficient vapor is released by a liquid or solid to form a flammable vapor-air mixture at atmospheric pressure.

Geological area means an area characterized by the presence of the same ore bodies, the same stratigraphic sequence of beds, or the same ore-bearing geological formation.

Highway means any public street, public alley or public road.

High potential means more than 650 volts.

Hoist means a power driven windlass or drum used for raising ore, rock, or other material from a mine, and for lowering or raising persons and material.

Igniter cord means a fuse, cordlike in appearance, which burns progressively along its length with an external flame at the zone of burning, and is used for lighting a series of safety fuses in the desired sequence.

Insulated means separated from other conducting surfaces by a dielectric substance permanently offering a high resistance to the passage of current and to disruptive discharge through the substance. When any substance is said to be insulated, it is understood to be insulated in a manner suitable for the conditions to which it is subjected. Otherwise, it is, within the purpose of this definition, uninsulated. Insulating covering is one means for making the conductor insulated.

Insulation means a dielectric substance offering a high resistance to the passage of current and to a disruptive discharge through the substance.

Laminated partition a partition composed of the following material and minimum nominal dimensions:1/2-inch-thick plywood,1/2-inch-thick gypsum wallboard,1/8-inch-thick low carbon steel, and1/4-inch-thick plywood, bonded together in that order (IME–22 Box). A laminated partition also includes alternative construction materials described in the Institute of Makers of Explosives (IME) Safety Library Publication No. 22, "Recommendations for the Safe Transportation of Detonators in a Vehicle with other Explosive Materials," (May 1993), and the "Generic Loading Guide for the IME–22 Container," (October 1993). This incorporation by reference has been approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. Copies are available at MSHA, 1100 Wilson Blvd., Room 2436, Arlington, Virginia 22209–3939, and at all Metal and Nonmetal Mine Safety and Health district offices, or available for inspection at the Office of the Federal Register, 800 North Capitol Street, NW., 7th Floor, suite 700, Washington, DC.

Lay means the distance parallel to the axis of the rope in which a strand makes one complete turn about the axis of the rope.

Loading means placing explosive material either in a blasthole or against the material to be blasted.

Low potential means 650 volts or less.

Magazine means a facility for the storage of explosives, blasting agents, or detonators.

Main fan means a fan that controls the entire airflow of the mine, or the airflow of one of the major air circuits.

Major electrical installation means an assemblage of stationary electrical equipment for the generation, transmission, distribution, or conversion of electrical power.

Mantrip means a trip on which persons are transported to and from a work area.

Mill includes any ore mill, sampling works, concentrator, and any crushing, grinding, or screening plant used at, and in connection with, an excavation or mine.

Mine atmosphere means any point at least 12 inches away from the back, face, rib, and floor in any mine; and additionally, in a Category IV mine, at least 3 feet laterally away from the collar of a borehole which releases gas into a mine.

Mine opening means any opening or entrance from the surface into a mine.

Misfire means the complete or partial failure of a blasting charge to explode as planned.

Mobile equipment means wheeled, skid-mounted, track-mounted, or rail-mounted equipment capable of moving or being moved.

Multipurpose dry-chemical fire extinguisher means an extinguisher having a rating of at least 2–A:10–B:C and containing a nominal 4.5 pounds or more of dry-chemical agent.

Noncombustible material means a material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat. Concrete, masonry block, brick, and steel are examples of noncombustible materials.

Non-electric delay blasting cap means a detonator with an integral delay element and capable of being initiated by miniaturized detonating cord.

Outburst means the sudden, violent release of solids and high-pressure occluded gases, including methane in a domal salt mine.

Overburden means material of any nature, consolidated or unconsolidated, that overlies a deposit of useful materials or ores that are to be mined.

Overload means that current which will cause an excessive or dangerous temperature in the conductor or conductor insulation.

Permissible means a machine, material, apparatus, or device which has been investigated, tested, and approved by the Bureau of Mines or the Mine Safety and Health Administration, and is maintained in permissible condition.

Potable water means water which shall meet the applicable minimum health requirements for drinking water established by the State or community in which the mine is located or by the Environmental Protection Agency in 40 CFR part 141, pages 169–182 revised as of July 1, 1977. Where no such requirements are applicable, the drinking water provided shall conform with the Public Health Service Drinking Water Standards, 42 CFR part 72, subpart J, pages 527–533, revised as of October 1, 1976. Publications to which references are made in

this definition are hereby made a part hereof. These incorporated publications are available for inspection at each Metal and Nonmetal Mine Safety and Health District Office of the Mine Safety and Health Administration.

Powder chest means a substantial, nonconductive portable container equipped with a lid and used at blasting sites for explosives other than blasting agents.

Primer means a unit, package, or cartridge of explosives used to initiate other explosives or blasting agents, and which contains a detonator.

Reverse-current protection means a method or device used on direct-current circuits or equipment to prevent the flow of current in a reverse direction.

Rock burst means a sudden and violent failure of overstressed rock resulting in the instantaneous release of large amounts of accumulated energy. Rock burst does not include a burst resulting from pressurized mine gases.

Rock fixture means any tensioned or nontensioned device or material inserted into the ground to strengthen or support the ground.

Roll protection means a framework, safety canopy or similar protection for the operator when equipment overturns.

Safety can means an approved container, of not over 5 gallons capacity, having a spring-closing lid and spout cover.

Safety fuse means a flexible cord containing an internal burning medium by which fire is conveyed at a continuous and uniform rate for the purpose of firing blasting caps or a black powder charge.

Safety switch means a sectionalizing switch that also provides shunt protection in blasting circuits between the blasting switch and the shot area.

Scaling means removal of insecure material from a face or highwall.

Secondary safety connection means a second connection between a conveyance and rope, intended to prevent the conveyance from running away or falling in the event the primary connection fails.

Shaft means a vertical or inclined shaft, a slope, incline, or winze.

Short circuit means an abnormal connection of relatively low resistance, whether made accidentally or intentionally, between two points of difference potential in a circuit.

Slurry (as applied to blasting). See “Water gel.”

Storage facility means the entire class of structures used to store explosive materials. A “storage facility” used to store blasting agents corresponds to a BATF Type 4 or 5 storage facility.

Storage tank means a container exceeding 60 gallons in capacity used for the storage of flammable or combustible liquids.

Stray current means that portion of a total electric current that flows through paths other than the intended circuit.

Substantial construction means construction of such strength, material, and workmanship that the object will withstand all reasonable shock, wear, and usage to which it will be subjected.

Suitable means that which fits, and has the qualities or qualifications to meet a given purpose, occasion, condition, function, or circumstance.

Travelway means a passage, walk or way regularly used and designated for persons to go from one place to another.

Water gel or Slurry (as applied to blasting) means an explosive or blasting agent containing substantial portions of water.

Wet drilling means the continuous application of water through the central hole of hollow drill steel to the bottom of the drill hole.

Working level (WL) means any combination of the short-lived radon daughters in one liter of air that will result in ultimate emission of 1.3×10^5 MeV (million electron volts) of potential alpha energy, and exposure to these radon daughters over a period of time is expressed in terms of “working level months” (WLM). Inhalation of air containing a radon daughter concentration of 1 WL for 173 hours results in an exposure of 1 WLM.”

Working place means any place in or about a mine where work is being performed.

[69 FR 38840, June 29, 2004]

Procedures

§ 57.1000 Notification of commencement of operations and closing of mines.

The owner, operator, or person in charge of any metal and nonmetal mine shall notify the nearest MSHA Metal and Nonmental Mine Safety and Health district office before starting operations, of the approximate or actual date mine operation will commence. The notification shall include the mine name, location, the company name, mailing address, person in charge, and whether operations will be continuous or intermittent. When any mine is closed, the person in charge shall notify the nearest district office as provided above and indicate whether the closure is temporary or permanent.

[51 FR 36198, Oct. 8, 1986, as amended at 60 FR 33723, June 29, 1995; 60 FR 35695, July 11, 1995; 71 FR 16667, Apr. 3, 2006]

Subpart B—Ground Control

Authority: 30 U.S.C. 811.

Source: 51 FR 36198, Oct. 8, 1986, unless otherwise noted.

§ 57.3000 Definitions.

The following definitions apply in this subpart.

Travelway. A passage, walk, or haulageway regularly used or designated for persons to go from one place to another.

[51 FR 36198, Oct. 8, 1986, as amended at 69 FR 38842, June 29, 2004]

Scaling and Support—Surface and Underground

§ 57.3200 Correction of hazardous conditions.

Ground conditions that create a hazard to persons shall be taken down or supported before other work or travel is permitted in the affected area. Until corrective work is completed, the area shall be posted with a warning against entry and, when left unattended, a barrier shall be installed to impede unauthorized entry.

§ 57.3201 Location for performing scaling.

Scaling shall be performed from a location which will not expose persons to injury from falling material, or other protection from falling material shall be provided.

§ 57.3202 Scaling tools.

Where manual scaling is performed, a scaling bar shall be provided. This bar shall be of a length and design that will allow the removal of loose material without exposing the person performing the work to injury.

§ 57.3203 Rock fixtures.

(a) For rock bolts and accessories addressed in ASTM F432–95, “Standard Specification for Roof and Rock Bolts and Accessories,” the mine operator shall—

(1) Obtain a manufacturer's certification that the material was manufactured and tested in accordance with the specifications of ASTM F432–95; and

(2) Make this certification available to an authorized representative of the Secretary and to the representative of miners.

(b) Fixtures and accessories not addressed in ASTM F432–95 may be used for ground support provided they—

(1) Have been successful in supporting the ground in an area with similar strata, opening dimensions and ground stresses in any mine; or

(2) Have been tested and shown to be effective in supporting ground in an area of the affected mine which has similar strata, opening dimensions, and ground stresses as the area where the fixtures are expected to be used. During the test process, access to the test area shall be limited to persons necessary to conduct the test.

(c) Bearing plates shall be used with fixtures when necessary for effective ground support.

(d) The diameter of finishing bits shall be within a tolerance of plus or minus 0.030 inch of the manufacturer's recommended hole diameter for the anchor used. When separate finishing bits are used, they shall be distinguishable from other bits.

(e) Damaged or deteriorated cartridges of grouting material shall not be used.

(f) When rock bolts tensioned by torquing are used as a means of ground support,

(1) Selected tension level shall be—

(i) At least 50 percent of either the yield point of the bolt or anchorage capacity of the rock, whichever is less; and

(ii) No greater than the yield point of the bolt or anchorage capacity of the rock.

(2) The torque of the first bolt, every tenth bolt, and the last bolt installed in each work area during the shift shall be accurately determined immediately after installation. If the torque of any fixture tested does not fall within the installation torque range, corrective action shall be taken.

(g) When grouted fixtures can be tested by applying torque, the first fixture installed in each work place shall be tested to withstand 150 foot-pounds of torque. Should it rotate in the hole, a second fixture shall be tested in the same manner. If the second fixture also turns, corrective action shall be taken.

(h) When other tensioned and nontensioned fixtures are used, test methods shall be established and used to verify their effectiveness.

(i) The mine operator shall certify that tests were conducted and make the certification available to an authorized representative of the Secretary.

[51 FR 36198, Oct. 8, 1986, as amended at 51 FR 36804, Oct. 16, 1986; 63 FR 20030, Apr. 22, 1998]

Scaling and Support—Underground Only

§ 57.3360 Ground support use.

Ground support shall be used where ground conditions, or mining experience in similar ground conditions in the mine, indicate that it is necessary. When ground support is necessary, the support system shall be designed, installed, and maintained to control the ground in places where persons work or travel in performing their assigned tasks. Damaged, loosened, or dislodged timber use for ground support which creates a hazard to persons shall be repaired or replaced prior to any work or travel in the affected area.

Precautions—Surface and Underground

§ 57.3400 Secondary breakage.

Prior to secondary breakage operations, the material to be broken, other than hanging material, shall be positioned or blocked to prevent movement which would endanger persons in the work area. Secondary breakage shall be performed from a location which would not expose persons to danger.

§ 57.3401 Examination of ground conditions.

Persons experienced in examining and testing for loose ground shall be designated by the mine operator. Appropriate supervisors or other designated persons shall examine and, where applicable, test ground conditions in areas where work is to be performed, prior to work commencing, after blasting, and as ground conditions warrant during the work shift. Underground haulageways and travelways and surface area highwalls and banks adjoining travelways shall be examined weekly or more often if changing ground conditions warrant.

Precautions—Surface Only

§ 57.3430 Activity between machinery or equipment and the highwall or bank.

Persons shall not work or travel between machinery or equipment and the highwall or bank where the machinery or equipment may hinder escape from falls or slides of the highwall or bank. Travel is permitted when necessary for persons to dismount.

Precautions—Underground Only

§ 57.3460 Maintenance between machinery or equipment and ribs.

Persons shall not perform maintenance work between machinery or equipment and ribs unless the area has been tested and, when necessary, secured.

§ 57.3461 Rock bursts.

(a) Operators of mines which have experienced a rock burst shall—

(1) Within twenty four hours report to the nearest MSHA office each rock burst which:

(i) Causes persons to be withdrawn;

(ii) Impairs ventilation;

(iii) Impedes passage; or

(iv) Disrupts mining activity for more than one hour.

(2) Develop and implement a rock burst control plan within 90 days after a rock burst has been experienced.

(b) The plan shall include—

(1) Mining and operating procedures designed to reduce the occurrence of rock bursts;

(2) Monitoring procedures where detection methods are used; and

(3) Other measures to minimize exposure of persons to areas which are prone to rock bursts.

(c) The plan shall be updated as conditions warrant.

(d) The plan shall be available to an authorized representative of the Secretary and to miners or their representatives.

Subpart C—Fire Prevention and Control

Authority: Sec. 101, Federal Mine Safety and Health Act of 1977, Pub. L. 91–173 as amended by Pub. L. 95–164, 91 Stat. 1291 (30 U.S.C. 811).

§ 57.4000 Definitions.

The following definitions apply in this subpart.

Combustible liquids. Liquids having a flash point at or above 100 °F (37.8 °C). They are divided into the following classes:

Class II liquids—those having flash points at or above 100 °F (37.8 °C) and below 140 °F (60 °C).

Class IIIA liquids—those having flash points at or above 140 °F (60 °C) and below 200 °F (93.4 °C).

Class IIIB liquids—those having flash points at or above 200 °F (93.4 °C).

Escapeway. A designated passageway by which persons can leave an underground mine.

Flash point. The minimum temperature at which sufficient vapor is released by a liquid to form a flammable vapor-air mixture near the surface of the liquid.

Main fan. A fan that controls the entire airflow of an underground mine or the airflow of one of the major air circuits of the mine.

Mine opening. Any opening or entrance from the surface into an underground mine.

Safety can. A container of not over five gallons capacity that is designed to safely relieve internal pressure when exposed to heat and has a spring-closing lid and spout cover.

[50 FR 4082, Jan. 29, 1985, as amended at 68 FR 32361, May 30, 2003; 69 FR 38842, June 29, 2004]

§ 57.4011 Abandoned electric circuits.

Abandoned electric circuits shall be deenergized and isolated so that they cannot become energized inadvertently.

§ 57.4057 Underground trailing cables.

Underground trailing cables shall be accepted or approved by MSHA as flame resistant.

[57 FR 61223, Dec. 23, 1992]

Prohibitions/Precautions/Housekeeping

§ 57.4100 Smoking and use of open flames.

No person shall smoke or use an open flame where flammable or combustible liquids, including greases, or flammable gases are—

(a) Used or transported in a manner that could create a fire hazard; or

(b) Stored or handled.

§ 57.4101 Warning signs.

Readily visible signs prohibiting smoking and open flames shall be posted where a fire or explosion hazard exists.

§ 57.4102 Spillage and leakage.

Flammable or combustible liquid spillage or leakage shall be removed in a timely manner or controlled to prevent a fire hazard.

§ 57.4103 Fueling internal combustion engines.

Internal combustion engines shall be switched off before refueling if the fuel tanks are integral parts of the equipment. This standard does not apply to diesel-powered equipment.

§ 57.4104 Combustible waste.

(a) Waste materials, including liquids, shall not accumulate in quantities that could create a fire hazard.

(b) Waste or rags containing flammable or combustible liquids that could create a fire hazard shall be placed in the following containers until disposed of properly:

(1) Underground—covered metal containers.

(2) On the surface—covered metal containers or equivalent containers with flame containment characteristics.

§ 57.4130 Surface electric substations and liquid storage facilities.

The requirements of this standard apply to surface areas only.

(a) If a hazard to persons could be created, no combustible materials shall be stored or allowed to accumulate within 25 feet of the following:

(1) Electric substations.

(2) Unburied, flammable or combustible liquid storage tanks.

(3) Any group of containers used for storage of more than 60 gallons of flammable or combustible liquids.

(b) The area within the 25-foot perimeter shall be kept free of dry vegetation.

§ 57.4131 Surface fan installations and mine openings.

(a) On the surface, no more than one day's supply of combustible materials shall be stored within 100 feet of mine openings or within 100 feet of fan installations used for underground ventilation.

(b) the one-day supply shall be kept at least 25 feet away from any mine opening except during transit into the mine.

(c) Dry vegetation shall not be permitted within 25 feet of mine openings.

§ 57.4160 Underground electric substations and liquid storage facilities.

The requirements of this standard apply to underground areas only.

(a) Areas within 25 feet of the following shall be free of combustible materials:

(1) Electric substations.

(2) Unburied, combustible liquid storage tanks.

(3) Any group of containers used for storage of more than 60 gallons of combustible liquids.

(b) This standard does not apply to installed wiring or timber that is coated with at least one inch of shotcrete, one-half inch of gunite, or other noncombustible materials with equivalent fire protection characteristics.

§ 57.4161 Use of fire underground.

Fires shall not be lit underground, except for open-flame torches. Torches shall be attended at all times while lit.

Firefighting Equipment

§ 57.4200 General requirements.

(a) For fighting fires that could endanger persons, each mine shall have—

(1) Onsite firefighting equipment for fighting fires in their early stages; and

(2) Onsite firefighting equipment for fighting fires beyond their early stages, or the mine shall have made prior arrangements with a local fire department to fight such fires.

(b) This onsite firefighting equipment shall be—

(1) Of the type, size, and quantity that can extinguish fires of any class which would occur as a result of the hazards present; and

(2) Strategically located, readily accessible, plainly marked, and maintained in fire-ready condition.

[50 FR 4082, Jan. 29, 1985, as amended at 50 FR 20100, May 14, 1985]

§ 57.4201 Inspection.

(a) Firefighting equipment shall be inspected according to the following schedules:

(1) Fire extinguishers shall be inspected visually at least once a month to determine that they are fully charged and operable.

(2) At least once every twelve months, maintenance checks shall be made of mechanical parts, the amount and condition of extinguishing agent and expellant, and the condition of the hose, nozzle, and vessel to determine that the fire extinguishers will operate effectively.

(3) Fire extinguishers shall be hydrostatically tested according to Table C–1 or a schedule based on the manufacturer's specifications to determine the integrity of extinguishing agent vessels.

(4) Water pipes, valves, outlets, hydrants, and hoses that are part of the mine's firefighting system shall be visually inspected at least once every three months for damage or deterioration and use-tested at least once every twelve months to determine that they remain functional.

(5) Fire suppression systems shall be inspected at least once every twelve months. An inspection schedule based on the manufacturer's specifications or the equivalent shall be established for individual components of a system and followed to determine that the system remains functional. Surface fire suppression systems are exempt from these inspection requirements if the systems are used solely for the protection of property and no persons would be affected by a fire.

(b) At the completion of each inspection or test required by this standard, the person making the inspection or test shall certify that the inspection or test has been made and the date on which it was made. Certifications of hydrostatic testing shall be retained until the fire extinguisher is retested or permanently removed from service. Other certifications shall be retained for one year.

Table C–1—Hydrostatic Test Intervals for Fire Extinguishers

Extinguisher type	Test interval (years)
Soda Acid	5
Cartridge-Operated Water and/or Antifreeze	5
Stored-Pressure Water and/or Antifreeze	5
Wetting Agent	5
Foam	5
AFFF (Aqueous Film Forming Foam)	5
Loaded Stream	5
Dry-Chemical with Stainless Steel Shells	5
Carbon Dioxide	5
Dry-Chemical, Stored Pressure, with Mild Steel Shells, Brazed Brass Shells, or Aluminum Shells	12

Dry-Chemical, Cartridge or Cylinder Operated, with Mild Steel Shells	12
Bromotrifluoromethane-Halon 1301	12
Bromochlorodifluoromethane-Halon 1211	12
Dry-Powder, Cartridge or Cylinder-Operated, with Mild Steel Shells[1]	12

[1]Except for stainless steel and steel used for compressed gas cylinders, all other steel shells are defined as “mild steel” shells.

§ 57.4202 Fire hydrants.

If fire hydrants are part of the mine's firefighting system, the hydrants shall be provided with—

(a) Uniform fittings or readily available adapters for onsite firefighting equipment;

(b) Readily available wrenches or keys to open the valves; and

(c) Readily available adapters capable of connecting hydrant fittings to the hose equipment of any firefighting organization relied upon by the mine.

§ 57.4203 Extinguisher recharging or replacement.

Fire extinguishers shall be recharged or replaced with a fully charged extinguisher promptly after any discharge.

§ 57.4230 Surface self-propelled equipment.

(a)(1) Whenever a fire or its effects could impede escape from self-propelled equipment, a fire extinguisher shall be on the equipment.

(2) Whenever a fire or its effects would not impede escape from the equipment but could affect the escape of other persons in the area, a fire extinguisher shall be on the equipment or within 100 feet of the equipment.

(b) A fire suppression system may be used as an alternative to fire extinguishers if the system can be manually activated.

(c) Fire extinguishers or fire suppression systems shall be of a type and size that can extinguish fires of any class in their early stages which could originate from the equipment's inherent fire hazards. Fire extinguishers or manual actuators for the suppression system shall be located to permit their use by persons whose escape could be impeded by fire.

§ 57.4260 Underground self-propelled equipment.

(a) Whenever self-propelled equipment is used underground, a fire extinguisher shall be on the equipment. This standard does not apply to compressed-air powered equipment without inherent fire hazards.

(b) A fire suppression system may be used as an alternative to fire extinguishers if the system can be manually actuated.

(c) Fire extinguishers or fire suppression systems shall be of a type and size that can extinguish fires of any class in their early stages which could originate from the equipment's inherent fire hazards. The fire extinguishers or the manual actuator for the suppression system shall be readily accessible to the equipment operator.

§ 57.4261 Shaft-station waterlines.

Waterline outlets that are located at underground shaft stations and are part of the mine's fire protection system shall have at least one fitting located for, and capable of, immediate connection to firefighting equipment.

§ 57.4262 Underground transformer stations, combustible liquid storage and dispensing areas, pump rooms, compressor rooms, and hoist rooms.

Transformer stations, storage and dispensing areas for combustible liquids, pump rooms, compressor rooms, and hoist rooms shall be provided with fire protection of a type, size, and quantity that can extinguish fires of any class in their early stages which could occur as a result of the hazards present.

§ 57.4263 Underground belt conveyors.

Fire protection shall be provided at the head, tail, drive, and take-up pulleys of underground belt conveyors. Provisions shall be made for extinguishing fires along the beltline. Fire protection shall be of a type, size, and quantity that can extinguish fires of any class in their early stages which could occur as a result of the fire hazards present.

Firefighting Procedures/Alarms/Drills

§ 57.4330 Surface firefighting, evacuation, and rescue procedures.

(a) Mine operators shall establish emergency firefighting, evacuation, and rescue procedures for the surface portions of their operations. These procedures shall be coordinated in advance with available firefighting organizations.

(b) Fire alarm procedures or systems shall be established to promptly warn every person who could be endangered by a fire.

(c) Fire alarm systems shall be maintained in operable condition.

§ 57.4331 Surface firefighting drills.

Emergency firefighting drills shall be held at least once every six months for persons assigned surface firefighting responsibilities by the mine operator.

§ 57.4360 Underground alarm systems.

(a) Fire alarm systems capable of promptly warning every person underground, except as provided in paragraph (b), shall be provided and maintained in operating condition.

(b) If persons are assigned to work areas beyond the warning capabilities of the system, provisions shall be made to alert them in a manner to provide for their safe evacuation in the event of a fire.

§ 57.4361 Underground evacuation drills.

(a) At least once every six months, mine evacuation drills shall be held to assess the ability of all persons underground to reach the surface or other designated points of safety within the time limits of the self-rescue devices that would be used during an actual emergency.

(b) The evacuation drills shall—

(1) Be held for each shift at some time other than a shift change and involve all persons underground;

(2) Involve activation of the fire alarm system; and

(3) Include evacuation of all persons from their work areas to the surface or to designated central evacuation points.

(c) At the completion of each drill, the mine operator shall certify the date and the time the evacuation began and ended. Certifications shall be retained for at least one year after each drill.

§ 57.4362 Underground rescue and firefighting operations.

Following evacuation of a mine in a fire emergency, only persons wearing and trained in the use of mine rescue apparatus shall participate in rescue and firefighting operations in advance of the fresh air base.

§ 57.4363 Underground evacuation instruction.

(a) At least once every twelve months, all persons who work underground shall be instructed in the escape and evacuation plans and procedures and fire warning signals in effect at the mine.

(b) Whenever a change is made in escape and evacuation plans and procedures for any area of the mine, all persons affected shall be instructed in the new plans or procedures.

(c) Whenever persons are assigned to work in areas other than their regularly assigned areas, they shall be instructed about the escapeway for that area at the time of such assignment. However, persons who normally work in more than one area of the mine shall be instructed at least once every twelve months about the location of escapeways for all areas of the mine in which they normally work or travel.

(d) At the completion of any instruction given under this standard, the mine operator shall certify the date that the instruction was given. Certifications shall be retained for at least one year.

Flammable and Combustible Liquids and Gases

§ 57.4400 Use restrictions.

(a) Flammable liquids shall not be used for cleaning.

(b) Solvents shall not be used near an open flame or other ignition source, near any source of heat, or in an atmosphere that can elevate the temperature of the solvent above the flash point.

§ 57.4401 Storage tank foundations.

Fixed, unburied, flammable or combustible liquid storage tanks shall be securely mounted on firm foundations. Piping shall be provided with flexible connections or other special fittings where necessary to prevent leaks caused by tanks settling.

§ 57.4402 Safety can use.

Small quantities of flammable liquids drawn from storage shall be kept in safety cans labeled to indicate the contents.

§ 57.4430 Surface storage facilities.

The requirements of this standard apply to surface areas only.

(a) Storage tanks for flammable or combustible liquids shall be—

(1) Capable of withstanding working pressures and stresses and compatible with the type of liquid stored;

(2) Maintained in a manner that prevents leakage;

(3) Isolated or separated from ignition sources to prevent fire or explosion; and

(4) Vented or otherwise constructed to prevent development of pressure or vacuum as a result of filling, emptying, or atmospheric temperature changes. Vents for storage of Class I, II, or IIIA liquids shall be isolated or separated from ignition sources. These pressure relief requirements do not apply to tanks used for storage of Class IIIB liquids that are larger than 12,000 gallons in capacity.

(b) All piping, valves, and fittings shall be—

(1) Capable of withstanding working pressures and stresses;

(2) Compatible with the type of liquid stored; and

(3) Maintained in a manner that prevents leakage.

(c) Fixed, unburied tanks located where escaping liquid could present a hazard to persons shall be provided with—

(1) Containment for the entire capacity of the largest tank; or

(2) Drainage to a remote impoundment area that does not endanger persons. However, storage of only Class IIIB liquids does not require containment or drainage to remote impoundment.

§ 57.4431 Surface storage restrictions.

(a) On the surface, no unburied flammable or combustible liquids or flammable gases shall be stored within 100 feet of the following:

(1) Mine openings or structures attached to mine openings.

(2) Fan installations for underground ventilation.

(3) Hoist houses.

(b) Under this standard, the following may be present in the hoist house in quantities necessary for the day-to-day maintenance of the hoist machinery:

(1) Flammable liquids in safety cans or in other containers placed in tightly closed cabinets. The safety cans and cabinets shall be kept away from any heat source, and each cabinet shall be labeled “flammables.”

(2) Combustible liquids in closed containers. The cointainers shall be kept away from any heat source and the hoist operator's work station.

§ 57.4460 Storage of flammable liquids underground.

(a) Flammable liquids shall not be stored underground, except—

(1) Small quantities stored in tightly closed cabinets away from any heat source. The small quantities shall be stored in safety cans or in non-glass containers of a capacity equal to or less than a safety can. Each cabinet shall be labeled “flammables.”

(2) Acetylene and liquefied petroleum gases stored in containers designed for that specific purpose.

(b) Gasoline shall not be stored underground in any quantity.

§ 57.4461 Gasoline use restrictions underground.

If gasoline is used underground to power internal combustion engines–

(a) The mine shall be nongassy and shall have multiple horizontal or inclined roadways from the surface large enough to accommodate vehicular traffic;

(b) All roadways and other openings shall connect with another opening every 100 feet by a passage large enough to accommodate any vehicle in the mine or alternate routes shall provide equivalent escape capabilities; and

(c) No roadway or other opening shall be supported or lined with wood or other combustible materials.

§ 57.4462 Storage of combustible liquids underground.

The requirements of this standard apply to underground areas only.

(a) Combustible liquids, including oil or grease, shall be stored in non-glass containers or storage tanks. The containers or storage tanks shall be—

(1) Capable of withstanding working pressures and stresses and compatible with the type of liquid stored;

(2) Maintained in a manner that prevents leakage;

(3) Located in areas free of combustible materials or in areas where any exposed combustible materials are coated with one inch of shotcrete, one-half inch of gunite, or other noncombustible material with equivalent fire protection characteristics; and

(4) Separated from explosives or blasting agents, shaft stations, and ignition sources including electric equipment that could create sufficient heat or sparks to pose a fire hazard. Separation shall be sufficient to prevent the occurrence or minimize the spread of fire.

(b) Storage tanks shall be vented or otherwise constructed to prevent development of pressure or vacuum as a result of filling, emptying, or atmospheric temperature changes. Vents for storage of Class II or IIIA liquids shall be isolated or separated from ignition sources.

(c) At permanent storage areas for combustible liquids, means shall be provided for confinement or removal of the contents of the largest storage tank in the event of tank rupture.

(d) All piping, valves, and fittings shall be:

(1) Capable of withstanding working pressures and stresses;

(2) Compatible with the type of liquid stored; and

(3) Maintained in a manner which prevents leakage.

§ 57.4463 Liquefied petroleum gas use underground.

Use of liquefied petroleum gases underground shall be limited to maintenance work.

Installation/Construction/Maintenance

§ 57.4500 Heat sources.

Heat sources capable of producing combustion shall be separated from combustible materials if a fire hazard could be created.

§ 57.4501 Fuel lines.

Fuel lines shall be equipped with valves capable of stopping the flow of fuel at the source and shall be located and maintained to minimize fire hazards. This standard does not apply to fuel lines on self-propelled equipment.

§ 57.4502 Battery-charging stations.

(a) Battery-charging stations shall be ventilated with a sufficient volume of air to prevent the accumulation of hydrogen gas.

(b) Smoking, use of open flames, or other activities that could create an ignition source shall be prohibited at the battery charging station during battery charging.

(c) Readily visible signs prohibiting smoking or open flames shall be posted at battery-charging stations during battery charging.

§ 57.4503 Conveyor belt slippage.

(a) Surface belt conveyors within confined areas where evacuation would be restricted in the event of a fire resulting from belt-slippage shall be equipped with a detection system capable of automatically stopping the drive pulley.

(b) Underground belt conveyors shall be equipped with a detection system capable of automatically stopping the drive pulley if slippage could cause ignition of the belt.

(c) A person shall attend the belt at the drive pulley when it is necessary to operate the conveyor while temporarily bypassing the automatic function.

§ 57.4504 Fan installations.

(a) Fan houses, fan bulkheads for main and booster fans, and air ducts connecting main fans to underground openings shall be constructed of noncombustible materials.

(b) Areas within 25 feet of main fans or booster fans shall be free of combustible materials, except installed wiring, ground and track support, headframes, and direct-fired heaters. Other timber shall be coated with one inch of shotcrete, one-half inch of gunite, or other noncombustible materials.

§ 57.4505 Fuel lines to underground areas.

Fuel lines into underground storage or dispensing areas shall be drained at the completion of each transfer of fuel unless the following requirements are met:

(a) The valve at the supply source shall be kept closed when fuel is not being transferred.

(b) The fuel line shall be—

(1) Capable of withstanding working pressures and stresses;

(2) Located to prevent damage; and

(3) Located in areas free of combustible materials or in areas where any exposed combustible materials are coated with one inch of shotcrete, one-half inch of gunite, or other noncombustible material with equivalent fire protection characteristics.

(c) Provisions shall be made for control or containment of the entire volume of the fuel line so that leakage will not create a fire hazard.

§ 57.4530 Exits for surface buildings and structures.

Surface buildings or structures in which persons work shall have a sufficient number of exits to permit prompt escape in case of fire.

§ 57.4531 Surface flammable or combustible liquid storage buildings or rooms.

(a) Surface storage buildings or storage rooms in which flammable or combustible liquids, including grease, are stored and that are within 100 feet of any person's work station shall be ventilated with a sufficient volume of air to prevent the accumulation of flammable vapors.

(b) In addition, the buildings or rooms shall be—

(1) Constructed to meet a fire resistance rating of at least one hour; or

(2) Equipped with an automatic fire supression system; or

(3) Equipped with an early warning fire detection device that will alert any person who could be endangered by a fire, provided that no person's work station is in the building.

(c) Flammable or combustible liquids in use for day-to-day maintenance and operational activities are not considered in storage under this standard.

§ 57.4532 Blacksmith shops.

Blacksmith shops located on the surface shall be—

(a) At least 100 feet from fan installations used for intake air and mine openings;

(b) Equipped with exhaust vents over the forge and ventilated to prevent the accumulation of the products of combustion; and

(c) Inspected for smoldering fires at the end of each shift.

§ 57.4533 Mine opening vicinity.

Surface buildings or other similar structures within 100 feet of mine openings used for intake air or within 100 feet of mine openings that are designated escapeways in exhaust air shall be—

(a) Constructed of noncombustible materials; or

(b) Constructed to meet a fire resistance rating of no less than one hour; or

(c) Provided with an automatic fire suppression system; or

(d) Covered on all combustible interior and exterior structural surfaces with noncombustible material or limited combustible material, such as five-eighth inch, type “X” gypsum wallboard.

§ 57.4560 Mine entrances.

For at least 200 feet inside the mine portal or collar timber used for ground support in intake openings and in exhaust openings that are designated as escapeways shall be—

(a) Provided with a fire suppression system, other than fire extinguishers and water hoses, capable of controlling a fire in its early stages; or

(b) Covered with shotcrete, gunite, or other material with equivalent fire protection characteristics; or

(c) Coated with fire-retardant paint or other material to reduce its flame spread rating to 25 or less and maintained in that condition.

[50 FR 4082, Jan. 29, 1985, as amended at 50 FR 20100, May 14, 1985]

§ 57.4561 Stationary diesel equipment underground.

Stationary diesel equipment underground shall be—

(a) Supported on a noncombustible base; and

(b) Provided with a thermal sensor that automatically stops the engine if overheating occurs.

Welding/Cutting/Compressed Gases

§ 57.4600 Extinguishing equipment.

(a) When welding, cutting, soldering, thawing, or bending—

(1) With an electric arc or with an open flame where an electrically conductive extinguishing agent could create an electrical hazard, a multipurpose dry-chemical fire extinguisher or other extinguisher with at least a 2–A:10–B:C rating shall be at the worksite.

(2) With an open flame in an area where no electrical hazard exists, a multipurpose dry-chemical fire extinguisher or equivalent fire extinguishing equipment for the class of fire hazard present shall be at the worksite.

(b) Use of halogenated fire extinguishing agents to meet the requirements of this standard shall be limited to Halon 1211 ($CBrClF_2$) and Halon 1301 ($CBrF_3$). When these agents are used in confined or unventilated areas, precautions based on the manufacturer's use instructions shall be taken so that the gases produced by thermal decomposition of the agents are not inhaled.

§ 57.4601 Oxygen cylinder storage.

Oxygen cylinders shall not be stored in rooms or areas used or designated for storage of flammable or combustible liquids, including grease.

§ 57.4602 Gauges and regulators.

Gauges and regulators used with oxygen or acetylene cylinders shall be kept clean and free of oil and grease.

§ 57.4603 Closure of valves.

To prevent accidental release of gases from hoses and torches attached to oxygen and acetylene cylinders or to manifold systems, cylinder or manifold system valves shall be closed when—

(a) The cylinders are moved;

(b) The torch and hoses are left unattended; or

(c) The task or series of tasks is completed.

§ 57.4604 Preparation of pipelines or containers.

Before welding, cutting, or applying heat with an open flame to pipelines or containers that have contained flammable or combustible liquids, flammable gases, or explosive solids, the pipelines or containers shall be—

(a) Drained, ventilated, and thoroughly cleaned of any residue;

(b) Vented to prevent pressure build-up during the application of heat; and

(c)(1) Filled with an inert gas or water, where compatible; or

(2) Determined to be free of flammable gases by a flammable gas detection device prior to and at frequent intervals during the application of heat.

§ 57.4660 Work in shafts, raises, or winzes and other activities involving hazard areas.

During performance of an activity underground described in Table C–2 or when falling sparks or hot metal from work performed in a shaft, raise, or winze could pose a fire hazard—

(a) A multipurpose dry-chemical fire extinguisher shall be at the worksite to supplement the fire extinguishing equipment required by §57.4600; and

(b) At least one of the following actions shall be taken:

(1) Wet down the area before and after the operation, taking precaution against any hazard of electrical shock.

(2) Isolate any combustible material with noncombustible material.

(3) Shield the activity so that hot metal and sparks cannot cause a fire.

(4) Provide a second person to watch for and extinguish any fire.

Table C–2

Activity	Distance	Fire hazard
Welding or cutting with an electric arc or open flame		More than 1 gallon of combustible liquid, unless in a closed, metal container.
Using an open flame to bend	Within 35	More than 50 pounds of non-fire-retardant

or heat materials	feet of—	wood.
Thawing pipes electrically, except with heat tape		More than 10 pounds of combustible plastics.
Soldering or thawing with an open flame	Within 10 feet of—	Materials in a shaft, raise, or winze that could be ignited by hot metal or sparks.

(5) Cover or bulkhead the opening immediately below and adjacent to the activity with noncombustible material to prevent sparks or hot metal from falling down the shaft, raise, or winze. This alternative applies only to activities involving a shaft, raise, or winze.

(c) The affected area shall be inspected during the first hour after the operation is completed. Additional inspections shall be made or other fire prevention measures shall be taken if a fire hazard continues to exist.

Ventilation Control Measures

§ 57.4760 Shaft mines.

(a) Shaft mines shall be provided with at least one of the following means to control the spread of fire, smoke, and toxic gases underground in the event of a fire: control doors, reversal of mechanical ventilaton, or effective evacuation procedures. Under this standard, “shaft mine” means a mine in which any designated escapeway includes a mechanical hoisting device or a ladder ascent.

(1) *Control doors.* If used as an alternative, control doors shall be—

(i) Installed at or near shaft stations of intake shafts and any shaft designated as an escapeway under §57.11053 or at other locations that provide equivalent protection;

(ii) Constructed and maintained according to Table C–3;

(iii) Provided with a means of remote closure at landings of timbered intake shafts unless a person specifically designated to close each door in the event of a fire can reach the door within three minutes;

(iv) Closed or opened only according to predetermined conditions and procedures;

(v) Constructed so that once closed they will not reopen as a result of a differential in air pressure;

(vi) Constructed so that they can be opened from either side by one person, or be provided with a personnel door that can be opened from either side; and

(vii) Clear of obstructions.

(2) *Mechanical ventilation reversal.* If used as an alternative, reversal of mechanical ventilation shall—

(i) Provide at all times at least the same degree of protection to persons underground as would be afforded by the installation of control doors;

(ii) Be accomplished by a main fan. If the main fan is located underground—

(A) The cable or conductors supplying power to the fan shall be routed through areas free of fire hazards; or

(B) The main fan shall be equipped with a second, independent power cable or set of conductors from the surface. The power cable or conductors shall be located so that an underground fire disrupting power in one cable or set of conductors will not affect the other; or

(C) A second fan capable of accomplishing ventilation reversal shall be available for use in the event of failure of the main fan;

(iii) Provide rapid air reversal that allows persons underground time to exit in fresh air by the second escapeway or find a place of refuge; and

(iv) Be done according to predetermined conditions and procedures.

(3) *Evacuation.* If used as an alternative, effective evacuation shall be demonstrated by actual evacuation of all persons underground to the surface in ten minutes or less through routes that will not expose persons to heat, smoke, or toxic fumes in the event of a fire.

(b) If the destruction of any bulkhead on an inactive level would allow fire contaminants to reach an escapeway, that bulkhead shall be constructed and maintained to provide at least the same protection as required for control doors under Table C–3.

Table C–3—Control Door Construction

Location	Minimum required construction
At least 50 feet from: timbered areas, exposed combustible rock, and any other combustible material[1]	Control door that meets the requirements for a ventilation door in conformance with 30 CFR 57.8531.
Within 50 feet but no closer than 20 feet of: timbered areas, exposed combustible rock, or other combustible material[1] Within 20 feet of: any timbered areas or combustible rock, provided that the timber and combustible rock within the 20 foot distance are coated with one inch of shotcrete, one-half inch of gunite, or other material with equivalent fire protection characteristics and no other combustible material[1]is within that distance	Control door that serves as a barrier to the effects of fire and air leakage. The control door shall provide protection at least equivalent to a door constructed of no less than one-quarter inch of plate steel with channel or angle-iron reinforcement to minimize warpage. The framework assembly of the door and the surrounding bulkhead, if any, shall be at least equivalent to the door in fire and air-leakage resistance, and in physical strength.
Within 20 feet of: timbered areas, exposed combustible rock, or other combustible material[1]	Control door that serves as a barrier to fire, the effects of fire, and air-leakage. The door shall provide protection at least equivalent to a door constructed of two layers of wood, each a minimum of three-quarters of an inch in thickness. The wood grain of one layer shall be perpendicular to the wood grain of the other layer. The wood construction shall be covered on all sides and edges with no less than twenty-four gauge sheet steel. The framework assembly of the door and the surrounding bulkhead, if any, shall be at least equivalent to the door in fire and air-leakage resistance, and in physical strength. Roll-down steel doors with a fire-resistance rating of 1 1/2 hours or greater, but without an insulation core, are acceptable if an automatic sprinkler or deluge system is installed that provides even coverage of the door on both sides.

[1]In this table, “combustible material” does not refer to installed wiring or track support.

[50 FR 4082, Jan. 29, 1985; 50 FR 20100, May 14, 1985]

§ 57.4761 Underground shops.

To confine or prevent the spread of toxic gases from a fire originating in an underground shop where maintenance work is routinely done on mobile equipment, one of the following measures shall be taken: use of control doors or bulkheads, routing of the mine shop air directly to an exhaust system, reversal of mechanical ventilation, or use of an automatic fire suppression system in conjunction with an alternate escape route. The alternative used shall at all times provide at least the same degree of safety as control doors or bulkheads.

(a) *Control doors or bulkheads.* If used as an alternative, control doors or bulkheads shall meet the following requirements:

(1) Each control door or bulkhead shall be constructed to serve as a barrier to fire, the effects of fire, and air leakage at each opening to the shop.

(2) Each control door shall be—

(i) Constructed so that, once closed, it will not reopen as a result of a differential in air pressure;

(ii) Constructed so that it can be opened from either side by one person or be provided with a personnel door that can be opened from either side;

(iii) Clear of obstructions; and

(iv) Provided with a means of remote or automatic closure unless a person specifically designated to close the door in the event of a fire can reach the door within three minutes.

(3) If located 20 feet or more from exposed timber or other combustible material, the control doors or bulkheads shall provide protection at least equivalent to a door constructed of no less than one-quarter inch of plate steel with channel or angle-iron reinforcement to minimize warpage. The framework assembly of the door and the surrounding bulkhead, if any, shall be at least equivalent to the door in fire and air-leakage resistance, and in physical strength.

(4) If located less than 20 feet from exposed timber or other combustibles, the control door or bulkhead shall provide protection at least equivalent to a door constructed of two layers of wood, each a minimum of three-quarters of an inch in thickness. The wood-grain of one layer shall be perpendicular to the wood-grain of the other layer. The wood construction shall be covered on all sides and edges with no less than 24-gauge sheet steel. The framework assembly of the door and the surrounding bulkhead, if any, shall be at least equivalent to the door in fire and air-leakage resistance, and in physical strength. Roll-down steel doors with a fire-resistance rating of 11/2hours or greater, but without an insulation core, are acceptable provided that an automatic sprinkler or deluge system is installed that provides even coverage of the door on both sides.

(b) *Routing air to exhaust system.* If used as an alternative, routing the mine shop exhaust air directly to an exhaust system shall be done so that no person would be exposed to toxic gases in the event of a shop fire.

(c) *Mechanical ventilation reversal.* If used as an alternative, reversal of mechanical ventilation shall—

(1) Be accomplished by a main fan. If the main fan is located underground:

(i) The cable or conductors supplying power to the fan shall be routed through areas free of fire hazards; or

(ii) The main fan shall be equipped with a second, independent power cable or set of conductors from the surface. The power cable or conductors shall be located so that an underground fire disrupting power in one cable or set of conductors will not affect the other; or

(iii) A second fan capable of accomplishing ventilation reversal shall be available for use in the event of failure of the main fan;

(2) Provide rapid air reversal that allows persons underground time to exit in fresh air by the second escapeway or find a place of refuge; and

(3) Be done according to predetermined conditions and procedures.

(d) *Automatic fire suppression system and escape route.* If used as an alternative, the automatic fire suppression system and alternate escape route shall meet the following requirements:

(1) The suppression system shall be—

(i) Located in the shop area;

(ii) The appropriate size and type for the particular fire hazards involved; and

(iii) Inspected at weekly intervals and properly maintained.

(2) The escape route shall bypasss the shop area so that the route will not be affected by a fire in the shop area.

Appendix I to Subpart C of Part 57—National Consensus Standards

Mine operators seeking further information in the area of fire prevention and control may consult the following national consensus standards.

MSHA standard	National consensus standard
§§57.4200, 57.4201, 57.4261, and 57.4262	NFPA No. 10—Portable Fire Extinguisher. NFPA No. 11—Low Expansion Foam and Combined Agent Systems. NFPA No. 11A—High Expansion Foam Systems.
	NFPA No. 12—Carbon Dioxide Extinguishing Systems.
	NFPA No. 12A—Halon 1301 Extinguishing Systems.
	NFPA No. 13—Water Sprinkler Systems.
	NFPA No. 14—Standpipe and Hose Systems.
	NFPA No. 15—Water Spray Fixed Systems.
	NFPA No. 16—Foam Water Spray Systems.
	NFPA No. 17—Dry-Chemical Extinguishing Systems.
	NFPA No. 121—Mobile Surface Mining Equipment.
	NFPA No. 291—Testing and Marking Hydrants.
	NFPA No. 1962—Care, Use, and Maintenance of Fire Hose, Connections, and Nozzles.
§57.4202	NFPA No. 14—Standpipe and Hose Systems.
	NFPA No. 291—Testing and Marking Hydrants.
§57.4203	NFPA No. 10—Portable Fire Extinguishers.
§57.4230	NFPA No. 10—Portable Fire Extinguishers.
	NFPA No. 121—Mobile Surface Mining Equipment.
§57.4260	NFPA No. 10—Portable Fire Extinguishers.
§57.4261	NFPA No. 14—Standpipe and Hose Systems.
§57.4533	NFPA Fire Protection Handbook.

§57.4560	ASTM E–162—Surface Flammability of Materials Using a Radiant Heat Energy Source.

Subpart D—Air Quality, Radiation, Physical Agents, and Diesel Particulate Matter

Air Quality—Surface and Underground

§ 57.5001 Exposure limits for airborne contaminants.

Except as permitted by §57.5005—

(a) Except as provided in paragraph (b), the exposure to airborne contaminants shall not exceed, on the basis of a time weighted average, the threshold limit values adopted by the American Conference of Governmental Industrial Hygienists, as set forth and explained in the 1973 edition of the Conference's publication, entitled “TLV's Threshold Limit Values for Chemical Substances in Workroom Air Adopted by ACGIH for 1973,” pages 1 through 54, which are hereby incorporated by reference and made a part hereof. This publication may be obtained from the American Conference of Governmental Industrial Hygienists by writing to 1330 Kemper Meadow Drive, Attn: Customer Service, Cincinnati, OH 45240, *http://www.acgih.org* , or may be examined in any Metal and Nonmetal Mine Safety and Health District Office of the Mine Safety and Health Administration. Excursions above the listed thresholds shall not be of a greater magnitude than is characterized as permissible by the Conference.

(b) *Asbestos standard* —(1) *Definitions.* Asbestos is a generic term for a number of asbestiform hydrated silicates that, when crushed or processed, separate into flexible fibers made up of fibrils.

Asbestos means chrysotile, cummingtonite-grunerite asbestos (amosite), crocidolite, anthophylite asbestos, tremolite asbestos, and actinolite asbestos.

Asbestos fiber means a fiber of asbestos that meets the criteria of a fiber.

Fiber means a particle longer than 5 micrometers (μm) with a length-to-diameter ratio of at least 3-to-1.

(2) *Permissible Exposure Limits (PELs)* —(i) *Full-shift limit.* A miner's personal exposure to asbestos shall not exceed an 8-hour time-weighted average full-shift airborne concentration of 0.1 fiber per cubic centimeter of air (f/cc).

(ii) *Excursion limit.* No miner shall be exposed at any time to airborne concentrations of asbestos in excess of 1 fiber per cubic centimeter of air (f/cc) as averaged over a sampling period of 30 minutes.

(3) *Measurement of airborne asbestos fiber concentration.* Potential asbestos fiber concentration shall be determined by phase contrast microscopy (PCM) using the OSHA Reference Method in OSHA's asbestos standard found in 29 CFR 1910.1001, Appendix A, or a method at least equivalent to that method in identifying a potential asbestos exposure exceeding the 0.1 f/cc full-shift limit or the 1 f/cc excursion limit. When PCM results indicate a potential exposure exceeding the 0.1 f/cc full-shift limit or the 1 f/cc excursion limit, samples shall be further analyzed using transmission electron microscopy according to NIOSH Method 7402 or a method at least equivalent to that method.

(c) Employees shall be withdrawn from areas where there is present an airborne contaminant given a “C” designation by the Conference and the concentration exceeds the threshold limit value listed for that contaminant.

[50 FR 4082, Jan. 29, 1985, as amended at 60 FR 35695, July 11, 1995; 71 FR 16667, Apr. 3, 2006; 73 FR 11303, Feb. 29, 2008; 73 FR 66172, Nov. 7, 2008]

§ 57.5002 Exposure monitoring.

Dust, gas, mist, and fume surveys shall be conducted as frequently as necessary to determine the adequacy of control measures.

§ 57.5005 Control of exposure to airborne contaminants.

Control of employee exposure to harmful airborne contaminants shall be, insofar as feasible, by prevention of contamination, removal by exhaust ventilation, or by dilution with uncontaminated air. However, where accepted engineering control measures have not been developed or when necessary by the nature of work involved (for example, while establishing controls or occasional entry into hazardous atmospheres to perform maintenance or investigation), employees may work for reasonable periods of time in concentrations of airborne contaminants exceeding permissible levels if they are protected by appropriate respiratory protective equipment. Whenever respiratory

protective equipment is used a program for selection, maintenance, training, fitting, supervision, cleaning, and use shall meet the following minimum requirements:

(a) Respirators approved by NIOSH under 42 CFR part 84 which are applicable and suitable for the purpose intended shall be furnished and miners shall use the protective equipment in accordance with training and instruction.

(b) A respirator program consistent with the requirements of ANSI Z88.2–1969, published by the American National Standards Institute and entitled "American National Standards Practices for Respiratory Protection ANSI Z88.2–1969," approved August 11, 1969, which is hereby incorporated by reference and made a part hereof. This publication may be obtained from the American National Standards Institute, Inc., 25 W. 43rd Street, 4th Floor, New York, NY 10036; *http://www.ansi.org* , or may be examined in any Metal and Nonmetal Mine Safety and Health District Office of the Mine Safety and Health Administration.

(c) When respiratory protection is used in atmospheres immediately harmful to life, the presence of at least one other person with backup equipment and rescue capability shall be required in the event of failure of the respiratory equipment.

[50 FR 4082, Jan. 29, 1985, as amended at 60 FR 30400, June 8, 1995; 60 FR 33723, June 29, 1995; 60 FR 35695, July 11, 1995; 71 FR 16667, Apr. 3, 2006]

§ 57.5006 Restricted use of chemicals.

The following chemical substances shall not be used or stored except by competent persons under laboratory conditions approved by a nationally recognized agency acceptable to the Secretary.

(a) Carbon tetrachloride,

(b) Phenol,

(c) 4-Nitrobiphenyl,

(d) Alpha-naphthylamine,

(e) 4,4-Methylene Bis (2-chloroaniline),

(f) Methyl-chloromethyl ether,

(g) 3,3 Dichlorobenzidine,

(h) Bis (chloromethyl) ether,

(i) Beta-napthylamine,

(j) Benzidine,

(k) 4-Aminodiphenyl,

(l) Ethyleneimine,

(m) Beta-propiolactone,

(n) 2-Acetylaminofluorene,

(o) 4-Dimethylaminobenzene, and

(p) N-Nitrosodimethylamine.

Air Quality—Surface Only [Reserved]

Air Quality—Underground Only

§ 57.5015 Oxygen deficiency.

Air in all active workings shall contain at least 19.5 volume percent oxygen.

Radiation—Underground Only

§ 57.5037 Radon daughter exposure monitoring.

(a) In all mines at least one sample shall be taken in exhaust mine air by a competent person to determine if concentrations of radon daughters are present. Sampling shall be done using suggested equipment and procedures described in section 14.3 of ANSI N13.8–1973, entitled “American National Standard Radiation Protection in Uranium Mines,” approved July 18, 1973, pages 13–15, by the American National Standards Institute, Inc., which is incorporated by reference and made a part of the standard or equivalent procedures and equipment acceptable to the Administrator, MSHA Metal and Nonmetal Mine Safety and Health district office. This publication may be examined at any Metal and Nonmetal Mine Safety and Health Subdistrict Office of the Mine Safety and Health Administration, or may be obtained from the American National Standards Institute, Inc., 25 W. 43rd Street, 4th Floor, New York, NY 10036; *http://www.ansi.org* . The mine operator may request that the required exhaust mine air sampling be done by the Mine Safety and Health Administration. If concentrations of radon daughters in excess of 0.1 WL are found in an exhaust air sample, thereafter—

(1) Where uranium is mined—radon daughter concentrations representative of worker's breathing zone shall be determined at least every two weeks at random times in all active working areas such as stopes, drift headings, travelways, haulageways, shops, stations, lunch rooms, magazines, and any other place or location where persons work, travel, or congregate. However, if concentrations of radon daughters are found in excess of 0.3 WL in an active working area, radon daughter concentrations thereafter shall be determined weekly in that working area until such time as the weekly determinations in that area have been 0.3 WL or less for 5 consecutive weeks.

(2) Where uranium is not mined—when radon daughter concentrations between 0.1 and 0.3 WL are found in an active working area, radon daughter concentration measurements representative of worker's breathing zone shall be determined at least every 3 months at random times until such time as the radon daughter concentrations in that area are below 0.1 WL, and annually thereafter. If concentrations of radon daughters are found in excess of 0.3 WL in an active working area radon daughter concentrations thereafter shall be determined at least weekly in that working area until such time as the weekly determinations in that area have been 0.3 WL or less for 5 consecutive weeks.

(b) If concentrations of radon daughters less than 0.1 WL are found in an exhaust mine air sample, thereafter:

(1) Where uranium is mined—at least one sample shall be taken in the exhaust mine air monthly.

(2) Where uranium is not mined—no further exhaust mine air sampling is required.

(c) The sample date, locations, and results obtained under (a) and (b) above shall be recorded and retained at the mine site or nearest mine office for at least two years and shall be made available for inspection by the Secretary or his authorized representative.

[50 FR 4082, Jan. 29, 1985, as amended at 60 FR 33723, June 29, 1995; 71 FR 16667, Apr. 3, 2006]

§ 57.5038 Annual exposure limits.

No person shall be permitted to receive an exposure in excess of 4 WLM in any calendar year.

§ 57.5039 Maximum permissible concentration.

Except as provided by standard §57.5005, persons shall not be exposed to air containing concentrations of radon daughters exceeding 1.0 WL in active workings.

§ 57.5040 Exposure records.

(a) The operator shall calculate and record complete individual exposures to concentrations of radon daughters as follows:

(1) Where uranium is mined—the complete individual exposures of all mine personnel working underground shall be calculated and recorded. These records shall include the individual's time in each active working area such as stopes, drift headings, travelways, haulageways, shops, stations, lunch rooms, magazines and any other place or location where persons work, travel or congregate, and the concentration of airborne radon daughters for each active working area.

(2) Where uranium is not mined—the complete individual exposure of all mine personnel working in active working areas with radon daughter concentrations in excess of 0.3 WL shall be calculated and recorded. These records shall include the individual's time in each active working area and the concentrations of airborne radon daughters for each active working area. The operator may discontinue

calculating and recording the individual exposures of any personnel assigned to work in active working areas where radon daughter concentrations have been reduced to 0.3 WL or less for 5 consecutive weeks provided that such exposure calculation and recordation shall not be discontinued with respect to any person who has accumulated more exposure than1/12(one-twelfth) of a WLM times the number of months for which exposures have been calculated and recorded in the calendar year in which the exposure calculation and recordation is proposed to be discontinued.

(b) The operator shall maintain the form entitled “Record of Individual Exposure to Radon Daughters” (Form 4000–9), or equivalent forms that are acceptable to the Administrator, Metal and Nonmetal Mine Safety and Health, Mine Safety and Health Administration, on which there shall be recorded the specific information required by the form with respect to each person's time-weighted current and cumulative exposure to concentrations of radon daughters.

(1) The form entitled “Record of Individual Exposure to Radon Daughters” (Form 4000–9), shall consist of an original of each form for the operator's records which shall be available for examination by the Secretary or his authorized representative.

(2) On or before February 15 of each calendar year, or within 45 days after the shutdown of mining operations for the calendar year, each mine operator shall submit to the Mine Safety and Health Administration a copy of the “Record of Individual Exposure to Radon Daughters” (Form 4000–9), or acceptable equivalent form, showing the data required by the form for all personnel for whom calculation and recording of exposure was required during the previous calendar year.

(3) Errors detected by the operator shall be corrected on any forms kept by the operator and a corrected copy of any forms submitted to the Mine Safety and Health Administration shall be submitted to the Mine Safety and Health Administration within 60 days of detection and shall identify the errors and indicate the date the corrections are made.

(4) The operator's records of individual exposure to concentrations of radon daughters and copies of “Record of Individual Exposure to Radon Daughters” (Form 4000–9) or acceptable equivalent form or true legible facsimiles thereof (microfilm or other), shall be retained at the mine or nearest mine office for a period as specified in paragraph 9.8, ANSI N13.8–1973, or shall be submitted to the Mine Safety and Health Administration. These records, if retained by the operator, shall be open for inspection by the Secretary of Labor, his authorized representative, and authorized representatives of the official mine inspection agency of the State in which the mine is located. Paragraph 9.8, ANSI N13.8–1973, is incorporated by reference and made a part of this standard. ANSI N13.8–1973 may be examined at any Metal and Nonmetal Mine Safety and Health District Office of the Mine Safety and Health Administration, and may be obtained from the American National Standards Institute, Inc., at 25 W. 43rd Street, 4th Floor, New York, NY 10036; *http://www.ansi.org* .

(5) Upon written request from a person who is a subject of these records, a statement of the year-to-date and cumulative exposure applicable to that person shall be provided to the person or to whomever such person designates.

(6) The blank form entitled “Record of Individual Exposure to Radon Daughters” (Form 4000–9) may be obtained on request from any MSHA Metal and Nonmetal Mine Safety and Health district office.

Note: To calculate an individual's exposure to WLM for a given period of time, multiply the total exposure time (hours to the nearest half-hour) in an active working area by the average concentration of airborne radon daughters for the applicable active working area (average working level calculated to the nearest hundredth working level) and divide the product by the constant 173 hours per month.

An average airborne radon daughter concentration for a designated active working area shall be determined by averaging all sampling results for that working area during the time that persons are present. Any sample taken by Federal or State mine inspectors, which represents exposure to miners and reported to the operator within three days of being taken, shall be included in the average concentration; except that if the mine operator samples simultaneously with the inspector, he may use his own sample results.

[50 FR 4082, Jan. 29, 1985, as amended at 60 FR 33723, June 29, 1995; 60 FR 35695, July 11, 1995; 71 FR 16667, Apr. 3, 2006]

§ 57.5041 Smoking prohibition.

Smoking shall be prohibited in all areas of a mine where exposure records are required to be kept in compliance with standard 57.5040.

§ 57.5042 Revised exposure levels.

If levels of permissible exposures to concentrations of radon daughters different from those prescribed in 57.5038 are recommended by the Environmental Protection Agency and approved by the President, no employee shall be permitted to receive exposures in excess of those levels after the effective dates established by the Agency.

§ 57.5044 Respirators.

In environments exceeding 1.0 WL, miners shall wear respirators approved by NIOSH for radon daughters prior to July 10, 1995 or under the equivalent section of 42 CFR part 84 and such respirator use shall be in compliance with §57.5005.

[60 FR 30400, June 8, 1995]

§ 57.5045 Posting of inactive workings.

Inactive workings in which radon daughter concentrations are above 1.0 WL, shall be posted against unauthorized entry and designated by signs indicating them as areas in which approved respirators shall be worn.

§ 57.5046 Protection against radon gas.

Where radon daughter concentrations exceed 10 WL, respirator protection against radon gas shall be provided in addition to protection against radon daughters. Protection against radon gas shall be provided by supplied air devices or by face masks containing absorbent material capable of removing both the radon and its daughters.

§ 57.5047 Gamma radiation surveys.

(a) Gamma radiation surveys shall be conducted annually in all underground mines where radioactive ores are mined.

(b) Surveys shall be in accordance with American National Standards (ANSI) Standard N13.8–1973, entitled “Radiation Protection in Uranium Mines”, section 14.1 page 12, which is hereby incorporated by reference and made a part hereof. This publication may be examined in any Metal and Nonmetal Mine Safety and Health District Office, Mine Safety and Health Administration, or may be obtained from the American National Standards Institute, Inc., 25 W. 43rd Street, 4th Floor, New York, NY 10036; *http://www.ansi.org* .

(c) Where average gamma radiation measurements are in excess of 2.0 milliroentgens per hour in the working place, gamma radiation dosimeters shall be provided for all persons affected, and records of cumulative individual gamma radiation exposure shall be kept.

(d) Annual individual gamma radiation exposure shall not exceed 5 rems.

[50 FR 4082, Jan. 29, 1985, as amended at 60 FR 33723, June 29, 1995; 60 FR 35695, July 11, 1995; 71 FR 16667, Apr. 3, 2006]

Diesel Particulate Matter—Underground Only

Source: 66 FR 5907, Jan. 19, 2001, unless otherwise noted.

§ 57.5060 Limit on exposure to diesel particulate matter.

(a) A miner's personal exposure to diesel particulate matter (DPM) in an underground mine must not exceed an average eight-hour equivalent full shift airborne concentration of 308 micrograms of elemental carbon per cubic meter of air ($308_{EC}\mu g/m^3$). [This interim permissible exposure limit (PEL) remains in effect until the final DPM exposure limit becomes effective. When the final DPM exposure limit becomes effective, MSHA will publish a document in theFederal Register.]

(b)(1) Effective May 20, 2006, a miner's personal exposure to diesel particulate matter (DPM) in an underground mine must not exceed an average eight-hour equivalent full shift airborne concentration of 308 micrograms of elemental carbon per cubic meter of air ($308_{EC}\mu g/m^3$).

(2) Effective January 20, 2007, a miner's personal exposure to diesel particulate matter (DPM) in an underground mine must not exceed an average eight-hour equivalent full shift airborne concentration of 350 micrograms of total carbon per cubic meter of air ($350_{TC}\mu g/m^3$).

(3) Effective May 20, 2008, a miner's personal exposure to diesel particulate matter (DPM) in an underground mine must not exceed an average eight-hour equivalent full shift airborne concentration of 160 micrograms of total carbon per cubic meter of air ($160_{TC}\mu g/m^3$).

(c)(1) If a mine requires additional time to come into compliance with the final DPM limit established in §57.5060 (b) due to technological or economic constraints, the operator of the mine may file an application with the District Manager for a special extension.

(2) The mine operator must certify on the application that the operator has posted one copy of the application at the mine site for at least 30 days prior to the date of application, and has provided another copy to the authorized representative of miners.

(3) No approval of a special extension shall exceed a period of one year from the date of approval. Mine operators may file for additional special extensions provided each extension does not exceed a period of one year. An application must include the following information:

(i) A statement that diesel-powered equipment was used in the mine prior to October 29, 1998;

(ii) Documentation supporting that controls are technologically or economically infeasible at this time to reduce the miner's exposure to the final DPM limit.

(iii) The most recent DPM monitoring results.

(iv) The actions the operator will take during the extension to minimize exposure of miners to DPM.

(4) A mine operator must comply with the terms of any approved application for a special extension, post a copy of the approved application for a special extension at the mine site for the duration of the special extension period, and provide a copy of the approved application to the authorized representative of miners.

(d) The mine operator must install, use, and maintain feasible engineering and administrative controls to reduce a miner's exposure to or below the applicable DPM PEL established in this section. When controls do not reduce a miner's DPM exposure to the PEL, controls are infeasible, or controls do not produce significant reductions in DPM exposures, controls must be used to reduce the miner's exposure to as low a level as feasible and must be supplemented with respiratory protection in accordance with §57.5005(a), (b), and paragraphs (d)(1) through (d)(8) of this section.

(1) Air purifying respirators must be equipped with the following:

(i) Filters certified by NIOSH under 30 CFR part 11 (appearing in the July 1, 1994 edition of 30 CFR, parts 1 to 199) as a high efficiency particulate air (HEPA) filter;

(ii) Filters certified by NIOSH under 42 CFR part 84 as 99.97% efficient; or

(iii) Filters certified by NIOSH for DPM.

(2) Non-powered, negative-pressure, air purifying, particulate-filter respirators shall use an R- or P-series filter or any filter certified by NIOSH for DPM. An R-series filter shall not be used for longer than one work shift.

(3) The mine operator must provide a confidential medical evaluation by a physician or other licensed health care professional (PLHCP), at no cost to the miner, to determine the miner's ability to use a respirator before the miner is required to be fit tested or to use a respirator at the mine. If the PLHCP determines that the miner cannot wear a negative pressure respirator, the mine operator must make certain that the PLHCP evaluates the miner's ability to wear a powered air purifying respirator (PAPR).

(4) The mine operator must provide the miner with an opportunity to discuss their evaluation results with the PLHCP before the PLHCP submits the written determination to the mine operator regarding the miner's ability to wear a respirator. If the miner disagrees with the evaluation results of the PLHCP, the miner may submit within 30 days additional evidence of his or her medical condition to the PLHCP.

(5) The mine operator must obtain a written determination from the PLHCP regarding the miner's ability to wear a respirator, and the mine operator must assure that the PLHCP provides a copy of the determination to the miner.

(6) The miner must be reevaluated when the mine operator has reason to believe that conditions have changed which could adversely affect the miner's ability to wear the respirator.

(7) Upon written notification that the PLHCP has determined that the miner is unable to wear a respirator, including a PAPR, the miner must be transferred to work in an existing position in an area of the same mine where respiratory protection is not required. The miner must be transferred within 30 days of the final determination by the PLHCP.

(i) The miner must continue to receive compensation at no less than the regular rate of pay in the classification held by that miner immediately prior to the transfer.

(ii) Increases in wages of the transferred miner must be based upon the new work classification.

(8) The mine operator must maintain a record of the identity of the PLHCP and the most recent written determination of each miner's ability to wear a respirator for the duration of the miner's employment plus six months.

(e) Rotation of miners shall not be considered an acceptable administrative control used for compliance with the DPM standard.

[70 FR 32966, June 6, 2005; 70 FR 37901, June 30, 2005, as amended at 70 FR 55019, Sept. 19, 2005; 71 FR 29011, May 18, 2006; 71 FR 29012, May 18, 2006; 71 FR 36483, June 27, 2006]

§ 57.5061 Compliance determinations.

(a) MSHA will use a single sample collected and analyzed by the Secretary in accordance with the requirements of this section as an adequate basis for a determination of noncompliance with the DPM limit.

(b) The Secretary will collect samples of DPM by using a respirable dust sampler equipped with a submicrometer impactor and analyze the samples for the amount of elemental carbon using the method described in NIOSH Analytical Method 5040, except that the Secretary also may use any methods of collection and analysis subsequently determined by NIOSH to provide equal or improved accuracy for the measurement of DPM.

(c) The Secretary will use full-shift personal sampling for compliance determinations.

[70 FR 32966, June 6, 2005]

§ 57.5065 Fueling practices.

(a) Diesel fuel used to power equipment in underground areas must not have a sulfur content greater than 0.05 percent. The operator must retain purchase records that demonstrate compliance with this requirement for one year after the date of purchase.

(b) The operator must only use fuel additives registered by the U.S. Environmental Protection Agency in diesel powered equipment operated in underground areas.

[66 FR 5907, Jan. 19, 2001; 66 FR 35520, July 5, 2001]

§ 57.5066 Maintenance standards.

(a) Any diesel powered equipment operated at any time in underground areas must meet the following maintenance standards:

(1) The operator must maintain any approved engine in approved condition;

(2) The operator must maintain the emission related components of any non-approved engine to manufacturer specifications; and

(3) The operator must maintain any emission or particulate control device installed on the equipment in effective operating condition.

(b)(1) A mine operator must authorize each miner operating diesel-powered equipment underground to affix a visible and dated tag to the equipment when the miner notes evidence that the equipment may require maintenance in order to comply with the maintenance standards of paragraph (a) of this section. The term *evidence* means visible smoke or odor that is unusual for that piece of equipment under normal operating procedures, or obvious or visible defects in the exhaust emissions control system or in the engine affecting emissions.

(2) A mine operator must ensure that any equipment tagged pursuant to this section is promptly examined by a person authorized to maintain diesel equipment, and that the affixed tag not be removed until the examination has been completed. The term *promptly* means before the end of the next shift during which a qualified mechanic is scheduled to work.

(3) A mine operator must retain a log of any equipment tagged pursuant to this section. The log must include the date the equipment is tagged, the date the equipment is examined, the name of the person examining the equipment, and any action taken as a result of the examination. The operator must retain the information in the log for one year after the date the tagged equipment was examined.

(c) Persons authorized by a mine operator to maintain diesel equipment covered by paragraph (a) of this section must be qualified, by virtue of training or experience, to ensure that the maintenance standards of paragraph (a) of this section are observed. An operator must retain appropriate evidence of the competence of any person to perform specific maintenance tasks in compliance with those standards for one year after the date of any maintenance, and upon request must provide the documentation to the authorized representative of the Secretary.

[66 FR 5907, Jan. 19, 2001, as amended at 67 FR 9184, Feb. 27, 2002]

Effective Date Note: At 66 FR 5907, Jan. 19, 2001, §57.5066 was added, effective July 5, 2001, except for paragraph (b). At 66 FR 35518, July 5, 2001, the effective date of paragraph (b) was delayed pending disposition of current litigation challenging the rule. At 67 FR 9184, Feb. 27, 2002, paragraphs (b)(1) and (b)(2) were revised, effective Mar. 29, 2002.

§ 57.5067 Engines.

(a) Any diesel engine introduced into an underground area of a mine covered by this part after July 5, 2001, other than an engine in an ambulance or fire fighting equipment which is utilized in accordance with mine fire fighting and evacuation plans, must either:

(1) Have affixed a plate evidencing approval of the engine pursuant to subpart E of Part 7 of this title or pursuant to Part 36 of this title; or

(2) Meet or exceed the applicable particulate matter emission requirements of the Environmental Protection Administration listed in Table 57.5067–1, as follows:

Table 57.5067–1

EPA requirement	EPA category	PM limit
40 CFR 86.094–8(a)(1)(i)(A)(2)	light duty vehicle	0.1 g/mile.
40 CFR 86.094–9(a)(1)(i)(A)(2)	light duty truck	0.1 g/mile.
40 CFR 86.094–11(a)(1)(iv)(B)	heavy duty highway engine	0.1 g/bhp-hr.
40 CFR 89.112(a)	nonroad (tier, power range)	varies by power range:
	tier 1 kW<8 (hp<11)	1.0 g/kW-hr (0.75 g/bhp-hr).
	tier 1 8≤kW<19 (11≤hp<25)	0.80 g/kW-hr (0.60 g/bhp-hr).
	tier 1 19≤kW<37 (25≤hp<50)	0.80 g/kW-hr (0.60 g/bhp-hr).
	tier 2 37≤kW<75 (50≤hp<100)	0.40 g/kW-hr (0.30 g/bhp-hr).
	tier 2 75≤kW<130 (100≤hp<175)	0.30 g/kW-hr (0.22 g/bhp-hr).
	tier 1 130≤kW<225 (175≤hp<300)	0.54 g/kW-hr (0.40 g/bhp-hr).
	tier 1 225≤kW<450 (300≤hp<600)	0.54 g/kW-hr (0.40 g/bhp-hr).
	tier 1 450≤kW<560 (600≤hp<750)	0.54 g/kW-hr (0.40 g/bhp-hr).
	tier 1 kW≥560 (hp≥750)	0.54 g/kW-hr (0.40 g/bhp-hr).

Notes:

“g” means grams.

“hp” means horsepower.

“g/bhp-hr” means grams/brake horsepower-hour.

“kW” means kilowatt.

“g/kW-hr” means grams/kilowatt-hour.

(b) For purposes of paragraph (a):

(1) The term “introduced” means any engine added to the underground inventory of engines of the mine in question, including:

(i) An engine in newly purchased equipment;

(ii) An engine in used equipment brought into the mine; and

(iii) A replacement engine that has a different serial number than the engine it is replacing; but

(2) The term “introduced” does not include engines that were previously part of the mine inventory and rebuilt.

(3) The term *introduced* does not include the transfer of engines or equipment from the inventory of one underground mine to another underground mine operated by the same mine operator.

[66 FR 5907, Jan. 19, 2001, as amended at 66 FR 27864, May 21, 2001; 67 FR 9184, Feb. 27, 2002]

§ 57.5070 Miner training.

(a) Mine operators must provide annual training to all miners at a mine covered by this part who can reasonably be expected to be exposed to diesel emissions on that property. The training must include—

(1) The health risks associated with exposure to diesel particulate matter;

(2) The methods used in the mine to control diesel particulate matter concentrations;

(3) Identification of the personnel responsible for maintaining those controls; and

(4) Actions miners must take to ensure the controls operate as intended.

(b) An operator must retain a record at the mine site of the training required by this section for one year after completion of the training.

§ 57.5071 Exposure monitoring.

(a) Mine operators must monitor as often as necessary to effectively determine, under conditions that can be reasonably anticipated in the mine, whether the average personal full-shift airborne exposure to DPM exceeds the DPM limit specified in §57.5060.

(b) The mine operator must provide affected miners and their representatives with an opportunity to observe exposure monitoring required by this section. Mine operators must give prior notice to affected miners and their representatives of the date and time of intended monitoring.

(c) If any monitoring performed under this section indicates that a miner's exposure to diesel particulate matter exceeds the DPM limit specified in §57.5060, the operator must promptly post notice of the corrective action being taken on the mine bulletin board, initiate corrective action by the next work shift, and promptly complete such corrective action.

(d)(1) The results of monitoring for diesel particulate matter, including any results received by a mine operator from sampling performed by the Secretary, must be posted on the mine bulletin board within 15 days of receipt and must remain posted for 30 days. The operator must provide a copy of the results to the authorized representative of miners.

(2) The mine operator must retain for five years (from the date of sampling), the results of any samples the operator collected as a result of monitoring under this section, and information about the sampling method used for obtaining the samples.

[70 FR 32966, June 6, 2005]

§ 57.5075 Diesel particulate records.

(a) The table entitled “Diesel Particulate Matter Recordkeeping Requirements” lists the records the operator must maintain pursuant to §§57.5060 through 57.5071, and the duration for which particular records need to be retained.

Table 57.5075(a)—Diesel Particulate Recordkeeping Requirements

Record	Section reference	Retention time
1. Approved application for extension of time to comply with exposure limits	§57.5060(c)	Duration of extension.
2. Identity of PLHCP and most recent written determination of miner's ability to wear a respirator	§57.5060(d)	Duration of miner's employment plus 6 months.
3. Purchase records noting sulfur content of diesel fuel	§57.5065(a)	1 year beyond date of purchase.
4. Maintenance log	§57.5066(b)	1 year after date any equipment is tagged.
5. Evidence of competence to perform maintenance	§57.5066(c)	1 year after date maintenance performed.
6. Annual training provided to potentially exposed miners	§57.5070(b)	1 year beyond date training completed.
7. Record of corrective action	§57.5071(c)	Until the corrective action is completed.
8. Sampling method used to effectively evaluate a miner's personal exposure, and sample results	§57.5071(d)	5 years from sample date.

(b)(1) Any record listed in this section which is required to be retained at the mine site may, notwithstanding such requirement, be retained elsewhere if the mine operator can immediately access the record from the mine site by electronic transmission.

(2) Upon request from an authorized representative of the Secretary of Labor, the Secretary of Health and Human Services, or from the authorized representative of miners, mine operators must promptly provide access to any record listed in the table in this section.

(3) An operator must provide access to a miner, former miner, or, with the miner's or former miner's written consent, a personal representative of a miner, to any record required to be maintained pursuant to §57.5071 or §57.5060(d) to the extent the information pertains to the miner or former miner. The operator must provide the first copy of a requested record at no cost, and any additional copies at reasonable cost.

(4) Whenever an operator ceases to do business, that operator must transfer all records required to be maintained by this part, or a copy thereof, to any successor operator who must maintain them for the required period.

[70 FR 32966, June 6, 2005; 70 FR 37901, June 30, 2005; 71 FR 29012, May 18, 2006]

Subpart E—Explosives

Source: 61 FR 36801, July 12, 1996, unless otherwise noted.

§ 57.6000 Definitions.

The following definitions apply in this subpart.

Blasting agent. Any substance classified as a blasting agent by the Department of Transportation in 49 CFR 173.114a(a). This document is available at any MSHA Metal and Nonmetal Safety and Health district office.

Detonating cord. A flexible cord containing a center core of high explosives which may be used to initiate other explosives.

Detonator. Any device containing a detonating charge used to initiate an explosive. These devices include electric or nonelectric instantaneous or delay blasting caps, and delay connectors. The term “detonator” does not include detonating cord. Detonators may be either “Class A” detonators or “Class C” detonators, as classified by the Department of Transportation in 49 CFR 173.53, and 173.100. This document is available at any MSHA Metal and Nonmetal Safety and Health district office.

Explosive. Any substance classified as an explosive by the Department of Transportation in 49 CFR 173.53, 173.88, and 173.100. This document is available at any MSHA Metal and Nonmetal Safety and Health district office.

Explosive material. Explosives, blasting agents, and detonators.

Flash point. The minimum temperature at which sufficient vapor is released by a liquid to form a flammable vapor-air mixture near the surface of the liquid.

Igniter cord. A fuse that burns progressively along its length with an external flame at the zone of burning, used for lighting a series of safety fuses in a desired sequence.

Magazine. A bullet-resistant, theft-resistant, fire-resistant, weather-resistant, ventilated facility for the storage of explosives and detonators (BATF Type 1 or Type 2 facility).

Misfire. The complete or partial failure of explosive material to detonate as planned. The term also is used to describe the explosive material itself that has failed to detonate.

Primer. A unit, package, or cartridge of explosives which contains a detonator and is used to initiate other explosives or blasting agents.

Safety switch. A switch that provides shunt protection in blasting circuits between the blast site and the switch used to connect a power source to the blasting circuit.

Slurry. An explosive material containing substantial portions of a liquid, oxidizers, and fuel, plus a thickener.

Water gel. An explosive material containing substantial portions of water, oxidizers, and fuel, plus a cross-linking agent.

[61 FR 36801, July 12, 1996, as amended at 67 FR 38385, June 4, 2002; 68 FR 32361, May 30, 2003; 69 FR 38842, June 29, 2004]

Storage—Surface and Underground

§ 57.6100 Separation of stored explosive material.

(a) Detonators shall not be stored in the same magazine with other explosive material.

(b) When stored in the same magazine, blasting agents shall be separated from explosives, safety fuse, and detonating cord to prevent contamination.

§ 57.6101 Areas around explosive material storage facilities.

(a) Areas surrounding storage facilities for explosive material shall be clear of rubbish, brush, dry grass, and trees for 25 feet in all directions, except that live trees 10 feet or taller need not be removed.

(b) Other combustibles shall not be stored or allowed to accumulate within 50 feet of explosive material. Combustible liquids shall be stored in a manner that ensures drainage will occur away from the explosive material storage facility in case of tank rupture.

§ 57.6102 Explosive material storage practices.

(a) Explosive material shall be—

(1) Stored in a manner to facilitate use of oldest stocks first;

(2) Stored according to brand and grade in such a manner as to facilitate identification; and

(3) Stacked in a stable manner but not more than 8 feet high.

(b) Explosives and detonators shall be stored in closed nonconductive containers except that nonelectric detonating devices may be stored on nonconductive racks provided the case-insert instructions and the date-plant-shift code are maintained with the product.

Storage—Surface Only

§ 57.6130 Explosive material storage facilities.

(a) Detonators and explosives shall be stored in magazines.

(b) Packaged blasting agents shall be stored in a magazine or other facility which is ventilated to prevent dampness and excessive heating, weather-resistant, and locked or attended. Drop trailers do not have to be ventilated if they are currently licensed by the Federal, State, or local authorities for over-the-road use. Facilities other than magazines used to store blasting agents shall contain only blasting agents.

(c) Bulk blasting agents shall be stored in weather-resistant bins or tanks which are locked, attended, or otherwise inaccessible to unauthorized entry.

(d) Facilities, bins or tanks shall be posted with the appropriate United States Department of Transportation placards or other appropriate warning signs that indicate the contents and are visible from each approach.

§ 57.6131 Location of explosive material storage facilities.

(a) Storage facilities for any explosive material shall be—

(1) Located so that the forces generated by a storage facility explosion will not create a hazard to occupants in mine buildings and will not damage dams or electric substations; and

(2) Detached structures located outside the blast area and a sufficient distance from powerlines so that the powerlines, if damaged, would not contact the magazines.

(b) Operators should also be aware of regulations affecting storage facilities in 27 CFR part 55, in particular, 27 CFR 55.218 and 55.220. This document is available at any MSHA Metal and Nonmetal Safety and Health district office.

§ 57.6132 Magazine requirements.

(a) Magazines shall be—

(1) Structurally sound;

(2) Noncombustible or the exterior covered with fire-resistant material;

(3) Bullet resistant;

(4) Made of nonsparking material on the inside;

(5) Ventilated to control dampness and excessive heating within the magazine;

(6) Posted with the appropriate United States Department of Transportation placards or other appropriate warning signs that indicate the contents and are visible from each approach, so located that a bullet passing through any of the signs will not strike the magazine;

(7) Kept clean and dry inside;

(8) Unlighted or lighted by devices that are specifically designed for use in magazines and which do not create a fire or explosion hazard;

(9) Unheated or heated only with devices that do not create a fire or explosion hazard;

(10) Locked when unattended; and

(11) Used exclusively for the storage of explosive material except for essential nonsparking equipment used for the operation of the magazine.

(b) Metal magazines shall be equipped with electrical bonding connections between all conductive portions so the entire structure is at the same electrical potential. Suitable electrical bonding methods include welding, riveting, or the use of securely tightened bolts where individual metal portions are joined. Conductive portions of nonmetal magazines shall be grounded.

(c) Electrical switches and outlets shall be located on the outside of the magazine.

§ 57.6133 Powder chests.

(a) Powder chests (day boxes) shall be—

(1) Structurally sound, weather-resistant, equipped with a lid or cover, and with only nonsparking material on the inside;

(2) Posted with the appropriate United States Department of Transportation placards or other appropriate warning signs that indicate the contents and are visible from each approach;

(3) Located out of the blast area once loading has been completed;

(4) Locked or attended when containing explosive material; and

(5) Emptied at the end of each shift with the contents returned to a magazine or other storage facility, or attended.

(b) Detonators shall be kept in chests separate from explosives or blasting agents, unless separated by 4-inches of hardwood or equivalent, or a laminated partition. When a laminated partition is used, operators must follow the provisions of the Institute of Makers of Explosives (IME) Safety Library Publication No. 22, (May 1993), “Recommendations for the Safe Transportation of Detonators in a Vehicle with other Explosive Materials,” (May 1993), and the “Generic Loading Guide for the IME–22 Container,” (October 1993). This incorporation by reference has been approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. Copies are available at MSHA, 1100 Wilson Blvd., Room 2436, Arlington, Virginia 22209–3939, and at all Metal and Nonmetal Mine Safety and Health district offices, or available for inspection at the National Archives and Records Administration (NARA). For information on the availability of this material at NARA, call 202–741–6030, or go to: *http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.html.*

[61 FR 36801, July 12, 1996, as amended at 67 FR 38385, June 4, 2002]

Storage—Underground Only

§ 57.6160 Main facilities.

(a) Main facilities used to store explosive material underground shall be located—

(1) In stable or supported ground;

(2) So that a fire or explosion in the storage facilities will not prevent escape from the mine, or cause detonation of the contents of another storage facility;

(3) Out of the line of blasts, and protected from vehicular traffic, except that accessing the facility;

(4) At least 200 feet from work places or shafts;

(5) At least 50 feet from electric substations;

(6) A safe distance from trolley wires; and

(7) At least 25 feet from detonator storage facilities.

(b) Main facilities used to store explosive material underground shall be—

(1) Posted with warning signs that indicate the contents and are visible from any approach;

(2) Used exclusively for the storage of explosive material and necessary equipment associated with explosive material storage and delivery:

(i) Portions of the facility used for the storage of explosives shall only contain nonsparking material or equipment.

(ii) The blasting agent portion of the facility may be used for the storage of other necessary equipment;

(3) Kept clean, suitably dry, and orderly;

(4) Provided with unobstructed ventilation openings;

(5) Kept securely locked unless all access to the mine is either locked or attended; and

(6) Unlighted or lighted only with devices that do not create a fire or explosion hazard and which are specifically designed for use in magazines.

(c) Electrical switches and outlets shall be located outside the facility.

§ 57.6161 Auxiliary facilities.

(a) Auxiliary facilities used to store explosive material near work places shall be wooden, box-type containers equipped with covers or doors, or facilities constructed or mined-out to provide equivalent impact resistance and confinement.

(b) The auxiliary facilities shall be—

(1) Constructed of nonsparking material on the inside when used for the storage of explosives;

(2) Kept clean, suitably dry, and orderly;

(3) Kept in repair;

(4) Located out of the line of blasts so they will not be subjected to damaging shock or flyrock;

(5) Identified with warning signs or coded to indicate the contents with markings visible from any approach;

(6) Located at least 15 feet from all haulageways and electrical equipment, or placed entirely within a mined-out recess in the rib used exclusively for explosive material;

(7) Filled with no more than a one-week supply of explosive material;

(8) Separated by at least 25 feet from other facilities used to store detonators; and

(9) Kept securely locked unless all access to the mine is either locked or attended.

Transportation—Surface and Underground

§ 57.6200 Delivery to storage or blast site areas.

Explosive material shall be transported without undue delay to the storage area or blast site.

§ 57.6201 Separation of transported explosive material.

Detonators shall not be transported on the same vehicle or conveyance with other explosives except as follows:

(a) Detonators in quantities of more than 1,000 may be transported in a vehicle or conveyance with explosives or blasting agents provided the detonators are—

(1) Maintained in the original packaging as shipped from the manufacturer; and

(2) Separated from explosives or blasting agents by 4 inches of hardwood or equivalent, or a laminated partition. The hardwood or equivalent shall be fastened to the vehicle or conveyance. When a laminated partition is used, operators must follow the provisions of the Institute of Makers of Explosives (IME) Safety Library Publication No. 22, "Recommendations for the Safe Transportation of Detonators in a Vehicle with other Explosive Materials" (May 1993), and the "Generic Loading Guide for the IME–22 Container" (October 1993). This incorporation by reference has been approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. Copies are available at MSHA, 1100 Wilson Blvd., Room 2436, Arlington, Virginia 22209–3939, and at all Metal and Nonmetal Mine Safety and Health district offices, or available for examination at the National Archives and Records Administration (NARA). For information on the availability of this material at NARA, call 202–741–6030, or go to: *http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.html.*

(b) Detonators in quantities of 1,000 or fewer may be transported with explosives or blasting agents provided the detonators are—

(1) Kept in closed containers; and

(2) Separated from explosives or blasting agents by 4 inches of hardwood or equivalent, or a laminated partition. The hardwood or equivalent shall be fastened to the vehicle or conveyance. When a laminated partition is used, operators must follow the provisions of IME Safety Library Publication No. 22, "Recommendations for the Safe Transportation of Detonators in a Vehicle with other Explosive Materials" (May 1993), and the "Generic Loading Guide for the IME–22 Container" (October 1993). This incorporation by reference has been approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. Copies are available at MSHA, 1100 Wilson Blvd., Room 2436, Arlington, Virginia 22209–3939, and at all Metal and Nonmetal Mine Safety and Health district offices, or available for examination at the National Archives and Records Administration (NARA). For information on the availability of this material at NARA, call 202–741–6030, or go to: *http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.html.*

[61 FR 36801, July 12, 1996, as amended at 67 FR 38385, June 4, 2002]

§ 57.6202 Vehicles.

(a) Vehicles containing explosive material shall be—

(1) Maintained in good condition and shall comply with the requirements of subpart M of this part;

(2) Equipped with sides and enclosures higher than the explosive material being transported or have the explosive material secured to a nonconductive pallet;

(3) Equipped with a cargo space that shall contain the explosive material (passenger areas shall not be considered cargo space);

(4) Equipped with at least two multipurpose dry-chemical fire extinguishers or one such extinguisher and an automatic fire suppression system;

(5) Posted with warning signs that indicate the contents and are visible from each approach;

(6) Occupied only by persons necessary for handling the explosive material;

(7) Attended or the cargo compartment locked at surface areas of underground mines, except when parked at the blast site and loading is in progress; and

(8) Secured while parked by having—

(i) The brakes set;

(ii) The wheels chocked if movement could occur; and

(iii) The engine shut off unless powering a device being used in the loading operation.

(b) Vehicles containing explosives shall have—

(1) No sparking material exposed in the cargo space; and

(2) Only properly secured nonsparking equipment in the cargo space with the explosives.

(c) Vehicles used for dispensing bulk explosive material shall—

(1) Have no zinc or copper exposed in the cargo space; and

(2) Provide any enclosed screw-type conveyors with protection against internal pressure and frictional heat.

§ 57.6203 Locomotives.

Explosive material shall not be transported on a locomotive. When explosive material is hauled by trolley locomotive, covered, electrically insulated cars shall be used.

§ 57.6204 Hoists.

(a) Before explosive material is transported in hoist conveyances—

(1) The hoist operator shall be notified; and

(2) Hoisting in adjacent shaft compartments, except for empty conveyances or counterweights, shall be stopped until transportation of the explosive material is completed.

(b) Explosive material transported in hoist conveyances shall be placed within a container which prevents shifting of the cargo that could cause detonation of the container by impact or by sparks. The manufacturer's container may be used if secured to a nonconductive pallet. When explosives are transported, they shall be secured so as not to contact any sparking material.

(c) No explosive material shall be transported during a mantrip.

§ 57.6205 Conveying explosives by hand.

Closed, nonconductive containers shall be used to carry explosives and detonators to and from blast sites. Separate containers shall be used for explosives and detonators.

USE—SURFACE AND UNDERGROUND

§ 57.6300 Control of blasting operations.

(a) Only persons trained and experienced in the handling and use of explosive material shall direct blasting operations and related activities.

(b) Trainees and inexperienced persons shall work only in the immediate presence of persons trained and experienced in the handling and use of explosive material.

§ 57.6301 Blasthole obstruction check.

Before loading, blastholes shall be checked and, wherever possible, cleared of obstructions.

§ 57.6302 Separation of explosive material.

Explosives and blasting agents shall be kept separated from detonators until loading begins.

§ 57.6303 Initiation preparation.

(a) Primers shall be made up only at the time of use and as close to the blast site as conditions allow.

(b) Primers shall be prepared with the detonator contained securely and completely within the explosive or contained securely and appropriately for its design in the tunnel or cap well.

(c) When using detonating cord to initiate another explosive, a connection shall be prepared with the detonating cord threaded through, attached securely to, or otherwise in contact with the explosive.

§ 57.6304 Primer protection.

(a) Tamping shall not be done directly on a primer.

(b) Rigid cartridges of explosives or blasting agents that are 4 inches (100 millimeters) in diameter or larger shall not be dropped on the primer except where the blasthole contains sufficient depth of water to protect the primer from impact. Slit packages of prill, water gel, or emulsions are not considered rigid cartridges and may be drop loaded.

§ 57.6305 Unused explosive material.

Unused explosive material shall be moved to a protected location as soon as practical after loading operations are completed.

§ 57.6306 Loading, blasting, and security.

(a) When explosive materials or initiating systems are brought to the blast site, the blast site shall be attended; barricaded and posted with warning signs, such as “Danger,” “Explosives,” or “Keep Out;” or flagged against unauthorized entry.

(b) Vehicles and equipment shall not be driven over explosive material or initiating systems in a manner which could contact the material or system, or create other hazards.

(c) Once loading begins, the only activities permitted within the blast site shall be those activities directly related to the blasting operation and the activities of surveying, stemming, sampling of geology, and reopening of holes, provided that reasonable care is exercised. Haulage activity is permitted near the base of bench faces being loaded or awaiting firing, provided no other haulage access exists.

(d) Loading and blasting shall be conducted in a manner designed to facilitate a continuous process, with the blast fired as soon as possible following the completion of loading. If blasting a loaded round may be delayed for more than 72 hours, the operator shall notify the appropriate MSHA district office.

(e) In electric blasting prior to connecting to the power source, and in nonelectric blasting prior to attaching an initiating device, all persons shall leave the blast area except persons in a blasting shelter or other location that protects them from concussion (shock wave), flying material, and gases.

(f) Before firing a blast—

(1) Ample warning shall be given to allow all persons to be evacuated;

(2) Clear exit routes shall be provided for persons firing the round; and

(3) All access routes to the blast area shall be guarded or barricaded to prevent the passage of persons or vehicles.

(g) Work shall not be resumed in the blast area until a post-blast examination addressing potential blast-related hazards has been conducted by a person with the ability and experience to perform the examination.

§ 57.6307 Drill stem loading.

Explosive material shall not be loaded into blastholes with drill stem equipment or other devices that could be extracted while containing explosive material. The use of loading hose, collar sleeves, or collar pipes is permitted.

§ 57.6308 Initiation systems.

Initiation systems shall be used in accordance with the manufacturer's instructions.

§ 57.6309 Fuel oil requirements for ANFO.

(a) Liquid hydrocarbon fuels with flash points lower than that of No. 2 diesel oil (125 °F) shall not be used to prepare ammonium nitrate-fuel oil, except that diesel fuels with flash points no lower than 100 °F may be used at ambient air temperatures below 45 °F.

(b) Waste oil, including crankcase oil, shall not be used to prepare ammonium nitrate-fuel oil.

§ 57.6310 Misfire waiting period.

When a misfire is suspected, persons shall not enter the blast area—

(a) For 30 minutes if safety fuse and blasting caps are used; or

(b) For 15 minutes if any other type detonators are used.

§ 57.6311 Handling of misfires.

(a) Faces and muck piles shall be examined for misfires after each blasting operation.

(b) Only work necessary to remove a misfire and protect the safety of miners engaged in the removal shall be permitted in the affected area until the misfire is disposed of in a safe manner.

(c) When a misfire cannot be disposed of safely, each approach to the area affected by the misfire shall be posted with a warning sign at a conspicuous location to prohibit entry, and the condition shall be reported immediately to mine management.

(d) Misfires occurring during the shift shall be reported to mine management not later than the end of the shift.

§ 57.6312 Secondary blasting.

Secondary blasts fired at the same time in the same work area shall be initiated from one source.

Electric Blasting—Surface and Underground

§ 57.6400 Compatibility of electric detonators.

All electric detonators to be fired in a round shall be from the same manufacturer and shall have similar electrical firing characteristics.

§ 57.6401 Shunting.

Except during testing—

(a) Electric detonators shall be kept shunted until connected to the blasting line or wired into a blasting round;

(b) Wired rounds shall be kept shunted until connected to the blasting line; and

(c) Blasting lines shall be kept shunted until immediately before blasting.

§ 57.6402 Deenergized circuits near detonators.

Electrical distribution circuits within 50 feet of electric detonators at the blast site shall be deenergized. Such circuits need not be deenergized between 25 to 50 feet of the electric detonators if stray current tests, conducted as frequently as necessary, indicate a maximum stray current of less than 0.05 ampere through a 1-ohm resistor as measured at the blast site.

§ 57.6403 Branch circuits.

(a) If electric blasting includes the use of branch circuits, each branch shall be equipped with a safety switch or equivalent method to isolate the circuits to be used.

(b) At least one safety switch or equivalent method of protection shall be located outside the blast area and shall be in the open position until persons are withdrawn.

§ 57.6404 Separation of blasting circuits from power source.

(a) Switches used to connect the power source to a blasting circuit shall be locked in the open position except when closed to fire the blast.

(b) Lead wires shall not be connected to the blasting switch until the shot is ready to be fired.

§ 57.6405 Firing devices.

(a) Power sources shall be capable of delivering sufficient current to energize all electric detonators to be fired with the type of circuits used. Storage or dry cell batteries are not permitted as power sources.

(b) Blasting machines shall be tested, repaired, and maintained in accordance with manufacturer's instructions.

(c) Only the blaster shall have the key or other control to an electrical firing device.

§ 57.6406 Duration of current flow.

If any part of a blast is connected in parallel and is to be initiated from powerlines or lighting circuits, the time of current flow shall be limited to a maximum of 25 milliseconds. This can be accomplished by incorporating an arcing control device in the blasting circuit or by interrupting the circuit with an explosive device attached to one or both lead lines and initiated by a 25-millisecond delay electric detonator.

§ 57.6407 Circuit testing.

A blasting galvanometer or other instrument designed for testing blasting circuits shall be used to test the following:

(a) In surface operations—

(1) Continuity of each electric detonator in the blasthole prior to stemming and connection to the blasting line;

(2) Resistance of individual series or the resistance of multiple balanced series to be connected in parallel prior to their connection to the blasting line;

(3) Continuity of blasting lines prior to the connection of electric detonator series; and

(4) Total blasting circuit resistance prior to connection to the power source.

(b) In underground operations—

(1) Continuity of each electric detonator series; and

(2) Continuity of blasting lines prior to the connection of electric detonators.

Nonelectric Blasting—Surface and Underground

§ 57.6500 Damaged initiating material.

A visual check of the completed circuit shall be made to ensure that the components are properly aligned and connected. Safety fuse, igniter cord, detonating cord, shock or gas tubing, and similar material which is kinked, bent sharply, or damaged shall not be used.

§ 57.6501 Nonelectric initiation systems.

(a) When the nonelectric initiation system uses shock tube—

(1) Connections with other initiation devices shall be secured in a manner which provides for uninterrupted propagation;

(2) Factory-made units shall be used as assembled and shall not be cut except that a single splice is permitted on the lead-in trunkline during dry conditions; and

(3) Connections between blastholes shall not be made until immediately prior to clearing the blast site when surface delay detonators are used.

(b) When the nonelectric initiation system uses detonating cord—

(1) The line of detonating cord extending out of a blasthole shall be cut from the supply spool immediately after the attached explosive is correctly positioned in the hole;

(2) In multiple row blasts, the trunkline layout shall be designed so that the detonation can reach each blasthole from at least two directions;

(3) Connections shall be tight and kept at right angles to the trunkline;

(4) Detonators shall be attached securely to the side of the detonating cord and pointed in the direction in which detonation is to proceed;

(5) Connections between blastholes shall not be made until immediately prior to clearing the blast site when surface delay detonators are used; and

(6) Lead-in lines shall be manually unreeled if connected to the trunklines at the blast site.

(c) When nonelectric initiation systems use gas tube, continuity of the circuit shall be tested prior to blasting.

§ 57.6502 Safety fuse.

(a) The burning rate of each spool of safety fuse to be used shall be measured, posted in locations which will be conspicuous to safety fuse users, and brought to the attention of all persons involved with the blasting operation.

(b) When firing with safety fuse ignited individually using handheld lighters, the safety fuse shall be of lengths which provide at least the minimum burning time for a particular size round, as specified in the following table:

Table E–1—Safety Fuse—Minimum Burning Time

Number of holes in a round	Minimum burning time
1	2 min.[1]
2–5	2 min. 40 sec.
6–10	3 min. 20 sec.
11 to 15	5 min.

[1]For example, at least a 36-inch length of 40-second-per-foot safety fuse or at least a 48-inch length of 30-second-per-foot safety fuse would have to be used to allow sufficient time to evacuate the area.

(c) Where flyrock might damage exposed safety fuse, the blast shall be timed so that all safety fuses are burning within the blastholes before any blasthole detonates.

(d) Fuse shall be cut and capped in dry locations.

(e) Blasting caps shall be crimped to fuse only with implements designed for that purpose.

(f) Safety fuse shall be ignited only after the primer and the explosive material are securely in place.

(g) Safety fuse shall be ignited only with devices designed for that purpose. Carbide lights, liquefied petroleum gas torches, and cigarette lighters shall not be used to light safety fuse.

(h) At least two persons shall be present when lighting safety fuse, and no one shall light more than 15 individual fuses. If more than 15 holes per person are to be fired, electric initiation systems, igniter cord and connectors, or other nonelectric initiation systems shall be used.

Extraneous Electricity—Surface and Underground

§ 57.6600 Loading practices.

If extraneous electricity is suspected in an area where electric detonators are used, loading shall be suspended until tests determine that stray current does not exceed 0.05 amperes through a 1-ohm resister when measured at the location of the electric detonators. If greater levels of extraneous electricity are found, the source shall be determined and no loading shall take place until the condition is corrected.

§ 57.6601 Grounding.

Electric blasting circuits, including powerline sources when used, shall not be grounded.

§ 57.6602 Static electricity dissipation during loading.

When explosive material is loaded pneumatically into a blasthole in a manner that generates a static electricity hazard—

(a) An evaluation of the potential static electricity hazard shall be made and any hazard shall be eliminated before loading begins;

(b) The loading hose shall be of a semiconductive type, have a total of not more than 2 megohms of resistance over its entire length and not less than 1000 ohms of resistance per foot;

(c) Wire-countered hoses shall not be used;

(d) Conductive parts of the loading equipment shall be bonded and grounded and grounds shall not be made to other potential sources of extraneous electricity; and

(e) Plastic tubes shall not be used as hole liners if the hole contains an electric detonator.

§ 57.6603 Air gap.

At least a 15-foot air gap shall be provided between the blasting circuit and the electric power source.

§ 57.6604 Precautions during storms.

During the approach and progress of an electrical storm—

(a) Surface blasting operations shall be suspended and persons withdrawn from the blast area or to a safe location; or

(b) Underground electrical blasting operations that are capable of being initiated by lightning shall be suspended and all persons withdrawn from the blast area or to a safe location.

§ 57.6605 Isolation of blasting circuits.

Lead wires and blasting lines shall be isolated and insulated from power conductors, pipelines, and railroad tracks, and shall be protected from sources of stray or static electricity. Blasting circuits shall be protected from any contact between firing lines and overhead powerlines which could result from the force of a blast.

Equipment/Tools—Surface and Underground

§ 57.6700 Nonsparking tools.

Only nonsparking tools shall be used to open containers of explosive material or to punch holes in explosive cartridges.

§ 57.6701 Tamping and loading pole requirements.

Tamping and loading poles shall be of wood or other nonconductive, nonsparking material. Couplings for poles shall be nonsparking.

Maintenance—Surface and Underground

§ 57.6800 Storage facilities.

When repair work which could produce a spark or flame is to be performed on a storage facility—

(a) The explosive material shall be moved to another facility, or moved at least 50 feet from the repair activity and monitored; and

(b) The facility shall be cleaned to prevent accidental detonation.

§ 57.6801 Vehicle repair.

Vehicles containing explosive material and oxidizers shall not be taken into a repair garage or shop.

§ 57.6802 Bulk delivery vehicles.

No welding or cutting shall be performed on a bulk delivery vehicle until the vehicle has been washed down and all explosive material has been removed. Before welding or cutting on a hollow shaft, the shaft shall be thoroughly cleaned inside and out and vented with a minimum1/2-inch diameter opening to allow for sufficient ventilation.

§ 57.6803 Blasting lines.

Permanent blasting lines shall be properly supported. All blasting lines shall be insulated and kept in good repair.

General Requirements—Surface and Underground

§ 57.6900 Damaged or deteriorated explosive material.

Damaged or deteriorated explosive material shall be disposed of in a safe manner in accordance with the instructions of the manufacturer.

§ 57.6901 Black powder.

(a) Black powder shall be used for blasting only when a desired result cannot be obtained with another type of explosive, such as in quarrying certain types of dimension stone.

(b) Containers of black powder shall be—

(1) Nonsparking;

(2) Kept in a totally enclosed cargo space while being transported by a vehicle;

(3) Securely closed at all times when—

(i) Within 50 feet of any magazine or open flame;

(ii) Within any building in which a fuel-fired or exposed-element electric heater is operating; or

(iii) In an area where electrical or incandescent-particle sparks could result in powder ignition; and

(4) Opened only when the powder is being transferred to a blasthole or another container and only in locations not listed in paragraph (b)(3) of this section.

(c) Black powder shall be transferred from containers only by pouring.

(d) Spills shall be cleaned up promptly with nonsparking equipment. Contaminated powder shall be put into a container of water and shall be disposed of promptly after the granules have disintegrated, or the spill area shall be flushed promptly with water until the granules have disintegrated completely.

(e) Misfires shall be disposed of by washing the stemming and powder charge from the blasthole, and removing and disposing of the initiator in accordance with the requirement for damaged explosives.

(f) Holes shall not be reloaded for at least 12 hours when the blastholes have failed to break as planned.

§ 57.6902 Excessive temperatures.

(a) Where heat could cause premature detonation, explosive material shall not be loaded into hot areas, such as kilns or sprung holes.

(b) When blasting sulfide ores where hot holes occur that may react with explosive material in blastholes, operators shall—

(1) Measure an appropriate number of blasthole temperatures in order to assess the specific mine conditions prior to the introduction of explosive material;

(2) Limit the time between the completion of loading and the initiation of the blast to no more than 12 hours; and

(3) Take other special precautions to address the specific conditions at the mine to prevent premature detonation.

§ 57.6903 Burning explosive material.

If explosive material is suspected of burning at the blast site, persons shall be evacuated from the endangered area and shall not return for at least one hour after the burning or suspected burning has stopped.

§ 57.6904 Smoking and open flames.

Smoking and use of open flames shall not be permitted within 50 feet of explosive material except when separated by permanent noncombustible barriers. This standard does not apply to devices designed to ignite safety fuse or to heating devices which do not create a fire or explosion hazard.

§ 57.6905 Protection of explosive material.

(a) Explosive material shall be protected from temperatures in excess of 150 degrees Fahrenheit.

(b) Explosive material shall be protected from impact, except for tamping and dropping during loading.

General Requirements—Underground Only

§ 57.6960 Mixing of explosive material.

(a) The mixing of ingredients to produce explosive material shall not be conducted underground unless prior approval of the MSHA district manager is obtained. In granting or withholding approval, the district manager shall consider the potential hazards created by—

(1) The location of the stored material and the storage practices used;

(2) The transportation and use of the explosive material;

(3) The nature of the explosive material, including its sensitivity;

(4) Any other factor deemed relevant to the safety of miners potentially exposed to the hazards associated with the mixing of the bulk explosive material underground.

(b) Storage facilities for the ingredients to be mixed shall provide drainage away from the facilities for leaks and spills.

Subpart F—Drilling and Rotary Jet Piercing

Drilling—Surface Only

§ 57.7002 Equipment defects.

Equipment defects affecting safety shall be corrected before the equipment is used.

§ 57.7003 Drill area inspection.

The drilling area shall be inspected for hazards before starting the drilling operations.

§ 57.7004 Drill mast.

Persons shall not be on a mast while the drill-bit is in operation unless they are provided with a safe platform from which to work and they are required to use safety belts to avoid falling.

§ 57.7005 Augers and drill stems.

Drill crews and others shall stay clear of augers or drill stems that are in motion. Persons shall not pass under or step over a moving stem or auger.

§ 57.7008 Moving the drill.

When a drill is being moved from one drilling area to another, drill steel, tools, and other equipment shall be secured and the mast placed in a safe position.

§ 57.7009 Drill helpers.

If a drill helper assists the drill operator during movement of a drill to a new location, the helper shall be in sight of, or in communication with, the operator at all times.

§ 57.7010 Power failures.

In the event of power failure, drill controls shall be placed in the neutral position until power is restored.

§ 57.7011 Straightening crossed cables.

The drill stem shall be resting on the bottom of the hole or on the platform with the stem secured to the mast before attempts are made to straighten a crossed cable on a reel.

§ 57.7012 Tending drills in operation.

While in operation, drills shall be attended at all times.

§ 57.7013 Covering or guarding drill holes.

Drill holes large enough to constitute a hazard shall be covered or guarded.

§ 57.7018 Hand clearance.

Persons shall not hold the drill steel while collaring holes, or rest their hands on the chuck or centralizer while drilling.

Drilling—Underground Only

§ 57.7028 Hand clearance.

Persons shall not rest their hands on the chuck or centralizer while drilling.

§ 57.7032 Anchoring.

Columns and the drills mounted on them shall be anchored firmly before and during drilling.

Drilling—Surface and Underground

§ 57.7050 Tool and drill steel racks.

Receptacles or racks shall be provided for drill steel and tools stored or carried on drills.

§ 57.7051 Loose objects on the mast or drill platform.

To prevent injury to personnel, tools and other objects shall not be left loose on the mast or drill platform.

§ 57.7052 Drilling positions.

Persons shall not drill from—

(a) Positions which hinder their access to the control levers;

(b) Insecure footing or insecure staging; or

(c) Atop equipment not suitable for drilling.

§ 57.7053 Moving hand-held drills.

Before hand-held drills are moved from one working area to another, air shall be turned off and bled from the hose.

§ 57.7054 Starting or moving drill equipment.

Drill operators shall not start or move drilling equipment unless all miners are in the clear.

§ 57.7055 Intersecting holes.

Holes shall not be drilled where there is a danger of intersecting a misfired hole or a hole containing explosives, blasting agents, or detonators.

[56 FR 46517, Sept. 12, 1991; 56 FR 52193, Oct. 18, 1991]

§ 57.7056 Collaring in bootlegs.

Holes shall not be collared in bootlegs.

[56 FR 46517, Sept. 12, 1991]

Rotary Jet Piercing—Surface Only

§ 57.7801 Jet drills.

Jet piercing drills shall be provided with:

(a) A system to pressurize the equipment operator's cab, when a cab is provided; and

(b) A protective cover over the oxygen flow indicator.

§ 57.7802 Oxygen hose lines.

Safety chains or other suitable locking devices shall be provided across connections to and between high pressure oxygen hose lines of 1-inch inside diameter or larger.

§ 57.7803 Lighting the burner.

A suitable means of protection shall be provided for the employee when lighting the burner.

§ 57.7804 Refueling.

When rotary jet piercing equipment requires refueling at locations other than fueling stations, a system for fueling without spillage shall be provided.

§ 57.7805 Smoking and open flames.

Persons shall not smoke and open flames shall not be used in the vicinity of the oxygen storage and supply lines. Signs warning against smoking and open flames shall be posted in these areas.

§ 57.7806 Oxygen intake coupling.

The oxygen intake coupling on jet piercing drills shall be constructed so that only the oxygen hose can be coupled to it.

§ 57.7807 Flushing the combustion chamber.

The combustion chamber of a jet drill stem which has been sitting unoperated in a drill hole shall be flushed with a suitable solvent after the stem is pulled up.

Subpart G—Ventilation

Surface and Underground

§ 57.8518 Main and booster fans.

(a) All mine main and booster fans installed and used to ventilate the active workings of the mine shall be operated continuously while persons are underground in the active workings. However, this provision is not applicable during scheduled production-cycle shutdowns or planned or scheduled fan maintenance or fan adjustments where air quality is maintained in compliance with the applicable standards of subpart D of this part and all persons underground in the affected areas are advised in advance of such scheduled or planned fan shutdowns, maintenance, or adjustments.

(b) In the event of main or booster fan failure due to a malfunction, accident, power failure, or other such unplanned or unscheduled event:

(1) The air quality in the affected active workings shall be tested at least within 2-hours of the discovery of the fan failure, and at least every 4-hours thereafter by a competent person for compliance with the requirements of the applicable standards of subpart D of this part until normal ventilation is restored, or

(2) All persons, except those working on the fan, shall be withdrawn, the ventilation shall be restored to normal and the air quality in the affected active workings shall be tested by a competent person to assure that the air quality meets the requirements of the standards in subpart D of this part, before any other persons are permitted to enter the affected active workings.

§ 57.8519 Underground main fan controls.

All underground main fans shall have controls placed at a suitable protected location remote from the fan and preferably on the surface.

Underground Only

§ 57.8520 Ventilation plan.

A plan of the mine ventilation system shall be set out by the operator in written form. Revisions of the system shall be noted and updated at least annually. The ventilation plan or revisions thereto shall be submitted to the District Manager for review and comments upon his written request. The plan shall, where applicable, contain the following:

(a) The mine name.

(b) The current mine map or schematic or series of mine maps or schematics of an appropriate scale, not greater than five hundred feet to the inch, showing:

(1) Direction and quantity of principal air flows;

(2) Locations of seals used to isolate abandoned workings;

(3) Locations of areas withdrawn from the ventilation system;

(4) Locations of all main, booster and auxiliary fans not shown in paragraph (d) of this standard.

(5) Locations of air regulators and stoppings and ventilation doors not shown in paragraph (d) of this standard;

(6) Locations of overcasts, undercasts and other airway crossover devices not shown in paragraph (d) of this standard;

(7) Locations of known oil or gas wells;

(8) Locations of known underground mine openings adjacent to the mine;

(9) Locations of permanent underground shops, diesel fuel storage depots, oil fuel storage depots, hoist rooms, compressors, battery charging stations and explosive storage facilities. Permanent facilities are those intended to exist for one year or more; and

(10) Significant changes in the ventilation system projected for one year.

(c) Mine fan data for all active main and booster fans including manufacturer's name, type, size, fan speed, blade setting, approximate pressure at present operating point, and motor brake horsepower rating.

(d) Diagrams, descriptions or sketches showing how ventilation is accomplished in each typical type of working place including the approximate quantity of air provided, and typical size and type of auxiliary fans used.

(e) The number and type of internal combustion engine units used underground, including make and model of unit, type of engine, make and model of engine, brake horsepower rating of engine, and approval number.

[50 FR 4082, Jan. 29, 1985, as amended at 60 FR 33723, June 29, 1995]

§ 57.8525 Main fan maintenance.

Main fans shall be maintained according to either the manufacturer's recommendations or a written periodic schedule adopted by the operator which shall be available at the operation on request of the Secretary or his authorized representative.

[50 FR 4082, Jan. 29, 1985, as amended at 60 FR 33723, June 29, 1995]

§ 57.8527 Oxygen-deficiency testing.

Flame safety lamps or other suitable devices shall be used to test for acute oxygen deficiency.

§ 57.8528 Unventilated areas.

Unventilated areas shall be sealed, or barricaded and posted against entry.

§ 57.8529 Auxiliary fan systems

When auxiliary fan systems are used, such systems shall minimize recirculation and be maintained to provide ventilation air that effectively sweeps the working places.

§ 57.8531 Construction and maintenance of ventilation doors.

Ventilation doors shall be—

(a) Substantially constructed;

(b) Covered with fire-retardant material, if constructed of wood;

(c) Maintained in good condition;

(d) Self-closing, if manually operated; and

(e) Equipped with audible or visual warning devices, if mechanically operated.

§ 57.8532 Opening and closing ventilation doors.

When ventilation control doors are opened as a part of the normal mining cycle, they shall be closed as soon as possible to re-establish normal ventilation to working places.

§ 57.8534 Shutdown or failure of auxiliary fans.

(a) Auxiliary fans installed and used to ventilate the active workings of the mine shall be operated continuously while persons are underground in the active workings, *except* for scheduled production-cycle shutdowns or planned or scheduled fan maintenance or fan adjustments where air quality is maintained in compliance with the applicable standards of subpart D of this part, and all persons underground in the affected areas are advised in advance of such scheduled or planned fan shutdowns, maintenance, or adjustments.

(b) In the event of auxiliary fan failure due to malfunction, accident, power failure, or other such unplanned or unscheduled event:

(1) The air quality in the affected active workings shall be tested at least within 2 hours of the discovery of the fan failure, and at least every 4 hours thereafter by a competent person for compliance with the requirements of the applicable standards of subpart D of this part until normal ventilation is restored, or

(2) All persons, except those working on the fan, shall be withdrawn, the ventilation shall be restored to normal and the air quality in the affected active workings shall be tested by a competent person to assure that the air quality meets the requirements of the standards in subpart D of this part, before any other persons are permitted to enter the affected active workings.

§ 57.8535 Seals.

Seals shall be provided with a means for checking the quality of air behind the seal and a means to prevent a water head from developing unless the seal is designed to impound water.

Subpart H—Loading, Hauling, and Dumping

Source: 53 FR 32526, Aug. 25, 1988, unless otherwise noted.

Traffic Safety

§ 57.9100 Traffic control.

To provide for the safe movement of self-propelled mobile equipment—

(a) Rules governing speed, right-of-way, direction of movement, and the use of headlights to assure appropriate visibility, shall be established and followed at each mine; and

(b) Signs or signals that warn of hazardous conditions shall be placed at appropriate locations at each mine.

§ 57.9101 Operating speeds and control of equipment.

Operators of self-propelled mobile equipment shall maintain control of the equipment while it is in motion. Operating speeds shall be consistent with conditions of roadways, tracks, grades, clearance, visibility, and traffic, and the type of equipment used.

§ 57.9102 Movement of independently operating rail equipment.

Movement of two or more pieces of rail equipment operating independently on the same track shall be controlled for safe operation.

§ 57.9103 Clearance on adjacent tracks.

Railcars shall not be left on side tracks unless clearance is provided for traffic on adjacent tracks.

§ 57.9104 Railroad crossings.

Designated railroad crossings shall be posted with warning signs or signals, or shall be guarded when trains are passing. These crossings shall also be planked or filled between the rails.

§ 57.9160 Train movement during shift changes.

During shift changes, the movement of underground trains carrying rock or material shall be limited to areas where the trains do not present a hazard to persons changing shifts.

Transportation of Persons and Materials

§ 57.9200 Transporting persons.

Persons shall not be transported—

(a) In or on dippers, forks, clamshells, or buckets except shaft buckets during shaft-sinking operations or during inspection, maintenance and repair of shafts.

(b) In beds of mobile equipment or railcars, unless—

(1) Provisions are made for secure travel, and

(2) Means are taken to prevent accidental unloading if the equipment is provided with unloading devices;

(c) On top of loads in mobile equipment;

(d) Outside cabs, equipment operators' stations, and beds of mobile equipment, except when necessary for maintenance, testing, or training purposes, and provisions are made for secure travel. This provision does not apply to rail equipment.

(e) Between cars of trains, on the leading end of trains, on the leading end of a single railcar, or in other locations on trains that expose persons to hazards from train movement.

(1) This paragraph does not apply to car droppers if they are secured with safety belts and lines which prevent them from falling off the work platform.

(2) Brakemen and trainmen are prohibited from riding between cars of moving trains but may ride on the leading end of trains or other locations when necessary to perform their duties;

(f) To and from work areas in overcrowded mobile equipment;

(g) In mobile equipment with materials or equipment unless the items are secured or are small and can be carried safely by hand without creating a hazard to persons; or

(h) On conveyors unless the conveyors are designed to provide for their safe transportation.

§ 57.9201 Loading, hauling, and unloading of equipment or supplies.

Equipment and supplies shall be loaded, transported, and unloaded in a manner which does not create a hazard to persons from falling or shifting equipment or supplies.

§ 57.9202 Loading and hauling large rocks.

Large rocks shall be broken before loading if they could endanger persons or affect the stability of mobile equipment. Mobile equipment used for haulage of mined material shall be loaded to minimize spillage where a hazard to persons could be created.

§ 57.9260 Supplies, materials, and tools on mantrips.

Supplies, materials, and tools, other than small items that can be carried by hand, shall not be transported underground with persons in mantrips. Mantrips shall be operated independently of ore or supply trips.

§ 57.9261 Transporting tools and materials on locomotives.

Tools or materials shall not be carried on top of locomotives underground except for secured rerailing devices located in a manner which does not create a hazard to persons.

Safety Devices, Provisions, and Procedures for Roadways, Railroads, and Loading and Dumping Sites

§ 57.9300 Berms or guardrails.

(a) Berms or guardrails shall be provided and maintained on the banks of roadways where a drop-off exists of sufficient grade or depth to cause a vehicle to overturn or endanger persons in equipment.

(b) Berms or guardrails shall be at least mid-axle height of the largest self-propelled mobile equipment which usually travels the roadway.

(c) Berms may have openings to the extent necessary for roadway drainage.

(d) Where elevated roadways are infrequently traveled and used only by service or maintenance vehicles, berms or guardrails are not required when all of the following are met:

(1) Locked gates are installed at the entrance points to the roadway.

(2) Signs are posted warning that the roadway is not bermed.

(3) Delineators are installed along the perimeter of the elevated roadway so that, for both directions of travel, the reflective surfaces of at least three delineators along each elevated shoulder are always visible to the driver and spaced at intervals sufficient to indicate the edges and attitude of the roadway.

(4) A maximum speed limit is posted and observed for the elevated unbermed portions of the roadway. Factors to consider when establishing the maximum speed limit shall include the width, slope and alignment of the road, the type of equipment using the road, the road material, and any hazardous conditions which may exist.

(5) Road surface traction is not impaired by weather conditions, such as sleet and snow, unless corrective measures, such as the use of tire chains, plowing, or sanding, are taken to improve traction.

(e) This standard is not applicable to rail beds.

[53 FR 32526, Aug. 25, 1988, as amended at 55 FR 37218, Sept. 7, 1990]

§ 57.9301 Dump site restraints.

Berms, bumper blocks, safety hooks, or similar impeding devices shall be provided at dumping locations where there is a hazard of overtravel or overturning.

§ 57.9302 Protection against moving or runaway railroad equipment.

Stopblocks, derail devices, or other devices that protect against moving or runaway rail equipment shall be installed wherever necessary to protect persons.

§ 57.9303 Construction of ramps and dumping facilities.

Ramps and dumping facilities shall be designed and constructed of materials capable of supporting the loads to which they will be subjected. The ramps and dumping facilities shall provide width, clearance, and headroom to safely accommodate the mobile equipment using the facilities.

§ 57.9304 Unstable ground.

(a) Dumping locations shall be visually inspected prior to work commencing and as ground conditions warrant.

(b) Where there is evidence that the ground at a dumping location may fail to support the mobile equipment, loads shall be dumped a safe distance back from the edge of the unstable area of the bank.

§ 57.9305 Truck spotters.

(a) If truck spotters are used, they shall be in the clear while trucks are backing into dumping position or dumping.

(b) Spotters shall use signal lights to direct trucks where visibility is limited.

(c) When a truck operator cannot clearly recognize the spotter's signals, the truck shall be stopped.

§ 57.9306 Warning devices for restricted clearances.

Where restricted clearance creates a hazard to persons on mobile equipment, warning devices shall be installed in advance of the restricted area and the restricted area shall be conspicuously marked.

§ 57.9307 Design, installation, and maintenance of railroads.

Roadbeds and all elements of the railroad tracks shall be designed, installed, and maintained to provide safe operation consistent with the speed and type of haulage used.

§ 57.9308 Switch throws.

Switch throws shall be installed to provide clearance to protect switchmen from contact with moving trains.

§ 57.9309 Chute design.

Chute-loading installations shall be designed to provide a safe location for persons pulling chutes.

§ 57.9310 Chute hazards.

(a) Prior to chute-pulling, persons who could be affected by the draw or otherwise exposed to danger shall be warned and given time to clear the hazardous area.

(b) Persons attempting to free chute hangups shall be experienced and familiar with the task, know the hazards involved, and use the proper tools to free material.

(c) When broken rock or material is dumped into an empty chute, the chute shall be equipped with a guard or all persons shall be isolated from the hazard of flying rock or material.

§ 57.9311 Anchoring stationary sizing devices.

Grizzlies and other stationary sizing devices shall be securely anchored.

§ 57.9312 Working around drawholes.

Unless platforms or safety lines are used, persons shall not position themselves over drawholes if there is danger that broken rock or material may be withdrawn or bridged.

§ 57.9313 Roadway maintenance.

Water, debris, or spilled material on roadways which creates hazards to the operation of mobile equipment shall be removed.

§ 57.9314 Trimming stockpile and muckpile faces.

Stockpile and muckpile faces shall be trimmed to prevent hazards to persons.

§ 57.9315 Dust control.

Dust shall be controlled at muck piles, material transfer points, crushers, and on haulage roads where hazards to persons would be created as a result of impaired visibility.

§ 57.9316 Notifying the equipment operator.

When an operator of self-propelled mobile equipment is present, persons shall notify the equipment operator before getting on or off that equipment.

§ 57.9317 Suspended loads.

Persons shall not work or pass under the buckets or booms of loaders in operation.

§ 57.9318 Getting on or off moving equipment.

Persons shall not get on or off moving mobile equipment. This provision does not apply to trainmen, brakemen, and car droppers who are required to get on or off slowly moving trains in the performance of their work duties.

§ 57.9319 Going over, under, or between railcars.

Persons shall not go over, under, or between railcars unless—

(a) The train is stopped; and

(b) The train operator, when present, is notified and the notice acknowledged.

§ 57.9330 Clearance for surface equipment.

Continuous clearance of at least 30 inches from the farthest projection of moving railroad equipment shall be provided on at least one side of the tracks at all locations where possible or the area shall be marked conspicuously.

§ 57.9360 Shelter holes.

(a) Shelter holes shall be—

(1) Provided at intervals adequate to assure the safety of persons along underground haulageways where continuous clearance of at least 30 inches cannot be maintained from the farthest projection of moving equipment on at least one side of the haulageway; and

(2) At least four feet wide, marked conspicuously, and provide a minimum 40-inch clearance from the farthest projection of moving equipment.

(b) Shelter holes shall not be used for storage unless a 40-inch clearance is maintained.

§ 57.9361 Drawholes.

To prevent hazards to persons underground, collars of open drawholes shall be free of muck or materials except during transfer of the muck or material through the drawhole.

§ 57.9362 Protection of signalmen.

Signalmen used during slushing operations underground shall be located away from possible contact with cables, sheaves, and slusher buckets.

Subpart I—Aerial Tramways

§ 57.10001 Filling buckets.

Buckets shall not be overloaded, and feed shall be regulated to prevent spillage.

§ 57.10002 Inspection and maintenance.

Inspection and maintenance of carriers (including loading and unloading mechanisms), ropes and supports, and brakes shall be performed by competent persons according to the recommendations of the manufacturer.

§ 57.10003 Correction of defects.

Any hazardous defects shall be corrected before the equipment is used.

§ 57.10004 Brakes.

Positive-action-type brakes and devices which apply the brakes automatically in the event of a power failure shall be provided on aerial tramways.

§ 57.10005 Track cable connections.

Track cable connections shall not obstruct the passage of carriage wheels.

§ 57.10006 Tower guards.

Towers shall be suitably protected from swaying buckets.

§ 57.10007 Falling object protection.

Guard nets or other suitable protection shall be provided where tramways pass over roadways, walkways, or buildings.

§ 57.10008 Riding tramways.

Persons other than maintenance persons shall not ride aerial tramways unless the following features are provided.

(a) Two independent brakes, each capable of holding the maximum load;

(b) Direct communication between terminals;

(c) Power drives with emergency power available in case of primary power failure; and

(d) Buckets equipped with positive locks to prevent accidental tripping or dumping.

§ 57.10009 Riding loaded buckets.

Persons shall not ride loaded buckets.

§ 57.10010 Starting precautions.

Where possible, aerial tramways shall not be started until the operator has ascertained that everyone is in the clear.

Subpart J—Travelways and Escapeways

Travelways—Surface and Underground

§ 57.11001 Safe access.

Safe means of access shall be provided and maintained to all working places.

§ 57.11002 Handrails and toeboards.

Crossovers, elevated walkways, elevated ramps, and stairways shall be of substantial construction, provided with handrails, and maintained in good condition. Where necessary, toeboards shall be provided.

§ 57.11003 Construction and maintenance of ladders.

Ladders shall be of substantial construction and maintained in good condition.

§ 57.11004 Portable rigid ladders.

Portable rigid ladders shall be provided with suitable bases and placed securely when used.

§ 57.11005 Fixed ladder anchorage and toe clearance.

Fixed ladders shall be anchored securely and installed to provide at least 3 inches of toe clearance.

§ 57.11006 Fixed ladder landings.

Fixed ladders shall project at least 3 feet above landings, or substantial handholds shall be provided above the landings.

§ 57.11007 Wooden components of ladders.

Wooden components of ladders shall not be painted except with a transparent finish.

§ 57.11008 Restricted clearance.

Where restricted clearance creates a hazard to persons, the restricted clearance shall be conspicuously marked.

[53 FR 32528, Aug. 25, 1988]

§ 57.11009 Walkways along conveyors.

Walkways with outboard railings shall be provided wherever persons are required to walk alongside elevated conveyor belts. Inclined railed walkways shall be nonskid or provided with cleats.

§ 57.11010 Stairstep clearance.

Vertical clearance above stair steps shall be a minimum of seven feet, or suitable warning signs or similar devices shall be provided to indicate an impaired clearance.

§ 57.11011 Use of ladders.

Persons using ladders shall face the ladders and have both hands free for climbing and descending.

§ 57.11012 Protection for openings around travelways.

Openings above, below, or near travelways through which persons or materials may fall shall be protected by railings, barriers, or covers. Where it is impractical to install such protective devices, adequate warning signals shall be installed.

§ 57.11013 Conveyor crossovers.

Crossovers shall be provided where it is necessary to cross conveyors.

§ 57.11014 Crossing moving conveyors.

Moving conveyors shall be crossed only at designated crossover points.

§ 57.11016 Snow and ice on walkways and travelways.

Regularly used walkways and travelways shall be sanded, salted, or cleared of snow and ice as soon as practicable.

§ 57.11017 Inclined fixed ladders.

Fixed ladders shall not incline backwards.

Travelways—Surface Only

§ 57.11025 Railed landings, backguards, and other protection for fixed ladders.

Fixed ladders, except on mobile equipment, shall be offset and have substantial railed landings at least every 30 feet unless backguards or equivalent protection such as safety belts and safety lines, are provided.

§ 57.11026 Protection for inclined fixed ladders.

Fixed ladders 70 degrees to 90 degrees from the horizonal and 30 feet or more in length shall have backguards, cages or equivalent protection, starting at a point not more than seven feet from the bottom of the ladders.

§ 57.11027 Scaffolds and working platforms.

Scaffolds and working platforms shall be of substantial construction and provided with handrails and maintained in good condition. Floorboards shall be laid properly and the scaffolds and working platform shall not be overloaded. Working platforms shall be provided with toeboards when necessary.

Travelways—Underground Only

§ 57.11036 Ladderway trap doors and guards.

Trap doors or adequate guarding shall be provided in ladderways at each level. Doors shall be kept operable.

§ 57.11037 Ladderway openings.

Ladderways constructed after November 15, 1979, shall have a minimum unobstructed cross-sectional opening of 24 inches by 24 inches measured from the face of the ladder.

§ 57.11038 Entering a manway.

Before entering a manway where persons may be working or traveling, a warning shall be given by the person entering the manway and acknowledged by any person present in the manway.

§ 57.11040 Inclined travelways.

Travelways steeper than 35 degrees from the horizontal shall be provided with ladders or stairways.

§ 57.11041 Landings for inclined ladderways.

Fixed ladders with an inclination of more than 70 degrees from the horizontal shall be offset with substantial landings at least every 30 feet or have landing gates at least every 30 feet.

Escapeways—Underground Only

§ 57.11050 Escapeways and refuges.

(a) Every mine shall have two or more separate, properly maintained escapeways to the surface from the lowest levels which are so positioned that damage to one shall not lessen the effectiveness of the others. A method of refuge shall be provided while a second opening to the surface is being developed. A second escapeway is recommended, but not required, during the exploration or development of an ore body.

(b) In addition to separate escapeways, a method of refuge shall be provided for every employee who cannot reach the surface from his working place through at least two separate escapeways within a time limit of one hour when using the normal exit method. These refuges must be positioned so that the employee can reach one of them within 30 minutes from the time he leaves his workplace.

§ 57.11051 Escape routes.

Escape routes shall be—

(a) Inspected at regular intervals and maintained in safe, travelable condition; and

(b) Marked with conspicuous and easily read direction signs that clearly indicate the ways of escape.

§ 57.11052 Refuge areas.

Refuge areas shall be—

(a) Of fire-resistant construction, preferably in untimbered areas of the mine;

(b) Large enough to accommodate readily the normal number of persons in the particular area of the mine;

(c) Constructed so they can be made gastight; and

(d) Provided with compressed air lines, waterlines, suitable handtools, and stopping materials.

§ 57.11053 Escape and evacuation plans.

A specific escape and evacuation plan and revisions thereof suitable to the conditions and mining system of the mine and showing assigned responsibilities of all key personnel in the event of an emergency shall be developed by the operator and set out in written form. Within 45 calendar days after promulgation of this standard a copy of the plan and revisions thereof shall be available to the Secretary or his authorized representative. Also, copies of the plan and revisions thereof shall be posted at locations convenient to all persons on the surface and underground. Such a plan shall be updated as necessary and shall be reviewed jointly by the operator and the Secretary or his authorized representative at least once every six months from the date of the last review. The plan shall include:

(a) Mine maps or diagrams showing directions of principal air flow, location of escape routes and locations of existing telephones, primary fans, primary fan controls, fire doors, ventilation doors, and refuge chambers. Appropriate portions of such maps or diagrams shall be posted at all shaft stations and in underground shops, lunchrooms, and elsewhere in working areas where persons congregate;

(b) Procedures to show how the miners will be notified of emergency;

(c) An escape plan for each working area in the mine to include instructions showing how each working area should be evacuated. Each such plan shall be posted at appropriate shaft stations and elsewhere in working areas where persons congregate;

(d) A fire fighting plan;

(e) Surface procedure to follow in an emergency, including the notification of proper authorities, preparing rescue equipment, and other equipment which may be used in rescue and recovery operations; and

(f) A statement of the availability of emergency communication and transportation facilities, emergency power and ventilation and location of rescue personnel and equipment.

[50 FR 4082, Jan. 29, 1985, as amended at 60 FR 33722, June 29, 1995]

§ 57.11054 Communication with refuge chambers.

Telephone or other voice communication shall be provided between the surface and refuge chambers and such systems shall be independent of the mine power supply.

§ 57.11055 Inclined escapeways.

Any portion of a designated escapeway which is inclined more than 30 degrees from the horizontal and that is more than 300 feet in vertical extent shall be provided with an emergency hoisting facility.

§ 57.11056 Emergency hoists.

The procedure for inspection, testing and maintenance required by standard 57.19120 shall be utilized at least every 30 days for hoists designated as emergency hoists in any evacuation plan.

§ 57.11058 Check-in, check-out system.

Each operator of an underground mine shall establish a check-in and check-out system which shall provide an accurate record of persons in the mine. These records shall be kept on the surface in a place chosen to minimize the danger of destruction by fire or other hazards. Every person underground shall carry a positive means of being identified.

§ 57.11059 Respirable atmosphere for hoist operators underground.

For the protection of operators of hoists located underground which are part of the mine escape and evacuation plan required under standard 57.11053, the hoist operator shall be provided with a respirable atmosphere completely independent of the mine atmosphere. This independent ventilation system shall convert, without contamination, to an approved and properly maintained 2-hour self-contained breathing apparatus to provide a safe means of escape for the hoist operator after the hoisting duties have been completed as prescribed in the mine escape and evacuation plan for that hoist. The hoist operator's independent ventilation system shall be provided by one of the following methods:

(a) A suitable enclosure equipped with a positive pressure ventilation system which may be operated continuously or be capable of immediate activation from within the enclosure during an emergency evacuation. Air for the enclosure's ventilation system shall be provided in one of the following ways:

(1) Air coursed from the surface through a borehole into the hoist enclosure directly or through a metal pipeline from such borehole; or

(2) Air coursed from the surface through metal duct work into the hoist enclosure, although this duct work shall not be located in timber-supported active workings; or

(3) Air supplied by air compressors located on the surface and coursed through metal pipe into the hoist enclosure.

A back-up system shall be provided for a hoist enclosure ventilation system provided by either of the methods set forth in paragraphs (a) (2) and (3) of this section. This back-up system shall consist of compressed air stored in containers connected to the enclosure. This back-up system shall provide and maintain a respirable atmosphere in the enclosure for a period of time equal to at least twice the time necessary to complete the evacuation of all persons designated to use that hoist as prescribed in the mine escape and evacuation plan required under standard 57.11053; or

(b) An approved and properly maintained self-contained breathing apparatus system which shall consist of a mask connected to compressed air stored in containers adjacent to the hoist controls. The self-contained breathing system shall provide a minimum of 24 hours of respirable atmosphere to the hoist operator. In addition, the self-contained breathing system shall be capable of a quick connect with the approved 2-hour self-contained breathing apparatus above.

Subpart K—Electricity

Surface and Underground

§ 57.12001 Circuit overload protection.

Circuits shall be protected against excessive overloads by fuses or circuit breakers of the correct type and capacity.

§ 57.12002 Controls and switches.

Electric equipment and circuits shall be provided with switches or other controls. Such switches or controls shall be of approved design and construction and shall be properly installed.

§ 57.12003 Trailing cable overload protection.

Individual overload protection or short circuit protection shall be provided for the trailing cables of mobile equipment.

§ 57.12004 Electrical conductors.

Electrical conductors shall be of a sufficient size and current-carrying capacity to ensure that a rise in temperature resulting from normal operations will not damage the insulating materials. Electrical conductors exposed to mechanical damage shall be protected.

§ 57.12005 Protection of power conductors from mobile equipment.

Mobile equipment shall not run over power conductors, nor shall loads be dragged over power conductors, unless the conductors are properly bridged or protected.

§ 57.12006 Distribution boxes.

Distribution boxes shall be provided with a disconnecting device for each branch circuit. Such disconnecting devices shall be equipped or designed in such a manner that it can be determined by visual observation when such a device is open and that the circuit is deenergized, and the distribution box shall be labeled to show which circuit each device controls.

§ 57.12007 Junction box connection procedures.

Trailing cable and power-cable connections to junction boxes shall not be made or broken under load.

§ 57.12008 Insulation and fittings for power wires and cables.

Power wires and cables shall be insulated adequately where they pass into or out of electrical compartments. Cables shall enter metal frames of motors, splice boxes, and electrical compartments only through proper fittings. When insulated wires, other than cables, pass through metal frames, the holes shall be substantially bushed with insulated bushings.

§ 57.12010 Isolation or insulation of communication conductors.

Telephone and low-potential signal wire shall be protected, by isolation or suitable insulation, or both, from contacting energized power conductors or any other power source.

§ 57.12011 High-potential electrical conductors.

High-potential electrical conductors shall be covered, insulated, or placed to prevent contact with low potential conductors.

§ 57.12012 Bare signal wires.

The potential on bare signal wires accessible to contact by persons shall not exceed 48 volts.

§ 57.12013 Splices and repairs of power cables.

Permanent splices and repairs made in power cables, including the ground conductor where provided, shall be—

(a) Mechanically strong with electrical conductivity as near as possible to that of the original;

(b) Insulated to a degree at least equal to that of the original, and sealed to exclude moisture; and,

(c) Provided with damage protection as near as possible to that of the original, including good bonding to the outer jacket.

§ 57.12014 Handling energized power cables.

Power cables energized to potentials in excess of 150 volts, phase-to-ground, shall not be moved with equipment unless sleds or slings, insulated from such equipment, are used. When such energized cables are moved manually, insulated hooks, tongs, ropes, or slings shall be used unless suitable protection for persons is provided by other means. This does not prohibit pulling or dragging of cable by the equipment it powers when the cable is physically attached to the equipment by suitable mechanical devices, and the cable is insulated from the equipment in conformance with other standards in this part.

§ 57.12016 Work on electrically-powered equipment.

Electrically powered equipment shall be deenergized before mechanical work is done on such equipment. Power switches shall be locked out or other measures taken which shall prevent the equipment from being energized without the knowledge of the individuals working on it. Suitable warning notices shall be posted at the power switch and signed by the individuals who are to do the work. Such locks or preventive devices shall be removed only by the persons who installed them or by authorized personnel.

§ 57.12017 Work on power circuits.

Power circuits shall be deenergized before work is done on such circuits unless hot-line tools are used. Suitable warning signs shall be posted by the individuals who are to do the work. Switches shall be locked out or other measures taken which shall prevent the power circuits from being energized without the knowledge of the individuals working on them. Such locks, signs, or preventive devices shall be removed only by the person who installed them or by authorized personnel.

§ 57.12018 Identification of power switches.

Principal power switches shall be labeled to show which units they control, unless identification can be made readily by location.

§ 57.12019 Access to stationary electrical equipment or switchgear.

Where access is necessary, suitable clearance shall be provided at stationary electrical equipment or switchgear.

§ 57.12020 Protection of persons at switchgear.

Dry wooden platforms, insulating mats, or other electrically-nonconductive material shall be kept in place at all switchboards and power-control switches where shock hazards exist. However, metal plates on which a person normally would stand and which are kept at the same potential as the grounded, metal, non-current-carrying parts of the power switches to be operated may be used.

§ 57.12021 Danger signs.

Suitable danger signs shall be posted at all major electrical installations.

§ 57.12022 Authorized persons at major electrical installations.

Areas containing major electrical installations shall be entered only by authorized persons.

§ 57.12023 Guarding electrical connections and resistor grids.

Electrical connections and resistor grids that are difficult or impractical to insulate shall be guarded, unless protection is provided by location.

§ 57.12025 Grounding circuit enclosures.

All metal enclosing or encasing electrical circuits shall be grounded or provided with equivalent protection. This requirement does not apply to battery-operated equipment.

§ 57.12026 Grounding transformer and switchgear enclosures.

Metal fencing and metal buildings enclosing transformers and switchgear shall be grounded.

§ 57.12027 Grounding mobile equipment.

Frame grounding or equivalent protection shall be provided for mobile equipment powered through trailing cables.

§ 57.12028 Testing grounding systems.

Continuity and resistance of grounding systems shall be tested immediately after installation, repair, and modification; and annually thereafter. A record of the resistance measured during the most recent test shall be made available on a request by the Secretary or his duly authorized representative.

§ 57.12030 Correction of dangerous conditions.

When a potentially dangerous condition is found it shall be corrected before equipment or wiring is energized.

§ 57.12032 Inspection and cover plates.

Inspection and cover plates on electrical equipment and junction boxes shall be kept in place at all times except during testing or repairs.

§ 57.12033 Hand-held electric tools.

Hand-held electric tools shall not be operated at high potential voltages.

§ 57.12034 Guarding around lights.

Portable extension lights, and other lights that by their location present a shock or burn hazard, shall be guarded.

§ 57.12035 Weatherproof lamp sockets.

Lamp sockets shall be of a weatherproof type where they are exposed to weather or wet conditions that may interfere with illumination or create a shock hazard.

§ 57.12036 Fuse removal or replacement.

Fuses shall not be removed or replaced by hand in an energized circuit, and they shall not otherwise be removed or replaced in an energized circuit unless equipment and techniques especially designed to prevent electrical shock are provided and used for such purpose.

§ 57.12037 Fuses in high-potential circuits.

Fuse tongs or hotline tools, shall be used when fuses are removed or replaced in high-potential circuits.

§ 57.12038 Attachment of trailing cables.

Trailing cables shall be attached to machines in a suitable manner to protect the cable from damage and to prevent strain on the electrical connections.

§ 57.12039 Protection of surplus trailing cables.

Surplus trailing cables to shovels, cranes and similar equipment shall be—

(a) Stored in cable boats;

(b) Stored on reels mounted on the equipment; or

(c) Otherwise protected from mechanical damage.

§ 57.12040 Installation of operating controls.

Operating controls shall be installed so that they can be operated without danger of contact with energized conductors.

§ 57.12041 Design of switches and starting boxes.

Switches and starting boxes shall be of safe design and capacity.

§ 57.12042 Track bonding.

Both rails shall be bonded or welded at every joint and rails shall be crossbonded at least every 200 feet if the track serves as the return trolley circuit. When rails are moved, replaced, or broken bonds are discovered, they shall be rebonded within three working shifts.

§ 57.12045 Overhead powerlines.

Overhead high-potential powerlines shall be installed as specified by the National Electrical Code.

§ 57.12047 Guy wires.

Guy wires of poles supporting high-voltage transmission lines shall meet the requirements for grounding or insulator protection of the National Electrical Safety Code, part 2, entitled “Safety Rules for the Installation and Maintenance of Electric Supply and Communication Lines” (also referred to as National Bureau of Standards Handbook 81, Nov. 1, 1961), and Supplement 2 thereof issued March 1968, which are hereby incorporated by reference and made a part hereof. These publications and documents may be obtained from the National Institute of Science and Technology, 100 Bureau Drive, Stop 3460, Gaithersburg, MD 20899–3460. Telephone: 301–975–6478 (not a toll free number); *http://ts.nist.gov/nvl;* or from the Government Printing Office, Information Dissemination (Superintendent of Documents), P.O. Box 371954, Pittsburgh, PA 15250–7954; Telephone: 866–512–1800 (toll free) or 202–512–1800; *http://bookstore.gpo.gov* , or may be examined in any Metal and Nonmetal Mine Safety and Health District Office of the Mine Safety and Health Administration.

[53 FR 32526, Aug. 25, 1988, as amended at 60 FR 35695, July 11, 1995; 71 FR 16667, Apr. 3, 2006]

§ 57.12048 Communication conductors on power poles.

Telegraph, telephone, or signal wires shall not be installed on the same crossarm with power conductors. When carried on poles supporting powerlines, they shall be installed as specified by the National Electrical Code.

§ 57.12050 Installation of trolley wires.

Trolley wires shall be installed at least seven feet above rails where height permits, and aligned and supported to suitably control sway and sag.

§ 57.12053 Circuits powered from trolley wires.

Ground wires for lighting circuits powered from trolley wires shall be connected securely to the ground return circuit.

Surface Only

§ 57.12065 Short circuit and lightning protection.

Powerlines, including trolley wires, and telephone circuits shall be protected against short circuits and lightning.

§ 57.12066 Guarding trolley wires and bare powerlines.

Where metallic tools or equipment can come in contact with trolley wires or bare powerlines, the lines shall be guarded or deenergized.

§ 57.12067 Installation of transformers.

Transformers shall be totally enclosed, or shall be placed at least 8 feet above the ground, or installed in a transformer house, or surrounded by a substantial fence at least 6 feet high and at least 3 feet from any energized parts, casings, or wiring.

§ 57.12068 Locking transformer enclosures.

Transformer enclosures shall be kept locked against unauthorized entry.

§ 57.12069 Lightning protection for telephone wires and ungrounded conductors.

Each ungrounded conductor or telephone wire that leads underground and is directly exposed to lightning shall be equipped with suitable lightning arrestors of approved type within 100 feet of the point where the circuit enters the mine. Lightning arrestors shall be connected to a low resistance grounding medium on the surface and shall be separated from neutral grounds by a distance of not less than 25 feet.

§ 57.12071 Movement or operation of equipment near high-voltage powerlines.

When equipment must be moved or operated near energized high-voltage powerlines (other than trolley lines) and the clearance is less than 10 feet, the lines shall be deenergized or other precautionary measures shall be taken.

Underground Only

§ 57.12080 Bare conductor guards.

Trolley wires and bare power conductors shall be guarded at mantrip loading and unloading points, and at shaft stations. Where such trolley wires and bare power conductors are less than 7 feet above the rail, they shall be guarded at all points where persons work or pass regularly beneath.

§ 57.12081 Bonding metal pipelines to ground return circuits.

All metal pipelines, 1,000 feet or more in length running parallel to trolley tracks, that are used as a ground return circuit shall be bonded to the return circuit rail at the ends of the pipeline and at intervals not to exceed 500 feet.

§ 57.12082 Isolation of powerlines.

Powerlines shall be well separated or insulated from waterlines, telephone lines and air lines.

§ 57.12083 Support of power cables in shafts and boreholes.

Power cables in shafts and boreholes shall be fastened securely in such a manner as to prevent undue strain on the sheath, insulation, or conductors.

§ 57.12084 Branch circuit disconnecting devices.

Disconnecting switches that can be opened safely under load shall be provided underground at all branch circuits extending from primary power circuits near shafts, adits, levels and boreholes.

§ 57.12085 Transformer stations.

Transformer stations shall be enclosed to prevent persons from unintentionally or inadvertently contacting energized parts.

§ 57.12086 Location of trolley wire.

Trolley and trolley feeder wire shall be installed opposite the clearance side of haulageways. However, this standard does not apply where physical limitations would prevent the safe installation or use of such trolley and trolley feeder wire.

§ 57.12088 Splicing trailing cables.

No splice, except a vulcanized splice or its equivalent, shall be made in a trailing cable within 25 feet of the machine unless the machine is equipped with a cable reel or other power feed cable payout-retrieval system. However, a temporary splice may be made to move the equipment for repair.

Subpart L—Compressed Air and Boilers

§ 57.13001 General requirements for boilers and pressure vessels.

All boilers and pressure vessels shall be constructed, installed, and maintained in accordance with the standards and specifications of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code.

§ 57.13010 Reciprocating-type air compressors.

(a) Reciprocating-type air compressors rated over 10 horsepower shall be equipped with automatic temperature-actuated shutoff mechanisms which shall be set or adjusted to the compressor when the normal operating temperature is exceeded by more than 25 percent.

(b) However, this standard does not apply to reciprocating-type air compressors rated over 10 horsepower if equipped with fusible plugs that were installed in the compressor discharge lines before November 15, 1979, and designed to melt at temperatures at least 50 degrees below the flash point of the compressors' lubricating oil.

§ 57.13011 Air receiver tanks.

Air receiver tanks shall be equipped with one or more automatic pressure-relief valves. The total relieving capacity of the relief valves shall prevent pressure from exceeding the maximum allowable working pressure in a receiver tank by not more than 10 percent. Air receiver tanks also shall be equipped with indicating pressure gages which accurately measure the pressure within the air receiver tanks.

§ 57.13012 Compressor air intakes.

Compressor air intakes shall be installed to ensure that only clean, uncontaminated air enters the compressors.

§ 57.13015 Inspection of compressed-air receivers and other unfired pressure vessels.

(a) Compressed-air receivers and other unfired pressure vessels shall be inspected by inspectors holding a valid National Board Commission and in accordance with the applicable chapters of the National Board Inspection Code, a Manual for Boiler and Pressure Vessel Inspectors, 1979. This code is incorporated by reference and made a part of this standard. It may be examined at any Metal and Nonmetal Mine Safety and Health District Office of the Mine Safety and Health Administration, and may be obtained from the publisher, the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, Ohio 43229.

(b) Records of inspections shall be kept in accordance with requirements of the National Board Inspection Code, and the records shall be made available to the Secretary or his authorized representative.

§ 57.13017 Compressor discharge pipes.

Compressor discharge pipes where carbon build-up may occur shall be cleaned periodically as recommended by the manufacturer, but no less frequently than once every two years.

§ 57.13019 Pressure system repairs.

Repairs involving the pressure system of compressors, receivers, or compressed-air-powered equipment shall not be attempted until the pressure has been bled off.

§ 57.13020 Use of compressed air.

At no time shall compressed air be directed toward a person. When compressed air is used, all necessary precautions shall be taken to protect persons from injury.

§ 57.13021 High-pressure hose connections.

Except where automatic shutoff valves are used, safety chains or other suitable locking devices shall be used at connections to machines of high-pressure hose lines of3/4-inch inside diameter or larger, and between high-pressure hose lines of3/4-inch inside diameter or larger, where a connection failure would create a hazard.

§ 57.13030 Boilers.

(a) Fired pressure vessels (boilers) shall be equipped with water level gauges, pressure gauges, automatic pressure-relief valves, blowdown piping, and other safety devices approved by the American Society of Mechanical Engineers to protect against hazards from overpressure, flameouts, fuel interruptions and low water level, all as required by the appropriate sections, chapters and appendices listed in paragraphs (b) (1) and (2) of this section.

(b) These gauges, devices and piping shall be designed, installed, operated, maintained, repaired, altered, inspected, and tested by inspectors holding a valid National Board Commission and in accordance with the following listed sections, chapters and appendices:

(1) The ASME Boiler and Pressure Vessel Code, 1977, published by the American Society of Mechanical Engineers.

Section and Title

I Power Boilers

II Material Specifications—Part A—Ferrous

II Material Specifications—Part B—Non-ferrous

II Material Specifications—Part C—Welding Rods, Electrodes, and Filler Metals

IV Heating Boilers

V Nondestructive Examination

VI Recommended Rules for Care and Operation of Heating Boilers

VII Recommended Rules for Care of Power Boilers

(2) The National Board Inspection Code, a Manual for Boiler and Pressure Vessel Inspectors, 1979, published by the National Board of Boiler and Pressure Vessel Inspectors.

Chapter and Title

I Glossary of Terms

II Inspection of Boilers and Pressure Vessels

III Repairs and Alterations to Boiler and Pressure Vessels by Welding

IV Shop Inspection of Boilers and Pressure Vessels

V Inservice Inspection of Pressure Vessels by Authorized Owner-User Inspection Agencies

Appendix and Title

A Safety and Safety Relief Valves

B Non-ASME Code Boilers and Pressure Vessels

C Storage of Mild Steel Covered Arc Welding Electrodes

D-R National Board “R” (Repair) Symbol Stamp

D-VR National Board “VR” (Repair of Safety and Safety Relief Valve) Symbol Stamp

D-VR1 Certificate of Authorization for Repair Symbol Stamp for Safety and Safety Relief Valves

D-VR2 Outline of Basic Elements of Written Quality Control System for Repairers of ASME Safety and Safety Relief Valves

D-VR3 Nameplate Stamping for “VR”

E Owner-User Inspection Agencies

F Inspection Forms

(c) Records of inspections and repairs shall be kept in accordance with the requirements of the ASME Boiler and Pressure Vessel Code and the National Board Inspection Code. The records shall be made available to the Secretary or his authorized representative.

(d) Sections of the ASME Boiler and Pressure Vessel Code, 1977, listed in paragraph (b)(1) of this section, and chapters and appendices of the National Board Inspection Code, 1979, listed in paragraph (b)(2) of this section, are incorporated by reference and made a part of this standard. These publications may be obtained from the publishers, the American Society of Mechanical Engineers, 22 Law Drive, P.O. Box 2900, Fairfield, New Jersey 07007, Phone: 800–843–2763 (toll free); *http://www.asme.org* , and the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, Ohio 43229. The publication may be examined at any Metal and Nonmetal Mine Safety and Health District Office of the Mine Safety and Health Administration.

[50 FR 4082, Jan. 29, 1985, as amended at 71 FR 16667, Apr. 3, 2006]

Subpart M—Machinery and Equipment

Source: 53 FR 32528, Aug. 25, 1988, unless otherwise noted.

§ 57.14000 Definitions.

The following definitions apply in this subpart.

Travelway. A passage, walk, or way regularly used or designated for persons to go from one place to another.

[53 FR 32528, Aug. 25, 1988, as amended at 69 FR 38842, June 29, 2004]

Safety Devices and Maintenance Requirements

§ 57.14100 Safety defects; examination, correction and records.

(a) Self-propelled mobile equipment to be used during a shift shall be inspected by the equipment operator before being placed in operation on that shift.

(b) Defects on any equipment, machinery, and tools that affect safety shall be corrected in a timely manner to prevent the creation of a hazard to persons.

(c) When defects make continued operation hazardous to persons, the defective items including self-propelled mobile equipment shall be taken out of service and placed in a designated area posted for that purpose, or a tag or other effective method of marking the defective items shall be used to prohibit further use until the defects are corrected.

(d) Defects on self-propelled mobile equipment affecting safety, which are not corrected immediately, shall be reported to, and recorded by, the mine operator. The records shall be kept at the mine or nearest mine office from the date the defects are recorded, until the defects are corrected. Such records shall be made available for inspection by an authorized representative of the Secretary.

§ 57.14101 Brakes.

(a) *Minimum requirements.* (1) Self-propelled mobile equipment shall be equipped with a service brake system capable of stopping and holding the equipment with its typical load on the maximum grade it travels. This standard does not apply to equipment which is not originally equipped with brakes unless the manner in which the equipment is being operated requires the use of brakes for safe operation. This standard does not apply to rail equipment.

(2) If equipped on self-propelled mobile equipment, parking brakes shall be capable of holding the equipment with its typical load on the maximum grade it travels.

(3) All braking systems installed on the equipment shall be maintained in functional condition.

(b) *Testing.* (1) Service brake tests shall be conducted on surface-operated equipment at underground mines when an MSHA inspector has reasonable cause to believe that the service brake system does not function as required, unless the mine operator removes the equipment from service for the appropriate repair;

(2) The performance of the service brakes shall be evaluated according to Table M–1.

Table M–1

Gross vehicle weight lbs.	Equipment Speed, MPH										
	10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Service Brake Maximum Stopping Distance—Feet											
0–36,000	34	38	43	48	53	59	64	70	76	83	89
36,000–70,000	41	46	52	58	62	70	76	83	90	97	104
70,000–14,0000	48	54	61	67	74	81	88	95	103	111	119
140,000–250,000	56	62	69	77	84	92	100	108	116	125	133
250,000–400,000	59	66	74	81	89	97	105	114	123	132	141
Over–400,000	63	71	78	86	94	103	111	120	129	139	148

Stopping distances are computed using a constant deceleration of 9.66 $FPS^2$and system response times of .5.1, 1.5, 2, 2.25 and 2.5 seconds for each of increasing weight category respectively. Stopping distance values include a one-second operator response time.

Table M–2—The Speed of a Vehicle Can Be Determined by Clocking It Through a 100-Foot Measured Course at Constant Velocity Using Table M–2. When the Service Brakes Are Applied at the End of the Course, Stopping Distance Can Be Measured and Compared to Table M–1.

Miles per hour	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Seconds required to travel 100 feet	6.8	6.2	5.7	5.2	4.9	4.5	4.3	4.0	3.8	3.6	3.4

(3) Service brake tests shall be conducted under the direction of the mine operator in cooperation with and according to the instructions provided by the MSHA inspector as follows:

(i) Equipment capable of traveling at least 10 miles per hour shall be tested with a typical load for that particular piece of equipment. Front-end loaders shall be tested with the loader bucket empty. Equipment shall not be tested when carrying hazardous loads, such as explosives.

(ii) The approach shall be of sufficient length to allow the equipment operator to reach and maintain a constant speed between 10 and 20 miles per hour prior to entering the 100 foot measured area. The constant speed shall be maintained up to the point when the equipment operator receives the signal to apply the brakes. The roadway shall be wide enough to accommodate the size of the equipment being tested. The ground shall be generally level, packed, and dry in the braking portion of the test course. Ground moisture may be present to the extent that it does not adversely affect the braking surface.

(iii) Braking is to be performed using only those braking systems, including auxiliary retarders, which are designed to bring the equipment to a stop under normal operating conditions. Parking or emergency (secondary) brakes are not to be actuated during the test.

(iv) The tests shall be conducted with the transmission in the gear appropriate for the speed the equipment is traveling except for equipment which is designed for the power train to be disengaged during braking.

(v) Testing speeds shall be a minimum of 10 miles per hour and a maximum of 20 miles per hour.

(vi) Stopping distances shall be measured from the point at which the equipment operator receives the signal to apply the service brakes to the final stopped position.

(4) Test results shall be evaluated as follows:

(i) If the initial test run is valid and the stopping distance does not exceed the corresponding stopping distance listed in Table 1, the performance of the service brakes shall be considered acceptable. For tests to be considered valid, the equipment shall not slide sideways or exhibit other lateral motion during the braking portion of the test.

(ii) If the equipment exceeds the maximum stopping distance in the initial test run, the mine operator may request from the inspector up to four additional test runs with two runs to be conducted in each direction. The performance of the service brakes shall be considered acceptable if the equipment does not exceed the maximum stopping distance on at least three of the additional tests.

(5) Where there is not an appropriate test site at the mine or the equipment is not capable of traveling at least 10 miles per hour, service brake tests will not be conducted. In such cases, the inspector will rely upon other available evidence to determine whether the service brake system meets the performance requirements of this standard.

[53 FR 32528, Aug. 25, 1988; 53 FR 44588, Nov. 4, 1988]

§ 57.14102 Brakes for rail equipment.

Braking systems on railroad cars and locomotives shall be maintained in functional condition.

§ 57.14103 Operators' stations.

(a) If windows are provided on operators' stations of self-propelled mobile equipment, the windows shall be made of safety glass or material with equivalent safety characteristics. The windows shall be maintained to provide visibility for safe operation.

(b) If damaged windows obscure visibility necessary for safe operation, or create a hazard to the equipment operator, the windows shall be replaced or removed. Damaged windows shall be replaced if absence of a window would expose the equipment operator to hazardous environmental conditions which would affect the ability of the equipment operator to safely operate the equipment.

(c) The operators' stations of self-propelled mobile equipment shall—

(1) Be free of materials that may create a hazard to persons by impairing the safe operation of the equipment; and

(2) Not be modified, in a manner that obscures visibility necessary for safe operation.

§ 57.14104 Tire repairs.

(a) Before a tire is removed from a vehicle for tire repair, the valve core shall be partially removed to allow for gradual deflation and then removed. During deflation, to the extent possible, persons shall stand outside of the potential trajectory of the lock ring of a multi-piece wheel rim.

(b) To prevent injury from wheel rims during tire inflation, one of the following shall be used:

(1) A wheel cage or other restraining device that will constrain all wheel rim components during an explosive separation of a multi-piece wheel rim, or during the sudden release of contained air in a single piece rim wheel; or

(2) A stand-off inflation device which permits persons to stand outside of the potential trajectory of wheel components.

§ 57.14105 Procedures during repairs or maintenance.

Repairs or maintenance on machinery or equipment shall be performed only after the power is off, and the machinery or equipment blocked against hazardous motion. Machinery or equipment motion or activation is permitted to the extent that adjustments or testing cannot be performed without motion or activation, provided that persons are effectively protected from hazardous motion.

§ 57.14106 Falling object protection.

(a) Fork-lift trucks, front-end loaders, and bulldozers shall be provided with falling object protective structures if used in an area where falling objects could create a hazard to the operator.

(b) The protective structure shall be capable of withstanding the falling object loads to which it could be subjected.

§ 57.14107 Moving machine parts.

(a) Moving machine parts shall be guarded to protect persons from contacting gears, sprockets, chains, drive, head, tail, and takeup pulleys, flywheels, coupling, shafts, fan blades; and similar moving parts that can cause injury.

(b) Guards shall not be required where the exposed moving parts are at least seven feet away from walking or working surfaces.

§ 57.14108 Overhead drive belts.

Overhead drive belts shall be guarded to contain the whipping action of a broken belt if that action could be hazardous to persons.

§ 57.14109 Unguarded conveyors with adjacent travelways.

Unguarded conveyors next to travelways shall be equipped with—

(a) Emergency stop devices which are located so that a person falling on or against the conveyor can readily deactivate the conveyor drive motor; or

(b) Railings which—

(1) Are positioned to prevent persons from falling on or against the conveyor;

(2) Will be able to withstand the vibration, shock, and wear to which they will be subjected during normal operation; and

(3) Are constructed and maintained so that they will not create a hazard.

§ 57.14110 Flying or falling materials.

In areas where flying or falling materials generated from the operation of screens, crushers, or conveyors present a hazard, guards, shields, or other devices that provide protection against such flying or falling materials shall be provided to protect persons.

§ 57.14111 Slusher, backlash guards and securing.

(a) When persons are exposed to slushing operations, the slushers shall be equipped with rollers and drum covers and anchored securely before slushing operations are started to protect against hazardous movement before slushing operations are started.

(b) Slushers rated over 10 horsepower shall be equipped with backlash guards, unless the equipment operator is otherwise protected.

(c) This standard does not apply to air tuggers of 10 horsepower or less that have only one cable and one drum.

§ 57.14112 Construction and maintenance of guards.

(a) Guards shall be constructed and maintained to—

(1) Withstand the vibration, shock, and wear to which they will be subjected during normal operation; and

(2) Not create a hazard by their use.

(b) Guards shall be securely in place while machinery is being operated, except when testing or making adjustments which cannot be performed without removal of the guard.

§ 57.14113 Inclined conveyors: backstops or brakes.

Backstops or brakes shall be installed on drive units of inclined conveyors to prevent the conveyors from running in reverse, creating a hazard to persons.

§ 57.14114 Air valves for pneumatic equipment.

A manual master quick-close type air valve shall be installed on all pneumatic-powered equipment if there is a hazard of uncontrolled movement when the air supply is activated. The valve shall be closed except when the equipment is being operated.

[53 FR 32528, Aug. 25, 1988; 53 FR 44588, Nov. 4, 1988]

§ 57.14115 Stationary grinding machines.

Stationary grinding machines, other than special bit grinders, shall be equipped with—

(a) Peripheral hoods capable of withstanding the force of a bursting wheel and enclosing not less than 270°—of the periphery of the wheel;

(b) Adjustable tool rests set so that the distance between the grinding surface of the wheel and the tool rest is not greater than1/8inch; and

(c) A safety washer on each side of the wheel.

[53 FR 32528, Aug. 25, 1988; 53 FR 44588, Nov. 4, 1988]

§ 57.14116 Hand-held power tools.

(a) Power drills, disc sanders, grinders and circular and chain saws, when used in the hand-held mode shall be operated with controls which require constant hand or finger pressure.

(b) Circular saws and chain saws shall not be equipped with devices which lock-on the operating controls.

§ 57.14130 Roll-over protective structures (ROPS) and seat belts for surface equipment.

(a) *Equipment included.* Roll-over protective structures (ROPS) and seat belts shall be installed on—

(1) Crawler tractors and crawler loaders;

(2) Graders;

(3) Wheel loaders and wheel tractors;

(4) The tractor portion of semi-mounted scrapers, dumpers, water wagons, bottom-dump wagons, rear-dump wagons, and towed fifth wheel attachments;

(5) Skid-steer loaders; and

(6) Agricultural tractors.

(b) *ROPS construction.* ROPS shall meet the requirements of the following Society of Automotive Engineers (SAE) publications, as applicable, which are incorporated by reference:

(1) SAE J1040, “Performance Criteria for Roll-Over Protective Structures (ROPS) for Construction, Earthmoving, Forestry, and Mining Machines,”, 1986; or

(2) SAE J1194, “Roll-Over Protective Structures (ROPS) for Wheeled Agricultural Tractors”, 1983.

(c) *ROPS labeling.* ROPS shall have a label permanently affixed to the structure identifying—

(1) The manufacturer's name and address;

(2) The ROPS model number; and

(3) The make and model number of the equipment for which the ROPS is designed.

(d) *ROPS installation.* ROPS shall be installed on the equipment in accordance with the recommendations of the ROPS manufacturer.

(e) *ROPS maintenance.* (1) ROPS shall be maintained in a condition that meets the performance requirements applicable to the equipment. If the ROPS is subjected to a roll-over or abnormal structural loading, the equipment manufacturer or a registered professional engineer with knowledge and experience in ROPS design shall recertify that the ROPS meets the applicable performance requirements before it is returned to service.

(2) Alterations or repairs on ROPS shall be performed only with approval from the ROPS manufacturer or under the instructions of a registered professional engineer with knowledge and experience in ROPS design. The manufacturer or engineer shall certify that the ROPS meets the applicable performance requirements.

(f) *Exemptions.* (1) This standard does not apply to—

(i) Self-propelled mobile equipment manufactured prior to July 1, 1969;

(ii) Over-the-road type tractors that pull trailers or vans on highways;

(iii) Equipment that is only operated by remote control; and

(2) Self-propelled mobile equipment manufactured prior to October 24, 1988, that is equipped with ROPS and seat belts that meet the installation and performance requirements of 30 CFR 57.9088 (1986 edition) shall be considered in compliance with paragraphs (b) and (h) of this section.

(g) *Wearing seat belts.* Seat belts shall be worn by the equipment operator except that when operating graders from a standing position, the grader operator shall wear safety lines and a harness in place of a seat belt.

(h) *Seat belts construction.* Seat belts required under this section shall meet the requirement of SAE J386, “Operator Restraint System for Off-Road Work Machines” (1985, 1993, or 1997), or SAE J1194, “Roll-Over Protective Structures (ROPS) for Wheeled Agricultural Tractors” (1983, 1989, 1994, or 1999), as applicable, which are incorporated by reference.

(i) *Seat belt maintenance.* Seat belts shall be maintained in functional condition, and replaced when necessary to assure proper performance.

(j) *Publications.* The incorporation by reference of these publications is approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. Copies of these publications may be examined at any Metal and Nonmetal Mine Safety and Health District Office; at MSHA's Office of Standards, Regulations, and Variances, 1100 Wilson Boulevard, Room 2349, Arlington, Virginia 22209–3939; or at the National Archives and Records Administration (NARA). For information on the availability of this material at NARA, call 202–741–6030, or go to: *http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.html.* Copies may be purchased from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096–0001.

[53 FR 32528, Aug. 25, 1988; 53 FR 44588, Nov. 4, 1988, as amended at 60 FR 33722, June 29, 1995; 67 FR 38385, June 4, 2002; 68 FR 19347, Apr. 21, 2003]

§ 57.14131 Seat belts for surface haulage trucks.

(a) Seat belts shall be provided and worn in haulage trucks.

(b) Seat belts shall be maintained in functional condition, and replaced when necessary to assure proper performance.

(c) Seat belts required under this section shall meet the requirements of SAE J386, “Operator Restraint System for Off-Road Work Machines” (1985, 1993, or 1997), which are incorporated by reference.

(d) The incorporation by reference of these publications is approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. Copies of these publications may be examined at any Metal and Nonmetal Mine Safety and Health District Office; at MSHA's Office of Standards, Regulations, and Variances, 1100 Wilson Boulevard, Room 2349, Arlington, Virginia 22209–3939; or at the National Archives and Records Administration (NARA). For information on the availability of this material at NARA, call 202–741–6030, or go to: *http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.html.* Copies may be purchased from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096–0001.

[53 FR 32528, Aug. 25, 1988, as amended at 67 FR 38385, June 4, 2002; 68 FR 19347, Apr. 21, 2003]

§ 57.14132 Horns and backup alarms for surface equipment.

(a) Manually-operated horns or other audible warning devices provided on self-propelled mobile equipment as a safety device shall be maintained in a functional condition.

(b)(1) When the operator has an obstructed view to the rear, self-propelled mobile equipment shall have—

(i) An automatic reverse-activated signal alarm;

(ii) A wheel-mounted bell alarm which sounds at least once for each three feet of reverse movement;

(iii) A discriminating backup alarm that covers the area of obstructed view; or

(iv) An observer to signal when it is safe to back up.

(2) Alarms shall be audible above the surrounding noise level.

(3) An automatic reverse-activated strobe light may be used at night in lieu of an audible reverse alarm.

(c) This standard does not apply to rail equipment.

§ 57.14160 Mantrip trolley wire hazards underground.

Mantrips shall be covered if there is danger of persons contacting the trolley wire.

§ 57.14161 Makeshift couplings.

Couplings used on underground rail equipment shall be designed for that equipment, except that makeshift couplings may be used to move disabled rail equipment for repairs if no hazard to persons is created.

§ 57.14162 Trip lights.

On underground rail haulage, trip lights shall be used on the rear of pulled trips and on the front of pushed trips.

Safety Practices and Operational Procedures

§ 57.14200 Warnings prior to starting or moving equipment.

Before starting crushers or moving self-propelled mobile equipment, equipment operators shall sound a warning that is audible above the surrounding noise level or use other effective means to warn all persons who could be exposed to a hazard from the equipment.

§ 57.14201 Conveyor start-up warnings.

(a) When the entire length of a conveyor is visible from the starting switch, the conveyor operator shall visually check to make certain that all persons are in the clear before starting the conveyor.

(b) When the entire length of the conveyor is not visible from the starting switch, a system which provides visible or audible warning shall be installed and operated to warn persons that the conveyor will be started. Within 30 seconds after the warning is given, the conveyor shall be started or a second warning shall be given.

§ 57.14202 Manual cleaning of conveyor pulleys.

Pulleys of conveyors shall not be cleaned manually while the conveyor is in motion.

§ 57.14203 Application of belt dressing.

Belt dressings shall not be applied manually while belts are in motion unless a pressurized-type applicator is used that allows the dressing to be applied from outside the guards.

§ 57.14204 Machinery lubrication.

Machinery or equipment shall not be lubricated manually while it is in motion where application of the lubricant may expose persons to injury.

§ 57.14205 Machinery, equipment, and tools.

Machinery, equipment, and tools shall not be used beyond the design capacity intended by the manufacturer, where such use may create a hazard to persons.

§ 57.14206 Securing movable parts.

(a) When moving mobile equipment between workplaces, booms, forks, buckets, beds, and similar movable parts of the equipment shall be positioned in the travel mode and, if required for safe travel, mechanically secured.

(b) When mobile equipment is unattended or not in use, dippers, buckets and scraper blades shall be lowered to the ground. Other movable parts, such as booms, shall be mechanically secured or positioned to prevent movement which would create a hazard to persons.

§ 57.14207 Parking procedures for unattended equipment.

Mobile equipment shall not be left unattended unless the controls are placed in the park position and the parking brake, if provided, is set. When parked on a grade, the wheels or tracks of mobile equipment shall be either chocked or turned into a bank or rib.

§ 57.14208 Warning devices.

(a) Visible warning devices shall be used when parked mobile equipment creates a hazard to persons in other mobile equipment.

(b) Mobile equipment, other than forklifts, carrying loads that project beyond the sides or more than four feet beyond the rear of the equipment shall have a warning flag at the end of the projection. Under conditions of limited visibility these loads shall have a warning light at the end of the projection. Such flags or lights shall be attached to the end of the projection or be carried by persons walking beside or behind the projection.

§ 57.14209 Safety procedures for towing.

(a) A properly sized tow bar or other effective means of control shall be used to tow mobile equipment.

(b) Unless steering and braking are under the control of the equipment operator on the towed equipment, a safety chain or wire rope capable of withstanding the loads to which it could be subjected shall be used in conjunction with any primary rigging.

(c) This provision does not apply to rail equipment.

§ 57.14210 Movement of dippers, buckets, loading booms, or suspended loads.

(a) Dippers, buckets, loading booms, or suspended loads shall not be swung over the operators' stations of self-propelled mobile equipment until the equipment operator is out of the operator's station and in a safe location.

(b) This section does not apply when the equipment is specifically designed to protect the equipment operator from falling objects.

§ 57.14211 Blocking equipment in a raised position.

(a) Persons shall not work on top of, under, or work from mobile equipment in a raised position until the equipment has been blocked or mechanically secured to prevent it from rolling or falling accidentally.

(b) Persons shall not work on top of, under, or work from a raised component of mobile equipment until the component has been blocked or mechanically secured to prevent accidental lowering. The equipment must also be blocked or secured to prevent rolling.

(c) A raised component must be secured to prevent accidental lowering when persons are working on or around mobile equipment and are exposed to the hazard of accidental lowering of the component.

(d) Under this section, a raised component of mobile equipment is considered to be blocked or mechanically secured if provided with a functional load-locking device or devices which prevent free and uncontrolled descent.

(e) Blocking or mechanical securing of the raised component is required during repair or maintenance of elevated mobile work platforms.

§ 57.14212 Chains, ropes, and drive belts.

Chains, ropes, and drive belts shall be guided mechanically onto moving pulleys, sprockets, or drums except where equipment is designed specifically for hand feeding.

§ 57.14213 Ventilation and shielding for welding.

(a) Welding operations shall be shielded when performed at locations where arc flash could be hazardous to persons.

(b) All welding operations shall be well-ventilated.

§ 57.14214 Train warnings.

A warning that is audible above the surrounding noise level shall be sounded—

(a) Immediately prior to moving trains;

(b) When trains approach persons, crossing, other trains on adjacent tracks; and

(c) Any place where the train operator's vision is obscured.

§ 57.14215 Coupling or uncoupling cars.

Prior to coupling or uncoupling cars manually, trains shall be brought to a complete stop, and then moved at minimum tram speed until the coupling or uncoupling activity is completed. Coupling or uncoupling shall not be attempted from the inside of curves unless the railroad and cars are designed to eliminate hazards to persons.

§ 57.14216 Backpoling.

Backpoling of trolleys is prohibited except where there is inadequate clearance to reverse the trolley pole. Where backpoling is required, it shall be done only at the minimum tram speed of the trolley.

§ 57.14217 Securing parked railcars.

Parked railcars shall be blocked securely unless held effectively by brakes.

§ 57.14218 Movement of equipment on adjacent tracks.

When a locomotive on one track is used to move rail equipment on adjacent tracks, a chain, cable, or drawbar shall be used which is capable of withstanding the loads to which it could be subjected.

§ 57.14219 Brakeman signals.

When a train is under the direction of a brakeman and the train operator cannot clearly recognize the brakeman's signals, the train operator shall bring the train to a stop.

Appendix I to Subpart M of Part 57—National Consensus Standards

Mine operators seeking further information regarding the construction and installation of falling object protective structures (FOPS) may consult the following national consensus standards, as applicable.

MSHA Standard 57.14106, Falling Object Protection

Equipment	National consensus standard
Front-end loaders and bulldozers	Society of Automotive Engineers (SAE) minimum performance criteria for falling object protective structures (FOPS) SAE J231—January, 1981.
Fork-lift trucks	American National Standards Institute (ANSI) safety standard for low lift and high lift trucks, B 56.1, section 7.27—1983; or
	American National Standards Institute (ANSI) standard, rough terrain fork lift trucks, B 56.6—1987.

Subpart N—Personal Protection

Surface and Underground

§ 57.15001 First aid materials.

Adequate first-aid materials, including stretchers and blankets shall be provided at places convenient to all working areas. Water or neutralizing agents shall be available where corrosive chemicals or other harmful substances are stored, handled, or used.

§ 57.15002 Hard hats.

All persons shall wear suitable hard hats when in or around a mine or plant where falling objects may create a hazard.

§ 57.15003 Protective footwear.

All persons shall wear suitable protective footwear when in or around an area of a mine or plant where a hazard exists which could cause an injury to the feet.

§ 57.15004 Eye protection.

All persons shall wear safety glasses, goggles, or face shields or other suitable protective devices when in or around an area of a mine or plant where a hazard exists which could cause injury to unprotected eyes.

§ 57.15005 Safety belts and lines.

Safety belts and lines shall be worn when persons work where there is danger of falling; a second person shall tend the lifeline when bins, tanks, or other dangerous areas are entered.

§ 57.15006 Protective equipment and clothing for hazards and irritants.

Special protective equipment and special protective clothing shall be provided, maintained in a sanitary and reliable condition and used whenever hazards of process or environment, chemical hazards, radiological hazards, or mechancial irritants are encountered in a manner capable of causing injury or impairment.

§ 57.15007 Protective equipment or clothing for welding, cutting, or working with molten metal.

Protective clothing or equipment and face shields or goggles shall be worn when welding, cutting, or working with molten metal.

§ 57.15014 Eye protection when operating grinding wheels.

Face shields or goggles in good condition shall be worn when operating a grinding wheel.

[53 FR 32533, Aug. 25, 1988]

Surface Only

§ 57.15020 Life jackets and belts.

Life jackets or belts shall be worn where there is danger from falling into water.

Underground Only

§ 57.15030 Provision and maintenance of self-rescue devices.

A 1-hour self-rescue device approved by MSHA and NIOSH under 42 CFR part 84 shall be made available by the operator to all personnel underground. Each operator shall maintain self-rescue devices in good condition.

[60 FR 30401, June 8, 1995]

§ 57.15031 Location of self-rescue devices.

(a) Except as provided in paragraph (b) and (c) of this section, self-rescue devices meeting the requirements of standard 57.15030 shall be worn or carried by all persons underground.

(b) Where the wearing or carrying of self-rescue devices meeting the requirements of standard 57.15030 is hazardous to a person, such self-rescue devices shall be located at a distance no greater than 25 feet from such person.

(c) Where a person works on or around mobile equipment, self-rescue devices may be placed in a readily accessible location on such equipment.

Subpart O—Materials Storage and Handling

§ 57.16001 Stacking and storage of materials.

Supplies shall not be stacked or stored in a manner which creates tripping or fall-of-material hazards.

§ 57.16002 Bins, hoppers, silos, tanks, and surge piles.

(a) Bins, hoppers, silos, tanks, and surge piles, where loose unconsolidated materials are stored, handled or transferred shall be—

(1) Equipped with mechanical devices or other effective means of handling materials so that during normal operations persons are not required to enter or work where they are exposed to entrapment by the caving or sliding of materials; and

(2) Equipped with supply and discharge operating controls. The controls shall be located so that spills or overruns will not endanger persons.

(b) Where persons are required to move around or over any facility listed in this standard, suitable walkways or passageways shall be provided.

(c) Where persons are required to enter any facility listed in this standard for maintenance or inspection purposes, ladders, platforms, or staging shall be provided. No person shall enter the facility until the supply and discharge of materials have ceased and the supply and discharge equipment is locked out. Persons entering the facility shall wear a safety belt or harness equipped with a lifeline suitably fastened. A second person, similarly equipped, shall be stationed near where the lifeline is fastened and shall constantly adjust it or keep it tight as needed, with minimum slack.

§ 57.16003 Storage of hazardous materials.

Materials that can create hazards if accidentally liberated from their containers shall be stored in a manner that minimizes the dangers.

§ 57.16004 Containers for hazardous materials.

Containers holding hazardous materials must be of a type approved for such use by recognized agencies.

[67 FR 42389, June 21, 2002]

§ 57.16005 Securing gas cylinders.

Compressed and liquid gas cylinders shall be secured in a safe manner.

§ 57.16006 Protection of gas cylinder valves.

Valves on compressed gas cylinders shall be protected by covers when being transported or stored, and by a safe location when the cylinders are in use.

§ 57.16007 Taglines, hitches, and slings.

(a) Taglines shall be attached to loads that may require steadying or guidance while suspended.

(b) Hitches and slings used to hoist materials shall be suitable for the particular material handled.

§ 57.16009 Suspended loads.

Persons shall stay clear of suspended loads.

§ 57.16010 Dropping materials from overhead.

To protect personnel, material shall not be dropped from an overhead elevation until the drop area is first cleared of personnel and the area is then either guarded or a suitable warning is given.

§ 57.16011 Riding hoisted loads or on the hoist hook.

Persons shall not ride on loads being moved by cranes or derricks, nor shall they ride the hoisting hooks unless such method eliminates a greater hazard.

§ 57.16012 Storage of incompatible substances.

Chemical substances, including concentrated acids and alkalies, shall be stored to prevent inadvertent contact with each other or with other substances, where such contact could cause a violent reaction or the liberation of harmful fumes or gases.

§ 57.16013 Working with molten metal.

Suitable warning shall be given before molten metal is poured and before a container of molten metal is moved.

§ 57.16014 Operator-carrying overhead cranes.

Operator-carrying overhead cranes shall be provided with—

(a) Bumpers at each end of each rail;

(b) Automatic switches to halt uptravel of the blocks before they strike the hoist;

(c) Effective audible warning signals within easy reach of the operator; and

(d) A means to lock out the disconnect switch.

§ 57.16015 Work or travel on overhead crane bridges.

No person shall work from or travel on the bridge of an overhead crane unless the bridge is provided with substantial footwalks with toeboards and railings the length of the bridge.

§ 57.16016 Lift trucks.

Fork and other similar types of lift trucks shall be operated with the:

(a) Upright tilted back to steady and secure the load;

(b) Load in the upgrade position when ascending or descending grades in excess of 10 percent;

(c) Load not raised or lowered enroute except for minor adjustments; and

(d) Load-engaging device downgrade when traveling unloaded on all grades.

§ 57.16017 Hoisting heavy equipment or material.

Where the stretching or contraction of a hoist rope could create a hazard, chairs or other suitable blocking shall be used to support conveyances at shaft landings before heavy equipment or material is loaded or unloaded.

Subpart P—Illumination

§ 57.17001 Illumination of surface working areas.

Illumination sufficient to provide safe working conditions shall be provided in and on all surface structures, paths, walkways, stairways, switch panels, loading and dumping sites, and working areas.

§ 57.17010 Electric lamps.

Individual electric lamps shall be carried for illumination by all persons underground.

Subpart Q—Safety Programs

Surface and Underground

§ 57.18002 Examination of working places.

(a) A competent person designated by the operator shall examine each working place at least once each shift for conditions which may adversely affect safety or health. The operator shall promptly initiate appropriate action to correct such conditions.

(b) A record that such examinations were conducted shall be kept by the operator for a period of one year, and shall be made available for review by the Secretary or his authorized representative.

(c) In addition, conditions that may present an imminent danger which are noted by the person conducting the examination shall be brought to the immediate attention of the operator who shall withdraw all persons from the area affected (except persons referred to in section 104(c) of the Federal Mine Safety and Health Act of 1977) until the danger is abated.

§ 57.18006 New employees.

New employees shall be indoctrinated in safety rules and safe work procedures.

§ 57.18009 Designation of person in charge.

When persons are working at the mine, a competent person designated by the mine operator shall be in attendance to take charge in case of an emergency.

§ 57.18010 First aid.

An individual capable of providing first aid shall be available on all shifts. The individual shall be currently trained and have the skills to perform patient assessment and artificial respiration; control bleeding; and treat shock, wounds, burns, and musculoskeletal injuries. First aid training shall be made available to all interested miners.

[61 FR 50436, Sept. 26, 1996]

§ 57.18012 Emergency telephone numbers.

Emergency telephone numbers shall be posted at appropriate telephones.

§ 57.18013 Emergency communications system.

A suitable communication system shall be provided at the mine to obtain assistance in the event of an emergency.

§ 57.18014 Emergency medical assistance and transportation.

Arrangements shall be made in advance for obtaining emergency medical assistance and transportation for injured persons.

Surface Only

§ 57.18020 Working alone.

No employee shall be assigned, or allowed, or be required to perform work alone in any area where hazardous conditions exist that would endanger his safety unless he can communicate with others, can be heard, or can be seen.

Underground Only

§ 57.18025 Working alone.

No employee shall be assigned, or allowed, or be required to perform work alone in any area where hazardous conditions exist that would endanger his safety unless his cries for help can be heard or he can be seen.

§ 57.18028 Mine emergency and self-rescuer training.

(a) On an annual basis, all persons who are required to go underground shall be instructed in the Mine Safety and Health Administration approved course contained in Bureau of Mines Instruction Guide 19, "Mine Emergency Training" (September 1972). The instruction shall be given by MSHA personnel or by persons who are certified by the District Manager of the area in which the mine is located.

(b) On an annual basis, all persons who go underground shall be instructed in the Mine Safety and Health Administration course contained in Bureau of Mines Instruction Guide 2, "MSA W–65 Self-Rescuer" (March 1972) or Bureau of Mines Instruction Guide 3, "Permissible Drager 810 Respirator for Self-Rescue" (March 1972). The instruction shall be given by MSHA personnel or by persons who are certified by the District Manager of the area in which the mine is located: *Provided, however,* That if a Mine Safety and Health Administration instructor or a certified instructor is not immediately available such instruction of new employees in self-rescuers may be conducted by qualified company personnel who are not certified, but who have obtained provisional approval from the District Manager. Any person who has not had self-rescuer instruction within 12 months immediately preceding going underground shall be instructed in the use of self-rescuers before going underground.

(c) All instructional material, handouts, visual aids, and other such teaching accessories used by the operator in the courses prescribed in paragraphs (a) and (b) of this section shall be available for inspection by the Secretary or his authorized representative.

(d) Records of all instruction shall be kept at the mine site or nearest mine office at least 2 years from the date of instruction. Upon completion of such instruction, copies of the record shall be submitted to the District Manager.

(e) The Bureau of Mines instruction guides to which reference is made in items (a) and (b) of this standard are hereby incorporated by reference and made a part hereof. The incorporated instruction guides are available and shall be provided upon request made to any Metal and Nonmetal Mine Safety and Health district office.

[50 FR 4082, Jan. 29, 1985, as amended at 71 FR 16667, Apr. 3, 2006]

Subpart R—Personnel Hoisting

§ 57.19000 Application.

(a) The hoisting standards in this subpart apply to those hoists and appurtenances used for hoisting persons. However, where persons may be endangered by hoists and appurtenances used solely for handling ore, rock, and materials, the appropriate standards should be applied.

(b) Standards 57.19021 through 57.19028 shall apply to wire ropes in service used to hoist—

(1) Persons in shafts and slopes underground;

(2) Persons with an incline hoist on the surface; or

(3) Loads in shaft or slope development when persons work below suspended loads.

(4) These standards do not apply to wire ropes used for elevators.

(c) Emergency hoisting facilities should conform to the extent possible to safety requirements for other hoists, and should be adequate to remove the persons from the mine with a minimum of delay.

Hoists

§ 57.19001 Rated capacities.

Hoists shall have rated capacities consistent with the loads handled and the recommended safety factors of the ropes used.

§ 57.19002 Anchoring.

Hoists shall be anchored securely.

§ 57.19003 Driving mechanism connections.

Belt, rope, or chains shall not be used to connect driving mechanisms to man hoists.

§ 57.19004 Brakes.

Any hoist used to hoist persons shall be equipped with a brake or brakes which shall be capable of holding its fully loaded cage, skip, or bucket at any point in the shaft.

§ 57.19005 Locking mechanism for clutch.

The operating mechanism of the clutch of every man-hoist drum shall be provided with a locking mechanism, or interlocked electrically or mechanically with the brake to prevent accidental withdrawal of the clutch.

§ 57.19006 Automatic hoist braking devices.

Automatic hoists shall be provided with devices that automatically apply the brakes in the event of power failure.

§ 57.19007 Overtravel and overspeed devices.

All man hoists shall be provided with devices to prevent overtravel. When utilized in shafts exceeding 100 feet in depth, such hoists shall also be provided with overspeed devices.

§ 57.19008 Friction hoist synchronizing mechanisms.

Where creep or slip may alter the effective position of safety devices, friction hoists shall be equipped with synchronizing mechanisms that recalibrate the overtravel devices and position indicators.

§ 57.19009 Position indicator.

An accurate and reliable indicator of the position of the cage, skip, bucket, or cars in the shaft shall be provided.

§ 57.19010 Location of hoist controls.

Hoist controls shall be placed or housed so that the noise from machinery or other sources will not prevent hoistmen from hearing signals.

§ 57.19011 Drum flanges.

Flanges on drums shall extend radially a minimum of 4 inches or three rope diameters beyond the last wrap, whichever is the lesser.

§ 57.19012 Grooved drums.

Where grooved drums are used, the grooves shall be of suitable size and pitch for the ropes used.

§ 57.19013 Diesel- and other fuel-injection-powered hoists.

Where any diesel or similar fuel-injection engine is used to power a hoist, the engine shall be equipped with a damper or other cutoff in its air intake system. The control handle shall be clearly labeled to indicate that its intended function is for emergency stopping only.

§ 57.19014 Friction hoist overtravel protection.

In a friction hoist installation, tapered guides or other approved devices shall be installed above and below the limits of regular travel of the conveyance and arranged to prevent overtravel in the event of failure of other devices.

§ 57.19017 Emergency braking for electric hoists.

Each electric hoist shall be equipped with a manually-operable switch that will initiate emergency braking action to bring the conveyance and the counterbalance safely to rest. This switch shall be located within reach of the hoistman in case the manual controls of the hoist fail.

§ 57.19018 Overtravel by-pass switches.

When an overtravel by-pass switch is installed, the switch shall function so as to allow the conveyance to be moved through the overtravel position when the switch is held in the closed position by the hoistman. The overtravel by-pass switch shall return automatically to the open position when released by the hoistman.

Wire Ropes

Authority: Sec. 101, Federal Mine Safety and Health Act of 1977, Pub. L. 91–173 as amended by Pub. L. 95–164, 91 Stat. 1291 (30 U.S.C. 811).

§ 57.19019 Guide ropes.

If guide ropes are used in shafts for personnel hoisting applications other than shaft development, the nominal strength (manufacturer's published catalog strength) of the guide rope at installation shall meet the minimum value calculated as follows: Minimum value=Static Load×5.0.

§ 57.19021 Minimum rope strength.

At installation, the nominal strength (manufacturer's published catalog strength) of wire ropes used for hoisting shall meet the minimum rope strength values obtained by the following formulas in which “L” equals the maximum suspended rope length in feet:

(a) *Winding drum ropes* (all constructions, including rotation resistant).

For rope lengths less than 3,000 feet: Minimum Value=Static Load×(7.0−0.001L)

For rope lengths 3,000 feet or greater: Minimum Value=Static Load×4.0.

(b) *Friction drum ropes.*

For rope lengths less than 4,000 feet: Minimum Value=Static Load×(7.0−0.0005L)

For rope lengths 4,000 feet or greater: Minimum Value=Static Load×5.0.

(c) *Tail ropes* (balance ropes).

Minimum Value=Weight of Rope×7.0

§ 57.19022 Initial measurement.

After initial rope stretch but before visible wear occurs, the rope diameter of newly installed wire ropes shall be measured at least once in every third interval of active length and the measurements averaged to establish a baseline for subsequent measurements. A record of the measurements and the date shall be made by the person taking the measurements. This record shall be retained until the rope is retired from service.

[50 FR 4082, Jan. 29, 1985, as amended at 60 FR 33722, June 29, 1995]

§ 57.19023 Examinations.

(a) At least once every fourteen calendar days, each wire rope in service shall be visually examined along its entire active length for visible structural damage, corrosion, and improper lubrication or dressing. In addition, visual examination for wear and broken wires shall be made at stress points, including the area near attachments, where the rope rests on sheaves, where the rope leaves the drum, at drum crossovers, and at change-of-layer regions. When any visible condition that results in a reduction of rope strength is present, the affected portion of the rope shall be examined on a daily basis.

(b) Before any person is hoisted with a newly installed wire rope or any wire rope that has not been examined in the previous fourteen calendar days, the wire rope shall be examined in accordance with paragraph (a) of this section.

(c) At least once every six months, nondestructive tests shall be conducted of the active length of the rope, or rope diameter measurements shall be made—

(1) Wherever wear is evident;

(2) Where the hoist rope rests on sheaves at regular stopping points;

(3) Where the hoist rope leaves the drum at regular stopping points; and

(4) At drum crossover and change-of-layer regions.

(d) At the completion of each examination required by paragraph (a) of this section, the person making the examination shall certify, by signature and date, that the examination has been made. If any condition listed in paragraph (a) of this section is present, the person conducting the examination shall make a record of the condition and the date. Certifications and records of examinations shall be retained for one year.

(e) The person making the measurements or nondestructive tests as required by paragraph (c) of this section shall record the measurements or test results and the date. This record shall be retained until the rope is retired from service.

§ 57.19024 Retirement criteria.

Unless damage or deterioration is removed by cutoff, wire ropes shall be removed from service when any of the following conditions occurs:

(a) The number of broken wires within a rope lay length, excluding filler wires, exceeds either—

(1) Five percent of the total number of wires; or

(2) Fifteen percent of the total number of wires within any strand.

(b) On a regular lay rope, more than one broken wire in the valley between strands in one rope lay length.

(c) A loss of more than one-third of the original diameter of the outer wires.

(d) Rope deterioration from corrosion.

(e) Distortion of the rope structure.

(f) Heat damage from any source.

(g) Diameter reduction due to wear that exceeds six percent of the baseline diameter measurement.

(h) Loss of more than ten percent of rope strength as determined by nondestructive testing.

§ 57.19025 Load end attachments.

(a) Wire rope shall be attached to the load by a method that develops at least 80 percent of the nominal strength of the rope.

(b) Except for terminations where use of other materials is a design feature, zinc (spelter) shall be used for socketing wire ropes. Design feature means either the manufacturer's original design or a design approved by a registered professional engineer

(c) Load end attachment methods using splices are prohibited.

§ 57.19026 Drum end attachment.

(a) For drum end attachment, wire rope shall be attached—

(1) Securely by clips after making one full turn around the drum spoke;

(2) Securely by clips after making one full turn around the shaft, if the drum is fixed to the shaft; or

(3) By properly assembled anchor bolts, clamps, or wedges, provided that the attachment is a design feature of the hoist drum. Design feature means either the manufacturer's original design or a design approved by a registered professional engineer.

(b) A minimum of three full turns of wire rope shall be on the drum when the rope is extended to its maximum working length.

§ 57.19027 End attachment retermination.

Damaged or deteriorated wire rope shall be removed by cutoff and the rope reterminated where there is—

(a) More than one broken wire at an attachment;

(b) Improper installation of an attachment;

(c) Slippage at an attachment; or

(d) Evidence of deterioration from corrosion at an attachment.

§ 57.19028 End attachment replacement.

Wire rope attachments shall be replaced when cracked, deformed, or excessively worn.

§ 57.19030 Safety device attachments.

Safety device attachments to hoist ropes shall be selected, installed, and maintained according to manufacturers' specifications to minimize internal corrosion and weakening of the hoist rope.

Headframes and Sheaves

§ 57.19035 Headframe design.

All headframes shall be constructed with suitable design considerations to allow for all dead loads, live loads, and wind loads.

§ 57.19036 Headframe height.

Headframes shall be high enough to provide clearance for overtravel and safe stopping of the conveyance.

§ 57.19037 Fleet angles.

Fleet angles on hoists installed after November 15, 1979, shall not be greater than one and one-half degrees for smooth drums or two degrees for grooved drums.

§ 57.19038 Platforms around elevated head sheaves.

Platforms with toeboards and handrails shall be provided around elevated head sheaves.

Conveyances

§ 57.19045 Metal bonnets.

Man cages and skips used for hoisting or lowering employees or other persons in any vertical shaft or any incline shaft with an angle of inclination of forty-five degrees from the horizontal, shall be covered with a metal bonnet.

§ 57.19049 Hoisting persons in buckets.

Buckets shall not be used to hoist persons except during shaft sinking operations, inspection, maintenance, and repairs.

§ 57.19050 Bucket requirements.

Buckets used to hoist persons during vertical shaft sinking operations shall—

(a) Be securely attached to a crosshead when traveling in either direction between the lower and upper crosshead parking locations;

(b) Have overhead protection when the shaft depth exceeds 50 feet;

(c) Have sufficient depth or a suitably designed platform to transport persons safely in a standing position; and

(d) Have devices to prevent accidental dumping where the bucket is supported by a bail attached to its lower half.

§ 57.19054 Rope guides.

Where rope guides are used in shafts other than in shaft sinking operations, the rope guides shall be a type of lock coil construction.

Hoisting Procedures

§ 57.19055 Availability of hoist operator for manual hoists.

When a manually operated hoist is used, a qualified hoistman shall remain within hearing of the telephone or signal device at all times while any person is underground.

§ 57.19056 Availability of hoist operator for automatic hoists.

When automatic hoisting is used, a competent operator of the hoist shall be readily available at or near the hoisting device while any person is underground.

§ 57.19057 Hoist operator's physical fitness.

No person shall operate a hoist unless within the preceding 12 months he has had a medical examination by a qualified, licensed physician who shall certify his fitness to perform this duty. Such certification shall be available at the mine.

§ 57.19058 Experienced hoist operators.

Only experienced hoistmen shall operate the hoist except in cases of emergency and in the training of new hoistmen.

§ 57.19061 Maximum hoisting speeds.

The safe speed for hoisting persons shall be determined for each shaft, and this speed shall not be exceeded. Persons shall not be hoisted at a speed faster than 2,500 feet per minute, except in an emergency.

§ 57.19062 Maximum acceleration and deceleration.

Maximum normal operating acceleration and deceleration shall not exceed 6 feet per second per second. During emergency braking, the deceleration shall not exceed 16 feet per second per second.

§ 57.19063 Persons allowed in hoist room.

Only authorized persons shall be in hoist rooms.

§ 57.19065 Lowering conveyances by the brakes.

Conveyances shall not be lowered by the brakes alone except during emergencies.

§ 57.19066 Maximum riders in a conveyance.

In shafts inclined over 45 degrees, the operator shall determine and post in the conveyance or at each shaft station the maximum number of persons permitted to ride in a hoisting conveyance at any one time. Each person shall be provided a minimum of 1.5 square feet of floor space.

§ 57.19067 Trips during shift changes.

During shift changes, an authorized person shall be in charge of each trip in which persons are hoisted.

§ 57.19068 Orderly conduct in conveyances.

Persons shall enter, ride, and leave conveyances in an orderly manner.

§ 57.19069 Entering and leaving conveyances.

Persons shall not enter or leave conveyances which are in motion or after a signal to move the conveyance has been given to the hoistman.

§ 57.19070 Closing cage doors or gates.

Cage doors or gates shall be closed while persons are being hoisted; they shall not be opened until the cage has come to a stop.

§ 57.19071 Riding in skips or buckets.

Persons shall not ride in skips or buckets with muck, supplies, materials, or tools other than small hand tools.

§ 57.19072 Skips and cages in same compartment.

When combinations of cages and skips are used in the same compartment, the cages shall be enclosed to protect personnel from flying material and the hoist speed reduced to man-speed as defined in standard 57.19061, but not to exceed 1,000 feet per minute. Muck shall not be hoisted with personnel during shift changes.

§ 57.19073 Hoisting during shift changes.

Rock or supplies shall not be hoisted in the same shaft as persons during shift changes, unless the compartments and dumping bins are partitioned to prevent spillage into the cage compartment.

§ 57.19074 Riding the bail, rim, bonnet, or crosshead.

Persons shall not ride the bail, rim, bonnet, or crosshead of any shaft conveyance except when necessary for inspection and maintenance, and then only when suitable protection for persons is provided.

§ 57.19075 Use of open hooks.

Open hooks shall not be used to hoist buckets or other conveyances.

§ 57.19076 Maximum speeds for hoisting persons in buckets.

When persons are hoisted in buckets, speeds shall not exceed 500 feet per minute and shall not exceed 200 feet per minute when within 100 feet of the intended station.

§ 57.19077 Lowering buckets.

Buckets shall be stopped about 15 feet from the shaft bottom to await a signal from one of the crew on the bottom for further lowering.

§ 57.19078 Hoisting buckets from the shaft bottom.

All buckets shall be stopped after being raised about three feet above the shaft bottom. A bucket shall be stabilized before a hoisting signal is given to continue hoisting the bucket to the crosshead. After a hoisting signal is given, hoisting to the crosshead shall be at a minimum speed. The signaling device shall be attended constantly until a bucket reaches the guides. When persons are hoisted, the signaling devices shall be attended until the crosshead has been engaged.

§ 57.19079 Blocking mine cars.

Where mine cars are hoisted by cage or skip, means for blocking cars shall be provided at all landings and also on the cage.

§ 57.19080 Hoisting tools, timbers, and other materials.

When tools, timbers, or other materials are being lowered or raised in a shaft by means of a bucket, skip, or cage, they shall be secured or so placed that they will not strike the sides of the shaft.

§ 57.19081 Conveyances not in use.

When conveyances controlled by a hoist operator are not in use, they shall be released and the conveyances shall be raised or lowered a suitable distance to prevent persons from boarding or loading the conveyances.

§ 57.19083 Overtravel backout device.

A manually operated device shall be installed on each electric hoist that will allow the conveyance or counterbalance to be removed from an overtravel position. Such device shall not release the brake, or brakes, holding the overtravelled conveyance or counterbalance until sufficient drive motor torque has been developed to assure movement of the conveyance or counterbalance in the correct direction only.

Signaling

§ 57.19090 Dual signaling systems.

There shall be at least two effective approved methods of signaling between each of the shaft stations and the hoist room, one of which shall be a telephone or speaking tube.

§ 57.19091 Signaling instructions to hoist operator.

Hoist operators shall accept hoisting instructions only by the regular signaling system unless it is out of order. In such an event, and during other emergencies, the hoist operator shall accept instructions to direct movement of the conveyances only from authorized persons.

§ 57.19092 Signaling from conveyances.

A method shall be provided to signal the hoist operator from cages or other conveyances at any point in the shaft.

§ 57.19093 Standard signal code.

A standard code of hoisting signals shall be adopted and used at each mine. The movement of a shaft conveyance on a “one bell” signal is prohibited.

§ 57.19094 Posting signal code.

A legible signal code shall be posted prominently in the hoist house within easy view of the hoistmen, and at each place where signals are given or received.

§ 57.19095 Location of signal devices.

Hoisting signal devices shall be positioned within easy reach of persons on the shaft bottom or constantly attended by a person stationed on the lower deck of the sinking platform.

§ 57.19096 Familiarity with signal code.

Any person reponsible for receiving or giving signals for cages, skips, and mantrips when persons or materials are being transported shall be familiar with the posted signaling code.

Shafts

§ 57.19100 Shaft landing gates.

Shaft landings shall be equipped with substantial safety gates so constructed that materials will not go through or under them; gates shall be closed except when loading or unloading shaft conveyances.

§ 57.19101 Stopblocks and derail switches.

Positive stopblocks or a derail switch shall be installed on all tracks leading to a shaft collar or landing.

§ 57.19102 Shaft guides.

A means shall be provided to guide the movement of a shaft conveyance.

§ 57.19103 Dumping facilities and loading pockets.

Dumping facilities and loading pockets shall be constructed so as to minimize spillage into the shaft.

§ 57.19104 Clearance at shaft stations.

Suitable clearance at shaft stations shall be provided to allow safe movement of persons, equipment and materials.

§ 57.19105 Landings with more than one shaft entrance.

A safe means of passage around open shaft compartments shall be provided on landings with more than one entrance to the shaft.

§ 57.19106 Shaft sets.

Shaft sets shall be kept in good repair and clean of hazardous material.

§ 57.19107 Precautions for work in compartment affected by hoisting operation.

Hoistmen shall be informed when persons are working in a compartment affected by that hoisting operation and a “Men Working in Shaft” sign shall be posted at the hoist.

§ 57.19108 Posting warning signs during shaft work.

When persons are working in a shaft “Men Working in Shaft” signs shall be posted at all devices controlling hoisting operations that may endanger such persons.

§ 57.19109 Shaft inspection and repair.

Shaft inspection and repair work in vertical shafts shall be performed from substantial platforms equipped with bonnets or equivalent overhead protection.

§ 57.19110 Overhead protection for shaft deepening work.

A substantial bulkhead or equivalent protection shall be provided above persons at work deepening a shaft.

§ 57.19111 Shaft-sinking ladders.

Substantial fixed ladders shall be provided from the collar to as near the shaft bottom as practical during shaft-sinking operations, or an escape hoist powered by an emergency power source shall be provided. When persons are on the shaft bottom, a chain ladder, wire rope ladder, or other extension ladders shall be used from the fixed ladder or lower limit of the escape hoist to the shaft bottom.

Inspection and Maintenance

§ 57.19120 Procedures for inspection, testing, and maintenance.

A systematic procedure of inspection, testing and maintenance of shaft and hoisting equipment shall be developed and followed. If it is found or suspected that any part is not functioning properly, the hoist shall not be used until the malfunction has been located and repaired or adjustments have been made.

§ 57.19121 Recordkeeping.

At the time of completion, the person performing inspections, tests, and maintenance of shafts and hoisting equipment required in standard 57.19120 shall certify, by signature and date, that they have been done. A record of any part that is not functioning properly shall be made and dated. Certifications and records shall be retained for one year.

(Sec. 101, Pub. L. 91–173 as amended by Pub. L. 95–164, 91 Stat. 1291 (30 U.S.C. 811))

[50 FR 4082, Jan. 29, 1985, as amended at 60 FR 33722, June 29, 1995]

§ 57.19122 Replacement parts.

Parts used to repair hoists shall have properties that will ensure the proper and safe function of the hoist.

§ 57.19129 Examinations and tests at beginning of shift.

Hoistmen shall examine their hoists and shall test overtravel, deadman controls, position indicators, and braking mechanisms at the beginning of each shift.

§ 57.19130 Conveyance shaft test.

Before hoisting persons and to assure that the hoisting compartments are clear of obstructions, empty hoist conveyances shall be operated at least one round trip after—

(a) Any hoist or shaft repairs or related equipment repairs that might restrict or obstruct conveyance clearance;

(b) Any oversize or overweight material or equipment trips that might restrict or obstruct conveyance clearance;

(c) Blasting in or near the shaft that might restrict or obstruct conveyance clearance; or

(d) Remaining idle for one shift or longer.

§ 57.19131 Hoist conveyance connections.

Hoist conveyance connections shall be inspected at least once during any 24-hour period that the conveyance is used for hoisting persons.

§ 57.19132 Safety catches.

(a) A performance drop test of hoist conveyance safety catches shall be made at the time of installation, or prior to installation in a mockup of the actual installation. The test shall be certified to in writing by the manufacturer or by a registered professional engineer performing the test.

(b) After installation and before use, and at the beginning of any seven day period during which the conveyance is to be used, the conveyance shall be suitably rested and the hoist rope slackened to test for the unrestricted functioning of the safety catches and their activating mechanisms.

(c) The safety catches shall be inspected by a competent person at the beginning of any 24-hour period that the conveyance is to be used.

§ 57.19133 Shaft.

Shafts that have not been inspected within the past 7 days shall not be used until an inspection has been conducted by a competent person.

§ 57.19134 Sheaves.

Sheaves in operating shafts shall be inspected weekly and kept properly lubricated.

§ 57.19135 Rollers in inclined shafts.

Rollers used in operating inclined shafts shall be lubricated, properly aligned, and kept in good repair.

Subpart S—Miscellaneous

§ 57.20001 Intoxicating beverages and narcotics.

Intoxicating beverages and narcotics shall not be permitted or used in or around mines. Persons under the influence of alcohol or narcotics shall not be permitted on the job.

§ 57.20002 Potable water.

(a) An adequate supply of potable drinking water shall be provided at all active working areas.

(b) The common drinking cup and containers from which drinking water must be dipped or poured are prohibited.

(c) Where single service cups are supplied, a sanitary container for unused cups and a receptacle for used cups shall be provided.

(d) When water is cooled by ice, the ice shall either be of potable water or shall not come in contact with the water.

(e) Potable water outlets shall be posted.

(f) Potable water systems shall be constructed to prevent backflow or backsiphonage of non-potable water.

§ 57.20003 Housekeeping.

At all mining operations—

(a) Workplaces, passageways, storerooms, and service rooms shall be kept clean and orderly;

(b) The floor of every workplace shall be maintained in a clean and, so far as possible, dry condition. Where wet processes are used, drainage shall be maintained, and false floors, platforms, mats, or other dry standing places shall be provided where practicable; and

(c) Every floor, working place, and passageway shall be kept free from protruding nails, splinters, holes, or loose boards, as practicable.

§ 57.20005 Carbon tetrachloride.

Carbon tetrachloride shall not be used.

§ 57.20008 Toilet facilities.

(a) Toilet facilities shall be provided at locations that are compatible with the mine operations and that are readily accessible to mine personnel.

(b) The facilities shall be kept clean and sanitary. Separate toilet facilities shall be provided for each sex except where toilet rooms will be occupied by no more than one person at a time and can be locked from the inside.

§ 57.20009 Tests for explosive dusts.

Dusts suspected of being explosive shall be tested for explosibility. If tests prove positive, appropriate control measures shall be taken.

§ 57.20010 Retaining dams.

If failure of a water or silt retaining dam will create a hazard, it shall be of substantial construction and inspected at regular intervals.

§ 57.20011 Barricades and warning signs.

Areas where health or safety hazards exist that are not immediately obvious to employees shall be barricaded, or warning signs shall be posted at all approaches. Warning signs shall be readily visible, legible, and display the nature of the hazard and any protective action required.

§ 57.20013 Waste receptacles.

Receptacles with covers shall be provided at suitable locations and used for the disposal of waste food and associated materials. They shall be emptied frequently and shall be maintained in a clean and sanitary condition.

§ 57.20014 Prohibited areas for food and beverages.

No person shall be allowed to consume or store food or beverages in a toilet room or in any area exposed to a toxic material.

§ 57.20020 Unattended mine openings.

Access to unattended mine openings shall be restricted by gates or doors, or the openings shall be fenced and posted.

§ 57.20021 Abandoned mine openings.

Upon abandonment of a mine, the owner or operator shall effectively close or fence off all surface openings down which persons could fall or through which persons could enter. Upon or near all such safeguards, trespass warnings and appropriate danger notices shall be posted.

§ 57.20031 Blasting underground in hazardous areas.

In underground areas where dangerous accumulations of water, gas, mud, or fire atmosphere could be encountered, persons shall be removed to safe places before blasting.

§ 57.20032 Two-way communication equipment for underground operations.

Telephones or other two-way communication equipment with instructions for their use shall be provided for communication from underground operations to the surface.

Subpart T—Safety Standards for Methane in Metal and Nonmetal Mines

Authority: 30 U.S.C. 811.

Source: 52 FR 24941, July 1, 1987, unless otherwise noted.

General

§ 57.22001 Scope.

This subpart T sets forth procedures and safety standards for each metal and nonmetal underground mine subject to the Federal Mine Safety and Health Act of 1977. All metal and nonmetal mines will be placed into one of the categories or subcategories defined in this subpart. Mines shall operate in accordance with the applicable standards in this subpart to protect persons against the hazards of methane gas and dust containing volatile matter. The standards in this subpart apply to underground mines as well as surface mills at Subcategory I-C mines. These mines are also required to be operated in accordance with the other applicable health and safety standards published in 30 CFR part 57.

§ 57.22002 Definitions.

The following definitions apply in this subpart:

Competent person. A person designated by the mine operator who has sufficient experience and training to perform the assigned task.

Explosive material. Explosives, blasting agents, and detonators. Explosives are substances classified as explosives by the Department of Transportation in §§173.53, 173.88, and 173.100 of Title 49 of the Code of Federal Regulations (1986 Edition). Blasting agents are substances classified as blasting agents by the Department of Transportation in §173.114(a) of Title 49 of the Code of Federal Regulations (1986 Edition). Detonators are devices containing a detonating charge used to initiate explosives. Examples of detonators are blasting caps, electric or non-electric instantaneous or delay blasting caps and delay connectors. [A copy of Title 49 is available at any Metal and Nonmetal Mine Safety and Health District Office of the Mine Safety and Health Administration].

Substantial construction. Construction of such strength, material, and workmanship that the object will withstand air blasts, blasting shock, ground movement, pressure differentials, wear, and usage which may be expected to occur in the mining environment.

[52 FR 24941, July 1, 1987, as amended at 69 FR 38842, June 29, 2004]

Mine Categorization

§ 57.22003 Mine category or subcategory.

(a) All underground mines, and the surface mills of Subcategory I-C mines (gilsonite), shall be placed into one of the following categories or subcategories to protect persons against the hazards of methane and dusts containing volatile matter. Categories and subcategories are defined as follows:

(1) *Category I* applies to mines that operate within a combustible ore body and either liberate methane or have the potential to liberate methane based on the history of the mine or the geological area in which the mine is located. Category I is divided into Subcategories I-A, I-B, and I-C as follows:

(i) *Subcategory I-A* applies to mines that operate within a combustible ore body and liberate methane and in which—

(A) A concentration of 0.25 percent or more methane has been detected in the mine atmosphere and confirmed by laboratory analysis; or

(B) An ignition of methane has occurred.

(ii) *Subcategory I-B* applies to mines that operate within a combustible ore body and have the potential to liberate methane based on the history of the mine or geological area in which the mine is located and in which—

(A) A concentration of 0.25 percent or more methane has not been detected in the mine atmosphere; and

(B) An ignition of methane has not occurred.

(iii) *Subcategory I-C* applies to mines in which the product extracted is combustible and the dust has a volatile matter content of 60 percent or more measured on a moisture free basis[1] .

[1] Measured by the American Society for Testing and Materials, ASTM D 3175–82, Standard Test Method for Volatile Matter in the Analysis Sample of Coal and Coke. (This document is available at any Metal and Nonmetal Mine Safety and Health District Office of the Mine Safety and Health Administration).

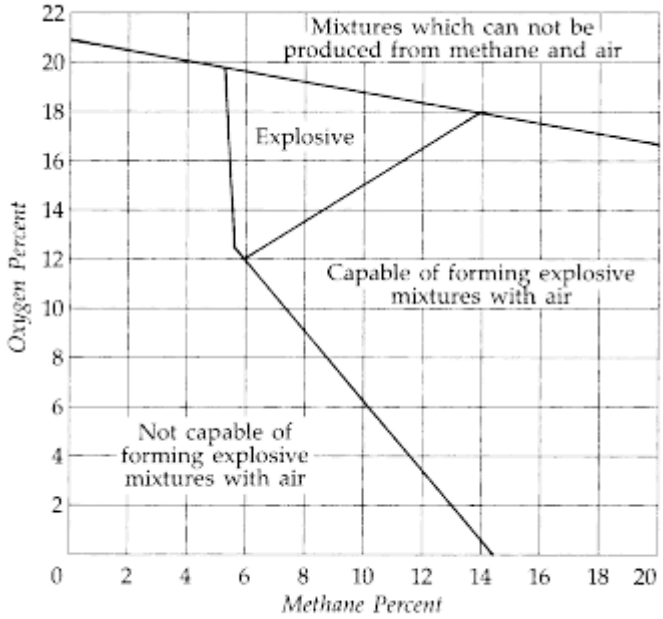
(2) *Category II* applies to domal salt mines where the history of the mine or geological area indicates the occurrence of or the potential for an outburst. Category II is divided into Subcategories II-A and II-B as follows:

(i) *Subcategory II-A* applies to domal salt mines where an outburst reportable under §57.22004(c)(1) has occurred.

(ii) *Subcategory II-B* applies to domal salt mines where an outburst reportable under §57.22004(c)(1) has not occurred, but which have the potential for an outburst based on the history of the mine or geological area in which the mine is located.

(3) *Category III* applies to mines in which noncombustible ore is extracted and which liberate a concentration of methane that is explosive, or is capable of forming explosive mixtures with air, or have the potential to do so based on the history of the mine or the geological area in which the mine is located. The concentration of methane in such mines is explosive or is capable of forming explosive mixtures if mixed with air as illustrated by Table 1 below, entitled “Relation Between Quantitative Composition and Explosibility of Mixtures of Methane and Air”.

Table 1



Relation Between Quantitative Composition and Explosibility of Mixtures of Methane and Air

(4) *Category IV* applies to mines in which noncombustible ore is extracted and which liberate a concentration of methane that is not explosive nor capable of forming explosive mixtures with air based on the history of the mine or the geological area in which the mine is located. The concentration of methane in such mines is not explosive nor capable of forming explosive mixtures if mixed with air as illustrated by Table 1 above, entitled “Relation Between Quantitative Composition and Explosibility of Mixtures of Methane and Air”.

(5) *Category V* applies to petroleum mines. Category V is divided into Subcategories V-A and V-B as follows:

(i) *Subcategory V-A* applies to petroleum mines that operate entirely or partially within an oil reservoir; and all other petroleum mines in which—

(A) A concentration of 0.25 percent or more methane has been detected in the mine atmosphere and confirmed by laboratory analysis; or

(B) An ignition of methane has occurred.

(ii) *Subcategory V-B* applies to petroleum mines that operate outside of and drill into an oil resevoir and in which—

(A) A concentration of 0.25 percent or more methane has not been detected in the mine atmosphere; and

(B) An ignition of methane has not occurred.

(6) *Category VI* applies to mines in which the presence of methane has not been established and are not included in another category or subcategory.

(b) Category or subcategory placement or change in placement shall include consideration of the following:

(1) The history and geology of the mine or of the geological area in which the mine is located;

(2) The ore body and host rock;

(3) The character, amount, duration, origin, and nature of methane emission and the presence of explosive dust and inert gases; and

(4) Whether or not conditions encountered during primary or access development are transient or permanent.

(c)(1) Gas samples for the purpose of category or subcategory placement or change in placement, and for determining action levels, shall be taken in the mine atmosphere. Gas samples taken to determine the nature and extent of an occurrence under §57.22004 (c) and (d) may be taken at any location, including the source, point of entry and the mine atmosphere.

(2) Tests for methane shall be made with hand-held methanometers, methane monitors, atmospheric monitoring systems, devices used to provide laboratory analysis of samples, or with other equally effective sampling devices. However, only methane samples that have been confirmed by laboratory analysis shall be used for category or subcategory placement or change in placement.

(d) Each mine and mill shall be required to operate in accordance with the safety standards applicable to its particular category or subcategory.

§ 57.22004 Category placement or change in placement.

The Administrator for Metal and Nonmetal Mine Safety and Health (Administrator) shall be responsible for category and subcategory placement, change in placement, and notification of placement of mines.

(a) The Administrator's proposed notice of placement or change in placement shall be sent to the mine operator and the appropriate representative of miners and shall include—

(1) The category or subcategory;

(2) The reasons for placement or change in placement;

(3) The data considered;

(4) The applicable standards and a time schedule for the mine operator to achieve compliance;

(5) Whether or not conditions encountered during primary or access development are transient or permanent; and

(6) Notification of the right to appeal the Administrator's determination under §57.22005.

(b) The operator or the representative of the miners shall have the right to request of the Administrator reassignment of the mine to a more appropriate category or subcategory if, based on operating experience, the conditions set forth in §57.22003(b) indicate that the hazards of methane exist under circumstances more appropriately governed by a different category or subcategory. In response to such a request, the procedures set forth in paragraph (d) of this section shall apply. While the request for category or subcategory reassignment is pending, the mine shall continue to operate under the standards for the category or subcategory to which originally assigned.

(c) MSHA shall be notified as soon as possible if any of the following events occur:

(1) An outburst that results in 0.25 percent or more methane in the mine atmosphere;

(2) A blowout that results in 0.25 percent or more methane in the mine atmosphere;

(3) An ignition of methane; or

(4) Air sample results that indicate 0.25 percent or more methane in the mine atmosphere of a Subcategory I-B, I-C, II-B, V-B or Category VI mine.

(d) The Administrator shall promptly appoint an MSHA committee to investigate occurrences reported in accordance with paragraph (c) of this section or requests filed in accordance with paragraph (b) of this section. Upon completion of an investigation, the committee shall make a written report of the findings. These investigations may include an evaluation of the following:

(1) Source, nature, and extent of occurrences;

(2) Conditions under which the incident occurred;

(3) Samples and tests;

(4) Physical conditions at the time of the occurrence;

(5) Charts, logs, and records related to the occurrence;

(6) Whether the occurrence is isolated, continuous, or could recur;

(7) Conditions indicating that the hazards of methane no longer exist or exist under circumstances more appropriately governed by a different category or subcategory;

(8) The geology of the mine and the geological area in which the mine is located; and

(9) Statements by witnesses, company officials, employees, and other persons having knowledge of the mine or the occurrence. Representatives of the mine operator, the miners and the appropriate State agency may participate in the investigation.

[52 FR, 24941, July 1, 1987, as amended at 52 FR 41397, Oct. 27, 1987; 60 FR 33722, June 29, 1995]

§ 57.22005 Notice and appeal of placement or change in placement.

(a) The Administrator's determination of category or subcategory placement or change in placement shall become final upon the 30th day after it is served on the mine operator and representative of miners, unless a request for a hearing has been filed. Service of the Administrator's determination is complete upon mailing by registered or certified mail, return receipt requested.

(b) The mine operator or representative of miners may obtain review of the Administrator's determination by filing a request for a hearing with the Assistant Secretary of Labor for Mine Safety and Health, Mine Safety and Health Administration, 1100 Wilson Blvd., Room 2322, Arlington, Virginia 22209–3939 within 30 days of the Administrator's determination. Service of a request for hearing is completed upon mailing by registered or certified mail, return receipt requested. Requests for a hearing shall be in writing and contain the following information:

(1) Name, address, and mine identification number;

(2) A concise statement of the reason why the Administrator's determination is inappropriate; and

(3) A copy of the Administrator's determination.

(c) The mine operator shall post a copy of the Administrator's determination and the request for a hearing on the mine bulletin board, and shall maintain the posting until the placement becomes final.

(d) Promptly after receipt of the request for a hearing, the Assistant Secretary shall refer to the Chief Administrative Law Judge, United States Department of Labor, the following:

(1) The request for a hearing;

(2) The Administrator's determination; and

(3) All information upon which the Administrator's determination was based.

(e) The hearing shall be regulated and conducted by an Administrative Law Judge in accordance with 29 CFR part 18, entitled, “Rules of Practice and Procedure for Administrative Hearings Before the Office of Administrative Law Judges.” Once the Administrative Law Judge has made an initial decision and served each party, the decision shall be final on the 30th day after service, unless discretionary review is undertaken by the Assistant Secretary or an appeal is filed by the mine operator or representative of the miners under paragraph (f) of this section.

(f) Within 30 days after service of an initial decision of an Administrative Law Judge, the Assistant Secretary for Mine Safety and Health may undertake a discretionary review of the initial decision, or the mine operator, or representative of the miners may appeal the initial decision of the Administrative Law Judge to the Assistant Secretary.

(1) The Assistant Secretary shall give notice of discretionary review to the mine operator and representative of the miners. The mine operator or representative of the miners shall give notice of an appeal to the other party. The notice shall specify the suggested changes and refer to the specific findings of fact, conclusions of law, and terms of the initial decision to be reviewed or appealed. The Assistant Secretary shall fix a time for filing any objections to the suggested changes and supporting reasons.

(2) The Assistant Secretary shall promptly notify the Administrative Law Judge of a discretionary review or an appeal. The entire record of the proceedings shall be transmitted to the Assistant Secretary for review.

(3) The Assistant Secretary shall make the final decision based upon consideration of the record of the proceedings. The final decision may affirm, modify, or set aside in whole or in part, the findings and conclusions contained in the initial decision. A statement of reasons for the

action taken shall be included in the final decision. The final decision shall be served upon the mine operator and representative of the miners.

(g) Unless a decision by the Administrator for Metal and Nonmetal Mine Safety and Health, or the initial decision of the Administrative Law Judge, is appealed within 30 days, it becomes final, and is not subject to judicial review for the purposes of 5 U.S.C. 704. Only a decision by the Assistant Secretary shall be considered final Agency action for purposes of judicial review. Any such appeal must be filed in the appropriate circuit of the United States Court of Appeal.

(h) While a final decision of category placement is pending the following procedures shall apply:

(1) Where a mine has been classified as gassy prior to the effective date of these standards, existing gassy mines standards 30 CFR 57.21001 through 57.21101 (1986 Edition) shall continue to be applicable until placement is final.

(2) Where a mine has not been classified as gassy prior to the effective date of these standards and it is placed in Categories I through V, the mine shall comply with Category VI standards (§§57.22231, 57.22232, 57.22236, and 57.22238) until placement is final.

(3) Where a mine has been classified in Categories I through V after the effective date of these standards and category reassignment is being considered, the mine shall comply with the standards applicable to the category to which presently assigned until category placement is final.

[52 FR 24941, July 1, 1987; 52 FR 27903, July 24, 1987, as amended at 67 FR 38385, June 4, 2002]

Fire Prevention and Control

Note: The Category or Subcategory applicability of each standard appears in the parentheses of each standard's title line].

§ 57.22101 Smoking (I-A, II-A, III, and V-A mines).

Persons shall not smoke or carry smoking materials, matches, or lighters underground. The operator shall institute a reasonable program to assure that persons entering the mine do not carry such items.

§ 57.22102 Smoking (I-C mines).

(a) Persons shall not smoke or carry smoking materials, matches, or lighters underground or within 50 feet of a mine opening. The operator shall institute a reasonable program to assure that persons entering the mine do not carry such items.

(b) Smoking is prohibited in surface milling facilities except in designated, dust-free smoking areas.

§ 57.22103 Open flames (I-A, II-A, III, and V-A mines).

Open flames shall not be permitted underground except for welding, cutting, and other maintenance operations, and for igniting underground retorts in a Subcategory I-A mine. When using open flames in other than fresh air, or in places where methane may enter the air current, tests for methane shall be conducted by a competent person before work is started and every 10 minutes until the job is completed. Continuous methane monitors with audible alarms may be used after the initital test has been conducted as an alternative to the ten-minute interval testing requirement. Open flames shall not be used in atmospheres containing 0.5 percent or more methane.

§ 57.22104 Open flames (I-C mines).

(a) Open flames, including cutting and welding, shall not be used underground.

(b) Welding and cutting shall not be done within 50 feet of a mine opening unless all persons are out of the mine and the mine opening is covered. The cover shall be a substantial material, such as metal or wood, topped with a layer of wetted material to prevent sparks and flames from entering the mine opening.

§ 57.22105 Smoking and open flames (IV mines).

Smoking or open flames shall not be permitted in a face or raise, or during release of gas from a borehole until tests have been conducted in accordance with §57.22226 and the methane level has been determined to be below 0.5 percent.

§ 57.22106 Dust containing volatile matter (I-C mines).

Dust containing volatile matter shall not be allowed to accumulate on the surfaces of enclosures, facilities, or equipment used in surface milling in amounts that, if suspended in air, would become an explosive mixture. An explosive mixture of dust containing volatile matter is 0.02 ounce or more per cubic foot of air.

Ventilation

§ 57.22201 Mechanical ventilation (I-A, I-B, I-C, II-A, II-B, III, IV, V-A, and V-B mines).

All mines shall be ventilated mechanically.

§ 57.22202 Main fans (I-A, I-B, I-C, II-A, III, V-A, and V-B mines).

(a) Main fans shall be—

(1) Installed on the surface in noncombustible housings provided with noncombustible air ducts;

(2) Except in Subcategory I-A mines, provided with an automatic signal device to give an alarm when the fan stops. The signal device shall be located so that it can be seen or heard by a person designated by the mine operator.

(b) Fan installations shall be—

(1) Offset so that the fan and its associated components are not in direct line with possible explosive forces;

(2) Equipped with explosion-doors, a weak-wall, or other equivalent devices located to relieve the pressure that would be created by an explosion underground. The area of the doors or weak-wall shall be at least equivalent to the average cross-sectional area of the airway.

(c) (1) All main fan-related electrical equipment and cables located within or exposed to the forward or reverse airstream shall be approved by MSHA under the appliable requirements of 30 CFR part 18;

(2) Drive belts and nonmetallic fan blades shall be constructed of static-conducting material; and

(3) Aluminum alloy fan blades shall not contain more than 0.5 percent magnesium. [Paragraph (c)(3) of this section does not apply to Subcategory I-C mines].

(d) When an internal combustion engine is used to power a main fan or as standby power, the engine shall be—

(1) Installed in a noncombustible housing;

(2) Protected from a possible fuel supply fire or explosion; and

(3) Located out of direct line with the forward and reverse airstream provided by the fan. Engine exhaust gases shall be vented to the atomsphere so that exhaust cannot contaminate mine intake air.

(e) For Subcategory I-A mines only: Main exhaust fans shall be equipped with methane monitors to give an alarm when methane in the return air reaches 0.5 percent. The alarm shall be located so that it can be seen or heard by a person designated by the mine operator.

[52 FR, 24941, July 1, 1987, as amended at 52 FR 41397, Oct. 27, 1987]

§ 57.22203 Main fan operation (I-C mines).

Main fans shall be operated continuously while ore production is in progress.

§ 57.22204 Main fan operation and inspection (I-A, II-A, III, and V-A mines).

Main fans shall be—

(a) Provided with a pressure-recording system; and

(b) Inspected daily while operating if persons are underground. Certification of inspections shall be made by signature and date. Certifications and pressure recordings shall be retained for at least one year and made available to an authorized representative of the Secretary.

[52 FR, 24941, July 1, 1987, as amended at 52 FR 41397, Oct. 27, 1987; 60 FR 33722, June 29, 1995]

§ 57.22205 Doors on main fans (I-A, II-A, III, and V-A mines).

In mines ventilated by multiple main fans, each main fan installation shall be equipped with noncombustible doors. Such doors shall automatically close to prevent air reversal through the fan. The doors shall be located so that they are not in direct line with explosive forces which could come out of the mine.

§ 57.22206 Main ventilation failure (I-A, II-A, III, and V-A mines).

(a) When there has been a main ventilation failure, such as stoppage of main fans or failure of other components of the main ventilation system, tests for methane shall be conducted in affected active workings until normal air flow has resumed.

(b) If a total failure of ventilation occurs while all persons are out of the mine and the failure lasts for more than 30 minutes, only competent persons shall be allowed underground to examine the mine or to make necessary ventilation changes. Other persons may reenter the mine after the main fans have been operational for at least 30 minutes, or after the mine atmosphere has been tested and contains less than 1.0 percent methane. Persons other than examiners shall not reenter a Subcategory II-A mine until the methane level is less than 0.5 percent.

§ 57.22207 Booster fans (I-A, II-A, III, and V-A mines).

(a) Booster fans shall be approved by MSHA under the applicable requirements of 30 CFR part 18, and be—

(1) Provided with an automatic signal device located so that it can be seen or heard by a person designated by the mine operator to give an alarm when the fan stops or when methane reaches the following levels:

(i) 1.0 percent at the fan in Subcategory I-A, Category III, and Subcategory V-A mines; and

(ii) 0.5 percent at the fan in Subcategory II-A mines.

(2) Equipped with a device that automatically deenergizes power in affected workings should the fan stop; and

(3) Equipped with starting and stopping controls located at the fan and at another accessible remote location.

(b) Booster fan installations, except for booster fans installed in ducts, shall be—

(1) Provided with doors which open automatically when all fans in the installation stop; and

(2) Provided with an air lock when passage through the fan bulkhead is necessary.

§ 57.22208 Auxiliary fans (I-A, II-A, III, and V-A mines).

(a) Auxiliary fans, except fans used in shops and other areas which have been so designed that methane cannot enter the airway, shall be approved by MSHA under the applicable requirements of 30 CFR part 18, and be operated so that recirculation is minimized. Auxiliary fans shall not be used to ventilate work places during the interruption of normal mine ventilatioin.

(b) Tests for methane shall be made at auxiliary fans before they are started.

§ 57.22209 Auxiliary fans (I-C mines).

Electric auxiliary fans shall be approved by MSHA under the applicable requirements of 30 CFR part 18. Tests for methane shall be made at electric auxiliary fans before they are started. Such fans shall not be operated when air passing over or through them contains 0.5 percent or more methane.

§ 57.22210 In-line filters (I-C mines).

Filters or separators shall be installed on air-lift fan systems to prevent explosive concentrations of dust from passing through the fan.

§ 57.22211 Air flow (I-A mines).

The average air velocity in the last open crosscut in pairs or sets of developing entries, or through other ventilation openings nearest the face, shall be at least 40 feet per minute. The velocity of air ventilating each face at a work place shall be at least 20 feet per minute.

§ 57.22212 Air flow (I-C, II-A, and V-A mines).

Air flow across each working face shall be sufficient to carry away any accumulation of methane, smoke, fumes, and dust.

§ 57.22213 Air flow (III mines).

The quantity of air coursed through the last open crosscut in pairs or sets of entries, or through other ventilation openings nearest the face, shall be at least 6,000 cubic feet per minute, or 9,000 cubic feet per minute in longwall and continuous miner sections. The quantity of air across each face at a work place shall be at least 2,000 cubic feet per minute.

§ 57.22214 Changes in ventilation (I-A, II-A, III, and V-A mines).

(a) Changes in ventilation which affect the main air current or any split thereof and which adversely affect the safety of persons in the mine shall be made only when the mine is idle.

(b) Only persons engaged in making such ventilation changes shall be permitted in the mine during changes.

(c) Power shall be deenergized in affected areas prior to making ventilation changes, except power to monitoring equipment determined by MSHA to be intrinsically safe under 30 CFR part 18. Power shall not be restored until the results of the change have been determined and a competent person has examined affected working places for methane.

§ 57.22215 Separation of intake and return air (I-A, II-A, III, and V-A mines).

Main intake and return air currents shall be coursed through separate mine openings and shall be separated throughout the mine, except—

(a) Where multiple shafts are used for ventilation and a single shaft contains a curtain wall or partition for separation of air currents. Such wall or partition shall be constructed of reinforced concrete or other noncombustible equivalent, and provided with pressure-relief devices.

(b) During development of openings to the surface—

(1) Ventilation tubing approved by MSHA in accordance with 30 CFR part 7 or previously issued a BC or VT acceptance number by the MSHA Approval and Certification Center may be used for separation of main air currents in the same opening. Flexible ventilation tubing shall not exceed 250 feet in length.

(2) Only development related to making a primary ventilation connection may be performed beyond 250 feet of the shaft.

[52 FR 24941, July 1, 1987, as amended at 54 FR 30508, July 20, 1989]

§ 57.22216 Separation of intake and return air (I-C mines).

The main intake and return air currents in single shafts shall be separated by ventilation tubing, curtain walls, or partitions. Ventilation tubing shall be constructed of noncombustible material. Curtain walls or partitions shall be constructed of reinforced concrete or other noncombustible equivalent, and provided with pressure-relief devices.

§ 57.22217 Seals and stoppings (I-A, I-B, and I-C mines).

All seals, and those stoppings that separate main intake from main return airways, shall be of substantial construction and constructed of noncombustible materials, except that stoppings constructed of brattice materials may be used in face areas.

§ 57.22218 Seals and stoppings (III, V-A, and V-B mines).

(a) All seals, and those stoppings that separate main intake from main return airways, shall be of substantial construction, except that stoppings constructed of brattice materials may be used in face areas.

(b) Exposed surfaces on the intake side of stoppings constructed of combustible materials or foam-type blocks shall be coated with at least one inch of construction plaster containing perlite and gypsum; at least one inch of expanded vermiculite, Portland cement and limestone; or other coatings with equivalent fire resistance. Stoppings constructed to phenolic foam blocks at least 12 inches thick need not be coated for fire resistance. All foam-type blocks used for stopping construction shall be solid.

(c) Exposed surfaces on the fresh air side of seals constructed of combustible materials shall be coated with at least one inch of construction plaster containing perlite and gypsum; at least one inch of expanded vermiculite, Portland cement and limestone; or other coatings with equivalent fire resistance. Foam-type blocks shall not be used for seals.

§ 57.22219 Seals and stoppings (II-A mines).

(a) Exposed surfaces on the intake side of stoppings constructed of combustible materials, except brattice, shall be coated with at least one inch of construction plaster containing perlite and gypsum; at least one inch of expanded vermiculite, Portland cement and limestone; or other coatings with equivalent fire resistance.

(b) Seals shall be of substantial construction. Exposed surfaces on the fresh air side of seals constructed of combustible materials shall be coated with at least one inch of construction plaster containing perlite and gypsum; at least one inch of expanded vermiculite, Portland cement and limestone; or other coatings with equivalent fire resistance. Foam-type blocks shall not be used for seals.

§ 57.22220 Air passing unsealed areas (I-A, II-A, III, and V-A mines).

Air that has passed by or through unsealed abandoned or unsealed inactive areas and contains 0.25 percent or more methane shall—

(a) Be coursed directly to a return airway;

(b) Be tested daily for methane by a competent person; and

(c) Not be used to ventilate work places.

§ 57.22221 Overcast and undercast construction (I-A, II-A, III, and V-A mines).

Overcasts and undercasts shall be—

(a) Of substantial construction;

(b)(1) Constructed of noncombustible materials; or

(2) Where constructed of combustible materials, the outside surfaces shall be coated with at least one inch of construction plaster containing perlite and gypsum; at least one inch of expanded vermiculite, Portland cement and limestone; or other coatings with equivalent fire resistance;

(c) Kept clear of obstructions.

§ 57.22222 Ventilation materials (I-A, I-B, I-C, II-A, III, V-A, and V-B mines).

Brattice cloth and ventilation tubing shall be approved by MSHA in accordance with 30 CFR part 7, or shall bear a BC or VT acceptance number issued by the MSHA Approval and Certification Center.

[54 FR 30508, July 20, 1989]

§ 57.22223 Crosscuts before abandonment (III mines).

A means of ventilating faces shall be provided before workings are abandoned in unsealed areas, unless crosscuts are provided within 30 feet of the face.

§ 57.22224 Auxiliary equipment stations (I-A and III mines).

Battery charging stations, compressor stations, pump stations, and transformer stations shall be installed in intake air at locations which are sufficiently ventilated to prevent the accumulation of methane.

§ 57.22225 Auxiliary equipment stations (I-C mines).

Battery charging stations, compressor stations, and electrical substations shall not be installed underground or within 50 feet of a mine opening.

§ 57.22226 Testing for methane (IV mines).

Tests for methane shall be conducted in the mine atmosphere by a competent person—

(a) At least once each shift prior to starting work in each face and raise; and

(b) Upon initial release of gas into the mine atmosphere from boreholes.

§ 57.22227 Approved testing devices (I-A, I-B, I-C, II-A, II-B, III, IV, V-A, and V-B mines).

(a) Methane monitoring devices and portable, battery-powered, self-contained devices used for measuring methane, other gases, and contaminants in mine air shall be approved by MSHA under the applicable requirements of 30 CFR parts 18, 21, 22, 23, 27, and 29. Such devices shall be maintained in accordance with manufacturers' instructions, or an equivalent maintenance and calibration procedure.

(b)(1) Flame safety lamps shall not be used to test for methane except as supplementary devices.

(2) Flame safety lamps shall not be used in Subcategory I-C mines.

(c)(1) If electrically powered, remote sensing devices are used, that portion of the instrument located in return air or other places where combustible gases may be present shall be approved by MSHA under the applicable requirements of 30 CFR parts 18, 22, 23, 27, and 29.

(2) If air samples are delivered to remote analytical devices through sampling tubes, such tubes shall be provided with in-line flame arrestors. Pumping equipment and analytical instruments shall be located in intake air.

§ 57.22228 Preshift examination (I-A, I-C, II-A, III, and V-A mines).

(a) Preshift examinations shall be conducted within three hours prior to the start of the shift for which the examination is being made.

(b) Prior to the beginning of a shift following an idle shift, a competent person shall test the mine atmosphere for methane at all work places before persons other than examiners enter the mine.

(c) When one shift immediately follows another, a competent person shall test the mine atmosphere at each active working face for methane before work is started on that shift.

(d) A competent person shall test the mine atmosphere at each face blasted before work is started.

(e) Except in Subcategory I-C or Category III mines, vehicles used for transportation when examining the mine shall be approved by MSHA under the applicable requirements of 30 CFR parts 18 through 36.

[52 FR, 24941, July 1, 1987, as amended at 53 FR 9615, Mar. 24, 1988]

§ 57.22229 Weekly testing (I-A, III, and V-A mines).

(a) The mine atmosphere shall be tested for methane and carbon monoxide at least once every seven days by a competent person or an atmospheric monitoring system, or a combination of the two. Such testing shall be done at the following locations:

(1) The return of each split where it enters the main return;

(2) Adjacent to retreat areas, if accessible;

(3) At least one seal of each sealed area, if accessible;

(4) Main returns;

(5) At least one entry of each intake and return;

(6) Idle workings; and

(7) Return air from unsealed abandoned workings.

(b) The volume of air (velocity in Subcategory I-A mines) shall be measured at least once every seven days by a competent person. Such measurement shall be done at the following locations:

(1) Entering main intakes;

(2) Leaving main returns;

(3) Entering each main split;

(4) Returning from each main split; and

(5) In the last open crosscuts or other ventilation openings nearest the active faces where the air enters the return.

(c) Where such examinations disclose hazardous conditions, affected persons shall be informed and corrective action shall be taken.

(d) Certification of examinations shall be made by signature and date. Certifications shall be retained for at least one year and made available to authorized representatives of the Secretary.

[52 FR, 24941, July 1, 1987, as amended at 52 FR 41397, Oct. 27, 1987]

§ 57.22230 Weekly testing (II-A mines).

(a) The mine atmosphere shall be tested for methane at least once every seven days by a competent person or an atmospheric monitoring system, or a combination of the two. Such testing shall be done at the following locations:

(1) Active mining faces and benches;

(2) Main returns;

(3) Returns from idle workings;

(4) Returns from abandoned workings; and

(5) Seals.

(b) Where such examinations disclose hazardous conditions, affected persons shall be informed and corrective action shall be taken.

(c) Certification of examinations shall be made by signature and date. Certifications shall be kept for at least one year and made available to authorized representatives of the Secretary.

[52 FR, 24941, July 1, 1987, as amended at 52 FR 41397, Oct. 27, 1987; 60 FR 33723, June 29, 1995]

§ 57.22231 Actions at 0.25 percent methane (I-B, II-B, V-B, and VI mines).

If methane reaches 0.25 percent in the mine atmosphere, changes shall be made to improve ventilation, and MSHA shall be notified immediately.

§ 57.22232 Actions at 0.5 percent methane (I-B, II-A, II-B, IV, V-B, and VI mines).

If methane reaches 0.5 percent in the mine atmosphere, ventilation changes shall be made to reduce the level of methane. Until methane is reduced to less than 0.5 percent, electrical power shall be deenergized in affected areas, except power to monitoring equipment determined by MSHA to be intrinsically safe under 30 CFR part 18. Diesel equipment shall be shut off or immediately removed from the area and no other work shall be permitted in affected areas.

[52 FR 24941, July 1, 1987; 52 FR 27903, July 24, 1987]

§ 57.22233 Actions at 0.5 percent methane (I-C mines).

If methane reaches 0.5 percent in the mine atmosphere, ventilation changes shall be made to reduce the level of methane. Until methane is reduced to less than 0.5 percent, no other work shall be permitted in affected areas.

[52 FR 24941, July 1, 1987; 52 FR 27903, July 24, 1987]

§ 57.22234 Actions at 1.0 percent methane (I-A, I-B, III, V-A, and V-B mines).

(a) If methane reaches 1.0 percent in the mine atmosphere, ventilation changes shall be made to reduce the methane. Until such changes are achieved—

(1) All persons other than competent persons necessary to make the ventilation changes shall be withdrawn from affected areas;

(2) Electrical power shall be deenergized in affected areas, except power to monitoring equipment determined by MSHA to be intrinsically safe under 30 CFR part 18; and

(3) Diesel equipment shall be shut off or immediately removed from the area.

(b) If methane reaches 1.0 percent at a main exhaust fan, electrical power underground shall be deenergized, except power to monitoring equipment determined by MSHA to be intrinsically safe under 30 CFR part 18, and all persons shall be withdrawn from the mine.

(c) If methane reaches 1.0 percent at a work place and there has been a failure of the main ventilation system, all persons shall be withdrawn from the mine.

[52 FR, 24941, July 1, 1987, as amended at 53 FR 9615, Mar. 24, 1988]

§ 57.22235 Actions at 1.0 percent methane (I-C, II-A, II-B, and IV mines).

(a) If methane reaches 1.0 percent in the mine atmoshpere, all persons other than competent persons necessary to make ventilation changes shall be withdrawn from affected areas until methane is reduced to less than 0.5 percent.

(b) If methane reaches 1.0 percent at a work place and there has been a failure of the main ventilation system, all persons shall be withdrawn from the mine.

§ 57.22236 Actions at 1.0 percent methane (VI mines).

If methane reaches 1.0 percent in the mine atmosphere, all persons other than competent persons necessary to make ventilation changes shall be withdrawn from affected areas until methane is reduced to less than 0.5 percent.

§ 57.22237 Actions at 2.0 to 2.5 percent methane in bleeder systems (I-A and III mines).

If methane reaches 2.0 percent in bleeder systems at the point where a bleeder split enters a main return split, mining shall not be permitted on ventilation splits affected by the bleeder system. If methane has not been reduced to less than 2.0 percent within 30 minutes, or if methane levels reach 2.5 percent, all persons other than competent persons necessary to take corrective action shall be withdrawn from affected areas.

§ 57.22238 Actions at 2.0 percent methane (I-B, II-B, V-B, and VI mines).

If methane reaches 2.0 percent in the mine atmosphere, all persons other than competent persons necessary to make ventilation changes shall be withdrawn from the mine until methane is reduced to less than 0.5 percent.

§ 57.22239 Actions at 2.0 percent methane (IV mines).

If methane reaches 2.0 percent in the mine atmosphere, all persons other than competent persons necessary to make ventilation changes shall be withdrawn from the mine until methane is reduced to less than 0.5 percent. MSHA shall be notified immediately.

[52 FR, 24941, July 1, 1987, as amended at 52 FR 41397, Oct. 27, 1987; 60 FR 33723, June 29, 1995]

§ 57.22240 Actions at 2.0 percent methane (V-A mines).

If methane reaches 2.0 percent in the mine atmosphere, all persons other than competent persons necessary to make ventilation changes shall be withdrawn from affected areas until methane is reduced to less than 1.0 percent.

[52 FR 24941, July 1, 1987; 52 FR 27903, July 24, 1987]

§ 57.22241 Advance face boreholes (I-C mines).

(a) Boreholes shall be drilled at least 25 feet in advance of a face whenever the work place is within—

(1) 50 feet of a surveyed abandoned mine or abandoned workings which cannot be inspected; or

(2) 200 feet of an unsurveyed abandoned mine or abandoned workings which cannot be inspected.

(b) Boreholes shall be drilled in such a manner to insure that the advancing face will not accidently break into an abandoned mine or abandoned working.

Equipment

§ 57.22301 Atmospheric monitoring systems (I-A, II-A, and V-A mines).

(a) An atmospheric monitoring system shall be installed to provide surface readings of methane concentrations in the mine atmosphere from underground locations. Components of the system shall be approved by MSHA under the applicable requirements of 30 CFR parts 18, 22, 23, and 27; or be determined by MSHA under 30 CFR part 18 to be intrinsically safe or explosion-proof.

(b) Atmospheric monitoring systems shall—

(1) Give warnings on the surface and underground when methane at any sensor reaches 0.5 percent or more, and when power to a sensor is interrupted. Warning devices shall be located so that they can be seen and heard by a person designated by the mine operator; and

(2) Automatically deenergize power in affected areas, except power to monitoring equipment determined by MSHA to be intrinsically safe under 30 CFR part 18, when methane at any sensor reaches—

(i) 1.0 percent in a Subcategory I-A or V-A mine; or

(ii) 0.5 percent while persons are underground and 1.0 percent during blasting in a Subcategory II-A mine. Timing devices are permitted to avoid nuisance tripping for periods not to exceed 30 seconds, except during blasting or the ventilation time following a blast in a Subcategory II-A mine.

(c) Atmospheric monitoring systems shall be checked with a known mixture of methane, and calibrated if necessary at least once every 30 days. Certification of calibration tests shall be made by signature and date. Certifications of tests shall be retained for at least one year and made available to authorized representatives of the Secretary.

§ 57.22302 Approved equipment (I-A and V-A mines).

Equipment used in or beyond the last open crosscut shall be approved by MSHA under the applicable requirements of 30 CFR parts 18 through 36. Equipment shall not be operated in atmospheres containing 1.0 percent or more methane.

§ 57.22303 Approved equipment (I-C mines).

Only electrical equipment that is approved by MSHA under the applicable requirements of 30 CFR parts 18 through 28 or approved under 30 CFR part 29 contained in the 30 CFR, parts 1–199, edition, revised as of July 1, 1999, shall be used underground, except for submersible sump pumps.

[64 FR 43283, Aug. 10, 1999]

§ 57.22304 Approved equipment (II-A mines).

(a) Cutting and drilling equipment used at a face or bench shall be approved by MSHA under the applicable requirements of 30 CFR parts 18 through 36.

(b) While cutting or drilling is in progress, equipment not approved by MSHA under the applicable requirements of 30 CFR parts 18 through 36 shall remain at least 100 feet from the face or bench being mined.

(c) Tests for methane shall be conducted immediately before nonapproved equipment is taken to a face or bench after blasting.

(d) Mine power transformers and stationary equipment not approved by MSHA under the applicable requirements of 30 CFR parts 18 through 36 shall be installed in fresh air or downwind from an atmospheric methane monitor sensor.

§ 57.22305 Approved equipment (III mines).

Equipment used in or beyond the last open crosscut and equipment used in areas where methane may enter the air current, such as pillar recovery workings, longwall faces and shortwall faces, shall be approved by MSHA under the applicable requirements of 30 CFR parts 18 through 36. Equipment shall not be operated in atmospheres containing 1.0 percent or more methane.

§ 57.22306 Methane monitors (I-A mines).

(a) Methane monitors shall be installed on continuous mining machines, longwall mining systems, and on loading and haulage equipment used in or beyond the last open crosscut.

(b) The monitors shall—

(1) Give warning at 1.0 percent methane;

(2) Automatically deenergize electrical equipment, except power to monitoring equipment determined by MSHA to be intrinsically safe under 30 CFR part 18, and prevent starting such equipment when methane levels reach 1.5 percent. Diesel equipment shall be shut off or immediately removed from the affected area; and

(3) Automatically deenergize electrical equipment when power to a sensor is interrupted. Diesel equipment shall not be operated if the monitor is inoperative.

(c) Sensing units of monitors shall be positioned at a location which provides for the most effective measurement of methane.

§ 57.22307 Methane monitors (II-A mines).

(a) Methane monitors shall be installed on continuous mining machines, longwall mining systems, bench and face drills, and undercutting machines used in or beyond the last open crosscut.

(b) The monitors shall—

(1) Give warning at 0.5 percent methane;

(2) Automatically deenergize electrical equipment, except power to monitoring equipment determined by MSHA to be intrinsically safe under 30 CFR part 18, and prevent starting such equipment when methane levels reach 1.0 percent; and

(3) Automatically deenergize the equipment when power to a sensor is interrupted.

(c) Sensing units of monitors shall be positioned at a location which provides for the most effective measurement of methane.

§ 57.22308 Methane monitors (III mines).

(a) Methane monitors shall be installed on continuous mining machines and longwall mining systems.

(b) The monitors shall—

(1) Give warning at 1.0 percent methane;

(2) Automatically deenergize electrical equipment, except power to monitoring equipment determined by MSHA to be intrinsically safe under 30 CFR part 18, and prevent starting such equipment when methane levels reach 1.5 percent; and

(3) Automatically deenergize the equipment when power to a sensor is interrupted.

(c) Sensing units of monitors shall be positioned at a location which provides for the most effective measurement of methane.

§ 57.22309 Methane monitors (V-A mines).

(a) Methane monitors shall be installed on continuous mining machines used in or beyond the last open crosscut.

(b) The monitors shall—

(1) Give warning at 1.0 percent methane.

(2) Automatically deenergize electrical equipment, except power to monitoring equipment determined by MSHA to be intrinsically safe under 30 CFR part 18, and prevent starting of such equipment when methane levels reach 1.5 percent; and

(3) Automatically deenergize the equipment when power to a sensor is interrupted.

(c) Sensing units of monitors shall be positioned at a location which provides for the most effective measurement of methane.

§ 57.22310 Electrical cables (I-C mines).

Electrical cables used to power submersible sump pumps shall be accepted or approved by MSHA as flame resistant, or be installed in continuous metal conduit or metal pipe. The ends of such conduit or pipe shall be sealed to prevent entry of explosive gas or dust.

[57 FR 61223, Dec. 23, 1992]

§ 57.22311 Electrical cables (II-A mines).

Only jacketed electrical cables accepted or approved by MSHA as flame resistant shall be used to supply power to distribution boxes and electrical equipment operating in face and bench areas.

[57 FR 61223, Dec. 23, 1992]

§ 57.22312 Distribution boxes (II-A and V-A mines).

Distribution boxes containing short circuit protection for trailing cables of approved equipment shall be approved by MSHA under 30 CFR part 18.

§ 57.22313 Explosion-protection systems (I-C mines).

Pressure-relief systems including vents, or explosion suppression systems, shall be provided on explosive dust handling and processing equipment and on facilities housing such equipment. Vents shall be installed so that forces are directed away from persons should an explosion occur. The ratio of vent size to internal size of the equipment or facility shall not be less than one square foot of vent for each 80 cubic feet of volume or space.

§ 57.22314 Flow-control devices (V-A and V-B mines).

Oil recovery drill holes that penetrate oil bearing formations shall have devices to control the release of liquid hydrocarbons and hazardous gases during the drilling process. Such devices may be recovered for reuse after the formation has been depressurized or the well or borehole has been capped or connected to a collection system.

§ 57.22315 Self-contained breathing apparatus (V-A mines).

Self-contained breathing apparatus of a duration to allow for escape from the mine and sufficient in number to equip all persons underground shall be strategically located throughout the mine. Such apparatus shall be approved by MSHA and NIOSH under 42 CFR part 84 and shall be maintained in accordance with manufacturers' specifications. This standard does not apply to double entry mining systems where crosscut intervals do not exceed 250 feet.

[52 FR, 24941, July 1, 1987, as amended at 60 FR 30401, June 8, 1995]

Underground Retorts

§ 57.22401 Underground retorts (I-A and I-B mines).

(a) Retorts shall be provided with—

(1) Two independent power sources for main mine ventilation fans and those fans directly ventilating retort bulkheads, and for retort blowers, and provisions for switching promptly from one power source to the other; and

(2) An alarm system for blower malfunctions and an evacuation plan to assure safety of personnel in the event of a failure.

(b) Prior to the ignition of underground retorts, a written ignition and operation plan shall be submitted to the MSHA District Manager for the area in which the mine is located. The mine operator shall comply with all provisions of the retort plan. The retort plan shall include—

(1) Acceptable levels of combustible gases and oxygen in retort off-gases during start-up and during burning; levels at which corrective action will be initiated; levels at which personnel will be removed from the retort areas, from the mine, and from endangered surface areas; and the conditions for reentering the mine;

(2) Specification and locations of off-gas monitoring procedures and equipment;

(3) Specifications for construction of retort bulkheads and seals, and their locations;

(4) Procedures for ignition of a retort and for reignition following a shutdown; and

(5) Details of area monitoring and alarm systems for hazardous gases and actions to be taken to assure safety of personnel.

[52 FR, 24941, July 1, 1987, as amended at 52 FR 41397, Oct. 27, 1987; 60 FR 33723, June 29, 1995]

Illumination

§ 57.22501 Personal electric lamps (I-A, I-B, I-C, II-A, II-B, III, IV, V-A, and V-B mines).

Electric lamps used for personal illumination shall be approved by MSHA under the requirements of 30 CFR parts 19 or 20, as applicable.

Explosives

§ 57.22601 Blasting from the surface (I-A mines).

(a) All development, production, and bench rounds shall be initiated from the surface after all persons are out of the mine. Persons shall not enter the mine until ventilating air has passed over the blast area and through at least one atmospheric monitoring sensor.

(b) After blasting, if the monitoring system indicates that methane in the mine is less than 1.0 percent, persons may enter the mine. All places blasted shall be tested for methane by a competent person before work is started.

(c) If the monitoring system indicates the presence of 1.0 percent or more methane, persons other than examiners shall not enter the mine until the mine has been examined by a competent person and the methane content has been reduced to less than 1.0 percent.

(d) Vehicles used for transportation when examining the mine shall be approved by MSHA under the applicable requirements of 30 CFR parts 18 through 36.

[52 FR, 24941, July 1, 1987, as amended at 53 FR 9615, Mar. 24, 1988]

Effective Date Note: At 53 FR 9615, Mar. 24, 1988, §57.22601 was stayed until further notice.

§ 57.22602 Blasting from the surface (I-C mines).

(a) All blasting shall be initiated from the surface after all persons are out of the mine and any connecting mines.

(b) Persons shall not enter the mine until a competent person has examined the blast sites and methane concentrations are less than 0.5 percent.

§ 57.22603 Blasting from the surface (II-A mines).

(a) All development, production, and bench rounds shall be initiated from the surface after all persons are out of the mine. Persons shall not enter the mine until the mine has been ventilated for at least 15 minutes and the ventilating air has passed over the blast area and through at least one atmospheric monitoring sensor.

(b) If the monitoring system indicates that methane in the mine is less than 0.5 percent, competent persons may enter the mine to test for methane in all blast areas.

(c) If the monitoring system indicates that methane in the mine is 0.5 percent or more, the mine shall be ventilated and persons shall not enter the mine until the monitoring system indicates that methane in the mine is less than 0.5 percent.

(d) If the monitoring system is inoperable or malfunctions, the mine shall be ventilated for at least 45 minutes and the mine power shall be deenergized before persons enter the mine. Only competent persons necessary to test for methane may enter the mine until the methane in the mine is less than 0.5 percent.

(e) Vehicles used for transportation when examining the mine shall be approved by MSHA under the applicable requirements of 30 CFR parts 18 through 36. Vehicles shall not be used to examine the mine if the monitoring system is inoperable or has malfunctioned.

§ 57.22604 Blasting from the surface (II-B mines).

All development, production, and bench rounds shall be initiated from the surface after all persons are out of the mine. Persons other than those designated by the mine operator to make methane tests shall not enter the mine until all blast areas have been tested for methane.

§ 57.22605 Blasting from the surface (V-A mines).

(a) All development and production blasting shall be initiated from the surface after all persons are out of the mine. Persons shall not enter the mine until ventilating air has passed over the blast area and through at least one atmospheric monitoring sensor.

(b) If the monitoring system indicates that methane in the mine is less than 1.0 percent, persons may enter the mine, and all places blasted shall be tested for methane by a competent person before work is started.

(c) If the monitoring system indicates the presence of 1.0 percent or more methane, persons other than examiners shall not enter the mine until the mine has been examined by a competent person and the methane level is less than 1.0 percent.

(d) Vehicles used for transportation when examining the mine shall be approved by MSHA under the applicable requirements of 30 CFR parts 18 through 36.

(e) This standard applies only to mines blasting within an oil reservoir.

§ 57.22606 Explosive materials and blasting units (III mines).

(a) Mine operators shall notify the appropriate MSHA District Manager of all nonapproved explosive materials and blasting units to be used prior to their use. Explosive materials used for blasting shall be approved by MSHA under 30 CFR part 15, or nonapproved explosive materials shall be evaluated and determined by the District Manager to be safe for blasting in a potentially gassy environment. The notice shall also include the millisecond-delay interval between successive shots and between the first and last shot in a round.

(b) Faces shall be examined for proper placement of holes, possible breakthrough, and water. Ammonium nitrate blasting agents shall not be loaded into wet holes.

(c) Multiple-shot blasts shall be initiated with detonators encased in copper-based alloy shells. Aluminum and aluminum alloy-cased detonators, nonelectric detonators, detonating cord, and safety fuses shall not be used. All detonators in a round shall be made by the same manufacturer.

(d) Nonapproved explosives shall be used only as primers with ammonium nitrate-fuel oil blasting agents. Such primers shall be placed at the back or bottom of the hole.

(e) Blast holes shall be stemmed with a noncombustible material in an amount to confine the explosive charge. Breakthrough holes shall be stemmed at both ends.

(f) Mudcaps or other nonapproved unconfined shots shall not be blasted.

(g)(1) Blasting units shall be approved by MSHA under 30 CFR part 25; or

(2) Blasting units used to fire more than 20 detonators shall provide at least 2 amperes through each detonator but not more than an average of 100 amperes through one ohm for 10 milliseconds, and provide the necessary current for at least the first 5 milliseconds with a cutoff not to exceed 10 milliseconds.

[52 FR, 24941, July 1, 1987, as amended at 52 FR 41397, Oct. 27, 1987]

§ 57.22607 Blasting on shift (III mines).

When blasting on shift, tests for methane shall be made in the mine atmosphere by a competent person before blasting. Blasting shall not be done when 1.0 percent or more methane is present.

§ 57.22608 Secondary blasting (I-A, II-A, and V-A mines).

Prior to secondary blasting, tests for methane shall be made in the mine atmosphere at blast sites by a competent person. Secondary blasting shall not be done when 0.5 percent or more methane is present.

Statistical Analysis to Evaluate Methane and Hydrogen Concentrations in Filled Panels at the Waste Isolation Pilot Plant

Revision 0

September 2012

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I. Introduction

The Waste Isolation Pilot Plant (WIPP) Hazardous Waste Facility Permit (Permit) requires monitoring for hydrogen and methane in filled Panels 3 through 8, unless an explosion isolation wall is installed. A *filled panel* is an underground Hazardous Waste Disposal Unit (HWDU) that will no longer receive waste for emplacement. The filled panels consist of seven closed rooms filled with vented containers of transuranic (TRU) waste. The monitoring process includes collecting samples of closed room air to determine hydrogen and methane concentrations that may be emitted from the waste containers. The purpose of the monitoring is to determine if changes in hydrogen and methane concentrations in filled panels can be correlated to early gas-generation modeling studies (Wang & Brush 1996, Mercer 2006, Golder Associates 2006).

II. Purpose and Scope

The purpose of this report is to evaluate using statistical methods the hydrogen and methane data collected to date, in accordance with Permit Part 4.6.5 and as specified in Permit Attachment N1. This evaluation will be used as input to the design of an appropriate panel closure system. The scope of this report covers hydrogen and methane data obtained between April 2008 and December 2011 for Panel 3 and between May 2009 and December 2011 for Panel 4. Panel 5 is a filled panel that does not require monitoring since an explosion isolation wall is installed. Panel 6 is currently being filled, and Panels 7 and 8 are not yet available for TRU waste disposal.

The current panel closure system is designed to withstand a postulated flammable gas explosion. However, this element of the design may not be necessary if a postulated explosion is not possible prior to closure of the WIPP repository.

III. Background

Hydrogen and methane monitoring was conducted in compliance with Permit Attachment N1 because TRU wastes disposed in the WIPP underground panels have the potential to generate hydrogen and methane. Hydrogen can be generated by radiolysis (Mercer 2006) and by corrosion of iron-based materials under anoxic conditions (Wang & Brush 1996). Methane can be produced from microbial degradation of organic materials such as cellulosics, plastics, and rubber (CPR) under humid or inundated conditions (Wang & Brush). However, only humid conditions are expected to occur during operations and closure.

IV. Monitoring Methods and Data

Based on concepts of EPA Compendium Method TO-15, samples were collected in six-liter passivated canisters using passivated stainless steel sample lines after purging. Samples were collected using sub-atmospheric sampling methods, which included a pressure dilution by the analytical laboratory with ultra-high purity nitrogen prior to

analysis. Hydrogen and methane concentrations were measured with a Gas Chromatograph/Thermal Conductivity Detector (GC/TCD). Identification of eluted analytes was based solely on known retention times determined during calibration of the instrumentation. Quantitation was based on the results of a 5-point calibration and results were corrected for sample dilutions. The method detection limit (MDL) was determined in accordance with 40 CFR Part 136 and corrected for the sample dilutions. Data for methane and hydrogen in Panels 3 and 4 appear in Appendices C through F. When the reported result is less than the dilution-corrected MDL, the value used for the statistical evaluation is 1/2 the dilution-corrected MDL. The appendices indicate the reported results, dilution factors, MDLs, the dilution-corrected MDLs, and the values used for the statistical evaluation.

An underground HWDU is a single excavated panel consisting of seven rooms and two access drifts designated for disposal of TRU waste. Each room is approximately 300 ft (91 m) long, 33 ft (10 m) wide, and 13 ft (4 m) high. Access drifts connect the rooms and have the same cross-section. Figure 1 is a diagram of an underground disposal panel and room layout at the WIPP facility. The rooms and the two interconnecting access drifts are the areas containing emplaced wastes in Figure 1 (hexagons used to depict waste drums) and have increasing numbers starting with Room 1 for the room closest to the main access drift (known as E-300 for Panels 3 and 4), and culminating in Room 7, the room furthest from the main access drift. Two sample head locations for filled panel monitoring are shown in Figure 1 for each room, corresponding to intake and exhaust locations. Bulkheads separate Room 1 from the main access drift and the bulkhead areas also contains sample heads on both sides (Waste (W) and Accessible (A)). Sample data are identified by the source panel number, room number or “B” for bulkhead, and intake (i) or exhaust (e) function (first and capitalized for bulkheads). For example, the Panel 3 Room 7 exhaust location is Panel 3 7e. Similarly, Panel 3 Exhaust Bulkhead’s Waste side is coded Panel 3 EBW.

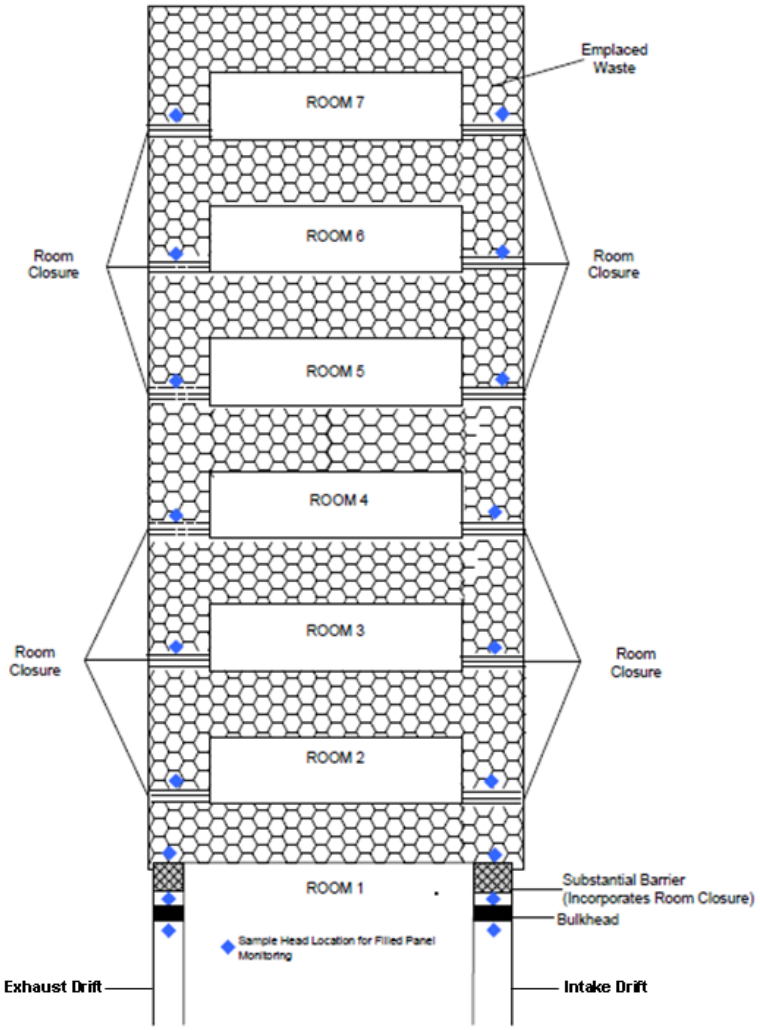

Figure 1: WIPP Disposal Panel Design and Monitoring Locations

The data set for this statistical analysis contains 691 samples in Panel 3 for hydrogen and methane and 566 samples in Panel 4. All of the samples for methane in both Panels 3 and 4 were reported as below the MDL. As such, a statistical analysis is unnecessary. Hydrogen samples exhibited both detectable and nondetectable concentrations in both Panels 3 and 4, with minimum detection limits ranging from approximately 14 ppmv to 30 ppmv.

This statistical analysis includes data for a maximum of 53 sampling events for most of the Panel 3 rooms and a maximum of 32 sampling events for most of the Panel 4 rooms. Rooms with fewer sampling events are associated with unusable sampling lines. The following sampling lines in Panels 3 and 4 were determined to be unusable:

- Panel 3 7i and 1i sampling lines were determined to be unusable on July 14, 2008 (Note: Only three samples were collected for each of these two lines and the June 2008 sample collected for Panel 3 7i was voided)

- The Panel 3 7e sampling line was determined to be unusable on August 30, 2010
- The Panel 3 6i sampling line was determined to be unusable on September 22, 2010
- The Panel 4 4e sampling line was determined to be unusable on April 7, 2011
- The Panel 4 6e sampling line was determined to be unusable on December 13, 2011
- The Panel 3 IBW sampling line was determined to be unusable on April 21, 2010 (Note: The sampling line was replaced and sampling resumed on May 25, 2010)

The sampling line for Panel3 IBW was replaced because it is in an accessible location. The other unusable sampling line locations listed above are not accessible and were not replaced.

Hydrogen and methane measurement levels are monitored with respect to Action Levels (AL) specified in Table 4.6.5.3 of the Permit. Action Level 1 (the lowest Action Level) is set at 10 percent of the lower explosive limit (LEL) in air. As such, Action Level 1 is set at 4,000 ppmv for hydrogen and 5,000 ppmv for methane. Specified reporting and remedial actions are initiated if a monitoring level exceeds an Action Level.

V. Statistical Analysis

A. Room Averages

Mean (average) hydrogen concentrations were calculated for each room in Panels 3 and 4. Each room is represented by two values, an *exhaust mean* and an *intake mean*. This partitioning also applies to the bulkhead area. Results are presented in Tables 1 and 2 for Panels 3 and 4 respectively. The designations “exhaust” and “intake” only refer to the geographic locations of the respective sampling points. They do not indicate a flow direction for the panel because both Panels 3 and 4 are isolated from the mine ventilation system.

Table 1: Mean Concentrations of Hydrogen in Panel 3 Rooms

WIPP - Hydrogen Levels (ppmv)			
Panel	Room	Mean	
		Exhaust	Intake
3	7	104	10.8
	6	62.7	47.9
	5	67.0	44.0
	4	52.5	28.6
	3	49.2	19.4
	2	34.2	15.9
	1	24.6	10.8
	EBW	23.8	NA
	EBA	14.1	NA
	IBW	NA	14.9
	IBA	NA	13.3

The mean data for exhaust measurements in Panel 3 are presented graphically in Figure 2.

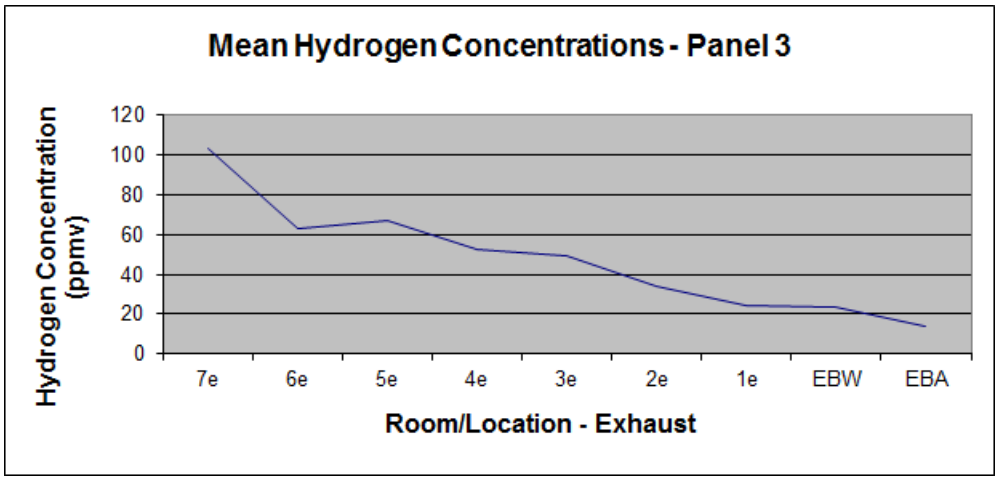

Figure 2: Average Hydrogen Concentrations at Exhaust Locations by Room/Location in Panel 3

The mean data for intake measurements in Panel 3 are presented graphically in Figure 3. Note that the maximum concentration observed for both intake and exhaust locations was 104 ppmv, with the remaining concentrations below 70 ppmv. There is also a general downward trend in hydrogen concentrations from Room 7 toward the E-300 drift.

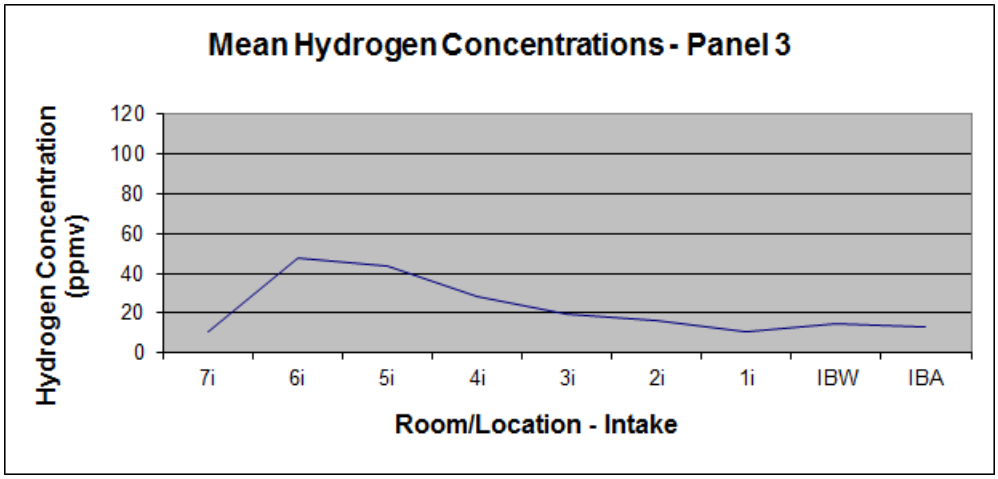

Figure 3: Average Hydrogen Concentrations at Intake Locations by Room/Location in Panel 3

Table 2 and Figures 4 and 5 present the average hydrogen concentrations for rooms and locations in Panel 4, which shows a downward trend in the hydrogen concentration from Room7 toward the E-300 drift.

Table 2: Mean Concentrations of Hydrogen in Panel 4 Rooms

WIPP - Hydrogen Levels (ppmv)			
Panel	Room	Mean	
		Exhaust	Intake
4	7	567	502
	6	526	471
	5	495	471
	4	395	401
	3	450	401
	2	336	328
	1	268	279
	EBW	112	NA
	EBA	13.0	NA
	IBW	NA	197
	IBA	NA	22.1

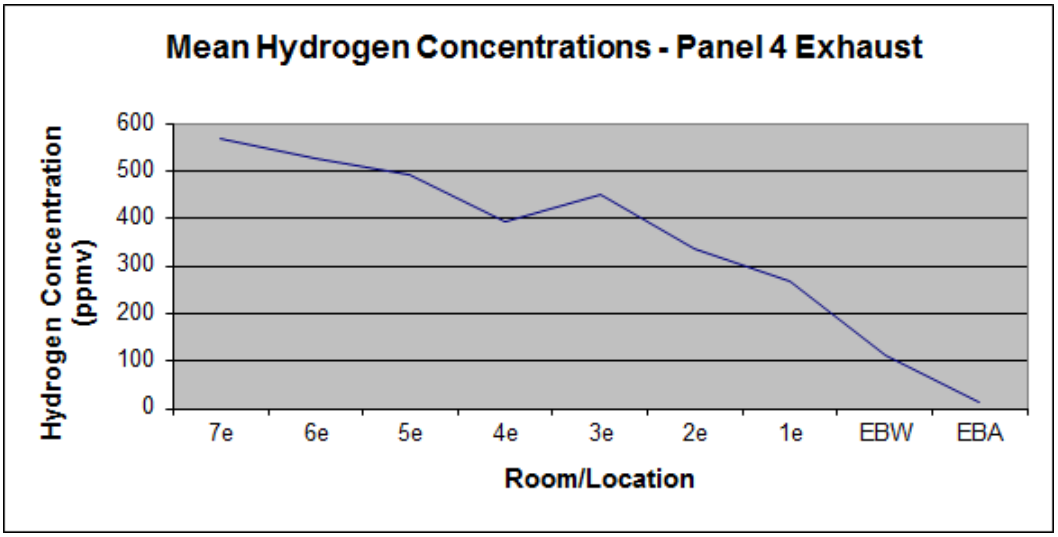

Figure 4: Average Hydrogen Concentrations at Exhaust Locations by Room/Location in Panel 4

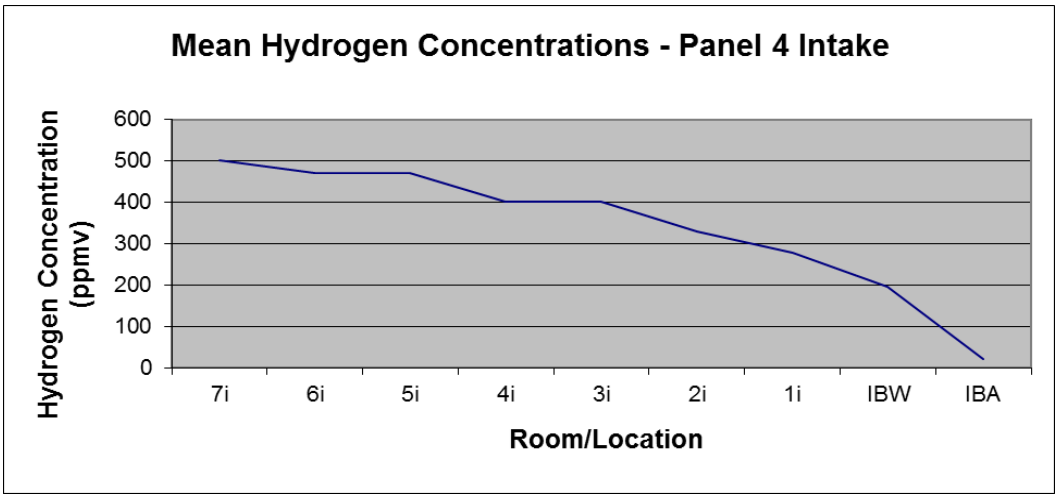

Figure 5: Average Hydrogen Concentrations at Intake Locations by Room/Location in Panel 4

B. Box-and-Whisker Plots

Figure 6 is a *box-and-whisker plot* (BW) of the hydrogen data in Panel 3. In contrast to the mean, which describes the central tendency of a data set, a box-and-whisker plot displays the range of concentration values observed in the sample data. A box-and-whisker plot is composed of a central box divided by a median line, with two lines extending out from the box, called whiskers. The length of the central box indicates the spread of the bulk of the data, the central 50%, which is called the *interquartile range* (IQR). The IQR is bounded by the 25th and 75th percentiles, with the median located at the 50th percentile. The length of the whiskers shows how extensive the tails of the distribution are. The width of the box has no particular meaning.

The sample median (50% of the data above, 50% below) is displayed as a line through the box on the BW plot. Unusually large or small data are displayed by white (hollow circles) and red dots (solid circles) on the plot. The white dots indicate data that are less than three IQRs from the 25th and 75th percentiles, whereas the red dots are data that are more than three IQRs from the 25th and 75th percentiles. Using these conventions, the graphs show the relative ranges of the distributions being compared, the central tendencies, outliers, and other aspects that allow for a visual, qualitative comparison of two or more distributions.

Figure 6 displays the distribution of monitoring data from each monitoring location in Panel 3. Sample values range from a high of approximately 350 ppmv in Room 7e to non-detects in rooms and locations closer to the E-300 drift. The general downward trend from Room 7 toward the E-300 drift is also apparent.

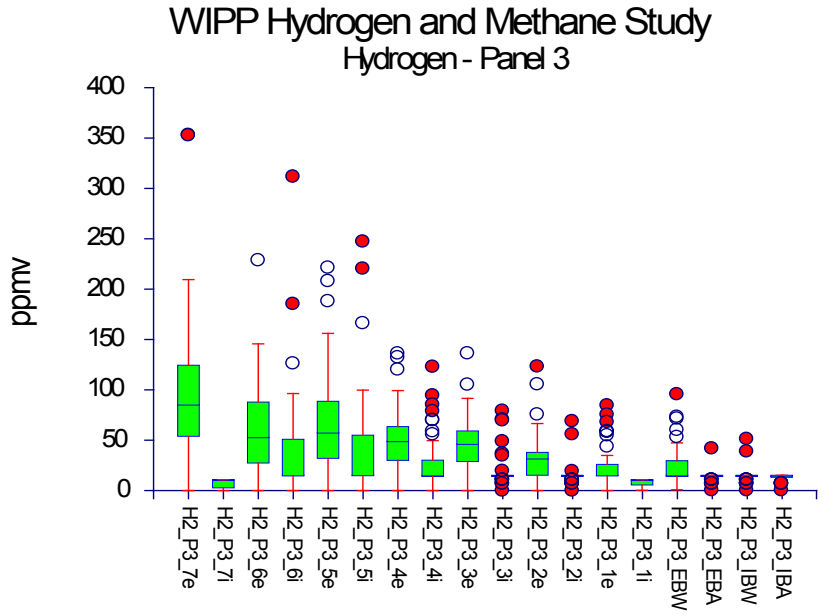

Figure 6: Box-and-Whisker Plot of Hydrogen Concentrations in Panel 3

Figure 7 is a box-and-whisker plot of Panel 3 data with the lower AL (i.e. Action Level 1) plotted on the graph. The lower AL for hydrogen is 4,000 ppmv, which is substantially greater than any concentration observed in Panel 3 monitoring.

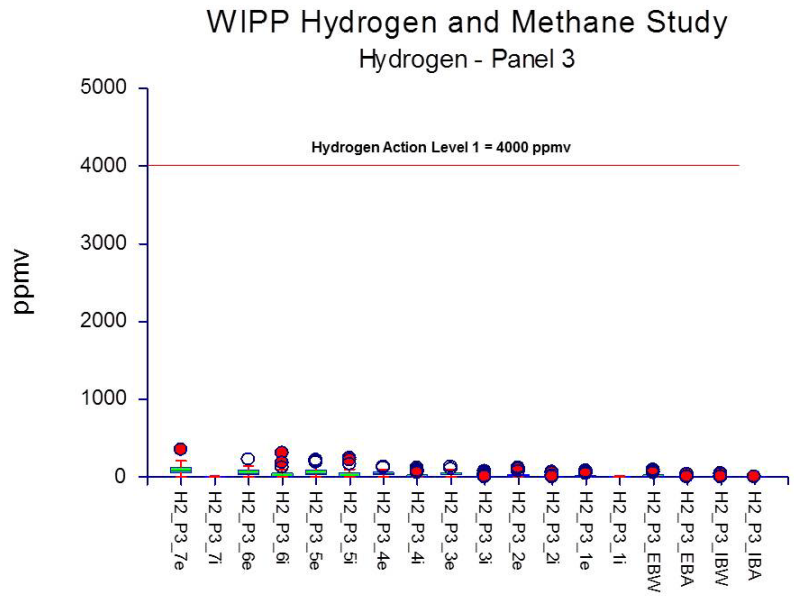

Figure 7: Box-and-Whisker Plot of Hydrogen Concentrations in Panel 3 Compared to Action Level 1

Figure 8 is a box-and-whisker plot of the monitoring data for Panel 4. Figure 8 shows that the sample data in Panel 4 span a greater range than those for Panel 3, with Panel 4 data slightly exceeding 1,000 ppmv in the Room 6 exhaust monitoring location. The general downward trend from Room 7 toward the E-300 drift is also apparent. Figure 9 plots the Panel 4 data in relation to the hydrogen lower AL. None of the data poses a challenge to the lower AL.

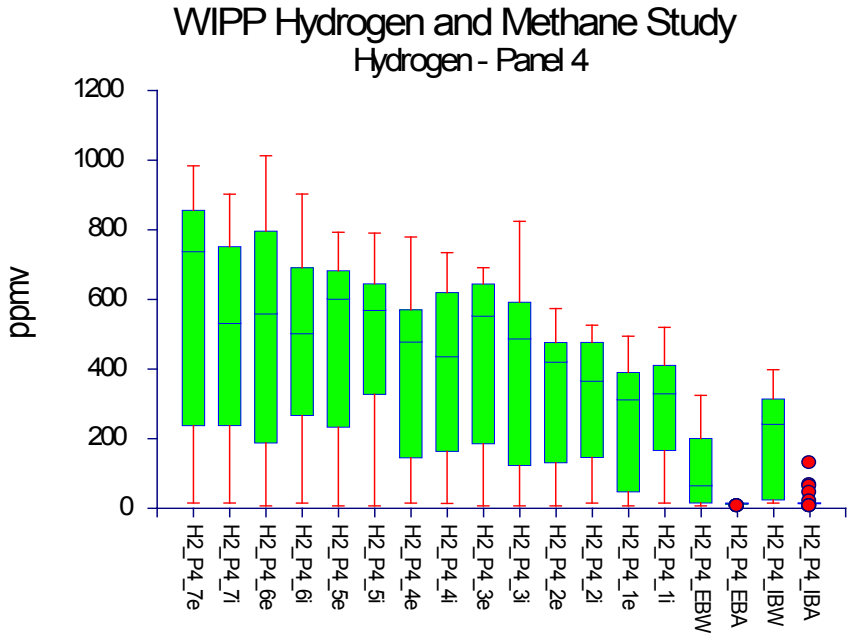

Figure 8: Box-and-Whisker Plot of Hydrogen Concentrations in Panel 4

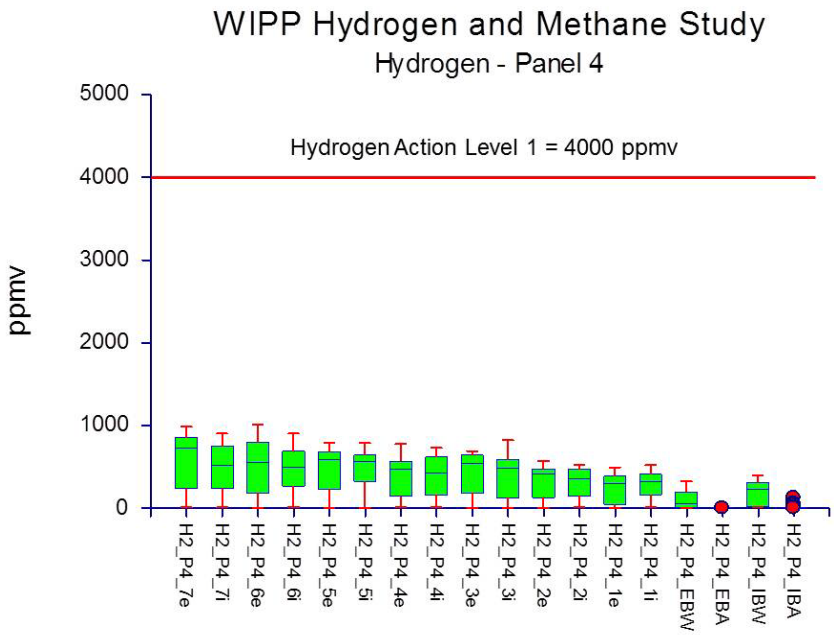

Figure 9: Box-and-Whisker Plot of Hydrogen Concentrations in Panel 4 Compared to Action Level 1

C. Time Series Plots

In addition to the central tendencies and concentration ranges (minimums/maximums), how the data are distributed over time is of interest for correlating concentration data to the early gas-generation modeling studies. Figures 10 and 11 show time series plots for hydrogen concentrations in Panel 3, Room 7. Note that only two samples are available to construct Figure 11, both of which are nondetects and equal in value. Figures 12 and 13 show time series plots for hydrogen concentrations in Panel 4, Room 7. Full suites of time series plots for Panels 3 and 4 appear in Appendices A and B respectively.

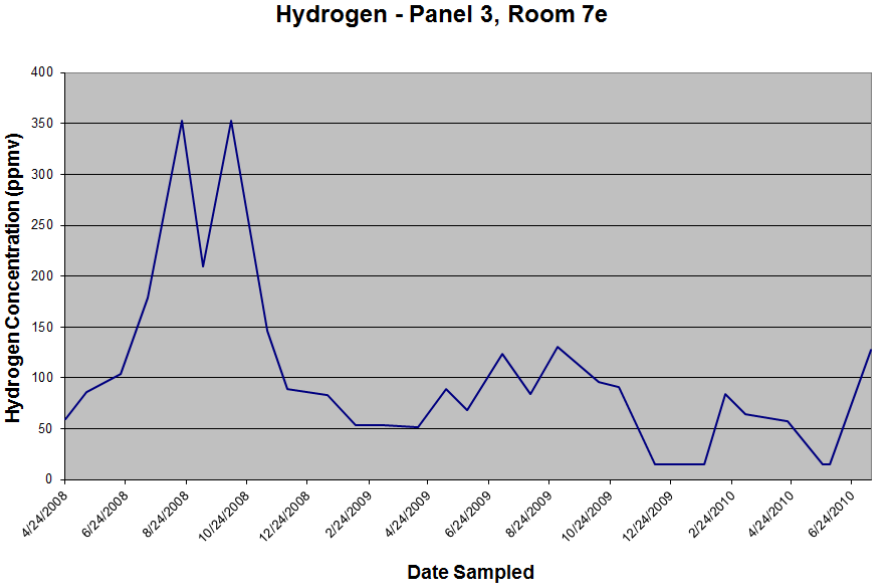

Figure 10: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 7e

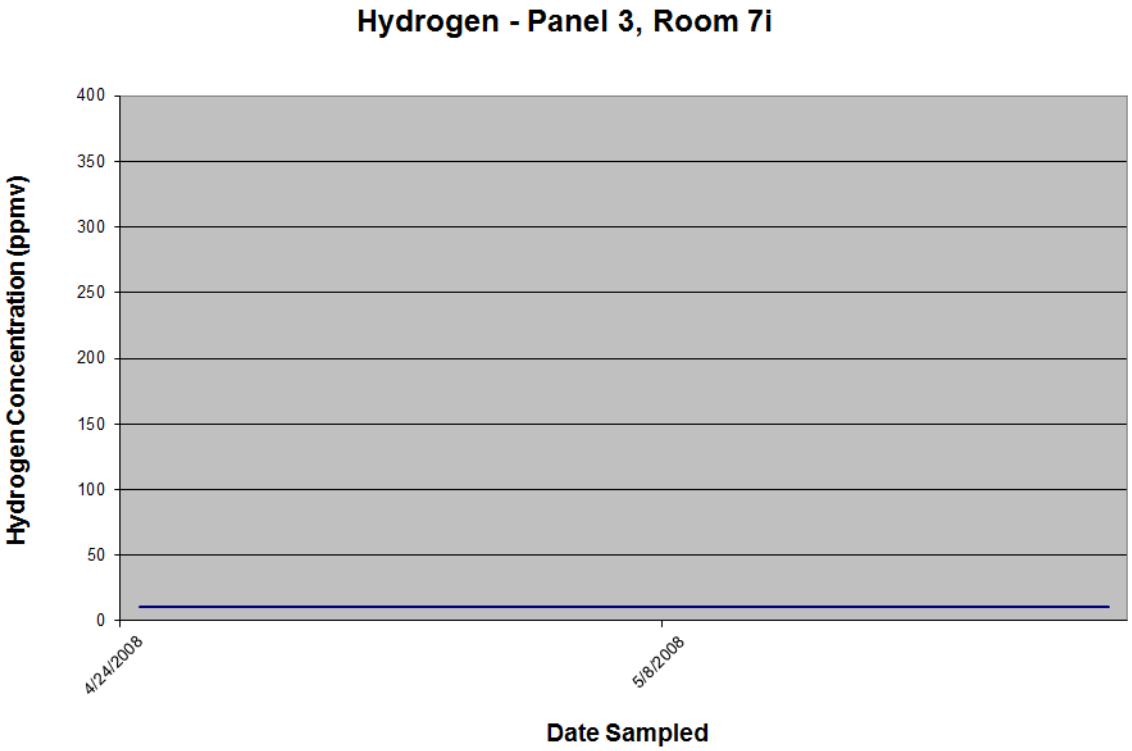

Figure 11: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 7i

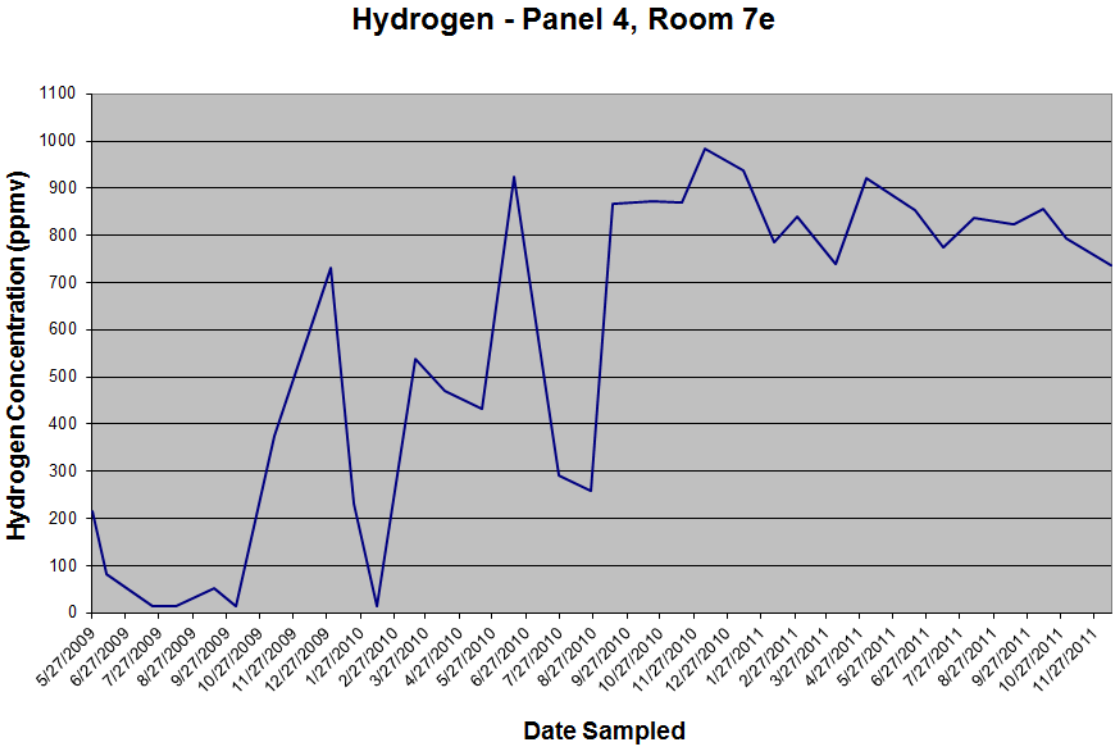

Figure 12: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 7e

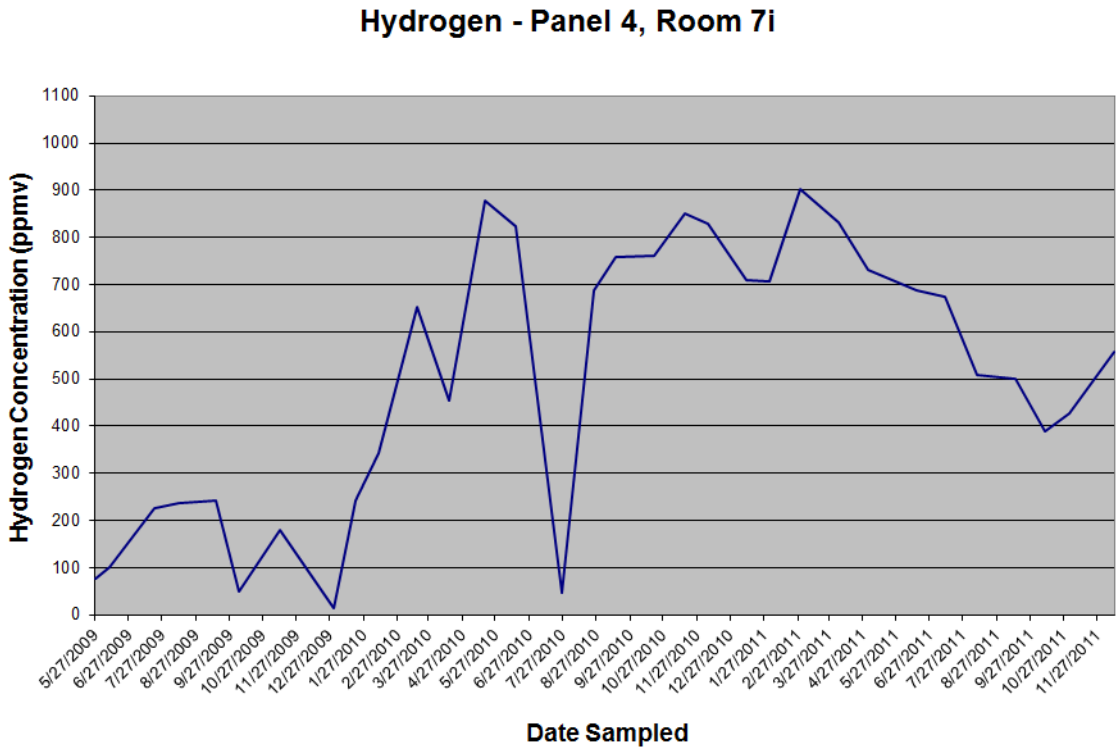

Figure 13: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 7i

D. Hydrogen Concentration Plots

Time series plots show how hydrogen concentrations vary at specific points in time for individual rooms and present an aggregated picture of the rooms and bulkhead locations simultaneously. Most importantly, hydrogen concentration plots display the degree to which hydrogen concentrations fluctuate from the time a panel was closed.

1. Panel 3 Hydrogen Concentration Plots

Figure 14 presents the hydrogen concentration data for rooms in Panel 3. The graph plots the number of months since the associated room was closed on the x-axis and the hydrogen concentration on the y-axis. Figures 15 through 17 plot respectively the median, mean, and maximum hydrogen concentrations vs. months since the room was closed.

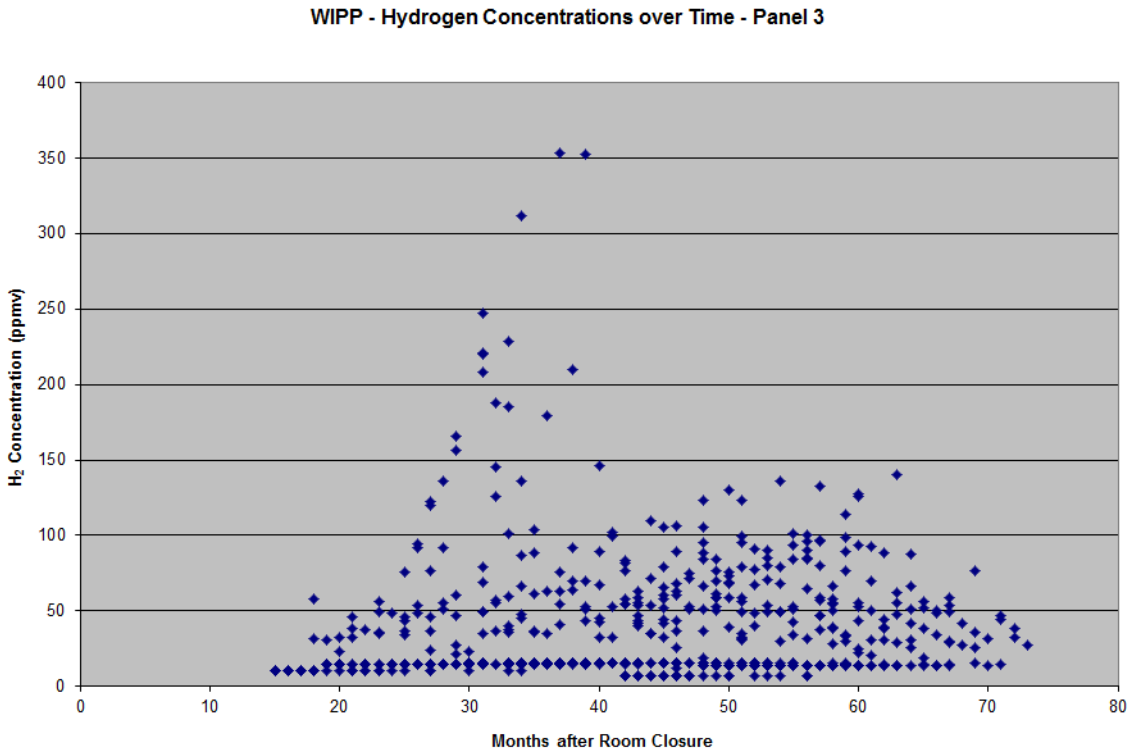

Figure 14: Plot of Hydrogen Concentrations in Panel 3

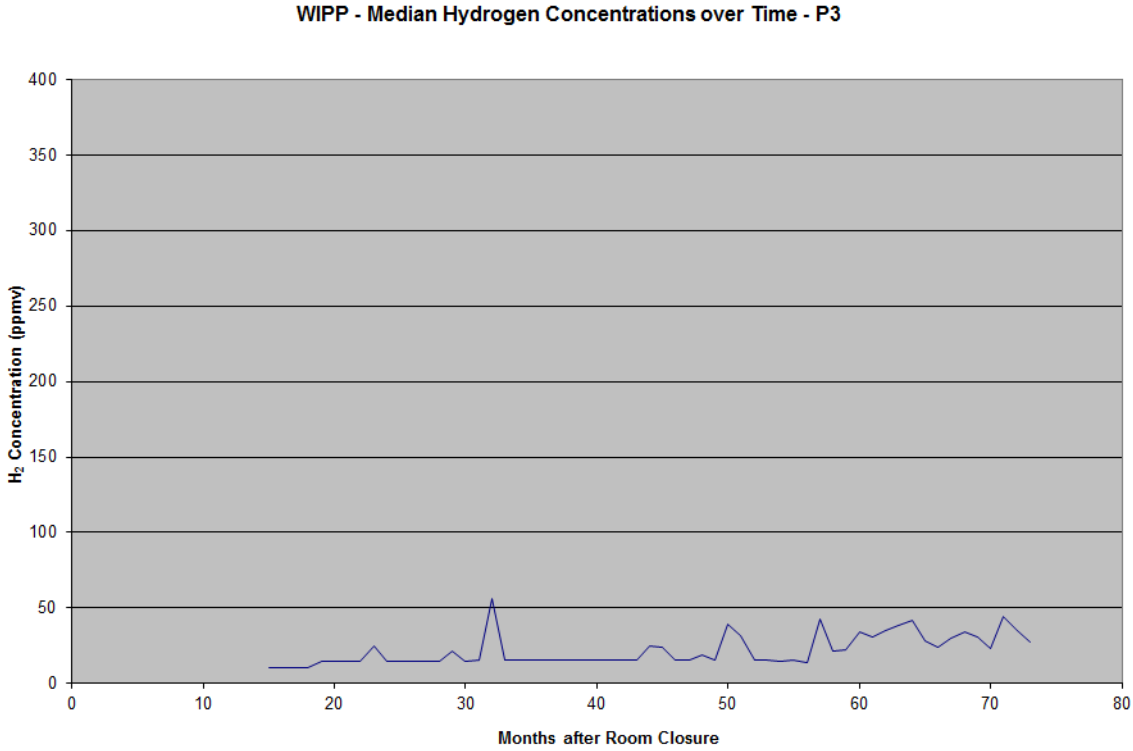

Figure 15: Plot of Median Hydrogen Concentrations in Panel 3

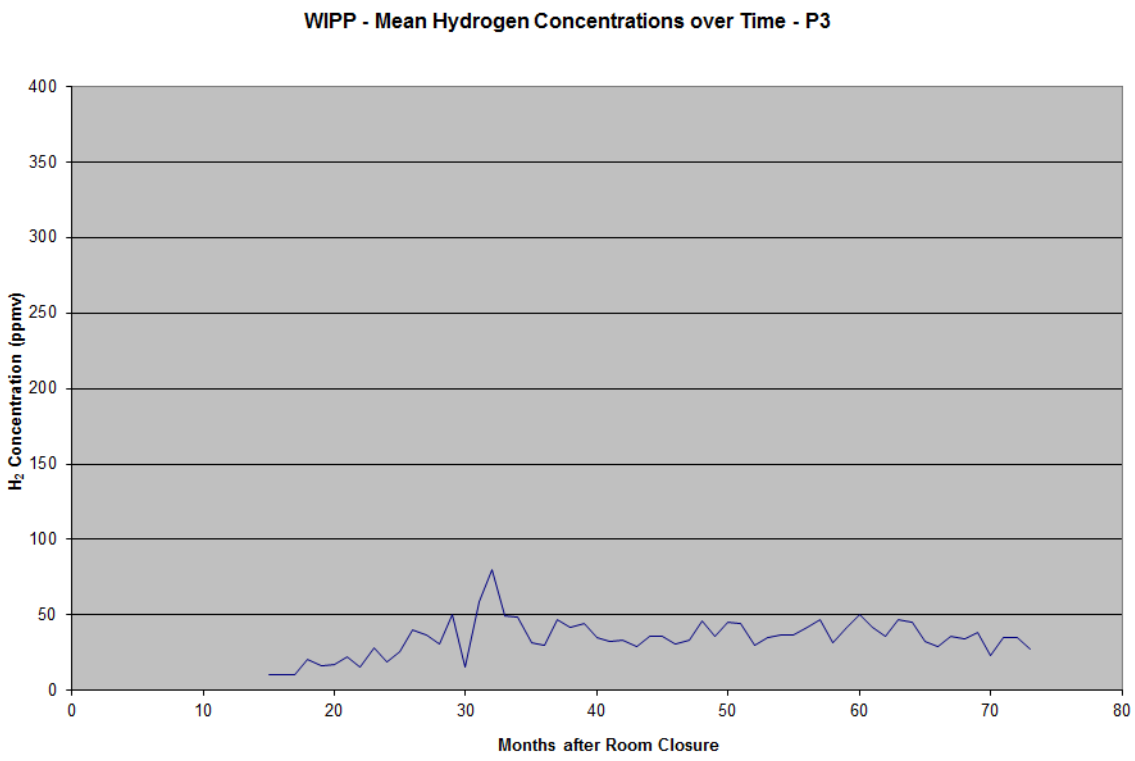

Figure 16: Plot of Mean Hydrogen Concentrations in Panel 3

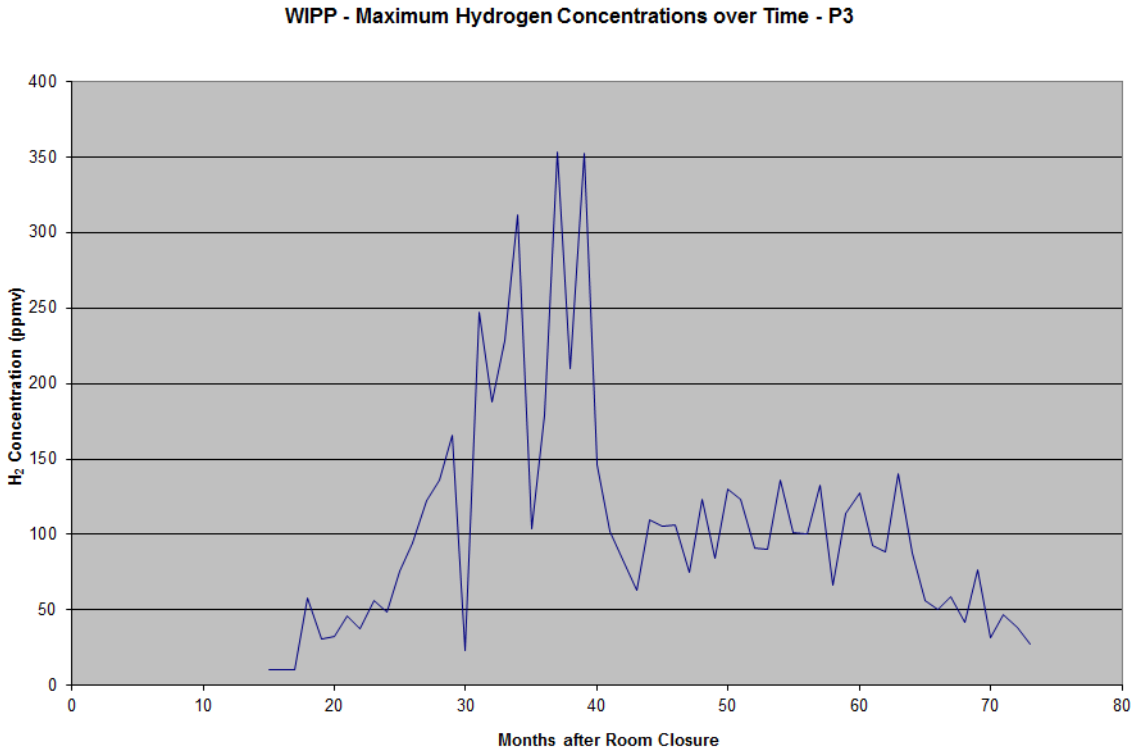

Figure 17: Plot of Maximum Hydrogen Concentrations in Panel 3

2. Panel 4 Hydrogen Concentration Plots

Figure 18 presents the hydrogen concentration data for rooms in Panel 4. Figures 19 through 21 plot respectively the median, mean, and maximum hydrogen concentrations vs. months since the room was closed.

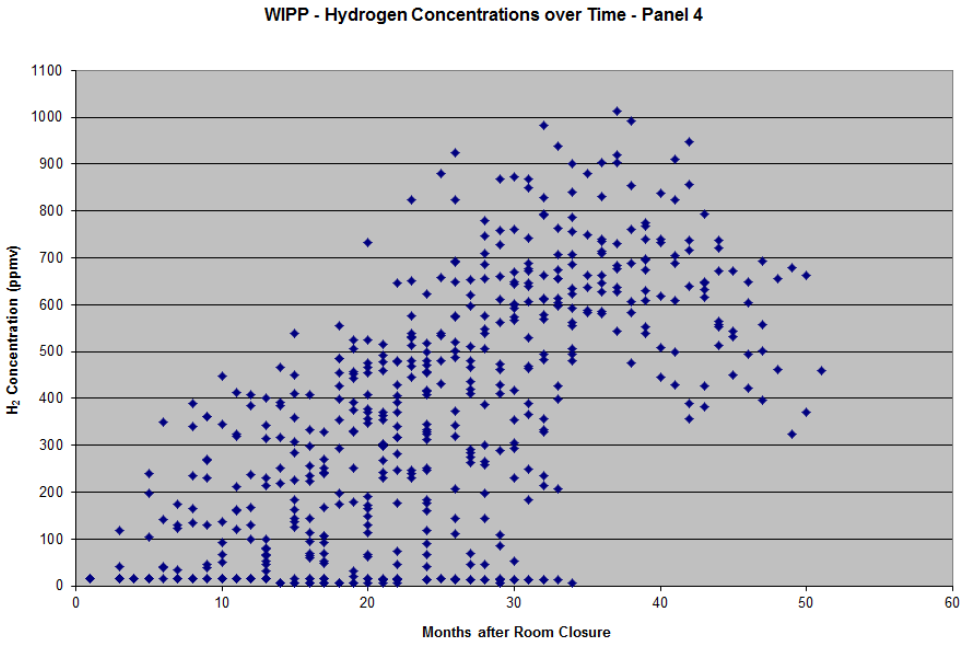

Figure 18: Plot of Hydrogen Concentrations in Panel 4

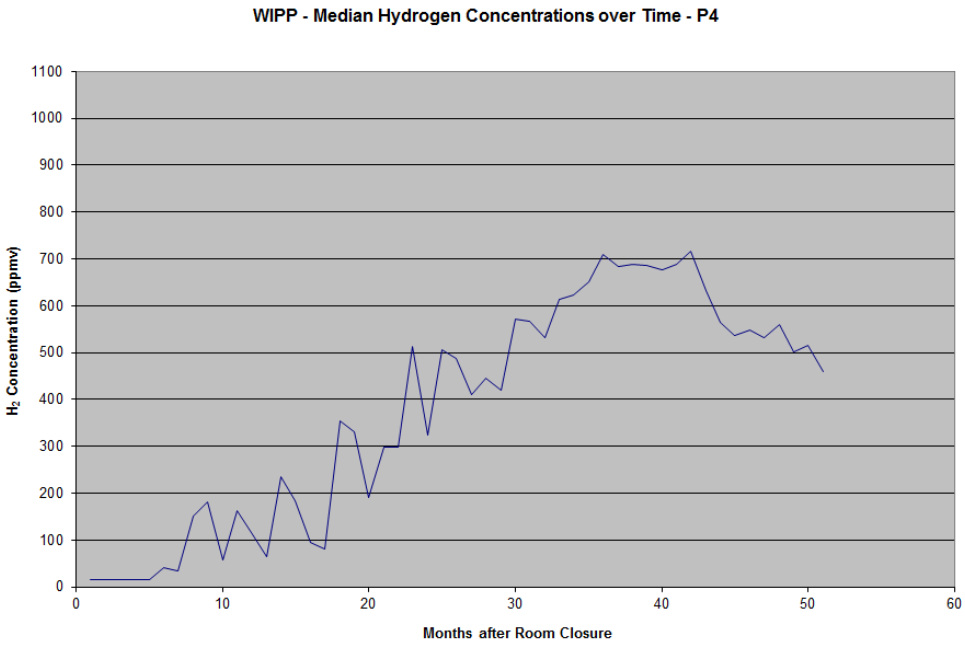

Figure 19: Plot of Median Hydrogen Concentrations in Panel 4

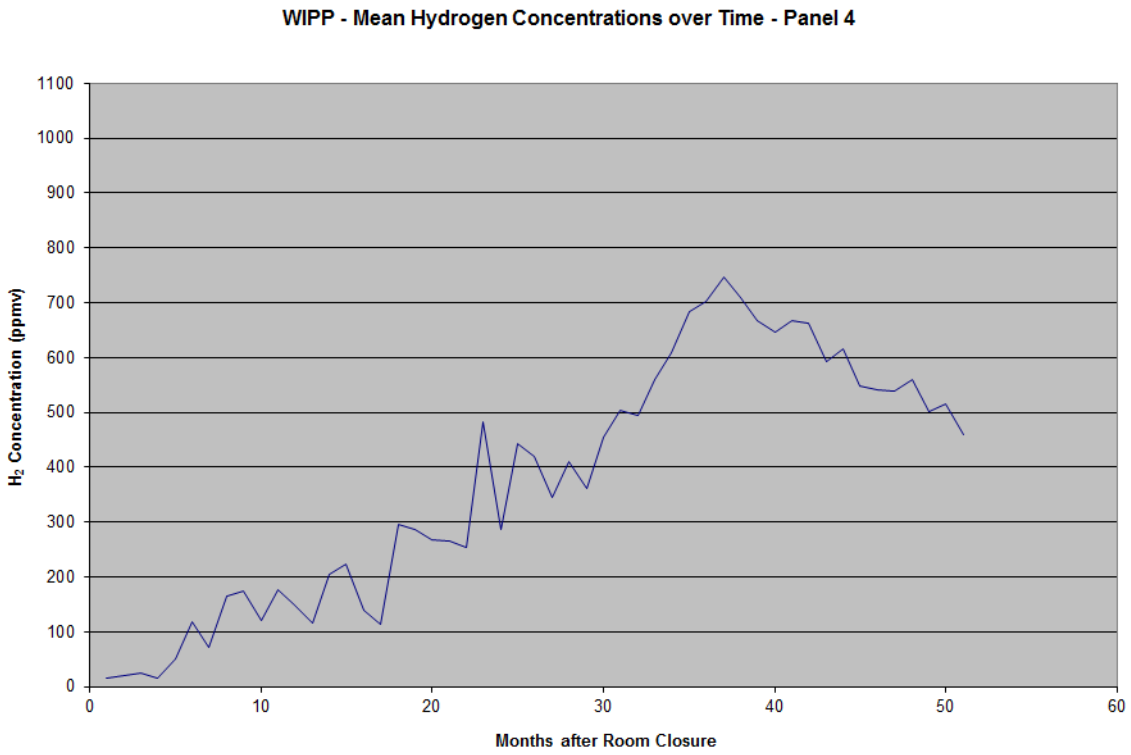

Figure 20: Plot of Mean Hydrogen Concentrations in Panel 4

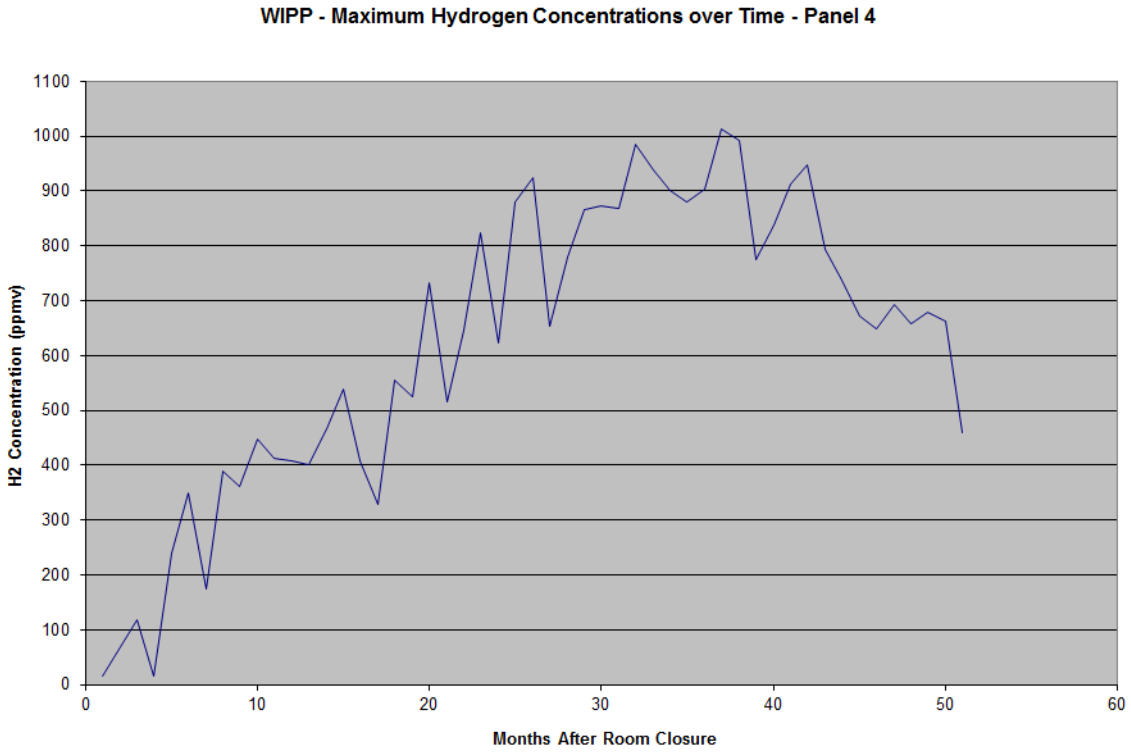

Figure 21: Plot of Maximum Hydrogen Concentrations in Panel 4

E. Linear Regression on Hydrogen Concentration Data

Hydrogen concentration plots show the concentration of hydrogen in closed panels over time. The change in hydrogen concentration over time is believed to be related to the hydrogen generation rate and the rate at which hydrogen leaves the disposal room. The change in hydrogen concentration over time can be analyzed in a quantitative way to predict the length of time necessary for hydrogen concentrations to accumulate to explosive levels. Linear regression has been used to quantify the change in hydrogen concentration with time in Panels 3 and 4.

1. Panel 3 Regression Plots

Figures 22 through 24 plot respectively the median, mean, and maximum hydrogen concentrations vs. the number of months since rooms in Panel 3 were closed. Figures 25 and 26 plot the maximum hydrogen concentrations in relation to Action Level 1 (4,000 ppmv) and the Lower Explosive Limit (LEL) (40,000 ppmv).

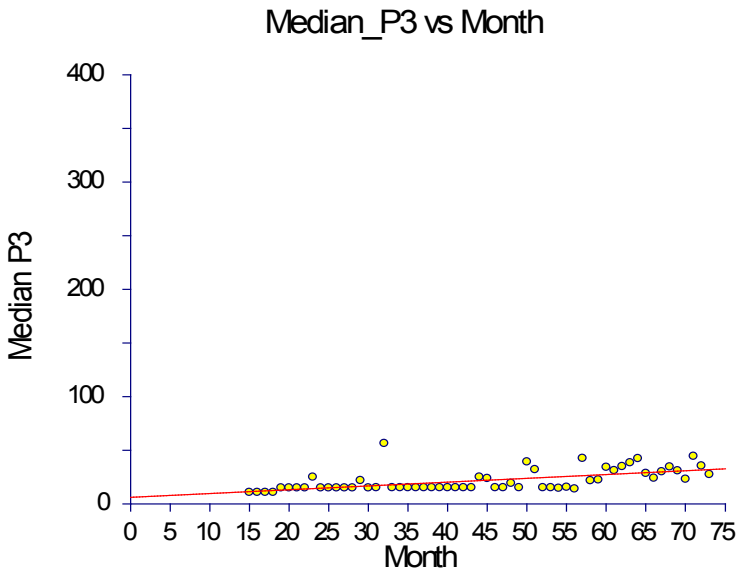

Figure 22: Regression of Median Hydrogen Concentrations in Panel 3

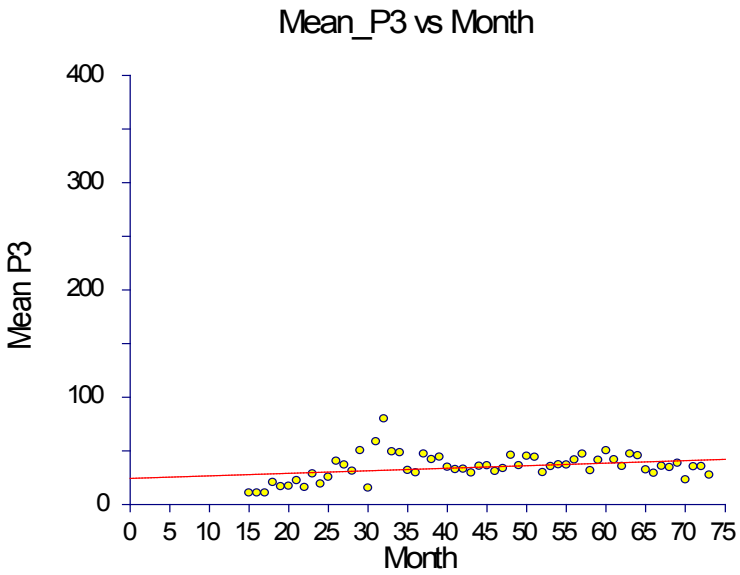

Figure 23: Regression of Mean Hydrogen Concentrations in Panel 3

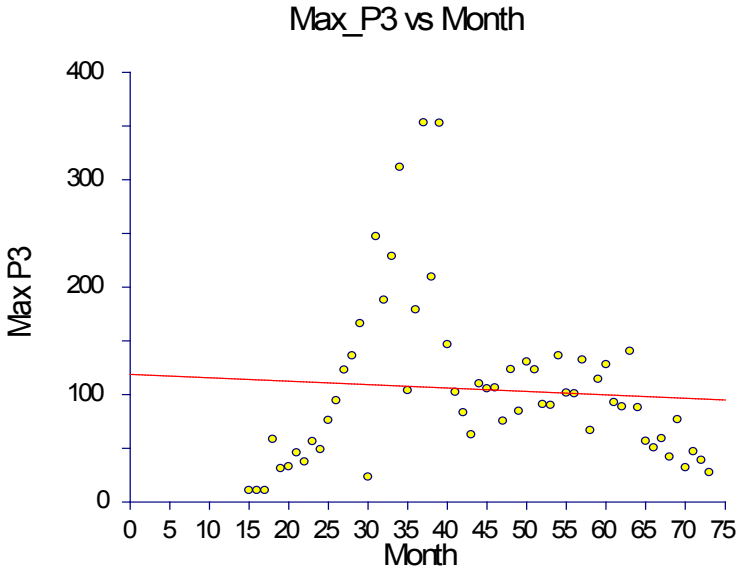

Figure 24: Regression of Maximum Hydrogen Concentrations in Panel 3

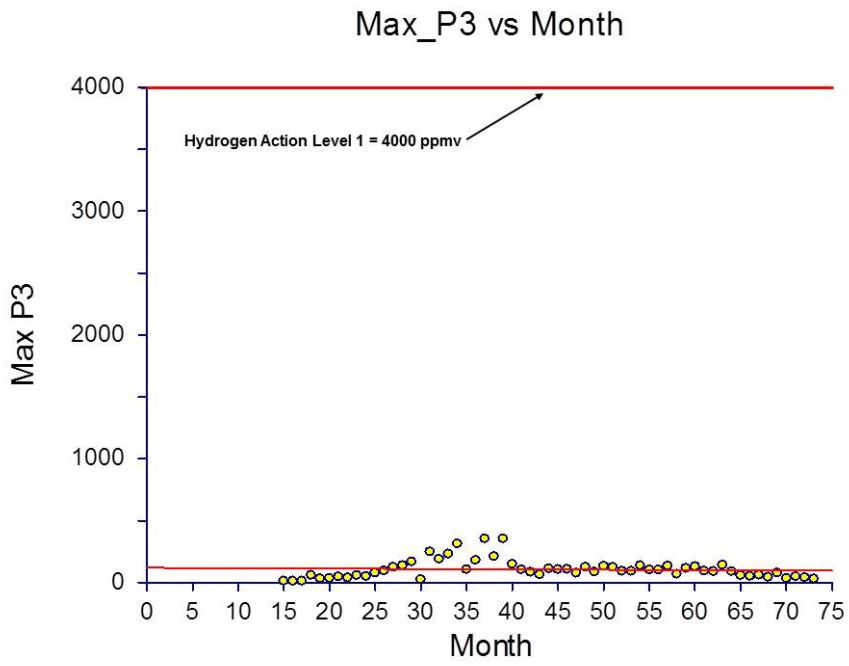

Figure 25: Regression of Maximum Hydrogen Concentrations in Panel 3 Compared to Action Level 1

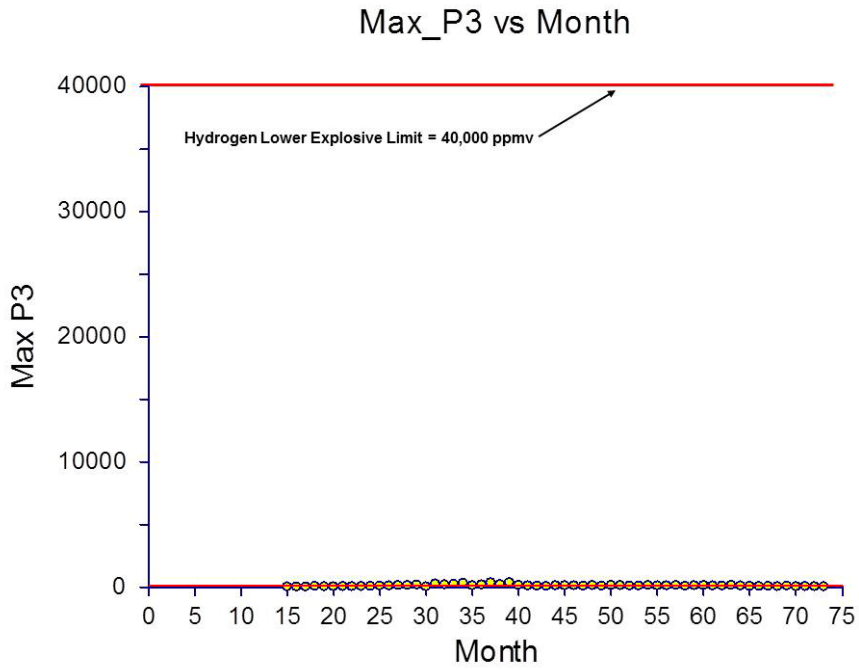

Figure 26: Regression of Maximum Hydrogen Concentrations in Panel 3 Compared to the Lower Explosive Limit

Because the regression equation for the maximum hydrogen concentrations shown in Figures 24 through 26 has a negative slope (i.e. downward trend), the hydrogen concentration will not reach Action Level 1 or LEL.

2. Panel 4 Regression Plots

Figures 27 through 29 plot respectively the median, mean, and maximum hydrogen concentrations vs. the number of months since rooms in Panel 4 were closed. Figures 30 and 31 plot the maximum hydrogen concentrations in relation to Action Level 1 (4,000 ppmv) and the LEL (40,000 ppmv).

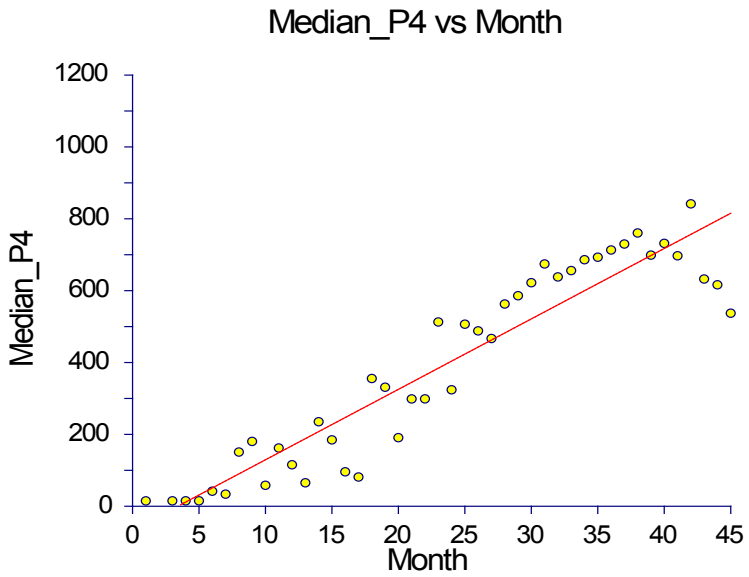

Figure 27: Regression of Median Hydrogen Concentrations in Panel 4

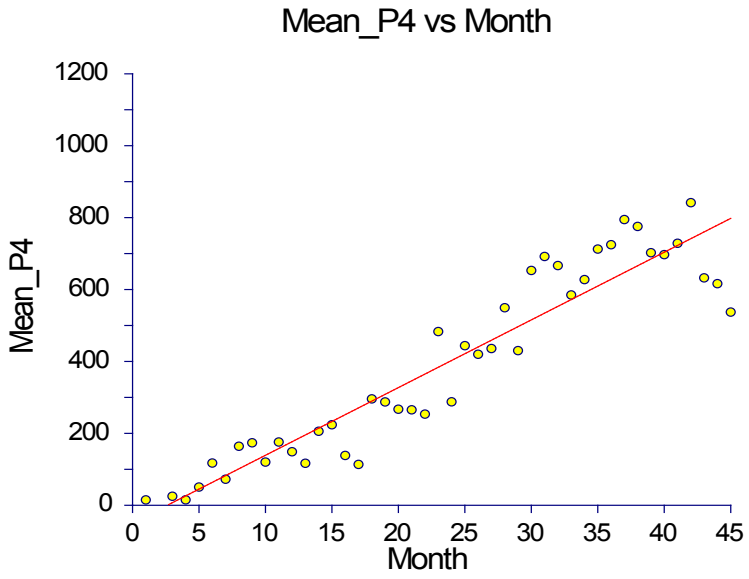

Figure 28: Regression of Mean Hydrogen Concentrations in Panel 4

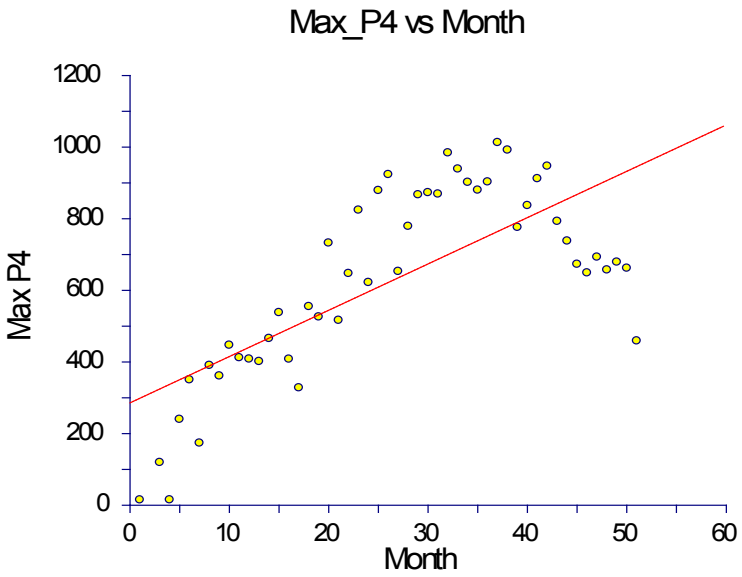

Figure 29: Regression of Maximum Hydrogen Concentrations in Panel 4

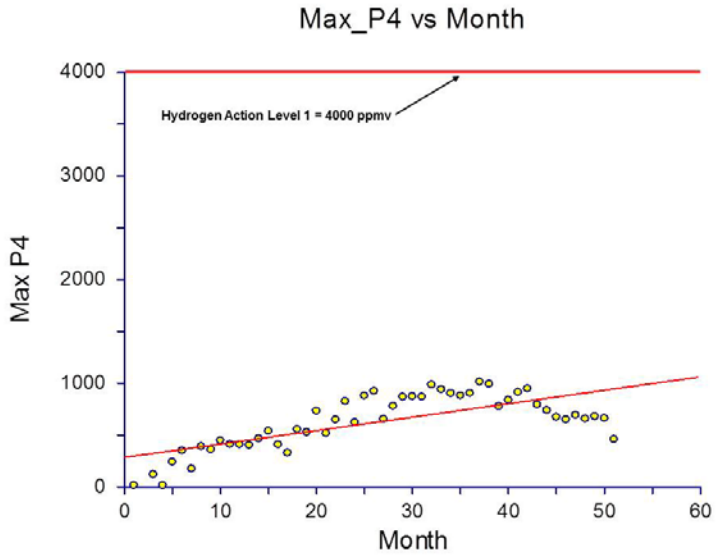

Figure 30: Regression of Maximum Hydrogen Concentrations in Panel 4 Compared to Action Level 1

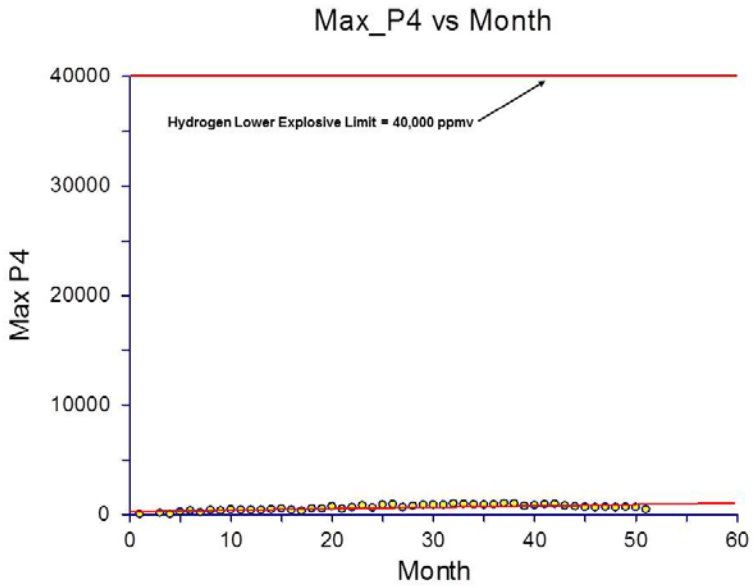

Figure 31: Regression of Maximum Hydrogen Concentrations in Panel 4 Compared to the Lower Explosive Limit

Using the regression equation for the maximum hydrogen concentrations shown in Figures 29 through 31, the hydrogen concentrations will reach Action Level 1 in approximately 23 years, assuming this historical rate of hydrogen concentration change.

VI. Discussion

The statistical analysis has revealed several pertinent results:

- Rooms further from the main access drift tend to show higher average concentrations than rooms closer to the drift. This phenomenon can be seen in Figures 2 through 5. Rooms further from the main access drift have a longer time period during which hydrogen may accumulate.

- Box-and-whisker plots show that all sample data are substantially below Action Level 1 (Figures 6 through 9). Box-and-whisker plots also show that rooms closer to the main access drift generally have lower hydrogen than rooms further away.

- Time series plots reveal that hydrogen concentration maximums are temporary and that concentrations can fall to near non-detectable levels after peaking.

- Hydrogen concentration plots in Panel 3 rooms show a peak in hydrogen concentrations followed by a sustained period of low hydrogen levels, which is ongoing according to the latest sample data. Hydrogen concentration plots in Panel 4 rooms show erratically rising concentrations, with maximum levels exhibiting a leveling off trend or most recently a decline.

- Linear regression of hydrogen concentration data shows varying results in Panels 3 and 4. Hydrogen concentrations in Panel 3 are declining, which indicates neither Action Level 1 nor the LEL will be reached, as shown by the infinity sign in Table 3. In Panel 4, the hydrogen levels have risen slowly since the panel was blocked to ventilation. The regression model predicts it will be over 23 years in Panel 4 before hydrogen levels rise to Action Level 1. Moreover, the regression models indicate it would take more than 250 years for the hydrogen levels to rise to the LEL in Panel 4 (Table 3).

Table 3: Expected Time to Exceedance of Hydrogen Regulatory Thresholds in Panels 3 and 4

WIPP - Hydrogen Levels		
Panel	Predicted Time to Exceedance (Years)	
	Action Level 1	Lower Explosive Limit
3	∞	∞
4	23+	250+

The rooms and panels are not completely sealed to the outside areas of the mine, which may contribute to the fluctuations observed in the room hydrogen levels. Changes in mine ventilation, changes in the efficacy of bulkheads in a dynamic environment subject to salt creep, and other factors could influence hydrogen concentrations to an unknown degree.

VII. Summary

The air monitoring data in Panels 3 and 4 indicate methane concentrations are below the MDL.

Hydrogen concentrations in Panels 3 and 4 have remained substantially below the AL of 4,000 ppmv during the entire monitoring program. The maximum hydrogen concentration observed (1,013 ppmv) slightly exceeded 25 percent of the lower AL, indicating no challenge to either the AL or LEL of 4 percent (40,000 ppmv). Regression models indicate that hydrogen levels would not rise to the LEL in Panels 3 or 4 during the operational period of the WIPP (Table 3).

VIII. References

Golder Associates, November 30, 2006. Letter to Rick Chavez: *Early Time Generation of Methane and Hydrogen in Filled Panels at the WIPP*.

Sandia National Laboratories, January 26, 1996. Letter from Yifeng Wang and Larry Brush to Martin S. Tierney: *Estimates of Gas-Generation Parameters for the Long-Term WIPP Performance*.

U.S. Environmental Protection Agency (EPA), 1999. *Compendium Method TO-15: Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry*, EPA 625/R-96/010b. Center for Environmental Research Information, Office of Research and Development, Cincinnati, OH, January 1999.

Washington Group International, July26, 2006. Letter to D. Mercer, CBFO: *Estimation of Hydrogen Rates from Radiolysis in WIPP Panels*.

Appendix A

Time Series Plots for Hydrogen Concentrations in Panel 3

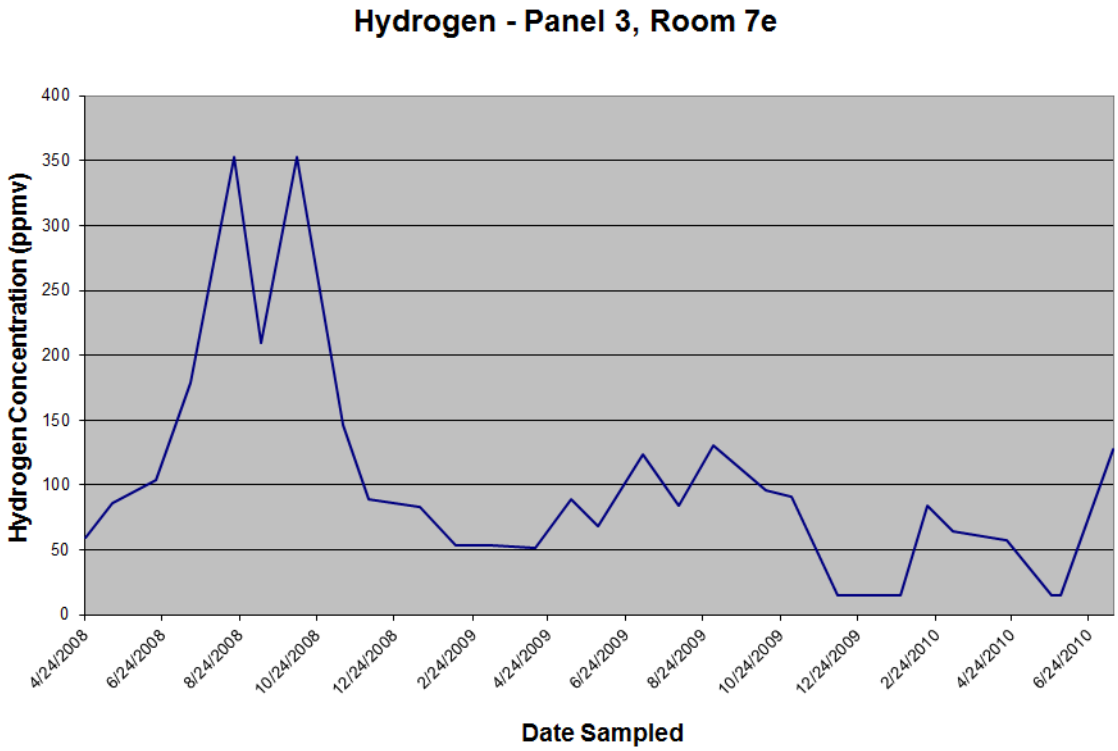

Figure 10: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 7e

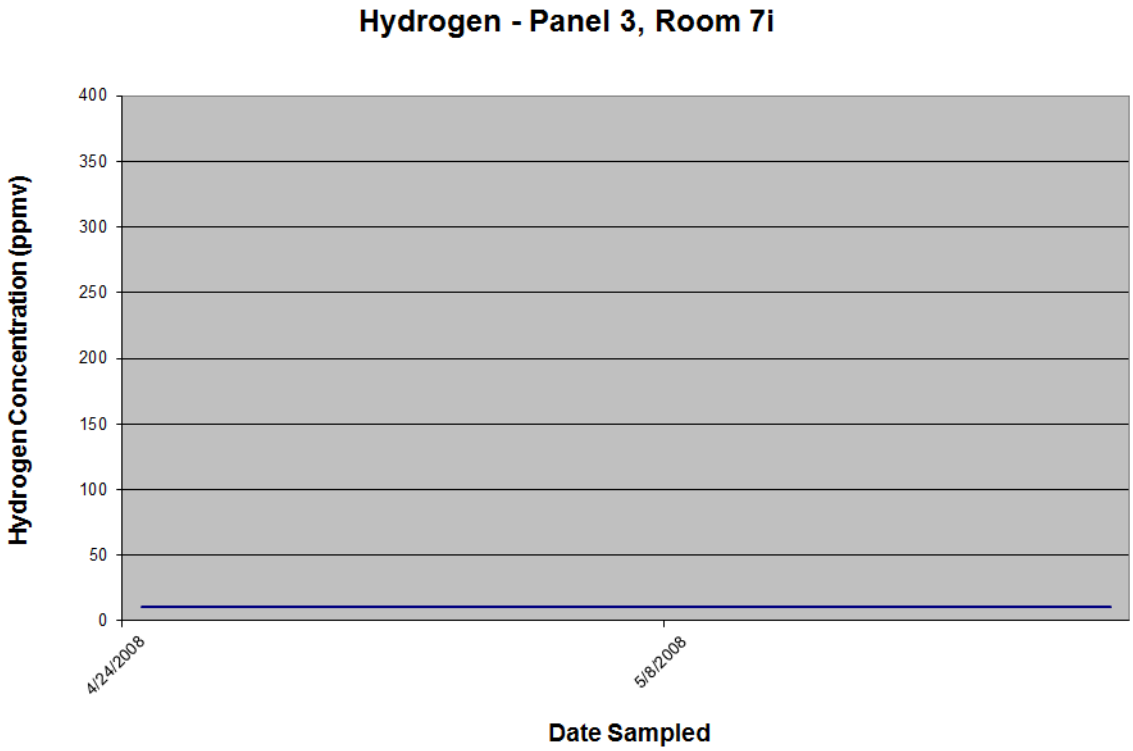

Figure 11: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 7i

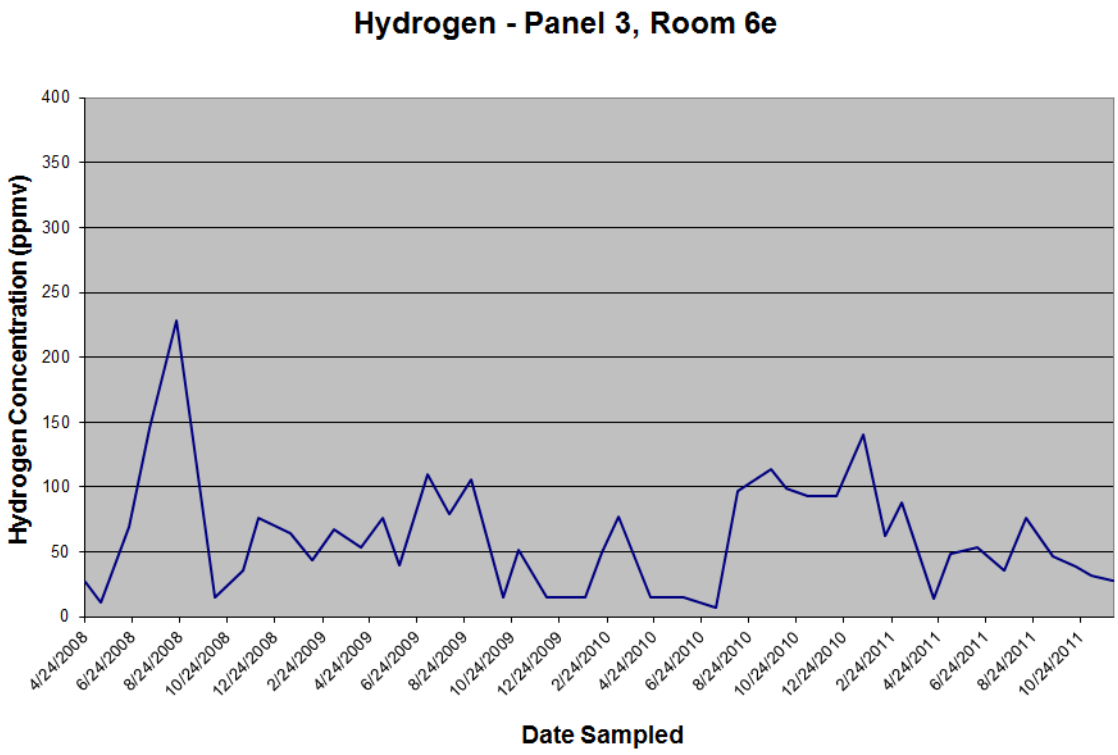

Figure 12: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 6e

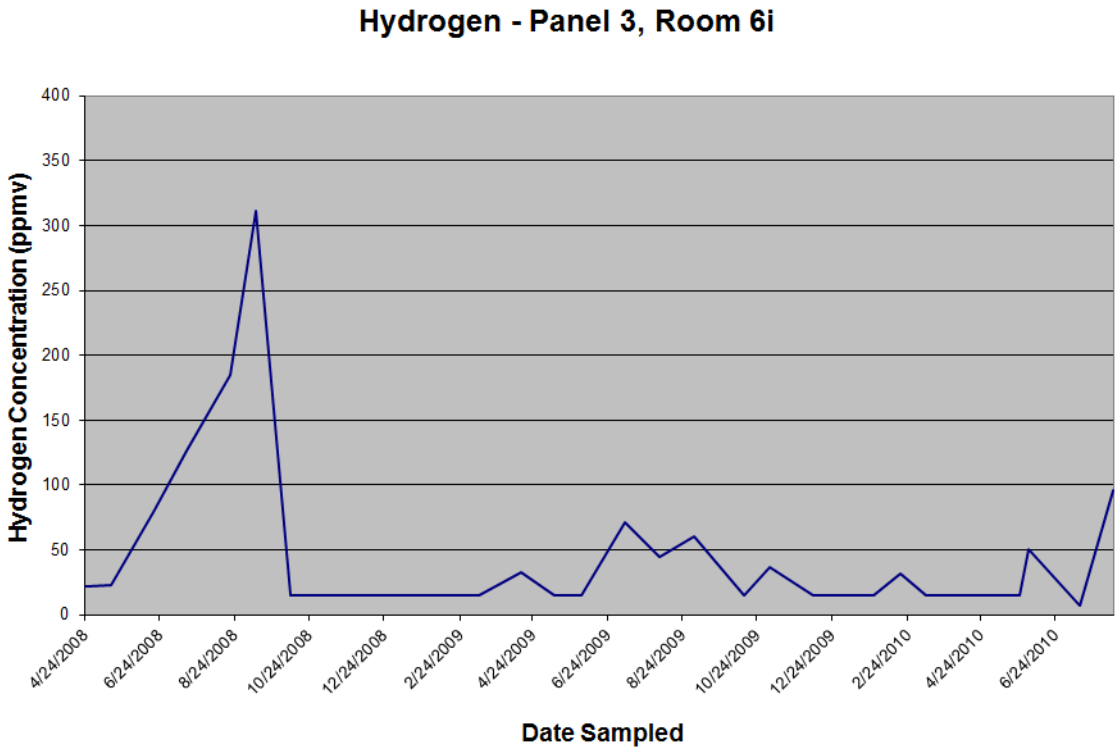

Figure 13: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 6i

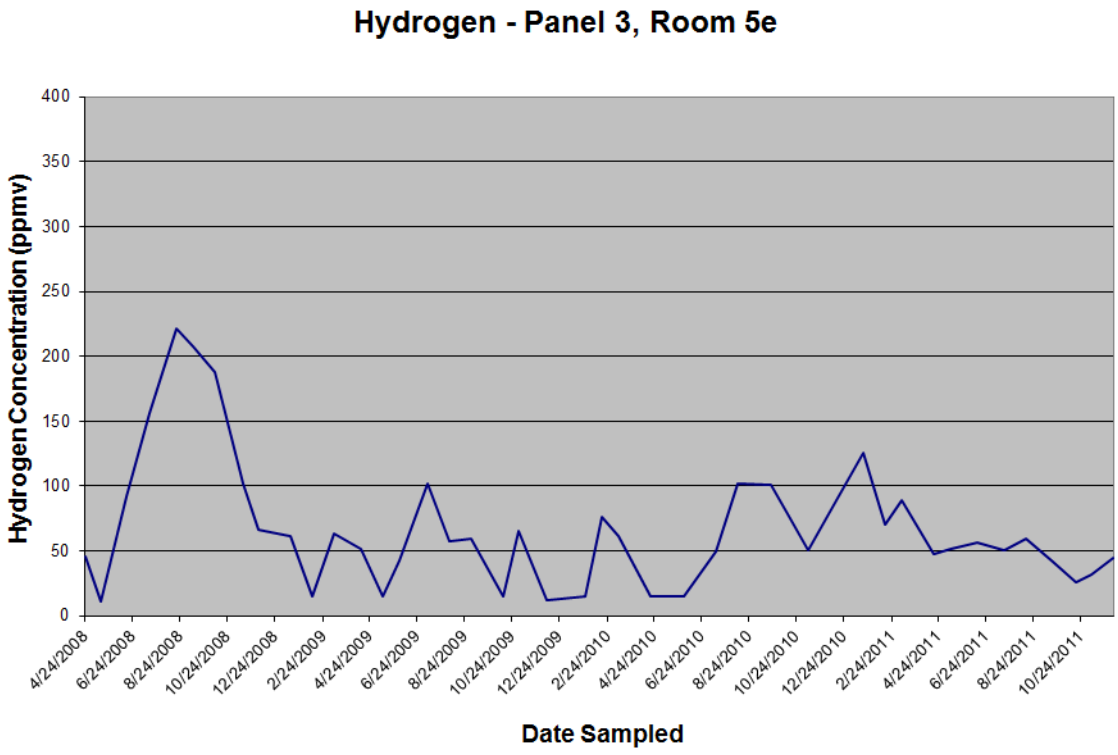

Figure 14: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 5e

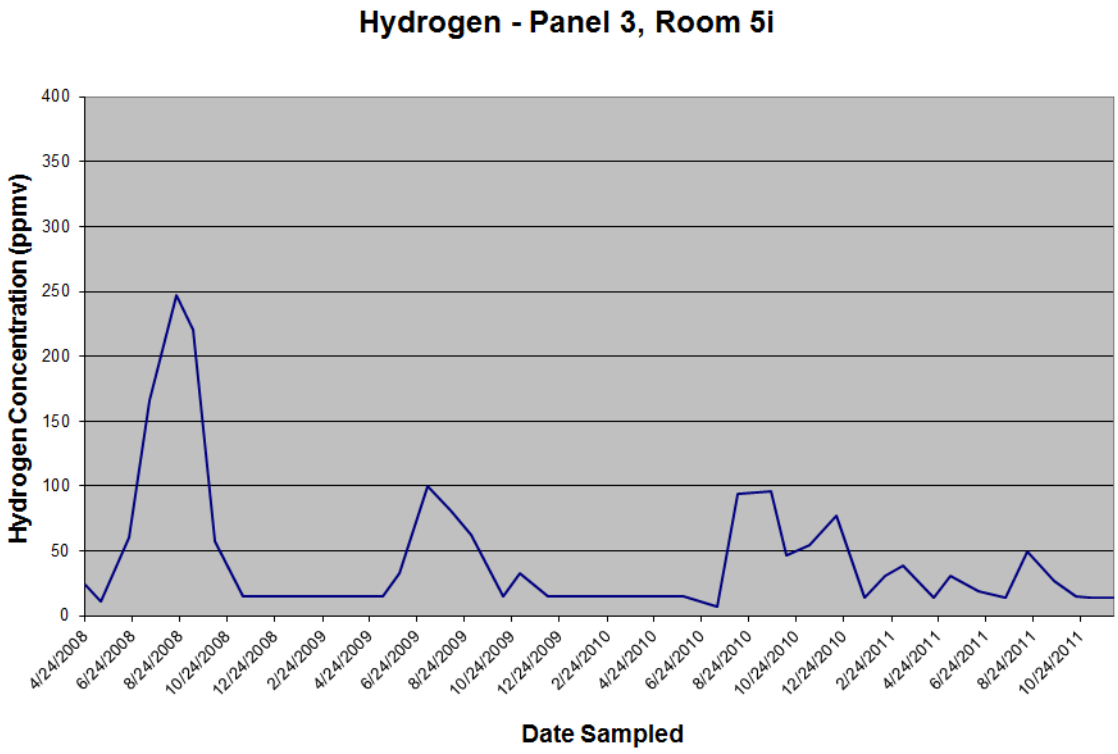

Figure 15: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 5i

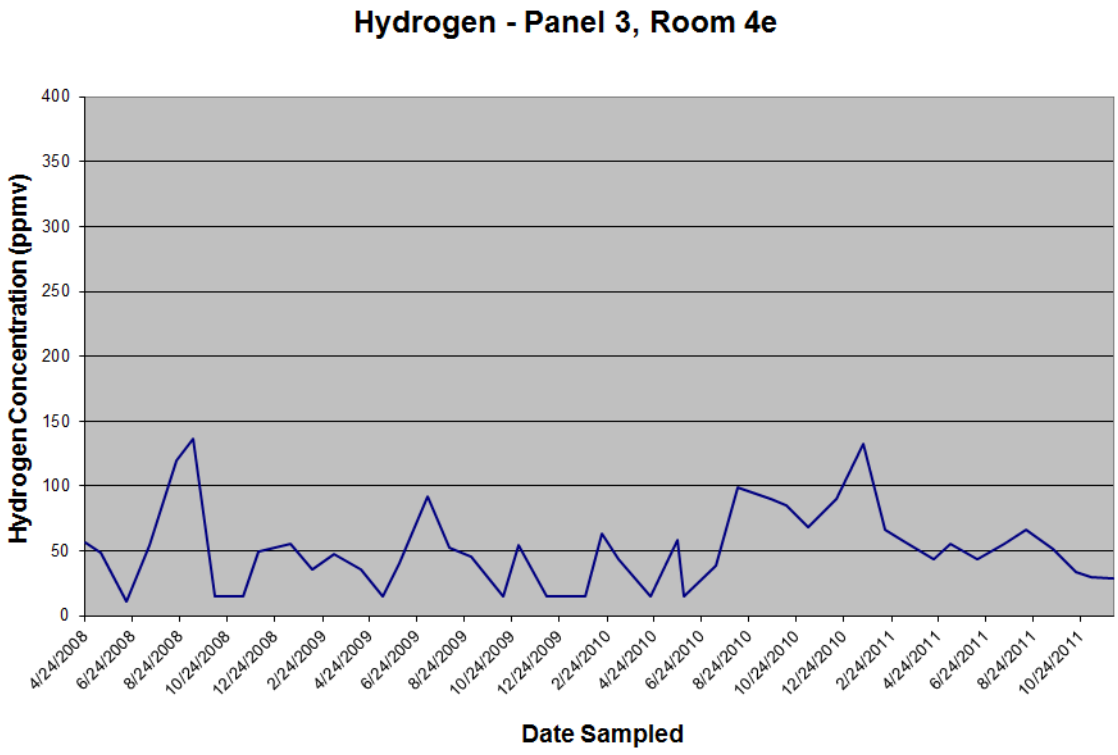

Figure 16: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 4e

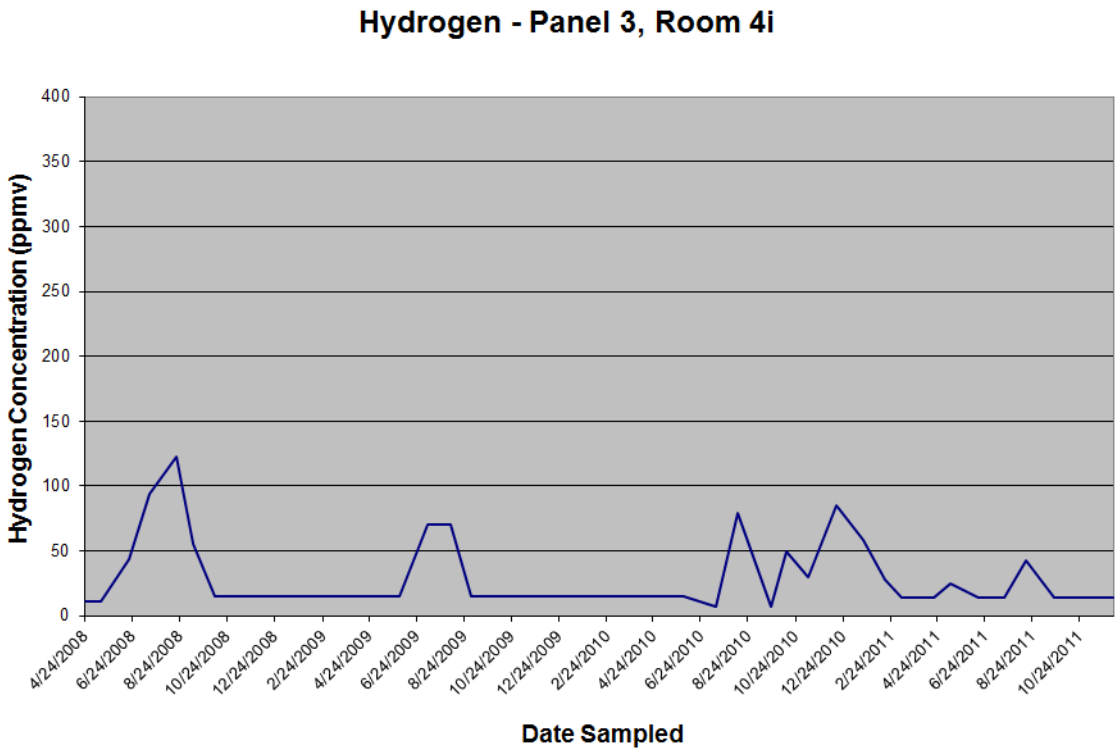

Figure 17: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 4i

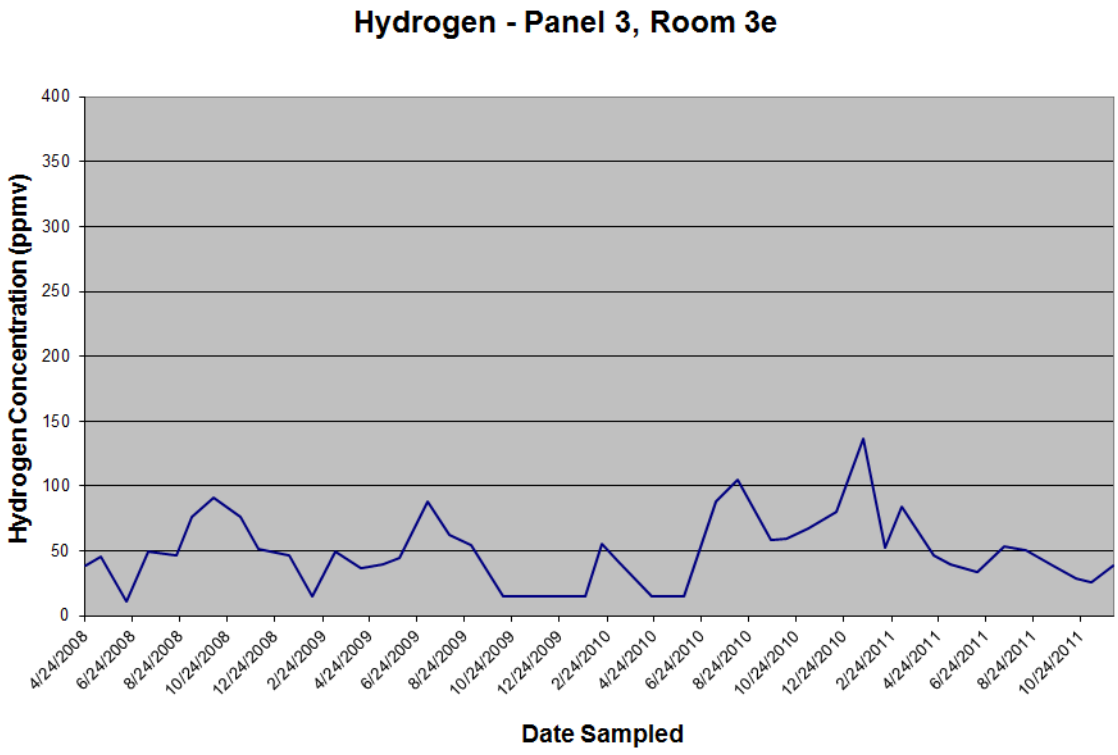

Figure 18: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 3e

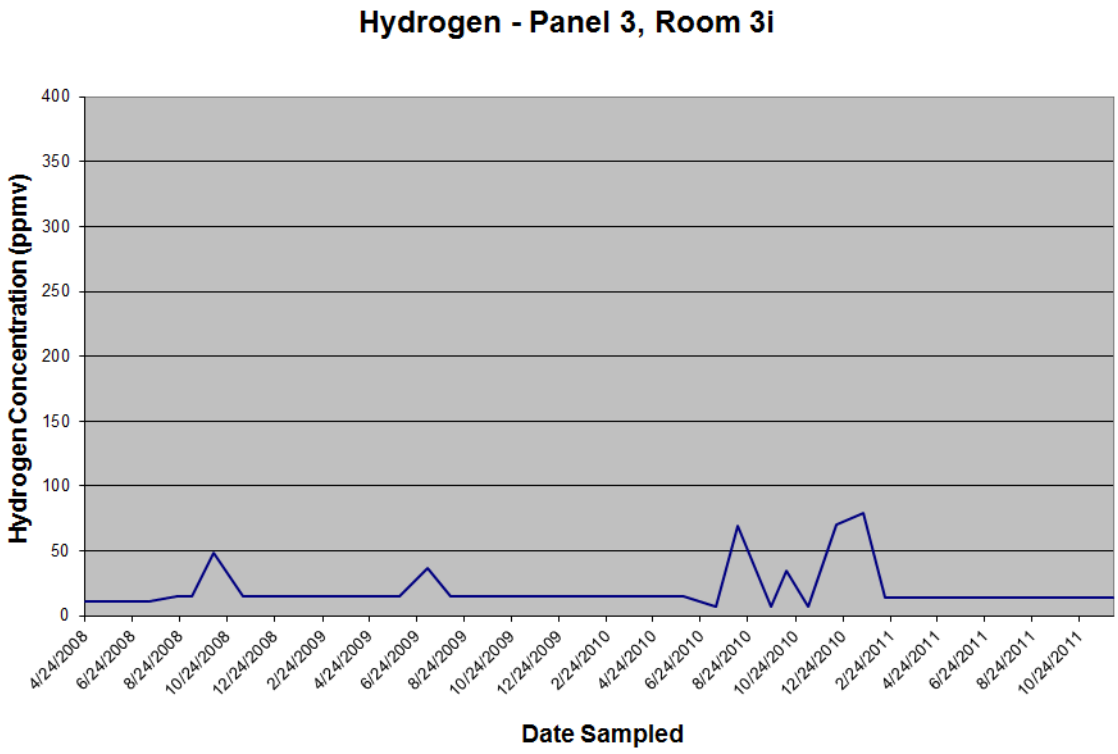

Figure 19: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 3i

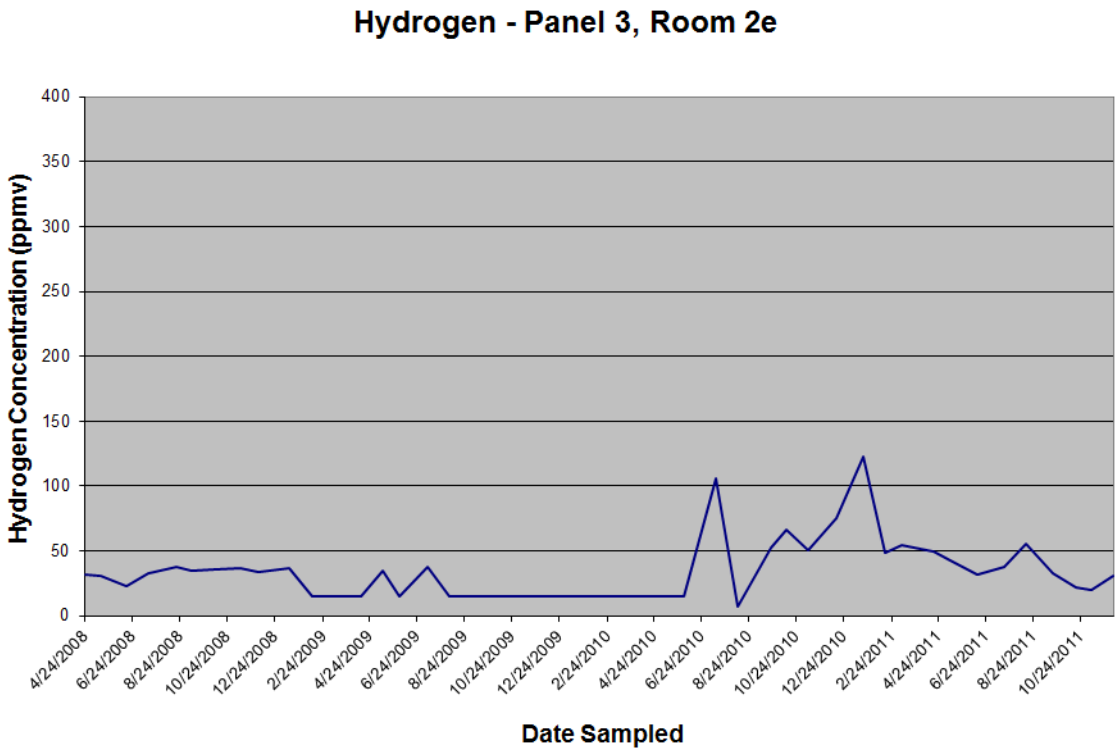

Figure 20: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 2e

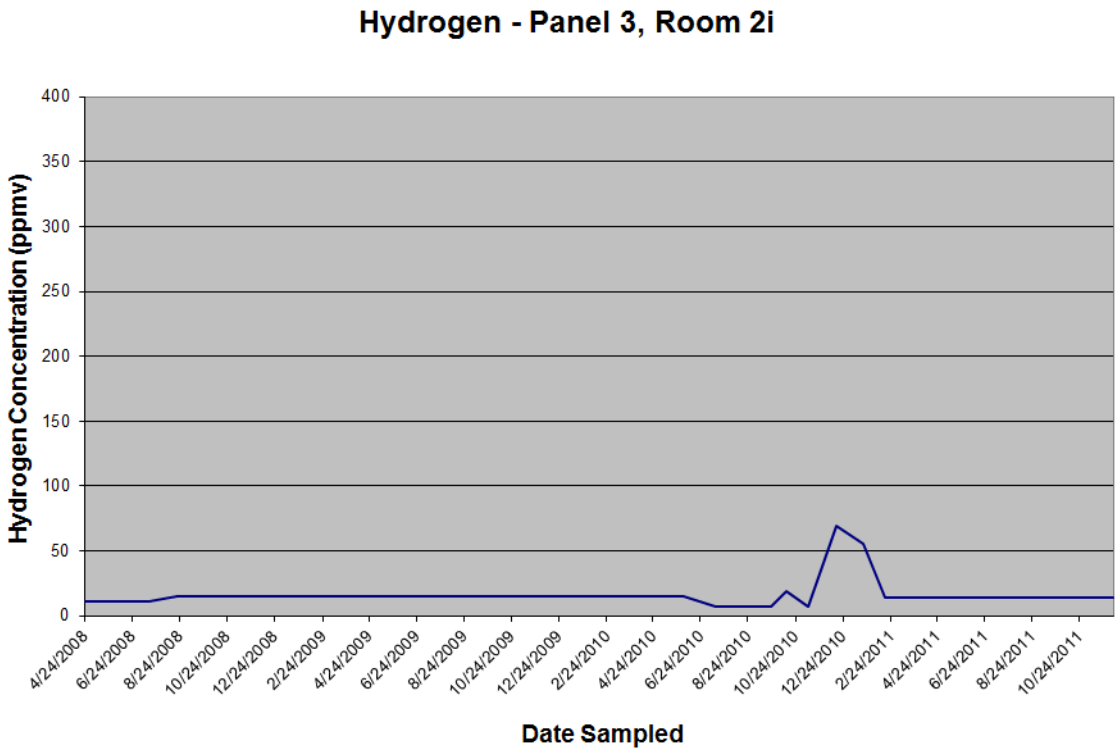

Figure 21: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 2i

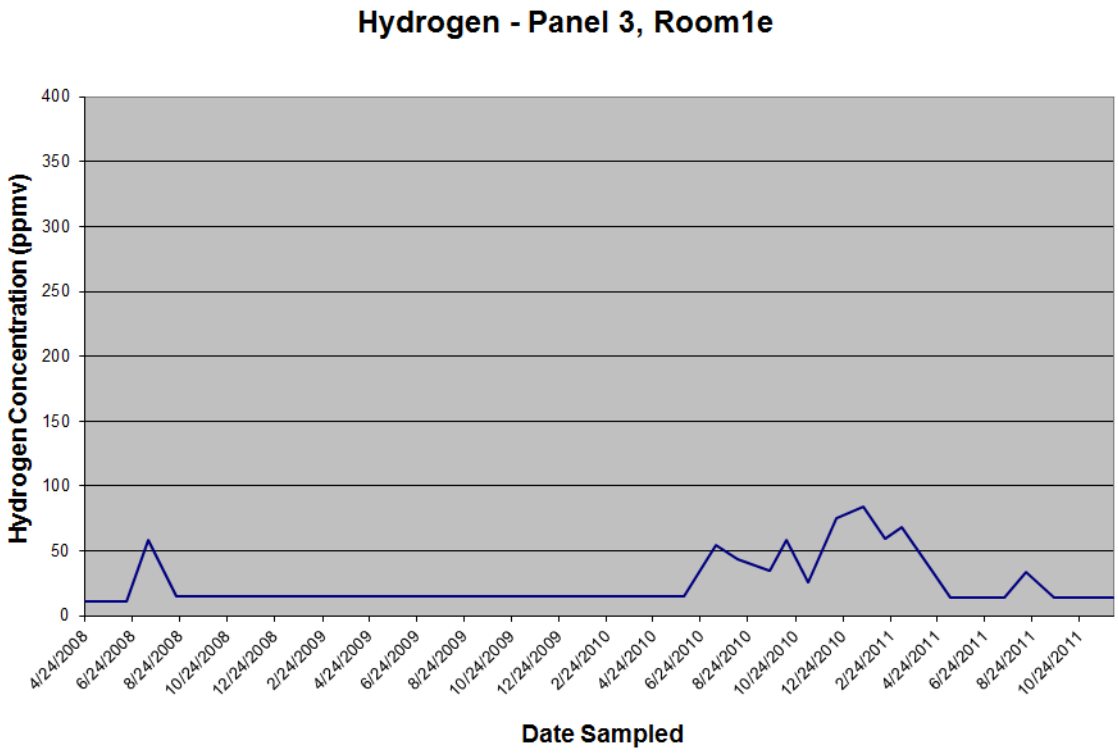

Figure 22: Time Series Plot of Hydrogen Concentrations in Panel 3, Room 1e

The *Time Series Plot of Hydrogen Concentrations in Panel 3, Room 1i* has been omitted due to a lack of data. Only three samples exist at this location, each of which has a statistical evaluation concentration of 10.79 ppmv. These data appear in the table on page 99.

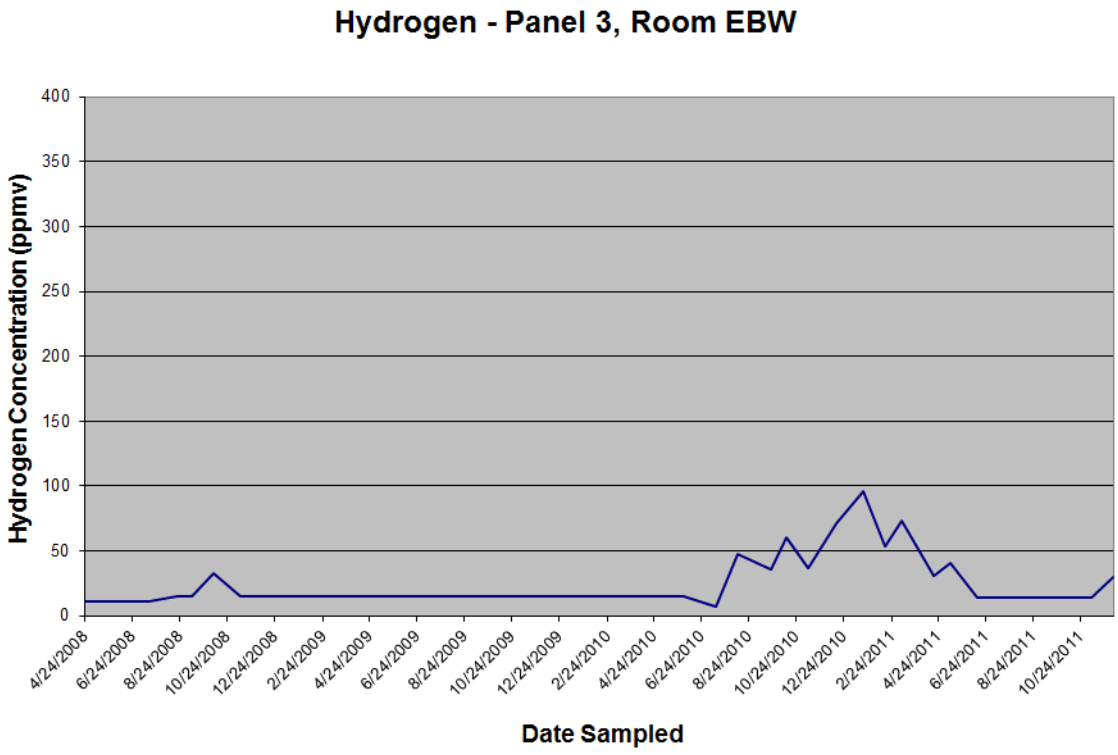

Figure 23: Time Series Plot of Hydrogen Concentrations in Panel 3, EBW

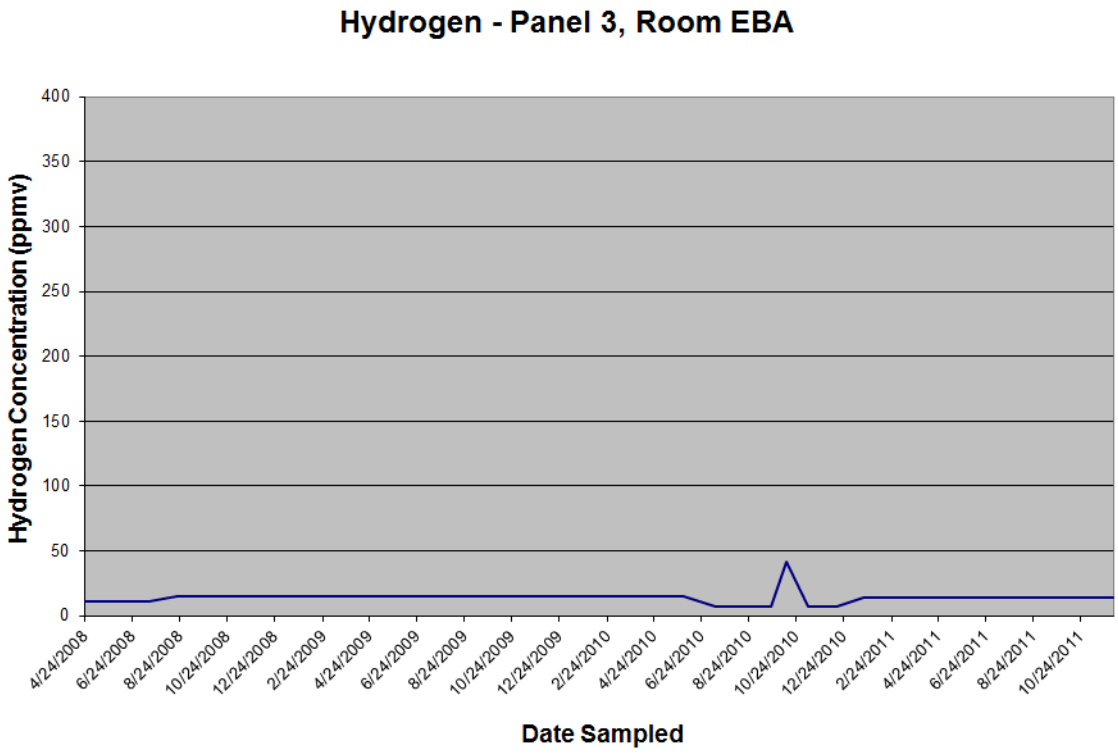

Figure 24: Time Series Plot of Hydrogen Concentrations in Panel 3, EBA

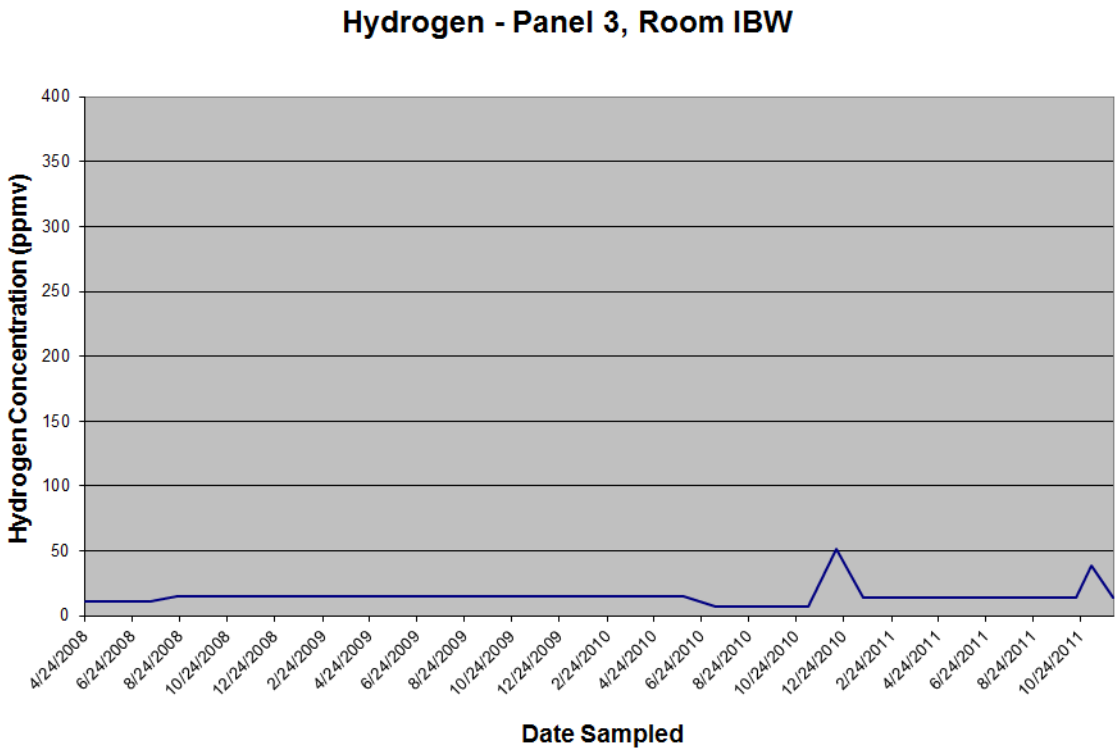

Figure 25: Time Series Plot of Hydrogen Concentrations in Panel 3, IBW

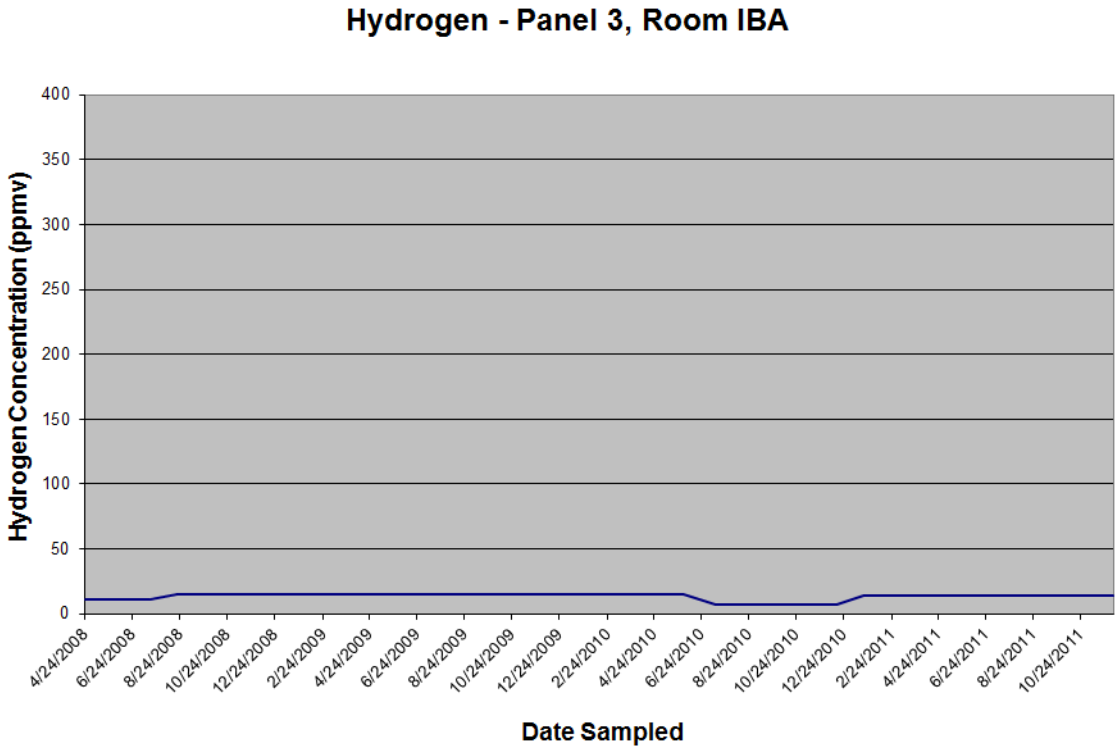

Figure 26: Time Series Plot of Hydrogen Concentrations in Panel 3, IBA

Appendix B

Time Series Plots for Hydrogen Concentrations in Panel 4

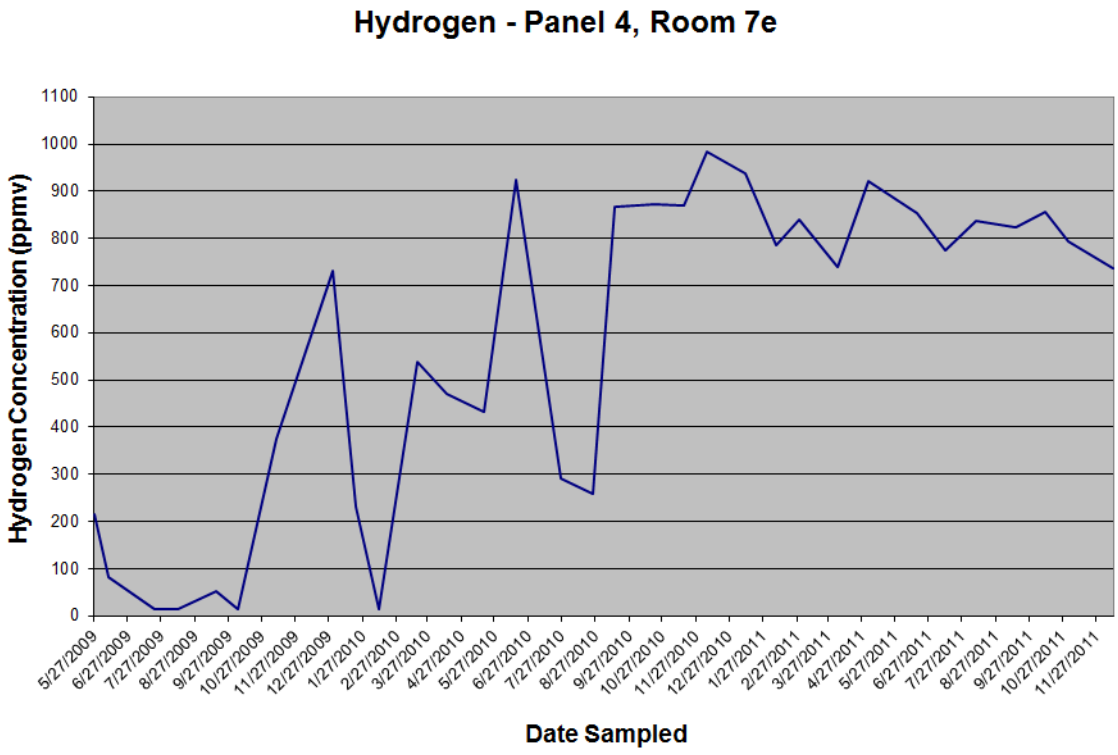

Figure 27: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 7e

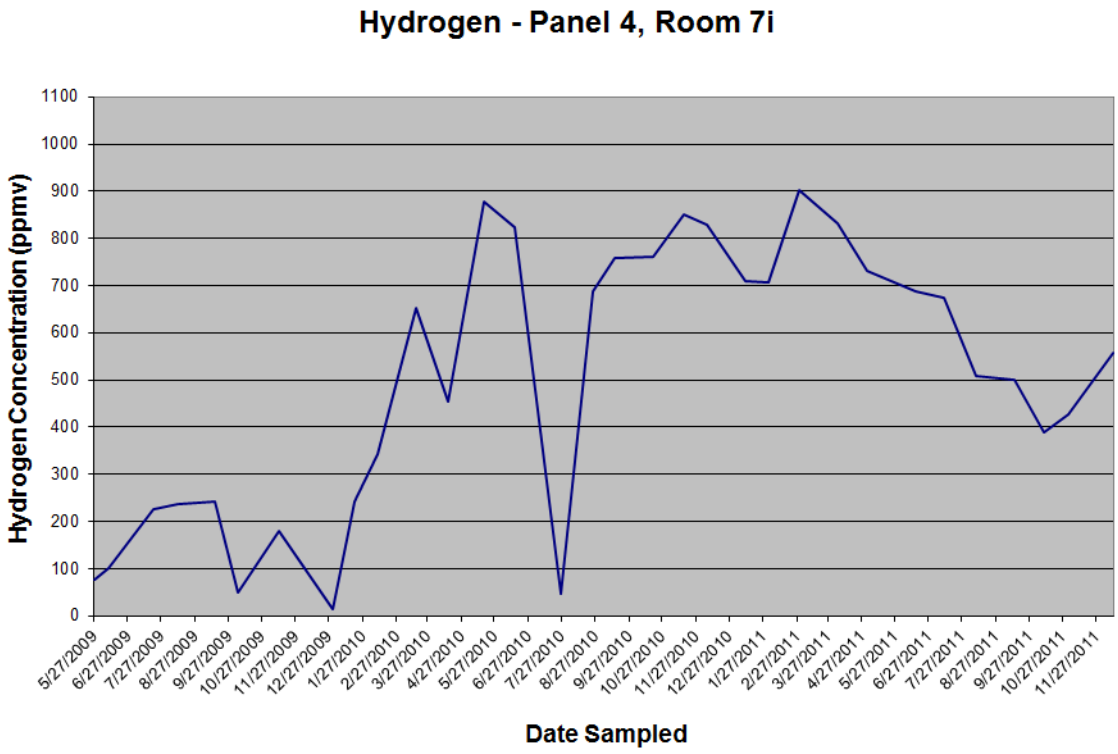

Figure 28: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 7i

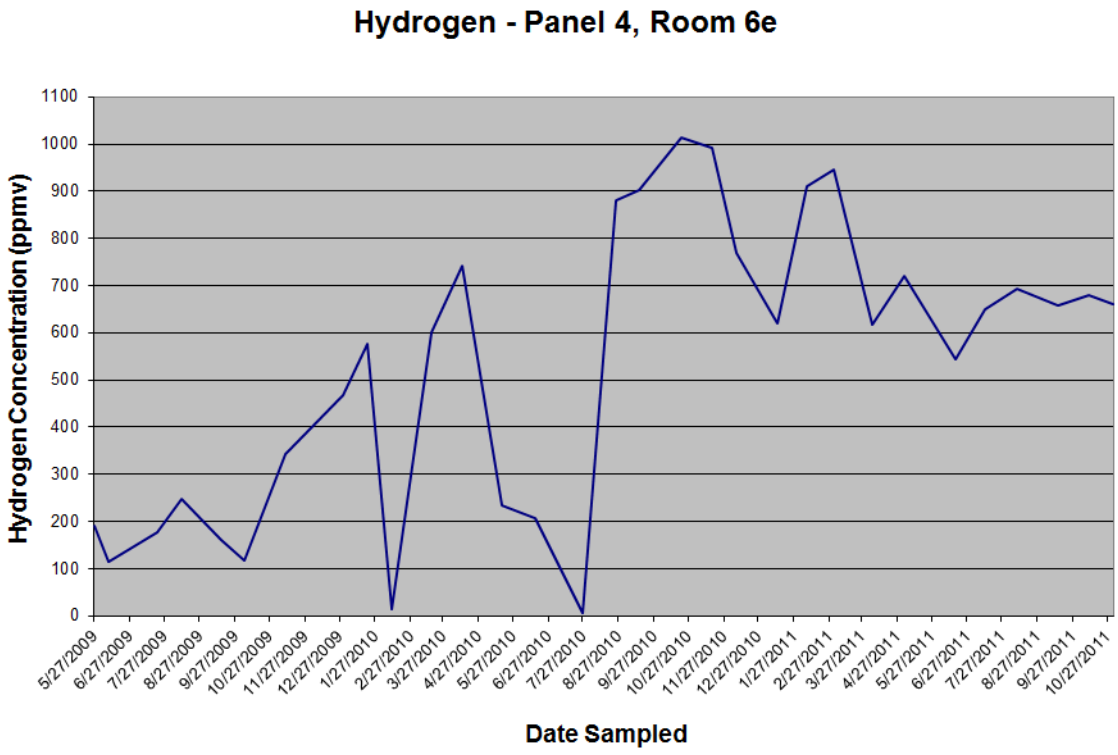

Figure 29: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 6e

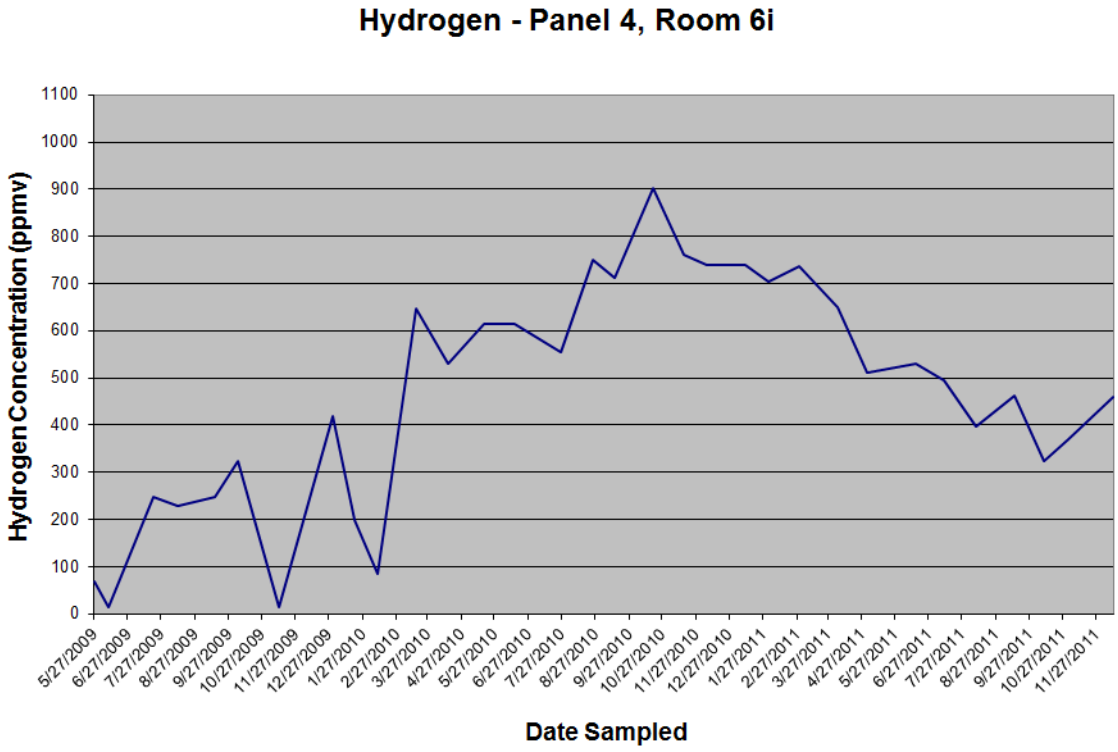

Figure 30: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 6i

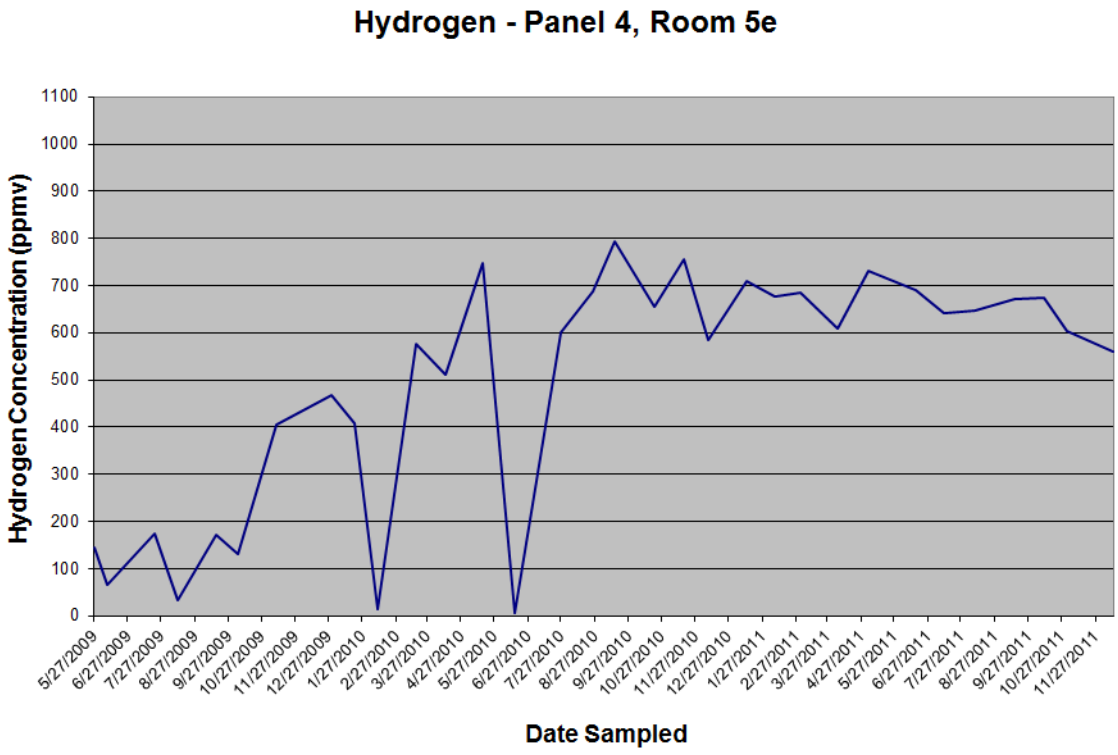

Figure 31: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 5e

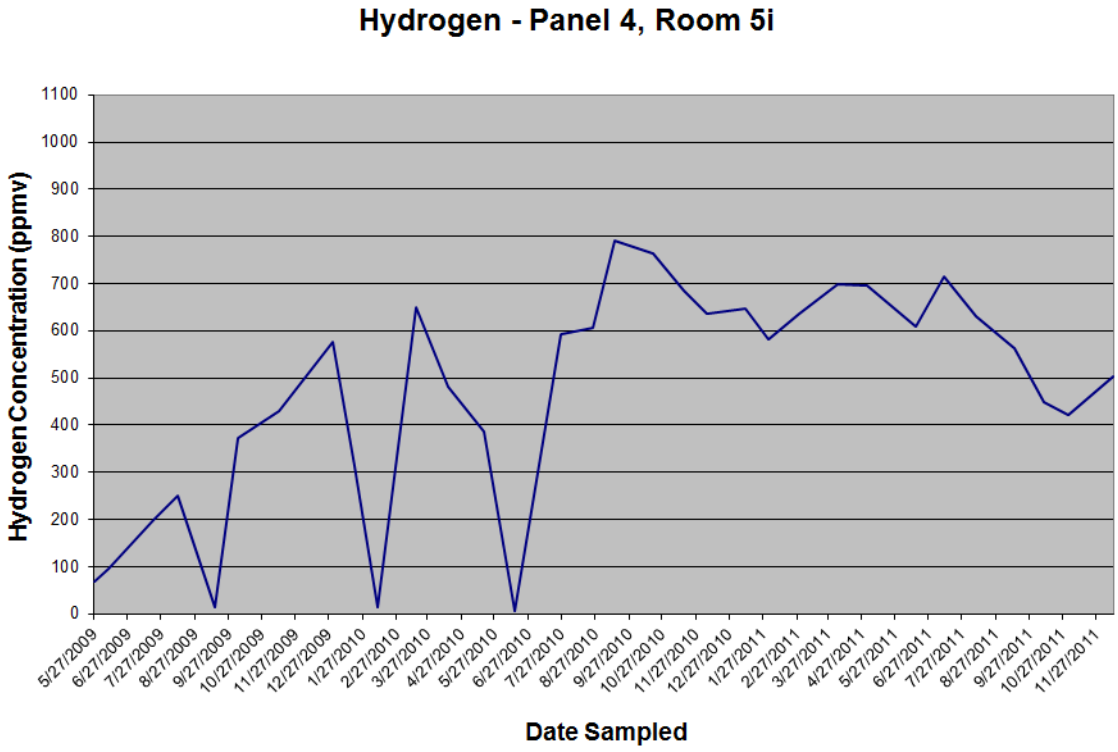

Figure 32: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 5i

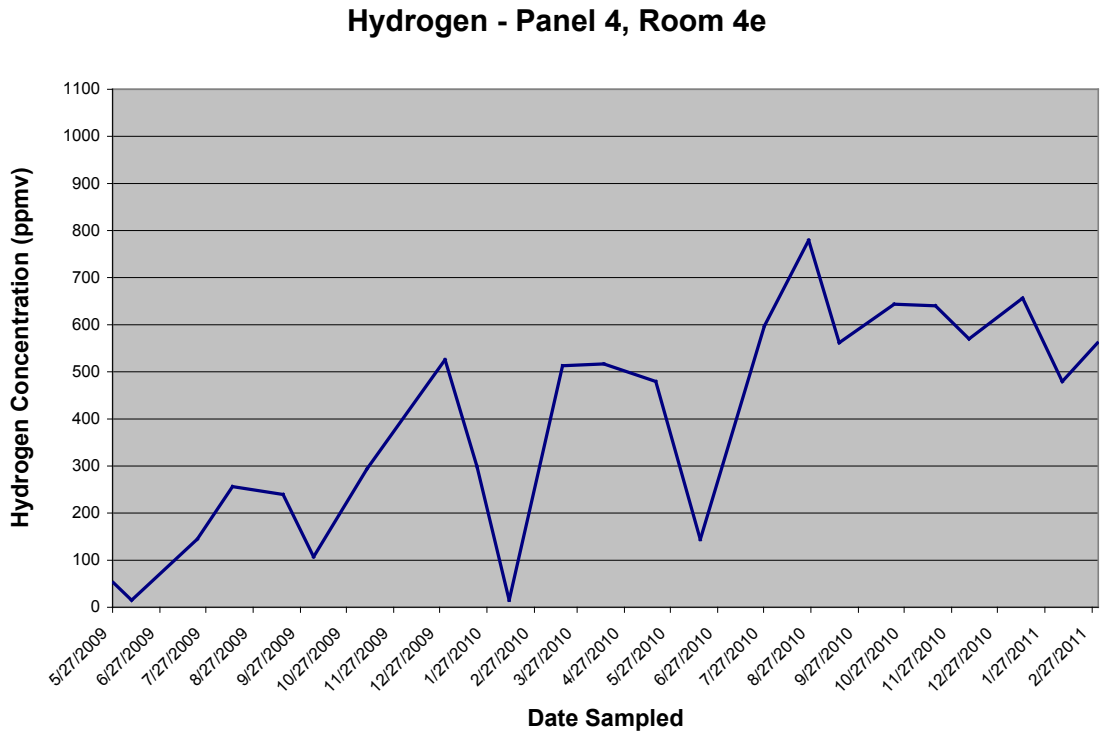

Figure 33: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 4e

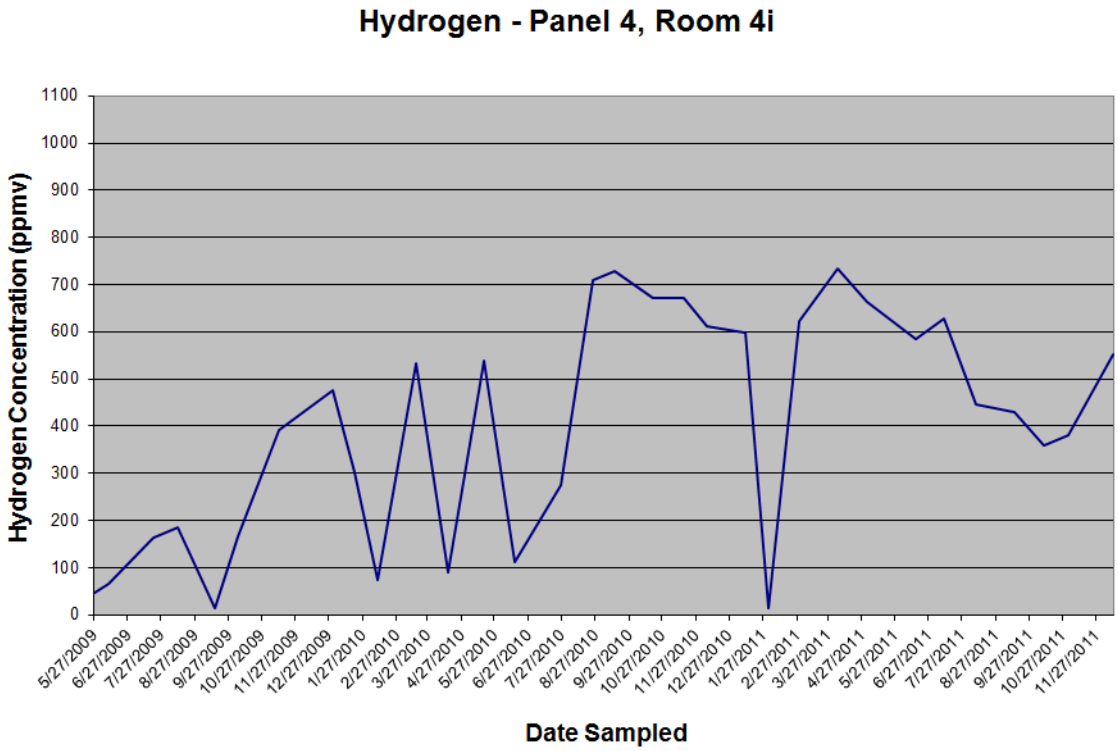

Figure 34: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 4i

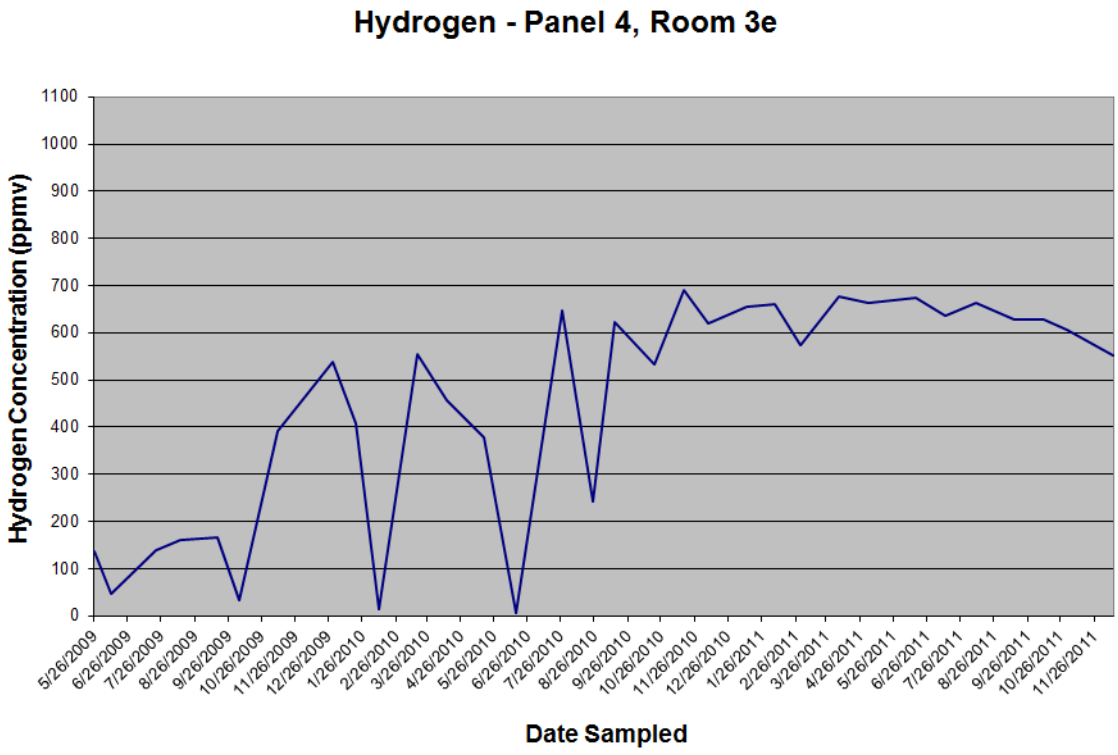

Figure 35: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 3e

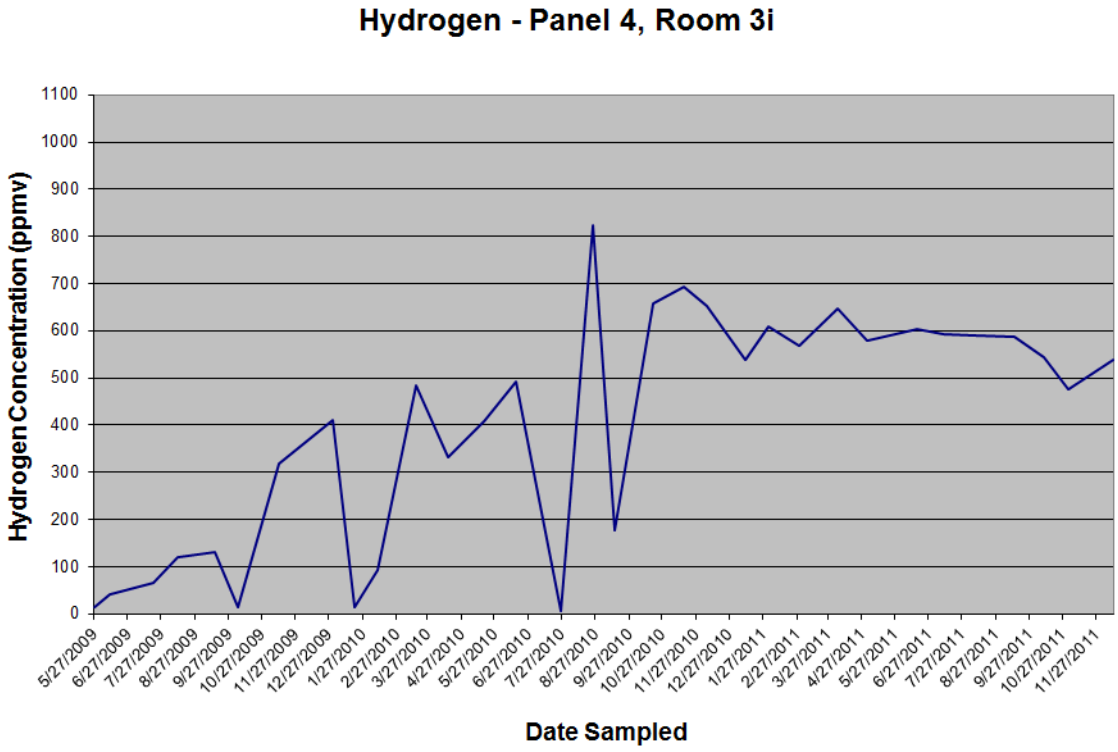

Figure 36: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 3i

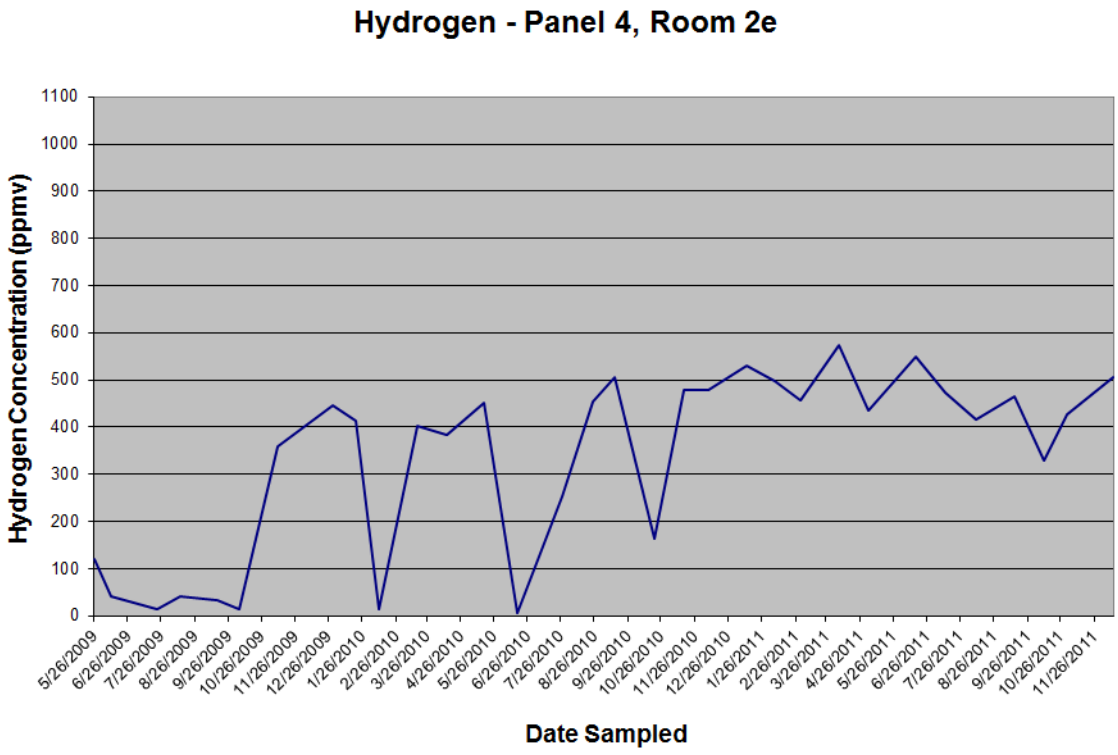

Figure 37: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 2e

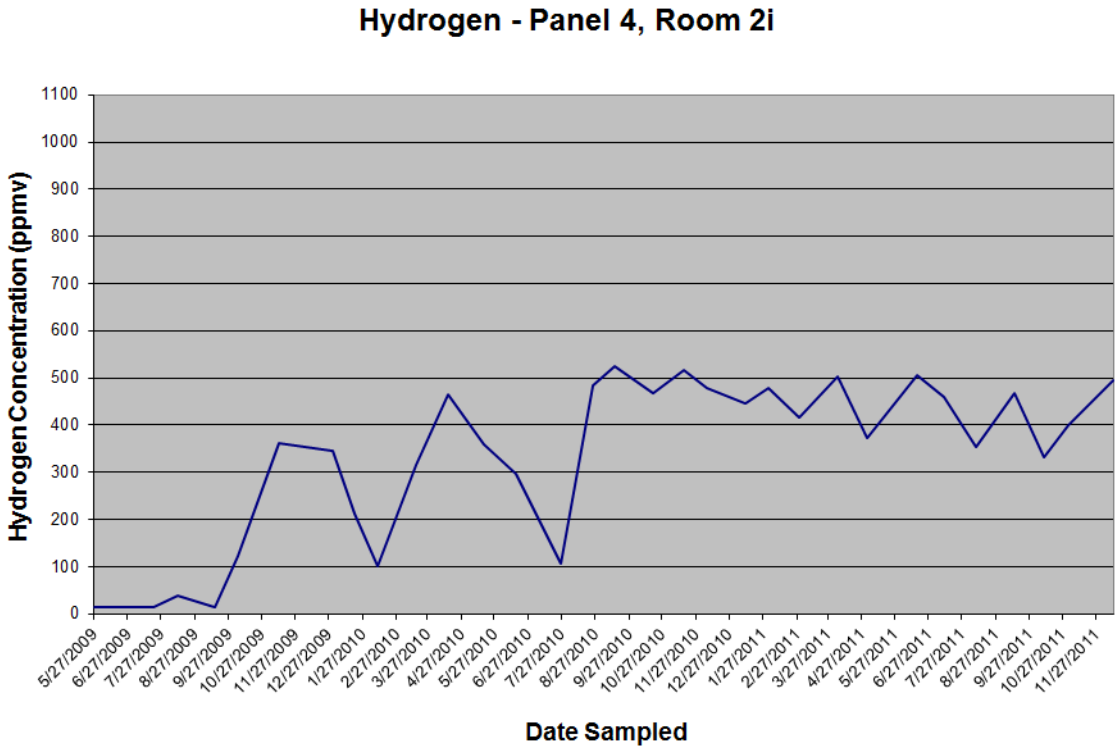

Figure 38: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 2i

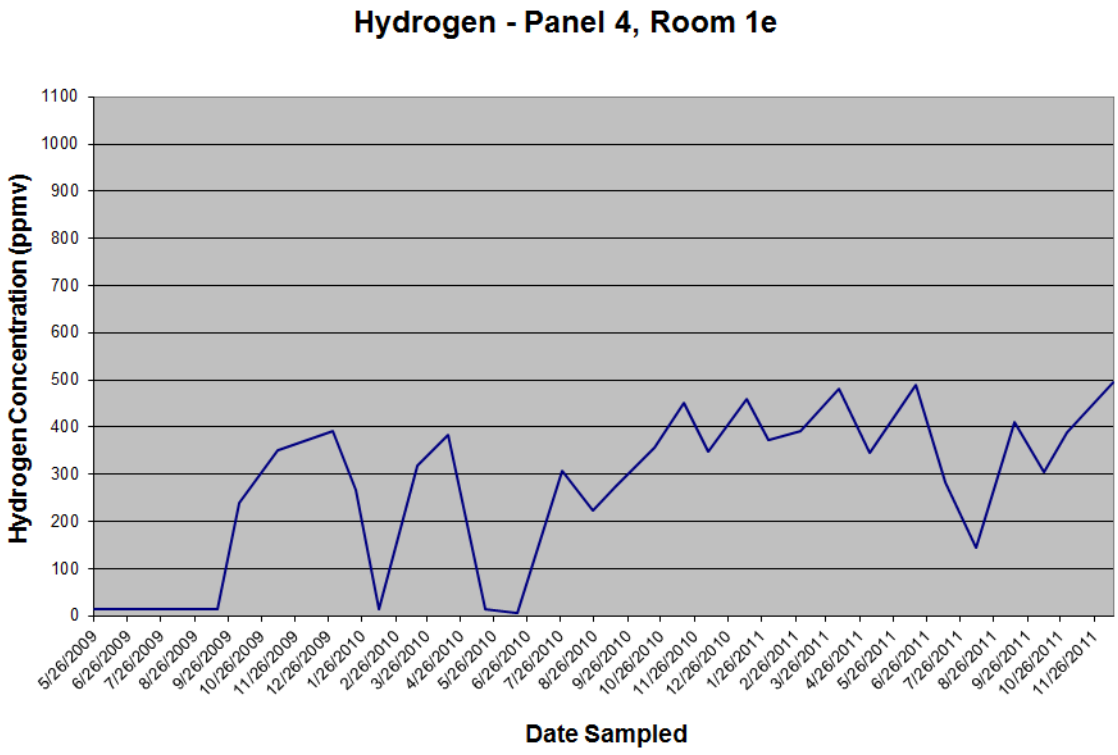

Figure 39: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 1e

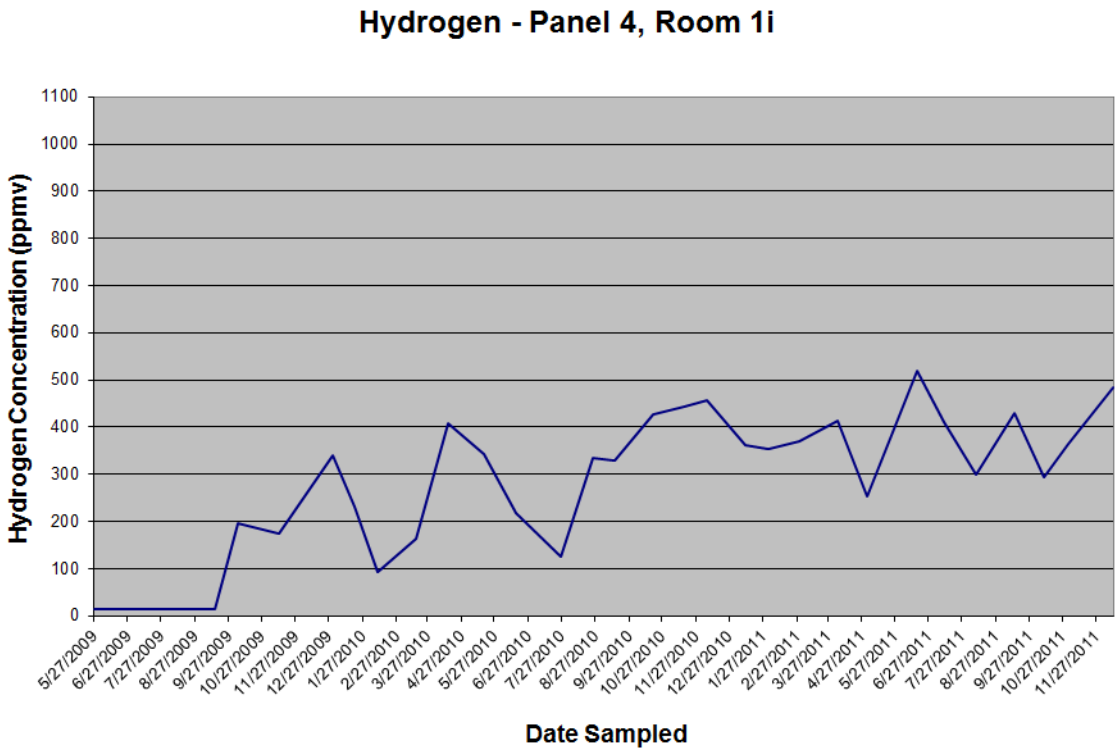

Figure 40: Time Series Plot of Hydrogen Concentrations in Panel 4, Room 1i

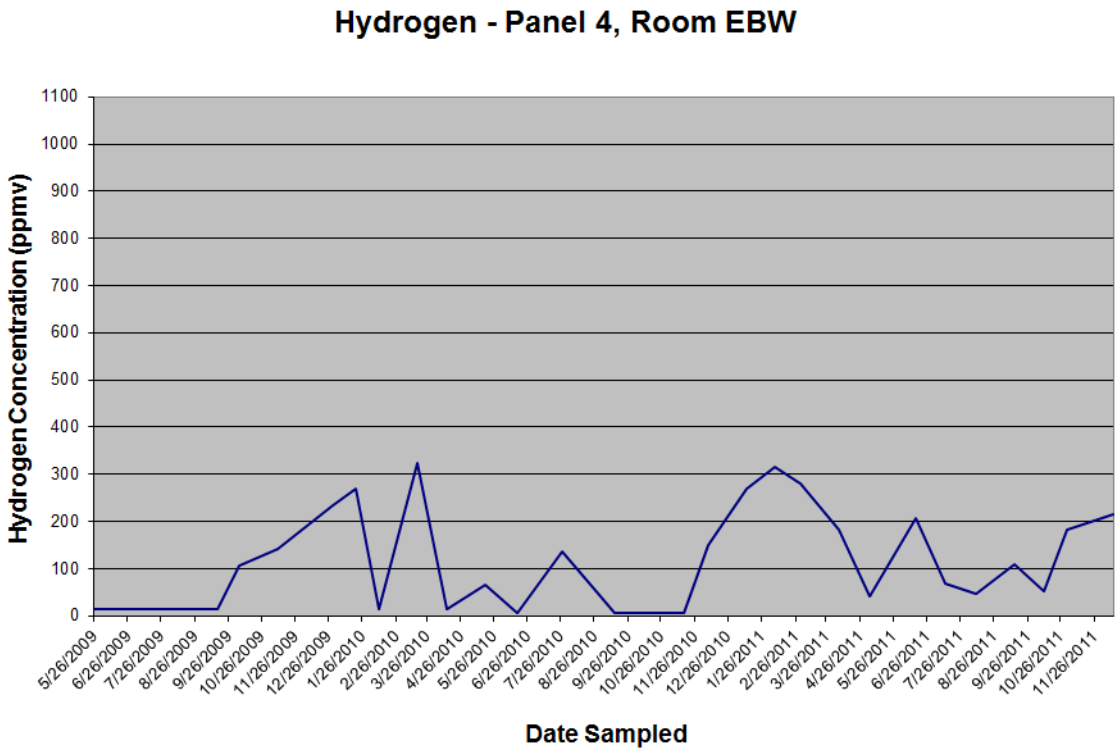

Figure 41: Time Series Plot of Hydrogen Concentrations in Panel 4, Room EBW

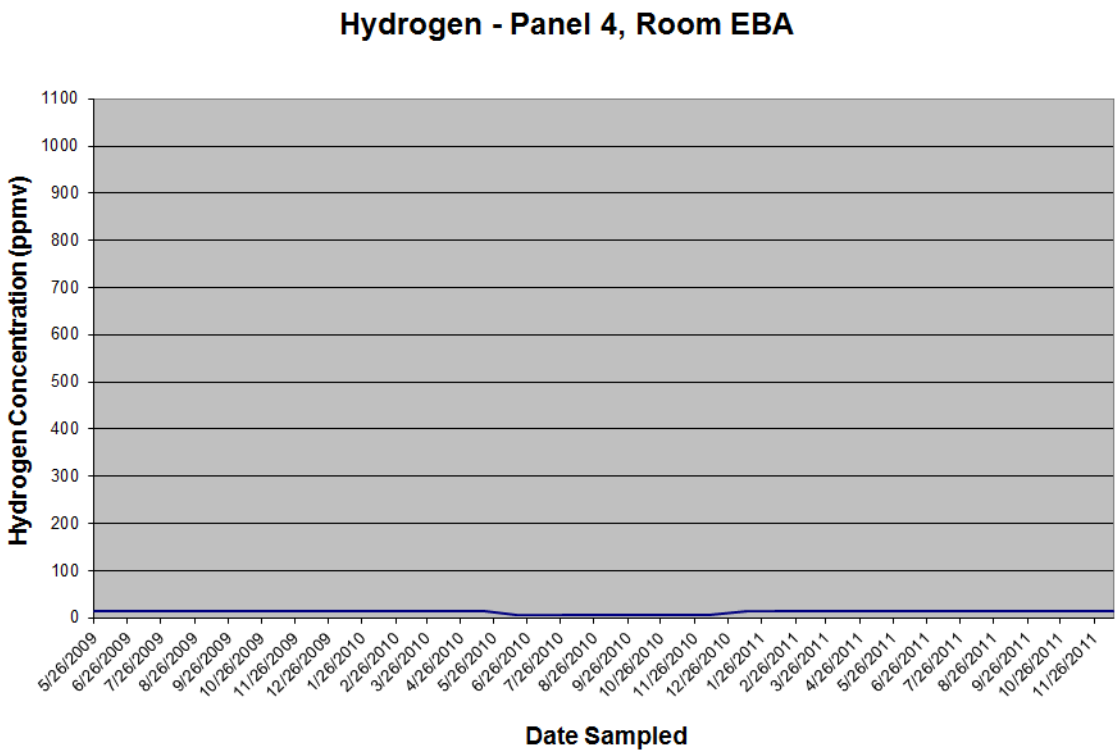

Figure 42: Time Series Plot of Hydrogen Concentrations in Panel 4, Room EBA

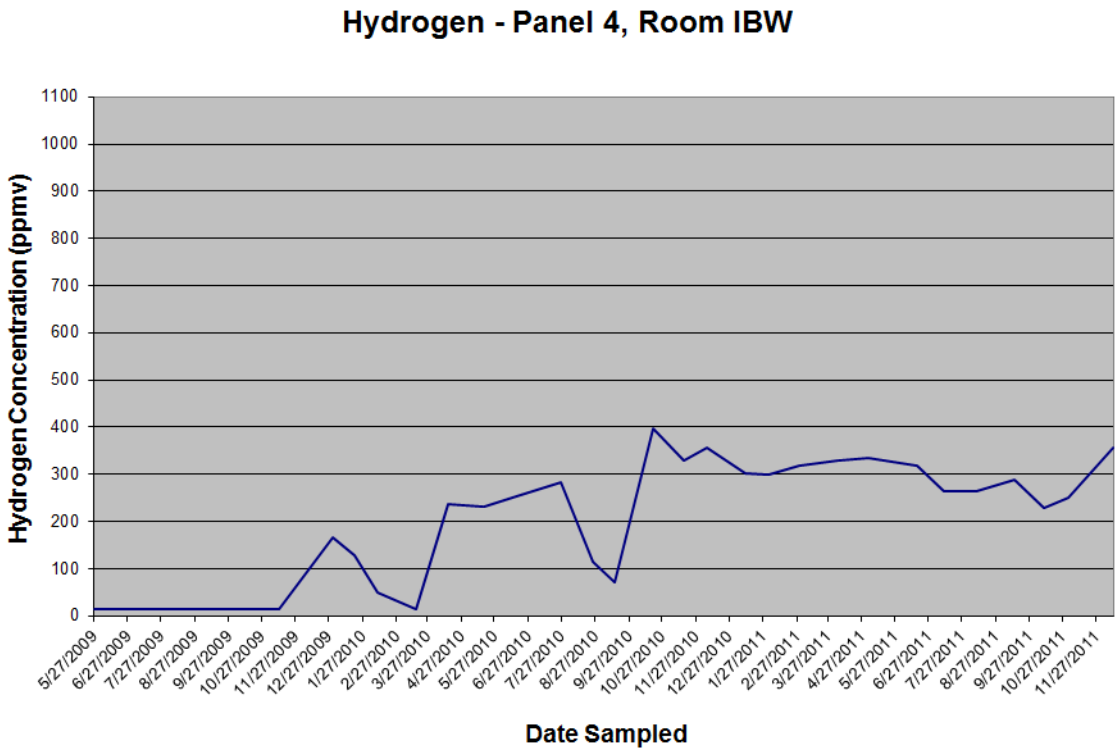

Figure 43: Time Series Plot of Hydrogen Concentrations in Panel 4, Room IBW

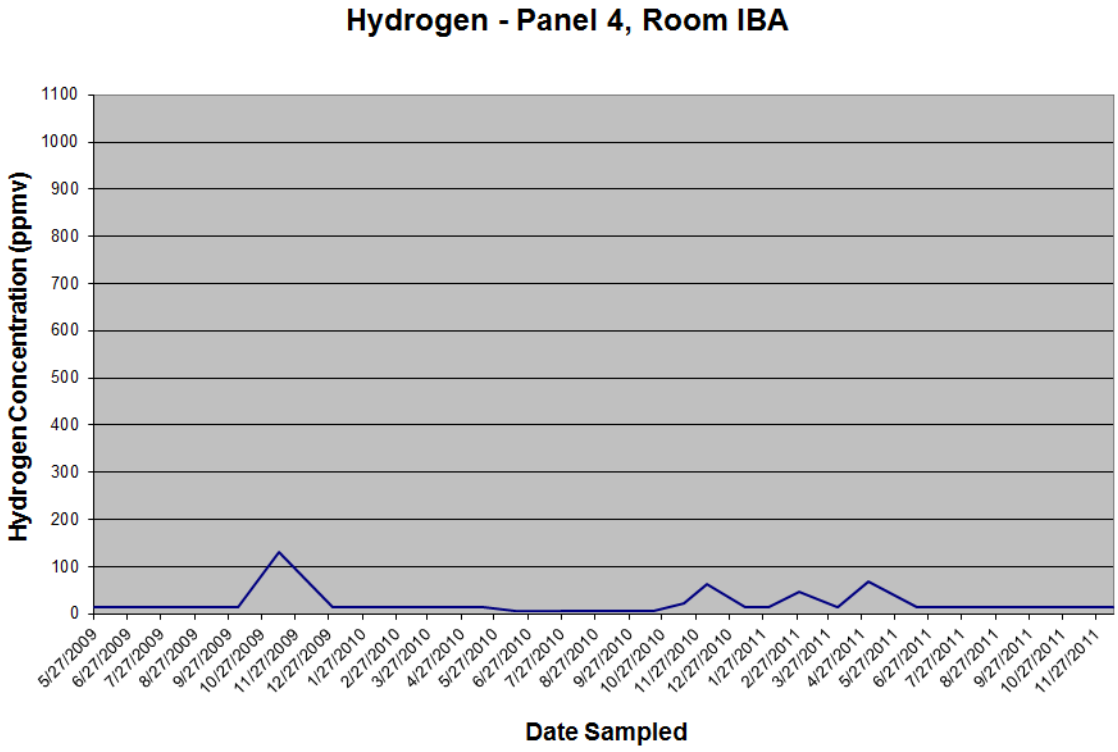

Figure 44: Time Series Plot of Hydrogen Concentrations in Panel 4, Room IBA

Appendix C

Panel 3 Methane Data

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 7e	3176	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3213	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3281	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3340	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3405	8/19/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3453	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3509	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3582	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3621	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3720	1/13/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3777	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3844	3/11/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3919	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3990	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4048	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4106	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4165	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4236	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4333	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4375	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4465	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4626	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4724	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4790	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4958	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5082	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5117	6/1/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5255	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 7i	3175	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3222	5/19/2008	5/23/2008	N.D.	2	17.99	35.98	17.99

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 6e	3178	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3212	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3280	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3339	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3426	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3452	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3508	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3581	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3620	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3719	1/13/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3776	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3843	3/10/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3918	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3989	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4047	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4107	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4166	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4237	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4334	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4376	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4466	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4627	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4725	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4791	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4959	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5083	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5118	6/1/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5256	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5349	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5475	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5534	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5627	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5746	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5844	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5930	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6018	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6131	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6213	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6313	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6427	7/18/2011	7/28/2011	N.D.	2	23.97	47.94	23.97
	6495	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6573	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6646	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6718	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6773	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 6i	3166	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3221	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3289	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3348	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3412	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3460	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3516	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3589	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3628	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3723	1/14/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3784	2/11/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3847	3/11/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3922	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3986	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4055	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4114	7/8/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4171	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4244	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4341	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4383	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4473	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4634	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4732	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4800	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4966	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5090	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5125	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5263	7/14/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5356	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 5e	3179	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3211	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3279	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3338	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3403	8/19/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3451	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3507	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3580	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3619	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3718	1/13/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3775	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3842	3/10/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3917	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3988	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4046	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4108	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4167	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4238	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4335	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4377	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4467	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4628	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4726	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4792	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4960	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5084	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5119	6/1/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5257	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5350	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5476	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5535	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5628	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5747	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5845	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5931	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6019	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6132	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6214	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6314	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6428	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6496	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6574	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6647	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6719	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6774	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45
	4726	2/17/2010	2/23/2010	76.68	2	15.17	30.34	76.68
	4792	3/9/2010	3/12/2010	61.28	2	15.17	30.34	61.28
	4960	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5084	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5119	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5257	7/13/2010	7/19/2010	24.86	2	7.00	14.00	24.86
	5350	8/9/2010	8/17/2010	101.44	2	7.00	14.00	101.44
	5476	9/21/2010	9/27/2010	100.80	2	7.00	14.00	100.80
	5535	10/11/2010	10/18/2010	80.42	2	7.00	14.00	80.42
	5628	11/8/2010	11/15/2010	50.66	2	7.00	14.00	50.66
	5747	12/14/2010	12/20/2010	89.50	2	7.00	14.00	89.50
	5845	1/18/2011	1/24/2011	125.50	2	14.03	28.06	125.50
	5931	2/15/2011	2/21/2011	69.84	2	14.03	28.06	69.84
	6019	3/8/2011	3/11/2011	88.68	2	14.03	28.06	88.68
	6132	4/19/2011	4/26/2011	47.86	2	14.03	28.06	47.86
	6214	5/9/2011	5/13/2011	51.18	2	14.03	28.06	51.18
	6314	6/14/2011	6/21/2011	56.52	2	14.03	28.06	56.52
	6428	7/18/2011	7/22/2011	50.44	2	14.03	28.06	50.44
	6496	8/15/2011	8/22/2011	59.04	2	14.03	28.06	59.04
	6574	9/19/2011	9/27/2011	41.84	2	14.03	28.06	41.84
	6647	10/17/2011	10/25/2011	12.87	2	14.03	28.06	14.03
	6719	11/7/2011	11/11/2011	32.00	2	14.03	28.06	32.00
	6774	12/5/2011	12/9/2011	44.44	2	14.40	28.80	44.44

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 5i	3177	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3220	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3288	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3347	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3411	8/19/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3459	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3515	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3588	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3627	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3722	1/13/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3783	2/11/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3846	3/11/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3921	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3985	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4054	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4115	7/8/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4176	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4245	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4342	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4384	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4474	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4635	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4733	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4801	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4967	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5091	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5126	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5264	7/14/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5357	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5483	9/22/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5541	10/12/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5634	11/9/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5753	12/15/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5851	1/19/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5937	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6025	3/9/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6138	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6220	5/10/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6320	6/15/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6436	7/19/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6502	8/16/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6580	9/20/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6651	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6725	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6780	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 4e	3174	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3210	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3278	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3337	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3402	8/19/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3450	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3506	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3579	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3618	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3717	1/13/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3774	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3841	3/10/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3916	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3987	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4045	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4109	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4168	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4239	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4336	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4378	11/2/2009	11/12/2009	N.D.	2.1	22.21	46.64	23.32
	4468	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4629	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4727	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4793	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4961	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5085	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5120	6/1/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5258	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5351	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5477	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5536	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5629	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5748	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5846	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5932	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6020	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6133	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6215	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6315	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6429	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6497	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6575	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6648	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6720	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6775	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 4i	3170	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3219	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3287	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3346	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3410	8/19/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3458	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3514	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3587	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3626	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3721	1/13/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3782	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3845	3/11/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3920	4/14/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3984	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4053	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4116	7/8/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4177	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4246	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4343	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4385	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4475	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4636	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4734	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4802	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4968	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5092	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5127	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5265	7/14/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5358	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5484	9/22/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5542	10/12/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5635	11/9/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5754	12/15/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5852	1/19/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5938	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6026	3/9/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6139	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6221	5/10/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6321	6/15/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6437	7/19/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6503	8/16/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6581	9/20/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6656	10/18/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6726	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6781	12/6/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 3e	3172	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3209	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3277	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3336	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3401	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3449	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3505	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3578	11/10/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3617	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3712	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3773	2/9/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3834	3/12/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3911	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3979	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4044	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4110	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4169	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4240	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4337	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4379	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4469	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4630	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4728	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4796	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4962	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5086	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5121	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5259	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5352	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5478	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5537	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5630	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5749	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5847	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5933	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6021	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6134	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6216	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6316	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6430	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6498	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6576	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6649	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6721	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6776	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 3i	3171	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3218	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3286	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3345	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3409	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3457	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3513	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3586	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3625	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3714	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3781	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3836	3/12/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3913	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3981	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4052	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4117	7/8/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4178	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4247	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4344	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4386	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4476	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4637	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4735	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4803	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4969	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5093	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5128	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5266	7/14/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5359	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5485	9/22/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5543	10/12/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5636	11/9/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5755	12/15/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5853	1/19/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5939	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6027	3/9/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6140	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6222	5/10/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6322	6/15/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6438	7/19/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6504	8/16/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6582	9/20/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6657	10/18/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6727	11/8/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6782	12/6/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 2e	3164	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3208	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3276	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3335	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3400	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3448	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3504	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3577	11/10/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3616	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3711	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3772	2/9/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3833	3/12/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3910	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3978	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4043	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4111	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4170	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4241	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4338	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4380	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4470	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4631	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4729	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4797	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4963	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5087	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5122	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5260	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5353	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5479	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5538	10/12/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5631	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5750	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5848	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5934	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6022	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6135	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6217	5/10/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6317	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6431	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6499	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6577	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6650	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6722	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6777	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 2i	3162	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3217	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3285	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3344	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3408	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3456	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3512	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3585	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3624	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3713	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3780	2/10/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3835	3/12/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3912	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3980	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4051	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4118	7/8/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4179	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4248	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4345	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4387	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4477	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4638	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4736	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4804	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4970	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5094	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5129	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5267	7/14/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5360	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5486	9/22/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5544	10/12/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5637	11/9/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5756	12/15/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5854	1/19/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5940	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6028	3/9/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6141	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6223	5/10/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6323	6/15/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6439	7/19/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6505	8/16/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6583	9/20/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6658	10/18/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6728	11/8/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6783	12/6/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 1e	3163	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3207	5/14/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3293	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3334	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3399	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3447	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3503	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3575	11/10/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3614	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3709	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3770	2/9/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3831	3/11/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3908	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3976	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4041	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4112	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4172	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4242	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4339	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4381	11/3/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4471	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4632	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4730	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4798	3/10/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4964	4/21/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5088	5/26/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5123	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5261	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5354	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5480	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5539	10/12/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5632	11/9/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5751	12/15/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5849	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5935	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6023	3/9/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6136	4/19/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6218	5/10/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6318	6/15/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6433	7/19/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6506	8/16/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6584	9/20/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6659	10/18/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6729	11/8/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6784	12/6/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 1i	3169	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3216	5/19/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3284	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Location EBW	3165	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3215	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3283	6/17/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3342	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3407	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3455	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3511	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3584	11/10/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3623	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3716	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3779	2/9/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3838	3/12/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3915	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3983	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4049	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4105	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4164	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4235	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4332	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4374	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4464	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4625	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4723	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4789	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4957	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5081	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5116	6/1/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5254	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5347	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5474	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5533	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5626	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5745	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5843	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5929	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6017	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6130	4/18/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6212	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6312	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6432	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6500	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6578	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6652	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6723	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6778	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Location EBA	3167	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3214	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3282	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3341	7/15/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3406	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3454	9/8/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3510	10/6/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3583	11/10/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3622	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3715	1/12/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3778	2/9/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3837	3/12/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3914	4/13/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3982	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4050	6/2/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4104	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4163	8/5/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4234	9/1/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4331	10/12/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4373	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4463	12/8/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4624	1/26/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4722	2/17/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4788	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4956	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5080	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5115	6/1/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5253	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5346	8/9/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5473	9/21/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5532	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5625	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5744	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5842	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5928	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6016	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6129	4/18/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6211	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6311	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6435	7/19/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6501	8/16/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6579	9/20/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6653	10/17/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6724	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6779	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Location IBW	3173	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3224	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3292	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3350	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3414	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3462	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3518	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3591	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3630	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3725	1/14/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3786	2/11/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3840	3/10/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3924	4/15/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3992	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4040	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4103	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4181	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4250	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4347	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4372	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4479	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4640	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4738	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4795	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	5078	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5130	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5252	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5362	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5487	9/22/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5531	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5624	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5743	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5841	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5927	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6015	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6128	4/18/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6210	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6309	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6426	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6494	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6571	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6654	10/18/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6716	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6771	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Location IBA	3168	4/24/2008	4/30/2008	N.D.	2	17.99	35.98	17.99
	3223	5/15/2008	5/23/2008	N.D.	2	17.99	35.98	17.99
	3291	6/19/2008	6/25/2008	N.D.	2	17.99	35.98	17.99
	3349	7/16/2008	7/22/2008	N.D.	2	17.99	35.98	17.99
	3413	8/20/2008	8/22/2008	N.D.	2	23.74	47.48	23.74
	3461	9/10/2008	9/12/2008	N.D.	2	23.74	47.48	23.74
	3517	10/8/2008	10/10/2008	N.D.	2	23.74	47.48	23.74
	3590	11/13/2008	11/18/2008	N.D.	2	23.74	47.48	23.74
	3629	12/3/2008	12/6/2008	N.D.	2	23.74	47.48	23.74
	3724	1/14/2009	1/21/2009	N.D.	2	23.74	47.48	23.74
	3785	2/11/2009	2/13/2009	N.D.	2	23.74	47.48	23.74
	3839	3/10/2009	3/27/2009	N.D.	2	23.74	47.48	23.74
	3923	4/15/2009	4/22/2009	N.D.	2	23.74	47.48	23.74
	3991	5/12/2009	5/15/2009	N.D.	2	23.74	47.48	23.74
	4039	6/1/2009	6/8/2009	N.D.	2	23.74	47.48	23.74
	4102	7/7/2009	7/10/2009	N.D.	2	22.21	44.42	22.21
	4180	8/6/2009	8/13/2009	N.D.	2	22.21	44.42	22.21
	4249	9/2/2009	9/4/2009	N.D.	2	22.21	44.42	22.21
	4346	10/13/2009	10/15/2009	N.D.	2	22.21	44.42	22.21
	4371	11/2/2009	11/12/2009	N.D.	2	22.21	44.42	22.21
	4478	12/9/2009	12/15/2009	N.D.	2	22.21	44.42	22.21
	4639	1/27/2010	2/2/2010	N.D.	2	22.21	44.42	22.21
	4737	2/18/2010	2/23/2010	N.D.	2	22.21	44.42	22.21
	4794	3/9/2010	3/12/2010	N.D.	2	22.21	44.42	22.21
	4954	4/20/2010	4/28/2010	N.D.	2	22.21	44.42	22.21
	5079	5/25/2010	5/28/2010	N.D.	2	22.21	44.42	22.21
	5131	6/2/2010	6/7/2010	N.D.	2	22.21	44.42	22.21
	5251	7/13/2010	7/19/2010	N.D.	2	21.39	42.78	21.39
	5361	8/10/2010	8/17/2010	N.D.	2	21.39	42.78	21.39
	5488	9/22/2010	9/27/2010	N.D.	2	21.39	42.78	21.39
	5530	10/11/2010	10/18/2010	N.D.	2	21.39	42.78	21.39
	5623	11/8/2010	11/15/2010	N.D.	2	21.39	42.78	21.39
	5742	12/14/2010	12/20/2010	N.D.	2	21.39	42.78	21.39
	5840	1/18/2011	1/24/2011	N.D.	2	23.97	47.94	23.97
	5926	2/15/2011	2/21/2011	N.D.	2	23.97	47.94	23.97
	6014	3/8/2011	3/11/2011	N.D.	2	23.97	47.94	23.97
	6127	4/18/2011	4/26/2011	N.D.	2	23.97	47.94	23.97
	6209	5/9/2011	5/13/2011	N.D.	2	23.97	47.94	23.97
	6310	6/14/2011	6/21/2011	N.D.	2	23.97	47.94	23.97
	6425	7/18/2011	7/22/2011	N.D.	2	23.97	47.94	23.97
	6493	8/15/2011	8/22/2011	N.D.	2	23.97	47.94	23.97
	6572	9/19/2011	9/27/2011	N.D.	2	23.97	47.94	23.97
	6655	10/18/2011	10/25/2011	N.D.	2	23.97	47.94	23.97
	6717	11/7/2011	11/11/2011	N.D.	2	23.97	47.94	23.97
	6772	12/5/2011	12/9/2011	N.D.	2	17.45	34.9	17.45

Appendix D

Panel 4 Methane Data

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 7e	4032	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4069	6/9/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4139	7/21/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4200	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4274	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4315	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4404	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4531	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4595	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4680	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4833	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4915	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5050	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5175	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5310	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5396	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5450	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5569	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5661	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5718	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5816	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5892	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5980	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6083	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6182	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6333	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6409	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6477	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6553	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6627	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6700	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6804	12/12/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 7i	4028	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4073	6/9/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4130	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4191	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4265	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4306	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4413	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4522	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4586	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4671	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4824	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4925	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5041	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5166	6/14/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5301	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5387	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5441	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5560	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5652	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5709	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5807	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5881	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5971	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6074	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6173	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6324	6/15/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6400	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6461	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6544	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6618	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6691	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6795	12/12/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 6e	4031	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4068	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4140	7/21/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4201	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4275	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4316	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4403	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4532	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4596	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4681	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4834	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4916	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5051	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5176	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5311	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5397	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5451	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5570	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5662	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5719	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5817	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5893	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5981	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6084	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6183	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6334	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6410	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6478	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6554	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6628	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6701	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 6i	4027	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4072	6/9/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4131	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4192	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4266	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4307	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4412	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4523	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4587	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4672	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4825	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4926	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5042	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5167	6/14/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5302	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5388	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5442	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5561	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5653	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5710	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5808	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5882	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5972	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6075	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6174	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6325	6/15/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6401	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6469	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6545	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6619	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6692	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6796	12/12/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 5e	4030	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4067	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4141	7/21/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4202	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4276	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4317	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4402	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4533	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4597	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4682	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4835	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4917	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5052	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5177	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5312	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5398	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5452	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5571	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5663	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5720	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5818	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5894	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5982	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6085	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6184	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6335	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6411	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6479	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6557	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6629	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6702	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6806	12/13/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 5i	4026	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4071	6/9/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4132	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4193	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4267	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4308	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4411	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4524	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4588	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4673	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4826	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4927	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5043	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5168	6/14/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5303	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5389	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5443	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5562	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5654	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5711	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5809	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5883	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5973	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6076	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6175	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6326	6/15/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6402	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6470	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6546	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6620	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6693	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6797	12/12/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 4e	4029	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4066	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4142	7/21/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4203	8/13/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4277	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4318	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4401	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4534	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4598	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4683	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4836	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4918	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5053	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5178	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5313	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5399	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5453	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5572	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5664	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5721	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5819	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5895	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5983	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 4i	4025	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4070	6/9/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4133	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4194	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4268	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4309	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4410	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4525	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4589	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4674	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4827	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4928	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5044	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5169	6/14/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5304	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5390	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5444	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5563	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5655	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5712	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5810	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5884	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5974	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6077	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6176	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6327	6/15/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6403	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6471	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6547	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6621	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6694	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6798	12/12/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 3e	4019	5/26/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4077	6/10/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4143	7/21/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4204	8/13/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4278	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4319	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4400	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4535	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4599	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4684	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4837	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4919	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5054	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5179	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5314	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5400	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5454	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5573	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5665	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5722	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5820	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5896	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5984	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6087	4/6/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6185	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6336	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6412	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6480	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6558	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6630	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6703	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6807	12/13/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 3i	4024	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4079	6/10/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4134	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4195	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4269	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4310	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4409	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4526	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4590	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4675	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4828	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4929	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5045	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5170	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5305	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5391	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5445	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5564	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5656	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5713	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5811	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5885	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5975	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6078	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6177	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6328	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6404	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6472	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6548	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6622	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6695	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6799	12/12/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 2e	4018	5/26/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4076	6/10/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4144	7/22/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4205	8/13/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4279	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4320	10/6/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4399	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4536	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4600	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4685	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4838	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4920	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5055	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5180	6/16/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5315	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5401	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5455	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5574	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5666	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5723	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5821	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5897	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5985	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6088	4/6/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6186	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6337	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6413	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6481	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6559	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6631	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6704	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6808	12/13/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 2i	4023	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4078	6/10/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4135	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4196	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4270	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4311	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4408	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4527	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4591	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4676	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4829	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4930	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5046	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5171	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5306	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5392	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5446	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5565	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5657	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5714	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5812	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5886	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5976	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6079	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6178	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6329	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6405	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6473	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6549	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6623	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6696	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6800	12/12/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 1e	4016	5/26/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4074	6/9/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4145	7/22/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4206	8/13/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4280	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4321	10/6/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4397	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4537	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4601	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4686	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4839	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4923	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5056	5/18/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5181	6/16/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5316	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5402	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5456	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5575	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5667	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5724	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5822	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5890	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5986	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6089	4/6/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6187	5/4/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6338	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6414	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6482	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6560	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6634	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6707	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6811	12/13/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Room 1i	4020	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4061	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4136	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4197	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4271	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4312	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4407	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4528	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4592	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4677	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4830	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4931	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5047	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5172	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5307	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5393	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5447	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5566	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5658	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5715	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5813	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5887	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5977	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6080	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6179	5/2/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6330	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6406	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6474	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6550	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6624	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6697	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6801	12/12/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Location EBW	4015	5/26/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4065	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4147	7/22/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4208	8/13/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4282	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4323	10/6/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4396	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4539	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4603	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4688	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4841	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4921	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5058	5/18/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5183	6/16/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5318	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5404	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5458	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5577	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5669	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5726	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5824	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5898	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5988	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6091	4/6/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6189	5/4/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6340	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6416	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6484	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6562	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6632	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6705	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6809	12/13/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Location EBA	4014	5/26/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4064	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4148	7/22/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4209	8/13/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4283	9/15/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4324	10/6/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4395	11/9/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4540	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4604	1/20/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4689	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4842	3/17/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4922	4/13/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5059	5/18/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5184	6/16/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5319	7/27/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5405	8/25/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5459	9/14/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5578	10/20/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5670	11/16/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5727	12/8/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5825	1/12/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5899	2/7/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5989	3/2/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6092	4/6/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6190	5/4/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6341	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6417	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6485	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6563	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6633	10/11/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6706	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6810	12/13/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Location IBW	4022	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4063	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4137	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4198	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4272	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4313	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4406	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4529	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4593	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4678	2/9/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4831	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4932	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5048	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5173	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5308	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5394	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5448	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5567	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5659	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5716	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5814	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5888	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5978	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6081	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6180	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6331	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6407	7/11/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6475	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6551	9/13/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6625	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6698	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6802	12/12/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Methane (CH_4)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution Corrected MDL (ppmv)	Concentration for Statistical Analysis (ppmv)
Panel 4 Location IBA	4021	5/27/2009	5/29/2009	N.D.	2	23.74	47.48	23.74
	4062	6/8/2009	6/12/2009	N.D.	2	23.74	47.48	23.74
	4138	7/20/2009	7/24/2009	N.D.	2	22.21	44.42	22.21
	4199	8/11/2009	8/17/2009	N.D.	2	22.21	44.42	22.21
	4273	9/14/2009	9/18/2009	N.D.	2	22.21	44.42	22.21
	4314	10/5/2009	10/12/2009	N.D.	2	22.21	44.42	22.21
	4405	11/11/2009	11/16/2009	N.D.	2	22.21	44.42	22.21
	4530	12/30/2009	1/12/2010	N.D.	2	22.21	44.42	22.21
	4594	1/19/2010	1/22/2010	N.D.	2	22.21	44.42	22.21
	4679	2/10/2010	2/12/2010	N.D.	2	22.21	44.42	22.21
	4832	3/16/2010	3/29/2010	N.D.	2	22.21	44.42	22.21
	4933	4/14/2010	4/20/2010	N.D.	2	22.21	44.42	22.21
	5049	5/17/2010	5/24/2010	N.D.	2	22.21	44.42	22.21
	5174	6/15/2010	6/21/2010	N.D.	2	21.39	42.78	21.39
	5309	7/26/2010	8/2/2010	N.D.	2	21.39	42.78	21.39
	5395	8/24/2010	8/30/2010	N.D.	2	21.39	42.78	21.39
	5449	9/13/2010	9/20/2010	N.D.	2	21.39	42.78	21.39
	5568	10/19/2010	10/25/2010	N.D.	2	21.39	42.78	21.39
	5660	11/15/2010	11/22/2010	N.D.	2	21.39	42.78	21.39
	5717	12/7/2010	12/13/2010	N.D.	2	21.39	42.78	21.39
	5815	1/11/2011	1/18/2011	N.D.	2	23.97	47.94	23.97
	5889	2/1/2011	2/10/2011	N.D.	2	23.97	47.94	23.97
	5979	3/1/2011	3/4/2011	N.D.	2	23.97	47.94	23.97
	6082	4/5/2011	4/20/2011	N.D.	2	23.97	47.94	23.97
	6181	5/3/2011	5/6/2011	N.D.	2	23.97	47.94	23.97
	6332	6/16/2011	6/24/2011	N.D.	2	23.97	47.94	23.97
	6408	7/12/2011	7/15/2011	N.D.	2	23.97	47.94	23.97
	6476	8/9/2011	8/19/2011	N.D.	2	23.97	47.94	23.97
	6552	9/14/2011	9/16/2011	N.D.	2	23.97	47.94	23.97
	6626	10/10/2011	10/14/2011	N.D.	2	23.97	47.94	23.97
	6699	11/1/2011	11/4/2011	N.D.	2	23.97	47.94	23.97
	6803	12/12/2011	12/16/2011	N.D.	2	17.45	34.90	17.45

Appendix E

Panel 3 Hydrogen Data

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 7e	3176	4/24/2008	4/30/2008	59.74	2	10.79	21.58	59.74
	3213	5/15/2008	5/23/2008	86.52	2	10.79	21.58	86.52
	3281	6/19/2008	6/25/2008	103.78	2	10.79	21.58	103.78
	3340	7/16/2008	7/22/2008	178.92	2	10.79	21.58	178.92
	3405	8/19/2008	8/22/2008	353.02	2	14.93	29.86	353.02
	3453	9/10/2008	9/12/2008	209.46	2	14.93	29.86	209.46
	3509	10/8/2008	10/10/2008	352.68	2	14.93	29.86	352.68
	3582	11/13/2008	11/18/2008	146.54	2	14.93	29.86	146.54
	3621	12/3/2008	12/6/2008	89.50	2	14.93	29.86	89.50
	3720	1/13/2009	1/21/2009	83.18	2	14.93	29.86	83.18
	3777	2/10/2009	2/13/2009	53.76	2	14.93	29.86	53.76
	3844	3/11/2009	3/27/2009	53.88	2	14.93	29.86	53.88
	3919	4/14/2009	4/22/2009	51.82	2	14.93	29.86	51.82
	3990	5/12/2009	5/15/2009	88.94	2	14.93	29.86	88.94
	4048	6/2/2009	6/8/2009	68.52	2	14.93	29.86	68.52
	4106	7/7/2009	7/10/2009	123.32	2	15.17	30.34	123.32
	4165	8/5/2009	8/13/2009	84.52	2	15.17	30.34	84.52
	4236	9/1/2009	9/4/2009	130.44	2	15.17	30.34	130.44
	4333	10/12/2009	10/15/2009	95.60	2	15.17	30.34	95.60
	4375	11/2/2009	11/12/2009	90.80	2	15.17	30.34	90.80
	4465	12/8/2009	12/15/2009	23.62	2	15.17	30.34	15.17
	4626	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4724	2/17/2010	2/23/2010	84.12	2	15.17	30.34	84.12
	4790	3/9/2010	3/12/2010	64.72	2	15.17	30.34	64.72
	4958	4/20/2010	4/28/2010	57.18	2	15.17	30.34	57.18
	5082	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5117	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5255	7/13/2010	7/19/2010	127.94	2	7.00	14.00	127.94

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 7i	3175	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
	3222	5/19/2008	5/23/2008	10.40	2	10.79	21.58	10.79

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 6e	3178	4/24/2008	4/30/2008	27.34	2	10.79	21.58	27.34
	3212	5/14/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
	3280	6/19/2008	6/25/2008	69.22	2	10.79	21.58	69.22
	3339	7/16/2008	7/22/2008	145.62	2	10.79	21.58	145.62
	3426	8/20/2008	8/22/2008	228.66	2	14.93	29.86	228.66
	3452	9/10/2008	9/12/2008	136.30	2	14.93	29.86	136.30
	3508	10/8/2008	10/10/2008	12.42	2	14.93	29.86	14.93
	3581	11/13/2008	11/18/2008	35.30	2	14.93	29.86	35.30
	3620	12/3/2008	12/6/2008	76.10	2	14.93	29.86	76.10
	3719	1/13/2009	1/21/2009	64.12	2	14.93	29.86	64.12
	3776	2/10/2009	2/13/2009	43.60	2	14.93	29.86	43.60
	3843	3/10/2009	3/27/2009	67.46	2	14.93	29.86	67.46
	3918	4/14/2009	4/22/2009	53.12	2	14.93	29.86	53.12
	3989	5/12/2009	5/15/2009	76.46	2	14.93	29.86	76.46
	4047	6/2/2009	6/8/2009	39.94	2	14.93	29.86	39.94
	4107	7/7/2009	7/10/2009	110.02	2	15.17	30.34	110.02
	4166	8/5/2009	8/13/2009	79.50	2	15.17	30.34	79.50
	4237	9/1/2009	9/4/2009	106.26	2	15.17	30.34	106.26
	4334	10/12/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4376	11/2/2009	11/12/2009	51.54	2	15.17	30.34	51.54
	4466	12/8/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4627	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4725	2/17/2010	2/23/2010	24.60	2	15.17	30.34	49.20
	4791	3/9/2010	3/12/2010	77.26	2	15.17	30.34	77.26
	4959	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5083	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5118	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5256	7/13/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
	5349	8/9/2010	8/17/2010	97.04	2	7.00	14.00	97.04
	5475	9/21/2010	9/27/2010	114.26	2	7.00	14.00	114.26
	5534	10/11/2010	10/18/2010	98.94	2	7.00	14.00	98.94
	5627	11/8/2010	11/15/2010	93.20	2	7.00	14.00	93.20
	5746	12/14/2010	12/20/2010	92.60	2	7.00	14.00	92.60
	5844	1/18/2011	1/24/2011	140.32	2	14.03	28.06	140.32
	5930	2/15/2011	2/21/2011	62.32	2	14.03	28.06	62.32
	6018	3/8/2011	3/11/2011	87.88	2	14.03	28.06	87.88
	6131	4/19/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
	6213	5/9/2011	5/13/2011	48.58	2	14.03	28.06	48.58
	6313	6/14/2011	6/21/2011	53.46	2	14.03	28.06	53.46
	6427	7/18/2011	7/28/2011	36.06	2	14.03	28.06	36.06
	6495	8/15/2011	8/22/2011	76.68	2	14.03	28.06	76.68
	6573	9/19/2011	9/27/2011	46.88	2	14.03	28.06	46.88
	6646	10/17/2011	10/25/2011	38.82	2	14.03	28.06	38.82
	6718	11/7/2011	11/11/2011	32.08	2	14.03	28.06	32.08
	6773	12/5/2011	12/9/2011	13.74	2	14.40	28.80	14.40

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 6i	3166	4/24/2008	4/30/2008	21.80	2	10.79	21.58	21.80
	3221	5/15/2008	5/23/2008	23.28	2	10.79	21.58	23.28
	3289	6/19/2008	6/25/2008	78.90	2	10.79	21.58	78.90
	3348	7/16/2008	7/22/2008	126.18	2	10.79	21.58	126.18
	3412	8/20/2008	8/22/2008	185.26	2	14.93	29.86	185.26
	3460	9/10/2008	9/12/2008	311.62	2	14.93	29.86	311.62
	3516	10/8/2008	10/10/2008	19.46	2	14.93	29.86	14.93
	3589	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
	3628	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
	3723	1/14/2009	1/21/2009	25.66	2	14.93	29.86	14.93
	3784	2/11/2009	2/13/2009	22.22	2	14.93	29.86	14.93
	3847	3/11/2009	3/27/2009	27.96	2	14.93	29.86	14.93
	3922	4/14/2009	4/22/2009	32.58	2	14.93	29.86	32.58
	3986	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
	4055	6/2/2009	6/8/2009	28.90	2	14.93	29.86	14.93
	4114	7/8/2009	7/10/2009	71.36	2	15.17	30.34	71.36
	4171	8/5/2009	8/13/2009	44.14	2	15.17	30.34	44.14
	4244	9/2/2009	9/4/2009	60.60	2	15.17	30.34	60.60
	4341	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4383	11/3/2009	11/12/2009	36.66	2	15.17	30.34	36.66
	4473	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4634	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4732	2/18/2010	2/23/2010	15.74	2	15.17	30.34	31.48
	4800	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
	4966	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5090	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5125	6/2/2010	6/7/2010	50.92	2	15.17	30.34	50.92
	5263	7/14/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
	5356	8/10/2010	8/17/2010	96.30	2	7.00	14.00	96.30

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 5e	3179	4/24/2008	4/30/2008	45.70	2	10.79	21.58	45.70
	3211	5/14/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
	3279	6/17/2008	6/25/2008	91.62	2	10.79	21.58	91.62
	3338	7/16/2008	7/22/2008	156.04	2	10.79	21.58	156.04
	3403	8/19/2008	8/22/2008	221.24	2	14.93	29.86	221.24
	3451	9/10/2008	9/12/2008	207.98	2	14.93	29.86	207.98
	3507	10/8/2008	10/10/2008	187.98	2	14.93	29.86	187.98
	3580	11/13/2008	11/18/2008	101.64	2	14.93	29.86	101.64
	3619	12/3/2008	12/6/2008	66.24	2	14.93	29.86	66.24
	3718	1/13/2009	1/21/2009	61.18	2	14.93	29.86	61.18
	3775	2/10/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
	3842	3/10/2009	3/27/2009	63.18	2	14.93	29.86	63.18
	3917	4/14/2009	4/22/2009	51.28	2	14.93	29.86	51.28
	3988	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
	4046	6/1/2009	6/8/2009	42.80	2	14.93	29.86	42.80
	4108	7/7/2009	7/10/2009	102.20	2	15.17	30.34	102.20
	4167	8/5/2009	8/13/2009	57.74	2	15.17	30.34	57.74
	4238	9/1/2009	9/4/2009	59.18	2	15.17	30.34	59.18
	4335	10/12/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4377	11/2/2009	11/12/2009	65.18	2	15.17	30.34	65.18
	4467	12/8/2009	12/15/2009	6.20	2	15.17	30.34	15.17
	4628	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4726	2/17/2010	2/23/2010	76.68	2	15.17	30.34	76.68
	4792	3/9/2010	3/12/2010	61.28	2	15.17	30.34	61.28
	4960	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5084	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5119	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5257	7/13/2010	7/19/2010	24.86	2	7.00	14.00	49.72
	5350	8/9/2010	8/17/2010	101.44	2	7.00	14.00	101.44
	5476	9/21/2010	9/27/2010	100.80	2	7.00	14.00	100.80
	5535	10/11/2010	10/18/2010	80.42	2	7.00	14.00	80.42
	5628	11/8/2010	11/15/2010	50.66	2	7.00	14.00	50.66
	5747	12/14/2010	12/20/2010	89.50	2	7.00	14.00	89.50
	5845	1/18/2011	1/24/2011	125.50	2	14.03	28.06	125.50
	5931	2/15/2011	2/21/2011	69.84	2	14.03	28.06	69.84
	6019	3/8/2011	3/11/2011	88.68	2	14.03	28.06	88.68
	6132	4/19/2011	4/26/2011	47.86	2	14.03	28.06	47.86
	6214	5/9/2011	5/13/2011	51.18	2	14.03	28.06	51.18
	6314	6/14/2011	6/21/2011	56.52	2	14.03	28.06	56.52
	6428	7/18/2011	7/22/2011	50.44	2	14.03	28.06	50.44
	6496	8/15/2011	8/22/2011	59.04	2	14.03	28.06	59.04
	6574	9/19/2011	9/27/2011	41.84	2	14.03	28.06	41.84
	6647	10/17/2011	10/25/2011	12.87	2	14.03	28.06	25.74
	6719	11/7/2011	11/11/2011	32.00	2	14.03	28.06	32.00
	6774	12/5/2011	12/9/2011	44.44	2	14.40	28.80	44.44

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 5i	3177	4/24/2008	4/30/2008	24.18	2	10.79	21.58	24.18
	3220	5/15/2008	5/23/2008	17.68	2	10.79	21.58	10.79
	3288	6/19/2008	6/25/2008	60.62	2	10.79	21.58	60.62
	3347	7/16/2008	7/22/2008	166.08	2	10.79	21.58	166.08
	3411	8/19/2008	8/22/2008	247.14	2	14.93	29.86	247.14
	3459	9/10/2008	9/12/2008	220.32	2	14.93	29.86	220.32
	3515	10/8/2008	10/10/2008	57.40	2	14.93	29.86	57.40
	3588	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
	3627	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
	3722	1/13/2009	1/21/2009	26.62	2	14.93	29.86	14.93
	3783	2/11/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
	3846	3/11/2009	3/27/2009	16.56	2	14.93	29.86	14.93
	3921	4/14/2009	4/22/2009	18.66	2	14.93	29.86	14.93
	3985	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
	4054	6/2/2009	6/8/2009	32.80	2	14.93	29.86	32.80
	4115	7/8/2009	7/10/2009	99.70	2	15.17	30.34	99.70
	4176	8/6/2009	8/13/2009	81.66	2	15.17	30.34	81.66
	4245	9/2/2009	9/4/2009	62.66	2	15.17	30.34	62.66
	4342	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4384	11/3/2009	11/12/2009	32.30	2	15.17	30.34	32.30
	4474	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4635	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4733	2/18/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
	4801	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
	4967	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5091	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5126	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5264	7/14/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
	5357	8/10/2010	8/17/2010	93.94	2	7.00	14.00	93.94
	5483	9/22/2010	9/27/2010	96.22	2	7.00	14.00	96.22
	5541	10/12/2010	10/18/2010	23.49	2	7.00	14.00	46.98
	5634	11/9/2010	11/15/2010	54.98	2	7.00	14.00	54.98
	5753	12/15/2010	12/20/2010	76.98	2	7.00	14.00	76.98
	5851	1/19/2011	1/24/2011	N.D.	2	14.03	28.06	14.03
	5937	2/15/2011	2/21/2011	31.10	2	14.03	28.06	31.10
	6025	3/9/2011	3/11/2011	39.10	2	14.03	28.06	39.10
	6138	4/19/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
	6220	5/10/2011	5/13/2011	30.62	2	14.03	28.06	30.62
	6320	6/15/2011	6/21/2011	9.32	2	14.03	28.06	14.03
	6436	7/19/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
	6502	8/16/2011	8/22/2011	49.46	2	14.03	28.06	49.46
	6580	9/20/2011	9/27/2011	13.58	2	14.03	28.06	14.03
	6651	10/17/2011	10/25/2011	7.69	2	14.03	28.06	14.03
	6725	11/7/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
	6780	12/5/2011	12/9/2011	N.D.	2	14.40	28.80	14.40

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 4e	3174	4/24/2008	4/30/2008	56.32	2	10.79	21.58	56.32
	3210	5/14/2008	5/23/2008	48.84	2	10.79	21.58	48.84
	3278	6/17/2008	6/25/2008	20.00	2	10.79	21.58	10.79
	3337	7/16/2008	7/22/2008	54.12	2	10.79	21.58	54.12
	3402	8/19/2008	8/22/2008	120.12	2	14.93	29.86	120.12
	3450	9/10/2008	9/12/2008	136.06	2	14.93	29.86	136.06
	3506	10/8/2008	10/10/2008	N.D.	2	14.93	29.86	14.93
	3579	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
	3618	12/3/2008	12/6/2008	49.22	2	14.93	29.86	49.22
	3717	1/13/2009	1/21/2009	55.40	2	14.93	29.86	55.40
	3774	2/10/2009	2/13/2009	35.76	2	14.93	29.86	35.76
	3841	3/10/2009	3/27/2009	47.92	2	14.93	29.86	47.92
	3916	4/14/2009	4/22/2009	35.76	2	14.93	29.86	35.76
	3987	5/12/2009	5/15/2009	15.26	2	14.93	29.86	14.93
	4045	6/1/2009	6/8/2009	41.08	2	14.93	29.86	41.08
	4109	7/7/2009	7/10/2009	91.98	2	15.17	30.34	91.98
	4168	8/5/2009	8/13/2009	52.92	2	15.17	30.34	52.92
	4239	9/1/2009	9/4/2009	45.46	2	15.17	30.34	45.46
	4336	10/12/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4378	11/2/2009	11/12/2009	54.43	2.1	15.17	31.86	54.43
	4468	12/8/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4629	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4727	2/17/2010	2/23/2010	63.46	2	15.17	30.34	63.46
	4793	3/9/2010	3/12/2010	21.73	2	15.17	30.34	43.46
	4961	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5085	5/25/2010	5/28/2010	58.64	2	15.17	30.34	58.64
	5120	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5258	7/13/2010	7/19/2010	19.57	2	7.00	14.00	39.14
	5351	8/9/2010	8/17/2010	99.22	2	7.00	14.00	99.22
	5477	9/21/2010	9/27/2010	90.04	2	7.00	14.00	90.04
	5536	10/11/2010	10/18/2010	85.22	2	7.00	14.00	85.22
	5629	11/8/2010	11/15/2010	68.10	2	7.00	14.00	68.10
	5748	12/14/2010	12/20/2010	89.98	2	7.00	14.00	89.98
	5846	1/18/2011	1/24/2011	132.24	2	14.03	28.06	132.24
	5932	2/15/2011	2/21/2011	66.56	2	14.03	28.06	66.56
	6020	3/8/2011	3/11/2011	58.04	2	14.03	28.06	58.04
	6133	4/19/2011	4/26/2011	43.64	2	14.03	28.06	43.64
	6215	5/9/2011	5/13/2011	55.34	2	14.03	28.06	55.34
	6315	6/14/2011	6/21/2011	43.96	2	14.03	28.06	43.96
	6429	7/18/2011	7/22/2011	55.78	2	14.03	28.06	55.78
	6497	8/15/2011	8/22/2011	66.62	2	14.03	28.06	66.62
	6575	9/19/2011	9/27/2011	51.62	2	14.03	28.06	51.62
	6648	10/17/2011	10/25/2011	34.04	2	14.03	28.06	34.04
	6720	11/7/2011	11/11/2011	30.00	2	14.03	28.06	30.00
	6775	12/5/2011	12/9/2011	29.26	2	14.40	28.80	29.26

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 4i	3170	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
	3219	5/15/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
	3287	6/19/2008	6/25/2008	43.70	2	10.79	21.58	43.70
	3346	7/16/2008	7/22/2008	94.38	2	10.79	21.58	94.38
	3410	8/19/2008	8/22/2008	122.86	2	14.93	29.86	122.86
	3458	9/10/2008	9/12/2008	55.78	2	14.93	29.86	55.78
	3514	10/8/2008	10/10/2008	14.80	2	14.93	29.86	14.93
	3587	11/13/2008	11/18/2008	21.26	2	14.93	29.86	14.93
	3626	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
	3721	1/13/2009	1/21/2009	14.98	2	14.93	29.86	14.93
	3782	2/10/2009	2/13/2009	19.84	2	14.93	29.86	14.93
	3845	3/11/2009	3/27/2009	5.50	2	14.93	29.86	14.93
	3920	4/14/2009	4/22/2009	18.42	2	14.93	29.86	14.93
	3984	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
	4053	6/2/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
	4116	7/8/2009	7/10/2009	70.10	2	15.17	30.34	70.10
	4177	8/6/2009	8/13/2009	69.88	2	15.17	30.34	69.88
	4246	9/2/2009	9/4/2009	19.66	2	15.17	30.34	15.17
	4343	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4385	11/3/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
	4475	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4636	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4734	2/18/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
	4802	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
	4968	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5092	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5127	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5265	7/14/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
	5358	8/10/2010	8/17/2010	78.80	2	7.00	14.00	78.80
	5484	9/22/2010	9/27/2010	N.D.	2	7.00	14.00	7.00
	5542	10/12/2010	10/18/2010	24.80	2	7.00	14.00	49.60
	5635	11/9/2010	11/15/2010	15.11	2	7.00	14.00	30.22
	5754	12/15/2010	12/20/2010	85.24	2	7.00	14.00	85.24
	5852	1/19/2011	1/24/2011	58.84	2	14.03	28.06	58.84
	5938	2/15/2011	2/21/2011	28.12	2	14.03	28.06	28.12
	6026	3/9/2011	3/11/2011	N.D.	2	14.03	28.06	14.03
	6139	4/19/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
	6221	5/10/2011	5/13/2011	12.36	2	14.03	28.06	14.03
	6321	6/15/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
	6437	7/19/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
	6503	8/16/2011	8/22/2011	42.26	2	14.03	28.06	42.26
	6581	9/20/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
	6656	10/18/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
	6726	11/7/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
	6781	12/6/2011	12/9/2011	N.D.	2	14.40	28.80	14.40

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 3e	3172	4/24/2008	4/30/2008	38.24	2	10.79	21.58	38.24
	3209	5/14/2008	5/23/2008	45.78	2	10.79	21.58	45.78
	3277	6/17/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
	3336	7/15/2008	7/22/2008	49.56	2	10.79	21.58	49.56
	3401	8/20/2008	8/22/2008	46.38	2	14.93	29.86	46.38
	3449	9/8/2008	9/12/2008	76.02	2	14.93	29.86	76.02
	3505	10/6/2008	10/10/2008	91.54	2	14.93	29.86	91.54
	3578	11/10/2008	11/18/2008	76.38	2	14.93	29.86	76.38
	3617	12/3/2008	12/6/2008	51.44	2	14.93	29.86	51.44
	3712	1/12/2009	1/21/2009	46.52	2	14.93	29.86	46.52
	3773	2/9/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
	3834	3/12/2009	3/27/2009	49.78	2	14.93	29.86	49.78
	3911	4/13/2009	4/22/2009	36.44	2	14.93	29.86	36.44
	3979	5/12/2009	5/15/2009	40.06	2	14.93	29.86	40.06
	4044	6/1/2009	6/8/2009	44.98	2	14.93	29.86	44.98
	4110	7/7/2009	7/10/2009	88.52	2	15.17	30.34	88.52
	4169	8/5/2009	8/13/2009	62.82	2	15.17	30.34	62.82
	4240	9/1/2009	9/4/2009	54.22	2	15.17	30.34	54.22
	4337	10/12/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4379	11/3/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
	4469	12/8/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4630	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4728	2/17/2010	2/23/2010	55.36	2	15.17	30.34	55.36
	4796	3/10/2010	3/12/2010	20.71	2	15.17	30.34	41.42
	4962	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5086	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5121	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5259	7/13/2010	7/19/2010	88.48	2	7.00	14.00	88.48
	5352	8/9/2010	8/17/2010	105.14	2	7.00	14.00	105.14
	5478	9/21/2010	9/27/2010	58.68	2	7.00	14.00	58.68
	5537	10/11/2010	10/18/2010	59.18	2	7.00	14.00	59.18
	5630	11/8/2010	11/15/2010	66.94	2	7.00	14.00	66.94
	5749	12/14/2010	12/20/2010	80.20	2	7.00	14.00	80.20
	5847	1/18/2011	1/24/2011	136.16	2	14.03	28.06	136.16
	5933	2/15/2011	2/21/2011	53.02	2	14.03	28.06	53.02
	6021	3/8/2011	3/11/2011	84.28	2	14.03	28.06	84.28
	6134	4/19/2011	4/26/2011	47.04	2	14.03	28.06	47.04
	6216	5/9/2011	5/13/2011	39.22	2	14.03	28.06	39.22
	6316	6/14/2011	6/21/2011	34.02	2	14.03	28.06	34.02
	6430	7/18/2011	7/22/2011	53.20	2	14.03	28.06	53.20
	6498	8/15/2011	8/22/2011	50.46	2	14.03	28.06	50.46
	6576	9/19/2011	9/27/2011	38.60	2	14.03	28.06	38.60
	6649	10/17/2011	10/25/2011	28.86	2	14.03	28.06	28.86
	6721	11/7/2011	11/11/2011	13.00	2	14.03	28.06	14.03
	6776	12/5/2011	12/9/2011	38.26	2	14.40	28.80	38.26

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 3i	3171	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
	3218	5/14/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
	3286	6/17/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
	3345	7/15/2008	7/22/2008	N.D.	2	10.79	21.58	10.79
	3409	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
	3457	9/8/2008	9/12/2008	N.D.	2	14.93	29.86	14.93
	3513	10/6/2008	10/10/2008	48.84	2	14.93	29.86	48.84
	3586	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
	3625	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
	3714	1/12/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
	3781	2/10/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
	3836	3/12/2009	3/27/2009	N.D.	2	14.93	29.86	14.93
	3913	4/13/2009	4/22/2009	N.D.	2	14.93	29.86	14.93
	3981	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
	4052	6/2/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
	4117	7/8/2009	7/10/2009	36.74	2	15.17	30.34	36.74
	4178	8/6/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
	4247	9/2/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
	4344	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4386	11/3/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
	4476	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4637	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4735	2/18/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
	4803	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
	4969	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5093	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5128	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5266	7/14/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
	5359	8/10/2010	8/17/2010	69.66	2	7.00	14.00	69.66
	5485	9/22/2010	9/27/2010	N.D.	2	7.00	14.00	7.00
	5543	10/12/2010	10/18/2010	17.39	2	7.00	14.00	34.78
	5636	11/9/2010	11/15/2010	N.D.	2	7.00	14.00	7.00
	5755	12/15/2010	12/20/2010	70.66	2	7.00	14.00	70.66
	5853	1/19/2011	1/24/2011	79.18	2	14.03	28.06	79.18
	5939	2/15/2011	2/21/2011	N.D.	2	14.03	28.06	14.03
	6027	3/9/2011	3/11/2011	N.D.	2	14.03	28.06	14.03
	6140	4/19/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
	6222	5/10/2011	5/13/2011	N.D.	2	14.03	28.06	14.03
	6322	6/15/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
	6438	7/19/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
	6504	8/16/2011	8/22/2011	N.D.	2	14.03	28.06	14.03
	6582	9/20/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
	6657	10/18/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
	6727	11/8/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
	6782	12/6/2011	12/9/2011	N.D.	2	14.40	28.80	14.40

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 2e	3164	4/24/2008	4/30/2008	32.02	2	10.79	21.58	32.02
	3208	5/14/2008	5/23/2008	31.20	2	10.79	21.58	31.20
	3276	6/17/2008	6/25/2008	22.78	2	10.79	21.58	22.78
	3335	7/15/2008	7/22/2008	32.36	2	10.79	21.58	32.36
	3400	8/20/2008	8/22/2008	37.30	2	14.93	29.86	37.30
	3448	9/8/2008	9/12/2008	35.04	2	14.93	29.86	35.04
	3504	10/6/2008	10/10/2008	36.14	2	14.93	29.86	36.14
	3577	11/10/2008	11/18/2008	36.90	2	14.93	29.86	36.90
	3616	12/3/2008	12/6/2008	33.86	2	14.93	29.86	33.86
	3711	1/12/2009	1/21/2009	36.68	2	14.93	29.86	36.68
	3772	2/9/2009	2/13/2009	24.04	2	14.93	29.86	14.93
	3833	3/12/2009	3/27/2009	16.42	2	14.93	29.86	14.93
	3910	4/13/2009	4/22/2009	23.94	2	14.93	29.86	14.93
	3978	5/12/2009	5/15/2009	35.24	2	14.93	29.86	35.24
	4043	6/1/2009	6/8/2009	14.40	2	14.93	29.86	14.93
	4111	7/7/2009	7/10/2009	37.48	2	15.17	30.34	37.48
	4170	8/5/2009	8/13/2009	18.32	2	15.17	30.34	15.17
	4241	9/1/2009	9/4/2009	21.32	2	15.17	30.34	15.17
	4338	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4380	11/3/2009	11/12/2009	22.38	2	15.17	30.34	15.17
	4470	12/8/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4631	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4729	2/17/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
	4797	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
	4963	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5087	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5122	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5260	7/13/2010	7/19/2010	105.46	2	7.00	14.00	105.46
	5353	8/9/2010	8/17/2010	N.D.	2	7.00	14.00	7.00
	5479	9/21/2010	9/27/2010	52.60	2	7.00	14.00	52.60
	5538	10/12/2010	10/18/2010	66.54	2	7.00	14.00	66.54
	5631	11/8/2010	11/15/2010	50.14	2	7.00	14.00	50.14
	5750	12/14/2010	12/20/2010	75.48	2	7.00	14.00	75.48
	5848	1/18/2011	1/24/2011	123.08	2	14.03	28.06	123.08
	5934	2/15/2011	2/21/2011	48.58	2	14.03	28.06	48.58
	6022	3/8/2011	3/11/2011	54.10	2	14.03	28.06	54.10
	6135	4/19/2011	4/26/2011	49.12	2	14.03	28.06	49.12
	6217	5/10/2011	5/13/2011	42.72	2	14.03	28.06	42.72
	6317	6/14/2011	6/21/2011	31.62	2	14.03	28.06	31.62
	6431	7/18/2011	7/22/2011	37.94	2	14.03	28.06	37.94
	6499	8/15/2011	8/22/2011	55.18	2	14.03	28.06	55.18
	6577	9/19/2011	9/27/2011	33.10	2	14.03	28.06	33.10
	6650	10/17/2011	10/25/2011	11.07	2	14.03	28.06	14.03
	6722	11/7/2011	11/11/2011	10.18	2	14.03	28.06	14.03
	6777	12/5/2011	12/9/2011	31.18	2	14.40	28.80	31.18

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 2i	3162	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
	3217	5/14/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
	3285	6/17/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
	3344	7/15/2008	7/22/2008	N.D.	2	10.79	21.58	10.79
	3408	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
	3456	9/8/2008	9/12/2008	N.D.	2	14.93	29.86	14.93
	3512	10/6/2008	10/10/2008	13.24	2	14.93	29.86	14.93
	3585	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
	3624	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
	3713	1/12/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
	3780	2/10/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
	3835	3/12/2009	3/27/2009	N.D.	2	14.93	29.86	14.93
	3912	4/13/2009	4/22/2009	N.D.	2	14.93	29.86	14.93
	3980	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
	4051	6/2/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
	4118	7/8/2009	7/10/2009	N.D.	2	15.17	30.34	15.17
	4179	8/6/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
	4248	9/2/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
	4345	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4387	11/3/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
	4477	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4638	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4736	2/18/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
	4804	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
	4970	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5094	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5129	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5267	7/14/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
	5360	8/10/2010	8/17/2010	N.D.	2	7.00	14.00	7.00
	5486	9/22/2010	9/27/2010	N.D.	2	7.00	14.00	7.00
	5544	10/12/2010	10/18/2010	9.62	2	7.00	14.00	19.24
	5637	11/9/2010	11/15/2010	N.D.	2	7.00	14.00	7.00
	5756	12/15/2010	12/20/2010	68.86	2	7.00	14.00	68.86
	5854	1/19/2011	1/24/2011	55.84	2	14.03	28.06	55.84
	5940	2/15/2011	2/21/2011	N.D.	2	14.03	28.06	14.03
	6028	3/9/2011	3/11/2011	N.D.	2	14.03	28.06	14.03
	6141	4/19/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
	6223	5/10/2011	5/13/2011	N.D.	2	14.03	28.06	14.03
	6323	6/15/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
	6439	7/19/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
	6505	8/16/2011	8/22/2011	N.D.	2	14.03	28.06	14.03
	6583	9/20/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
	6658	10/18/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
	6728	11/8/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
	6783	12/6/2011	12/9/2011	N.D.	2	14.40	28.80	14.40

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 1e	3163	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
	3207	5/14/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
	3293	6/17/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
	3334	7/15/2008	7/22/2008	58.36	2	10.79	21.58	58.36
	3399	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
	3447	9/8/2008	9/12/2008	19.46	2	14.93	29.86	14.93
	3503	10/6/2008	10/10/2008	21.18	2	14.93	29.86	14.93
	3575	11/10/2008	11/18/2008	14.10	2	14.93	29.86	14.93
	3614	12/3/2008	12/6/2008	23.54	2	14.93	29.86	14.93
	3709	1/12/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
	3770	2/9/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
	3831	3/11/2009	3/27/2009	8.86	2	14.93	29.86	14.93
	3908	4/13/2009	4/22/2009	8.00	2	14.93	29.86	14.93
	3976	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
	4041	6/1/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
	4112	7/7/2009	7/10/2009	N.D.	2	15.17	30.34	15.17
	4172	8/6/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
	4242	9/1/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
	4339	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4381	11/3/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
	4471	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4632	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4730	2/17/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
	4798	3/10/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
	4964	4/21/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5088	5/26/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5123	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5261	7/13/2010	7/19/2010	54.82	2	7.00	14.00	54.82
	5354	8/10/2010	8/17/2010	21.82	2	7.00	14.00	43.64
	5480	9/21/2010	9/27/2010	17.43	2	7.00	14.00	34.86
	5539	10/12/2010	10/18/2010	58.30	2	7.00	14.00	58.30
	5632	11/9/2010	11/15/2010	13.00	2	7.00	14.00	26.00
	5751	12/15/2010	12/20/2010	75.32	2	7.00	14.00	75.32
	5849	1/18/2011	1/24/2011	84.54	2	14.03	28.06	84.54
	5935	2/15/2011	2/21/2011	58.96	2	14.03	28.06	58.96
	6023	3/9/2011	3/11/2011	67.98	2	14.03	28.06	67.98
	6136	4/19/2011	4/26/2011	32.52	2	14.03	28.06	32.52
	6218	5/10/2011	5/13/2011	N.D.	2	14.03	28.06	14.03
	6318	6/15/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
	6433	7/19/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
	6506	8/16/2011	8/22/2011	34.00	2	14.03	28.06	34.00
	6584	9/20/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
	6659	10/18/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
	6729	11/8/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
	6784	12/6/2011	12/9/2011	N.D.	2	14.40	28.80	14.40

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Room 1i	3169	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
	3216	5/19/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
	3284	6/19/2008	6/25/2008	N.D.	2	10.79	21.58	10.79

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Location EBW	3165	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
	3215	5/15/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
	3283	6/17/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
	3342	7/15/2008	7/22/2008	N.D.	2	10.79	21.58	10.79
	3407	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
	3455	9/8/2008	9/12/2008	N.D.	2	14.93	29.86	14.93
	3511	10/6/2008	10/10/2008	32.88	2	14.93	29.86	32.88
	3584	11/10/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
	3623	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
	3716	1/12/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
	3779	2/9/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
	3838	3/12/2009	3/27/2009	N.D.	2	14.93	29.86	14.93
	3915	4/13/2009	4/22/2009	N.D.	2	14.93	29.86	14.93
	3983	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
	4049	6/2/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
	4105	7/7/2009	7/10/2009	N.D.	2	15.17	30.34	15.17
	4164	8/5/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
	4235	9/1/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
	4332	10/12/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4374	11/2/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
	4464	12/8/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4625	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4723	2/17/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
	4789	3/9/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
	4957	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5081	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5116	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5254	7/13/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
	5347	8/9/2010	8/17/2010	23.66	2	7.00	14.00	47.32
	5474	9/21/2010	9/27/2010	17.64	2	7.00	14.00	35.28
	5533	10/11/2010	10/18/2010	60.22	2	7.00	14.00	60.22
	5626	11/8/2010	11/15/2010	18.45	2	7.00	14.00	36.90
	5745	12/14/2010	12/20/2010	71.48	2	7.00	14.00	71.48
	5843	1/18/2011	1/24/2011	95.56	2	14.03	28.06	95.56
	5929	2/15/2011	2/21/2011	53.14	2	14.03	28.06	53.14
	6017	3/8/2011	3/11/2011	73.22	2	14.03	28.06	73.22
	6130	4/18/2011	4/26/2011	31.08	2	14.03	28.06	31.08
	6212	5/9/2011	5/13/2011	40.20	2	14.03	28.06	40.20
	6312	6/14/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
	6432	7/18/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
	6500	8/15/2011	8/22/2011	N.D.	2	14.03	28.06	14.03
	6578	9/19/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
	6652	10/17/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
	6723	11/7/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
	6778	12/5/2011	12/9/2011	29.60	2	14.40	28.80	29.60

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Location EBA	3167	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
	3214	5/15/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
	3282	6/19/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
	3341	7/15/2008	7/22/2008	N.D.	2	10.79	21.58	10.79
	3406	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
	3454	9/8/2008	9/12/2008	N.D.	2	14.93	29.86	14.93
	3510	10/6/2008	10/10/2008	15.14	2	14.93	29.86	14.93
	3583	11/10/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
	3622	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
	3715	1/12/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
	3778	2/9/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
	3837	3/12/2009	3/27/2009	N.D.	2	14.93	29.86	14.93
	3914	4/13/2009	4/22/2009	N.D.	2	14.93	29.86	14.93
	3982	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
	4050	6/2/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
	4104	7/7/2009	7/10/2009	N.D.	2	15.17	30.34	15.17
	4163	8/5/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
	4234	9/1/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
	4331	10/12/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4373	11/2/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
	4463	12/8/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4624	1/26/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4722	2/17/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
	4788	3/9/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
	4956	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5080	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5115	6/1/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5253	7/13/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
	5346	8/9/2010	8/17/2010	N.D.	2	7.00	14.00	7.00
	5473	9/21/2010	9/27/2010	N.D.	2	7.00	14.00	7.00
	5532	10/11/2010	10/18/2010	20.90	2	7.00	14.00	41.80
	5625	11/8/2010	11/15/2010	N.D.	2	7.00	14.00	7.00
	5744	12/14/2010	12/20/2010	N.D.	2	7.00	14.00	7.00
	5842	1/18/2011	1/24/2011	N.D.	2	14.03	28.06	14.03
	5928	2/15/2011	2/21/2011	N.D.	2	14.03	28.06	14.03
	6016	3/8/2011	3/11/2011	N.D.	2	14.03	28.06	14.03
	6129	4/18/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
	6211	5/9/2011	5/13/2011	N.D.	2	14.03	28.06	14.03
	6311	6/14/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
	6435	7/19/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
	6501	8/16/2011	8/22/2011	N.D.	2	14.03	28.06	14.03
	6579	9/20/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
	6653	10/17/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
	6724	11/7/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
	6779	12/5/2011	12/9/2011	N.D.	2	14.40	28.80	14.40

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Location IBW	3173	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
	3224	5/15/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
	3292	6/19/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
	3350	7/16/2008	7/22/2008	N.D.	2	10.79	21.58	10.79
	3414	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
	3462	9/10/2008	9/12/2008	N.D.	2	14.93	29.86	14.93
	3518	10/8/2008	10/10/2008	N.D.	2	14.93	29.86	14.93
	3591	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
	3630	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
	3725	1/14/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
	3786	2/11/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
	3840	3/10/2009	3/27/2009	N.D.	2	14.93	29.86	14.93
	3924	4/15/2009	4/22/2009	N.D.	2	14.93	29.86	14.93
	3992	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
	4040	6/1/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
	4103	7/7/2009	7/10/2009	N.D.	2	15.17	30.34	15.17
	4181	8/6/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
	4250	9/2/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
	4347	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4372	11/2/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
	4479	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4640	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4738	2/18/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
	4795	3/9/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
	5078	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5130	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5252	7/13/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
	5362	8/10/2010	8/17/2010	N.D.	2	7.00	14.00	7.00
	5487	9/22/2010	9/27/2010	N.D.	2	7.00	14.00	7.00
	5531	10/11/2010	10/18/2010	N.D.	2	7.00	14.00	7.00
	5624	11/8/2010	11/15/2010	N.D.	2	7.00	14.00	7.00
	5743	12/14/2010	12/20/2010	51.16	2	7.00	14.00	51.16
	5841	1/18/2011	1/24/2011	N.D.	2	14.03	28.06	14.03
	5927	2/15/2011	2/21/2011	N.D.	2	14.03	28.06	14.03
	6015	3/8/2011	3/11/2011	N.D.	2	14.03	28.06	14.03
	6128	4/18/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
	6210	5/9/2011	5/13/2011	N.D.	2	14.03	28.06	14.03
	6309	6/14/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
	6426	7/18/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
	6494	8/15/2011	8/22/2011	N.D.	2	14.03	28.06	14.03
	6571	9/19/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
	6654	10/18/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
	6716	11/7/2011	11/11/2011	38.82	2	14.03	28.06	38.82
	6771	12/5/2011	12/9/2011	N.D.	2	14.40	28.80	14.40

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 3 Location IBA	3168	4/24/2008	4/30/2008	N.D.	2	10.79	21.58	10.79
	3223	5/15/2008	5/23/2008	N.D.	2	10.79	21.58	10.79
	3291	6/19/2008	6/25/2008	N.D.	2	10.79	21.58	10.79
	3349	7/16/2008	7/22/2008	N.D.	2	10.79	21.58	10.79
	3413	8/20/2008	8/22/2008	N.D.	2	14.93	29.86	14.93
	3461	9/10/2008	9/12/2008	N.D.	2	14.93	29.86	14.93
	3517	10/8/2008	10/10/2008	N.D.	2	14.93	29.86	14.93
	3590	11/13/2008	11/18/2008	N.D.	2	14.93	29.86	14.93
	3629	12/3/2008	12/6/2008	N.D.	2	14.93	29.86	14.93
	3724	1/14/2009	1/21/2009	N.D.	2	14.93	29.86	14.93
	3785	2/11/2009	2/13/2009	N.D.	2	14.93	29.86	14.93
	3839	3/10/2009	3/27/2009	N.D.	2	14.93	29.86	14.93
	3923	4/15/2009	4/22/2009	N.D.	2	14.93	29.86	14.93
	3991	5/12/2009	5/15/2009	N.D.	2	14.93	29.86	14.93
	4039	6/1/2009	6/8/2009	N.D.	2	14.93	29.86	14.93
	4102	7/7/2009	7/10/2009	N.D.	2	15.17	30.34	15.17
	4180	8/6/2009	8/13/2009	N.D.	2	15.17	30.34	15.17
	4249	9/2/2009	9/4/2009	N.D.	2	15.17	30.34	15.17
	4346	10/13/2009	10/15/2009	N.D.	2	15.17	30.34	15.17
	4371	11/2/2009	11/12/2009	N.D.	2	15.17	30.34	15.17
	4478	12/9/2009	12/15/2009	N.D.	2	15.17	30.34	15.17
	4639	1/27/2010	2/2/2010	N.D.	2	15.17	30.34	15.17
	4737	2/18/2010	2/23/2010	N.D.	2	15.17	30.34	15.17
	4794	3/9/2010	3/12/2010	N.D.	2	15.17	30.34	15.17
	4954	4/20/2010	4/28/2010	N.D.	2	15.17	30.34	15.17
	5079	5/25/2010	5/28/2010	N.D.	2	15.17	30.34	15.17
	5131	6/2/2010	6/7/2010	N.D.	2	15.17	30.34	15.17
	5251	7/13/2010	7/19/2010	N.D.	2	7.00	14.00	7.00
	5361	8/10/2010	8/17/2010	N.D.	2	7.00	14.00	7.00
	5488	9/22/2010	9/27/2010	N.D.	2	7.00	14.00	7.00
	5530	10/11/2010	10/18/2010	N.D.	2	7.00	14.00	7.00
	5623	11/8/2010	11/15/2010	N.D.	2	7.00	14.00	7.00
	5742	12/14/2010	12/20/2010	N.D.	2	7.00	14.00	7.00
	5840	1/18/2011	1/24/2011	N.D.	2	14.03	28.06	14.03
	5926	2/15/2011	2/21/2011	N.D.	2	14.03	28.06	14.03
	6014	3/8/2011	3/11/2011	N.D.	2	14.03	28.06	14.03
	6127	4/18/2011	4/26/2011	N.D.	2	14.03	28.06	14.03
	6209	5/9/2011	5/13/2011	N.D.	2	14.03	28.06	14.03
	6310	6/14/2011	6/21/2011	N.D.	2	14.03	28.06	14.03
	6425	7/18/2011	7/22/2011	N.D.	2	14.03	28.06	14.03
	6493	8/15/2011	8/22/2011	N.D.	2	14.03	28.06	14.03
	6572	9/19/2011	9/27/2011	N.D.	2	14.03	28.06	14.03
	6655	10/18/2011	10/25/2011	N.D.	2	14.03	28.06	14.03
	6717	11/7/2011	11/11/2011	N.D.	2	14.03	28.06	14.03
	6772	12/5/2011	12/9/2011	N.D.	2	14.40	28.80	14.40

Appendix F

Panel 4 Hydrogen Data

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 7e	4032	5/27/2009	5/29/2009	214.50	2	14.93	29.86	214.50
	4069	6/9/2009	6/12/2009	81.40	2	14.93	29.86	81.40
	4139	7/21/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
	4200	8/11/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
	4274	9/15/2009	9/18/2009	52.08	2	15.17	30.34	52.08
	4315	10/5/2009	10/12/2009	29.58	2	15.17	30.34	15.17
	4404	11/9/2009	11/16/2009	376.32	2	15.17	30.34	376.32
	4531	12/30/2009	1/12/2010	732.38	2	15.17	30.34	732.38
	4595	1/20/2010	1/22/2010	230.68	2	15.17	30.34	230.68
	4680	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
	4833	3/17/2010	3/29/2010	538.04	2	15.17	30.34	538.04
	4915	4/13/2010	4/20/2010	470.54	2	15.17	30.34	470.54
	5050	5/17/2010	5/24/2010	432.10	2	15.17	30.34	432.10
	5175	6/15/2010	6/21/2010	923.52	2	7.00	14.00	923.52
	5310	7/26/2010	8/2/2010	291.14	2	7.00	14.00	291.14
	5396	8/24/2010	8/30/2010	257.50	2	7.00	14.00	257.50
	5450	9/13/2010	9/20/2010	867.36	2	7.00	14.00	867.36
	5569	10/20/2010	10/25/2010	873.20	2	7.00	14.00	873.20
	5661	11/16/2010	11/22/2010	868.52	2	7.00	14.00	868.52
	5718	12/7/2010	12/13/2010	983.72	2	7.00	14.00	983.72
	5816	1/11/2011	1/18/2011	938.74	2	14.03	28.06	938.74
	5892	2/7/2011	2/10/2011	785.90	2	14.03	28.06	785.90
	5980	3/1/2011	3/4/2011	841.20	2	14.03	28.06	841.20
	6083	4/5/2011	4/20/2011	739.96	2	14.03	28.06	739.96
	6182	5/3/2011	5/6/2011	920.04	2	14.03	28.06	920.04
	6333	6/16/2011	6/24/2011	854.28	2	14.03	28.06	854.28
	6409	7/12/2011	7/15/2011	775.72	2	14.03	28.06	775.72
	6477	8/9/2011	8/19/2011	837.04	2	14.03	28.06	837.04
	6553	9/14/2011	9/16/2011	823.62	2	14.03	28.06	823.62
	6627	10/11/2011	10/14/2011	856.32	2	14.03	28.06	856.32
	6700	11/1/2011	11/4/2011	793.36	2	14.03	28.06	793.36
	6804	12/12/2011	12/16/2011	737.98	2	14.40	28.80	737.98

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 7i	4028	5/27/2009	5/29/2009	77.78	2	14.93	29.86	77.78
	4073	6/9/2009	6/12/2009	100.20	2	14.93	29.86	100.20
	4130	7/20/2009	7/24/2009	226.46	2	15.17	30.34	226.46
	4191	8/11/2009	8/17/2009	235.94	2	15.17	30.34	235.94
	4265	9/14/2009	9/18/2009	242.14	2	15.17	30.34	242.14
	4306	10/5/2009	10/12/2009	48.62	2	15.17	30.34	48.62
	4413	11/11/2009	11/16/2009	179.38	2	15.17	30.34	179.38
	4522	12/30/2009	1/12/2010	N.D.	2	15.17	30.34	15.17
	4586	1/19/2010	1/22/2010	242.94	2	15.17	30.34	242.94
	4671	2/9/2010	2/12/2010	341.44	2	15.17	30.34	341.44
	4824	3/16/2010	3/29/2010	652.14	2	15.17	30.34	652.14
	4925	4/14/2010	4/20/2010	453.88	2	15.17	30.34	453.88
	5041	5/17/2010	5/24/2010	879.08	2	15.17	30.34	879.08
	5166	6/14/2010	6/21/2010	823.70	2	7.00	14.00	823.70
	5301	7/26/2010	8/2/2010	45.56	2	7.00	14.00	45.56
	5387	8/24/2010	8/30/2010	686.82	2	7.00	14.00	686.82
	5441	9/13/2010	9/20/2010	758.66	2	7.00	14.00	758.66
	5560	10/19/2010	10/25/2010	761.02	2	7.00	14.00	761.02
	5652	11/15/2010	11/22/2010	849.62	2	7.00	14.00	849.62
	5709	12/7/2010	12/13/2010	828.18	2	7.00	14.00	828.18
	5807	1/11/2011	1/18/2011	708.12	2	14.03	28.06	708.12
	5881	2/1/2011	2/10/2011	707.46	2	14.03	28.06	707.46
	5971	3/1/2011	3/4/2011	902.20	2	14.03	28.06	902.20
	6074	4/5/2011	4/20/2011	831.04	2	14.03	28.06	831.04
	6173	5/2/2011	5/6/2011	729.88	2	14.03	28.06	729.88
	6324	6/15/2011	6/24/2011	687.94	2	14.03	28.06	687.94
	6400	7/11/2011	7/15/2011	674.94	2	14.03	28.06	674.94
	6461	8/9/2011	8/19/2011	507.68	2	14.03	28.06	507.68
	6544	9/13/2011	9/16/2011	500.24	2	14.03	28.06	500.24
	6618	10/10/2011	10/14/2011	388.58	2	14.03	28.06	388.58
	6691	11/1/2011	11/4/2011	425.88	2	14.03	28.06	425.88
	6795	12/12/2011	12/16/2011	557.70	2	14.40	28.80	557.70

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 6e	4031	5/27/2009	5/29/2009	190.82	2	14.93	29.86	190.82
	4068	6/8/2009	6/12/2009	114.46	2	14.93	29.86	114.46
	4140	7/21/2009	7/24/2009	177.58	2	15.17	30.34	177.58
	4201	8/11/2009	8/17/2009	247.88	2	15.17	30.34	247.88
	4275	9/15/2009	9/18/2009	159.46	2	15.17	30.34	159.46
	4316	10/5/2009	10/12/2009	117.88	2	15.17	30.34	117.88
	4403	11/9/2009	11/16/2009	341.80	2	15.17	30.34	341.80
	4532	12/30/2009	1/12/2010	466.88	2	15.17	30.34	466.88
	4596	1/20/2010	1/22/2010	576.72	2	15.17	30.34	576.72
	4681	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
	4834	3/17/2010	3/29/2010	599.50	2	15.17	30.34	599.50
	4916	4/13/2010	4/20/2010	741.36	2	15.17	30.34	741.36
	5051	5/17/2010	5/24/2010	234.98	2	15.17	30.34	234.98
	5176	6/15/2010	6/21/2010	207.18	2	7.00	14.00	207.18
	5311	7/27/2010	8/2/2010	N.D.	2	7.00	14.00	7.00
	5397	8/25/2010	8/30/2010	880.34	2	7.00	14.00	880.34
	5451	9/14/2010	9/20/2010	902.54	2	7.00	14.00	902.54
	5570	10/20/2010	10/25/2010	1012.68	2	7.00	14.00	1012.68
	5662	11/16/2010	11/22/2010	991.58	2	7.00	14.00	991.58
	5719	12/8/2010	12/13/2010	768.08	2	7.00	14.00	768.08
	5817	1/12/2011	1/18/2011	619.40	2	14.03	28.06	619.40
	5893	2/7/2011	2/10/2011	911.52	2	14.03	28.06	911.52
	5981	3/2/2011	3/4/2011	946.96	2	14.03	28.06	946.96
	6084	4/5/2011	4/20/2011	616.24	2	14.03	28.06	616.24
	6183	5/3/2011	5/6/2011	720.54	2	14.03	28.06	720.54
	6334	6/16/2011	6/24/2011	543.56	2	14.03	28.06	543.56
	6410	7/12/2011	7/15/2011	648.56	2	14.03	28.06	648.56
	6478	8/9/2011	8/19/2011	692.68	2	14.03	28.06	692.68
	6554	9/14/2011	9/16/2011	656.56	2	14.03	28.06	656.56
	6628	10/11/2011	10/14/2011	679.30	2	14.03	28.06	679.30
	6701	11/1/2011	11/4/2011	661.62	2	14.03	28.06	661.62

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 6i	4027	5/27/2009	5/29/2009	67.96	2	14.93	29.86	67.96
	4072	6/9/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
	4131	7/20/2009	7/24/2009	247.58	2	15.17	30.34	247.58
	4192	8/11/2009	8/17/2009	230.00	2	15.17	30.34	230.00
	4266	9/14/2009	9/18/2009	247.62	2	15.17	30.34	247.62
	4307	10/5/2009	10/12/2009	324.08	2	15.17	30.34	324.08
	4412	11/11/2009	11/16/2009	N.D.	2	15.17	30.34	15.17
	4523	12/30/2009	1/12/2010	419.66	2	15.17	30.34	419.66
	4587	1/19/2010	1/22/2010	199.04	2	15.17	30.34	199.04
	4672	2/9/2010	2/12/2010	85.18	2	15.17	30.34	85.18
	4825	3/16/2010	3/29/2010	647.86	2	15.17	30.34	647.86
	4926	4/14/2010	4/20/2010	528.88	2	15.17	30.34	528.88
	5042	5/17/2010	5/24/2010	613.98	2	15.17	30.34	613.98
	5167	6/14/2010	6/21/2010	613.10	2	7.00	14.00	613.10
	5302	7/26/2010	8/2/2010	555.22	2	7.00	14.00	555.22
	5388	8/24/2010	8/30/2010	750.22	2	7.00	14.00	750.22
	5442	9/13/2010	9/20/2010	713.28	2	7.00	14.00	713.28
	5561	10/19/2010	10/25/2010	902.74	2	7.00	14.00	902.74
	5653	11/15/2010	11/22/2010	760.56	2	7.00	14.00	760.56
	5710	12/7/2010	12/13/2010	740.56	2	7.00	14.00	740.56
	5808	1/11/2011	1/18/2011	740.30	2	14.03	28.06	740.30
	5882	2/1/2011	2/10/2011	704.76	2	14.03	28.06	704.76
	5972	3/1/2011	3/4/2011	736.38	2	14.03	28.06	736.38
	6075	4/5/2011	4/20/2011	648.88	2	14.03	28.06	648.88
	6174	5/2/2011	5/6/2011	512.20	2	14.03	28.06	512.20
	6325	6/15/2011	6/24/2011	531.00	2	14.03	28.06	531.00
	6401	7/11/2011	7/15/2011	494.48	2	14.03	28.06	494.48
	6469	8/9/2011	8/19/2011	397.04	2	14.03	28.06	397.04
	6545	9/13/2011	9/16/2011	461.88	2	14.03	28.06	461.88
	6619	10/10/2011	10/14/2011	323.52	2	14.03	28.06	323.52
	6692	11/1/2011	11/4/2011	370.18	2	14.03	28.06	370.18
	6796	12/12/2011	12/16/2011	459.02	2	14.40	28.80	459.02

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 5e	4030	5/27/2009	5/29/2009	143.28	2	14.93	29.86	143.28
	4067	6/8/2009	6/12/2009	65.66	2	14.93	29.86	65.66
	4141	7/21/2009	7/24/2009	175.06	2	15.17	30.34	175.06
	4202	8/11/2009	8/17/2009	33.02	2	15.17	30.34	33.02
	4276	9/15/2009	9/18/2009	172.86	2	15.17	30.34	172.86
	4317	10/5/2009	10/12/2009	129.82	2	15.17	30.34	129.82
	4402	11/9/2009	11/16/2009	406.36	2	15.17	30.34	406.36
	4533	12/30/2009	1/12/2010	468.60	2	15.17	30.34	468.60
	4597	1/20/2010	1/22/2010	408.40	2	15.17	30.34	408.40
	4682	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
	4835	3/17/2010	3/29/2010	575.58	2	15.17	30.34	575.58
	4917	4/13/2010	4/20/2010	510.30	2	15.17	30.34	510.30
	5052	5/17/2010	5/24/2010	747.14	2	15.17	30.34	747.14
	5177	6/15/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
	5312	7/27/2010	8/2/2010	601.06	2	7.00	14.00	601.06
	5398	8/25/2010	8/30/2010	688.94	2	7.00	14.00	688.94
	5452	9/14/2010	9/20/2010	792.94	2	7.00	14.00	792.94
	5571	10/20/2010	10/25/2010	655.86	2	7.00	14.00	655.86
	5663	11/16/2010	11/22/2010	756.48	2	7.00	14.00	756.48
	5720	12/8/2010	12/13/2010	583.38	2	7.00	14.00	583.38
	5818	1/12/2011	1/18/2011	709.40	2	14.03	28.06	709.40
	5894	2/7/2011	2/10/2011	677.24	2	14.03	28.06	677.24
	5982	3/2/2011	3/4/2011	683.92	2	14.03	28.06	683.92
	6085	4/5/2011	4/20/2011	608.70	2	14.03	28.06	608.70
	6184	5/3/2011	5/6/2011	731.70	2	14.03	28.06	731.70
	6335	6/16/2011	6/24/2011	689.48	2	14.03	28.06	689.48
	6411	7/12/2011	7/15/2011	640.36	2	14.03	28.06	640.36
	6479	8/9/2011	8/19/2011	646.18	2	14.03	28.06	646.18
	6557	9/14/2011	9/16/2011	671.18	2	14.03	28.06	671.18
	6629	10/11/2011	10/14/2011	673.00	2	14.03	28.06	673.00
	6702	11/1/2011	11/4/2011	604.10	2	14.03	28.06	604.10
	6806	12/13/2011	12/16/2011	558.76	2	14.40	28.80	558.76

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 5i	4026	5/27/2009	5/29/2009	68.62	2	14.93	29.86	68.62
	4071	6/9/2009	6/12/2009	95.90	2	14.93	29.86	95.90
	4132	7/20/2009	7/24/2009	198.24	2	15.17	30.34	198.24
	4193	8/11/2009	8/17/2009	250.44	2	15.17	30.34	250.44
	4267	9/14/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
	4308	10/5/2009	10/12/2009	371.50	2	15.17	30.34	371.50
	4411	11/11/2009	11/16/2009	429.94	2	15.17	30.34	429.94
	4524	12/30/2009	1/12/2010	576.48	2	15.17	30.34	576.48
	4588	1/19/2010	1/22/2010	312.66	2	15.17	30.34	312.66
	4673	2/9/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
	4826	3/16/2010	3/29/2010	649.22	2	15.17	30.34	649.22
	4927	4/14/2010	4/20/2010	480.98	2	15.17	30.34	480.98
	5043	5/17/2010	5/24/2010	386.14	2	15.17	30.34	386.14
	5168	6/14/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
	5303	7/26/2010	8/2/2010	593.42	2	7.00	14.00	593.42
	5389	8/24/2010	8/30/2010	606.30	2	7.00	14.00	606.30
	5443	9/13/2010	9/20/2010	790.44	2	7.00	14.00	790.44
	5562	10/19/2010	10/25/2010	764.12	2	7.00	14.00	764.12
	5654	11/15/2010	11/22/2010	686.16	2	7.00	14.00	686.16
	5711	12/7/2010	12/13/2010	636.06	2	7.00	14.00	636.06
	5809	1/11/2011	1/18/2011	647.44	2	14.03	28.06	647.44
	5883	2/1/2011	2/10/2011	580.90	2	14.03	28.06	580.90
	5973	3/1/2011	3/4/2011	636.12	2	14.03	28.06	636.12
	6076	4/5/2011	4/20/2011	698.90	2	14.03	28.06	698.90
	6175	5/2/2011	5/6/2011	695.86	2	14.03	28.06	695.86
	6326	6/15/2011	6/24/2011	608.70	2	14.03	28.06	608.70
	6402	7/11/2011	7/15/2011	715.64	2	14.03	28.06	715.64
	6470	8/9/2011	8/19/2011	631.96	2	14.03	28.06	631.96
	6546	9/13/2011	9/16/2011	564.12	2	14.03	28.06	564.12
	6620	10/10/2011	10/14/2011	449.38	2	14.03	28.06	449.38
	6693	11/1/2011	11/4/2011	421.78	2	14.03	28.06	421.78
	6797	12/12/2011	12/16/2011	502.48	2	14.40	28.80	502.48

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 4e	4029	5/27/2009	5/29/2009	52.26	2	14.93	29.86	52.26
	4066	6/8/2009	6/12/2009	29.26	2	14.93	29.86	14.93
	4142	7/21/2009	7/24/2009	145.02	2	15.17	30.34	145.02
	4203	8/13/2009	8/17/2009	256.40	2	15.17	30.34	256.40
	4277	9/15/2009	9/18/2009	239.74	2	15.17	30.34	239.74
	4318	10/5/2009	10/12/2009	107.02	2	15.17	30.34	107.02
	4401	11/9/2009	11/16/2009	293.96	2	15.17	30.34	293.96
	4534	12/30/2009	1/12/2010	525.70	2	15.17	30.34	525.70
	4598	1/20/2010	1/22/2010	298.72	2	15.17	30.34	298.72
	4683	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
	4836	3/17/2010	3/29/2010	512.92	2	15.17	30.34	512.92
	4918	4/13/2010	4/20/2010	516.80	2	15.17	30.34	516.80
	5053	5/17/2010	5/24/2010	479.40	2	15.17	30.34	479.40
	5178	6/15/2010	6/21/2010	144.16	2	7.00	14.00	144.16
	5313	7/27/2010	8/2/2010	597.18	2	7.00	14.00	597.18
	5399	8/25/2010	8/30/2010	779.30	2	7.00	14.00	779.30
	5453	9/14/2010	9/20/2010	561.66	2	7.00	14.00	561.66
	5572	10/20/2010	10/25/2010	643.42	2	7.00	14.00	643.42
	5664	11/16/2010	11/22/2010	640.36	2	7.00	14.00	640.36
	5721	12/8/2010	12/13/2010	570.10	2	7.00	14.00	570.10
	5819	1/12/2011	1/18/2011	656.70	2	14.03	28.06	656.70
	5895	2/7/2011	2/10/2011	479.42	2	14.03	28.06	479.42
	5983	3/2/2011	3/4/2011	561.46	2	14.03	28.06	561.46

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 4i	4025	5/27/2009	5/29/2009	46.62	2	14.93	29.86	46.62
	4070	6/9/2009	6/12/2009	66.00	2	14.93	29.86	66.00
	4133	7/20/2009	7/24/2009	162.30	2	15.17	30.34	162.30
	4194	8/11/2009	8/17/2009	184.72	2	15.17	30.34	184.72
	4268	9/14/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
	4309	10/5/2009	10/12/2009	167.38	2	15.17	30.34	167.38
	4410	11/11/2009	11/16/2009	390.88	2	15.17	30.34	390.88
	4525	12/30/2009	1/12/2010	476.76	2	15.17	30.34	476.76
	4589	1/19/2010	1/22/2010	302.16	2	15.17	30.34	302.16
	4674	2/9/2010	2/12/2010	73.90	2	15.17	30.34	73.90
	4827	3/16/2010	3/29/2010	532.06	2	15.17	30.34	532.06
	4928	4/14/2010	4/20/2010	91.48	2	15.17	30.34	91.48
	5044	5/17/2010	5/24/2010	537.96	2	15.17	30.34	537.96
	5169	6/14/2010	6/21/2010	111.78	2	7.00	14.00	111.78
	5304	7/26/2010	8/2/2010	275.10	2	7.00	14.00	275.10
	5390	8/24/2010	8/30/2010	709.50	2	7.00	14.00	709.50
	5444	9/13/2010	9/20/2010	728.04	2	7.00	14.00	728.04
	5563	10/19/2010	10/25/2010	670.12	2	7.00	14.00	670.12
	5655	11/15/2010	11/22/2010	672.26	2	7.00	14.00	672.26
	5712	12/7/2010	12/13/2010	610.84	2	7.00	14.00	610.84
	5810	1/11/2011	1/18/2011	597.58	2	14.03	28.06	597.58
	5884	2/1/2011	2/10/2011	N.D.	2	14.03	28.06	14.03
	5974	3/1/2011	3/4/2011	622.32	2	14.03	28.06	622.32
	6077	4/5/2011	4/20/2011	734.34	2	14.03	28.06	734.34
	6176	5/2/2011	5/6/2011	663.88	2	14.03	28.06	663.88
	6327	6/15/2011	6/24/2011	583.40	2	14.03	28.06	583.40
	6403	7/11/2011	7/15/2011	629.18	2	14.03	28.06	629.18
	6471	8/9/2011	8/19/2011	445.40	2	14.03	28.06	445.40
	6547	9/13/2011	9/16/2011	428.76	2	14.03	28.06	428.76
	6621	10/10/2011	10/14/2011	357.76	2	14.03	28.06	357.76
	6694	11/1/2011	11/4/2011	381.34	2	14.03	28.06	381.34
	6798	12/12/2011	12/16/2011	552.18	2	14.40	28.80	552.18

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 3e	4019	5/26/2009	5/29/2009	135.72	2	14.93	29.86	135.72
	4077	6/10/2009	6/12/2009	46.60	2	14.93	29.86	46.60
	4143	7/21/2009	7/24/2009	137.72	2	15.17	30.34	137.72
	4204	8/13/2009	8/17/2009	160.64	2	15.17	30.34	160.64
	4278	9/15/2009	9/18/2009	166.84	2	15.17	30.34	166.84
	4319	10/5/2009	10/12/2009	33.06	2	15.17	30.34	33.06
	4400	11/9/2009	11/16/2009	391.36	2	15.17	30.34	391.36
	4535	12/30/2009	1/12/2010	538.14	2	15.17	30.34	538.14
	4599	1/20/2010	1/22/2010	407.96	2	15.17	30.34	407.96
	4684	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
	4837	3/17/2010	3/29/2010	554.86	2	15.17	30.34	554.86
	4919	4/13/2010	4/20/2010	458.06	2	15.17	30.34	458.06
	5054	5/17/2010	5/24/2010	377.58	2	15.17	30.34	377.58
	5179	6/15/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
	5314	7/27/2010	8/2/2010	647.24	2	7.00	14.00	647.24
	5400	8/25/2010	8/30/2010	241.08	2	7.00	14.00	241.08
	5454	9/14/2010	9/20/2010	622.18	2	7.00	14.00	622.18
	5573	10/20/2010	10/25/2010	533.98	2	7.00	14.00	533.98
	5665	11/16/2010	11/22/2010	691.12	2	7.00	14.00	691.12
	5722	12/8/2010	12/13/2010	620.50	2	7.00	14.00	620.50
	5820	1/12/2011	1/18/2011	656.18	2	14.03	28.06	656.18
	5896	2/7/2011	2/10/2011	661.56	2	14.03	28.06	661.56
	5984	3/2/2011	3/4/2011	573.94	2	14.03	28.06	573.94
	6087	4/6/2011	4/20/2011	676.52	2	14.03	28.06	676.52
	6185	5/3/2011	5/6/2011	662.62	2	14.03	28.06	662.62
	6336	6/16/2011	6/24/2011	674.22	2	14.03	28.06	674.22
	6412	7/12/2011	7/15/2011	635.28	2	14.03	28.06	635.28
	6480	8/9/2011	8/19/2011	663.40	2	14.03	28.06	663.40
	6558	9/14/2011	9/16/2011	626.82	2	14.03	28.06	626.82
	6630	10/11/2011	10/14/2011	628.78	2	14.03	28.06	628.78
	6703	11/1/2011	11/4/2011	605.58	2	14.03	28.06	605.58
	6807	12/13/2011	12/16/2011	552.70	2	14.40	28.80	552.70

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 3i	4024	5/27/2009	5/29/2009	15.48	2	14.93	29.86	14.93
	4079	6/10/2009	6/12/2009	40.10	2	14.93	29.86	40.10
	4134	7/20/2009	7/24/2009	65.92	2	15.17	30.34	65.92
	4195	8/11/2009	8/17/2009	120.62	2	15.17	30.34	120.62
	4269	9/14/2009	9/18/2009	130.34	2	15.17	30.34	130.34
	4310	10/5/2009	10/12/2009	23.22	2	15.17	30.34	15.17
	4409	11/11/2009	11/16/2009	317.70	2	15.17	30.34	317.70
	4526	12/30/2009	1/12/2010	410.20	2	15.17	30.34	410.20
	4590	1/19/2010	1/22/2010	N.D.	2	15.17	30.34	15.17
	4675	2/9/2010	2/12/2010	92.42	2	15.17	30.34	92.42
	4828	3/16/2010	3/29/2010	484.76	2	15.17	30.34	484.76
	4929	4/14/2010	4/20/2010	331.22	2	15.17	30.34	331.22
	5045	5/17/2010	5/24/2010	408.70	2	15.17	30.34	408.70
	5170	6/15/2010	6/21/2010	491.76	2	7.00	14.00	491.76
	5305	7/26/2010	8/2/2010	N.D.	2	7.00	14.00	7.00
	5391	8/24/2010	8/30/2010	824.28	2	7.00	14.00	824.28
	5445	9/13/2010	9/20/2010	177.42	2	7.00	14.00	177.42
	5564	10/19/2010	10/25/2010	658.14	2	7.00	14.00	658.14
	5656	11/15/2010	11/22/2010	693.76	2	7.00	14.00	693.76
	5713	12/7/2010	12/13/2010	653.24	2	7.00	14.00	653.24
	5811	1/11/2011	1/18/2011	539.18	2	14.03	28.06	539.18
	5885	2/1/2011	2/10/2011	610.30	2	14.03	28.06	610.30
	5975	3/1/2011	3/4/2011	567.88	2	14.03	28.06	567.88
	6078	4/5/2011	4/20/2011	647.26	2	14.03	28.06	647.26
	6177	5/2/2011	5/6/2011	579.32	2	14.03	28.06	579.32
	6328	6/16/2011	6/24/2011	604.84	2	14.03	28.06	604.84
	6404	7/11/2011	7/15/2011	592.78	2	14.03	28.06	592.78
	6472	8/9/2011	8/19/2011	589.06	2	14.03	28.06	589.06
	6548	9/13/2011	9/16/2011	586.56	2	14.03	28.06	586.56
	6622	10/10/2011	10/14/2011	543.54	2	14.03	28.06	543.54
	6695	11/1/2011	11/4/2011	476.68	2	14.03	28.06	476.68
	6799	12/12/2011	12/16/2011	538.20	2	14.40	28.80	538.20

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 2e	4018	5/26/2009	5/29/2009	119.42	2	14.93	29.86	119.42
	4076	6/10/2009	6/12/2009	40.70	2	14.93	29.86	40.70
	4144	7/22/2009	7/24/2009	21.58	2	15.17	30.34	15.17
	4205	8/13/2009	8/17/2009	41.80	2	15.17	30.34	41.80
	4279	9/15/2009	9/18/2009	33.74	2	15.17	30.34	33.74
	4320	10/6/2009	10/12/2009	N.D.	2	15.17	30.34	15.17
	4399	11/9/2009	11/16/2009	360.32	2	15.17	30.34	360.32
	4536	12/30/2009	1/12/2010	447.06	2	15.17	30.34	447.06
	4600	1/20/2010	1/22/2010	412.04	2	15.17	30.34	412.04
	4685	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
	4838	3/17/2010	3/29/2010	401.50	2	15.17	30.34	401.50
	4920	4/13/2010	4/20/2010	384.86	2	15.17	30.34	384.86
	5055	5/17/2010	5/24/2010	450.50	2	15.17	30.34	450.50
	5180	6/16/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
	5315	7/27/2010	8/2/2010	252.22	2	7.00	14.00	252.22
	5401	8/25/2010	8/30/2010	453.70	2	7.00	14.00	453.70
	5455	9/14/2010	9/20/2010	505.30	2	7.00	14.00	505.30
	5574	10/20/2010	10/25/2010	164.70	2	7.00	14.00	164.70
	5666	11/16/2010	11/22/2010	478.96	2	7.00	14.00	478.96
	5723	12/8/2010	12/13/2010	477.24	2	7.00	14.00	477.24
	5821	1/12/2011	1/18/2011	530.64	2	14.03	28.06	530.64
	5897	2/7/2011	2/10/2011	498.90	2	14.03	28.06	498.90
	5985	3/2/2011	3/4/2011	456.92	2	14.03	28.06	456.92
	6088	4/6/2011	4/20/2011	573.66	2	14.03	28.06	573.66
	6186	5/3/2011	5/6/2011	435.26	2	14.03	28.06	435.26
	6337	6/16/2011	6/24/2011	549.10	2	14.03	28.06	549.10
	6413	7/12/2011	7/15/2011	472.86	2	14.03	28.06	472.86
	6481	8/9/2011	8/19/2011	416.32	2	14.03	28.06	416.32
	6559	9/14/2011	9/16/2011	465.28	2	14.03	28.06	465.28
	6631	10/11/2011	10/14/2011	327.84	2	14.03	28.06	327.84
	6704	11/1/2011	11/4/2011	426.68	2	14.03	28.06	426.68
	6808	12/13/2011	12/16/2011	506.18	2	14.40	28.80	506.18

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 2i	4023	5/27/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
	4078	6/10/2009	6/12/2009	9.74	2	14.93	29.86	14.93
	4135	7/20/2009	7/24/2009	18.58	2	15.17	30.34	15.17
	4196	8/11/2009	8/17/2009	39.14	2	15.17	30.34	39.14
	4270	9/14/2009	9/18/2009	27.80	2	15.17	30.34	15.17
	4311	10/5/2009	10/12/2009	123.80	2	15.17	30.34	123.80
	4408	11/11/2009	11/16/2009	360.98	2	15.17	30.34	360.98
	4527	12/30/2009	1/12/2010	345.20	2	15.17	30.34	345.20
	4591	1/19/2010	1/22/2010	212.78	2	15.17	30.34	212.78
	4676	2/9/2010	2/12/2010	100.50	2	15.17	30.34	100.50
	4829	3/16/2010	3/29/2010	315.38	2	15.17	30.34	315.38
	4930	4/14/2010	4/20/2010	465.72	2	15.17	30.34	465.72
	5046	5/17/2010	5/24/2010	359.90	2	15.17	30.34	359.90
	5171	6/15/2010	6/21/2010	297.24	2	7.00	14.00	297.24
	5306	7/26/2010	8/2/2010	106.64	2	7.00	14.00	106.64
	5392	8/24/2010	8/30/2010	484.80	2	7.00	14.00	484.80
	5446	9/13/2010	9/20/2010	525.82	2	7.00	14.00	525.82
	5565	10/19/2010	10/25/2010	466.74	2	7.00	14.00	466.74
	5657	11/15/2010	11/22/2010	516.38	2	7.00	14.00	516.38
	5714	12/7/2010	12/13/2010	479.42	2	7.00	14.00	479.42
	5812	1/11/2011	1/18/2011	445.86	2	14.03	28.06	445.86
	5886	2/1/2011	2/10/2011	479.84	2	14.03	28.06	479.84
	5976	3/1/2011	3/4/2011	417.06	2	14.03	28.06	417.06
	6079	4/5/2011	4/20/2011	501.76	2	14.03	28.06	501.76
	6178	5/2/2011	5/6/2011	373.08	2	14.03	28.06	373.08
	6329	6/16/2011	6/24/2011	505.80	2	14.03	28.06	505.80
	6405	7/11/2011	7/15/2011	460.76	2	14.03	28.06	460.76
	6473	8/9/2011	8/19/2011	353.70	2	14.03	28.06	353.70
	6549	9/13/2011	9/16/2011	468.10	2	14.03	28.06	468.10
	6623	10/10/2011	10/14/2011	332.94	2	14.03	28.06	332.94
	6696	11/1/2011	11/4/2011	399.78	2	14.03	28.06	399.78
	6800	12/12/2011	12/16/2011	494.62	2	14.40	28.80	494.62

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 1e	4016	5/26/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
	4074	6/9/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
	4145	7/22/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
	4206	8/13/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
	4280	9/15/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
	4321	10/6/2009	10/12/2009	239.96	2	15.17	30.34	239.96
	4397	11/9/2009	11/16/2009	350.24	2	15.17	30.34	350.24
	4537	12/30/2009	1/12/2010	390.52	2	15.17	30.34	390.52
	4601	1/20/2010	1/22/2010	267.72	2	15.17	30.34	267.72
	4686	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
	4839	3/17/2010	3/29/2010	319.58	2	15.17	30.34	319.58
	4923	4/14/2010	4/20/2010	384.86	2	15.17	30.34	384.86
	5056	5/18/2010	5/24/2010	N.D.	2	15.17	30.34	15.17
	5181	6/16/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
	5316	7/27/2010	8/2/2010	307.08	2	7.00	14.00	307.08
	5402	8/25/2010	8/30/2010	223.64	2	7.00	14.00	223.64
	5456	9/14/2010	9/20/2010	270.82	2	7.00	14.00	270.82
	5575	10/20/2010	10/25/2010	355.54	2	7.00	14.00	355.54
	5667	11/16/2010	11/22/2010	451.70	2	7.00	14.00	451.70
	5724	12/8/2010	12/13/2010	347.96	2	7.00	14.00	347.96
	5822	1/12/2011	1/18/2011	460.36	2	14.03	28.06	460.36
	5890	2/1/2011	2/10/2011	371.40	2	14.03	28.06	371.40
	5986	3/2/2011	3/4/2011	391.48	2	14.03	28.06	391.48
	6089	4/6/2011	4/20/2011	480.62	2	14.03	28.06	480.62
	6187	5/4/2011	5/6/2011	345.60	2	14.03	28.06	345.60
	6338	6/16/2011	6/24/2011	488.10	2	14.03	28.06	488.10
	6414	7/12/2011	7/15/2011	283.24	2	14.03	28.06	283.24
	6482	8/9/2011	8/19/2011	143.48	2	14.03	28.06	143.48
	6560	9/14/2011	9/16/2011	410.04	2	14.03	28.06	410.04
	6634	10/11/2011	10/14/2011	305.92	2	14.03	28.06	305.92
	6707	11/1/2011	11/4/2011	388.88	2	14.03	28.06	388.88
	6811	12/13/2011	12/16/2011	494.32	2	14.40	28.80	494.32

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Room 1i	4020	5/27/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
	4061	6/8/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
	4136	7/20/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
	4197	8/11/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
	4271	9/14/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
	4312	10/5/2009	10/12/2009	197.06	2	15.17	30.34	197.06
	4407	11/11/2009	11/16/2009	173.66	2	15.17	30.34	173.66
	4528	12/30/2009	1/12/2010	340.76	2	15.17	30.34	340.76
	4592	1/19/2010	1/22/2010	231.74	2	15.17	30.34	231.74
	4677	2/9/2010	2/12/2010	93.12	2	15.17	30.34	93.12
	4830	3/16/2010	3/29/2010	163.52	2	15.17	30.34	163.52
	4931	4/14/2010	4/20/2010	408.26	2	15.17	30.34	408.26
	5047	5/17/2010	5/24/2010	342.24	2	15.17	30.34	342.24
	5172	6/15/2010	6/21/2010	218.42	2	7.00	14.00	218.42
	5307	7/26/2010	8/2/2010	125.26	2	7.00	14.00	125.26
	5393	8/24/2010	8/30/2010	333.46	2	7.00	14.00	333.46
	5447	9/13/2010	9/20/2010	328.02	2	7.00	14.00	328.02
	5566	10/19/2010	10/25/2010	427.46	2	7.00	14.00	427.46
	5658	11/15/2010	11/22/2010	443.82	2	7.00	14.00	443.82
	5715	12/7/2010	12/13/2010	455.58	2	7.00	14.00	455.58
	5813	1/11/2011	1/18/2011	362.94	2	14.03	28.06	362.94
	5887	2/1/2011	2/10/2011	353.66	2	14.03	28.06	353.66
	5977	3/1/2011	3/4/2011	370.72	2	14.03	28.06	370.72
	6080	4/5/2011	4/20/2011	414.54	2	14.03	28.06	414.54
	6179	5/2/2011	5/6/2011	252.54	2	14.03	28.06	252.54
	6330	6/16/2011	6/24/2011	519.66	2	14.03	28.06	519.66
	6406	7/11/2011	7/15/2011	411.26	2	14.03	28.06	411.26
	6474	8/9/2011	8/19/2011	300.02	2	14.03	28.06	300.02
	6550	9/13/2011	9/16/2011	429.54	2	14.03	28.06	429.54
	6624	10/10/2011	10/14/2011	294.66	2	14.03	28.06	294.66
	6697	11/1/2011	11/4/2011	365.72	2	14.03	28.06	365.72
	6801	12/12/2011	12/16/2011	483.68	2	14.40	28.80	483.68

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Location EBW	4015	5/26/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
	4065	6/8/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
	4147	7/22/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
	4208	8/13/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
	4282	9/15/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
	4323	10/6/2009	10/12/2009	105.10	2	15.17	30.34	105.10
	4396	11/9/2009	11/16/2009	141.00	2	15.17	30.34	141.00
	4539	12/30/2009	1/12/2010	235.40	2	15.17	30.34	235.40
	4603	1/20/2010	1/22/2010	270.16	2	15.17	30.34	270.16
	4688	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
	4841	3/17/2010	3/29/2010	324.28	2	15.17	30.34	324.28
	4921	4/13/2010	4/20/2010	N.D.	2	15.17	30.34	15.17
	5058	5/18/2010	5/24/2010	64.70	2	15.17	30.34	64.70
	5183	6/16/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
	5318	7/27/2010	8/2/2010	137.54	2	7.00	14.00	137.54
	5404	8/25/2010	8/30/2010	60.18	2	7.00	14.00	60.18
	5458	9/14/2010	9/20/2010	N.D.	2	7.00	14.00	7.00
	5577	10/20/2010	10/25/2010	N.D.	2	7.00	14.00	7.00
	5669	11/16/2010	11/22/2010	N.D.	2	7.00	14.00	7.00
	5726	12/8/2010	12/13/2010	149.84	2	7.00	14.00	149.84
	5824	1/12/2011	1/18/2011	268.54	2	14.03	28.06	268.54
	5898	2/7/2011	2/10/2011	316.50	2	14.03	28.06	316.50
	5988	3/2/2011	3/4/2011	281.32	2	14.03	28.06	281.32
	6091	4/6/2011	4/20/2011	182.90	2	14.03	28.06	182.90
	6189	5/4/2011	5/6/2011	42.48	2	14.03	28.06	42.48
	6340	6/16/2011	6/24/2011	206.20	2	14.03	28.06	206.20
	6416	7/12/2011	7/15/2011	68.52	2	14.03	28.06	68.52
	6484	8/9/2011	8/19/2011	45.78	2	14.03	28.06	45.78
	6562	9/14/2011	9/16/2011	109.38	2	14.03	28.06	109.38
	6632	10/11/2011	10/14/2011	51.88	2	14.03	28.06	51.88
	6705	11/1/2011	11/4/2011	183.10	2	14.03	28.06	183.10
	6809	12/13/2011	12/16/2011	214.68	2	14.40	28.80	214.68

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Location EBA	4014	5/26/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
	4064	6/8/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
	4148	7/22/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
	4209	8/13/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
	4283	9/15/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
	4324	10/6/2009	10/12/2009	N.D.	2	15.17	30.34	15.17
	4395	11/9/2009	11/16/2009	N.D.	2	15.17	30.34	15.17
	4540	12/30/2009	1/12/2010	N.D.	2	15.17	30.34	15.17
	4604	1/20/2010	1/22/2010	N.D.	2	15.17	30.34	15.17
	4689	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
	4842	3/17/2010	3/29/2010	N.D.	2	15.17	30.34	15.17
	4922	4/13/2010	4/20/2010	N.D.	2	15.17	30.34	15.17
	5059	5/18/2010	5/24/2010	N.D.	2	15.17	30.34	15.17
	5184	6/16/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
	5319	7/27/2010	8/2/2010	N.D.	2	7.00	14.00	7.00
	5405	8/25/2010	8/30/2010	N.D.	2	7.00	14.00	7.00
	5459	9/14/2010	9/20/2010	N.D.	2	7.00	14.00	7.00
	5578	10/20/2010	10/25/2010	N.D.	2	7.00	14.00	7.00
	5670	11/16/2010	11/22/2010	N.D.	2	7.00	14.00	7.00
	5727	12/8/2010	12/13/2010	N.D.	2	7.00	14.00	7.00
	5825	1/12/2011	1/18/2011	N.D.	2	14.03	28.06	14.03
	5899	2/7/2011	2/10/2011	N.D.	2	14.03	28.06	14.03
	5989	3/2/2011	3/4/2011	N.D.	2	14.03	28.06	14.03
	6092	4/6/2011	4/20/2011	N.D.	2	14.03	28.06	14.03
	6190	5/4/2011	5/6/2011	N.D.	2	14.03	28.06	14.03
	6341	6/16/2011	6/24/2011	N.D.	2	14.03	28.06	14.03
	6417	7/12/2011	7/15/2011	N.D.	2	14.03	28.06	14.03
	6485	8/9/2011	8/19/2011	N.D.	2	14.03	28.06	14.03
	6563	9/14/2011	9/16/2011	N.D.	2	14.03	28.06	14.03
	6633	10/11/2011	10/14/2011	N.D.	2	14.03	28.06	14.03
	6706	11/1/2011	11/4/2011	N.D.	2	14.03	28.06	14.03
	6810	12/13/2011	12/16/2011	N.D.	2	14.40	28.80	14.40

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Location IBW	4022	5/27/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
	4063	6/8/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
	4137	7/20/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
	4198	8/11/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
	4272	9/14/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
	4313	10/5/2009	10/12/2009	12.56	2	15.17	30.34	15.17
	4406	11/11/2009	11/16/2009	N.D.	2	15.17	30.34	15.17
	4529	12/30/2009	1/12/2010	166.08	2	15.17	30.34	166.08
	4593	1/19/2010	1/22/2010	129.08	2	15.17	30.34	129.08
	4678	2/9/2010	2/12/2010	50.74	2	15.17	30.34	50.74
	4831	3/16/2010	3/29/2010	N.D.	2	15.17	30.34	15.17
	4932	4/14/2010	4/20/2010	236.70	2	15.17	30.34	236.70
	5048	5/17/2010	5/24/2010	230.88	2	15.17	30.34	230.88
	5173	6/15/2010	6/21/2010	252.06	2	7.00	14.00	252.06
	5308	7/26/2010	8/2/2010	283.86	2	7.00	14.00	283.86
	5394	8/24/2010	8/30/2010	114.94	2	7.00	14.00	114.94
	5448	9/13/2010	9/20/2010	70.54	2	7.00	14.00	70.54
	5567	10/19/2010	10/25/2010	398.20	2	7.00	14.00	398.20
	5659	11/15/2010	11/22/2010	329.56	2	7.00	14.00	329.56
	5716	12/7/2010	12/13/2010	357.10	2	7.00	14.00	357.10
	5814	1/11/2011	1/18/2011	302.90	2	14.03	28.06	302.90
	5888	2/1/2011	2/10/2011	298.64	2	14.03	28.06	298.64
	5978	3/1/2011	3/4/2011	317.72	2	14.03	28.06	317.72
	6081	4/5/2011	4/20/2011	329.26	2	14.03	28.06	329.26
	6180	5/3/2011	5/6/2011	334.28	2	14.03	28.06	334.28
	6331	6/16/2011	6/24/2011	319.28	2	14.03	28.06	319.28
	6407	7/11/2011	7/15/2011	263.72	2	14.03	28.06	263.72
	6475	8/9/2011	8/19/2011	264.52	2	14.03	28.06	264.52
	6551	9/13/2011	9/16/2011	289.72	2	14.03	28.06	289.72
	6625	10/10/2011	10/14/2011	229.52	2	14.03	28.06	229.52
	6698	11/1/2011	11/4/2011	249.70	2	14.03	28.06	249.70
	6802	12/12/2011	12/16/2011	356.14	2	14.40	28.80	356.14

Hydrogen (H_2)								
Location	Sample ID	Sample Date	Analysis Date	Reported Results (ppmv)	Dilution Factor	MDL (ppmv)	Dilution corrected MDL (ppmv)	Concentration for Statistical Evaluation (ppmv)
Panel 4 Location IBA	4021	5/27/2009	5/29/2009	N.D.	2	14.93	29.86	14.93
	4062	6/8/2009	6/12/2009	N.D.	2	14.93	29.86	14.93
	4138	7/20/2009	7/24/2009	N.D.	2	15.17	30.34	15.17
	4199	8/11/2009	8/17/2009	N.D.	2	15.17	30.34	15.17
	4273	9/14/2009	9/18/2009	N.D.	2	15.17	30.34	15.17
	4314	10/5/2009	10/12/2009	N.D.	2	15.17	30.34	15.17
	4405	11/11/2009	11/16/2009	130.72	2	15.17	30.34	130.72
	4530	12/30/2009	1/12/2010	N.D.	2	15.17	30.34	15.17
	4594	1/19/2010	1/22/2010	N.D.	2	15.17	30.34	15.17
	4679	2/10/2010	2/12/2010	N.D.	2	15.17	30.34	15.17
	4832	3/16/2010	3/29/2010	N.D.	2	15.17	30.34	15.17
	4933	4/14/2010	4/20/2010	N.D.	2	15.17	30.34	15.17
	5049	5/17/2010	5/24/2010	N.D.	2	15.17	30.34	15.17
	5174	6/15/2010	6/21/2010	N.D.	2	7.00	14.00	7.00
	5309	7/26/2010	8/2/2010	N.D.	2	7.00	14.00	7.00
	5395	8/24/2010	8/30/2010	N.D.	2	7.00	14.00	7.00
	5449	9/13/2010	9/20/2010	N.D.	2	7.00	14.00	7.00
	5568	10/19/2010	10/25/2010	N.D.	2	7.00	14.00	7.00
	5660	11/15/2010	11/22/2010	42.12	2	7.00	14.00	42.12
	5717	12/7/2010	12/13/2010	63.50	2	7.00	14.00	63.50
	5815	1/11/2011	1/18/2011	N.D.	2	14.03	28.06	14.03
	5889	2/1/2011	2/10/2011	N.D.	2	14.03	28.06	14.03
	5979	3/1/2011	3/4/2011	45.52	2	14.03	28.06	45.52
	6082	4/5/2011	4/20/2011	N.D.	2	14.03	28.06	14.03
	6181	5/3/2011	5/6/2011	67.86	2	14.03	28.06	67.86
	6332	6/16/2011	6/24/2011	N.D.	2	14.03	28.06	14.03
	6408	7/12/2011	7/15/2011	N.D.	2	14.03	28.06	14.03
	6476	8/9/2011	8/19/2011	N.D.	2	14.03	28.06	14.03
	6552	9/14/2011	9/16/2011	N.D.	2	14.03	28.06	14.03
	6626	10/10/2011	10/14/2011	N.D.	2	14.03	28.06	14.03
	6699	11/1/2011	11/4/2011	N.D.	2	14.03	28.06	14.03
	6803	12/12/2011	12/16/2011	N.D.	2	14.40	28.80	14.40

Radiolytic Hydrogen Generation and Methanogenesis in WIPP: An Empirical Point of View – 11040

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ABSTRACT

Geologic disposal of radioactive waste is internationally recognized as the most prudent management approach to the back end of the nuclear fuel cycle. Alpha-emitting isotopes in waste matrices containing hydrogenous materials generate radiolytic hydrogen, which must be managed to ensure concentrations never exceed flammability limits. In addition, past concerns have been raised that methanogenesis could also present explosion hazards during a geologic repository's operational lifetime.

Early (pre-operational) planning for the Waste Isolation Pilot Plant (WIPP) lead its original design to include explosion walls as part of the closure design in the event of a build-up of hydrogen or methane. This conservative approach simply assumed explosive gases could be present without detailed prediction of their concentration and extent. As the Department of Energy (DOE) emplaced waste after opening, the first two disposal panels were isolated from the ventilation circuit with the previously planned 4-meter thick explosion walls of robust concrete blocks. A separate requirement for an additional massive panel closure structure, which would make the closure system even more robust is also required, however a regulatory decision on their need is proposed for the near future.

When the third disposal panel was filled (WIPP plans a total of 10), DOE petitioned its primary repository regulators (The New Mexico Environment Department – NMED, and the Environmental Protection Agency – EPA) to allow monitoring of gases interior to the disposal panel in lieu of installing explosion walls. DOE argued that by routine monitoring, it could determine if flammable gases were building to potentially explosive levels or not. If concentrations approached action levels or if the monitoring system failed, DOE proposed to construct the explosion walls as originally conceived. This approach allowed DOE to conduct monitoring to potentially demonstrate that explosion walls, and eventually even more robust panel closures, might not be necessary for safe operation of the repository.

This paper describes the results of the first 3 years of hydrogen and methane monitoring in Panels 3 and 4 at WIPP. Flammable volatile organic compounds are also present in many of the waste streams emplaced at WIPP, but liquids are prohibited. Measurements of these flammable organic compounds are also made, but they play a minor role in the argument to eliminate explosion walls as part of the closure design at WIPP. Over 1000 air samples from all interior reaches of Panels 3 and 4 have been collected to date. Every single methane sample has been determined as "Non Detectable" at detection levels of about 30 parts per million. Radiolytically generated hydrogen in these same samples was typically found at levels in the few hundred parts per million, well below the action levels specified in the permit (~4 parts per thousand). The monitoring results indicate that the initial WIPP planning was overly conservative and that explosion walls and robust panel closures may not be needed during the operational lifetime of WIPP.

INTRODUTION

WIPP was constructed and its first disposal panel mined by the end of 1988. Although DOE considered WIPP ready for waste receipt, an 11-year period of regulatory licensing and permitting passed before the first shipment arrived for emplacement (1999). During this delay, several iterations of planning for final disposal panel closure resulted in a design for the panel closures that was based on very conservative assumptions [1].

With limited data on the expected concentrations of volatile organic compounds (VOCs) in the diverse array of transuranic (TRU) waste streams, and limited understanding of the potential for gas generation within the waste, conservative calculations resulted in a proposed design that included a massive concrete structure to be placed in the inlet and outlet drifts of each disposal panel. An assumed potential for a build-up of explosive gases within each panel also led to the proposal to install a massive explosion wall that would itself protect the panel closure from the blast effects so that the closure would continue to serve as a barrier to the VOCs.

In retrospect, these very conservative assumptions and calculations now appear unnecessary. It is prudent to re-examine the need for such robust structures to avoid cost and industrial accident vulnerability. Based on all the monitoring (both within the waste drums before ever shipping to WIPP, and monitoring of conditions in the filled disposal rooms of the repository), it is likely that a much lower cost closure can protectively serve the purpose.

GAS GENERATION MECHANISMS

This section describes the 3 primary sources of flammable gases that might pose a risk to WIPP workers and, to a much lesser extent, potentially exposed members of the public.

Potential Sources of Hydrogen

Hydrogen can be generated by two widely different radiological and chemical processes:

1) Radiolysis (ionizing radiation breaks bonds as it slows in hydrogenous materials), and
2) Corrosion of iron based materials under inundated conditions (no oxygen present).

Of the three primary types of ionizing radiation, radiolytic production of hydrogen is dominated by alpha radiation because of its high energy deposition rate as the alpha particles slow down in a solid matrix. This high energy deposition rate also comes with a short stopping range. The reader may recall their high school physics lesson when shown that a piece of paper is adequate to shield from alpha radiation. All the hydrogen bonds that the alpha particle can break are in the first few microns of the sheet of paper because the alpha radiation does not penetrate further into the solid. This short range also leads to another attribute of radiolysis in a solid matrix that is typically ignored. Because there is no physical movement of the matrix to expose new hydrogen atoms within the solid, radiolytic hydrogen generation rates monotonically decrease over time in all solids. This effect, known as “matrix depletion” occurs because the alpha radiation is coming from a solid source. In the case of transuranic (TRU) waste destined for disposal in WIPP, the dominant source of radiation is plutonium. Plutonium in intimate contact with organic matter (e.g., paper or plastic) will generate hydrogen at a rate that continually declines over time as more and more available hydrogen is released from the matrix. Because the source doesn’t move with respect to the available hydrogen atoms, the probability of breaking a hydrogen bond and releasing that proton declines over time (and in direct proportion to cumulative dose deposited.

Note this decline in hydrogen generation rate is not associated with the radioactive lifetime of the source. The matrix depletion effect is more a measure of the homogeneity of mixing the radioactive source material within the hydrogenous matrix than of the specific radioactivity of the source [2].

In addition to radiolysis, hydrogen can be generated by anoxic (without oxygen) corrosion of various metal components of the waste and packaging (primarily iron and aluminum based materials). Anoxic conditions can only be expected under inundated conditions, where brine has somehow accumulated and completely surrounds the waste [3]. It should be noted that aluminum and aluminum alloy corrosion rates are much slower than those for iron based materials. Estimates of the rates of hydrogen production under anoxic and fully brine inundated conditions may be made, however these rates are quite uncertain in the short-term during disposal operations, and the likelihood of inundating brine accumulation in this time frame is highly unlikely in light of its observed absence since the first disposal rooms was mined over 20 years ago.

Other arguments against significant hydrogen generation by corrosion include the obvious fact that waste containers (typically drums) are painted. Initially corrosion will be inhibited until painted drum surfaces become exposed and internal steel components become accessible. In addition, after initial closure of a panel, oxygen-rich conditions will prevail, and the iron will oxidize (rust) with no hydrogen generation possible until all of the oxygen has been consumed. The oxidation rate is highly dependent on humidity as well [4]. The low humidity in deep reaches of the WIPP (away from fresh air intakes) minimizes oxidation, even of unpainted steel surfaces. This is evidenced from observation of un-rusted surfaces on many pieces of equipment or structures installed when the first openings were mined at WIPP in the early 1980's. In the routinely low humidity levels found in WIPP, steel surfaces become passivated and oxidation slows. Therefore, oxygen depletion in closed disposal panels is not expected quickly. But only after oxygen is depleted and in the presence of brine, could anoxic corrosion be expected to generate significant hydrogen.

In 2007, a calculation was made to bound the upper limit of hydrogen generation in panel 3 [5]. This radiolysis estimate was based on the actual waste types that had been emplaced at the time, and used the actual hydrogen measurements of head-space gas in individual payload containers made to demonstrate compliance with the license requirements of the shipping containers. That conservative estimate of the production rate of hydrogen by radiolysis was about 4.5E-05 moles per second for the entire inventory of waste in panel 3 (about 1 ml/s). Generation at this rate would lead to an average concentration of 4% by volume in an air-tight sealed panel in about 20 years (neglecting any loss of hydrogen by diffusion). This should be considered a lower bound on the time required to reach a lower flammability limit since the accumulation of hydrogen is mitigated by its ease of diffusion through even highly impermeable materials. The reader is also reminded of the many fractures and openings in the disturbed rock zone of a salt mine, which will not completely heal for many decades after disposal operations cease.

Potential Source of Methane

Methanogenesis or biomethanation is the formation of methane by microbes known as methanogens. Methanogenesis in microbes is a form of anaerobic respiration [6]. Methanogens do not use oxygen to breathe; in fact, oxygen inhibits the growth of methanogens. Organisms capable of producing methane have been identified only from the domain Archaea, a group

phylogenetically distinct from both eukaryotes and bacteria, although many live in close association with anaerobic bacteria. The production of methane is an important and widespread form of microbial metabolism. In most environments in the biosphere, it is the final step in the decomposition of biomass.

In addition, methanogenesis also requires the presence of liquid water, within which the methanogens metabolize. If there is oxygen present, methanogenesis is not. Conversely, if liquid water is not present, neither is methanogenesis. Therefore, just like hydrogen generation via anoxic iron corrosion, no methane can be expected as long as oxygen is present and inundating brine is not.

Flammable Volatile Organic Compounds

There are flammable VOCs in the waste. However these represent a fixed source which will deplete over time, and a source which is limited to levels well below flammability by the transportation requirements. Thus, flammable VOC components in filled panels are expected to remain quite small and further diminish over time. Hence they are not considered a significant issue related to the development of an explosive atmosphere in a full panel.

GAS MONITORING PROGRAM DESCRIPTION

In 2001, the National Academy of Sciences recommended DOE conduct pre-closure monitoring of gases in WIPP [7]:

> *The committee recommends pre-closure monitoring of gas generation rates, as well as the volume of hydrogen, carbon dioxide, and methane produced. Such monitoring could enhance confidence in the performance of the repository, especially if no gas generation is observed. Observation should continue at least until the repository shafts are sealed and longer if possible. The results of the gas generation monitoring program should be used to improve the performance assessment for recertification purposes.*

Then in 2003 [8] and again in 2004 [9], Congress directed the DOE to change the process used to characterize waste for WIPP (these statutes are referred to as Section 311 in this paper). Using nearly identical language in both years, Congress stated:

> *(a) The Secretary of Energy is directed to file a permit modification to the Waste Analysis Plan (WAP) and associated provisions contained in the Hazardous Waste Facility Permit for the Waste Isolation Pilot Plant (WIPP) …. (b) Compliance with the disposal room performance standards of the WAP hereafter shall be demonstrated exclusively by monitoring airborne volatile organic compounds in underground disposal rooms in which waste has been emplaced until panel closure.*

Section (b) essentially directed DOE to monitor VOC concentrations in the WIPP underground in lieu of the intrusive sampling and analysis required under the permit from the NMED. This gave DOE a way to conduct the hydrogen and methane monitoring recommended by the National Academy of Science by using the same sampling lines that were mandated by Section 311 for monitoring VOC concentrations in closed disposal rooms. While unrelated, the Section 311 permit modification was linked to approval to dispose of remote-handled waste at WIPP,

which was strongly rejected by WIPP critics. This delayed implementation of the sampling program until the modification became effective in October 2006, and sampling for VOCs began shortly thereafter in Panel 3, the active disposal unit at that time. It took several more months to obtain a permit modification to delay construction of explosion walls in panel 3 and begin making hydrogen and methane measurements in lieu of installing explosion walls. Sampling for hydrogen and methane began in August 2007.

The sampling is performed using long stainless steel tubing with a passivated inner surface and ~7mm in diameter. Sampling tubes were installed along the outer walls of each disposal room after panel excavation, and before waste emplacement operations began. There are two sampling tubes per disposal room; one that terminates at the inlet side of each room and another that terminates at the outlet side. Each sampling line terminates at a 3-way splitter that allows air to be simultaneously drawn from locations about 50 cm above the floor, 50 cm below the roof, and approximately at the mid-height of each room. Figure 1 schematically shows the sampling line network in a typical disposal panel (blue diamonds represent sample intake locations).

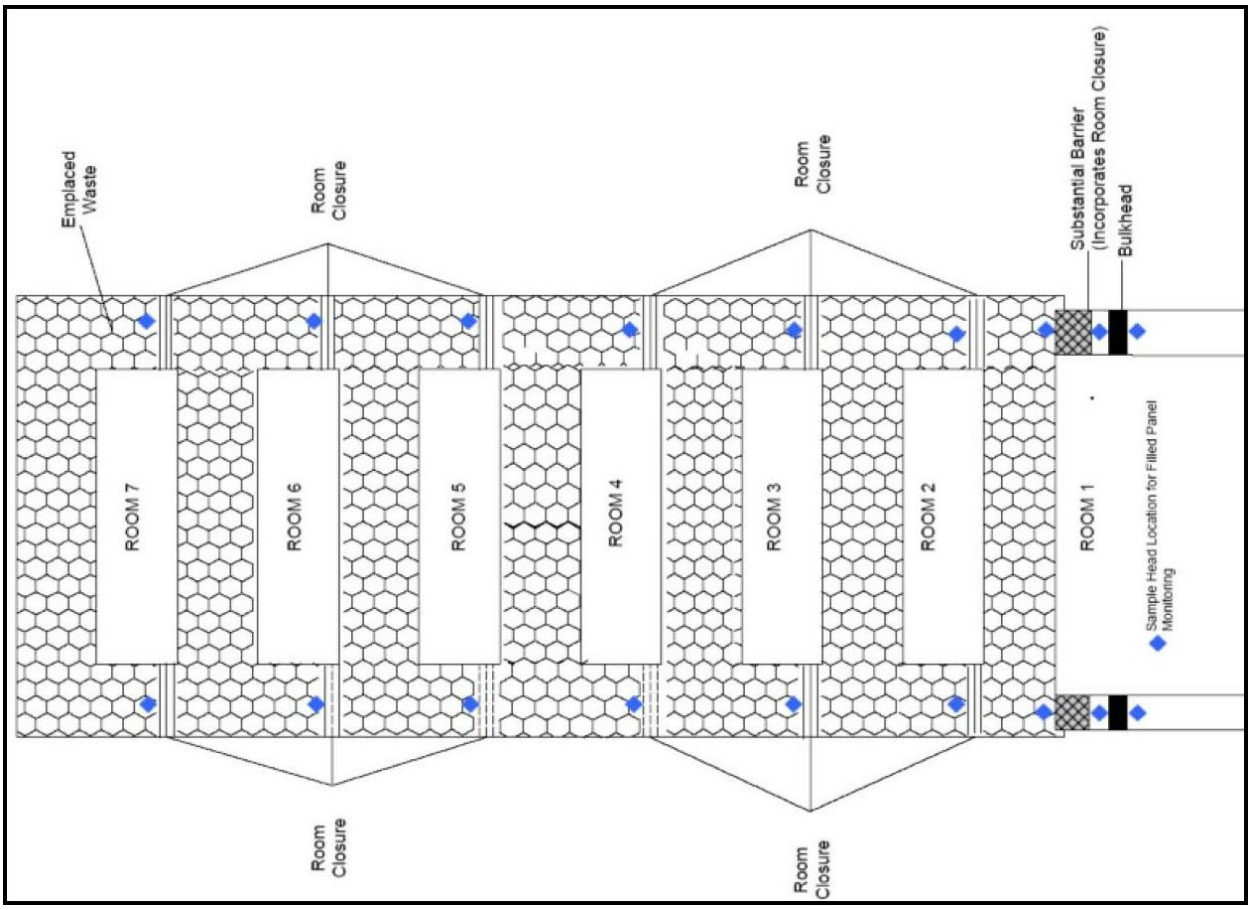

Fig. 1 Plan view of typical disposal panel showing disposal rooms separated by brattice cloth ventilation barriers (room closures) and gas sampling locations in the inlet and outlet sides of each of the seven disposal rooms.

In addition to the VOC monitoring lines, five more sampling locations are used to monitor for hydrogen and methane. These additional locations use a single inlet sampling point placed near the roof and include:

- the inlet of room 1,
- the waste side of the exhaust bulkhead,
- the accessible side of the exhaust bulkhead,
- the waste side of the intake bulkhead,
- the accessible side of the intake bulkhead.

Samples for analysis of hydrogen and methane concentrations are collected using the sub-atmospheric pressure grab sampling technique described in EPA Method TO-15 [10]. This method, which is the same for VOC sampling, uses an evacuated canister under vacuum (~0.05 mmHg) to draw an air sample through sample lines into a ~6 liter stainless steel canister with passivated interior surfaces. The passivation of tubing and canisters effectively seals the inner walls and prevents compounds from being retained on the surfaces of the sampling equipment. Sample lines are purged prior to collection as recommended by the method (about 3 times the sample line volume). At the end of each sampling period (about 6 minute grab sample at ~1 lpm), the canisters reach near atmospheric pressure.

There are no EPA-specific analytical methods which address hydrogen or methane. However, non-EPA methods are available. For the hydrogen and methane sampling, DOE uses a specially developed analytical test method for determination of hydrogen and methane using Gas Chromatography/Thermal Conductivity Detection.

The permit provisions include Action Levels based on the lower flammability limits for hydrogen and methane, referred to in the permit as lower explosive limits (LELs). In air, the lower flammability limit for hydrogen is generally considered to be 4 percent while that for methane is 5 percent. Both limits assume atmospheric oxygen levels are present.

The permit Action Level 1 for hydrogen and methane in a panel is 10 percent of the LEL which, for hydrogen, is 0.4 percent or 4000 ppm and for methane is 0.5 percent or 5000 ppm. If this Action Level is reached or exceeded, the monitoring will be increased to weekly. If the concentrations measured in subsequent sampling fall back below Action Level 1, the sampling frequency relaxes back from weekly to monthly.

Action Level 2 for hydrogen and methane in a panel is 20 percent of the LEL which, for hydrogen is 0.8 percent or 8000 ppm and for methane is 1 percent or 10,000 ppm. If Action Level 2 is achieved or exceeded for two successive weekly samples, the permit requires that monitoring cease and DOE is required to install the explosion isolation walls within 180 days.

When two flammable gases are mixed, the mixture may exhibit a different LEL than the individual gases. This is referred to as the composite LEL for the mixture. DOE evaluated whether or not the composite LEL should be used in determining the Action Levels and concluded that using the 10 percent and 20 percent thresholds was sufficiently conservative to assure action would be taken before potentially explosive levels of hydrogen or methane built up in filled panels. The additional conservatism added by using the composite LEL was not justified considering the additional complexity for demonstrating compliance (i.e., compliance using the composite value is based upon application of a mathematical formula and not on fixed, tabulated values in the permit).

As waste emplacement operations progress and each disposal room is filled within a panel, the filled room is cut off from ventilation by a barrier called a brattice curtain (or cloth), which is a simple canvas-like cloth suspended from the roof and attached to the sides and floor of the drift to effectively cut off the filled room from air ventilation underground. While some attention is given to sealing air flow from going around the barrier, the brattice cloth is by no means an air-tight seal. Small (millimeter scale) gaps remain. After panels 3 and 4 were filled, a metal bulkhead was constructed in both the inlet and outlet drifts (see Figure 1). This final ventilation barrier in each panel was augmented by a rubber (conveyor belt material) gasket bolted to the salt and bulkhead to form a seal. Again, small gaps remained. The reader is reminded that the salt creep process results in fractures and partings within the rock salt walls themselves that make the concept of a perfect gas seal impossible during the operational phase of the repository. Figure 2 shows photos of typical brattice cloth and metal bulkhead construction in WIPP.

Fig. 2 Photos of a typical ventilation barrier called a brattice curtain (top) separating each disposal room, and of a typical metal bulkhead (bottom) “sealing” the inlet and outlet drifts of each disposal panel from ventilation air in the rest of the mine.

DOE believes the use of the bulkhead, the accompanying monitoring, and related Action Levels will maintain safe and protective operations by ensuring that:

- physical access to the full panel is prevented,
- the panel is removed from active ventilation, and
- conditions inside the panel are regularly monitored so that preventive actions can be taken well in advance of the existence of a hazardous condition.

MONITORING RESULTS

Panel 3 was filled and closed in August 2007, while panel 4 was filled and closed in May 2009. Monthly hydrogen and methane sampling began in both panels the same month they were closed. Two results from over 1,000 samples collected since then stand out:

- All samples assayed less than the minimum detectable level for methane (<~20-30 ppm).
- Hydrogen results typically assay at several hundred ppm, when detected at all.

The monthly monitoring results for hydrogen in panels 3 and 4 are presented in Figures 3 and 4, respectively.

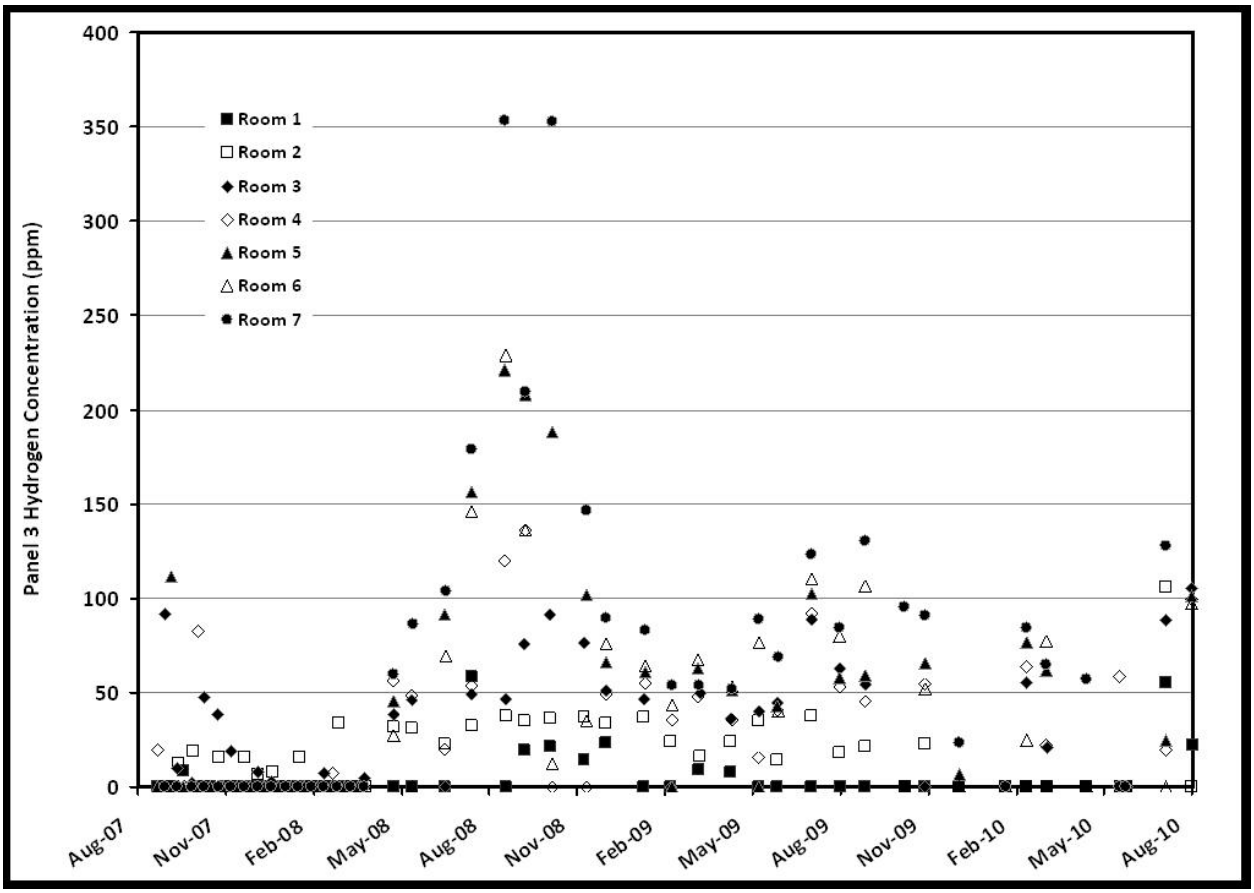

Fig. 3 Time series history of hydrogen monitoring results taken from the outlet sides of disposal rooms in closed panel 3 over a 3-year period.

In these time series plots, only the results from sampling the outlet sides of each disposal room are plotted. Only a handful (out of over 500) of samples taken from the inlet side assayed above the minimum detectable limit for hydrogen (~20-30 ppm), and therefore are not plotted. When outlet sample results assayed below the minimum detectable limit, the value was plotted at a concentration of zero in Figures 3 and 4.

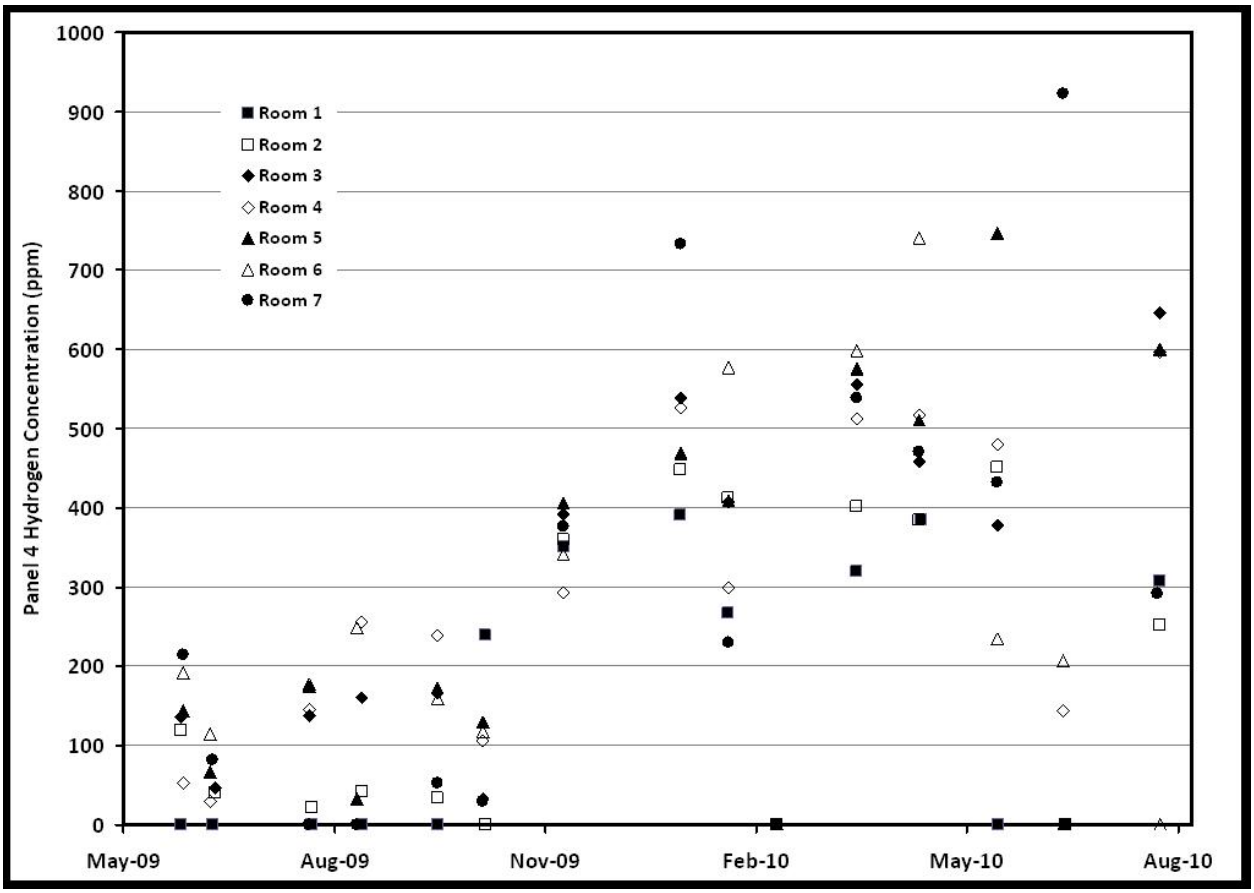

Fig. 4 Time series history of hydrogen monitoring results taken from the outlet side of disposal rooms in closed panel 4 over an 18-month period.

Interpreting these results is easy. There is no detectable methanogenesis occurring in either panels 3 or 4, and thereby by inference, no methanogenesis in panels 1 or 2 either. In contrast hydrogen generation by radiolysis is occurring and at levels easily detected by the analytic method used for assay. No steadily rising concentrations imply that the hydrogen is removed from the disposal rooms on a continuous basis. The removal process appears to be two-fold. The fact that the results from samples collected on the inlet side almost always assay below minimum detectable limits and those from the outlet side typically range in the few hundred ppm levels implies that there is a leakage flow due to differential pressure between the inlet and outlet sides of each disposal panel. The high sample-to-sample variability from each location implies that the release of hydrogen from the waste containers themselves varies over periods of weeks to months. This can be explained by normal barometric breathing.

The highest value of hydrogen measured to date was 923 ppm at the outlet side of room 7 (furthest into the disposal panel) in panel 4 in June 2010. This value is 25% of the Action Level 1 for hydrogen established in the permit (which in turn is 10% of the concentration considered

flammable - if oxygen were present at atmospheric levels). It should be noted that actions to minimize leakage ventilation through panel 4 began in earnest in November 2009, when running annual average carbon tetrachloride levels in the exhaust flow from the entire underground began climbing. A companion paper in session 063 (11039) at this symposium describes this effort in more detail [11].

Active disposal operations with high carbon tetrachloride content were ongoing in panel 5 at that time, but it was prudent to assume that some of the carbon tetrachloride originated from leakage flow through closed panel 4 since it held some of the high carbon tetrachloride waste as well. Therefore, DOE built an additional bulkhead at the inlet and outlet drifts of panel 4 and made extra efforts to seal panel 4 from leakage ventilation. These efforts were coincident with the slight step increase in the peak hydrogen concentration results as seen in Figure 4 in November 2009. The apparent increase may be attributed to the enhanced sealing efforts to minimize carbon tetrachloride leakage out of panel 4. However, the fact that hydrogen concentrations vary so much from one sample to the next indicates that it easily escapes the systems designed to block the carbon tetrachloride.

ELIMINATING EXPLOSION WALLS AND OPTIMIZING PANEL CLOSURES

Based on the monitoring results from 2007 to date, it would seem that massive panel closures and explosion walls to protect those closures might not be necessary and yet still be protective of workers and the environment. A companion paper in session 063 at this symposium discusses DOE's plans to seek regulatory approval to modify the massive closure design and replace it with a simple 30 meter long wall of run of mine salt [12]. Such a panel closure would likely be a better barrier in preventing panel-to-panel hydrologic communication in an assumed future human intrusion scenario, and would be a lot less costly. Upon filling a disposal panel with waste, the run of mine salt closure would simply be placed in the inlet and outlet drifts. A blower may be used to bring the pile up to the full height of the drifts. While this closure would not be air-tight, it would behave at least as well as the metal bulkheads in panels 3 and 4 described herein (the same leaky pathways around the closure through the disturbed rock zone would exist). Over time (a few decades), the salt creep closure would compact and begin reconsolidating the run of mine salt. Within a few hundred years, this panel closure would resemble the properties of intact salt. In contrast a massive monolith of concrete (the current panel closure stipulated for WIPP by its regulators) would not exhibit the immeasurably low permeability of healed intact salt, but would be considered more permeable.

CONCLUSIONS

Although basic knowledge and laboratory measurements made during the licensing and permitting phase showed that little or no gas generation would occur during the operational life of WIPP, in an abundance of caution, DOE and its regulators still proposed massive panel closures and large explosion walls to protect them. Based on monitoring results (at least for panel 3 and 4), these do not appear to be necessary, since levels of flammable gases and VOCs are present in only trace levels. The only VOC present in significant amounts in the TRU waste stream inventory (and then only in a small fraction of drums) is carbon tetrachloride, which ironically is not flammable.

Over 1000 gas samples collected in all areas of panels 3 and 4 show undetectable levels of methane, thereby confirming the expectation that methanogenesis is not occurring (oxygen is

present, and brine inundation is not). Hydrogen levels in those same samples are in the few hundred ppm range and vary significantly from sample to sample, thereby implying a continuous source, but an intermittent pathway out. This is consistent with barometric pumping of waste containers, superimposed on a steady leakage air flow, even through the further back disposal rooms in a panel.

DOE will continue to monitor for flammable gases in filled disposal panels and take steps to protect workers and the environment if levels rise and explosions walls become necessary. In the meantime, DOE will continue to make the case that there are more prudent and cost effective panel closure designs that should be considered.

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DESIGN REPORT FOR A
PANEL CLOSURE SYSTEM
AT THE WASTE ISOLATION PILOT PLANT

October 2012

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Certification

I certify that this document was prepared under my supervision for Nuclear Waste Partnership LLC, under WP13-1 Nuclear Waste Partnership LLC Quality Assurance Program Description. Based on my inquiry of the persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate and complete.

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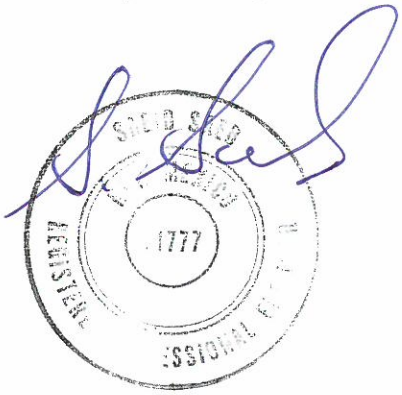

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11/27/12

Executive Summary

Scope. This report describes the design and evaluation of a Waste Isolation Pilot Plant (WIPP) Panel Closure (WPC) system consisting of run-of-mine (ROM) salt and steel bulkheads.

Purpose. The purpose of the WPC is to comply with the closure performance standard in Permit Attachment G, Section G-1a pursuant to 20.4.1.500 NMAC (incorporating 40 CFR 264 Subpart X).

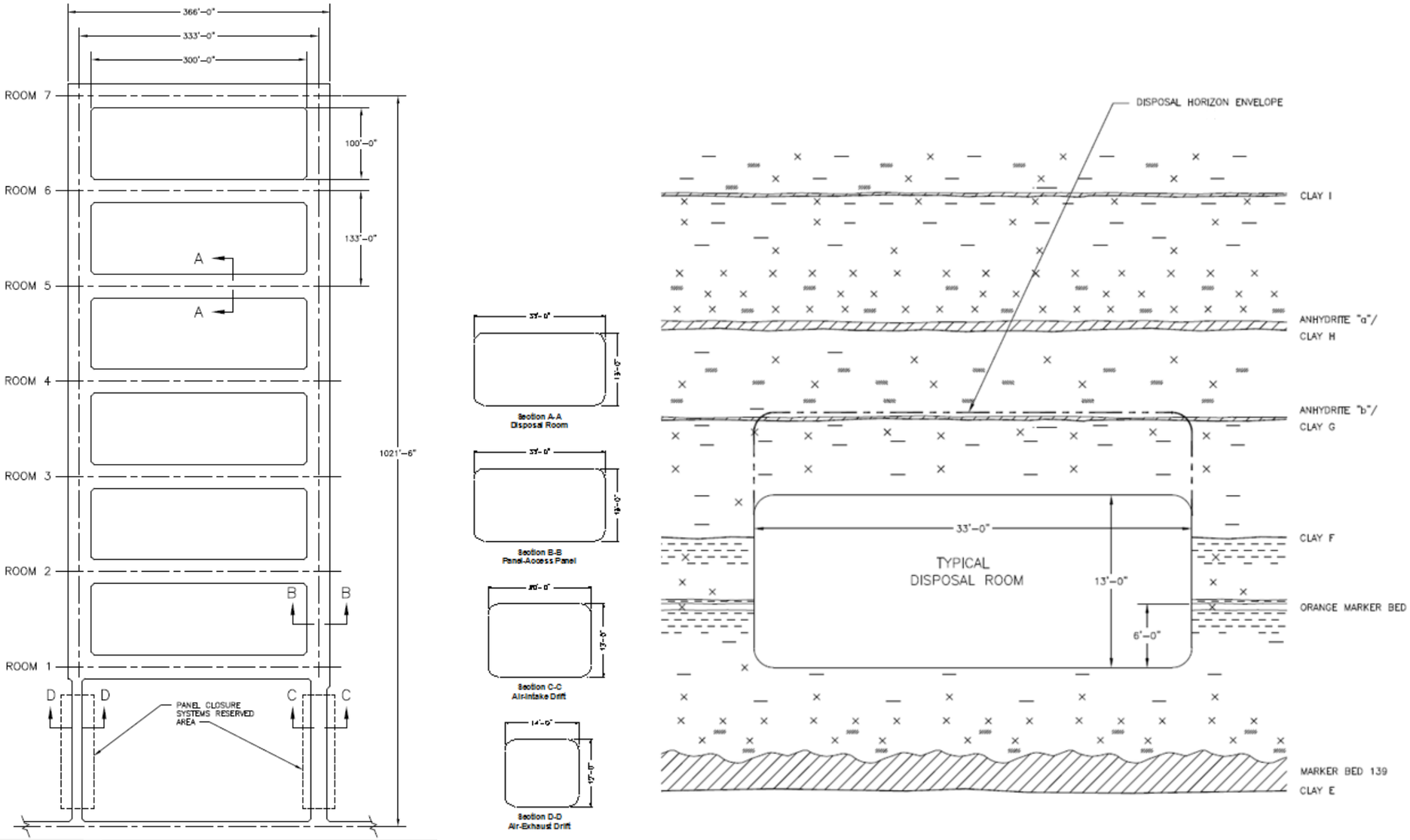
The WPC will be located in the panel air-intake and panel air-exhaust drifts of each waste-filled panel as shown in Figure ES-1. Two steel bulkheads will be placed at the ends of the ROM salt. This report also presents an alternate design for filled Panels 1, 2 and 5 where explosion isolation walls have been installed. The alternate design consists of one steel bulkhead and a block wall placed at the ends of the ROM salt.

Volatile Organic Compounds (VOCs) flow analyses through the WPC and then from the repository show that VOC concentrations will not exceed VOC Health Based Levels (HBLs) at the WIPP site boundary. In addition, the WPC will comply with the applicable requirements of the Mine Safety and Health Administration (MSHA). Finally the WPC will use common construction practices according to existing standards to the extent practicable.

Background. In 1996, a report entitled "Detailed Design Report for an Operational Phase Panel-Closure System" was prepared. This design was submitted as part of the original Hazardous Waste Facility Permit (Permit) application to the New Mexico Environment Department (NMED). The NMED subsequently selected portions of the report and included them in the issued permit.

Section 4.6.2 of the current Permit establishes limits and actions for VOCs of concern. The VOCs of concern in the Permit include carbon tetrachloride (CCl_4), chlorobenzene, chloroform, 1,1-dichloroethene, 1,2-dichloroethane, methylene chloride, 1,1,2,2-tetrachloroethane, toluene and 1,1,1-trichloroethane. Additional VOCs that contribute lesser risks are considered in this report. New VOCs and HBLs for the VOCs have been identified for the WIPP site boundary and are used in the report (Kehrman, 2012, Table 11).

Revised performance requirements are presented in this report. The WPC is evaluated against these revised performance requirements.



The figure shows the plan view of a waste panel (left), vertical cross sections (middle), and a stratigraphic cross section at the repository horizon (right). The disposal horizon may be selected within the envelope shown based on geomechanical, operational and safety considerations (Westinghouse, 1995).

Figure ES-1 Typical Panel Layout with Drift Cross Sections

Design. The WPC consists of two steel bulkheads and ROM salt. An alternate WPC for Panels 1, 2, and 5 consists of one steel bulkhead, ROM salt and one block wall. The construction methods and materials used in the design represent available technologies from previous mining projects (Fernandez et al., 1994, pp. 5-11 to 5-20) and as demonstrated by recent insitu testing of ROM salt (Zimmerly and Zavicar, 2012). No special requirements are identified for these components during the operational period of the repository. The fabrication, installation and maintenance of ventilation bulkheads are standard practice. Salt can be pushed reasonably tight to the underground surfaces of the drifts. A variety of techniques are available for placing the salt. These construction methods are simple and allow flexibility in construction scheduling and construction materials transportation.

Evaluation of WPC Performance. The evaluation of the WPC presented in this report included a review of current information on repository ventilation, VOC source terms and expected concentrations of VOCs in the mine exhaust air stream. Based upon a review of this information, a design performance specification was developed to emplace salt over a minimum length of 100 ft.

The ROM salt may be emplaced in a series of layers. The emplacement density is expressed in terms of fractional density which is represented as a percentage of the intact density (135 lbf/ft^3 [2,160 kg/m^3]). The ROM salt is emplaced at an assumed fractional density of 65% (88 lbf/ft^3 [1,400 kg/m^3]).

Steel bulkheads with flexible flashing to accommodate salt creep are used in the WPC design. Farnsworth (2011) indicated that smaller drifts with bulkheads near the Exhaust Shaft in the WIPP underground have resistances as high as 2,200 Practical Units [2,200 (milli-in wg)/kcfm^2]. The smaller drifts with bulkheads near the Exhaust Shaft are the closest in size to the Panel intake and exhaust drifts.

Structural analyses of the ROM salt in a single zone were performed using a FLAC3D computer code. FLAC3D is used by the WIPP site for geotechnical analyses and was used for the previous WPC design analyses. The FLAC3D analyses showed that an air gap between panel entry ceilings and the top of the run-of mine salt forms and increases over a period of several years. The air gap forms because initially the rate of settlement of the ROM salt exceeds the rate of panel-entry creep closure. Two years after WPC installation, the air gap starts to close. The air gap reaches a maximum value of 19 inches (47 cm). After approximately 23 years, the air gap is eliminated. Also, the fractional density of ROM salt increases with time. These calculations are

input into the VOCs Flow Model.

VOCs Flow Model. The VOC flow analyses evaluate the flow of VOCs of concern through the WPC. The VOCs Flow Model considers VOCs emissions from open rooms (Kehrman, 2012, Table 12) up until the time that air gaps close within individual WPCs. When air gaps are present, air flow resistance is predominately due to steel bulkhead resistances for individual panels. After approximately 23 years, the air gap closes and the air flow resistance is predominately due to the consolidated ROM salt. VOCs flow equals the product of the air flow rate and the average headspace concentration for individual panels at this time. The VOCs flow model is based upon inventory average headspace concentrations (Kehrman, 2012, Table 1). The analysis compares the predicted results to measured results. The model is then used to evaluate future VOCs emissions considering ventilation air flow effects, other source terms for air flow (panel creep closure and gas generation) and average headspace concentrations of individual VOCs. Air flow due to ventilation through the air gap and ROM salt zone of the WPC is evaluated considering the air conductivity of ROM salt and the surrounding disturbed rock zone (DRZ), and the air flow resistance of steel bulkheads. The air conductivity values for all components are discussed in Section 3.

The results show a reduction in the air gap and air conductivity with time from panel intake drift and exhaust drift creep closure that isolates the waste from the underground ventilation air stream starting approximately 2 years after WPC installation with complete air gap closure after 23 years. The results indicate that for a period of about 23 years after WPC installation (28 years after panel excavation), the air flow induced from ventilation effects is dominant and that after this period of time, gas generation and panel creep closure would become dominant.

The analysis accounts for the reduction of VOC concentrations at the Exhaust Shaft of the WIPP due to underground repository ventilation, and then due to atmospheric dispersion to the WIPP site boundary (Kehrman, 2012, Table 6). The analyses consider only this receptor boundary, and do not provide calculations at other intermediate surface and underground receptor points.

The analysis uses HBLs that have been identified by the WIPP Project (Kehrman, 2012, Table 11). The projected concentrations from the VOC flow model are compared to the HBLs at the site boundary through calculation of risk fractions. These evaluations include the case for peak

emissions from the WIPP repository.

The predicted mass flow rates for VOCs through the WPC (including flow through the air gap; the ROM salt; DRZ and the steel bulkheads) from ventilation, panel creep closure and gas generation are estimated to result in concentrations that are below the HBLs (Kehrman, 2012, Table 11) for the receptor point at the WIPP site boundary. Concentrations at other surface and underground receptor locations were not analyzed as part of this scope of work.

While no specific requirements exist for closing disposal areas under MSHA regulations, the intent of the regulations is to safely isolate abandoned areas from active workings using barricades of substantial construction.

This report presents the WPC system description with supporting calculations (Appendices A to B), Specifications (Appendix C), and Engineering Drawings (Appendix D) that comply with the design requirements for the WPC. Structural and air flow analyses are used to select the design features and are based upon data acquired from the WIPP underground. The Drawings illustrate the construction and details for the WPC. The Specifications cover the general requirements of the system, quality assurance and quality control, site work, and ROM salt emplaced in the panel entries. The WPC can be built to generally accepted national design and construction standards.

The design complies with the revised design requirements established for the WPC. The design can be constructed in the underground environment with no special requirements at the WIPP facility.

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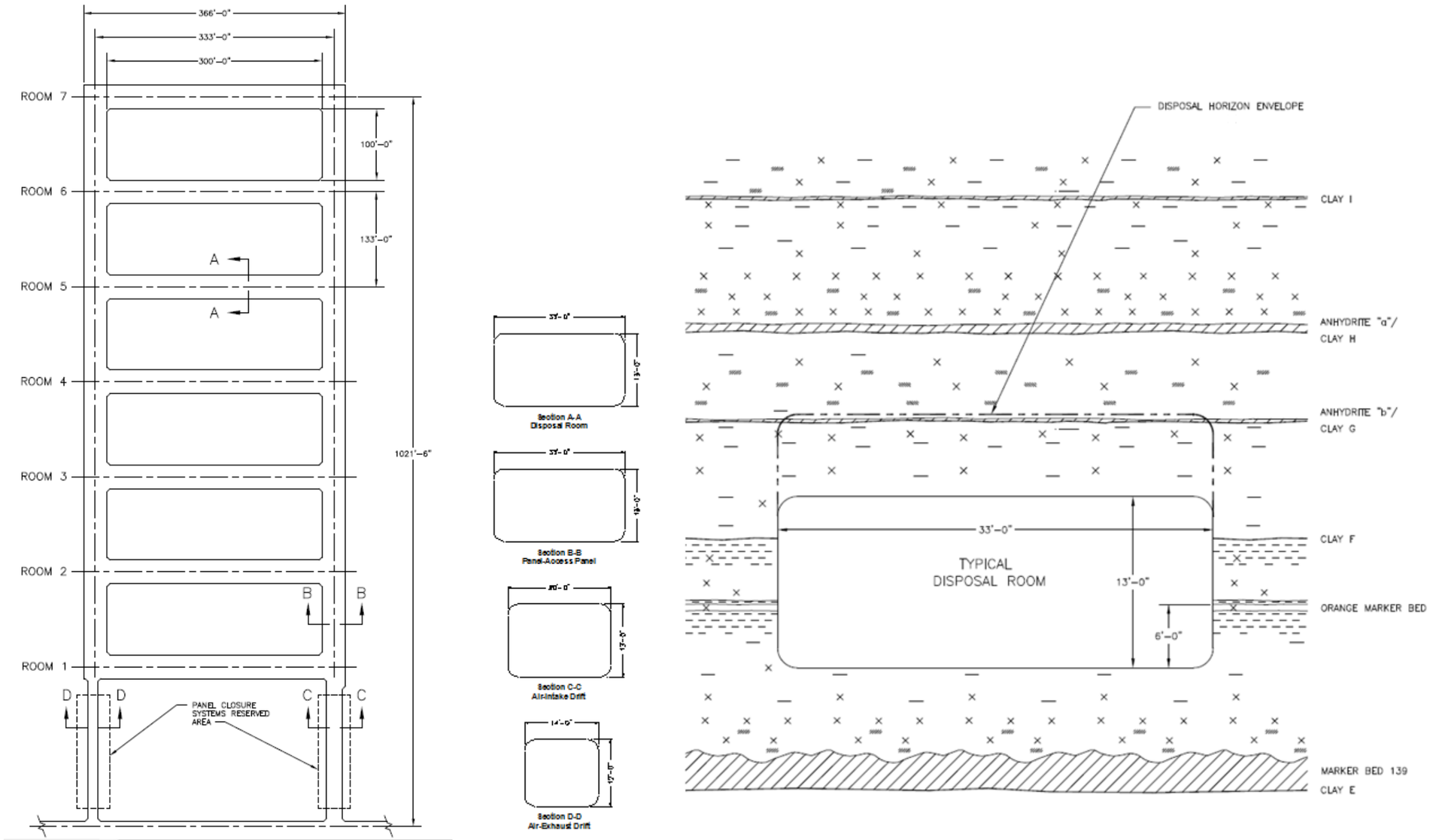
1.0 Introduction

The Waste Isolation Pilot Plant (**WIPP**) facility is a U.S. Department of Energy (**DOE**) facility located near Carlsbad, New Mexico, established for the safe disposal of defense-generated transuranic (**TRU**) waste. The WIPP repository is 2,150 feet (ft) (655 meters [m]) below the surface, in the Salado Formation.

One important aspect of repository operations at the WIPP facility is the activity associated with closure of waste disposal panels. Each panel consists of a panel air-intake drift, a panel air-exhaust drift, and seven rooms (Figure 1-1). After completion of waste disposal activities in a panel, it must be closed. The closure of individual panels during the operational period is conducted in compliance with the WIPP Hazardous Waste Facility Permit (**Permit**).

In 1996, a report entitled "Detailed Design Report for an Operational Phase Panel-Closure System" (DOE, 1996) was prepared. That design was submitted as part of the original Permit application to the New Mexico Environment Department (**NMED**). The NMED subsequently selected portions of the 1996 report and included them in the Permit.

This report builds on data collection and presents a design consisting of a run-of-mine (**ROM**) salt and steel bulkheads as are currently used in the WIPP repository. ROM salt is defined as a porous salt in the loose state derived from underground mining operations.



The figure shows the plan view of a waste panel (left), vertical cross sections (middle), and a stratigraphic cross section at the repository horizon (right). The disposal horizon may be selected within the envelope shown based on geomechanical, operational and safety considerations (Westinghouse, 1995).

Figure 1-1 Typical Panel Layout with Drift Cross Sections

1.1 Scope

This report describes the design of the WIPP Panel Closure (**WPC**), presents WPC analyses relating to structural response and VOCs flow, and provides an evaluation of the WPC against revised design requirements presented in Chapter 2. The WPC consists of ROM salt and steel bulkheads for 10 panels. The WPC relies on air flow resistance of ventilation bulkheads to control VOCs emissions at the WIPP site receptor boundary for 23 years following each individual panel closure installation. The work scope does not include other intermediate receptor points.

The design complies with the revised design requirements established for the WPC. The proposed design is of substantial construction and complies with applicable requirements promulgated by the U. S. Department of Labor, Mine Safety and Health Administration (**MSHA**).

1.2 Regulatory Requirements

The following subsections discuss the regulatory requirements specified in the Resource Conservation and Recovery Act (**RCRA**) and MSHA that apply to closure.

1.2.1 Resource Conservation and Recovery Act (40 CFR 264 and 270)

The Closure Plan in the WIPP Permit (NMED, 2012) was prepared in accordance with the requirements of 20.4.1.500 New Mexico Administrative Code (incorporating Title 40, Code of Federal Regulations [CFR], Part 264, Subparts G, I and X). The WPC design incorporates measures to mitigate VOC migration for compliance with environmental performance standards.

1.2.2 Mine Safety and Health Administration

Under 30 CFR 57 (MSHA, 2012), "seals and stoppings" must be constructed of noncombustible materials appropriate for the specific mine category and must be of "substantial construction." "Substantial construction" implies construction of such strength, material and workmanship that the barrier could withstand conditions expected in the mining environment. As discussed subsequently in this report, the WPC complies with relevant requirements.

1.3 Report Organization

This report presents the engineering analysis of the WPC in each panel entry consisting of two steel bulkheads and ROM salt emplaced to a minimum length of 100 feet. Chapter 2 presents the Permit Design Requirements and a description of the final design in terms of WPC design components. Chapter 3 presents the design evaluations addressing the structural adequacy and the VOC flow of the WPC. Chapter 4 presents a list of the technical specifications for the design. Chapter 5 presents a list of the design drawings. Chapter 6 presents conclusions. Chapter 7 presents supporting references.

2.0 Design Descriptions

This chapter presents the WPC evaluated in this report, including its design requirements and design components.

2.1 Permit Design Requirements

Original design requirements were presented in Table 7-1 of DOE, 1996, and were accepted in the Permit. Since then, the Permittees have collected gas emission and mined opening performance data that has greatly increased the understanding of current and future conditions in the repository. This increased understanding has led to a reassessment of the design requirements for a panel closure system. The WPC was evaluated against the following revised design requirements:

- The panel closure system shall contribute to meeting the environmental performance standards in Permit Part 4 Section 4.6.2 by mitigating the migration of VOCs from closed panels.
- The panel closure system shall consider potential flow of VOCs through the disturbed rock zone (**DRZ**) in addition to flow through closure components.
- The panel closure system shall perform its intended functions under loads generated by creep closure of the tunnels.
- The nominal operational life of the closure system is 35 years.
- The panel closure system may require minimal maintenance per 20.4.1.500 NMAC (incorporating 40 CFR 264.111).
- The panel closure system shall address the expected ground conditions in the waste disposal areas.
- The panel closure system shall be built of substantial construction and non-combustible material except for flexible flashing used to accommodate salt movement.

- The design and construction shall follow conventional mining practices.
- Structural analysis shall use data acquired from the WIPP underground.
- Materials shall be compatible with their emplacement environment and function.
- Treatment of surfaces in the closure areas shall be considered in the design.
- A Quality Assurance/Quality Control (**QA/QC**) program shall verify material properties and construction.
- Construction of the panel closure system shall consider shaft and underground access and services for materials handling.

Chapter 6 presents the expected compliance of the WPC with these requirements and identifies the sections of this report where each requirement is addressed.

Figure 2-1 and Figure 2-2 illustrate the design that is evaluated in this report. Figure 2-1 applies to drifts without existing block walls. Figure 2-2 shows the configuration for drifts with existing block walls.

Conventional mining practices will be used in construction of the WPC. After completion of waste emplacement operations in future active panels, in-by steel bulkheads will be installed in the intake and exhaust panel entries as illustrated in Figure 2-1. Work packages prepared for the fabrication and installation of bulkheads will list the materials used, the equipment used, special precautions and limitations. Each work package will address prerequisites for installing the WPC and the required performance and documentation of such performance.

The ROM salt can be emplaced using conventional mining equipment in such a manner as to maintain a slope of 2 horizontal to 1 vertical at the ends. The ROM salt can be emplaced as is from the mining operations at an assumed fractional density of 65% (Zimmerly and Zavicar, 2012). After salt emplacement, the outer steel bulkhead is installed.

Three panels have block walls[1] installed and an alternate design is presented for these panels. The installation of the WPC in these panels shall follow preapproved work packages as outlined previously. In these cases (Figure 2-2), the ROM salt is emplaced up to the block wall. After salt emplacement, the outer steel bulkhead is installed.

2.2 Design Components

The following subsection presents system and component design features. Appendices C and D present specifications and drawings for the WPC, respectively. Individual specifications address shaft and underground access and materials handling, construction quality control, treatment of surfaces in the closure areas, and applicable design and construction standards.

2.2.1 Steel Bulkhead

The steel bulkhead (Figure 2-3) serves to block ventilation at the intake and exhaust of the panel and prevents personnel access. This use of a bulkhead is a standard practice and will be constructed as a typical WIPP bulkhead with no access (NMED, 2012, Figure N1-2). The bulkhead will consist of a noncombustible steel member frame covered with sheet metal. Telescoping tubular steel is used to bolt the bulkhead to the floor and roof. Flexible flashing material such as a rubber conveyor belt (or other appropriate material) will be attached to the steel frame and the salt as a gasket, thereby providing an effective yet flexible blockage to ventilation air. The steel bulkheads need maintenance for air flow resistance and the accommodation of panel entry salt creep during a 23-year period following each individual panel closure installation. The out-by bulkhead will be repaired, renovated or replaced as required. The WPC relies upon bulkheads for approximately 23 years to control VOCs flow. During this period steel bulkheads may need to be maintained or replaced and the surrounding Disturbed Rock Zone (DRZ) may need to be treated or removed to provide air flow resistance as intended.

[1] The block wall was originally designed to resist underground methane deflagration due to a

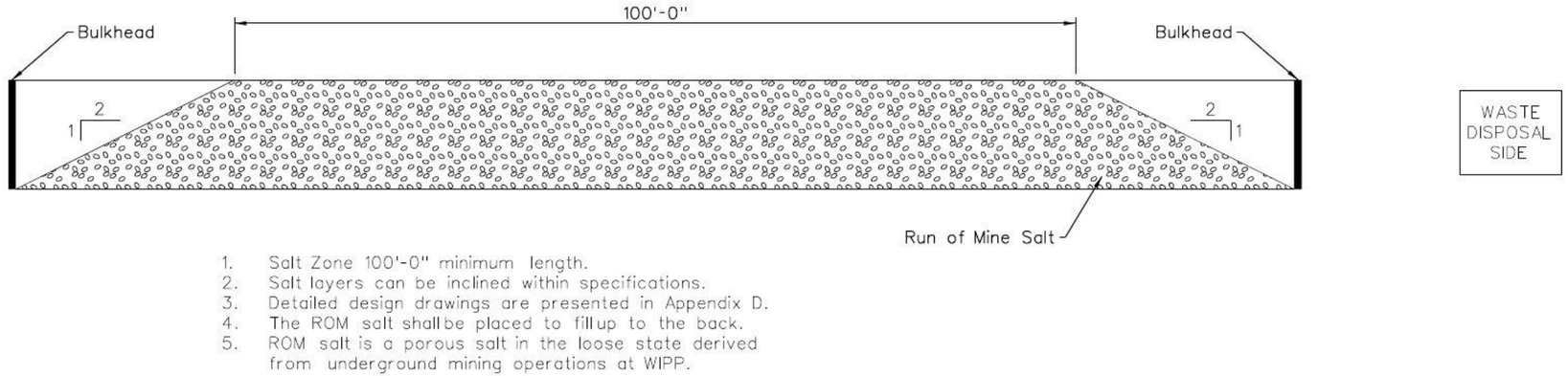
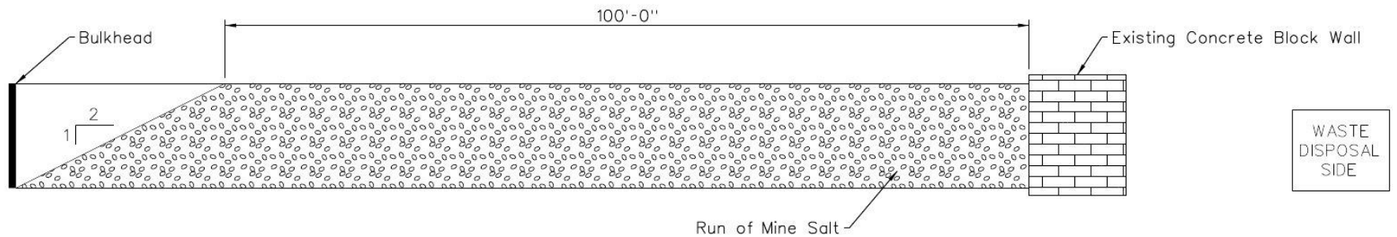


Figure 2-1 Typical WPC for Drifts without Block Walls



1. Salt Zone 100'-0" minimum length.
2. Salt layers can be inclined within specifications.
3. Detailed design drawings are presented in Appendix D.
4. The ROM salt shall be placed to fill up to the back.
5. ROM salt is a porous salt in the loose state derived from underground mining operations at WIPP.

TYPICAL INTAKE/EXHAUST DRIFT

Figure 2-2 Typical WPC for Drifts with Existing Block Walls

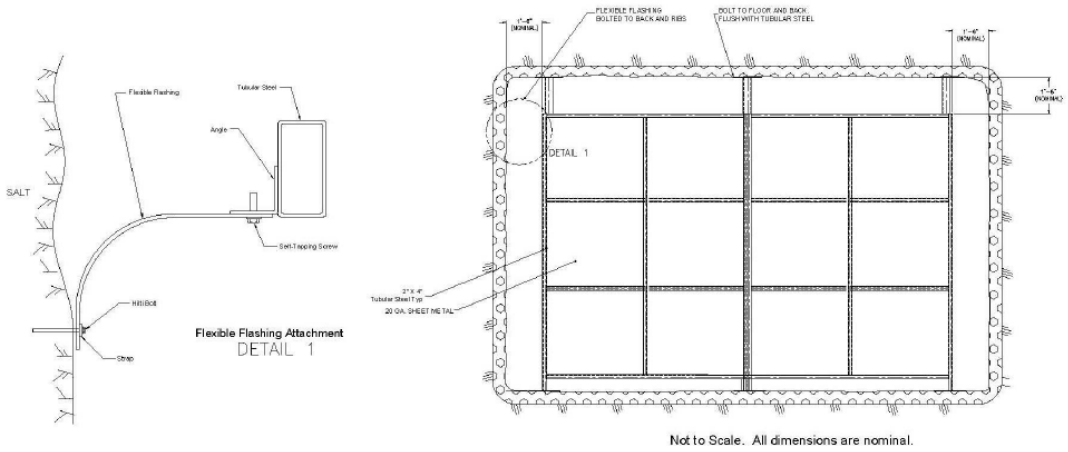


Figure 2-3 Typical Bulkhead for the WPC

2.2.2 ROM Salt

ROM salt material from mining operations is as delivered by haul truck or LHD units to the panel closure area in a loose state. As such, it is a noncombustible natural material that is completely compatible with the repository environment. The ROM salt is emplaced over a minimum length of 100 feet. The ROM salt at the ends would be emplaced at a slope of approximately 2 horizontal 1 vertical.

The air flow and structural modeling analyses (Chapter 3) use the basic design for the WPC. Air flow resistance through a panel closure is proportional to flow path length and inversely proportional to the product of the air conductivity and the flow path cross sectional area.

Figures 2-1 and 2-2 illustrate the design for typical cases with and without block walls. Variations in entry height are expected for individual WPCs. For WPCs emplaced in panel entries with block walls, the end slope for the ROM salt can be steepened to 1.4 horizontal to 1.0 vertical to accommodate the full length of ROM salt. The emplacement of ROM salt will avoid putting significant lateral pressure on bulkheads.

The bulk density of the ROM salt is not prescribed in this report. A fractional density of 64% to

65% for ROM salt is nearly universal for WIPP and other salt mining operations throughout the world (Hansen, et. al, 1998 and Rothfuchs and Wieczorek, 2010). It is assumed that any additional salt compaction that occurs during construction will improve the performance by reducing the air gap that forms above and lowering permeability within the ROM salt.

2.3 Constructability, Environmental and Worker Safety, Operational Considerations, and Longevity

This section presents information on the constructability, environmental and worker safety, operational considerations, and longevity. More detailed information is presented in the supporting Appendices C and D that present specifications and engineering drawings.

2.3.1 Constructability

The WPC can be constructed using available technologies for the construction of steel bulkheads and placement of salt. The construction methods and materials used in the design represent available technologies from previous mining projects (Fernandez et al., 1994, pp. 5-11 to 5-20) and as demonstrated by recent insitu testing of ROM salt at WIPP (Zimmerly and Zavicar, 2012). Field tests and construction experience at the WIPP facility will guide the emplacement and construction methods used to construct these barriers. Construction quality control and quality assurance requirements will be based on the construction method employed. The steel bulkheads are commonly used and ROM salt is available in sufficient quantities at minimum cost.

2.3.2 Environmental and Worker Safety

The proposed WPC is not expected to adversely impact environmental safety. The construction materials are primarily natural material removed from the mine, with the exception of the bulkheads, which are already used throughout the underground. The construction methods use equipment identical or similar to day-to-day mining operations or in construction.

Note that the analysis presented in this report does not address specific compliance with HBLs for worker exposure at WIPP during installation and operation of the WPC. Such analyses are beyond the scope of this report.

The following qualitative discussion addresses the complexity and risks in the current design as compared to those in the previous design. Two factors are involved in qualitatively estimating the increase in worker safety and risk reduction associated with installation of the proposed

WPC. One factor involves the complexity of the construction project. The other related factor is the number of workers and the time that they spend transporting, handling, and installing the WPC. The exposure of workers to VOCs relates to exposure times during the construction and emplacement of individual WPCs.

The Permittees reviewed the complexity of the construction project associated with Option D versus the construction of the current WPC. The previous design (DOE, 1996) used complex steel formwork and concrete with removal of portions of the DRZ and closure of the interface zones. The current design is easier to construct as there is no need for complex formwork or the production and placement of Salado Mass Concrete.

As part of a previous redesign process, the Permittees prepared installation schedules for the Option D PCS and WPC (NMED, 2002). The underground construction activities for Option D were estimated to require approximately 14 months. The comparable period for construction of the WPC is estimated at six months or less (40 CFR 264.113 (b)). The WPC construction project uses more common materials for the steel bulkheads and salt than Salado Mass Concrete, thus reducing the number of workers required and the time required for workers to be in the construction area. Less complex construction translates into less time for transportation, handling, and emplacement of materials. Shorter construction time translates to an increase in worker safety and lower risk to workers.

2.3.3 Operational Considerations

The construction of the current WPC can be stopped and re-started as necessary to accommodate operational concerns and reduce or eliminate impact on waste handling. Temporarily stopping construction will not affect the performance of the WPC. The equipment used to construct the WPC can be quickly mobilized and demobilized to accommodate waste handling and other operational needs. Shaft schedules would not be impacted as the majority of the construction materials are already underground.

2.3.4 Longevity

As discussed in Chapter 3, the WPC closures derive their air flow resistances primarily from steel bulkheads for a period of 23 years and from ROM salt thereafter. During the 23 year period of time that steel bulkheads are relied on for air flow resistance, the steel bulkheads will be maintained in the underground environment. The panel entry creep closure with time reduces the air gap at the interface of the ROM salt and entry roof as well as the porosity of the ROM salt, which in turn reduces the air conductivity due to the plastic deformation of the ROM salt.

ROM salt is completely compatible with the underground environment. This results in improved performance with time or longevity. Eventually, the ROM salt will become structurally indistinguishable from the surrounding intact salt.

3.0 Analysis

This chapter presents evaluations of the engineered WPC: (1) structural analyses; (2) projected VOC emissions from air flow analysis and advection analysis; and (3) a material compatibility evaluation.

3.1 Analyses Addressing Operational Requirements

To evaluate the effectiveness of the panel closure system, structural analyses were performed to examine the geomechanical performance of the WPC over the operational period of the repository. Air flow analyses were then performed to evaluate the change in WPC air flow resistance, and then evaluate VOCs flow through the WPC. Structural analyses predict a gap forms between the roof and top of the ROM and reduction of the fractional density due to creep of intact rock salt of the surrounding panel entry surfaces. Air flow analyses are then conducted to predict the release of VOCs through the panel closure system due to gas generation, panel creep closure and the effects of underground ventilation. These analyses support the WPC design for the protection of human health and the environment at the WIPP site boundary. Explosion effects on the WPC were not analyzed because monitoring of methane and hydrogen concentrations indicates that they will not reach minimum explosive concentrations during the operational period (Myers, 2012 and Nelson, 2011).

3.2 Structural Analyses of ROM Salt Emplacements

Three dimensional geomechanical models of a 100-foot long section of ROM salt were analyzed using FLAC3D. The following discussion presents the properties of the ROM salt, the structural modeling method, a crushed salt benchmark calculation, model geometry, modeling sequence, and modeling results.

3.2.1 ROM Salt Properties

The FLAC3D requires the initial densities and material properties of the ROM salt. As discussed previously, the ROM salt initial density is assumed to be 65% of the intact density of salt. The intact density used in this study is 2,160 kg/m^3 (Callahan, 1999).

3.2.2 Structural Modeling Method

The settlement and change in density with time (and implicitly intrinsic permeability) of the

ROM salt was calculated using the three-dimensional geomechanical modeling program Fast Lagrangian Analysis of Continua in Three Dimensions (FLAC3D) (Itasca Consulting Group, 2006). The predecessor program Fast Lagrangian Analysis of Continua (FLAC) and FLAC3D have been used for 20 years for the WIPP project, including structural analyses for the previous panel closure design. FLAC3D implements the Callahan and DeVries (1991) crushed salt creep constitutive model. This model is based on Sjaardema and Krieg (1987) and was verified by Callahan (1999) through comparisons of numerical analysis predictions with laboratory test results. Material properties for the other materials in the surrounding salt are from Krieg (1984).

3.2.3 Crushed Salt Benchmark Calculation

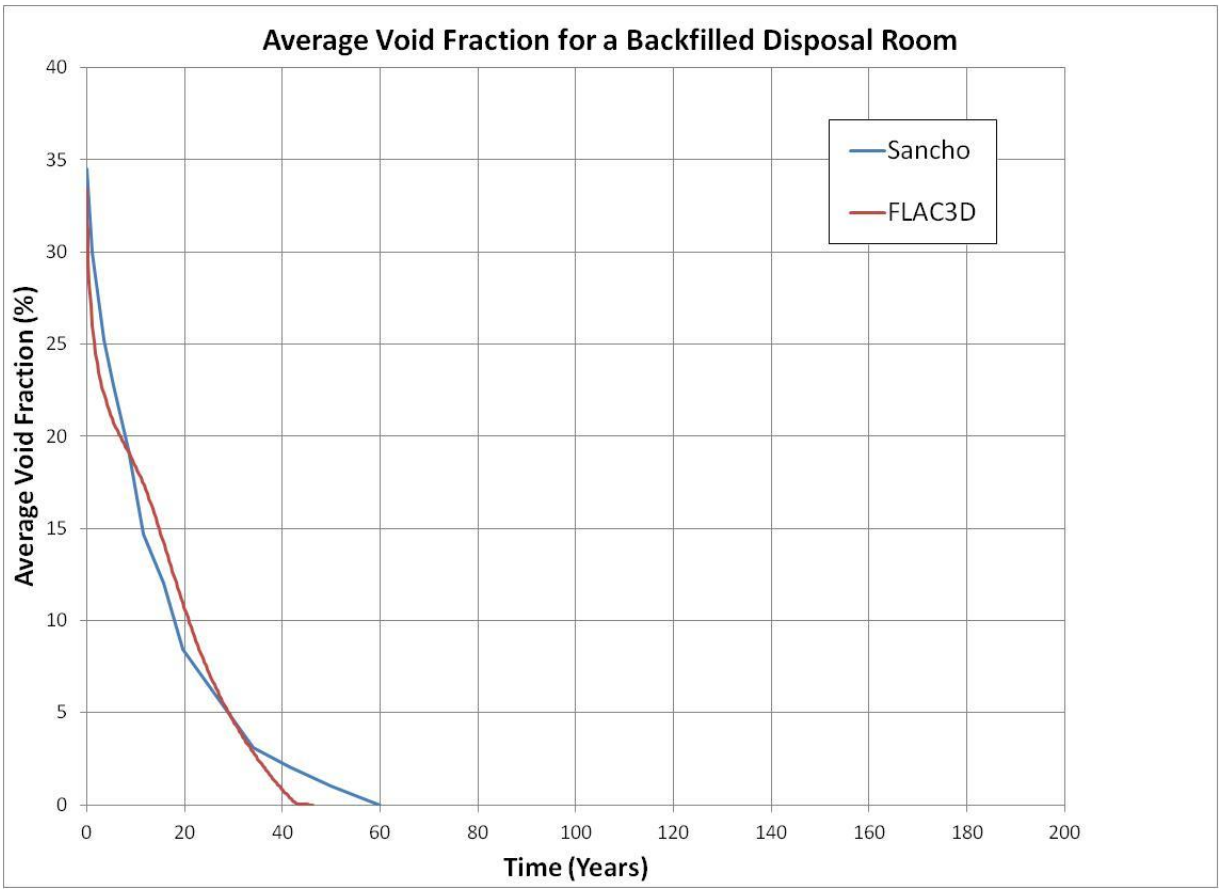
A benchmark calculation (Wagner et al., 1990) was performed to provide comparisons of the predicted consolidation of salt from several models. These included the SANCHO model developed by SNL. A FLAC3D model was developed for comparison to Wagner's results. The FLAC3D three-dimensional model consisted of a backfilled disposal room at the repository horizon that is subjected to a lithostatic stress of 2070 psi (14.3 MPa). In order to simulate the two-dimensional model in FLAC3D, the lateral displacements were set to zero for the plane strain condition. The FLAC3D model used the material properties and crushed salt constitutive model in the room-scale model developed by RE/SPEC for Sandia National Laboratories (SNL).

Figure 3-1 compares the FLAC3D results to the SNL SANCHO results from a previous calculation. The FLAC3D results were reasonably close to the SANCHO results because both use the same constitutive model and backfill type as implemented in FLAC3D.

3.2.4 Model Geometry

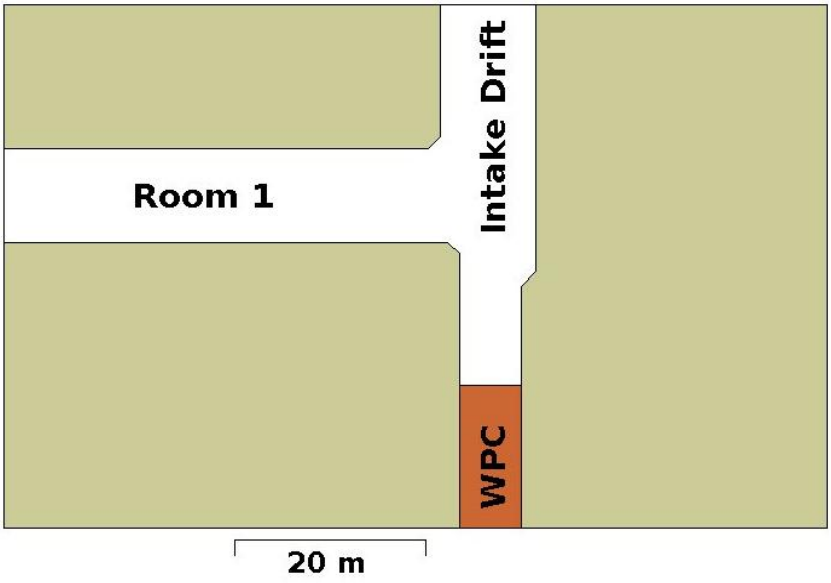
The horizontal extents of the intake and exhaust models are shown in Figure 3-2 and Figure 3-3 respectively. Separate models were developed for the panel intake and exhaust drifts. These figures show the model extents for each case below the roof of the room. The model includes half of Room 1 of a generic panel and the access drift from a line halfway between the rib of Room 1 and the ventilation drift (E-300 or W-170, depending on the panel). The north-south extents go from halfway between panels to an east-west line bisecting the panel. The salt fill is modeled in half-symmetry so only the half nearest Room 1 is modeled. The vertical extents run from about 250 ft (75 m) above and below the floor of the openings.

The crushed salt is modeled in half-symmetry along its length to reduce the run-time of the model, which in turn allows a more refined discretization, producing more accurate



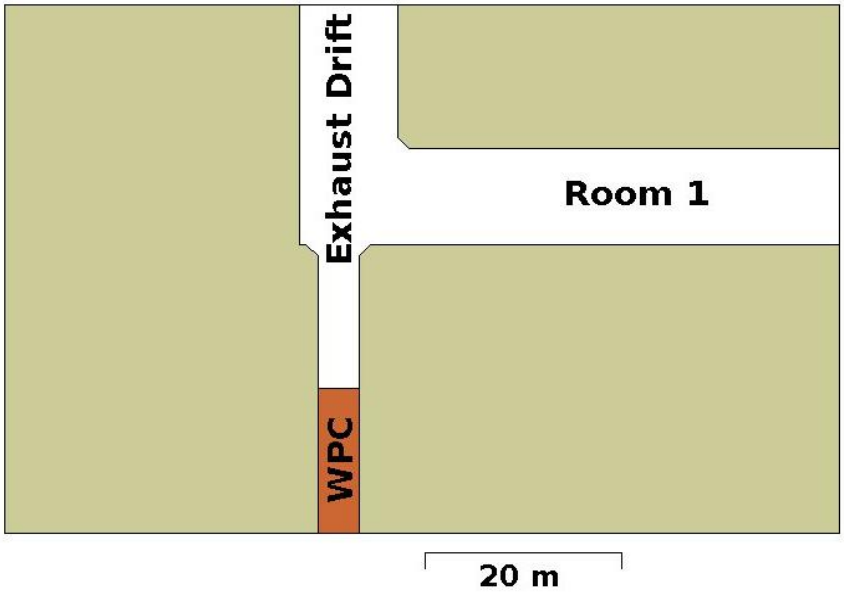
The average void fraction equals 1 minus the porosity.

Figure 3-1 Comparison of FLAC3D and Previous SANCHO Results for the Crushed Salt Benchmark Problem



The lower edge shown is the center of the emplaced fill. All edges are considered planes of symmetry in the analysis.

Figure 3-2 Horizontal Extents for Intake Drift Model



The lower edge shown is the center of the emplaced fill. All edges are considered planes of symmetry in the analysis.

Figure 3-3 Horizontal Extents for Panel Exhaust Drift Model

results. The behavior of the out-by end of the emplaced salt is not expected to be significantly different than the in-by end. This is because the closure rates that would affect the void or pore space of the WPC do not vary significantly along the length of the WPC. Additionally, the end effects are assumed to be essentially identical at each end.

The stratigraphy consists of rock salt with the inclusion of the anhydrite Marker Bed 139 located below the floor of the repository horizon and thin clay seams E, G and H. The roof of the entry corresponds to Clay G. The model grid is made up of over 313,000 three-dimensional zones. The model uses interface elements at the boundary between the emplaced salt and the surrounding drift. These interface elements provide a sliding boundary condition along this surface.

The ROM salt is emplaced at an assumed initial density of 65 % of intact density (88 lbf/ft^3 [1,404 kg/m^3]). This is the natural fractional density of ROM salt.

3.2.5 Modeling Sequence

The openings in the model are excavated instantaneously to reduce model run time. The model is then run without the ROM salt to five years after excavation to simulate the waste emplacement period in the active panel. This time was chosen based on estimates for the time between excavation and closure of Panel 5. In the models, the creep rates that control salt compaction reach steady state within the first two years, so the timing of ROM salt emplacement only affects the volume of the ROM salt, not the consolidation or permeability. Figure 3-4 shows the model-calculated vertical (roof-to-floor) and horizontal (wall-to-wall) closure rate histories at the center of the panel intake drift where the ROM salt will be located. Elapsed time in the FLAC3D analysis is from the time of excavation with the completion of waste emplacement activities in five years.

Figure 3-5 shows the same calculations for the panel exhaust drift. The horizontal measurements were only recorded after the ROM salt was emplaced. Oscillations in the curves occur at Year 28 when the top of the salt fill re-contacts the excavation roof (see Figures 3-7 and 3-8).

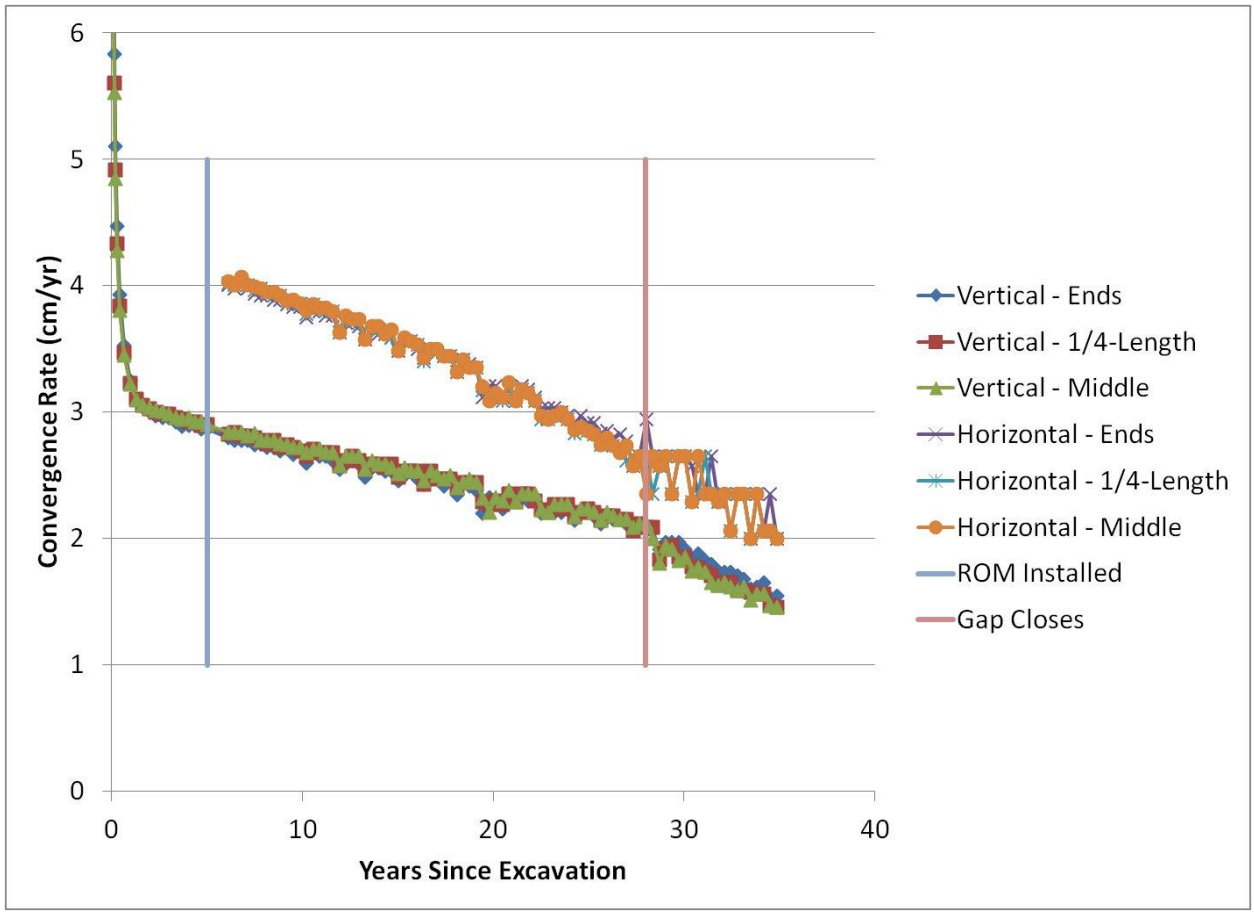


Figure 3-4 Calculated Vertical and Horizontal Panel Intake Entry Convergence Rates Before and After ROM Salt Emplacement

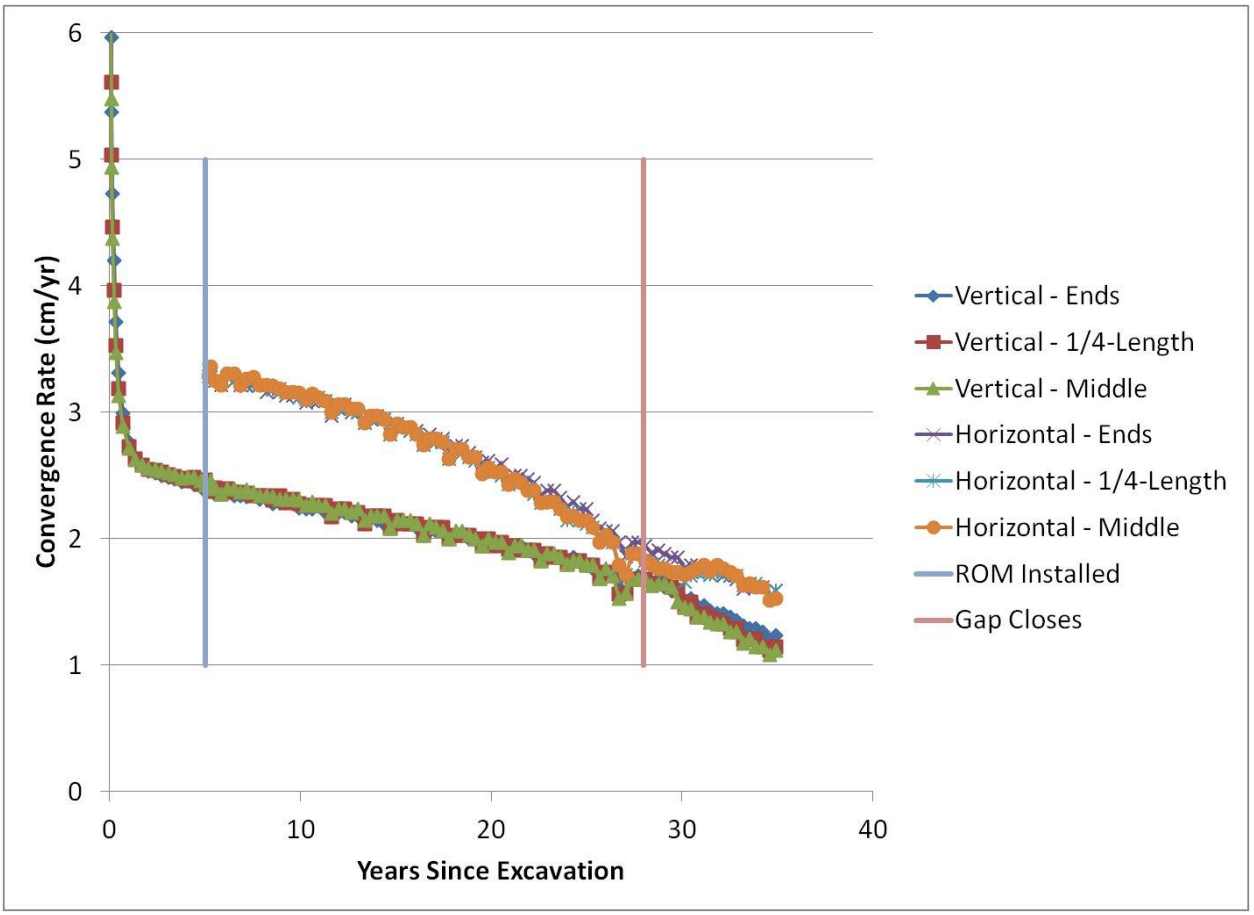


Figure 3-5 Calculated Vertical and Horizontal Panel Exhaust Entry Convergence Rates Before and After ROM Salt Emplacement

3.2.6 Structural Modeling Results

The variation with time of the fractional density of the emplaced salt in each drift is shown in Figure 3-6. These calculations are input into the air flow calculations. The values in Figure 3-6 were calculated by taking a volumetric average of the fractional density of all zones (model elements) in the compacted salt. The fractional density values for the panel intake and exhaust drifts are nearly identical. The intake drift is about 30% wider than the exhaust drift. The larger span results in larger intact rock displacement rates, but it also leads to a larger volume of fill under consolidation. In this case, the effect of the higher displacement rates in the intake drift is nearly balanced by the larger volume of material undergoing compaction. In other words, the

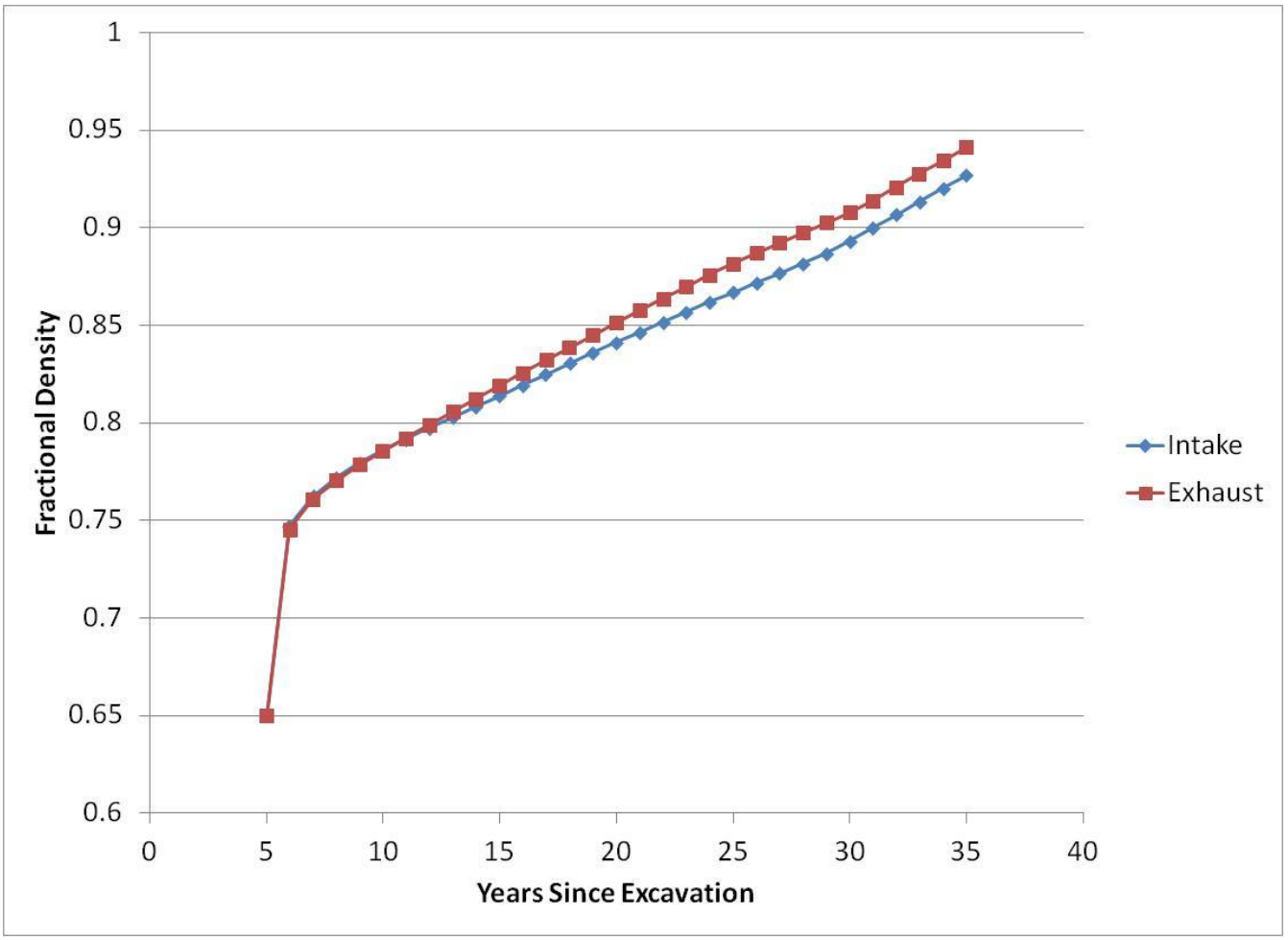


Figure 3-6 Fractional Density of ROM Salt vs. Time for Both Drifts

larger volume in the intake drift requires larger displacements to reach the same level of compaction (volumetric strain) as seen in the exhaust drift.

As a result of the self-settlement of the ROM salt, the post-installation consolidation rate is faster in this case than the roof-to-floor convergence rate. This results in an air gap forming between the roof of the excavation and the top of the emplaced salt. Figure 3-7 shows the gap magnitude versus time for points at the center and ends of the fill in the intake drift. Figure 3-8 shows the gap magnitude versus time in the exhaust drift. The gap reaches a maximum of 18.5 inches (47 cm) in the intake drift and 16.5 inches (42 cm) in the exhaust drift. The maximum gap occurs 2.5 years after installation in the intake drift and 1.8 years after installation in the exhaust drift. The gap magnitude reduces when the consolidation rate slows to less than the excavation closure

rate. The gap closes in approximately 23 years after installation in both drifts. Gap magnitude and duration is slightly lower at the ends of the fill.

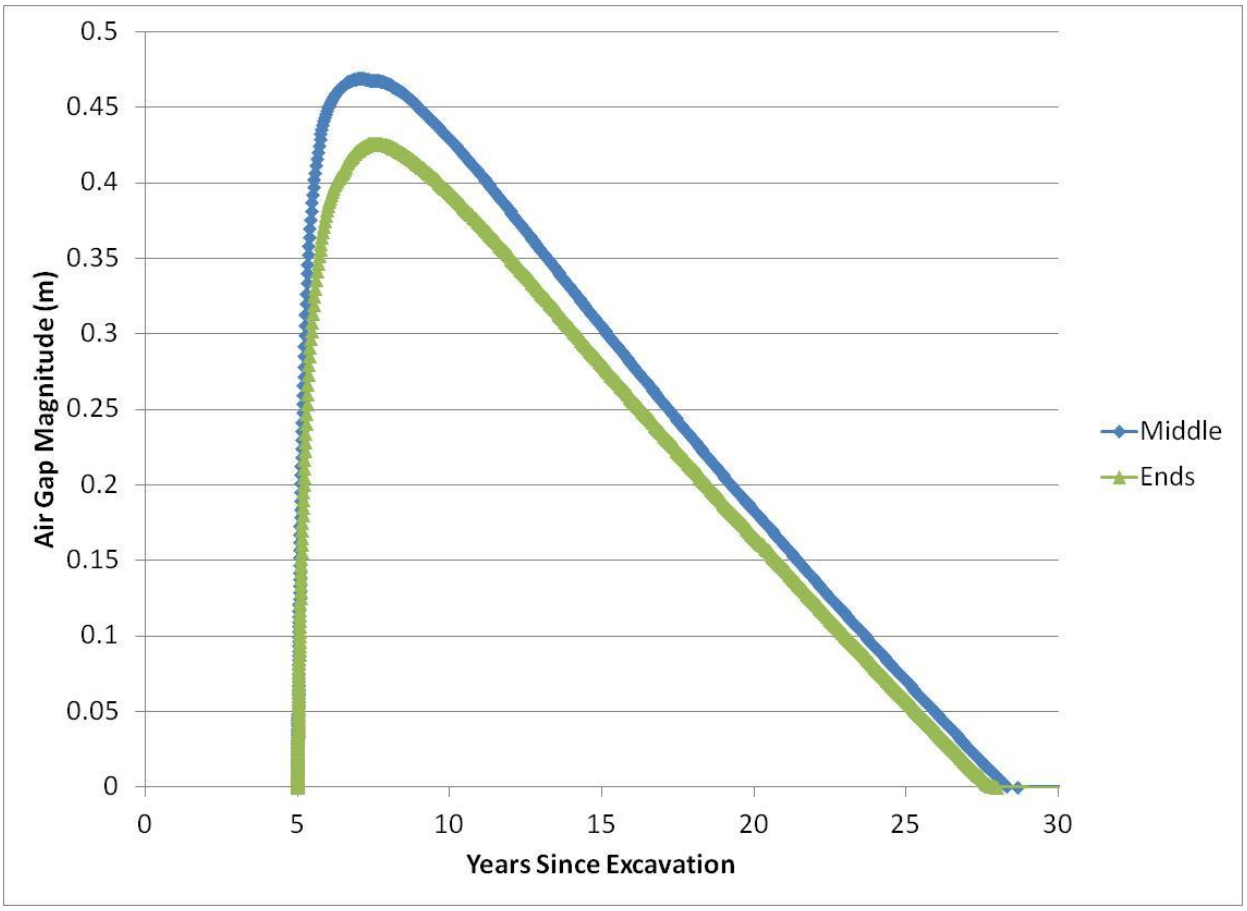


Figure 3-7 Air Gap Magnitude in Intake Drift

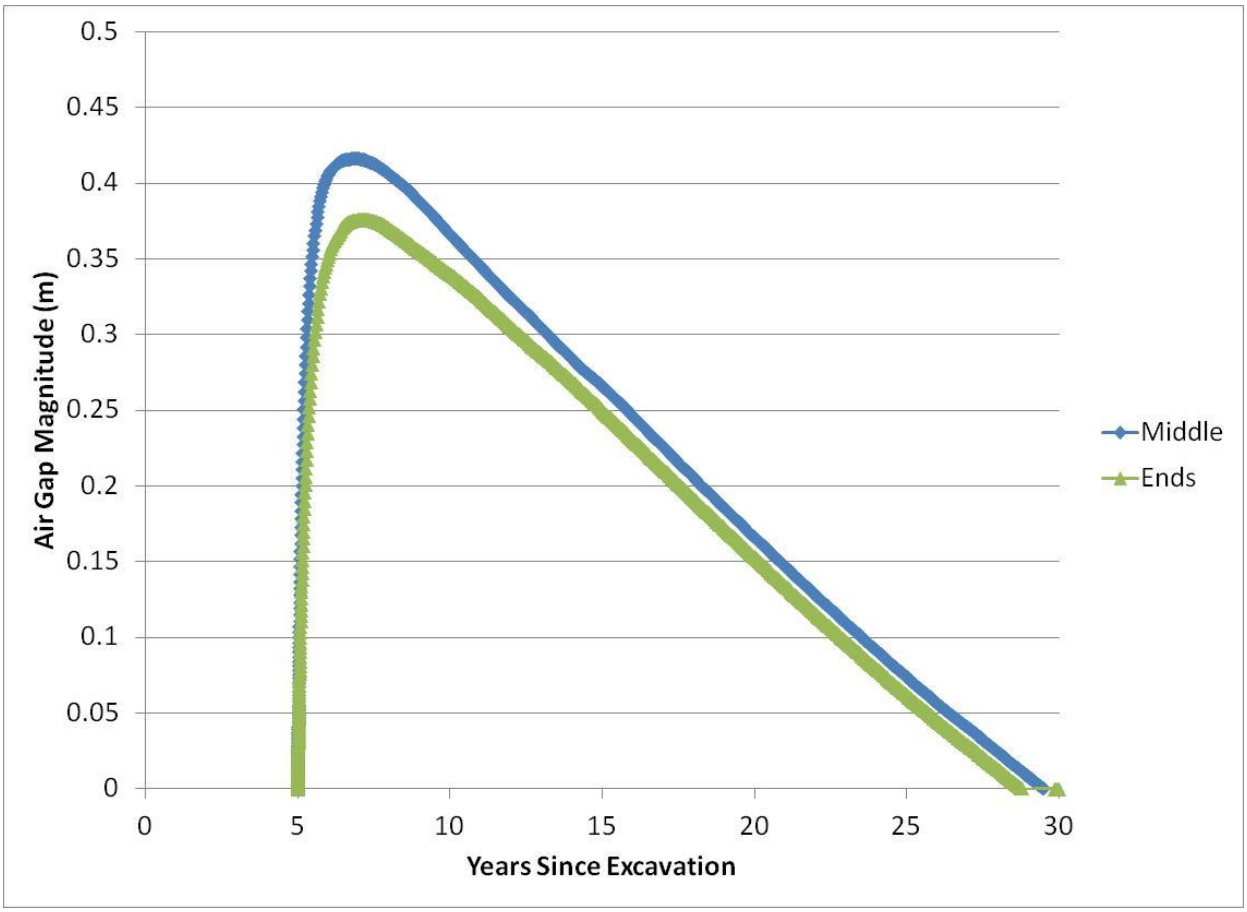


Figure 3-8 Air Gap Magnitude in Exhaust Drift

3.3 VOCs Flow Analyses

The VOCs flow analyses evaluate the flow of VOCs of concern through the WPC to the time of completion of waste emplacement operations at the WIPP facility. These analyses address the VOCs of concern; the VOC concentration data; the current emission rate of VOCs of concern; the schedule for closure of panels; and the future projected VOC emission rates. Also, the effective air conductivity of the panel closure system is evaluated and used as input to the air flow model (DOE, 1996) to assess VOCs flow performance.

Three sources for air flow are considered in projecting future emission rates. These include: (1) an average gas generation rate due to microbial degradation (Kehrman, 2012, Table 2); (2) a volumetric closure rate due to salt creep; and (3) an underground ventilation rate.

3.3.1 WPC VOCs Evaluation Procedure

The WPC VOCs evaluation procedure includes the analysis of air flow rates from a single panel. A detailed evaluation is then made of VOC concentrations for carbon tetrachloride (CCl_4) based upon open room emissions prior to closure of the air gap, and average headspace CCl_4 concentrations after closure of the air gap. A schedule is considered for individual WPC closure assuming approval of a Class 3 Permit Modification to include the WPC in the Permit in December 2013. The contributions from individual panels are superimposed to obtain the repository CCl_4 emissions. The risk fractions at the WIPP site boundary receptor point are then evaluated for CCl_4. The risk fractions for other VOCs are then calculated at the time of peak VOC emissions.

The WPC VOC analysis for a single panel closure includes: (1) evaluation of air flow rates after placement of a single layer of salt (65% fractional density) and the construction of steel bulkheads; (2) the period of time when a gap exists and air flow resistance is provided by steel bulkheads; (3) a period of time when the air gap is closed and air flow resistance is increased; and (4) a final period of time when air flows through consolidating ROM salt. The VOC concentrations are evaluated as the CCl_4 emission rate for open rooms (Kehrman, 2012, Table 12) during time periods when the air gap exists. After the gap is closed in 23 years, the dominant air flow resistance is through the pore space of the ROM salt. VOC emission then equals the product of the air flow rate and the average headspace concentration. These analyses compare predicted VOC concentrations from the model with existing VOC emissions measurements for Panels 1 through 5 and part of 6 to July 2012. Other assumptions used in the analysis are:

- Air flow occurs under quasi-steady state conditions. Air flows from gas generation and panel creep closure are source terms from each panel while air flow from underground ventilation occurs under Darcy's Law between the panel entries.
- The gas generation rate is 4,020 moles per panel per year (0.1 moles per drum per year) (Kehrman, 2012).
- Volumetric reduction of a panel due to creep closure reduces the void space at a rate of 28,680 ft^3 per year (812 m^3 per year) (DOE 1996, Appendix B).

- Underground ventilation in the adjacent main exhaust drift[2] results in a pressure drop between the panel air-intake and panel air-exhaust drifts for each panel (See Appendix A). The ventilation air flow entering each panel air-intake drift equals the air flow leaving the panel air-exhaust drift for each waste panel under a pressure drop of 170 milli-inches (4.3 mm) of water gage. The ventilation network analysis results in an average flow rate of several hundred cfm prior to closure of the air gap. The air flow rate is then reduced to less than 0.1 cfm.

- Steel bulkheads (Section 2.2.1) with flexible flashing to accommodate salt creep are used in the WPC design. Farnsworth (2011) indicated that smaller drifts with bulkheads near the Exhaust Shaft in the WIPP underground have air flow resistances as high as 2,200 Practical Units. The smaller drifts with bulkheads near the Exhaust Shaft are the closest in size to the Panel intake and exhaust drifts. Steel bulkheads will be maintained to accommodate panel entry salt creep to achieve a minimum air flow resistance of 2,200 Practical Units for as long as the bulkheads are needed to provide flow resistance.

- VOC transport occurs by advection. Hydrodynamic dispersion through the WPC is neglected. The VOC releases are determined for individual panels and then are superimposed in time.

The WPC VOC flow analyses are considered bounding because: (1) the pressure drop of 170 milli-inches (4 mm) of water gage is considered a maximum value; (2) a permeability vs. porosity relationship provides a maximum envelope for measured data (See Figure 3-9); and (3) the analysis models panel creep closure and gas generation as point-source at the panel air exhaust drift. These bounds are discussed in the following subsections.

3.3.2 Existing VOCs Emissions Measurements for Panels 1 through 5

The WIPP collected measurements on VOC concentration data and ventilation rates at the E-300

[2] The E-300 drift is the adjacent main exhaust drift for Panels 1 through 4, while W-170 is the adjacent main exhaust drift for Panels 5 through 8.

point of compliance were collected during the period from January 2008 to July 2012 for the VOCs of concern. The E-300 point is located at the intersection of the E-300 main exhaust drift, and S-1300 cross drift. The existing measurements reflect VOC emissions from Panels 1 through 6, with Panel 6 being the active panel during the measurement time period.

3.3.3 Estimation of Air flow Rates

Three sources for air flow are considered in projecting future emission rates. These include: (1) a gas generation rate due to microbial degradation; (2) a volumetric closure rate due to salt creep; and (3) an air flow rate due to underground ventilation in the adjacent exhaust drift. The air flow rate due to ventilation in the adjacent exhaust drift includes estimates of the potential air flow boundary condition for the WPC, the air flow resistances for components of the WPC and how these resistances change with time due to closure of the air gap, and consolidation of the salt.

Underground ventilation measurements and the analysis of these measurements are provided by the operating staff (Appendix B). This information is used to assess VOC emissions rates for the underground repository.

Figure A-1 shows the configuration for evaluating ventilation effects. A comparison of the analyses presented in Appendix A and DOE (1996, Appendix B) indicates that ventilation effects in the adjacent main exhaust drift are more significant than gas generation and panel creep closure. Since the flow in the adjacent exhaust drift is the path of least resistance for air flow, the pressure drop or potential is set by the head loss down the adjacent main exhaust drift. The potential difference then provides the pressure or head differential for flow through the WPC. It is much smaller than flow through the adjacent exhaust drift. However, it is much larger than flow generated by gas generation and panel creep closure used in previous studies (DOE, 1996).

Appendix B presents information on ventilation rates in thousands of cubic feet per minute (kcfm) and pressure drops in milli-inches of water gage for the WIPP underground ventilation network. The measurements include pressure drop measurements in the main exhaust drift adjacent to each WPC as shown in Figure A-1.

The normal and full operating modes provide measurements during testing and balancing that are representative of underground ventilation conditions. Appendix B describes the normal and full operating modes. For the normal operating mode, the average value for the pressure drop was 163 milli-inches of water gage. The range of pressure drops was from 12 to 350 milli-inches

(0.3 to 9 mm) of water gage. For the full operating mode, the average value was 165 milli-inches of water gage with a range of values from 0 to 394 milli-inches (0 to 10 mm) of water gage.

The FLAC3D analysis provides the settlement time histories of ROM salt that results in the reduction of the air gap and increase in fractional density or reduction in porosity of the ROM salt.

The FLAC3D analysis indicates closure of the air gap at different locations within the ROM salt over time. The analyses of both the WPC Intake and Exhaust drift show an increase in air gap occurs for two years followed by a reduction in the air gap after this time. The air gap closes first near the ends, and then followed by the middle of the ROM salt. These times are approximately 23 years after panel closure. Prior to the time of closure of the air gap, air flow resistance through the WPC is predominately due to the steel bulkhead resistance. After approximately 20 years, the air gap closes to a point at which the air flow resistance offered by the consolidating salt equals the air flow resistance through steel bulkheads. Flow rates through the WPC are calculated using methods presented in Appendix A Section A5.0. The estimated flow rates are of the order of several hundred cfm.

After closure of the air gap, the dominant air flow resistance is through the consolidating salt. Air flow is reduced to a small percentage of the air flow through the gap. The air conductivities were then calculated based upon the intrinsic permeability relationship that accounts for both the relative density and the average particle size of the ROM salt backfill (Kelsall et al., 1983, Equation A-4). This relationship is illustrated in Figure 3-9 and is based upon the investigations made by Shor, et al. (1981) and bounds the intrinsic permeability relationship derived from laboratory investigations of crushed salt (Case et al., 1987, Figure 1, and from Mellegard, 1999, Figure 4-15). The analysis is bounding in that measured intrinsic permeabilities of ROM salt from measured relationships (Case et al., 1987, Figure 1 and Mellegard, 1999, Figure 4-15) are lower than those predicted on the basis of the Shor relationship for a particle size of 0.13 inches (0.34 cm). Figure 3-10 and Figure 3-11 present the air conductivities based upon the relative density vs. intrinsic permeability relationship for a single panel. The reduction in fractional density is anticipated to result in a reduction in air conductivity through the ROM salt over a 30-year period.

Small amounts of moisture exist in the ROM salt. Also small amounts of brine will flow from

the surrounding entries into the ROM salt (Deal and Case, 1987). Moisture within the salt is conservatively neglected in the analysis. The technical basis for this assumption is that moisture existing or being introduced in the pore space will reduce the intrinsic air permeability to the gas phase, and thus reduce the flow of VOCs.

Bear (1972, p. 712) provides an air flow network resistance method. Appendix A presents derivations for the air flow model. Air flow is governed by Darcy's Law under quasi steady state conditions.

The air flow analysis considers flow through other components as presented in Table 3-1 . Flow through the disturbed rock zone (referred to as fractured and dilated salt in Table 3-1), clay seams and Marker Bed 139 occur in parallel to air flow through the WPC.

Case and Kelsall (1987) evaluated permeability measurements performed by Peterson et al. (1985). These data showed a zone of increased permeability (10^{-18} ft^2 to 10^{-20} ft^2 [10^{-19} m^2 to 10^{-21} m^2]) from 3 ft to 42 ft (1 to 14 m) from the opening. Based on this observation, the calculations assumed that the cross-sectional area for flow through the DRZ and the panel closure system will equal nine times the panel intake or panel exhaust drift area or that the DRZ extends out three radii from the center (DOE 1996, Section 2.1.1.1).

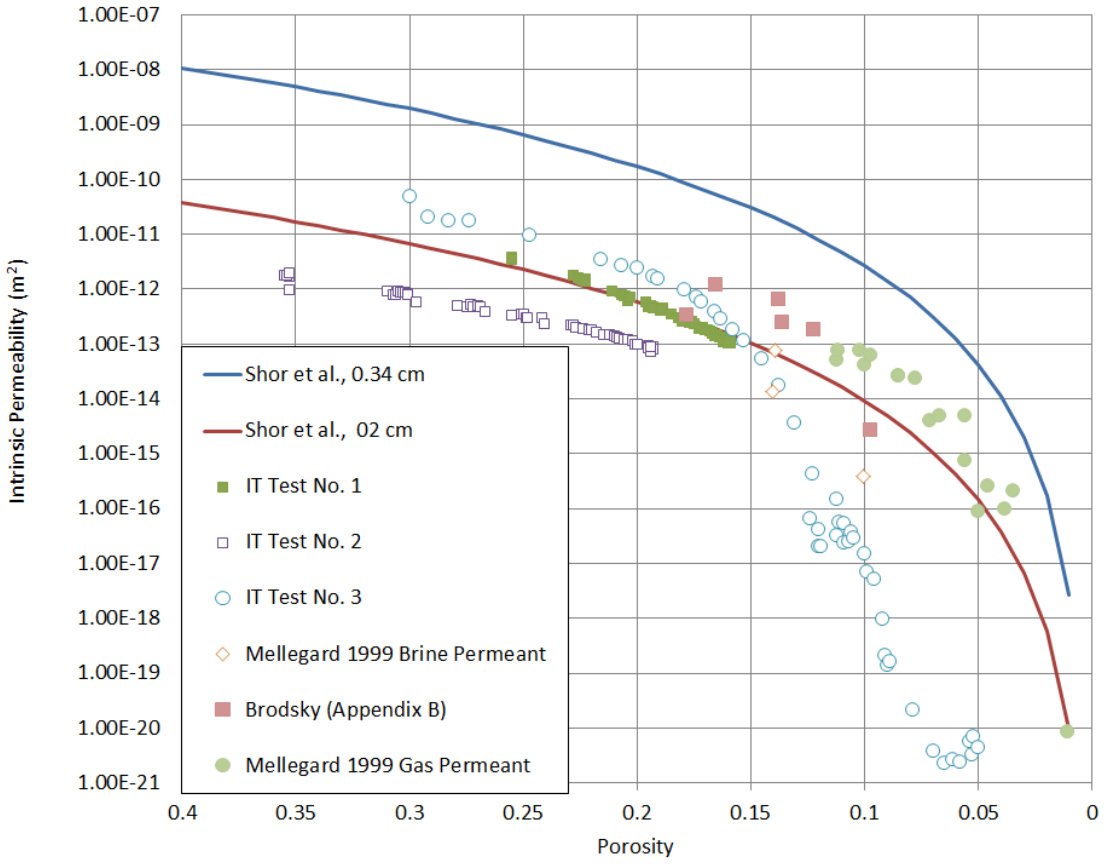


Figure 3-9 Relationship of Intrinsic Permeability to Porosity

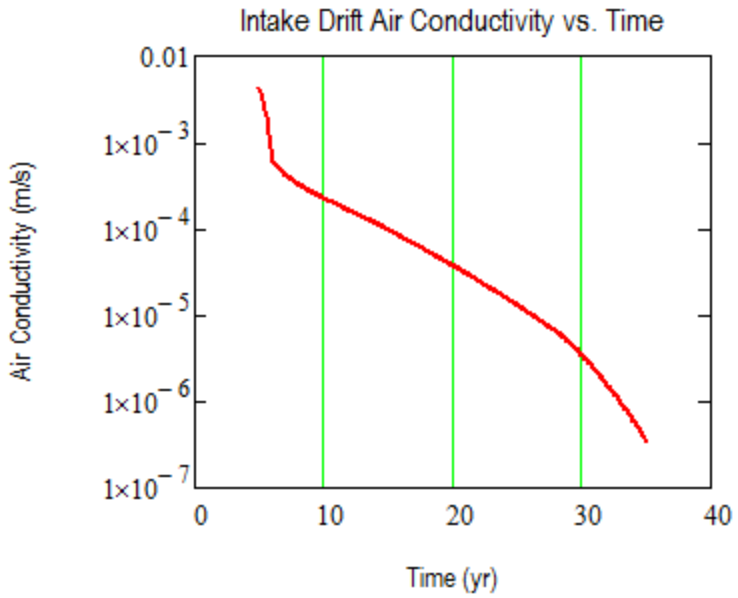


Figure 3-10 Panel Intake Drift Air Conductivity Through ROM Salt vs. Time

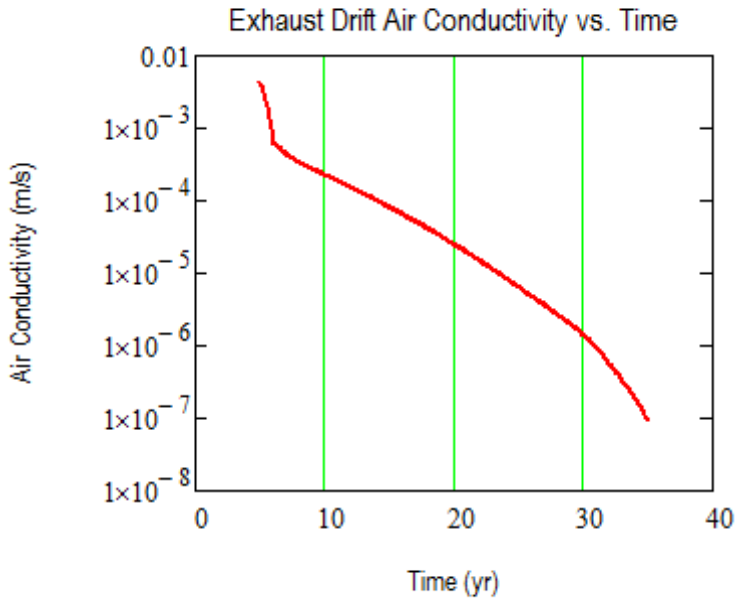


Figure 3-11 Panel Exhaust Drift Air Conductivity Through ROM Salt vs. Time

A distinction is made between "dilated rock salt" and "fractured rock salt." Dilated rock salt exhibits a higher permeability than intact rock salt due to stress relief from the lithostatic state of stress and this corresponds to the increased permeability zone observed by Case and Kelsall (1987). The value used here for the intrinsic permeability of dilated rock salt (10^{-18} ft^2 (10^{-19} m^2)) is more conservative than measurements using the guarded packer straddle system (Case and Kelsall, 1987, Figure 5). The fractured rock salt refers to the highly fractured zone in the immediate vicinity of the openings.

A comparison is made of the air conductance of the ROM salt emplaced in the drift to the air conductance in the surrounding DRZ. The flow resistance through the DRZ and the adjacent 100 ft (30.5 m) of ROM salt can be compared by considering the sum of the product of the air conductivities times the cross sectional areas of each DRZ component to the product of the air conductivity times the cross sectional area of the ROM salt. The estimated flow is several orders of magnitude lower through the DRZ. The analysis predicts the dominant flow path is through the ROM salt and flows through components of the DRZ are small.

Comparisons were made between the flow resistance of the ROM salt with a minimum length of 100 ft (30.5 m) with steel bulkheads. Using the fundamental relationship relating head loss to air flow and considering 170 milli-inches (4 mm) of water gage with bulkhead resistance of 2,200 Practical Units[3] (0.070 $mm/(m^3/min)^2$), the estimated air flow resistance through a gap above the ROM salt was about two orders of magnitude smaller than the resistance of bulkheads. After 23 years following WPC emplacement, the air gaps are closed and the resistance of the salt is much higher than that of steel bulkheads. Flow resistance through 100 ft (30.5 m) of ROM salt is dominant after 23 years. See Appendix A for details. Steel bulkheads will be maintained to provide a minimum air flow resistance of 2,200 Practical Units during the 23 year period following WPC construction.

[3] A Practical Unit equals 1 milli-inch of water gage divided by (1 kcfm [1000 cubic feet per minute)^2 (Mine Ventilation Services (2003, p. 10). 1 kcfm = 1000 ft^3/min (28.3 m^3/min). The Practical Unit is equivalent to 3.17 x 10^{-5} $mm/(m^3/min)^2$ in the metric system. The Practical Unit is derived from the Square Law used in underground ventilation analysis.

Table 3-1 Air Conductivity of Other Flow Components

Component	Air Conductivity		References
	ft/s	m/s	
Dilated salt	2.03×10^{-13}	6.2×10^{-14}	DOE, 1996
Fractured salt	2.03×10^{-9}	6.2×10^{-10}	DOE, 1996
Clay seams	2.03×10^{-11}	6.2×10^{-12}	DOE, 1996
Marker Bed 139	2.03×10^{-10}	6.2×10^{-11}	DOE, 1996

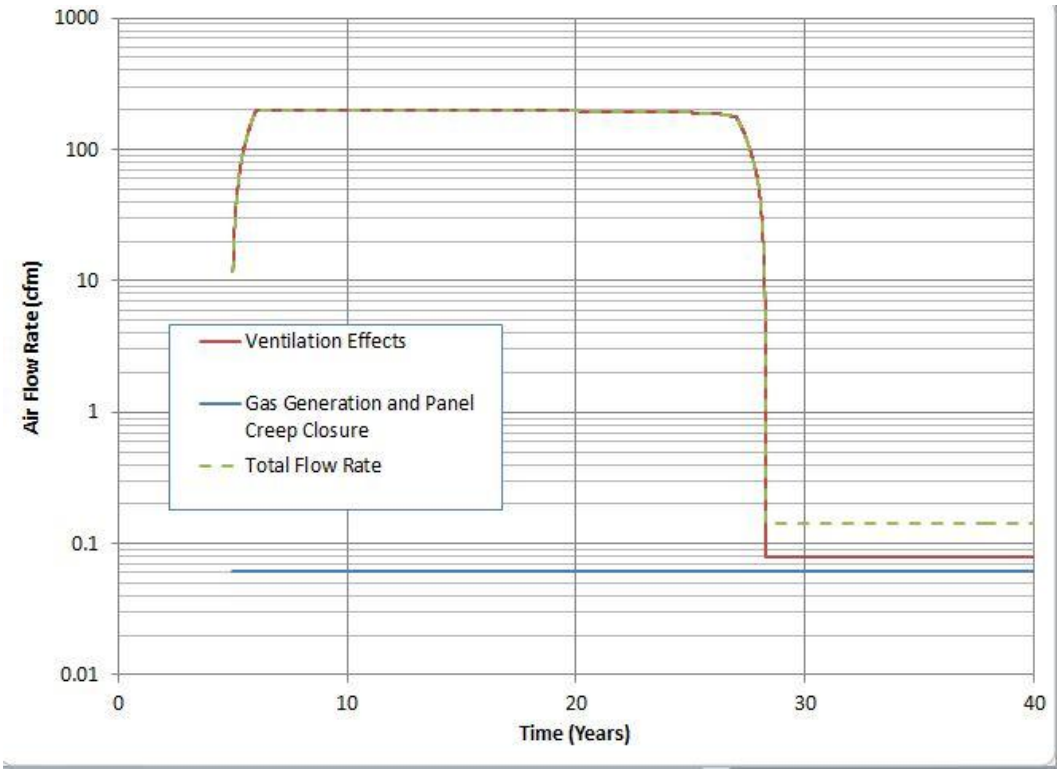


Figure 3-12 Air flow Rate for a Single Panel

Time shown is after panel excavation with panel closure occurring after 5 years.

Figure 3-12 presents the results of the single panel air flow analysis and compares air flow from air-ventilation effects of the adjacent main exhaust drift with the other point source terms for gas generation and panel creep closure. The analysis assumes that gas generation and panel creep closure are point source terms for air flow out of the WPC and that the total air flow is the sum of the air flow from ventilation effects of the adjacent main exhaust drift and the other source terms.

After ROM salt emplacement and installation of steel bulkheads, the analysis predicts that air flow through the WPC is initially of the order of 10 cubic feet per minute (cfm). Soon after emplacement, the air gap aperture quickly grows and air flow increases until flow is limited by the bulkheads to about 200 cfm. After about 20 years, the air flow resistance through closing air gap and the steel bulkheads are nearly equal. After about 23 years, closure of the air gaps above the consolidating salt is complete, and air flow resistance is dominantly through the pore space of the consolidating salt. The estimated flow through the WPC is of the order of 1cfm (0.028 m^3/min) and air flows from ventilation effects are twice the flow from gas generation and panel creep closure.

3.3.4 Transport of VOCs by Advection

Transport of VOCs occurs either from the open room emissions (Kehrman, 2012, Table 12) prior to closure of the air gap in each WPC, and then by advection with the projected emission rate determined as the product of the air flow rate times the average head space concentration for each VOC. When the air gap is closed, it is assumed for the air flow model that the average headspace concentrations serve as a constant source of VOCs. This assumption is conservative because some containers may only have trace quantities of VOCs, either trapped in the headspace or on the surfaces of the various waste components. The analysis uses the weighted average headspace concentration for VOCs (Kehrman, 2012, Table 1) and no VOC source depletion is assumed.

Previous analysis (DOE, 1996) evaluated the effects of hydrodynamic dispersion on VOC transport through the WPC, using a one-dimensional dispersion model (Freeze and Cherry, 1979). Analysis was performed to evaluate the breakthrough or travel time of a concentration front considering the average linear velocity of the air flow. The analysis shows that breakthrough times increase with time as the salt compacts to higher fractional densities. The analysis shows that breakthrough times range from 7 to 70 days over 10 years. Hydrodynamic effects can be neglected for this rapid breakthrough time.

Comparisons of the model predictions with existing VOCs running average measurements at E-300 provide model validation. Figure 3-13 presents the analysis of CCl_4 and compares predictions with existing CCl_4 measurements from January 2008 to July 2012. The measurements include the emission rates during the time period when Panels 1 through 3 were closed and Panels 4 through 6 were active. The analysis initially predicts a higher rate of VOC emissions than what has been measured. This is because Panels 1 and 2 received smaller inventories of Type IV solidified organic wastes. At the time that Panel 6 is in operation, the VOCs model is in agreement with measurements of the running annual average (RAA) for CCl_4 at the E-300 location. The analysis predicts that the estimated CCl_4 emissions reach a value of about 300 ppbv at year 20, and then reduce with time as individual WPCs are constructed followed by closure of the air gap 23 years after each closure. The field measurements include a variety of factors that are not considered in the emissions model. These include changes in ventilation, temperature, barometric pressure, etc. This results in the oscillations in the field measurements that are not seen in the model predictions.

3.3.5 VOCS Analysis Results

The evaluation includes the case when all but one panel is closed using the WPC at the time of repository closure, and the single open active panel consists of six filled and closed rooms and one open room at current existing emissions rates. The case being evaluated is equivalent to the evaluations performed for other panel closures with the updated source term information.

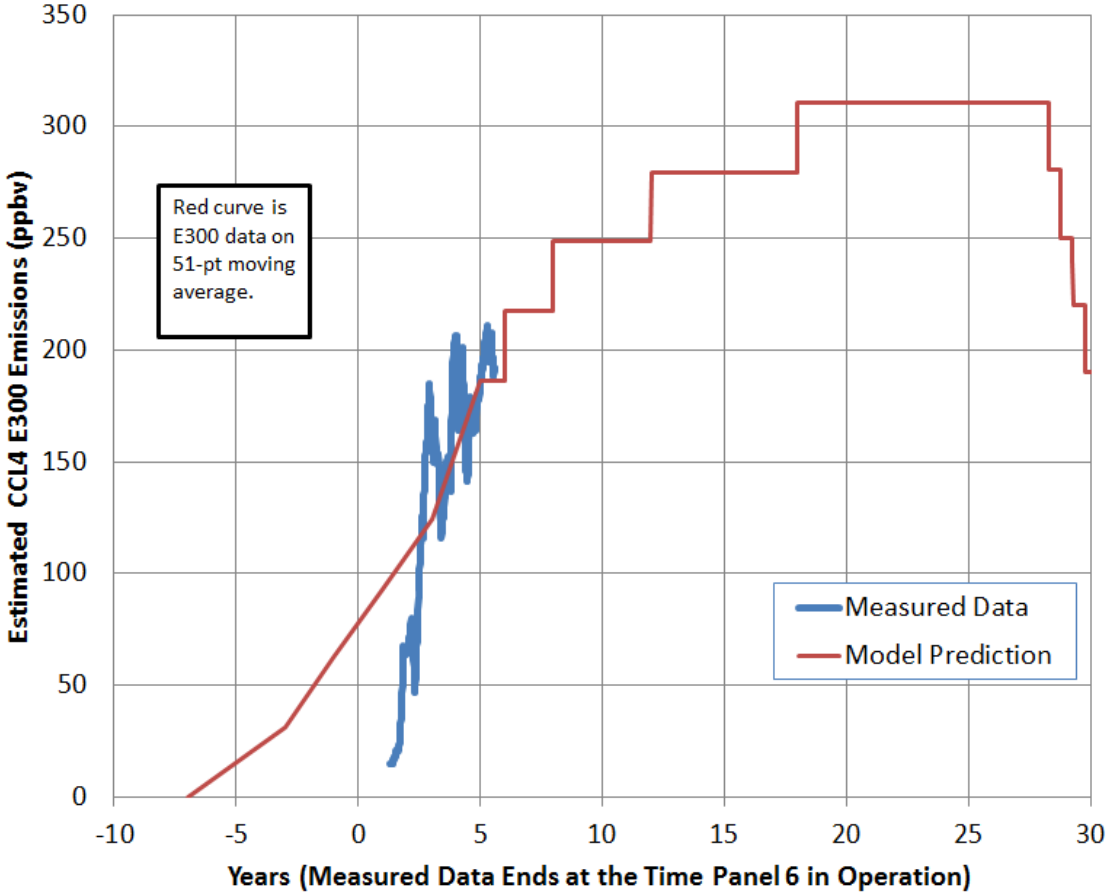


Figure 3-13 Comparison of Predicted and Measured Concentrations for CCl_4 at E-300.

The current Permit Application considers compliance with HBLs (Kehrman, 2012, Table 11) at the WIPP site boundary. Kehrman (2012, Table 6) provides the air dispersion factor for evaluating concentrations at this point. Kehrman (2012, Table 11) provides HBLs for these WIPP boundary receptor points for CCl_4 for carcinogenic risk and noncarcinogenic risk scenarios.

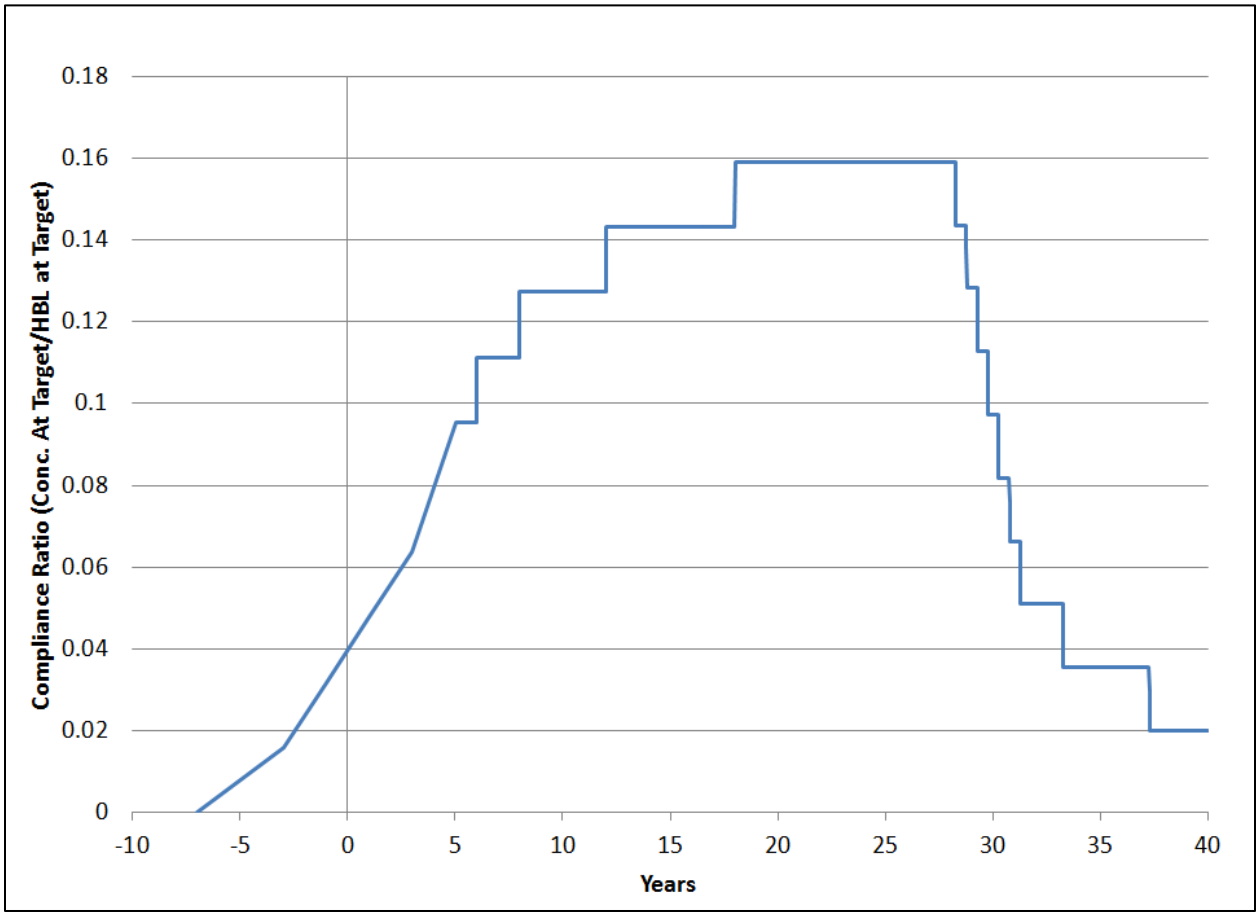


Figure 3-14 Risk Fractions For CCl4 At WIPP Boundary Receptor Points

Figure 3-14 presents the risk fractions for the carcinogenic scenario for CCl_4 at the WIPP site boundary. Noncarcinogenic scenarios result in lower risk fractions than for carcinogenic scenarios (see Table 3-2). The figure also shows the average risk fractions for CCl_4 at the WIPP boundary receptor location are about 0.16 or less.

The predicted mass flow rates for CCl_4 through the WPC due to open room emissions prior to closure of the interface gap and then through the WPC after interface gap closure (including flow through the DRZ, the steel bulkheads and ROM salt) from gas generation, panel creep closure

and ventilation effects of the adjacent main exhaust drift are predicted to result in concentrations that are below the limits established at the WIPP receptor boundary. The risk fractions are in compliance at the time of completion of waste emplacement operations in which nine WPCs have been installed, and there are six closed rooms with one open room in a single panel. The evaluation of risk fractions at intermediate locations has not been performed, and is not part of the scope of work.

3.3.6 Other VOCs

Table 3-2 presents an evaluation of risk fractions for all VOCs in the waste inventory at the time of maximum release. Risk fractions are the ratio of the predicted emissions to the HBLs. The analysis shows that the release fractions are less than one and that releases from the WIPP repository results in VOCs concentrations that are less than HBLs for VOCs of interest (Kehrman, 2012, Table 11) at the WIPP site boundary. Concentrations at other surface and underground locations were not analyzed as part of this scope of work.

Table 3-2 Maximum Risk Fractions for VOCS at WIPP Site Boundary

VOC	Carcinogen Site Boundary Ratio	Non-carcinogen Site Boundary Ratio
Carbon Tetrachloride	1.59E-01	5.26E-04
Chloroform	1.13E-02	1.04E-05
Trichloroethylene	6.13E-03	1.50E-03
1,1,2,2-Tetrachloroethane	5.24E-03	N/A
1,2-Dichloroethane	2.95E-03	3.37E-05
Benzene	1.02E-03	8.85E-06
1,1-Dichloroethane	5.11E-04	N/A
Ethyl Benzene	2.35E-04	1.88E-07
Bromoform	4.81E-05	N/A
Tetrachloroethylene	4.59E-05	8.82E-06
Methylene Chloride	1.25E-05	4.18E-06
1,2,4-Trimethlybenzene	N/A	1.81E-05
Butanol	N/A	1.41E-05
Methyl Chloride	N/A	1.31E-05
1,1,1-Trichloroethane	N/A	8.46E-06
trans-1,2-Dichloroethylene	N/A	4.52E-06
1,1-Dichloroethylene	N/A	4.26E-06
m,p-Xylene	N/A	3.34E-06
Chlorobenzene	N/A	2.93E-06
o-Xylene	N/A	1.95E-06
Methanol	N/A	1.61E-06
Carbon Disulfide	N/A	1.11E-06
1,1,2-Trichloro-1,2,2-Trifluoroethane	N/A	4.43E-07
Methyl Isobutyl Ketone	N/A	2.15E-07
Methyl Ethyl Ketone	N/A	1.71E-07
Toluene	N/A	1.37E-07
Acetone	N/A	1.17E-07
Cyclohexane	N/A	1.05E-07
Total	**1.87E-01**	**2.17E-03**

Note: N/A indicates there is no regulatory limit for the VOC.

3.4 ROM Salt Material Compatibility Evaluation

The WPC consists of bulkheads and ROM salt. Additional steel from bulkheads used in the WPC for individual panels is not expected to affect repository modeling and analysis. Since only the outer steel bulkheads are subject to repository ventilation, only trace amounts of brine would contact the steel bulkheads over the operational period. This is due to the low moisture content of the halite. The outer steel bulkheads can be replaced or repaired if needed. ROM salt is entirely compatible with the underground environment.

4.0 Technical Specifications

The specifications are in the engineering file room at the WIPP facility. These specifications are included as an attachment in Appendix C and are summarized in Table 4-1.

Table 4-1 Technical Specifications for the WIPP Panel Closure System

Division 1 - General Requirements	
Section 01010	Summary of Work
Section 01090	Reference Standards
Section 01400	Contractor Quality Control
Section 01600	Material and Equipment
Division 2 - Site Work	
Section 02010	Mobilization and Demobilization
Section 02222	Excavation
Division 4 - Salt	
Section 04100	Run-of-Mine Salt

5.0 Drawings

The Drawings (Appendix D) are in the engineering file room at the WIPP facility and are summarized in Table 5-1.

Table 5-1 WIPP Panel Closure System Drawings

Drawing Number	Title
262-001	WIPP Panel Closure System Title Sheet
262-002	WIPP Panel Closure System, Underground Waste Disposal Panel Configurations (3,4,6,7,8)
262-003	WIPP Panel Closure System, Underground Waste Disposal Panel Configurations (1,2,5)
262-004	WIPP Panel Closure System, Construction Details

6.0 Conclusions

This chapter presents the conclusions for the design activities for the WPC. Table 6-1 shows the Permit design requirements for the WPC and the compliance of the design with these requirements. The design configuration and essential features for the WPC include ROM salt, and two barriers. The barriers consist of two steel bulkheads placed at the ends of the ROM salt or alternatively, one steel bulkhead and a block wall. The design includes a minimum length of 100 ft of ROM salt.

This report presents the design as a series of calculations and Engineering Drawings and Specifications that comply with the design requirements for the WPC. Structural and air flow analyses are used to select the design features and are based upon data acquired from the WIPP underground. The Drawings illustrate and describe the construction and details for the WPC. The Specifications cover the general requirements of the system, quality assurance and quality control, site work, and ROM salt emplaced in the panel entries. The WPC can be built to generally accepted national design and construction standards. Bulkheads are not included in the Specifications (Section 2.1) since they are routinely constructed and used at the WIPP facility. There is no construction or materials specification for bulkheads, only a performance requirement (2,200 P.U. air flow resistance).

The design complies with all aspects of the design basis established for the WPC. The design can be constructed in the underground environment with no special requirements at the WIPP facility. To investigate several key aspects of the design and to implement the design, design evaluations were performed. The conclusions reached from the evaluations are as follows:

- An air gap forms between the excavation roof and the top of the fill due to the settlement of the ROM salt. Structural modeling results using the three dimensional finite difference code FLAC3D predict the change in gap height and density of the salt with time. The salt compacts from its initial placement density to approximately 90% of the intact salt density under its own weight 23 years after panel closure.

- A VOC Flow Model accounts for gas generation, panel-creep closure, and the effects of underground ventilation of the adjacent main exhaust drift. The VOC Flow Model evaluates the reduction in air conductivity that occurs with the increase in salt density, reduction in gap size and reduction in porosity. The low air flow through the WPC is

initially caused by the effects of ventilation of the adjacent main exhaust drift. About 23 years after closure, the air gap above the ROM salt is eliminated. The ROM salt consolidates due to panel-entry closure and air conductivity is significantly reduced. This results in low air flow rates.

- The passive design components of the WPC require minimal routine maintenance during the nominal operational life. Out-by bulkheads must be maintained to provide 2,200 P.U. resistance for 23 years after installation.

- The WPC provides for flexibility over the remaining operational life in construction scheduling and construction material transportation and therefore minimizes the effect on waste receipt.

In addition to the design requirements presented above, the design includes a construction QA/QC program to verify material properties and construction practices.

The predicted mass flow rates for CCl_4 and other VOCs through the WPC (including flow through the DRZ, the steel bulkheads and the ROM salt) will result in concentrations that are below the HBLs established at the WIPP site boundary. Concentrations at other surface and underground locations were not analyzed. Modeling results of the WPC did not produce VOC concentrations from combined effects that would exceed limits for the repository. If the HBLs, air dispersion factors, or the average headspace values change, the calculations should be re-evaluated to ensure that compliance is maintained.

It is also concluded that:

- The WPC provides for flexibility over the remaining operational life in construction scheduling and construction material transportation effects on facility operations.

- The existing shafts and underground access can accommodate the construction of the WPC.

While no specific requirements exist for closing disposal areas under MSHA regulations, the intent of the regulations is to safely isolate abandoned areas from active workings using barricades of substantial construction. The ROM salt is considered substantial construction.

Table 6-1 Expected Compliance with Performance Specifications

No.	Current Design Requirement	Expected Compliance with Requirement	Section in Report	Notes on Compliance
1	The panel closure system shall contribute to meeting the environmental performance standards in Permit Part 4 Section 4.6.2 by mitigating the migration of VOCs from closed panels.	Complies	3.3.5, Appendix A	Complies with the use of ventilation bulkheads with flexible flashing to accommodate salt creep and ROM salt a minimum of 100 ft in length.
2	The panel closure system shall consider potential flow of VOCs through the disturbed rock zone (DRZ) in addition to flow through closure components.	Complies	3.3.3	VOCs flow model considers flow through the DRZ.
3	The panel closure system shall perform its intended functions under loads generated by creep closure of the tunnels.	Complies	3.2.7	The flexible flashing and maintenance of the steel bulkhead accommodates panel entry creep closure. The plastic deformation of the ROM salt will result in a reduction in porosity and permeability with time.
4	The nominal operational life of the closure system is thirty-five (35) years.	Complies	3.2.7, 3.3.5	The combination of maintaining the outer bulkheads with ROM salt can accommodate a design life of 35 years.
5	The panel closure system may require minimal maintenance per 20.4.1.500 NMAC (incorporating 40 CFR 264.111)	Complies	2.2.1	The ROM salt requires no future maintenance. The outbye bulkhead can be maintained or replaced with minimal maintenance.

No.	Current Design Requirement	Expected Compliance with Requirement	Section in Report	Notes on Compliance
6	The panel closure system addresses the expected ground conditions in the waste disposal areas.	Complies	2.2, 3.2.6	Design is based upon structural analyses and flow for the most severe ground conditions.
7	The panel closure system shall be built of substantial construction and non-combustible material except for flexible flashing used to accommodate salt movement.	Complies	Appendix C Section 04100	The panel closure system uses ROM salt which is of substantial construction. The materials are noncombustible except for the flexible flashing.
8	The design and construction shall follow conventional mining practices.	Complies	2.3	The future construction sequence for the design will follow conventional civil and mining practices.
9	Structural analysis shall use data acquired from the WIPP underground.	Complies	3.2, 3.3	Available geomechanical, air flow and gas generation measurements were used in the analysis.
10	Materials shall be compatible with their emplacement environment and function.	Complies	3.4	ROM salt is compatible with the surrounding environment. The out bye steel bulkheads can be replaced when the design life is exceeded.
11	Treatment of surfaces in the closure areas shall be considered in the design.	Complies	2.1, Appendix C Section 02222	Surface scaling of loose material surrounding the WPC is included in the design specifications.
12	A QA/QC program shall verify material properties and construction.	Complies	2.1, Appendix C Section 01400	Future submittals according to the design specifications will utilize materials testing to verify material properties and future construction practices as necessary.
13	The construction of the panel closure system shall consider shaft and underground access and services for materials handling.	Complies	2.1, Appendix C, Section 01010	The specification allows future construction within the capacities of the underground access.

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APPENDIX A
DERIVATION OF RELATIONSHIPS FOR THE AIR-FLOW MODELS

APPENDIX A
DERIVATION OF RELATIONSHIPS FOR THE AIR-FLOW MODELS

A1.0 Introduction

This appendix presents the derivation of the air-flow model used to determine the performance of the WIPP Panel Closure (**WPC**). These derivations were used in the analyses in Section 3 to determine air flow from a single panel. These analyses provide an estimate of the volatile organic compound (**VOC**) flow for the Waste Isolation Pilot Plant (**WIPP**).

A2.0 Air Flow Model

The waste-emplacement capacity of a panel includes the seven rooms and the panel-access drifts from Rooms 1 to 7. Field data from geotechnical engineering measurements was used to determine closure rates for 35 years as presented in DOE (1996, Appendix B). Appendix B provides review and analysis of existing information with the conclusion that the underground ventilation effects of the adjacent exhaust drift are significant for **VOC** transport.

Consider a simple resistance model from Figure A-1. The rooms of the waste emplacement panel are interconnected with air gaps along the sides and the tops of the waste stack. Assuming air flow through a resistance network, Bear (1972, p. 712) and Chapman (1974, pp. 171 -174) provides a heat flow network resistance model for heat transfer that is analogous to an air flow model for VOCs transport. Air flow is governed by Darcy's Law under quasi steady state conditions:

$$Q = -K \cdot i \cdot A$$

Equation A-1

Where

Q Flow rate (ft^3/s [m^3/s]),

i Air flow gradient,

A Flow Area (ft^2 [m^2]), and

K Air conductivity (ft/s [m/s])

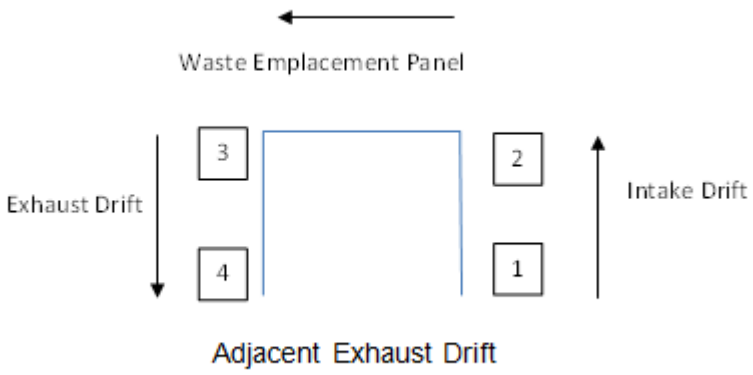

Figure A-1 Network for WPC Analysis

The effective air conductivity (K) can be further expressed in terms of the effective intrinsic permeability of the panel closure system and the fluid properties of air as (Freeze and Cherry, 1979, p. 27):

$$K_s = \frac{k_s \cdot \rho \cdot g}{\mu}$$

Equation A-2

where

K_s Effective air conductivity of panel closure system (ft/s [m/s]),

k_s Effective intrinsic permeability of panel closure system (ft^2 [m^2]),

ρ Air mass density (lb/ft^3 [kg/m^3]),

g Acceleration due to gravity (ft/s^2 [m/s^2]), and

μ Absolute air viscosity (lb/(ft s) [kg/(m·s)]).

A3.0 Effective Intrinsic Permeability of a Parallel System

Air conductance is defined as the product of the air conductivity and cross sectional area divided by the flow path length. The effective flow conductance for a parallel system consisting of n flow components can be obtained in terms of the conductances of its flow components as follows (Freeze and Cherry, 1979):

$$C_t = \sum_{i=1}^{n} C_i$$

Equation A-3

where

C_t Total flow conductance of the system, and

C_i Flow conductance of the ith component.

Based on the definition of flow conductance, this can be rewritten as:

$$K_t \frac{A_t}{L} = \sum_{i=1}^{n} K_i \frac{A_i}{L}$$

Equation A-4

or

$$K_t = \frac{\sum_{i=1}^{n} K_i A_i}{A_t}$$

Equation A-5

where

K_t Effective conductivity of the system (ft/s [m/s]),

A_i Cross-sectional area of the ith component (ft^2 [m^2]),

A_t Total cross-sectional area of the system ($\sum_{i=1}^{n} A_i$)(ft^2 [m^2]), and

L Length of flow path (ft [m]).

A4.0 Effective Intrinsic Permeability of a Series System

The effective flow conductance for a series system consisting of n flow components can be obtained in terms of the conductances of its flow components as follows (Freeze and Cherry, 1979):

$$\frac{1}{C_t} = \sum_{i=1}^{n} \frac{1}{C_i}$$

Equation A-6

where

C_t Total flow conductance of the system (ft^2/s) [m^2/s]), and

C_i Flow conductance of the ith component (ft^2/s) [m^2/s]).

Based on the definition of flow conductance (Equation A-3), Equation A-6 can be rewritten as follows:

$$\frac{L_t}{K_t A} = \sum_{i=1}^{n} \frac{L_i}{K_i A}$$

Equation A-7

or

$$K_t = \frac{L_t}{\sum_{i=1}^{n} \frac{L_i}{K_i}}$$

Equation A-8

where

K_t Effective conductivity of the system (ft/s [m/s])

L_i Length of flow path for i^{th} component (ft [m])

L_t Total length of flow path ($\sum_{i=1}^{n} L_i$) (ft [m]), and

A Cross-sectional area of the flow path (ft^2 [m^2])

Now write expressions for the flow rate $Q_{12}(t)$, and $Q_{34}(t)$. Assume the resistance to flow in branch 23 of Figure A-1 is small since there might exist an air gap at the top and on the sides of the waste stack. However, there are source terms for gas generation, and panel creep closure. The flow rates are written as functions of time to account for consolidation of the emplaced salt. Express the total head in terms of water gage:

$$Q_{12}(t) = -\left[\sum_{i=1}^{4}\left(\frac{K_i \cdot A_i}{L}\right) + \frac{\rho_a \cdot g}{\mu} \cdot \frac{k_{ID}(t) \cdot A_{ID}}{L}\right] \cdot \left(h_1 \cdot \frac{\rho_w}{\rho_a} - h_2 \cdot \frac{\rho_w}{\rho_a}\right)$$

Equation A-9

$$Q_{34}(t) = -\left[\sum_{i=1}^{4}\left(\frac{K_i \cdot A'_i}{L}\right) + \frac{\rho_a \cdot g}{\mu} \cdot \frac{k_{ED}(t) \cdot A_{ED}}{L}\right] \cdot \left(h_3 \cdot \frac{\rho_w}{\rho_a} - h_4 \cdot \frac{\rho_w}{\rho_a}\right)$$

Equation A-10

Where

$Q_{12}(t)$ Air flow rate through the intake drift (ft^3 /s [m^3/s]) as a function of t,

$Q_{34}(t)$ Air flow rate through the exhaust drift (ft^3/s [m^3/s]) as a function of t,

K_i Air conductivity of the ith component of the DRZ (ft/s [m/s]),

$k_{ID}(t)$ Average intrinsic permeability (ft^2 [m^2])for the run-of-mine (ROM) salt in the intake drift as a function of t (s),

$k_{ED}(t)$ Average intrinsic permeability (ft^2 [m^2]) for the three layers of compacted salt in the exhaust drift as a function of t,

A_{ID} Area of the intake drift (ft^2 [m^2]),

A_{ED} Area of the exhaust drift (ft^2 [m^2]),

A_i Area of the ith component of the DRZ for the intake drift (ft^2 [m^2]),

A'_i Area of the ith component of the DRZ for the exhaust drift (ft^2 [m^2]),

L Length of the compacted salt (ft [m]),

ρ_a Mass density of air (lb/ft^3 [kg/m^3]),

ρ_w Mass density of water(lb/ft^3 [kg/m^3]),

μ Absolute viscosity (lb/(ft s) [kg/(m s)]),

g Acceleration due gravity (ft/s^2 [m/s^2]),

h_1 Water gage at point 1(ft [m]),

h_2 Water gage at point 2(ft [m]),

h_3 Water gage at point 3(ft [m]),

h_4 Water gage at point 4(ft [m]), and

t Time(s)

Noting that h_3 equals h_2 based upon the low air flow resistance in Branch 23, and equating the air flow rates:

$$-\left[\sum_{i=1}^{4}\left(\frac{K_i \cdot A_i}{L}\right)+\frac{\rho_a \cdot g}{\mu}\cdot\frac{k_{ID}(t)\cdot A_{ID}}{L}\right]\cdot\left(h_1\cdot\frac{\rho_w}{\rho_a}-h_2\cdot\frac{\rho_w}{\rho_a}\right)=-\left[\sum_{i=1}^{4}\left(\frac{K_i \cdot A'_i}{L}\right)+\frac{\rho_a \cdot g}{\mu}\cdot\frac{k_{ED}(t)\cdot A_{ED}}{L}\right]\cdot\left(h_2\cdot\frac{\rho_w}{\rho_a}-h_4\cdot\frac{\rho_w}{\rho_a}\right)$$

Equation A-11

Define time dependent functions for the conductances of the air intake and air exhaust panels:

$$A(t) = \sum_{i=1}^{4} \left(\frac{K_i \cdot A_i}{L} \right) + \frac{\rho_a \cdot g}{\mu} \cdot \frac{k_{ID}(t) \cdot A_{ID}}{L}$$

Equation A-12

$$B(t) = \sum_{i=1}^{4} \left(\frac{K_i \cdot A'_i}{L} \right) + \frac{\rho_a \cdot g}{\mu} \cdot \frac{k_{ED}(t) \cdot A_{ED}}{L}$$

Equation A-13

$$A(t) \cdot h_2 \cdot \frac{\rho_w}{\rho_a} - A(t) \cdot \left(h_1 \cdot \frac{\rho_w}{\rho_a} \right) = -\left(B(t) \cdot h_2 \cdot \frac{\rho_w}{\rho_a} \right) + B(t) \cdot h_4 \cdot \frac{\rho_w}{\rho_a}$$

Equation A-14

Solving for the potential at node h_2 and noting that potential is a function of time:

$$h_2(t) = \frac{h_1 \cdot A(t) + h_4 \cdot B(t)}{A(t) + B(t)}$$

Equation A-15

The function for $h_2(t)$ is then substituted into the relationships for $Q_{12}(t)$, and $Q_{34}(t)$ in Equations A-9 and A-10. The function $Q_{34}(t)$ is then used to produce the relationship of air flow through the WPC as discussed subsequently.

A5.0 Flow Through Ventilation Bulkheads and an Air Gap

The analysis presented above applies to panel closures in which the air gap has been closed. Consider an air gap forms at the top of the ROM salt backfill. For laminar flow in a narrow slit, the flow rate is given by (Bird et al., 1960, p. 62):

$$Q = \frac{2}{3} \cdot \frac{(P_U - P_L) \cdot B^3 \cdot W}{\mu \cdot L}$$

Equation A-16

Where

Q Flow rate (ft^3 /s [m^3/s]),

P_U Upstream pressure (psi [Pa]) ,

P_L Downstream pressure (psi [Pa]),

B One half width of the aperture (ft [m]),

L Length over which the pressure drop takes place (ft [m]),

μ Absolute viscosity (lb/(ft s) [kg/(m s)]), and

W Flow width (ft [m]).

An equivalent conductivity can be derived by considering Darcy's Law:

$$Q = K \cdot i \cdot A$$

Equation A-17

Where

K Air conductivity (ft/s [m/s],

i Air gradient, and

A Flow Area (ft^2 [m^2])

Substituting in Equation A-16 into Equation. A-17:

$$Q = \frac{1}{3} \cdot \frac{B^2}{\mu} \cdot \gamma \cdot \frac{(H_U - H_L)}{L} \cdot W \cdot 2B$$

Equation A-18

In the above relationship, the pressure equals the head times the weight density (γ). Substituting in the mass density:

$$Q = \frac{1}{3} \cdot \frac{B^2}{\mu} \cdot \rho \cdot g \cdot \frac{(H_U - H_L)}{L} \cdot W \cdot 2B$$

Equation A-19

The expression for the air conductivity becomes:

$$K = \frac{1}{3} \cdot B^2 \cdot \frac{\rho \cdot g}{\mu}$$

Equation A-20

$$k = \frac{1}{3} \cdot B^2$$

Equation A-21

Expressing the intrinsic permeability in terms of the full aperture width (B=b/2):

$$k = \frac{b^2}{12}$$

Equation A-22

The flow through a single bulkhead in the ventilation circuit shown in Figure A-1 is expressed as:

$$h_{12} = R_{12} \cdot {Q_{12}}^2$$

Equation A-23

Where

h_{12} Head loss through a single bulkhead (milli inches water gage),

R_{12} Bulkhead resistance (Practical Units), and

Q_{12} Flow rate through the bulkhead (kcfm).

For this ventilation analysis, the flow path 12 and 24 represents flow through bulkheads while the flow path 23 represents the flow through air gap above the crushed salt.

Solve for the flow rate Q_{12} in terms of h_{12}:

$$Q_{12} = \sqrt{\frac{h_{12}}{R_{12}}}$$

Equation A-24

Equating the flow rate to the flow rate through the air gap:

$$Q_{12} = Q_{23}$$

Equation A-25

$$\sqrt{\frac{h_{12}}{R_{12}}} = \frac{K_s \cdot A_{Gap}}{L_{Path}} \cdot H_{23}$$

Equation A-26

Invoking symmetry ($h_{12} = h_{24}$) and that the total head loss is given by:

$$h_{Total} = 2 \cdot h_{12} + h_{23}$$

Equation A-27

Solving for h_{23}:

$$H_{23} = H_{Total} - 2H_{12}$$

Equation A-28

Substituting this equation into Equation A-26 and expressing the head loss in terms of water gage:

$$\sqrt{\frac{h_{12}}{R_{12}}} = \frac{K_s \cdot A_{Gap}}{L_{Path}} \cdot (h_{Total} - 2 \cdot h_{12} \cdot) \cdot \frac{\gamma_h}{\gamma_a}$$

Equation A-28

This equation is solved graphically for the h_{12}.

A5.0 Current Closure Plan and Projected Panel Closure Schedule

The current Resource Conservation and Recovery Act (**RCRA**) Closure Plan for the WIPP includes monitoring for compliance with individual VOCs limits for the WIPP repository. The repository VOCs concentration limits are listed in Table A-1 and are applied at the E-300 Point of Compliance. The E-300 point of compliance is located at the intersection of the E-300 exhaust drift, and S-1300 cross drift as illustrated in Figure N-1 of the Permit. Panel closures, in conjunction with operational practices in the active panel are used to meet limits on these concentrations of concern. The following discussion presents the schedule for panel closures.

The WIPP Permit currently includes the original design for Option D. Following completion of the design report for the WPC, an updated RCRA Permit submittal is planned by December 2012. The updated WIPP Permit would be evaluated for a period of one year with approval of the new WIPP permit modification by December 2013. At that time, the panel closures would be implemented in Panels 1 through 6 by January 31, 2016. Panel 7 would be closed six months after this time by July 2016. Table A-1 shows the estimated schedule for future panel closures.

Table A-1 Estimated Schedule for Future Panel Closure Activities

Closure Activity	Date
Submit WPC Permit Modification	12/31/2011
Complete Ventilation Barriers to Panel 6	3/16/2013
Receive WPC Permit Approval	12/30/2013
Close Panel 6	6/1/2014
Close Panel 4	7/1/2014
Close Panel 3	1/1/2015
Close Panel 2	1/1/2015
Close Panel 1	7/1/2015
Close Panel 5	1/31/2016
Close Panel 7	2/1/2018
Close Panel 8	10/1/2021
Close Panel 9	6/1/2025
Close Panel 10	2/1/2029

Source: Washington, TRU (2011)

A5.0 References

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Washington TRU Solutions Solutions, 2011, Revised Panel Closure Design Criteria, Washington TRU Solutions, Carlsbad, NM.

APPENDIX B
Analysis and Review of Existing Information

B1 Existing Panel Operations

Since March 1999, contact-handled TRU (**CH TRU**) waste has been emplaced in the WIPP underground repository starting with Panel 1, and continuing to the present with active operations in Panel 6. Block walls have been installed for Panels 1, 2, and 5. Currently the project has installed steel bulkheads for Panels 3 and 4. VOCs, hydrogen, and methane are monitored at various locations within these panels.

The current active CH TRU waste panel is Panel 6 with waste emplacement activities commencing in July 2011 upon retreat according to the waste emplacement plan. Completion of waste emplacement activities in the active Panel 6 is anticipated to occur during 2013.

B2 Ventilation Information

Consistent with Permit requirements, the WIPP facility operating staff maintains a minimum repository ventilation exhaust rate of 260,000 standard ft^3/min (7,360 m^3/min) and a minimum ventilation rate of 35,000 standard ft^3/min (990 m^3/min) in the active room when workers are present. Ventilation barricades are used in active underground hazardous waste disposal units (**HWDUs**) to prevent the flow of mine ventilation air through full disposal rooms, as specified in Attachment A2 of the Permit.

The WIPP operations provide ventilation in four underground circuits. These include the Waste Disposal Circuit; the Construction Ventilation Circuit; the Waste Shaft Station Circuit, and the North Area Circuit. Ventilation analysis has been performed for the WIPP repository during various stages of operation and underground repository development. Appendix B presents pressure drops in the exhaust drifts adjacent to closed or inactive panels for the normal operating and full flow operating modes. Normal Mode is comprised of operating two of the three 700 fans at an exhaust ventilation rate of 460 kacfm[1] (13,030 m^3/min). Regulators are configured to obtain flows in the four underground ventilation circuits as described as follows:

[1] kacfm = 1000 actual cubic feet per minute

Circuit	Ventilation Rate (kacfm)
Waste Disposal Ventilation Circuit	170
Construction Ventilation Circuit	140
Waste Shaft Station Circuit	70
Northern Area Circuit	80

Full Flow is comprised of two of three main 700 area fans running (approximately 460 kacfm (13,030 m^3/min) of exhaust) with regulators opened to "reasonable" settings based on underground ventilation experience. The regulators are not adjusted to achieve particular flows in the different circuits. Measurements are taken to determine resistance throughout the underground and to quantify the air flow distribution with as little regulation as possible. This initial data gathering guides the regulation of air to achieve the desired distribution when testing and balancing under Normal Mode operations. Full Flow and Normal Mode provide representative flow in the active and inactive waste emplacement areas.

The WIPP project performed ventilation analysis for the repository during various stages of operation and underground development. Table B-1 presents pressure drop measurements in the exhaust drifts adjacent to closed or inactive panels for the normal operating mode. Table B-2 presents pressure drop measurements for the full flow operating mode. For the normal operating mode, the average value for the pressure drop was 163 milli inches (4.14 mm) of water gage. The range of pressure drops was from 12 to 350 milli inches (0.31 to 8.90 mm) water gage. For the full operating mode, the average value was 165 milli inches (4.19 mm) of water gage with a range of values from 0 to 394 milli inches (0 to 10 mm) of water gage.

Table B-1 Ventilation Analysis for the Normal Operating Mode

Date	Mar-08		Aug-09	
Panel	Panel Status	Pressure Drop (milli inches Water Gage)	Panel Status	Pressure Drop (milli inches Water Gage)
1	Closed	356	Closed	133
2	Closed	118	Closed	74
3	Closed	12	Closed	96
4	Active	NA	Inactive	350
5	Under Construction	NA	Active	NA
6	NA	NA	Under Construction	NA
7	NA	NA	NA	NA
8	NA	NA	NA	NA
9	NA	NA	NA	NA
10	NA	NA	NA	NA

Average	163	(milli inches Water Gage)
Minimum Value	12	(milli inches Water Gage)
Maximum Value	350	(milli inches Water Gage)

Source: Mine Ventilation Services (2008, 2009)

Table B-2 Ventilation Analysis for the Full Flow Operating Mode

Date	Mar-04		Aug-05		Oct-06		Aug-09		Oct-10	
Panel	Panel Status	Pressure Drop (milli inches Water Gage)	Panel Status	Pressure Drop (milli inches Water Gage)	Panel Status	Pressure Drop (milli inches Water Gage)	Panel Status	Pressure Drop (milli inches Water Gage)	Panel Status	Pressure Drop (milli inches Water Gage)
1	Closed	25	Closed	394	Closed	236	Closed	113	Closed	263
2	Active	NA	Inactive	204	Closed	128	Closed	62	Closed	202
3	Under Construction	NA	Active	NA	Inactive	101	Inactive	78	Inactive	68
4	NA	NA	Under Construction	NA	Active	NA	Inactive	456	Inactive	0
5	NA	NA	NA		Under Construction	NA	Active	NA	Active	NA
6	NA	NA	NA		NA	NA	Under Construction	NA	Active	NA
7	NA	NA	NA		NA	NA	NA	NA	Under Construction	NA
8	NA	NA	NA		NA	NA	NA	NA	NA	NA
9	NA	NA	NA		NA	NA	NA	NA	NA	NA
10	NA	NA	NA		NA	NA	NA	NA	NA	NA

Average Value	166	(milli inches Water Gage)
Minimum Value	0	(milli inches Water Gage)
Maximum Value	394	(milli inches Water Gage)

Source: Mine Ventilation Services (2004), 2005, 2006, 2009, 2010)

During future WIPP repository operations and development, overall WIPP repository air flow resistance could increase. For example if Panels 9 and 10 are developed to the south of Panels 4 and 5, air exhaust lengths might increase. For purposes of analysis, it is assumed that the pressure drop for air flow between the panel intake drift and the panel exhaust drift is 170 milli inches of water gage.

B3 References

Mine Ventilation Services, 2004, "Testing and Balancing of the Underground Ventilation System at the WIPP Facility, Mine Ventilation Services, Inc., Clovis California.

Mine Ventilation Services, 2005, "Testing and Balancing of the Underground Ventilation System at the WIPP Facility, Mine Ventilation Services, Inc., Clovis California.

Mine Ventilation Services, 2006, "Testing and Balancing of the Underground Ventilation System at the WIPP Facility, Mine Ventilation Services, Inc., Clovis California.

Mine Ventilation Services, 2008, "Testing and Balancing of the Underground Ventilation System at the WIPP Facility, Mine Ventilation Services, Inc., Clovis California.

Mine Ventilation Services, 2009, "Testing and Balancing of the Underground Ventilation System at the WIPP Facility, Mine Ventilation Services, Inc., Clovis California

Mine Ventilation Services, 2010, "Testing and Balancing of the Underground Ventilation System at the WIPP Facility, Mine Ventilation Services, Inc., Clovis California

APPENDIX C

TECHNICAL SPECIFICATIONS

SECTION 01010

SUMMARY OF WORK

PART 1 - GENERAL

1.1 Scope

This section includes:

- Scope of Work
- Definitions and Abbreviations
- List of Drawings
- Work by Others
- Contractor's Use of Site
- Contractor's Use of Facilities
- Work Sequence
- Work Plan
- Health and Safety Plan (HASP)
- Contractor Quality Control Plan (CQCP)
- Submittals

1.2 Scope of Work

The Contractor shall furnish all labor, materials, equipment and tools to construct two (2) WIPP panel closure systems for Panels 1 through 10. Each WIPP Panel closure system consists of two steel bulkheads and ROM salt, one of each to be installed in the air-intake drift and the air-exhaust drift of a waste disposal panel, as shown on the Drawings and described in these Specifications. Unless otherwise agreed by Nuclear Waste Partnership, the Contractor shall use Nuclear Waste Partnership supplied equipment underground. Such use shall be coordinated with Nuclear Waste Partnership and may include the use of Nuclear Waste Partnership qualified operators.

The scope of work shall include but not necessarily be limited to the following units of work:

- Develop work plan, health and safety plan (HASP) and contractors quality control plan (CQCP) and submit it for approval
- Prepare and submit all plans requiring approval
- Mobilize to site

- Coordinate construction with WIPP operations
- Perform the following operations for the air-intake entry and the air-exhaust entries that do not contain block walls:
    1. Construct the inner steel bulkhead
    2. Prepare the surfaces for the ROM salt.
    3. Construct the inner steel bulkhead
    4. Place ROM salt material in multiple layers
    5. Construct the outer steel bulkhead
    6. Clean up construction areas in underground and above ground
    7. Submit all required record documents
    8. Demobilize from site

Perform the following operations for the air-intake entry and the air exhaust entries that do contain existing block walls

1. Prepare the surfaces for the ROM salt
2. Place ROM salt material in multiple layers
3. Construct the outer steel bulkhead
4. Clean up construction areas in underground and above ground
5. Submit all required record documents
6. Demobilize from site

1.3 Definitions and Abbreviations

Definitions

Creep—Viscoplastic deformation of salt under deviatoric stress.

Block Wall— Existing mortared concrete brick wall adjacent to the panel waste disposal area as shown in the drawings.

Methane explosion—A postulated deflagration caused by methane gas at an explosive level.

Partial closure—The process of rendering a part of the hazardous waste management unit in the underground repository inactive and closed according to approved facility closure plans.

Run of Mine Salt (ROM) — A salt obtained from mining operations emplaced in an uncompacted state.

Volatile Organic Compound (VOC) —Any VOC with Hazardous Waste Facility Permit emission limits.

Nuclear Waste Partnership—Nuclear Waste Partnership, LLC as the construction management authority.

Abbreviations/Acronyms

ACI	American Concrete Institute
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
CFR	Code of Federal Regulations
CQCP	Contractor Quality Control Plan
DOE	U.S. Department of Energy
DWG	Drawing
EPA	U.S. Environmental Protection Agency
HASP	Health And Safety Plan
JHA	Job Hazard Analysis
LHD	Load Haul Dump
LLC	Limited Liability Corporation
MSHA	U.S. Mine Safety and Health Administration
RCRA	Resource Conservation and Recovery Act
USACE	U.S. Army Corps of Engineers
VOC	Volatile Organic Compound
WIPP	Waste Isolation Pilot Plant

1.4 List of Drawings

The following Drawings are made apart of this Specification:

Drawing No.	Title
DWG 262-001	WIPP Panel Closure System Title Sheet
DWG 262-002	WIPP Panel Closure System, Underground Waste Disposal Panel Configurations (3,4,6,7,8)
DWG 262-003	WIPP Panel Closure System, Underground Waste Disposal Panel Configurations (1,2,5)
DWG 262-004	Construction Details

1.5 Work by Others

Survey

All survey work to locate, control, confirm, and complete the work will be performed by Nuclear Waste Partnership. All survey work for record purposes will be performed by Nuclear Waste Partnership. The Contractor shall be responsible for developing the salt backfill to fit the excavation.

Nuclear Waste Partnership may elect to perform certain portions, or all, of the work. The work performed by the Nuclear Waste Partnership will be defined prior to the contract. Unless otherwise agreed by Nuclear Waste Partnership, the Contractor shall use underground equipment furnished by Nuclear Waste Partnership for construction of the steel bulkheads and placement of ROM salt. Underground mining personnel who are qualified for the operation of such underground construction equipment may be made available to the Contractor. The use of Nuclear Waste Partnership equipment shall be coordinated with Nuclear Waste Partnership.

1.6 Contractor's Use of Site

Site Conditions

The WIPP site is located near Carlsbad in southeastern New Mexico, as shown on the Drawings. The underground arrangements and location of the WIPP waste disposal panels are shown on the Drawings. The work is to construct steel bulkheads and place ROM salt in the air-intake and air-exhaust drifts of one of the panels upon completion of the disposal phase of that panel. The

waste disposal panels are located approximately 2,150 ft. (655 m) below the ground surface. The Contractor shall visit the site and become familiar with the site and site conditions prior to preparing his bid proposal.

Contractor's Use of Site

Areas at the ground surface will be designated for the Contractor's use in assembling and storing his equipment and materials. The Contractor shall utilize only those areas so designated.

Limited space within the underground area will be designated for the Contractor's use for storage of material and setup of equipment.

Coordination of Contractor's Work

The Contractor is advised that on-going waste emplacement and excavation operations will be conducted throughout the period of construction of the panel closure system. These operations have priority over the Contractor's work. The Contractor shall coordinate his construction operations with that of the waste emplacement and mining operations. All coordination shall be through Nuclear Waste Partnership.

1.7 Contractor's Use of Facilities

Existing facilities at the site available for use by the Contractor are:

- Waste shaft conveyance
- Salt skip hoist
- 460 volt AC**,** 3 phase power
- Water (underground, at waste shaft only) (above ground, at location designated by Nuclear Waste Partnership)

Additional information on mobilization and demobilization to these facilities is presented in Section 02010.

1.8 Work Sequence

Work Sequence shall be as shown on the Drawings and as directed by Nuclear Waste Partnership.

1.9 Work Plans

The Contractor shall prepare Work Plans fully describing the proposed fabrication, installation and construction for each WIPP Panel Closure System. The work plan shall define all proposed

materials, equipment and construction methods. The Work Plan shall state all supporting processes, procedures, materials safety data sheets, and regulations by reference. The work plans shall address precautions related to the Job Hazards Check List. The Work Plan shall address limitations such as hold and witness points. The Work Plans shall address all prerequisites for work. Nuclear Waste Partnership shall approve the Work Plan and no work shall be performed prior to approval of the Work Plan.

1.10 Health and Safety Plan (HASP)

The Contractor shall obtain, review, and agree to applicable portions of the existing WIPP Safety Manual, WP 12-1. The Contractor shall prepare a project-specific HASP taking into account all applicable sections of the WIPP Safety Manual. All personnel shall be qualified to work underground. All personnel operating heavy construction equipment shall be qualified to operate such equipment. The Contractor shall also perform a Job Hazard Analysis (JHA) in accordance with WP 12-111. Nuclear Waste Partnership shall approve the HASP and JHA and no work shall be performed prior to approval of the HASP and JHA.

1.11 Contractor Quality Control Plan (CQCP)

The Contractor shall prepare a CQCP identifying all personnel and procedures necessary to produce an end product, which complies with the contract requirements. The CQCP shall comply with all Nuclear Waste Partnership requirements, including operator training and qualification; and Section 01400, Contractor Quality Control, of this Specification. Nuclear Waste Partnership shall approve the CQCP and no work shall be performed prior to approval of the CQCP.

1.12 Submittals

Submittals shall be in accordance with Nuclear Waste Partnership Submittal Procedures and as required by the individual Specifications.

PART 2 - PRODUCTS

Not used

PART 3 - EXECUTION

Not used

End of section

SECTION 01090

REFERENCE STANDARDS

PART 1 - GENERAL

1.1 Scope

This section includes:

- Provision of Reference Standards at Site
- Acronyms used in Contract Documents for Reference Standards

1.2 Quality Assurance

For products or workmanship specified by association, trade, or Federal Standards, the Contractor shall comply with requirements of the standard, except when more rigid requirements are specified or are required by applicable codes.

Conform to reference by date of issue current on the date of the owner-contractor agreement.

The Contractor shall obtain, at his own expense; a copy of the standards referenced in the individual Specification sections and shall maintain that copy at the jobsite until completion and acceptance of the work.

Should specified Reference Standards conflict with the contract documents, the Contractor shall request clarification from Nuclear Waste Partnership before proceeding.

1.3 Schedule of References

Various publications referenced in other sections of the Specifications establish requirements for the work. These references are identified by document number and title. The addresses of the organizations responsible for these publications are listed below.

ANSI	American National Standards Institute 25 West 43rd St. New York NY 10036 Ph: 212-642-4900 Fax: 212-398-0023
ASTM	ASTM International 100 Barr Harbor Drive P.O. Box C700, West Conshohocken, Pennsylvania 19428-2959 Ph: 610-832-9585 Fax: 610-832-9555
CFR	Code of Federal Regulations Government Printing Office 732 N. Capital Street, NW Washington D. C. Ph: 202-512-1530 Fax: 202 512-1262
EPA	Environmental Protection Agency 1445 Ross Avenue Suite 1200 Dallas Texas 75202-2733 Ph: 214-665-2200 Fax: 800-887-6063
FTM-STD	Federal Test Method Standards Standardization Documents Order Desk Bldg. 4D 700 Robbins Ave. Philadelphia, PA 19111-5094 Ph: 215-697-2179 Fax**:** 215-697-2978

NIST National Institute of Standards and Technology
100 Bureau Drive, Stop 1000
Gaithersburg, MD 20899-1000
Ph: 301-975-6478
Fax: 301-975-8295

NTIS National Technical Information Service
U.S. Department of Commerce
5301 Shawnee Rd
Alexandria, Virginia 22312
Ph: 703- 605-6000
Fax: 703-321-8547

End of section

SECTION 01400

CONTRACTOR QUALITY CONTROL

PART 1 - GENERAL

1.1 Scope

This section includes:

- Contractor Quality Control Plan (CQCP)
- Reference Standards
- Quality Assurance
- Tolerances
- Testing Services
- Inspection Services
- Submittals

1.2 Related Sections

- 01090 - Reference Standards
- 01600 - Material and Equipment
- 02222 - Excavation
- 04100 – Run-of-Mine Salt

1.3 Contractor Quality Control Plan (CQCP)

The Contractor shall prepare a Contractor Quality Control Plan (CQCP describing the methods to be used to verify the performance of the engineered components of the Panel Closure System. The quality control plan for the run-of-mine (ROM) salt shall detail the methods the Contractor proposes to meet the minimum requirements, and the standard quality control test methods to be used to verify that minimum requirements have been complied with. All equipment methods employed shall be traceable to standard quality control tests as approved in the CQCP. No work shall be performed prior to Nuclear Waste Partnership approval of the CQCP.

1.4 Reference Standards

Refer to individual Specification sections for standards referenced therein, and to Section 01090, Reference Standards, for general listing. Additional standards will be identified in the CQCP.

Standards referenced in this section are as follows:

ASTM E 329-01b	Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection
ASTM E 543-02	Standard Practice for Agencies Performing Nondestructive Testing

1.5 Quality Assurance

The Contractor shall:

- Monitor suppliers, manufacturers, products, services, site conditions, and workmanship to produce work of specified quality
- Comply with specified standards as minimum quality for the work except where more stringent tolerances, codes, or specified requirements indicate higher standards or more precise workmanship
- Perform work with qualified persons to produce required and specified quality

1.6 Tolerances

The Contractor shall:

- Monitor excavation, fabrication, and tolerances in order to produce acceptable work. The Contractor shall not permit tolerances to accumulate.

1.7 Testing Services

Unless otherwise agreed by Nuclear Waste Partnership, the Contractor shall employ an independent firm qualified to perform the testing services and other services specified in the individual Specification sections, and as may otherwise be required by Nuclear Waste Partnership. Testing and source quality control may occur on or off the project site.

The testing laboratory shall comply with applicable sections of the Reference Standards and shall be authorized to operate in the State of New Mexico.

Testing equipment shall be calibrated at reasonable intervals traceable to either the National Institute of Standards and Technology or accepted values of natural physical constants.

1.8 Inspection Services

The Contractor may employ an independent firm to perform inspection services as a supplement to the Contractor's quality control as specified in the individual Specification sections, and as may be required by Nuclear Waste Partnership. Inspection may occur on or off the project site.

The inspection firm shall comply with applicable sections of the Reference Standards.

1.9 Submittals

The Contractor shall submit a CQCP as described herein.

Prior to start of work, the Contractor shall submit for approval, the testing laboratory name, address, telephone number and name of responsible officer of the firm as well as a copy of the testing laboratory compliance with the reference ASTM standards and a copy of report of laboratory facilities inspection made by Materials Reference Laboratory of National Institute of Standards and Technology with memorandum of remedies of any deficiencies reported by the inspection.

The Contractor shall submit the names and qualifications of personnel proposed to perform the required inspections, along with their individual qualifications and certifications. Once approved by Nuclear Waste Partnership these personnel shall be available as may be required to promptly and efficiently complete the work.

PART 2 - PRODUCTS

Not used

PART 3 - EXECUTION

3.1 General

The Contractor is responsible for quality control and shall establish and maintain an effective quality control system. The quality control system shall consist of plans, procedures, and

organization necessary to produce an end product which complies with the contract requirements. The system shall cover all construction operations, both on site and off site, and shall be keyed to the proposed construction sequence. The project superintendent will be held responsible for the quality of work on the job. The project superintendent in this context is the individual with the responsibility for the overall management of the project including quality and production.

3.2 Contractor Quality Control Plan

3.2.1 General

The Contractor shall supply, not later than 30 days after receipt of notice to proceed, the Contractor Quality Control Plan (CQCP) which implements the requirements of the Contract. The CQCP shall identify personnel, procedures, control, instructions, tests, records, and forms to be used. Construction shall not begin until the CQCP is approved by Nuclear Waste Partnership.

3.2.2 Content of the CQCP

The CQCP shall cover all construction operations, both on site and off site, including work by subcontractors, fabricators, suppliers, and purchasing agents and shall include, as a minimum, the following items:

- A description of the quality control organization, including a chart showing lines of authority and acknowledgment that the Contractor Quality Control (CQC) staff shall implement the control system for all aspects of the work specified.
- The name, qualifications (in resume format), duties, responsibilities, and authorities of each person assigned a CQC function.
- A description of CQCP responsibilities and a delegation of authority to adequately perform the functions described in the CQCP, including authority to stop work.
- Procedures for scheduling, reviewing, certifying, and managing submittals, including those of subcontractors, off site fabricators, suppliers, and purchasing agents. These procedures shall be in accordance with Nuclear Waste Partnership Submittal Procedures.
- Control, verification, and acceptance testing procedures as may be necessary to ensure that the work is completed to the requirements of the Drawings and Specifications.
- Procedures for tracking deficiencies from identification, through acceptable corrective action, to verification that identified deficiencies have been corrected.
- Reporting procedures, including proposed reporting formulas.

3.2.3 Acceptance of Plan

Acceptance of the Contractor's plan is conditional. Nuclear Waste Partnership reserves the right to require the Contractor to make changes in his CQCP and operations, including removal of personnel, if necessary, to obtain the quality specified.

3.2.4 Notification of Changes

After acceptance of the CQCP, the Contractor shall notify Nuclear Waste Partnership in writing of any proposed change. Proposed changes are subject to acceptance by Nuclear Waste Partnership.

3.3. Tests

3.3.1 Testing Procedure

The Contractor shall perform specified or required tests to verify that control measures are adequate to complete the work to contract requirements. Upon request, the Contractor shall furnish, at his own expense, duplicate samples of test specimens for testing by Nuclear Waste Partnership. The Contractor shall perform, as necessary, the following activities and permanently record the results:

- Verify that testing procedures comply with contract requirements.
- Verify that facilities and testing equipment are available and comply with testing standards.
- Check test instrument calibration data against certified standards.
- Verify that recording forms and test identification control number system, including all of the test documentation requirements, have been prepared.
- Record the results of all tests taken, both passing and failing. Specification paragraph reference, location where tests were taken, and the sequential control number identifying the test will be given. If approved by Nuclear Waste Partnership, actual test reports may be submitted later with a reference to the test number and date taken. An information copy of tests performed by an offsite or commercial test facility will be provided directly to Nuclear Waste Partnership.
- The contractor may elect to develop an equipment specification with construction parameters based upon test results of a test section of compacted salt. The equipment specification based upon construction parameters shall be traceable to standard test results identified in the CQCP. Specification paragraph reference, location where construction parameters were taken, and the sequential control number identifying the construction

parameters will be given. If approved by Nuclear Waste Partnership, actual construction parameter reports may be submitted later with a reference to the recording of construction parameters, location, time and date taken.

3.4 Testing Laboratory

The testing laboratory shall provide qualified personnel to perform specified sampling and testing of products in accordance with specified standards, and the requirements of Contract Documents.

Reports indicating results of tests, and compliance or noncompliance with the contract documents will be submitted in accordance with Nuclear Waste Partnership submittal procedures. Testing by an independent firm does not relieve the Contractor of the responsibility to perform the work to the contract requirements.

3.5 Inspection Services

The inspection firm shall provide qualified personnel to perform specified inspection of products in accordance with specified standards.

Reports indicating results of the inspection and compliance or noncompliance with the contract documents will be submitted in accordance with Nuclear Waste Partnership submittal procedures.

Inspection by the independent firm does not relieve the Contractor of the responsibility to perform the work to the contract requirements.

3.6 Completion Inspection

3.6.1 Pre-Final Inspection

At appropriate times and at the completion of all work, the Contractor shall conduct an inspection of the work and develop a punch list of items which do not conform to the Drawings and Specifications. The Contractor shall then notify Nuclear Waste Partnership that the work is ready for inspection. Nuclear Waste Partnership will perform this inspection to verify that the work is satisfactory and appropriately complete. A final punch list will be developed as a result of this inspection. The Contractor shall ensure that all items on this list are corrected and notify Nuclear Waste Partnership so that a final inspection can be scheduled. Any items noted on the final inspection shall be corrected in a timely manner. These inspections and any deficiency

corrections required by this paragraph will be accomplished within the time slated for completion of the entire work**.**

3.6.2 Final Acceptance Inspection

The final acceptance inspection will be formally scheduled by Nuclear Waste Partnership based upon notice from the Contractor. This notice will be given to Nuclear Waste Partnership at least 14 days prior to the final acceptance inspection. The Contractor shall assure that all specific items previously identified as unacceptable, along with all remaining work performed under the contract, will be complete and acceptable by the date scheduled for the final acceptance inspection.

3.7 Documentation

The Contractor shall maintain current records providing factual evidence that required quality control activities and/or tests have been performed. These records shall include the work of subcontractors and suppliers and shall be on an acceptable form approved by Nuclear Waste Partnership.

3.8 Notification of Noncompliance

Nuclear Waste Partnership will notify the Contractor of any noncompliance with the foregoing requirements. The Contractor shall take immediate corrective action after receipt of such notice. Such notice, when delivered to the Contractor at the worksite, shall be deemed sufficient for the purpose of notification. If the Contractor fails or refuses to comply promptly, Nuclear Waste Partnership may issue an order stopping all or part of the work until satisfactory corrective action has been taken. No part of the time lost due to such stop orders shall be made the subject of claim for extension of time or for excess costs or damages by the Contractor.

End of section

SECTION 01600

MATERIAL AND EQUIPMENT

PART 1 - GENERAL

1.1 Scope

This section includes:

- Equipment
- Products
- Transportation and Handling
- Storage and Protection
- Substitutions

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 02010 - Mobilization and Demobilization
- 02222 - Excavation
- 04100 Run of Mine Salt

1.3 Equipment

The Contractor shall specify his proposed equipment in the Work Plan. Power equipment for use underground shall be either electrical or diesel engine driven. All diesel engine equipment shall be certified for use underground at the WIPP site.

1.4 Products

The Contractor shall specify in the Work Plan, or in subsequently required submittals, the proposed products including, but not limited to steel bulkheads and ROM salt. The proposed products shall be supported by laboratory test results as required by the Specifications. All products shall be subject to approval by Nuclear Waste Partnership.

1.5 Transportation and Handling

The Contractor shall:

- Transport and handle products in accordance with manufacturer's instructions.
- Promptly inspect shipments to ensure that products comply with requirements, quantities are correct, and products are undamaged.
- Provide equipment and personnel to handle products by methods to prevent soiling, disfigurement, or damage.

1.6 Storage and Protection

The Contractor shall:

- Store and protect products in accordance with manufacturers' instructions.
- Store with seals and labels intact and legible.
- Store sensitive products in weather tight, climate controlled, enclosures in an environment favorable to product.
- Provide ventilation to prevent condensation and degradation of products.
- Store loose granular materials on solid flat surfaces in a well-drained area and prevent mixing with foreign matter.
- Provide equipment and personnel to store products by methods to prevent soiling, disfigurement, or damage.
- Arrange storage of products to permit access for inspection and periodically inspect to verify products are undamaged and are maintained in acceptable condition.

1.7 Substitutions

1.7.1 Equipment Substitutions

The Contractor may substitute equipment for that proposed in the Work Plan subject to Nuclear Waste Partnership approval.

1.7.2 Product Substitutions

The Contractor may not substitute products after the proposed products have been approved by Nuclear Waste Partnership unless he can demonstrate that the supplier/source of that product no longer exists in which case he shall submit alternate products with lab test results to Nuclear Waste Partnership for approval.

PART 2 – PRODUCTS

Not used

PART 3 - EXECUTION

Not used

End of section

SECTION 02010

MOBILIZATION AND DEMOBILIZATION

PART 1 - GENERAL

1.1 Scope

This section includes:

- Mobilization of Equipment and Facilities to Site
- Contractor Use of Site
- Use of Existing Facilities
- Demobilization of Equipment and Facilities
- Site Cleanup

1.2 Related Sections

- 01010 - Summary of Work
- 01600 - Material and Equipment

PART 2 - PRODUCTS

Not used

PART 3 - EXECUTION

3.1 Mobilization of Equipment and Facilities to Site

Upon authorization to proceed, the Contractor shall mobilize his equipment and facilities to the jobsite. Equipment and facilities shall be as specified and as defined in the Contractor's Work Plan.

Nuclear Waste Partnership will provide utilities at designated locations. The Contractor shall be responsible for all hookups and tie-ins required for his operations.

The Contractor shall be responsible for providing his own office, storage, and sanitary facilities.

Areas will be designated for the Contractor's use in the underground area in the vicinity of the panel closure system installation. These areas are limited.

3.2 Contractor Use of Site

The Contractor shall use only those areas specifically designated for his use by Nuclear Waste Partnership. The Contractor shall limit his on-site travel to the specific routes required for performance of his work, and designated by Nuclear Waste Partnership.

3.3 Use of Existing Facilities

Existing facilities available for use by the Contractor are:

- Waste shaft conveyance
- Salt skip hoist
- 460 Volt AC, 3 phase power
- Water underground at waste shaft only
- Water on surface at location designated by Nuclear Waste Partnership

The Contractor shall arrange for use of the facilities with Nuclear Waste Partnership and coordinate his actions and requirements with ongoing Nuclear Waste Partnership operations.

Use of water in the underground will be restricted. No washout or cleanup will be permitted in the underground except as designated by Nuclear Waste Partnership. Above ground washout or cleanup of equipment will be allowed in the areas designated by Nuclear Waste Partnership.

The Contractor is cautioned to be aware of the physical dimensions of the waste conveyance and the air lock.

The Contractor shall be responsible for any damage incurred by the existing site facilities as a result of his operations. Any damage shall be reported immediately to Nuclear Waste Partnership and repaired at the Contractor's cost.

3.4 Demobilization of Equipment and Facilities

At completion of this work, the Contractor shall demobilize his equipment and facilities from the job site. All Contractor's equipment and materials shall be removed and all disturbed areas restored. Utilities shall be removed to their connection points unless otherwise directed by Nuclear Waste Partnership.

3.5 Site Cleanup

At conclusion of the work, the Contractor shall remove all trash, waste, debris, excess construction materials, and restore the affected areas to their prior condition, to the satisfaction of

Nuclear Waste Partnership. A final inspection will be conducted by Nuclear Waste Partnership and the Contractor before final payment is approved.

End of section

SECTION 02222

EXCAVATION

PART 1 - GENERAL

1.1 Scope

This section includes:

- Excavation for surface preparation and leveling of surrounding areas for compacted salt
- Disposition of excavated materials
- Field measurement and survey

1.2 Related Sections

- 01010 - Summary of Work
- 01600 - Material and Equipment

1.3 Reference Documents

Krieg, R. D., 1984, "Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant," SAND83-1908, Sandia National Laboratories, Albuquerque, New Mexico.

1.4 Field Measurements and Survey

All survey required for performance of the work will be provided by Nuclear Waste Partnership.

PART 2 - PRODUCTS

Not used

PART 3 - EXECUTION

3.1 Excavation for Surface Preparation and Leveling of Surrounding Areas for Salt

The Contractor shall inspect the panel entry excavations for loose material at locations where the panel closure system is emplaced. If loose material is found, the contractor shall excavate and prepare the surface for the panel closure system component.by removing all loose material, and cleaning all rock surfaces. The surface preparation of the floor shall produce a surface suitable for placing the first layer of ROM salt. Excavation may be performed by either mechanical or manual means. Use of explosives is prohibited.

3.2 Disposition of Excavated Materials

The Contractor shall dispose of all excavated materials as directed by Nuclear Waste Partnership.

3.3 Field Measurements and Survey

All survey required for performance of the work will be provided by Nuclear Waste Partnership. The Contractor shall protect all survey control points, benchmarks, etc., from damage by his operations. Nuclear Waste Partnership will verify that the Contractor has excavated to the required lines and grades. No salt shall be emplaced until approved by Nuclear Waste Partnership.

End of section

SECTION 04100

RUN OF MINE SALT

PART 1 - GENERAL

1.1 Scope

This section includes:

- Salt Placement

1.2 Related Sections

- 01010 Summary of Work
- 01400 Contractor Quality Control
- 01600 Material and Equipment

1.3 Submittals for Revision and Approval

The salt emplacement method, dust control plan and other safety related material shall be approved by Nuclear Waste Partnership.

1.4 Quality Assurance

The Contractor shall perform the work in accordance with the CQCP.

PART 2 - PRODUCTS

2.1 Salt Material

The salt is ROM salt and requires no grading or compaction. The salt shall be free of organic material.

PART 3 - EXECUTION

3.1 General

The Contractor shall furnish all labor, material, equipment and tools to handle and place the salt.

The Contractor shall use underground equipment and underground mine personnel as required in Part 1.5 Work by Others in Section 01010 Summary of Work. Nuclear Waste Partnership will

supply ROM salt. The Contractor shall make suitable arrangements for transporting and placing the ROM salt.

3.2 Installation

ROM salt shall be transported to the panel closure area after the construction of the inner steel bulkhead. The ROM salt is not required to achieve a specified density. The salt shall be free of organic material.

Salt may be emplaced in layers to facilitate the construction. The ROM Salt is emplaced in layers with a 2:1 slope near the ends of the WIPP Panel Closure System. The inner and outer salt emplacements are designated on the drawings.

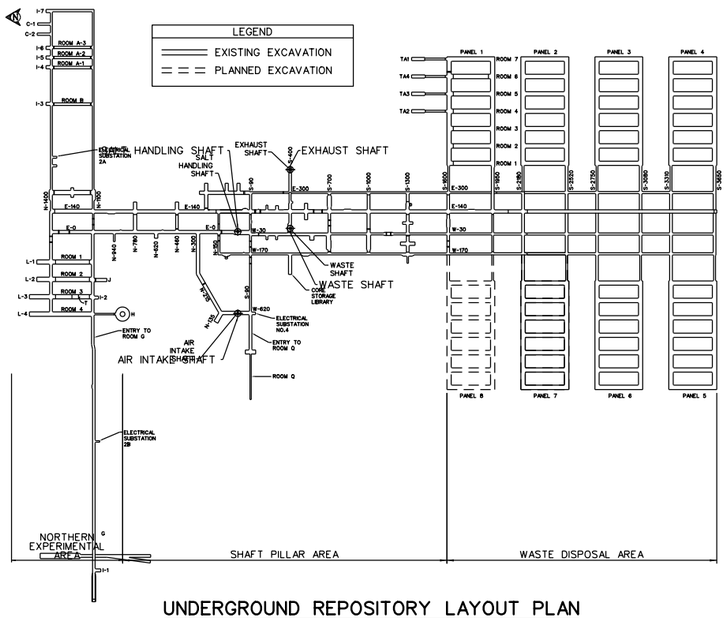
For the inner emplacement of the ROM Salt, the salt is emplaced at the angle of repose, of 1 (rise) to 2 (run) as designated on the drawings. There shall be no gap left between salt and roof or sidewalls. Hand placement or the use of push plates can be used to fill all the voids if necessary.

3.3 Field Quality Control

The Contractor shall provide a Quality Control Inspector to inspect the emplacement of salt.

APPENDIX D
DESIGN DRAWINGS

INDEX OF DRAWINGS	
DRAWING NO.	TITLE
262-001	TITLE SHEET
262-002	UNDERGROUND WASTE DISPOSAL PANEL CONFIGURATIONS (3,4,6,7,8)
262-003	UNDERGROUND WASTE DISPOSAL PANEL CONFIGURATIONS (1,2,5)
262-004	PANEL CLOSURE SYSTEM CONSTRUCTION DETAILS



UNDERGROUND REPOSITORY LAYOUT PLAN

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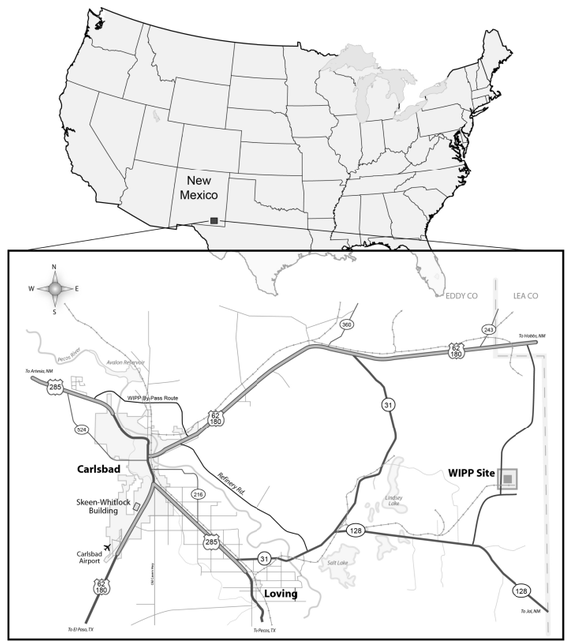
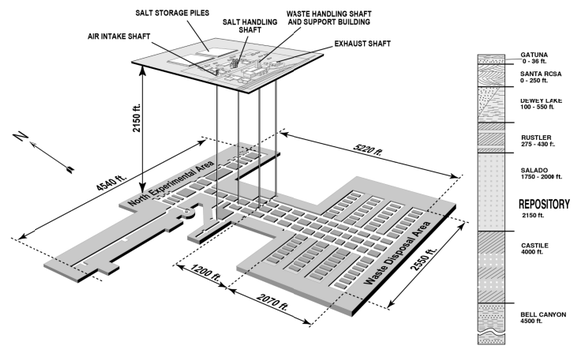
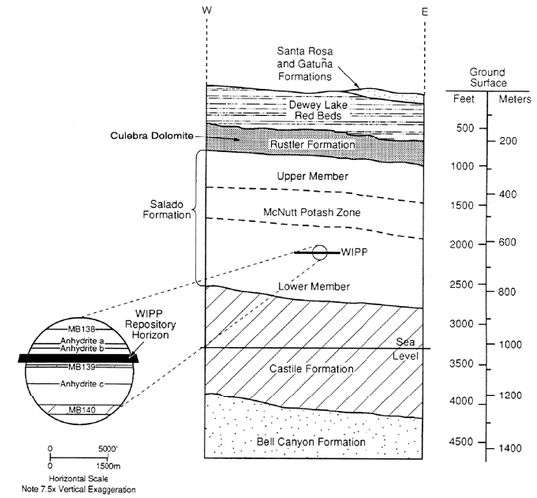


GENERAL LOCATION OF THE WIPP FACILITY

WIPP Facility and Stratigraphic Sequence





GENERAL STRATIGRAPHY AT THE REPOSITORY HORIZON

SCALE: NOT TO SCALE

WASTE ISOLATION PILOT PLANT
PANEL CLOSURE SYSTEM
CARLSBAD, NEW MEXICO

PREPARED BY
ROCKSOL CONSULTING GROUP INC.

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PANEL CLOSURE SYSTEM
TITLE SHEET

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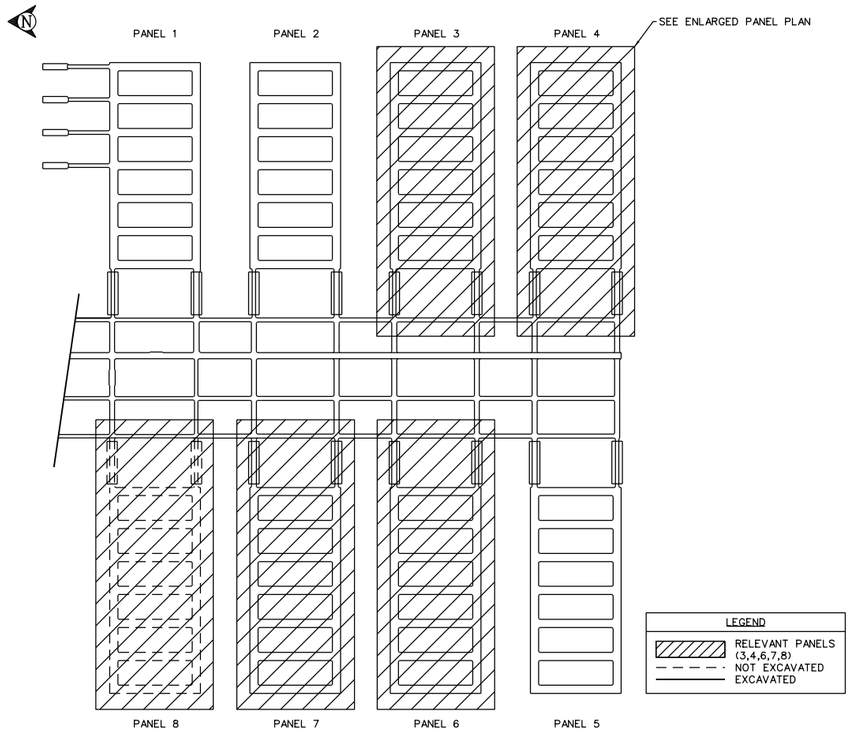
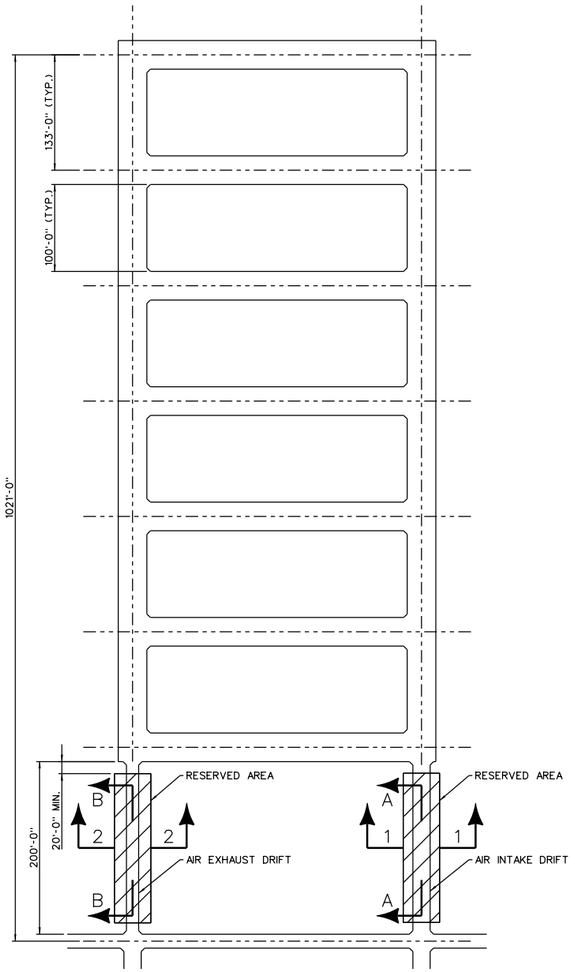


UNDERGROUND WASTE DISPOSAL PANELS

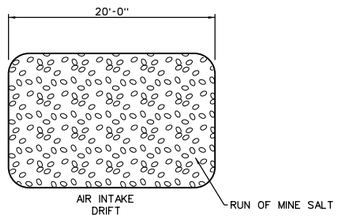
KEY PLAN



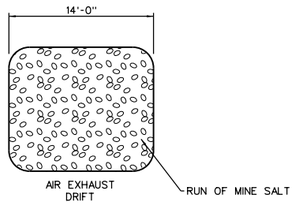
TYPICAL ENLARGED WASTE DISPOSAL PANEL PLAN

GENERAL NOTES

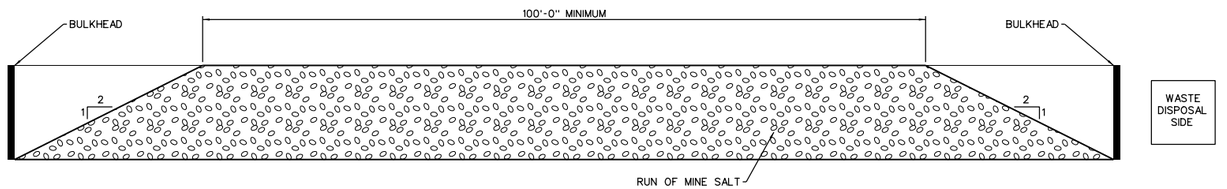
1. GROUND CONTROL NOT SHOWN. INSTALL IN ACCORDANCE WITH APPROVED GROUND CONTROL PLANS.
2. VENTILATION CONTROLS NOT SHOWN. INSTALL IN ACCORDANCE WITH APPROVED VENTILATION PLANS.
3. ALL DIMENSIONS REPRESENT NOMINAL VALUES AND MAY VARY FROM LOCATION TO LOCATION. CONSTRUCTION TOLERANCE ON THE PLACEMENT OF THE SALT IS 1'-0".
4. THE PANEL CLOSURE SYSTEM WILL BE POSITIONED IN THE RESERVED AREA AT A LOCATION TO BE DETERMINED BY WASHINGTON TRU. THE POSITION DOES NOT EFFECT CLOSURE PERFORMANCE AND CAN BE BASED ON A GENERAL ASSESSMENT OF THE GROUND CONDITIONS IN THE RESERVED AREA.
5. RUN OF MINE SHALL BE EMPLACED A MINIMUM OF 100'0".
6. SALT ZONES CAN BE INCLINED AS LONG AS LENGTH IS MAINTAINED.
7. FOR PANEL ENTRIES THAT ARE HIGHER THAN THE DESIGN HEIGHT, THE RUN OF MINE SHALL BE INCREASED IN HEIGHT TO ACCOMODATE THE PANEL ENTRY HEIGHT.
8. OUTER SLOPES ON RUN OF MINE SALT CAN BE INCREASED TO 1.4 HORIZONTAL TO 1 VERTICAL IF NEEDED DUE TO SPACE LIMITATIONS IN THE DRIFTS.
9. PLACEMENT OF RUN OF MINE SALT SHALL FILL THE GAP TO THE BACK.



SECTION 1-1



SECTION 2-2



TYPICAL PANEL CLOSURE SYSTEM CROSS SECTION A-A & B-B

(PANELS 3,4,6,7,8)

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PANEL CLOSURE SYSTEM
UNDERGROUND WASTE DISPOSAL
PANEL CONFIGURATIONS (3,4,6,7,8)

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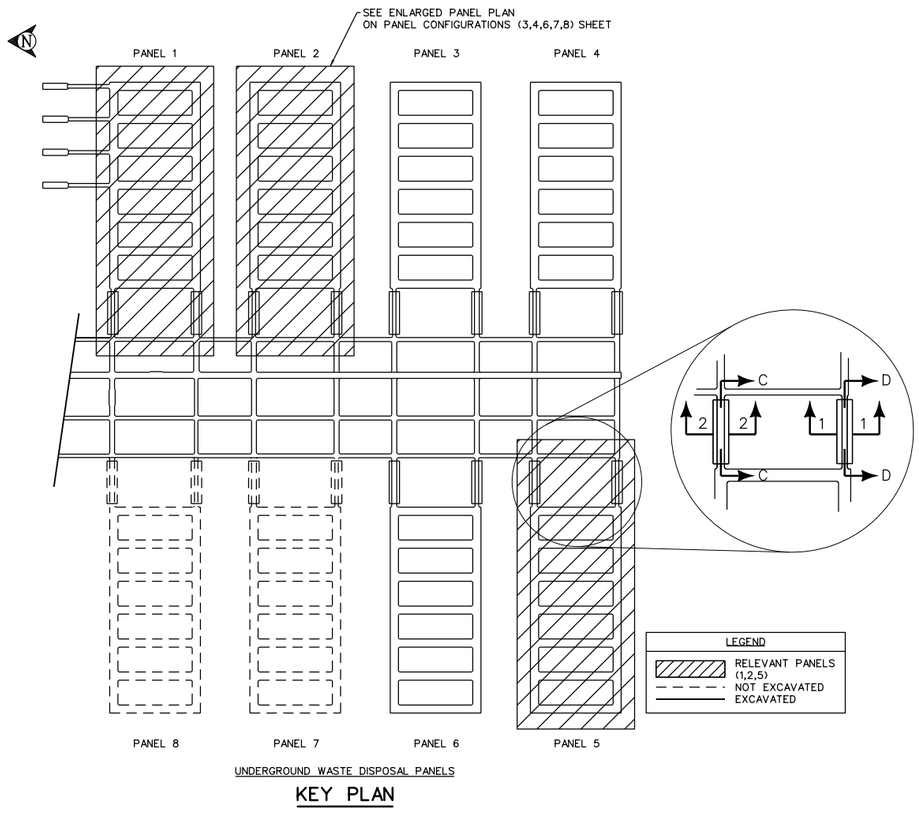
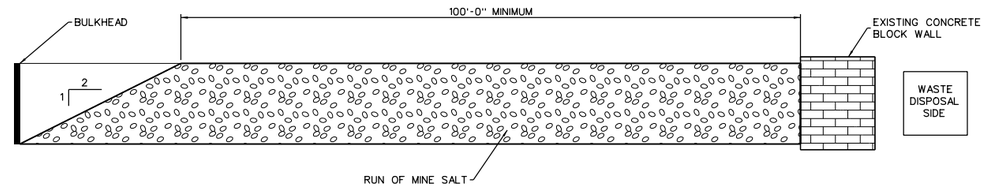


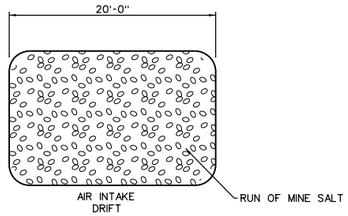
UNDERGROUND WASTE DISPOSAL PANELS

KEY PLAN

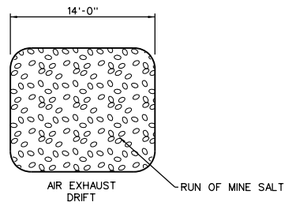


TYPICAL PANEL CLOSURE SYSTEM CROSS SECTION

(PANELS 1&2 INTAKE AND EXHAUST DRIFTS)



SECTION 1-1



SECTION 2-2

NOTES

1. FOR GENERAL NOTES SEE PANEL CONFIGURATIONS (3,4,6,7,8) SHEET.
2. FOR TYPICAL ENLARGED WASTE DISPOSAL PANEL PLAN AND TYPICAL DRIFT SECTIONS SEE PANEL CONFIGURATIONS (3,4,6,7,8) SHEET.

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PANEL CLOSURE SYSTEM
UNDERGROUND WASTE DISPOSAL
PANEL CONFIGURATIONS (1,2,5)

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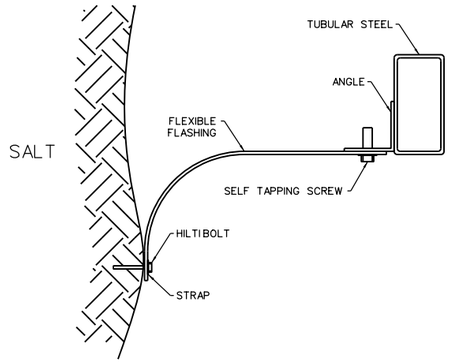
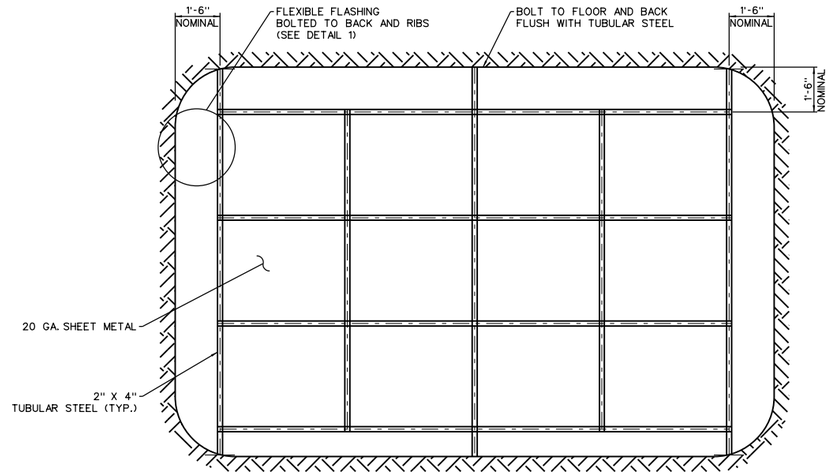


DETAIL 1

(FLEXIBLE FLASHING ATTACHMENT)



TYPICAL BULKHEAD DETAIL

CONSTRUCTION SEQUENCE

1. CONTRACTOR SHALL ENSURE THAT ROOM 1 CLOSURES ARE TIGHT AND EFFECTIVE IN ACCORDANCE WITH ROOM CLOSURE PLANS BEFORE COMMENCING WORK.
2. CONTRACTOR SHALL PLAN THE WORK IN CONSULTATION WITH WASHINGTON TRU AND SHALL EXECUTE IT ONLY AFTER APPROVAL BY WASHINGTON TRU.
3. PREPARE ALL SURFACES BY REMOVING ALL LOOSE MATERIAL AND GENERALLY SQUARING THE EXCAVATION CROSS-SECTION. THE FLOOR SURFACE SHOULD BE FLAT AND CLEAN AND SUITABLE FOR SALT PLACEMENT. OTHER SURFACES SHOULD BE CLEAN, TIGHT AND SOUND IN ACCORDANCE WITH SECTION 02222 OF THE SPECIFICATIONS.
4. RUN OF MINE SALT SHALL BE CONSTRUCTED AS REQUIRED BY SECTION 04100 OF THE SPECIFICATIONS. ASSUMED INTACT DENSITY OF COMPACTED SALT SHALL BE 135 PCF.
5. SALT SHALL BE EMPLACED FLUSH WITH THE RIBS.
6. THE VENTILATION BULKHEAD SHALL ACHIEVE 2,200 PRACTICAL UNITS.

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PANEL CLOSURE SYSTEM CONSTRUCTION DETAILS

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US-German Workshop on Salt Repository Research
May 25-28, 2010
Jackson, Mississippi USA

Backfill Compaction and EDZ Recovery

Tilmann Rothfuchs, Klaus Wieczorek
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, Braunschweig, Germany

Abstract

Most concepts for the disposal of radioactive waste in geological salt formations consider backfilling with crushed salt as a suitable measure to stabilize the underground repository and to provide long-term sealing of the waste from the biosphere by compaction of the backfill in consequence of room convergence.

In Germany, two emplacement concepts have been developed for the disposal of heat generating waste in a salt repository: First, ***the drift disposal concept*** for the direct disposal of spent nuclear fuel elements which considers the emplacement of self-shielding Pollux-disposal casks in underground drifts. Immediately after deposition of the casks the empty drift volume is backfilled with crushed salt. Second, ***the borehole disposal concept*** which considers the disposal of cut spent fuel rods in BSK-3-canisters or vitrified high-level waste from reprocessing of spent fuel in Cogéma steel canisters in up to 300-m-deep vertical boreholes. To provide for distribution of the canister weight load into the rock mass, the annulus between waste canisters and borehole wall is backfilled with crushed salt in case of the borehole disposal concept. In addition, to isolate the waste canisters from the drift, the remaining empty space of about 30 to 40 m between the top of the canister stack in the borehole and the drift may also be backfilled.

In contrast to the consideration of altered scenarios in the past, a new approach focusing on the proof of the safe containment of the waste within an Isolating Rock Zone (IRZ) is currently pursued in Germany. The radioactive waste is contained inside the IRZ in such a way that it essentially remains at the site of emplacement and that not more than minimal defined quantities of material are able/allowed to leave the IRZ [1]. The proper function of the IRZ is jointly guaranteed by the host rock in this zone and the engineered barrier system (EBS) consisting of technical seals and salt backfill.

Within the IRZ, the engineered barrier system plays an important role in the proof of long-term safety of the repository system. The seals in the shafts and connecting drifts are essential features to avoid an intrusion of brine from the overburden into the mine and especially into the disposal cell. In case of failure of a seal, another seal takes charge of the safety function within a multi barrier series arrangement. In the long term, the seal function of the EBS is taken over by the compacted backfill in the entire mine because a technical seal may fail due to its limited long term stability.

The assessment of the seal function of both the technical seal and the backfill in addition to that of the geological barrier represents an important task in long-term safety analyses. The credibility of the used models is significantly increased if the modeling results are in reasonable agreement with measuring results from large-scale field experiments performed under representative conditions. The TSDE experiment (Thermal Simulation of Drift Emplacement) and the DEBORA experiments (Development of Borehole Seals for Radioactive Waste) performed at the Asse mine/Germany within the BAMBUS project [2] were such large-scale simulation experiments.

In the TSDE experiment representing the direct drift disposal of spent fuel, six simulated Pollux casks were deposited in two test drifts backfilled with crushed salt. The decay heat of the spent fuel was simulated by electric heaters in the casks. Heating was kept up with a constant power over almost nine years from September 1990 until February 1999. The maximum temperature of 210 °C decreased to 170 °C at the termination in consequence of backfill compaction and increasing thermal conductivity. Until the end of the heating period, drift convergence led to a reduction of backfill porosity from initially 35 % to 20 % in the heated area. For the final confirmation of the achieved backfill compaction the drifts were uncovered after

termination of the experiment. A detailed determination of the remaining porosity and permeability distribution in the backfill material was performed during a post-test analysis program [3].

The DEBORA experiment consisted of two single tests simulating different conditions in a backfilled HLW disposal borehole. Both experiments were performed at the 800-m level of the Asse mine in 15 m deep boreholes with a diameter of 0.6 m. In DEBORA 1 the situation in the annulus between the waste canister stack and the borehole wall was investigated. In DEBORA 2 a non-lined borehole was used to simulate the seal region above the waste canister stack. The heat production of the waste canisters was simulated by four peripheral heaters located at a radius of 1.1 m from the borehole. The lower third of both boreholes was backfilled with crushed salt. Backfill temperature, borehole closure, and resulting backfill pressure were measured at three levels in the backfilled boreholes. Maximum backfill compaction to a remaining porosity of about 7% was achieved within a two years lasting test period.

Reduction of porosity close to that of the sound rock salt was not reached within the experimental period in both experiments, but are expected in a repository in the long term. However, data of both tests together with data from accelerated laboratory tests have been used for the calibration of constitutive models used by different institutions. It is important to mention that larger model uncertainties still exist in the porosity range below 1% due to limitations regarding the determination of very small porosity which is of special importance in long term safety assessments. Respective investigations will therefore be initiated in a new project named REPOPERM.

Evolution and especially re-compaction of the EDZ was and is still a further important issue within the German research program because of the above-mentioned new approach of the safe containment.

Three related projects were performed in the Asse salt mine during the recent 20 years. The first was the ALOHA project in which the extent and hydraulic properties of an EDZ under the floor of a drift were investigated [4]. The second was the EC-funded BAMBUS II project [3] which concentrated on EDZ anisotropy and self-sealing; the third project ADDIGAS [5] within the EC-funded NF-PRO project was completed in 2007 and investigated the effectiveness of EDZ removal and the subsequent evolution of a new EDZ.

Finally, the EC project THERESA (2007 - 2009) was performed to extend the geo-scientific data bases for an in-depth understanding of THM coupled processes and to provide advanced modeling capabilities for assessing the evolution of the EDZ before and after closure of the repository.

In situ investigations performed at Asse revealed that, depending on stress conditions and history, the EDZ can extend one to two metres into the rock salt. Permeability can increase by several orders of magnitude up to the range of 10^{-14} to 10^{-13} m^2, with the permeability of the undisturbed salt being below 10^{-20} m^2. EDZ removal by additional excavation is effective in the sense that it takes years for a new EDZ to evolve. The long-term evolution of the EDZ, particularly its re-compaction, however, is to be assessed by numerical simulations on the basis of models adequately validated with experimental data.

Hence, the focus of the salt group in the THERESA project has been on modeling of rock salt dilatancy and on re-compaction or healing effects. Since reliable data on these phenomena are scarce, laboratory experiments with different objectives were performed to produce data for further model calibration. A benchmark simulation of a laboratory test case was defined and performed using the calibrated models. Finally, one of the models was used to predict EDZ evolution and re-compaction around a sealed drift and the results were used as input for the analysis with GRS's Total System Performance Analysis (TSPA) code module LOPOS.

A special benefit of THERESA was that practically all European institutions that work in the field of radioactive waste disposal in rock salt were joined in the THERESA project. The THERESA project partners were BGR, CIMNE, DBE-TEC, FZK, GRS, IfG, NRG and TUC [6].

The shortcomings of characterization and modeling of the EDZ in rock salt, as they present themselves after THERESA, can be summarized as follows:

- The database for calibration of the models, i.e., the number of available well-defined and documented experiments, was not sufficient, even though additional laboratory tests for

THERESA were performed outside the EC funding. Additional experiments will be indispensable for sound model calibration.

- As a consequence, the calibration had to be carried out on a weak database and is therefore incomplete.
- Some models showed weaknesses during test case simulation and need further improvement.
- TSPA modeling was based on only one process-level model, which itself is not sufficiently calibrated and validated.

On the whole, however, THERESA was a success, as it provides a sound and complete basis for further investigations, especially with regard to the EDZ in rock salt. This future work, which is considered indispensable for completion of the EDZ complex, should comprise

- Further experimental investigation with well-defined objectives and boundary conditions to complete the database on dilatancy and recompaction, including investigation of brine influence on EDZ recompaction,
- Further development of some and extended calibration of all of the process-level models, including validation of their suitability for in-situ application,
- Implementation of time-dependent EDZ permeability functions derived from comprehensively calibrated models in the TSPA codes, and
- Performing reliable predictions of the impact of brine inflow into a repository with realistic assumptions.

References

[1] BMU (2009): Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste.- Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). Berlin, July 2009 (Source: Homepage of BMU).

[2] Bechthold, W., Rothfuchs, T., Poley, A., Ghoreychi, M., Heusermann, S., Gens, A., Olivella, S., 1999: Backfilling and Sealing of Underground Repositories for Radioactive Waste in Salt (BAMBUS Project), Final Report, European Commission, EUR19124 EN

[3] Bechthold, W., Smailos, E., Heusermann, S., Bollingerfehr, W., Bazargan Sabet, B., Rothfuchs, T., Kamlot, P., Grupa, L, Olivella, S., Hansen, F.D. (2004): Backfilling and Sealing of Underground Repositories for Radioactive Waste in Salt (BAMBUS-II Project), EUR 20621, Commission of the European Communities

[4] Wieczorek, K., and Zimmer, U. (1998): Untersuchungen zur Auflockerungszone um Hohlräume im Steinsalzgebirge, Final Report, GRS-A-2651, Braunschweig, Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH.

[5] Jockwer, N. and Wieczorek, K. (2007): Excavation Damaged Zones in Rock Salt Formations, 6th Conference on the Mechanical Behaviour of Salt (SaltMech6) -Understanding of THMC Processes in Salt Rocks, Hannover, May 22 - 25, 2007.

[6] Wieczorek, K., Rothfuchs, T., Förster, B., Heemann, U., Olivella, S., Lerch, C., Pudewills, A., Kamlot, P., Grupa, J., Herchen, K., 2009: Coupled Processes in Salt Host-Rock Repositories, Final Report of Work Package 3, THERESA project, Deliverable D9, Commission of the European Communities, Brussels

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Consolidation and Permeability of Salt in Brine

A. J. Shor
C. F. Baes, Jr.
C. M. Canonico

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CHEMISTRY DIVISION

CONSOLIDATION AND PERMEABILITY OF SALT IN BRINE

A. J. Shor, C. F. Baes, Jr., and C. M. Canonico

Date Published: July 1981

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U. S. Department of Energy

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CONSOLIDATION AND PERMEABILITY OF SALT IN BRINE

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ABSTRACT

The consolidation and loss of permeability of salt crystal aggregates, important in assessing the effects of water in salt repositories, has been studied as a function of several variables. The kinetic behavior was similar to that often observed in sintering and suggested the following expression for the time dependence of the void fraction:

$$\phi(t) = \phi(0) - (A/B)\ln(1 + Bt/\bar{z}(0)^3),$$

where A and B are rate constants and $\bar{z}(0)$ is initial average particle size. With brine present, A and $\phi(0)$ varied linearly with stress. The initial void fraction was also dependent to some extent on the particle size distribution. The rate of consolidation was most rapid in brine and least rapid in the presence of only air as the fluid. A brine containing 5 m $MgCl_2$ showed an intermediate rate, presumably because of the greatly reduced solubility of NaCl. A substantial wall effect was indicated by an observed increase in the void fraction of consolidated columns with distance from the top where the stress was applied and by a dependence of consolidation rate on the column height and radius. The distance through which the stress fell by a factor of e was estimated to change inversely as the fourth power of the column diameter. With increasing temperature (to 85°C), consolidation proceeded somewhat more rapidly and the wall effect was reduced. The permeability of the columns dropped rapidly with consolidation, decreasing with about the sixth power of the void fraction. In general, extrapolation of the results to repository conditions confirms the self-sealing properties of bedded salt as a storage medium for radioactive waste.

1. INTRODUCTION

Although the very presence of a subterranean salt deposit signifies isolation from flowing water over geologic time, somewhat ironically perhaps the suitability of bedded salt for the storage of radioactive waste remains questionable because the consequences of the presence of water (as brine) have not been fully assessed. Water is inevitably present in salt repositories as brine inclusions within salt crystals or as hydrate water in minerals such as gypsum. Water may gain access during the operational period when the repository is open to the surface, during the period of consolidation of backfilled salt, or conceivably during the period of long-term storage. In the temperature gradient around a waste canister, hydrate water could be released and brine could migrate up the thermal gradient.

To assess the consequences of water in a radioactive waste repository, investigators are measuring[1] and modeling[2] movement of brine in a thermal gradient and studying the mechanical properties of salt.[3] We have been studying the consolidation and permeability of granulated salt as a function of the composition of the liquid in which it is immersed, the stress applied, and the temperature.[4]

It has long been known that when the relative humidity is high enough (>75%) to produce water condensation on granulated salt, the crystals cake or stick together and remain caked after the water is removed by evaporation. A mechanism is easily imagined involving dissolution in and reprecipitation from the brine to produce crystals that fit together better and stick together. The driving forces include the enhanced solubility of salt at points of contact between crystals that are under stress from the weight of overlying salt and the energy released from reduction of the interfacial area between crystals and brine.

During deposition and consolidation of salt from evaporating seas to form halite deposits, the crystals quite obviously were not only reshaped to fit more perfectly, but probably grew in size. This suggests processes like those that produce grain growth in the sintering of metal and ceramic powders at temperatures well below their melting points. The mechanism is thought to involve the transfer of ions along or across grain boundaries between adjacent crystals. Here the driving force is reduction of the total area of the grain boundaries.

The consolidation of other mineral crystals has long been of interest to geologists concerned with the processes involved in the formation of rocks. Although the solubilities are lower, the same mechanisms of dissolution and precipitation are thought to be important.[6] The most elegant model appears to be that of Weyl,[6] wherein the rate-determining step is assumed to be the diffusion of excess dissolved material within the film of liquid between the stressed surfaces. This model and similar treatments by Kingery[7] and Rutter[8] lead to the conclusion that, for a given stress, the void fraction should depend on the ratio of the time to the cube of the particle size (t/z^3). Unfortunately, the experimental study of the consolidation of various crystalline materials has not progressed far enough to test properly these

models. Our attempts to apply such a model to the present results on the consolidation of salt in brine were not very successful.[4]

The process of sintering is of great technological importance and has received extensive study both experimentally and theoretically. Unfortunately, sintering is too complicated to be treated quantitatively by present theories. Coble[9] concluded from a highly idealized model that the rate at which the void fraction Φ decreased with time should be inversely proportional to the cube of the particle size z:

$$\frac{d\Phi}{dt} = -A/z^3 . \tag{1}$$

The constant A contains the volume, surface tension, and diffusion coefficient of the crystal vacancies assumed to be responsible for the change in crystal shape. Coble also observed that the cube of the average particle size $\bar{z}$ grew linearly with time during much of the sintering process:[10]

$$\bar{z}(t)^3 = \bar{z}(0)^3 + Bt . \tag{2}$$

Assuming that z in Eq. (1) can be replaced by the average particle size $\bar{z}$, these equations can be combined and integrated to give

$$\Phi(t) = \Phi(0) - (A/B)\ln[1 + Bt/\bar{z}(0)^3] . \tag{3}$$

There is a conceptual difficulty, however, in that Eq. (1) was derived for a lattice of crystals of identical size and shape while Eq. (2) must apply to crystals of varying size since it is not possible for some crystals to grow unless others decrease in size. Equation (3) must therefore be regarded as an approximation at best. Experimental studies,[11] however, have indicated that the forms of Eqs. (1) and (2) are approximately correct, with the exponent of $\bar{z}$ ranging from 2 to 3, and equations of the form of Eq. (3) have been found to be quite useful in representing the dependence of sintering rates on time and particle size. Equation (3) has also proved very useful in treating the present results.

2. EXPERIMENTAL

The apparatus used to measure the consolidation and permeability of beds of salt crystals in shown in Fig. 1. The beds were contained in a vertical glass or Monel tube (1.27 or 2.54 cm ID, respectively) and stressed by a perforated piston driven by a Bimba air-actuated ram. Liquid, usually presaturated brine, filled the tube and flowed slowly through the bed during the measurements. The hydrostatic pressure drop across the salt bed was transmitted to a Validyne differential-pressure sensor isolated from the brine by a hydrocarbon liquid to protect the sensor. The height of the bed (determined from the movement of the piston) and the flow rate (determined gravimetrically) were measured as a function of time. The void fraction was calculated from the weight of salt in the bed and the volume it occupied; the permeability was calculated from the hydraulic pressure drop and the flow rate.

Crystals of sodium chloride (CP grade) were sized (usually in the ranges of 75 to 150, 150 to 177, 177 to 250, and 250 to 420 μm) with standard copper sieves and were thoroughly dispersed in the liquid to be used before forming the settled beds. Grinding was used before sieving in preliminary runs, but this was found to produce fines that were not removed completely by sieving. Photomicrographs of samples in each size range were used to determine the size distribution. The material consisted almost entirely of well-formed cubic crystals.

After most runs the salt columns were sampled and the brine content determined by heating to constant weight at 200°C. Samples were taken from the 1.27-cm glass tubes by excavation with a spatula, a tedious and time-consuming procedure for extensively consolidated salt. In the Monel tubes, consolidated columns could be removed intact by ejection with the piston and sampled by sectioning. A number of sections were polished and etched for examination with optical and scanning electron microscopes.

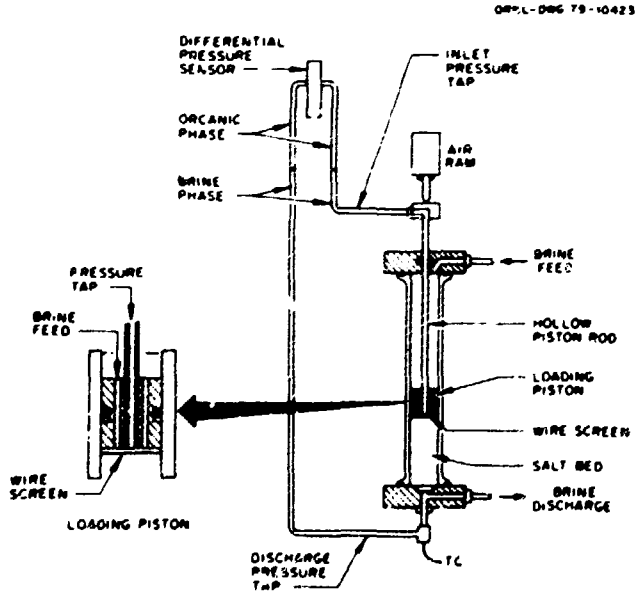

Fig. 1. Apparatus for study of salt consolidation and permeability under a uniaxial stress in brine and other fluids.

3. RESULTS

3.1 Consolidation Kinetics

Under constant stress, beds of salt crystals lost volume with the passage of time at a rate that approached linearity with the logarithm of time (Figs. 2 to 4). This dependence was observed to continue to void fractions as low as 0.02. Examination of compacted columns revealed that the void fraction remaining was not uniformly distributed throughout (Fig. 5) but increased with the distance from the top of the specimen where the stress was applied. This indicated a substantial wall effect, causing the stress on the salt to decrease with distance down the column. The effect was confirmed when it was found that under the same conditions consolidation proceeded more rapidly for short columns of salt than for longer ones (Fig. 3a), and more rapidly in the larger (2.54 cm) tubes than in the smaller (1.27 cm) ones (Fig. 3*b*). There was also some evidence that the consolidation rate depended on the smoothness of the tube wall and the material of which it was made (Fig. 3c).

The principal variables that affected the rate of consolidation in brine were the applied stress and average particle size (Figs. 2*a* and *b*)—the smaller the particles and the greater the applied stress, the more rapid the consolidation. Under a given set of conditions, the consolidation increased with temperature (Fig. 4), but the effect was not large. The extent of consolidation was affected by the particle size distribution (Fig. 6). When the fluid medium was varied (Fig. 7), consolidation proceeded most rapidly in brine, less rapidly with $MgCl_2$ dissolved in the brine (reducing the solubility of NaCl), and least rapidly when only air was present. Two runs in dodecane revealed that the consolidation rate was markedly increased by the presence of a small amount of water, wet dodecane being even more effective a medium for consolidation than a brine containing 6 *m* $MgCl_2$.

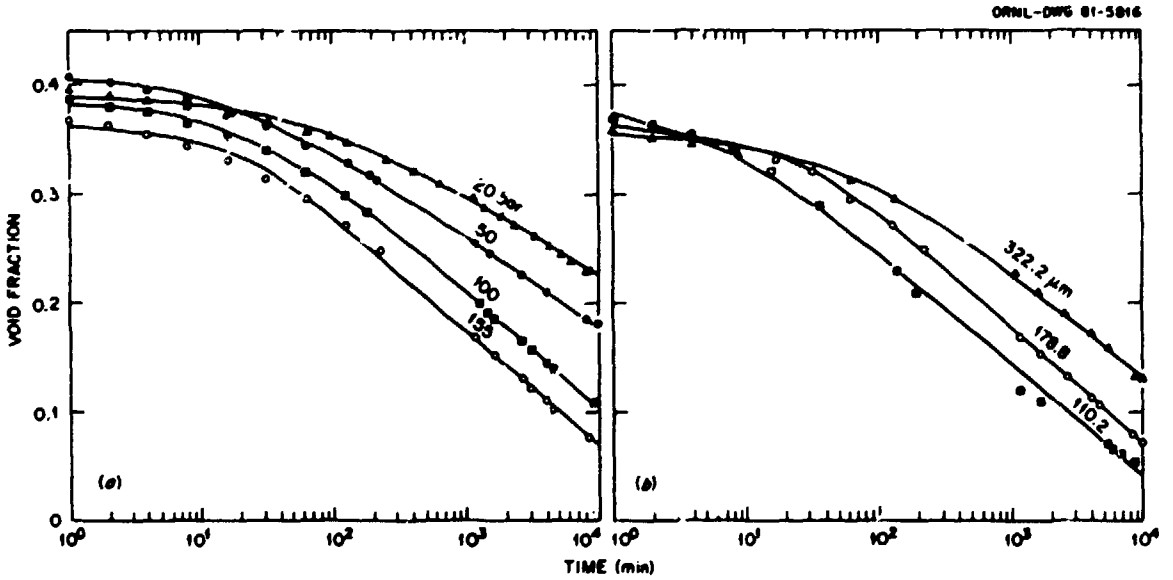

Fig. 2. Consolidation of salt columns (2.54 cm diam) in brine: (a) for various applied stresses and an initial average particle size of 178.8 μm; (*b*) for various initial average particle sizes at an applied stress of 155 bars.

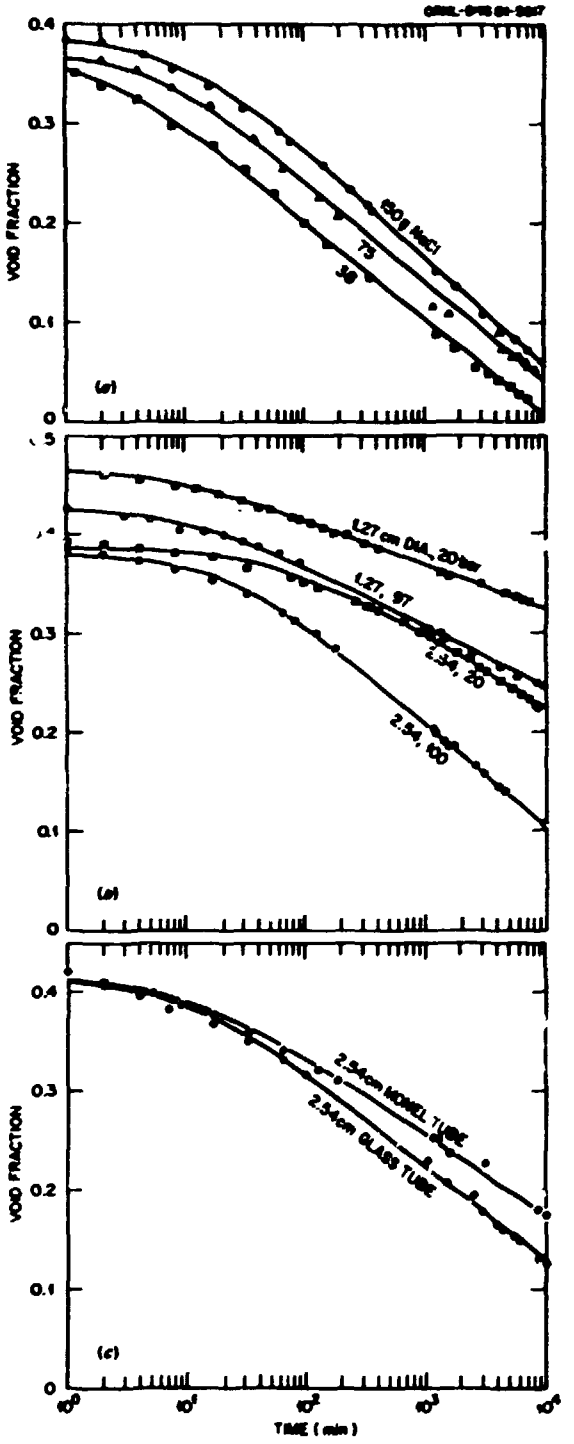

Fig. 3. Consolidation of salt in brine: (*a*) for various weights of salt in 2.54-cm-ID Monel tubes at an applied stress of 155 bars and initial average particle size of 110.2 μm; (*b*) for two tube diameters (the larger of Monel and the smaller of glass) with columns of similar height and applied stresses; (*c*) for Monel and glass tubes of 2.54 cm ID with a stress of 20 bars and an initial average particle size of 110.2 μm.

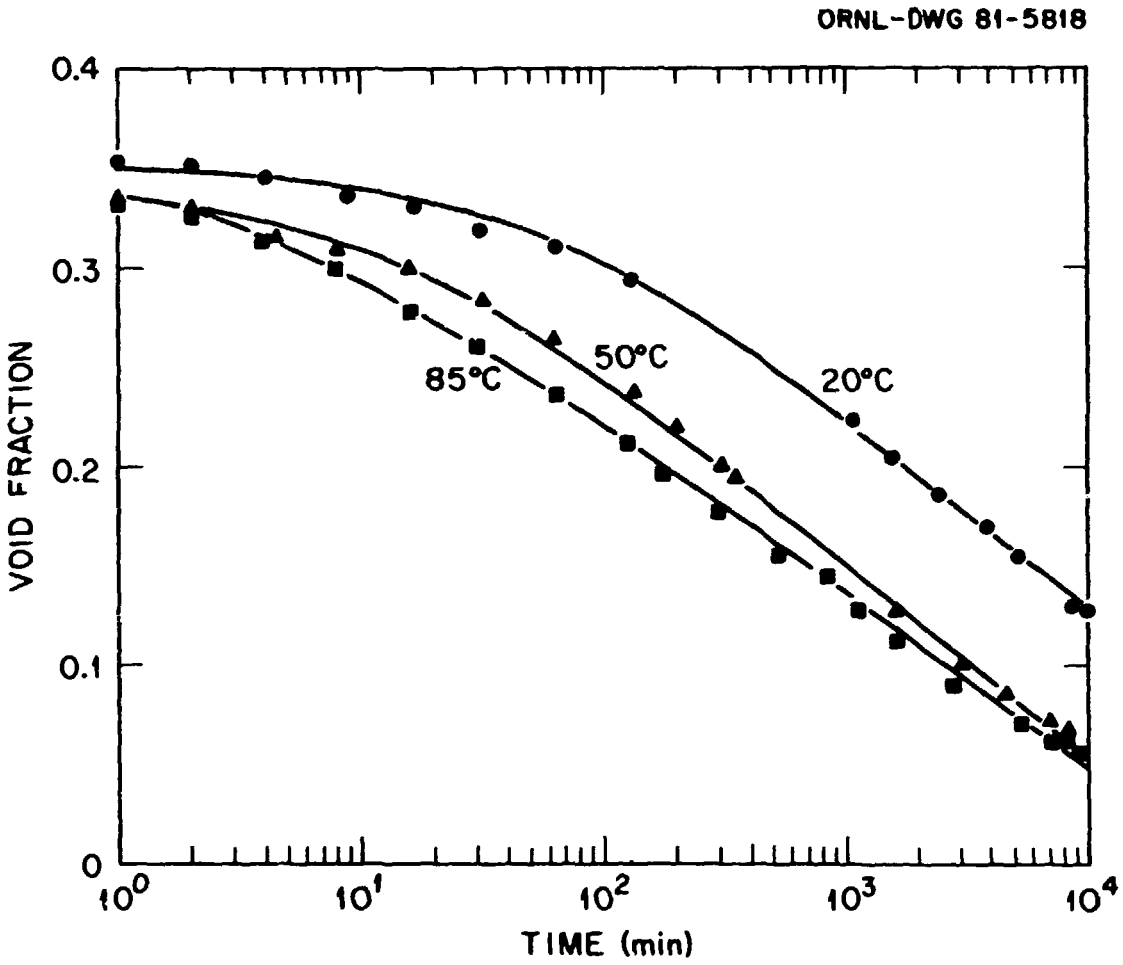

Fig. 4. Consolidation of salt columns (2.54 cm diam) in brine at various temperatures, with 155 bars applied stress and an initial average particle size of 322.2 μm.

The decrease in the observed void fraction ϕ during the isothermal consolidation of salt can be represented quite well by an equation of the form

$$\phi(t) = a - b \ln(c + t) , \qquad (4)$$

which is strikingly similar to the one suggested by Coble [Eq.(3)]. When the parameters a, b, and c were adjusted by least squares to obtain the best fit to each run (Table 1), the agreement between the observed and calculated void fraction was usually within experimental error, as may be seen from the curves in Figs. 2 to 4, 6, and 7, generated by use of Eq. (4). While the values of a, b, and c obviously reflect the effect of such variables as particle size, stress, and temperature, they are so strongly covariant with one another that it is not possible to assign these dependencies with much certainty.

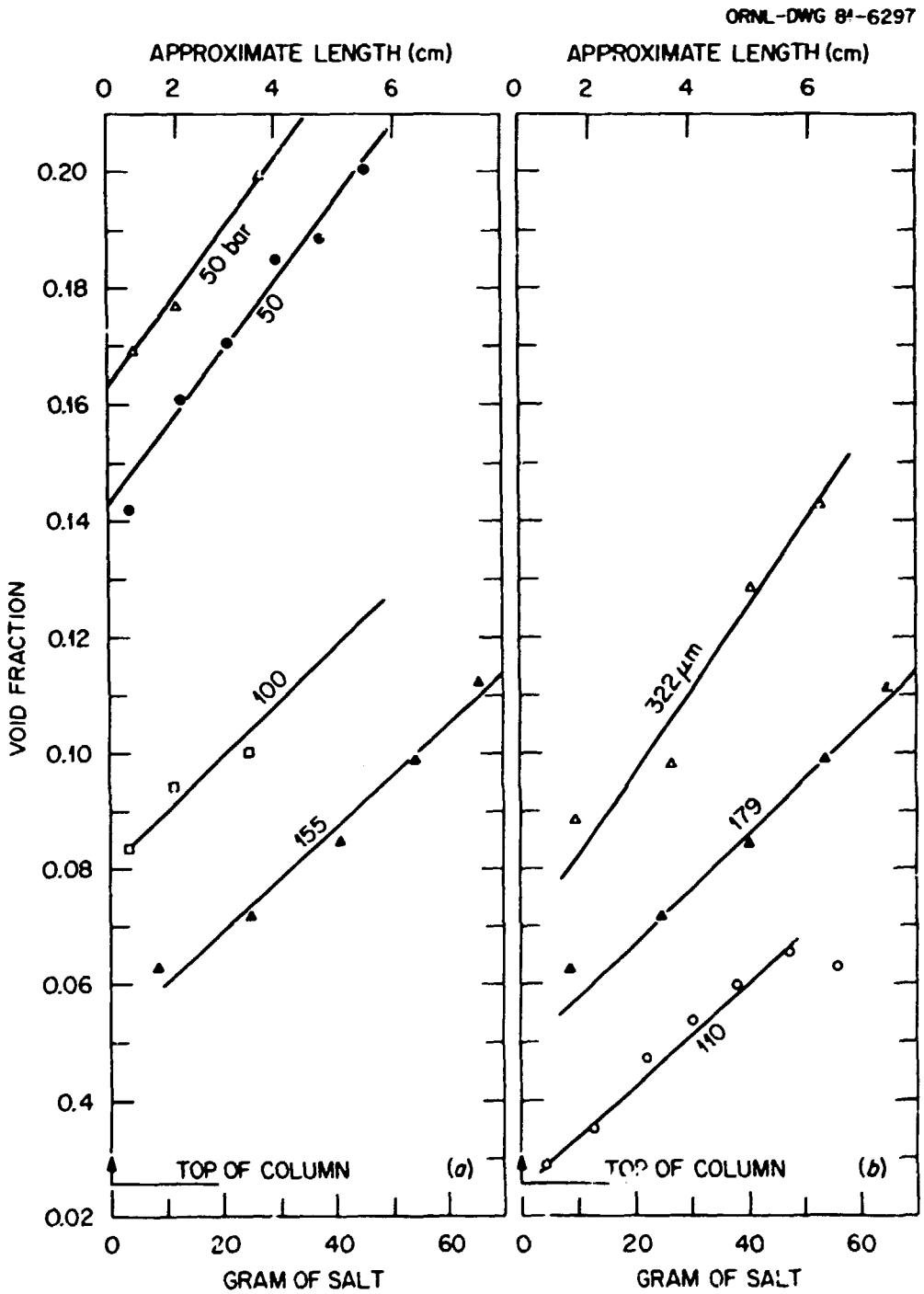

Fig. 6. Void fraction in consolidated salt columns vs. distance (weight of salt) from piston: (*a*) for various applied stress and an initial average particle size of 178.8 μm; (*b*) for various particle sizes at an applied stress of 155 bars.

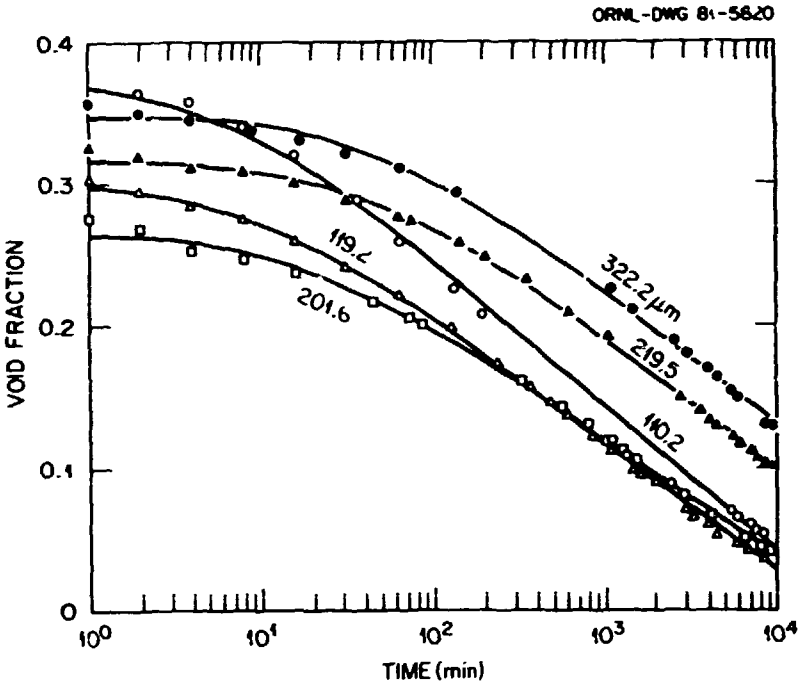

Fig. 6. Consolidation of salt columns (2.64 cm diam) in brine with various initial average particle sizes and distributions, at an applied stress of 155 bars.

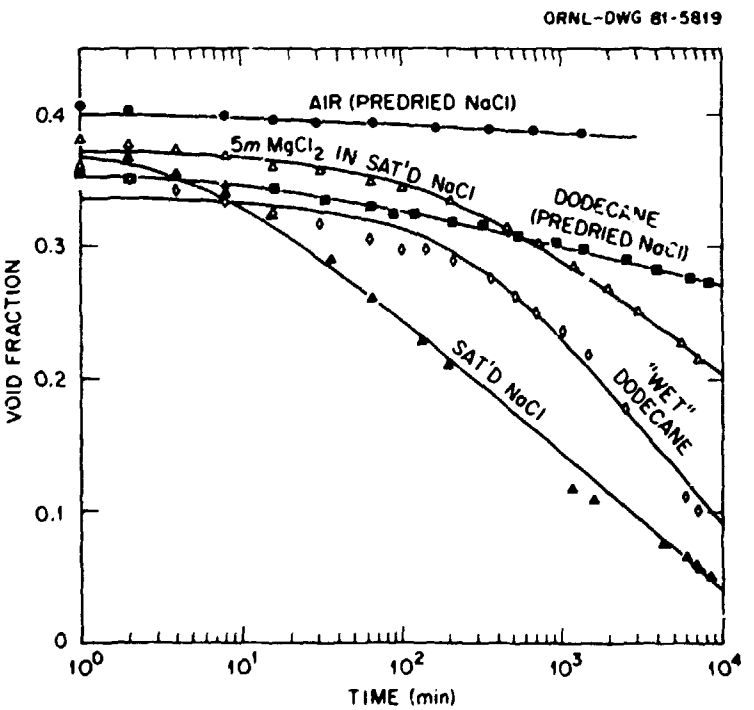

Fig. 7. Consolidation of salt columns (2.64 cm diam) in various fluids with an applied stress of 155 bars and an initial average particle size of 110.2 μm.

Table 1

KINETICS OF CONSOLIDATION OF SALT UNDER VARIOUS CONDITIONS

$$\phi(t) = a - b \ln (c + t)^{a}$$

Run No.	Crystal Size z(0)[b] cm	Appl. Stress bar	Wt. of Salt g	a	b	c min	Std. Err. of Fit[c]
		In NaCl Brine, 1.27 cm ID Glass Tubes, ~20°C					
25	0.0100	57.4	7.00	0.4877	0.02960	9.0	0.0031
15	"	57.4	17.4	0.5394	0.02815	5.1	0.0035
21	"	57.4	17.4	0.6732	0.04725	133 4	0.0064
18	"	96.5	17.8	0.4704	0.02961	0.6	0.0020
12	0.0165	20.1	17.8	0.5030	0.01930	7.1	0.0012
17	"	96.5	17.8	0.4947	0.02709	12.8	0.0026
20	0.0333	20.1	17.3	0.4866	0.01336	48.7	0.0014
24	"	57.4	7.06	0.4732	0.02017	67.9	0.0028
16	"	57.4	17.4	0.4694	0.01132	27.6	0.0021
13	"	57.4	17.4	0.5314	0.02620	97.7	0.0084
19	"	57.4	17.8	0.4883	0.01714	51.3	0.0034
		2.54 cm ID Monel Tubes, ~20°C					
115	0.01102	20	38	0.4745	0.025741	3.7	0.001
102	"	20	75	0.4965	0.034934	10.2	0.009
119	"	20	75	0.5047	0.032051	11.0	0.003
111	"	155	38	0.4039	0.043011	2.0	0.005
104	"	155	75	0.4501	0.044408	5.4	0.009
109	"	155	75	0.4386	0.044613	3.9	0.008
110	"	155	150	0.5010	0.048093	10.2	0.002
122	0.01192	155	75	0.3889	0.029485	8.8	0.002
108	0.01788	20	75	0.5126	0.031142	56.7	0.004
118	"	50	38	0.4868	0.035266	12.4	0.002
117	"	50	75	0.5039	0.035119	16.1	0.002
107	"	100	75	0.5226	0.045306	21.6	0.002
106	"	155	75	0.4978	0.046460	17.0	0.003
121	0.01877	50	75	0.4924	0.034544	41.4	0.003
120	"	100	75	0.4808	0.036193	22.5	0.002
132	0.02016	155	75	0.3643	0.035421	15.3	0.004
123	0.02195	155	75	0.4686	0.040131	43.2	0.004
116	0.03222	20	38	0.4740	0.021195	51.1	0.002
114	"	155	38	0.4151	0.031918	18.5	0.002
105	"	155	75	0.5037	0.040568	44.2	0.005
101[d]	0.01102	20	75	0.5062	0.040780	9.2	0.006
103[d]	0.01788	20	75	0.5006	0.034101	22.7	0.002
100[d]	0.03222	20	75	0.4304	0.020305	38.4	0.003

Table 1 (contd.)

Run No.	Crystal Size z(0)[b] cm	Appl. Stress bar	Wt. of Salt g	a	b	c min	Std. Err. of Fit[c]
				50°C			
127	0.01102	155	75	0.3950	0.043555	0.8	0.007
128	"	155	150	0.4676	0.049057	4.4	0.005
129	0.03222	155	75	0.4402	0.042143	12.1	0.008
				85°C			
131	0.01102	155	75	0.3720	0.043760	0.2	0.010
130	"	155	75	0.3896	0.036913	3.4	0.003
				In Other Fluids at ~20°C[e]			
124	0.01102	155	75	0.5480	0.037301	113.7	0.004
125	"	155	74	0.7173	0.068266	263.2	0.011
126	"	155	75	0.3798	0.011706	10.4	0.003
113	0.01788	155	75	0.4025	0.023010	-----	0.001

[a] $\phi(t)$ is the void fraction at time t (min).

[b] The average crystal size: Information about the size distribution is given in Table 3.

[c] Standard deviation of the calculated from the observed void fraction.

[d] These runs were carried out in 2.54 cm i.d. glass rather than monel tubes and were not included in determination of the parameters in Table 2.

[e] Run 113, in air; run 124, in a brine 6 m in $MgCl_2$; run 125, undried salt in dodecane; run 126, dried salt in dodecane (see Table 4). These runs were not included in determination of the parameters in Table 2.

3.2 Consolidation Model

Accordingly, we turn to the model suggested by Coble.[9,10] A comparison of Eqs. (3) and (4) show that they are equivalent if

$$\phi(0) = a - b\ln c\,. \tag{6a}$$

$$A = b\bar{z}(0)^3/C\,, \tag{6b}$$

$$B = \bar{z}(0)^3/C\,. \tag{6c}$$

We then examined the effect of conditions on the values of $\phi(0)$, A, and B given by these relationships. As might be expected, the initial void fraction $\phi(0)$ seemed to decrease with increasing applied stress. A linear decrease with stress seemed to be an adequate approximation, though $\phi(0)$ was obviously affected by particle size and size distribution as well. We will consider these effects presently. The quantity A was found to increase approximately linearly with increasing applied stress.

These correlations were obscured by the wall effect, which causes the local stress σ in a column to be less than the applied stress $\sigma(0)$ and the local void fraction to differ from the observed or integrated void fraction. These correlations did suggest, however that for the consolidation of salt in brine, a good representation of the time dependence of the local void fraction would be given by Eq. (3) if we assume that the local void fraction and A vary linearly with the local stress:

$$\phi(w,0) = P_0 - P_1\sigma\,, \tag{6a}$$

$$A = A_0 + A_1\sigma\,. \tag{6b}$$

Here we assume the local void fraction to be a function of the distance down the column expressed in terms of the weight of salt w as well as the time. (In view of the limited information we have on the wall effect, it was deemed appropriate not to consider explicitly the dependence of the local void fraction on the distance from the wall.) The wall effect was dealt with by assuming that the stress decreased exponentially with w:

$$\sigma(w) = \sigma(0)\exp(-w/C)\,, \tag{7}$$

where C is the weight of salt through which the stress falls by a factor of e. An expression for the observed void fraction is then derived by performing the integration

$$\phi(t) = \left(\frac{1}{W}\right)\int_0^W \phi(w,t)\,dw \tag{8}$$

where W is the total weight of salt in the column. The resulting expression for the observed void fraction is

$$\phi(t) = (P_0 - P_1\bar{\sigma}) - [(A_0 + A_1\bar{\sigma})/B]\ln[1 + Bt/\bar{z}(0)^3]\,. \tag{9}$$

In which $\bar{\sigma}$ is given by

$$\bar{\sigma} = \frac{1}{W}\int_0^W \sigma\, dw = \sigma(0)\frac{C}{W}[1 - \exp(-W/C)]\,. \tag{9a}$$

3.3 Consolidation in Brine at Room Temperature

All the consolidation data on room-temperature brine from the 2.54-cm Monel tube were fitted by least squares to Eq. (9). Included were the profiles of void fraction vs w from direct sectioning of consolidated columns (Fig. 5). The latter data were fitted by replacing $\bar{\sigma}$ in Eq. (9) with $\sigma(w)$ from Eq. (7). In making these fits, values of A_0, A_1, B, and C were adjusted for all the data simultaneously. The parameters P_0 and P_1 presented a problem because, as noted above, these were not the only quantities that determined the initial void fraction $\phi(0)$; therefore, P_0 was adjusted for each run so that it could include the effects being neglected in Eqs.(6). Even so, the overall fit to the data was so insensitive to the choice of P_1 that this parameter could not be freely adjusted simultaneously with A_0, A_1, B, and C. By inspection, P_1 seemed to be in the range 0.0007 to 0.0015 bar^{-1}. The parameter values obtained are summarized in Table 2. Values of P_0 were in the range 0.41 to 0.51, and the average deviation calculated from observed void fraction was 0.011.

The more limited data from 1.27-cm ID tubes for consolidation in brine were insufficient to provide an independent set of P_1, A_0, A_1, and B values, but they were consistent with the above values. With these values fixed, the parameter C, which is the measure of the wall effect, was adjusted for all the smaller tube data (Table 2). Again P_0 was adjusted for each run. The values were in the same range as for the 2.54-cm columns. The average deviation calculated from observed void fraction in this case was 0.014.

The much smaller value of C for the 1.27-cm-diam columns suggests that the wall effect decreases rapidly with increasing diameter. If there were no effect of diameter, we would expect C for the smaller columns to be one-fourth of the value for the larger columns. In fact, the ratio seems to be about 1 to 88, suggesting that C increases with about the sixth power of the diameter. Thus, when viewed in terms of the distance down the column through which the applied stress is reduced by a factor of e, the wall effect appears to decrease as about the fourth power of the column diameter.

The magnitude of B should be the rate of growth in volume of the average salt particle during consolidation. Thus, after a week (10,000 min) the average size should be about 0.16 cm, which is much greater than any value that might be estimated from a section of a consolidated column shown in Fig. 8. It may be more appropriate, however, to take the effective particle size as that of an aggregate from which the brine has been excluded. As may be seen from the figure, such aggregates are roughly of this size.

Table 2

AN EXPRESSION FOR THE CONSOLIDATION OF SALT IN BRINE[a]

$$\phi(t) = \phi(0) - (A/B) \ln [1 + Bt/z(0)^3]$$

$\phi(0) = P_0 - 0.001\ \bar{\sigma}$

$A(293\ K) = (8.63 \pm 0.59) \times 10^{-9} + (3.93 \pm 0.29) \times 10^{-11}\ \bar{\sigma}$

$B(293\ K) = (3.18 \pm 0.23) \times 10^{-7}$

$A(T\ K) = A(293\ K) \exp [D\ (1/T - 1/293)]$

$B(T\ K) = B(293\ K) \exp [D\ (1/T - 1/293)]$

$D = -5130 \pm 320$

$\bar{\sigma} = \sigma(0)\ (C/W)\ [1 - \exp(-W/C)]$

$C = 213 \pm 22$ (in 2.54 cm ID columns)

$C = 3.1 \pm 0.8$ (in 1.27 cm ID columns)

Run No., P_0									
12	0.481	21	0.476	107	0.447	116	0.415	123	0.465
13	0.433	24	0.424	108	0.425	117	0.435	127	0.524
15	0.508	26	0.467	109	0.501	118	0.427	128	0.521
17	0.447	102	0.434	110	0.509	119	0.457	129	0.445
18	0.451	104	0.510	111	0.495	120	0.462	130	0.486
19	0.440	105	0.460	114	0.448	121	0.417	131	0.524
20	0.461	106	0.485	115	0.472	122	0.468	132	0.409

[a] Fitted by least squares to the consolidation runs in NaCl brine summarized in Table 1, and to the data showing the wall effect in Fig. 5 (see text): $\phi(t)$ is the void fraction at time t (min); $\sigma(0)$ is the applied stress (bars); $z(0)$ is the initial mean particle size (cm); W is the weight of salt in the column (g); $\bar{\sigma}$ is the stress after correction for the wall effect. In the absence of a wall effect, $\sigma(0)$ replaces $\bar{\sigma}$ in the expressions for $\phi(0)$ and A.

Fig. 8. Section of salt column (2.54 cm diam) consolidated at an applied stress of 155 bars and an initial average particle size of 322.2 μm.

3.4 Effect of Temperature

The results at 50 and 85°C could be adequately accounted for by assuming that A_0, A_1, and B in Eq. (9) all had the same exponential dependence on the absolute temperature T, for example,

$$B(T) = B(293)\exp[D(1/T - 1/293)]\,. \qquad (10)$$

The parameter D was assumed to be the same for all three quantities (Table 2) because (1) the coefficient of the log term in Eq. (9)—$(A_0+A_1\bar{\sigma})/B$—was found to

have an inappreciable temperature dependence and (2) the temperature dependence of A_0 and A_1 could not be distinguished because the applied stress was not varied in these runs. The average deviation of the calculated from the observed void fraction in the five runs at elevated temperature was 0.012. Since one of the runs (128) involved twice the usual amount of salt, it was possible to test for a temperature dependence of the parameter C, related to the wall effect. It appeared that the wall effect decreases (C increases) rapidly with temperature, but the data are insufficient to define the magnitude of this dependence.

3.5 Initial Void Fraction

As already noted, while the initial void fraction seemed to decrease about linearly with the stress, it was also dependent on the particle size and size distribution. This effect is indicated by seven runs, all with the same amount of salt in brine under the same applied stress (Table 3). In four of these, the usual narrow size distributions (cuts) were used. The average crystal size increased from 0.0110 to 0.0322 cm, whereas $\phi(0)$ decreased from 0.38 to 0.33. In three runs, mixtures of cuts gave $\phi(0)$ values less than 0.34. Of this series, the run (132) that gave the lowest value of $\phi(0)$ (0.28) involved a mixture with a fairly uniform distribution of particle sizes across the full range from 75 to 420 μm. A mixture (Run 122) of a large number of the smallest particles with a small number of the largest particles and a mixture (Run 123) of equal numbers of the smallest and the largest particles gave higher $\phi(0)$ values (0.34 and 0.33). Such behavior is not surprising: for particles with a narrow size distribution, the initial void fraction should be relatively high. For a wider size distribution, the void fraction should be less because of more efficient packing; but if the size distribution is wide and bimodal (as in Run 123), the packing will be determined by the larger particles and the void fraction will be higher. The results in Table 3 suggest that the average fractional deviation from the mean particle size might be a better measure of this effect than the fractional root-mean-square deviation.

3.6 Effect of the Fluid Phase

Values of the parameters $\phi(0)$, A, and B calculated from Eqs. (4) and (5) are compared in Table 4 for a series of runs in which the fluid phase was varied. The value of $\phi(0)$ is in the range 0.34 to 0.38 for all fluids except air which gave a value of 0.41. The parameters A and B are highest for pure NaCl brine, and both decrease in the same order (NaCl brine > dry dodecane > NaCl-$MgCl_2$ brine > wet dodecane); however, B shows a wider variation than A. The resulting consolidation

Table 3

PARTICLE SIZE DISTRIBUTION IN SALT BATCHES AND EFFECT ON INITIAL VOID FRACTION

Cryst. Batch[a]	Ave. Part. Size (cm) z(0)	Standard Dev. (cm)[b] σ/z	Ave. Dev. (cm) σ/z	Fractional Deviations σ/z / z(0)	σ/z / z(0)	Run No.	Init. Void Fraction[c] φ(0)
Cut 1	0.01102	0.00290	0.00246	0.263	0.223	104 109	0.379 0.370
Mix 1	0.01192	0.00523	0.00320	0.439	0.269	122	0.337
Cut 2	0.01788	0.00195	0.00166	0.109	0.093	106	0.354
Cut 3	0.01877	0.00256	0.00220	0.137	0.117		
Mix 2	0.02016	0.00832	0.00750	0.413	0.372	132	0.278
Mix 3	0.02195	0.01149	0.01067	0.523	0.486	123	0.334
Cut 4	0.03222	0.00553	0.00469	0.172	0.145	105	0.329

[a] The nominal size ranges were: cut 1, 75–150μm; cut 2, 150–177μm; cut 3 177–250μm; cut 4, 250–420μm. The mixtures were made as follows: mixture 1, 37.5 g each of cut 1 and cut 4; mixture 2, 2.12 g, 8.98 g, 10.74 g, and 53.16 g of cuts 1, 2, 3, and 4, respectively; mixture 3, 3 g of cut 1 and 73 g of cut 4. These batches were used in runs in the 2.54 cm i.d. monel tube. In the 1.27 cm i.d. glass tubes, the size ranges used were: 75–125μm, 150–180μm, and 250–425μm. The size distributions were not determined

[b] The root mean square deviation from the mean particle size.

[c] With 75 g of salt in NaCl brine at about 20°C, in the 2.54 cm monel tube, and under an applied stress of 155 bars: φ(0) is calculated from the parameters in Table 2.

Table 4

EFFECT OF FLUID PHASE ON CONSOLIDATION[a]

Run No.	Fluid Phase	a	b	c (min)	Std. Err. of Fit	φ(0)	A (cm^3/sec)	B
104	6.1 m NaCl	0.4501	0.044408	5.4	0.009	0.375	1.10	25
109	6.1 m NaCl	0.4386	0.044613	3.9	0.008	0.378	1.53	34
124	0.14 m NaCl 5 m $MgCl_2$	0.5480	0.037301	113.7	0.004	0.371	0.044	1.18
125	Wet Dodecane	0.7173	0.068266	263.2	0.011	0.337	0.035	0.508
126	Dry Dodecane	0.3798	0.011706	10.4	0.003	0.352	0.151	12.9
113	Air	0.4025	0.023010	0	0.001			

[a] All runs were made with 75 g of salt cut 1 (cf. Table 3) in the 2.54 cm i.d. monel tube, with an applied stress of 155 bars, and at ~20°C. The parameters a,b,c (Eq. 4) were fitted by least squares with the indicated standard deviation. The parameters φ(0), A and B (Eq. 3) are derived from a,b, and c using Eq. 5.

curves in Fig. 7 have the order NaCl > wet dodecane > 5 *m* $MgCl_2$ > dry dodecane > air. This result is the expected one with the exception of wet dodecane, that is, dodecane in contact with undried salt. The small amount of NaCl brine present evidently greatly enhances the rate of consolidation. The 5 *m* $MgCl_2$ brine, involving much lower NaCl concentrations, considerably retards consolidation. The low consolidation rate in air indicates that mechanical deformation does not play a large role in consolidation.

3.7 Permeability of Consolidating Salt

The permeability *Pm* of a consolidating column of salt varied approximately as the square of the average particle size and decreased rapidly as consolidation proceeded. The results are summarized in Fig. 9, where the log of the ratio $Pm/\bar{z}(0)^2$ is plotted vs. the log of the void fraction. Though there is considerable scatter, a good correlation is obtained with a straight line corresponding to the expression

$$\ln Pm(t)/\bar{z}(0)^2 = 21 + 6 \ln \phi(t) , \tag{11}$$

where the permeability is defined as the brine flow (g/min) through a 1-cm^2 area under a hydrostatic pressure gradient of 1 bar/cm; that is, the units are g-cm^{-1} min^{-1} bar^{-1}. The right-hand scale in Fig. 9 shows the specific permeability *Ps* in darcy units, which is the flow (cm^3/s) of a liquid with a viscosity of 1 cP through 1-cm^2 area under a hydrostatic pressure gradient of 1 atm/cm. The specific permeability predicted from the Blake-Kozeny equation,[12] a good empirical correlation for porous media, is given by

$$Ps(\text{darcy}) = 6.76 \cdot 10^6 \bar{z}^2 \phi^3/(1-\phi)^2 . \tag{12}$$

For saturated brine at room temperature, with a density of 1.205 g/cm^3 and a viscosity of 1.27 cP, the predicted permeability is

$$Pm(\text{g-cm}^{-1}\text{min}^{-1}\text{bar}^{-1}) = 2.72 \cdot 10^7 \bar{z}^2 \phi^3/(1-\phi)^2 . \tag{13}$$

This equation was used to construct the dashed curve in Fig. 9.

The Blake-Kozeny equation gives a good estimate of the initial permeability of an unconsolidated bed of salt crystals. As consolidation proceeds, the expected dependence of permeability on the square of the initial particle size remains a good approximation; however, the permeability falls much more rapidly with the void fraction than this equation predicts, showing about a sixth power dependence. If this dependence continues below $\phi = 0.06$ (the lower limit of our measurements), then at void fractions of 0.02 in a bed of consolidated 100- μm crystals (which could be reached after only one week under some of our experimental conditions), the specific permeability would be about 0.2 μdarcy. Thus, consolidation of salt crystals may ultimately permit achievement of a permeability comparable to that of intact salt.

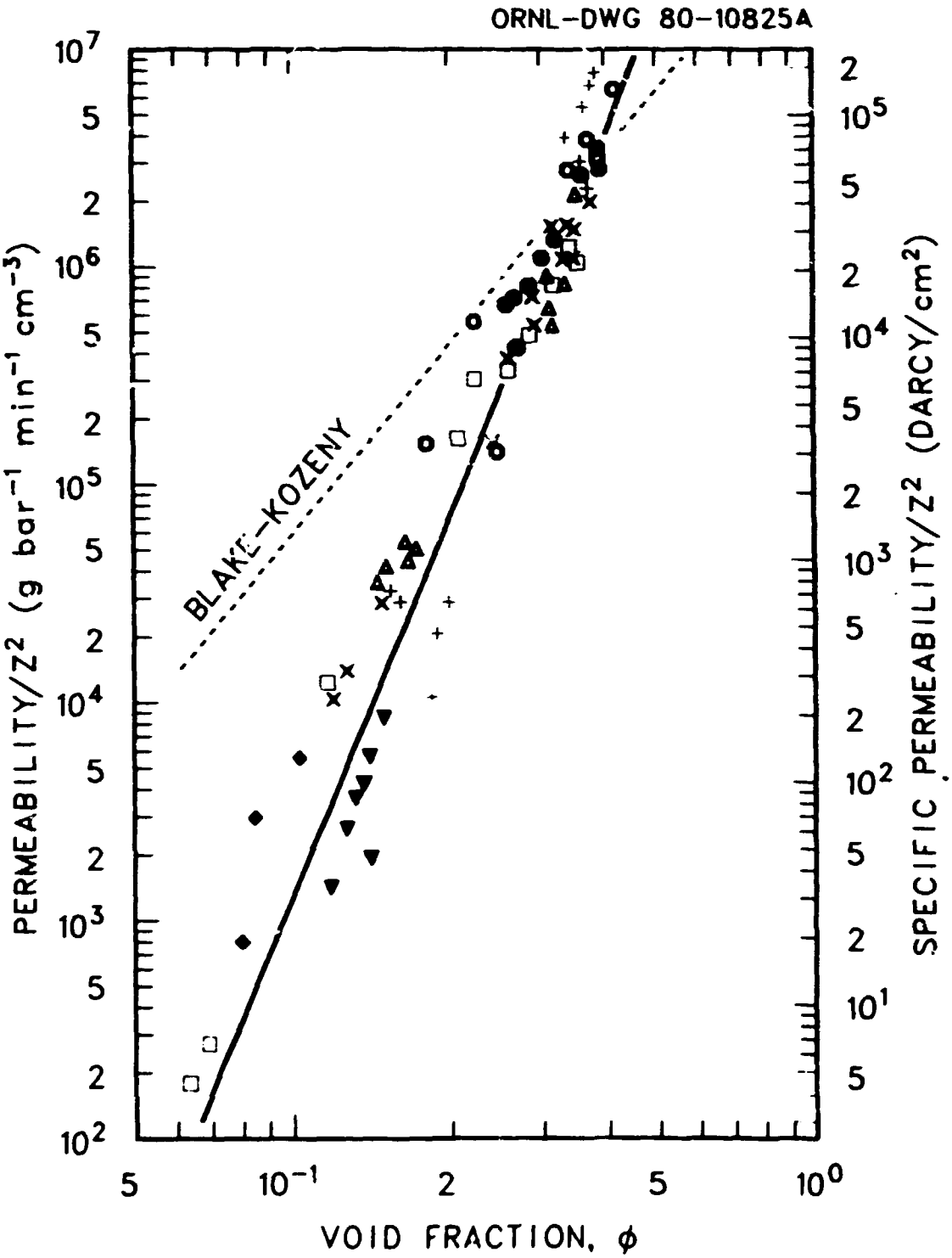

Fig. 9. Permeability of salt columns in which the void fraction is reduced by consolidation. The various symbols denote different runs. The solid line has been drawn with a slope of 6, and the dashed line represents permeability predicted by the Blake-Kozeny equation.

4. SUMMARY AND CONCLUSIONS

Beds of salt crystals in brine and other fluids subjected to a constant applied stress consolidated in an approximately linear fashion with the logarithm of time. The rate increased with increasing stress and decreased with increasing particle size. The decrease of the void fraction ϕ with time t could usually be described almost within experimental error (Figs. 2-6, 7, Table 1) by a simple three-parameter equation [Eq. (4)].

This equation can be transformed [Eqs. (5)] into one [Eq. (3)] suggested by Coble[9,10] to describe the kinetics of sintering in terms of three parameters—the initial average particle size $\bar{x}(0)$, a rate constant A for the loss of void volume, and a rate constant B for the growth of the average particle size. It was found that the initial void fraction $\phi(0)$ and A varied approximately linearly with the applied stress σ.

A substantial wall effect was indicated by an observed decrease of the void fraction with distance from the top of the consolidating column where the stress was applied (Fig. 5) and by the observation that shorter columns consolidated faster than taller ones of the same diameter (Fig. 3a). This effect was represented by an exponential decrease in the local stress with distance from the top of the column expressed as the weight of intervening salt w [Eq. (7)].

This correction for the wall effect and an assumed linear dependence of $\phi(0)$ and A on the local stress gave a general expression [Eq. (9) and Table 2] that could be fitted to all the consolidation data obtained in NaCl brine for both 2.54-cm-diam columns in Monel tubes and 1.27-cm columns in glass tubes and at temperatures from 20 to 85°C. The parameter C, the weight of salt through which the local stress is assumed to drop by a factor of e, was found to increase as about the sixth power of the column diameter. Thus, the distance down the column through which the local stress decreases by a given amount due to the wall effect appears to increase as about the fourth power of the diameter. The limited data at elevated temperatures (to 85°C) suggested that A and B increased with about the same exponential dependence on the absolute temperature (Table 3) and that the wall effect decreased with increasing temperature.

In fitting the data, it was necessary to adjust the initial void fraction $\phi(0)$ for each run (Table 2), evidently because this quantity depended to some extent on the particle size and the size distribution (Table 3) as well as the stress.

The rate of consolidation was found to decrease markedly when large amounts of $MgCl_2$ were added to the brine (Fig. 7), presumably because of the resulting decrease in the solubility of NaCl (Table 4). Even undried salt in dodecane consolidated more rapidly than salt in the magnesium-rich brine, suggesting that the concentration of NaCl in the brine is more important than the amount in determining the rate of consolidation. Dried salt in air showed the lowest consolidation rate, suggesting that mechanical deformation was not an important mechanism in consolidation.

The permeability of salt columns decreased with the second power of the initial particle size [Eq. (12)], as expected from the Blake-Kozeny equation;[12] but as consolidation proceeded the permeability decreased with the sixth power of the void fraction [Eq. (11)], much more rapidly than would be expected from the Blake-Kozeny correlation (Fig. 9).

Several important implications may be drawn from these studies regarding the suitability of bedded halite as a storage medium for radioactive waste. Perhaps most

important are (1) the rapidity with which consolidation can take place and (2) the low permeabilities that can result. Thus, from the general expression fitted to our data in NaCl brine, at a lithostatic stress of about 100 bars and a temperature of 30°C, we have

$$\phi(t) = \phi(0) - 0.04 \ln\left(1 + 0.3t/z(0)^3\right), \qquad (14)$$

when t is expressed in years and $z(0)$ in centimeters. Extrapolating this expression to larger crystals and longer times suggests that a medium of 1-cm crystals would consolidate and, from Eq. (11), lose its permeability to flowing NaCl brine about as follows:

	Time (y)						
	0	10	100	1000	10,000	27,000	34,700
ϕ	0.37	0.31	0.23	0.14	0.05	0.01	0.00
Pm (darcy)	86,000	30,000	5000	250	0.5	3×10^{-5}	

If the initial size of the crystals were reduced to 1 mm, these times would be reduced a thousand-fold; that is, consolidation would be complete in about 35 years. The permeability at a given void fraction would be reduced a factor of 100 and at 27 years would have fallen to 0.3 μdarcy. Thus, the self-sealing properties of bedded salt which originally attracted attention to this material as a storage medium are supported by the present measurements.

Another important implication is the fact that the present consolidation results can be rationalized in terms of an expression developed to treat sintering kinetics. If, as appears to be the case, salt consolidation is indeed analogous to sintering, then it involves the growth of crystals by the movement of grain boundaries. This would provide a means of including foreign ions within crystals. While NaCl is a poor sorber for all radionuclide ions except possibly Cs^+ and I^- in very small amounts, it is quite possible that other minerals and barrier materials could consolidate by a similar mechanism and thus provide a possibly important mechanism for the immobilization of radionuclide ions.

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A Constitutive Model for the Consolidation of WIPP Crushed Salt and Its Use in Analyses of Backfilled Shaft and Drift Configurations

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A Constitutive Model for the Consolidation of WIPP Crushed Salt and Its Use in Analyses of Backfilled Shaft and Drift Configurations

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Abstract

A constitutive model for the consolidation of wet crushed salt material is presented in this report. The material parameters for this model are derived from hydrostatic consolidation tests performed on wet salt taken from the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. The constitutive model is then used for analyses of the interaction between intact and crushed salt in realistic field configurations such as backfilled and open shafts and drifts. The calculations are used to show that the wet crushed salt does not significantly retard the rate of closure of shafts and drifts until the crushed salt is consolidated to approximately 95 percent of intact salt density. An approximate method for modeling the creep rate of intact salt is developed which more closely matches the closure data from empty drifts at the WIPP site in order to provide a more realistic estimate of the crushed salt response.

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A.1 Bulk Modulus Data for Dry Crushed Salt Material [8] 60

1. Introduction

The consolidation behavior of crushed, or granulated, salt is of interest to the Waste Isolation Pilot Plant (WIPP) project because salt removed from the excavations in the relatively pure rock salt is a likely material to be used as a backfill material and as a component of a multiple material sealing system. Crushed salt is expected to be an effective long term seal material because it readily consolidates to a dense state when subjected to sufficient confining pressure and because it is compatible with the host formation. It would be used around nuclear waste canisters, and then later as a void filler in storage rooms, shafts, and other openings when the facility is completed.

Rock salt has been used as backfill in mining operations in the past, particularly in potash mines. In that case, the crushed salt's primary function was to lessen subsidence seen at the ground level. For the WIPP it must also retard the migration of radionuclides and its performance in this regard must be predictable. Structural analyses are necessary to predict the long term response of storage drifts and the resulting compaction of the sealing and backfill material. These analyses require that a constitutive model describing the mechanical response of the crushed salt material be available.

At this time the type and composition of sealing materials for the WIPP has not been definitely decided because tests of the various candidate materials are still underway. However, the major sealing material will probably be crushed salt with a small amount of added water. Other candidate materials include mixtures of salt and bentonite, bentonite and sand, and bricks composed of compacted wet crushed salt or crushed salt and bentonite. This study was undertaken to determine the sensitivity of drift and shaft closure to the consolidation properties of the selected sealing material.

1.1 Testing of Crushed Salt Material

Laboratory testing of crushed salt has been performed by several investigators. The initial tests were performed with dry crushed salt. Hansen [3] performed a series of quasi-static and consolidation tests on granulated commercial-grade salt and Gnirk [2] performed consolidation tests on granulated salt from the Avery Island Mine. Holcomb and Hannum [8] performed several quasi-static and creep tests on salt from the Mississippi Chemical mine (south-east New Mexico) and from the

WIPP. These tests were done at temperatures of 20°, 40°, 60°, 80°, and 100° C, and hydrostatic stresses from 1.7 MPa to 21 MPa.

Recently Holcomb [5] showed that the addition of a small amount of water, less than approximately 2.5% by weight, to the crushed salt material significantly increases the consolidation rate relative to dry crushed salt material. Holcomb and Shields [4], and Pfeifle and Senseny [14] have since performed several tests on the wet crushed salt material. The results of Holcomb and Shields are of particular interest here because the tests were conducted on wet crushed salt material for long enough times and with a complete enough test matrix to characterize the volumetric creep behavior reasonably well. These test results have been used almost exclusively in this report.

1.2 Organization

This report presents a computational model for wet crushed salt including the derivation and integration of the constitutive model, the determination of the material parameters, and the results of several calculations performed using this model. Although models will have to be developed for each of the backfill materials selected for the WIPP and this entire process repeated each time, the procedures developed here for wet crushed salt should aid in the selection process. Preliminary experimental results have also shown that the consolidation behavior of the crushed salt and bentonite material is similar to the behavior of wet crushed salt [17]. If this trend is verified, the wet crushed salt constitutive model can be used to model the consolidation of the crushed salt and bentonite material simply with a change of material parameters.

The remainder of this report is organized as follows. The first section describes the experimental data upon which the model is based and the data fitting procedure used to determine the material constants. The next section is a derivation of the constitutive equation and describes how it is integrated. The results of several calculations performed with this model are then described. It then finishes with a summary of the report and a discussion of the direction of future work with the model.

2. Data Reduction Procedure

This section documents the data reduction method used to determine the parameters for the constitutive model describing the volumetric consolidation behavior of *wet* crushed salt material. The data used to determine these parameters are the results of the hydrostatic consolidation tests on WIPP salt with added water by Holcomb and Shields [4].

Wet crushed salt refers to crushed salt with a small amount of water added to increase the consolidation rate. The moisture content used in the tests varied from 0.5% to 3.0% water by weight. The minimum moisture content necessary to cause an increased consolidation rate has not yet been determined, but the increased consolidation rate has been seen for crushed salt with a moisture content of less than 0.5% by weight.

2.1 Basic Definitions and Nomenclature

The meanings of the symbols used in this chapter are:

e_v	=	Volumetric strain, positive in compression (decreasing volume)
P	=	Pressure, positive in compression
ρ	=	Absolute density measured in g/cc
ρ_0	=	Density of material when $e_v = 0$
ρ_∞	=	Density of intact salt, 2.14 g/cc
D	=	Fractional density = ρ/ρ_∞

The following conversions are used between volume strains and densities:

$$e_v = 1 - \rho_0/\rho \tag{2.1.1}$$

$$\dot{e}_v = \rho_0\dot{\rho}/\rho^2 \tag{2.1.2}$$

$$\rho = \rho_0/(1 - e_v) \tag{2.1.3}$$

$$\rho \approx \rho_0(1 + e_v) \quad \text{for small } e_v \tag{2.1.4}$$

$$\dot{\rho} = \frac{\rho_0\dot{e}_v}{(1 - e_v)^2} = \dot{e}_v\rho^2/\rho_0 \tag{2.1.5}$$

A superposed dot indicates the time rate of change of the quantity.

2.2 Experimental Work

Holcomb and Shields have performed several hydrostatic consolidation tests on WIPP salt with added water [4]. The samples were cylindrical specimens 10.4 cm in diameter by 14.6 cm long and encased in thin lead jackets. The samples were tested by applying a uniform pressure on the entire surface of the sample. The uniform pressure was applied for a short period of time and then removed to preconsolidate the samples. The pressure was then reapplied and held constant while the volumetric change was noted as a function of time. The test duration was typically 23 days. Tests were conducted at room temperature under hydrostatic pressures of 1.72 MPa (250 psi) and 3.44 MPa (500 psi), and a range of moisture contents from 0.5 percent to 3.0 percent water by weight. Two other tests have been completed since the data reduction procedure described below was documented. Test 27JU61 [6] was conducted at a hydrostatic pressure of 0.69 MPa (100 psi), and test 240C61 [7] was conducted with a confining pressure which varied from 0.35 MPa (50 psi) to 6.90 MPa (1000 psi) in 5 increments over the duration of the test as shown in Figure 2.1. These last two tests were not available when the model was developed and the data reduction procedure was carried out. Instead, these tests are used for verification of the model. The procedure described here will be reapplied to update the material parameters when the data from all of the tests become available.

The volume strain histories from each creep test were found to be fitted very well by an empirical equation of the form

$$e_v = a \log_{10} t + c \tag{2.2.1}$$

where t is the time in seconds, and a and c are constants which were fitted in a least square manner to the data for each test. The values of a and c for each of the tests are taken from Holcomb [4] and reproduced in Table 2.1.

2.3 Data Reduction Procedure

The relationship described by Equation (2.2.1) can be approximated by a differential equation of the form

$$\dot{\rho} = B(P)e^{A\rho} \tag{2.3.1}$$

where ρ is the density of the sample, $\dot{\rho}$ is the time rate of change of the density, $B(P)$ is a function of the applied pressure, and A is a parameter to be determined. The parameters are not necessarily constants and can be functions of pressure, water content, or some other quantity.

Equation (2.3.1) is preferable to Equation (2.2.1) for our purposes here because explicit references to time have been eliminated and because the consolidation rate is

explicitly given as a function of the absolute quantity, density, rather than a quantity such as e_v which has an arbitrary zero state. To determine the constants A and B in Equation (2.3.1), the volume strains were calculated using Equation (2.2.1) at 100 times equally spaced over the duration of the test. These volume strains were then converted to densities using Equation (2.1.3). The volumetric strain rate at each time interval was calculated by differentiating Equation (2.2.1) with respect to time. Equation (2.1.5) was then used to determine the consolidation rate corresponding to this volumetric strain rate. A linear regression procedure was then used to determine the least squares linear fit of the equation

$$\ln \dot{\rho} = B' + A\rho \tag{2.3.2}$$

to the calculated data for each test where B' is equal to $\ln B(P)$. The coefficients of correlation for each of the regression analyses were greater than 0.999 indicating that Equation (2.3.2) and therefore Equation (2.3.1) is an accurate approximation to Equation (2.2.1). The computed values of A and B' for each test are given in Table 2.2. Figure 2.2 is a plot of $\ln \dot{\rho}$ vs. ρ for each of the tests. The dashed lines indicate tests conducted at a confining pressure of 1.72 MPa; the solid lines indicate tests conducted at a confining pressure of 3.44 MPa; and the dotted line is the test conducted at a confining pressure of 0.69 MPa. The basic form of Equation (2.3.1) will be generalized to include the effect of pressure before the constants are determined.

2.4 Pressure Dependence of Consolidation Rate

The data shown in Figure 2.2 indicate that, at a given density, the consolidation rate is generally faster for the increased pressure tests, although test 19DC44 (curve K), consolidated at a slower rate than any of the 1.72 MPa tests. Another indication that the consolidation rate increases with increasing pressure is the 23JL51 (curve B) test data. This test was conducted with a confining pressure of 1.72 MPa for approximately 1.4 million seconds. The confining pressure was then increased to 2.52 MPa for approximately 150,000 seconds and then reduced to the original pressure for the remainder of the test. The consolidation rate during the increased pressure phase of this test is faster than the consolidation rates, at approximately the same densities, during the lower pressure phases of the test. Figure 2.3 is a plot of the fractional density vs. time for this test.

The 23JL51 test data were used to determine the pressure dependence of the consolidation rate. These data were used rather than determining the pressure dependence from two distinct tests at different pressures. In this way, the pressure dependence is isolated from the effects of the inherent sample-to-sample variation.

The different consolidation rates before and after the pressure changes are assumed to be caused only by the pressure variation. Therefore, the consolidation rates

are related by

$$\frac{\dot{\rho}_{1.72}}{f(P=1.72)} = \frac{\dot{\rho}_{2.52}}{f(P=2.52)} \tag{2.4.1}$$

where $f(P)$ is a pressure function. The form of the pressure function chosen to describe this behavior is

$$f(P) = \exp(B_1 P) - 1 \tag{2.4.2}$$

where P is the pressure, positive in compression, and B_1 is a constant to be determined from the data. This pressure dependence is the same as that found for dry crushed salt where data at four different pressures were available [18]. Since the wet salt consolidation tests were conducted at only two distinct pressures, the form of the pressure function is not completely defined by the wet salt data alone.

The consolidation rate prior to the pressure increase in test 23JL51 is estimated to be $\dot{\rho} = 4.1\times10^{-8}$ g/cc·s. During the increased pressure phase, the consolidation rate is estimated to be $\dot{\rho} = 9.2\times10^{-8}$ g/cc·s. Using Equations (2.4.1) and (2.4.2), the constant B_1 is determined such that

$$\frac{\exp(1.72B_1) - 1}{\exp(2.52B_1) - 1} = \frac{4.1\times10^{-8}}{9.2\times10^{-8}} = 0.4493 \tag{2.4.3}$$

Solution of this equation results in a value of $B_1 \approx 0.82$. The pressure dependence of the consolidation rate is therefore:

$$f(P) = \exp(0.82P) - 1 \tag{2.4.4}$$

2.5 Density Dependence of Consolidation Rate

The pressure effect can be removed from the test data by dividing the consolidation rate by the pressure function (Equation (2.4.4)). Figure 2.4 is a plot of $\ln(\dot{\rho}/f(P))$ vs. ρ for all of the test data. The data show some scatter, but a definite grouping of the tests can be observed; the slopes of these curves are about the same. The remaining constants in Equation (2.3.1) were determined from these *pressure-shifted* data. A linear regression was used to give a least squares fit of all of the pressure-shifted data to an equation that is only a function of density. The resulting equation is

$$\ln\left[\frac{\dot{\rho}}{\exp(B_1 P) - 1}\right] = B_0' + A\rho = 12.7 - 17.3\rho \tag{2.5.1}$$

where B_0' is equal to $B'/f(P)$. Using these results and Equation (2.4.4), the final form of the consolidation equation for wet crushed salt is

$$\dot{\rho} = 1.3\text{E}5[\text{e}^{0.82P} - 1]\text{e}^{-17.3\rho} \tag{2.5.2}$$

This equation is the same as Equation (2.3.1)

$$\begin{aligned} \text{where:} \quad B &= B_0\left[e^{B_1 P} - 1\right], \\ B_0 &= 1.3\times 10^5, \text{ and} \\ B_1 &= 0.82 \end{aligned}$$

Figures 2.5 and 2.6 are comparisons of the densities predicted by Equation (2.5.2) to those found in the consolidation tests for 1.72 MPa and 3.44 MPa confining pressures, respectively. The model falls almost in the middle of the data for each test. The model was then used to predict the responses of the two later tests that were not used to determine the model parameters. The results are shown in Figures 2.7 and 2.8 for tests 27JU61 and 240C61, respectively. Note that Equation (2.5.2) overpredicts the 27JU61 data at later times. This trend is also evident in the 240C61 comparison, however the agreement is remarkably good considering that these data were not used in the determination of the material parameters for the model.

2.6 Remarks

- The consolidation equation does not account for the effect of temperature on the consolidation rate—all of the tests were conducted at the same temperature. The form and constants of Equation (2.5.2) will have to be modified when data at other temperatures become available.

- Tests conducted at lower pressures are needed. Backfilled shaft and drift calculations performed with the model indicate that the maximum pressure in the backfill material is less than 0.5 MPa during most of the consolidation process for backfilled shafts and drifts at the WIPP. The consolidation behavior at these low pressures must be extrapolated by the model from the behavior at the test pressures (1.72 MPa and 3.44 MPa).

- The material constants developed in this section should only be used for the *wet* crushed salt material. The results of the tests on wet crushed salt backfill material do not show a strong correlation between the consolidation rate and the moisture content. The only correlation that has been found is that a small amount of added water greatly accelerates the consolidation rate compared to the consolidation rate of dry salt. The minimum moisture content required to achieve this accelerated rate has not yet been determined.

- The data from a limited number of tests were used to develop the model; additional tests are planned. The current constants may be modified as more test data become available.

- The results of consolidation tests on dry crushed salt backfill materials are also fitted very well [8] to an equation of the form of Equation (2.2.1). Therefore, the procedure outlined in this memo can also be used to reduce the data for those tests.

- A *slow* consolidation equation can be developed to bound the results of consolidation analyses. The stiffest or slowest consolidation rate was observed in test 19DC44. If the pressure dependence and the density dependence (constants A and B_1) are assumed to remain constant, a new value can be determined for the constant B_0 in Equation (2.5.1) to approximate the slow consolidation of this test. The resulting equation is

$$\dot{\rho}_{\text{stiff}} = 5.42 \times 10^4 \left[e^{0.82P} - 1 \right] e^{-17.3\rho} \tag{2.6.1}$$

Table 2.1. Results of Hydrostatic Consolidation Tests on WIPP Salt With Added Water [4]

Curve	Test-ID	P_C	H_2O	D_0	D_q	D_{fm}	D_{fd}	a	c
A	27JU61	0.69	.025	.67	.70	.82	.82	5.3×10^{-2}	−.18
B	23JL51	1.72	.005	.70	.74	.84	.85	5.2×10^{-2}	−.15
C	14NV51	1.72	.015	.69	.73	.87	.89	6.8×10^{-2}	−.22
D	16FE61	1.72	.020	.68	.71	.85	.87	6.2×10^{-2}	−.19
E	10MY51	1.72	.024	.66	.74	.85	.88	5.8×10^{-2}	−.12
F	20AU51	1.72	.030	.63	.71	.88	.86	6.0×10^{-2}	−.11
G	16JL51	3.44	.005	.65	.74	.89	.89	5.4×10^{-2}	−.06
H	18JU51	3.44	.010	.68	.77	.90	.95	5.8×10^{-2}	−.08
I	30OC51	3.44	.015	.69	.77	.91	.91	5.4×10^{-2}	−.09
J	16JA61	3.44	.020	.70	.76	.90	.91	5.3×10^{-2}	−.10
K	19DC44	3.44	.024	.66	.72	.87	.89	5.8×10^{-2}	−.14
L	13AU51	3.44	.030	.64	.74	.91	.89	5.2×10^{-2}	−.05

P_C is the hydrostatic pressure in MPa.
H_2O is the water content expressed as fraction of salt mass.
D_0 is the initial fractional sample density.
D_q is the fractional density after initial pressurization.
D_{fm} is the fractional density after the test as determined from immersion.
D_{fd} is the fractional density after the test as determined from the real time dilatometer readings.
All densities were computed using just the mass of the salt.
The test duration was typically 2,000,000 seconds.
Curve cross-references the Test-ID to the Figures.

Table 2.2. Calculated Constants for Equation (2.3.2)*

Curve	Test-ID	P_C	H_2O	ρ_0	A	B'
A	27JU61	0.69	.025	1.43	-22.3	20.2
B	23JL51	1.72	.005	1.50	-20.7	20.1
C	14NV51	1.72	.015	1.48	-14.9	10.6
D	16FE61	1.72	.020	1.46	-17.1	13.8
E	10MY51	1.72	.024	1.41	-16.6	13.8
F	20AU51	1.72	.030	1.35	-15.9	12.0
G	16JL51	3.44	.005	1.39	-16.5	14.6
H	18JU51	3.44	.010	1.46	-14.5	12.4
I	30OC51	3.44	.015	1.48	-17.1	16.2
J	16JA61	3.44	.020	1.50	-18.1	17.8
K	19DC44	3.44	.024	1.41	-17.5	14.6
L	13AU51	3.44	.030	1.37	-17.5	15.8

*See Notes for Table 2.1

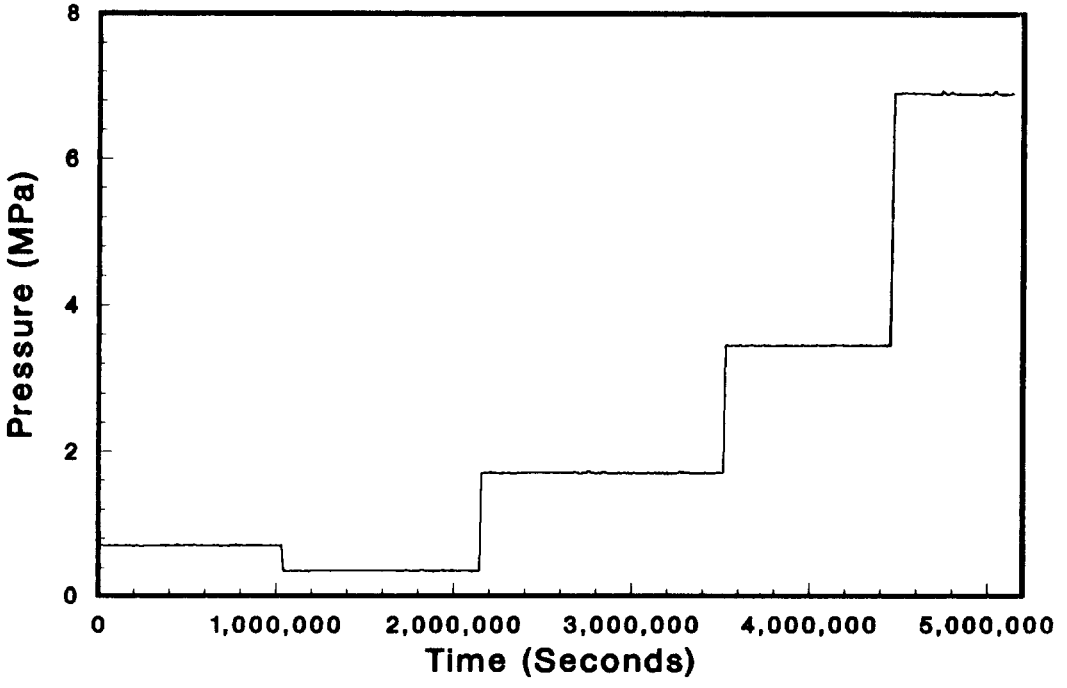

Figure 2.1. Pressure History for Test 240C61

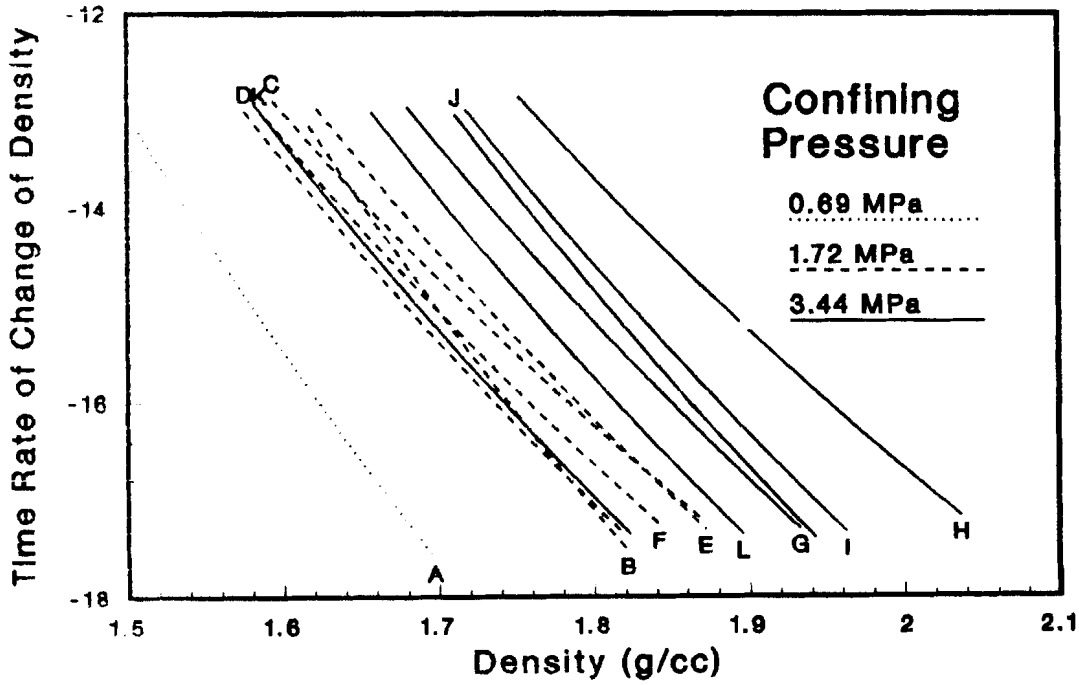

Figure 2.2. Consolidation Rate vs. Density for Hydrostatic Consolidation Tests on Wet Crushed Salt

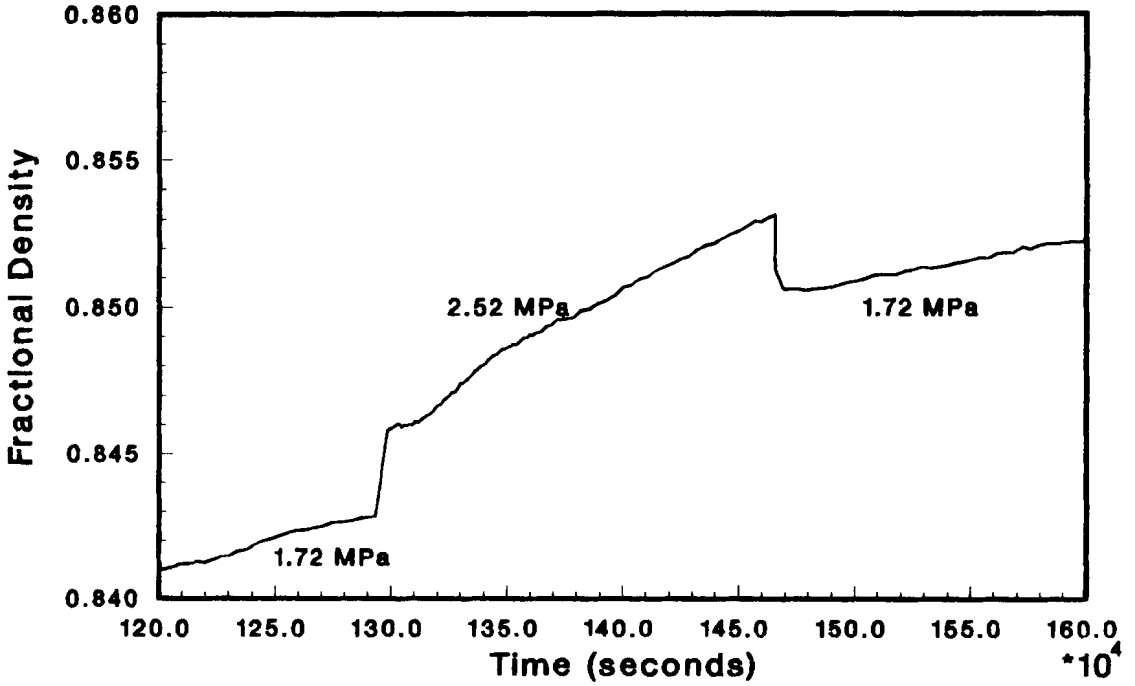

Figure 2.3. Fractional Density vs. Time for Test 23JL51

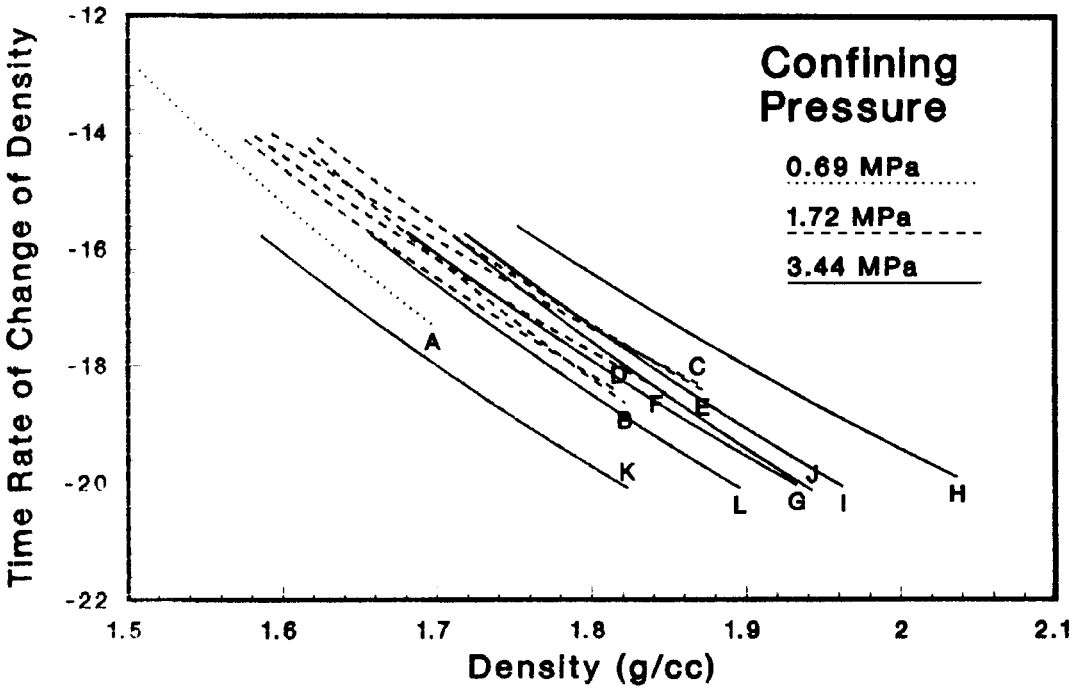

Figure 2.4. Consolidation Rate (Shifted for Pressure) vs. Density for Hydrostatic Consolidation Tests on Wet Crushed Salt

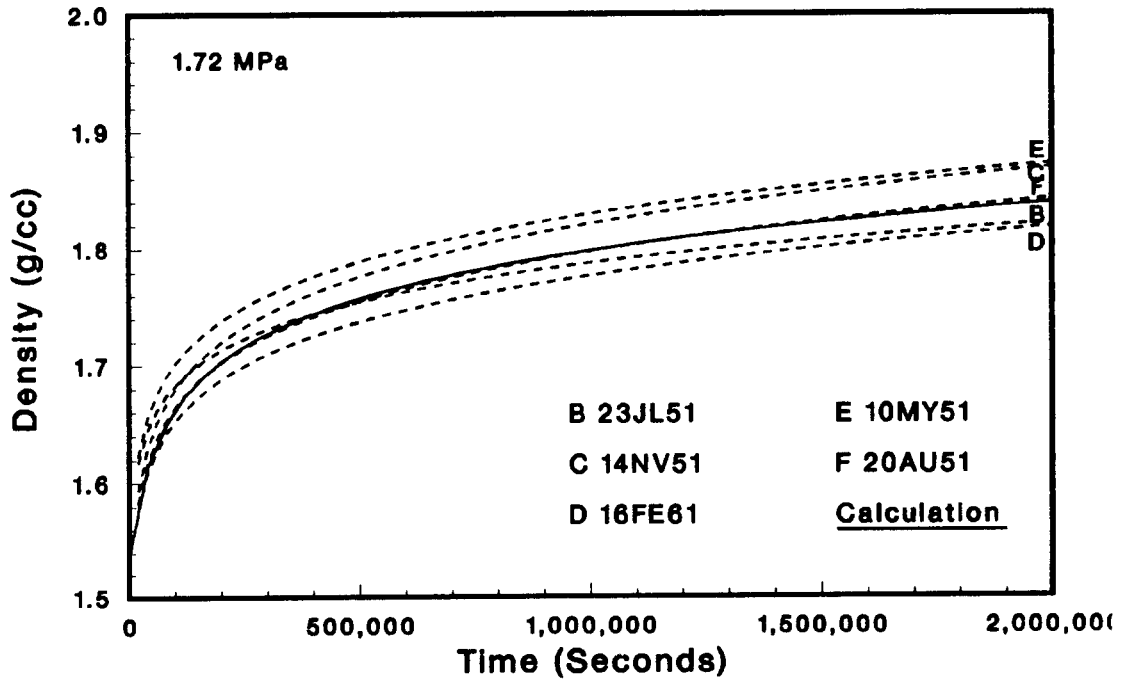

Figure 2.5. Comparison of Measured and Predicted Volumetric Creep for Confining Pressure = 1.72 MPa

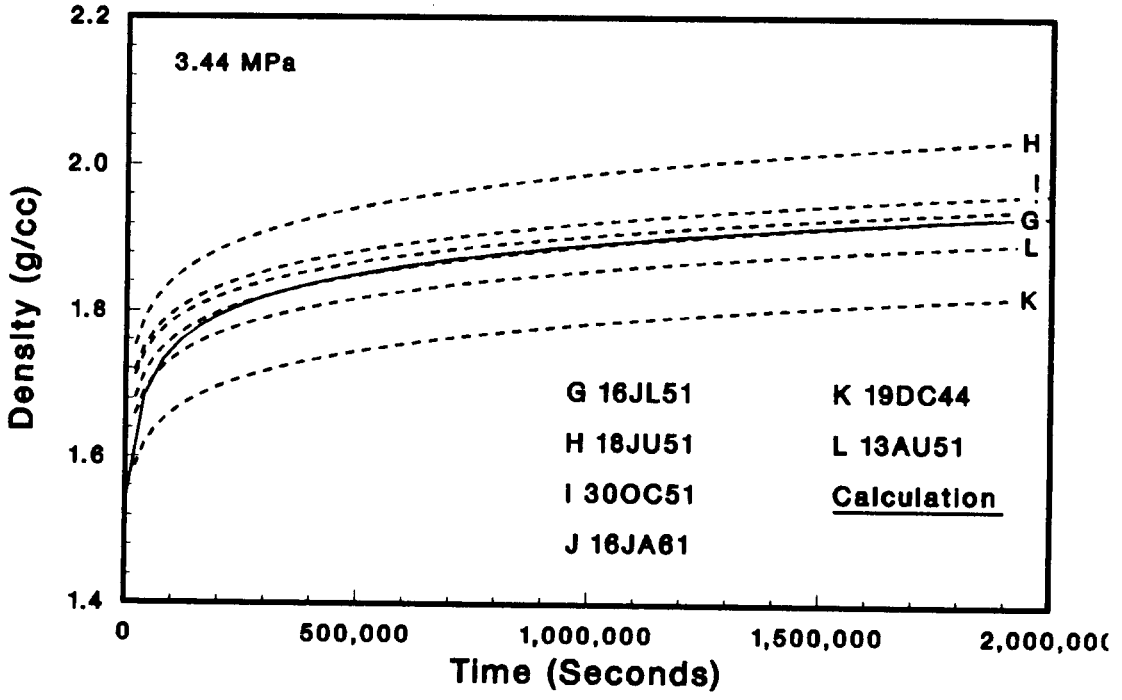

Figure 2.6. Comparison of Measured and Predicted Volumetric Creep for Confining Pressure = 3.44 MPa

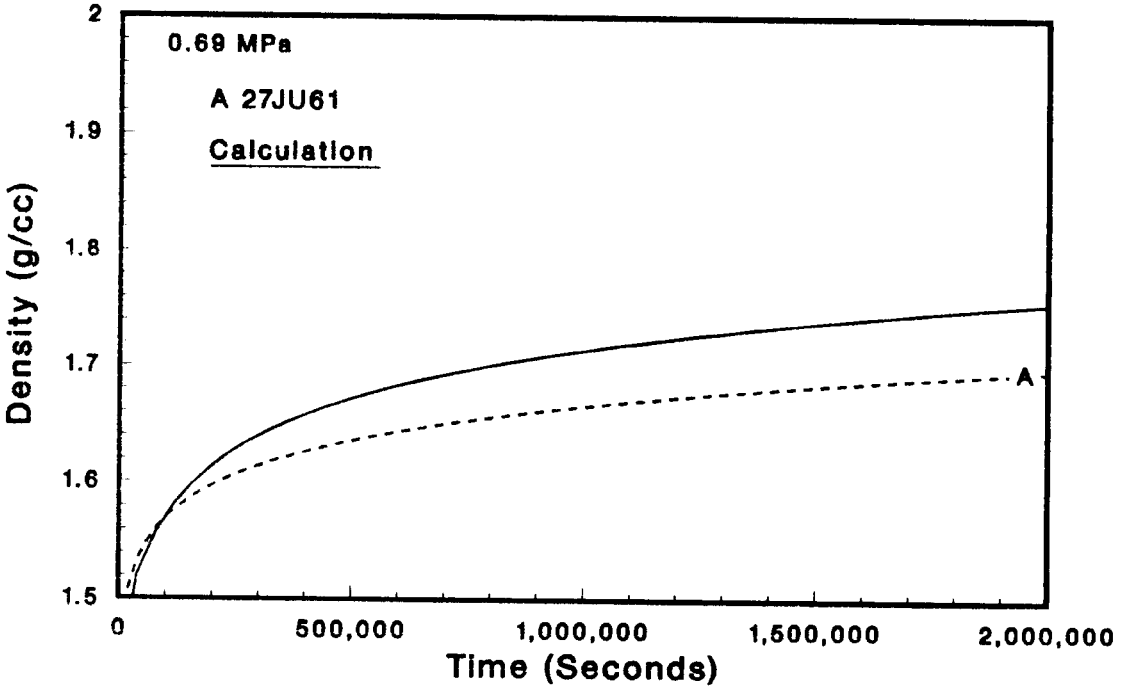

Figure 2.7. Comparison of Measured and Predicted Volumetric Creep for Confining Pressure = 0.69 MPa

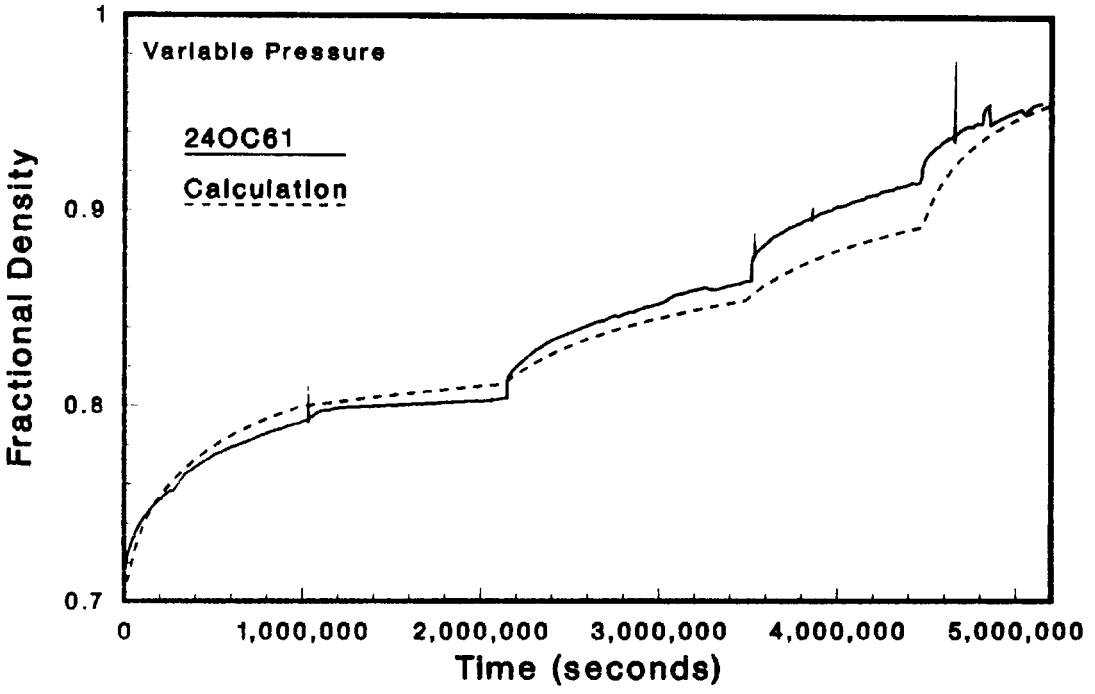

Figure 2.8. Comparison of Measured and Predicted Volumetric Creep for Variable Pressure Test 240C61

3. Constitutive Equation for Crushed Salt

This section describes the derivation of the constitutive model for crushed salt material. The model must describe an arbitrary stress state, including both volumetric and deviatoric terms. Here the volumetric behavior is assumed to be dominant because no laboratory data are presently available to describe the deviatoric behavior. The development of the deviatoric model is based entirely on judgement.

3.1 Previous Constitutive Models

Two of the more well known attempts to devise constitutive models for crushed salt are the empirical model of Ratigan and Wagner [16] and the sintering model of Zeuch, Holcomb and Lauson [24]. Both of these are based on data from tests on dry material and only describe the volumetric behavior. Ratigan and Wagner represented the creep behavior of dry crushed salt with the expression:

$$\dot{e}_{vc} = A(p/p_0)^n(T/T_0)^c(e_{vc})^{-m} \tag{3.1.1}$$

where: e_{vc} is the volumetric creep strain,
$\dot{e}_{vc}$ is the volumetric creep strain rate (1/s),
p is the pressure or mean stress (psi),
p_0 is the normalizing pressure (1450 psi),
T is the temperature (F),
T_0 is the normalizing temperature (32° F), and
A, m, n, and c are experimentally determined constants.

This expression is based on a limited amount of data and does not fit the data from the wet crushed salt tests particularly well. Zeuch, Holcomb and Lauson showed that a simple model for hot-pressing, used in the fields of ceramics and powder metallurgy to model the consolidation of powdered aggregates, fit the results of the individual creep consolidation tests in Reference [8] reasonably well. The equation is of the form

$$\frac{dD}{dt} = \frac{3P_c(1-D)}{4\eta}\left[\frac{1}{1-(1-D)^{2/3}} + \frac{\sqrt{2}\tau}{P_c}\ln(1-D)\right] \tag{3.1.2}$$

where: D is the fractional density,
t is the time,
P_c is the pressure,
η is the solid "viscosity", and
τ is the volumetric yield stress.

A limitation of this model is the prediction of a fractional endpoint density less than one. That is, the model implies that the density of intact salt may be unattainable. As shown in Reference [24] and also by McClelland in the original reference [11], setting the left side of Equation (3.1.2) to zero and solving for D_E gives

$$\left[1-(1-D_E)^{2/3}\right]\left[\ln\frac{1}{(1-D_E)}\right]=\frac{P_c}{\sqrt{2}\tau} \tag{3.1.3}$$

where D_E is the fractional endpoint density. An endpoint density less than one was a possibility based on the initial data from the dry crushed salt tests. However, the recent tests on wet crushed salt [4,14] show that creep consolidation does continue for long times to near intact densities and that the long term behavior is the phenomenon of interest so the sintering model was not developed further.

3.2 Basic Definitions and Assumptions

The current value of the stress and total strain rate are denoted by σ_{ij} and $\dot{\epsilon}_{ij}$, respectively. These are decomposed into volumetric and deviatoric parts using Equations (3.2.1)–(3.2.4):

$$P = -\tfrac{1}{3}\sigma_{kk} \tag{3.2.1}$$
$$S_{ij} = \sigma_{ij}-\tfrac{1}{3}\sigma_{kk} \tag{3.2.2}$$
$$\dot{e}_v = -\dot{\epsilon}_{kk} \tag{3.2.3}$$
$$\dot{e}_{ij} = \dot{\epsilon}_{ij}-\tfrac{1}{3}\dot{\epsilon}_{kk} \tag{3.2.4}$$

where: P is the pressure (positive in compression),
S_{ij} is the deviatoric stress,
$\dot{e}_v$ is the volumetric strain rate (positive for decreasing volume), and
$\dot{e}_{ij}$ is the deviatoric strain rate.

In most quasi-static finite element programs, the total strain rate $\dot{\epsilon}_{ij}$ is taken to be constant over a time step since higher derivatives are generally not available. For clarity the symbols r and $\dot{e}'_{ij}$ are used here to denote the constant values of the volumetric and deviatoric strain rates, respectively, at some arbitrary time step. The sub- or superscripts $()_0$ and $()_F$ will be used to denote the values of stresses and densities at the beginning and end of the time step, respectively and t will denote some instant of time within the current step. The relationships between volume strain, e_v, and density, ρ, are given in Section 2.1.

3.3 Volumetric Constitutive Model

In the previous chapter the consolidation behavior was shown to be described

by Equation (2.5.2). This is written in terms of the volumetric creep strain rate as:

$$\dot{e}_{vc} = \frac{\rho_0}{\rho^2} B_0 \left[e^{B_1 P} - 1 \right] e^{A\rho} \tag{3.3.1}$$

where ρ_0 is the density corresponding to zero volume strain and $\dot{e}_{vc} = \rho_0 \dot{\rho}/\rho^2$ from Equation (2.1.2). The total volumetric strain rate is written as the sum of the elastic strain rate and the creep strain rate

$$\dot{e}_v = \dot{P}/K + \dot{e}_{vc}$$

where $\dot{P}$ is the rate of change of the pressure and K is the elastic bulk modulus. Equation (3.3.1) is substituted into the above equation and the result restated as:

$$\dot{P} = K \left(\dot{e}_v - \frac{\rho_0}{\rho^2} B_0 \left[e^{B_1 P} - 1 \right] e^{A\rho} \right) \tag{3.3.2}$$

The bulk modulus is approximated by an exponential function of density that can be expressed as (see Appendix A):

$$K = K_0 e^{K_1 \rho} \tag{3.3.3}$$

where K_0 and K_1 are constants determined from a fitting procedure. The density terms appearing in the expression for the bulk modulus and in the term $e^{A\rho}$ in Equation (3.3.2) are expressed in terms of the volume strain using Equation (2.1.3).

$$K_0 e^{K_1 \rho} \approx K_0 e^{K_1 \rho_0 (1+e_v)} \tag{3.3.4}$$

$$e^{A\rho} \approx e^{A\rho_0 (1+e_v)} \tag{3.3.5}$$

The term ρ_0/ρ^2 in Equation (3.3.2) is expressed in terms of the volume strain using Equation (2.1.3)

$$\rho_0/\rho^2 = (1 - e_v)^2/\rho_0 \tag{3.3.6}$$

Using Equations (3.3.4), (3.3.5), and (3.3.6), Equation (3.3.2) can be written as

$$\dot{P} \approx K_0 e^{K_1 \rho_0 (1+e_v)} \left\{ \dot{e}_v - \frac{(1 - e_v)^2}{\rho_0} B_0 \left[e^{B_1 P} - 1 \right] e^{A\rho_0 (1+e_v)} \right\} \tag{3.3.7}$$

which is the constitutive equation relating the rate of change of the pressure to the volumetric strain rate and density.

3.3.1 Integration of the Volumetric Constitutive Equation

To integrate this expression in a quasi-static finite element program, $\dot{e}_v$ over a time step is approximated by the constant value r because higher derivatives are generally not available. Using this approximation,

$$\dot{e}_v = r \tag{3.3.8}$$

$$e_v = e_{v0} + rt \tag{3.3.9}$$

where e_{v0} is the volume strain at the beginning of the time step and t is the length of the time step. Since Equations (2.5.2) and (3.3.3) depend only on the current value of the density, the volume strain at the beginning of the time step can be set to zero and then ρ_0 is the density at the beginning of the time step. The volume strain at the end of the time step is then given by rt and the density by

$$\rho = \rho_0/(1 - rt) \approx \rho_0(1 + rt) \tag{3.3.10}$$

Equation (3.3.7) is rewritten in terms of r to give the following first-order non-homogeneous nonlinear ordinary differential equation for the pressure:

$$\dot{P} = K_0 e^{K_1\rho_0(1+rt)} \left\{ r - \frac{(1-rt)^2}{\rho_0} B_0 \left[e^{B_1 P} - 1 \right] e^{A\rho_0(1+rt)} \right\} \tag{3.3.11}$$

If $rt < 0.1$, then the quantity $(1 - rt)^2$ can be approximated as e^{-2rt} with an error of less than one percent and Equation (3.3.11) can be written as

$$\dot{P} = \frac{\hat{K} e^{\beta t}}{B_1} - \frac{\hat{B} e^{\alpha t} e^{B_1 P}}{B_1} + \frac{\hat{B} e^{\alpha t}}{B_1} \tag{3.3.12}$$

where: $\hat{K} = B_1 K_0 r e^{K_1\rho_0}$,
$\hat{B} = B_1 B_0 K_0 e^{\rho_0(A+K_1)}/\rho_0$,
$\beta = K_1\rho_0 r$,
$\alpha = (K_1\rho_0 + A\rho_0 - 2)\, r$.

A change of variables is used in the form:

$$w = e^{-B_1 P} \qquad \text{and} \qquad \dot{w} = -B_1 \dot{P} w$$

which are substituted into Equation (3.3.12) to obtain an equation linear in w:

$$\dot{w} + \hat{K} e^{\beta t} w + \hat{B} e^{\alpha t} w = \hat{B} e^{\alpha t} \tag{3.3.13}$$

This equation has the solution:

$$w = e^{-I} \int \hat{B} e^{\alpha t} e^{I}\, dt + C e^{-I}$$

where:

$$I = \int (\hat{K} e^{\beta t} + \hat{B} e^{\alpha t})\, dt = \frac{\hat{K} e^{\beta t}}{\beta} + \frac{\hat{B} e^{\alpha t}}{\alpha}$$

so that:

$$w(t) = \hat{B} \exp\left(-\frac{\hat{K} e^{\beta t}}{\beta} - \frac{\hat{B} e^{\alpha t}}{\alpha} \right) \int e^{\alpha t} \exp\left(\frac{\hat{K} e^{\beta t}}{\beta} + \frac{\hat{B} e^{\alpha t}}{\alpha} \right) dt + C \exp\left(-\frac{\hat{K} e^{\beta t}}{\beta} - \frac{\hat{B} e^{\alpha t}}{\alpha} \right) \tag{3.3.14}$$

where C depends on the initial conditions. To complete the integration note that if αt and βt are less than approximately 0.1 the following approximation can be used with less than a one percent error.

$$e^{\gamma} \approx 1 + \gamma \tag{3.3.15}$$

Using this approximation, the integral in Equation (3.3.14) is approximated as:

$$\begin{aligned}
\int \exp\left(\alpha t + \frac{\hat{K}e^{\beta t}}{\beta} + \frac{\hat{B}e^{\alpha t}}{\alpha}\right) dt &\approx \int \exp\left[\alpha t + \frac{\hat{K}}{\beta}(1+\beta t) + \frac{\hat{B}}{\alpha}(1+\alpha t)\right] dt \\
&= \exp\left(\frac{\hat{K}}{\beta} + \frac{\hat{B}}{\alpha}\right) \int e^{(\alpha+\hat{K}+\hat{B})t}\, dt \\
&= \frac{e^{(\alpha+\hat{K}+\hat{B})t}}{\alpha+\hat{K}+\hat{B}} \exp\left(\frac{\hat{K}}{\beta} + \frac{\hat{B}}{\alpha}\right)
\end{aligned} \tag{3.3.16}$$

Using Equations (3.3.15) and (3.3.16), Equation (3.3.14) is written as:

$$w(t) = \frac{\hat{B}e^{\alpha t}}{\alpha+\hat{K}+\hat{B}} + C\exp\left(-\frac{\hat{K}e^{\beta t}}{\beta} - \frac{\hat{B}e^{\alpha t}}{\alpha}\right) \tag{3.3.17}$$

At time $t = 0$:

$$w(0) = \frac{\hat{B}}{\alpha+\hat{K}+\hat{B}} + C\exp\left(-\frac{\hat{K}}{\beta} - \frac{\hat{B}}{\alpha}\right)$$

which can be solved for C giving

$$C = \left[w(0) - \frac{\hat{B}}{\alpha+\hat{K}+\hat{B}}\right] \exp\left(\frac{\hat{K}}{\beta} + \frac{\hat{B}}{\alpha}\right)$$

Changing back to the original variables and solving for the pressure, Equation (3.3.17) is written as:

$$P_F = \frac{-\ln}{B_1}\left\{\frac{\hat{B}e^{\alpha t}}{\alpha+\hat{K}+\hat{B}} + \left[e^{-B_1 P_0} - \frac{\hat{B}}{\alpha+\hat{K}+\hat{B}}\right] \exp\left\{\frac{\hat{K}}{\beta}(1-e^{\beta t}) + \frac{\hat{B}}{\alpha}(1-e^{\alpha t})\right\}\right\} \tag{3.3.18}$$

or, using Equation (3.3.15) to approximate the exponential terms $e^{\alpha t}$ and $e^{\beta t}$, the final form of the constitutive equation modeling the volumetric consolidation of crushed salt is:

$$P_F = \frac{-\ln}{B_1}\left\{\frac{\hat{B}(1+\alpha t)}{\alpha+\hat{K}+\hat{B}} + \left[e^{-B_1 P_0} - \frac{\hat{B}}{\alpha+\hat{K}+\hat{B}}\right] \exp\left\{-t(\hat{K}+\hat{B})\right\}\right\} \tag{3.3.19}$$

where: A, B_0, B_1, K_0, K_1 are material constants,

P_0 = is the pressure at the beginning of the time step,

r = is the volumetric strain rate during the time step,

$\hat{B} = B_0 B_1 K_0 e^{\rho_0 (A+K_1)} / \rho_0$

$\hat{K} = B_1 K_0 r e^{K_1 \rho_0}$

$\alpha = (K_1 \rho_0 + A\rho_0 - 2)r$

$\beta = K_1 \rho_0 r$

And the following assumptions were used:

$$\alpha t, \quad \beta t, \quad rt \quad \begin{cases} < 0.5 & \text{for} < 10\% \text{ error} \\ < 0.1 & \text{for} < 1\% \text{ error} \end{cases} \tag{3.3.20}$$

3.4 Deviatoric Constitutive Model

The previous section documented the derivation of the equation modeling the volumetric behavior of crushed salt material. The constitutive model must also model the deviatoric or shear behavior. At the current time, no tests which isolate the deviatoric behavior of crushed salt have been performed. The development reported in this section is therefore based totally on judgement.

Four models that could be used to model the deviatoric response of crushed salt are, in order of increasing complexity:

- Elastic,
- Elastic–Plastic,
- Elastic–Creep, and
- Elastic–Plastic–Creep.

The equations describing each of these, except for an *Elastic–Plastic–Creep* model, will be presented below. A more detailed deviatoric model will be developed when the correct deviatoric behavior of crushed salt is determined.

3.4.1 Elastic Deviatoric Model

The elastic deviatoric model can be written as

$$S_{ij}^F = S_{ij}^0 + 2G_\rho \dot{e}'_{ij} t \tag{3.4.1}$$

where G_ρ is the elastic shear modulus evaluated at some density within the time step and t is the length of the time step. Though this model is easily implemented, it is known that the deviatoric behavior of crushed salt is not elastic because intact salt is a deviatorically creeping material. The crushed salt behavior should approach intact behavior as the density approaches intact density. An elastic deviatoric model does have some merit, though, if it is used for parametric studies and in analyses seeking to bound the crushed salt response.

3.4.2 Elastic–Plastic Deviatoric Model

The elastic–plastic deviatoric model used here is based on a standard von Mises type yield condition with no hardening. Initially a trial stress S_{ij}^T is calculated assuming that no plasticity occurs during the time step

$$S_{ij}^T = S_{ij}^0 + 2G_\rho \dot{e}_{ij}' t \tag{3.4.2}$$

The magnitude of the trial deviatoric stress is then calculated as

$$S^T = \sqrt{S_{ij}^T S_{ij}^T} \tag{3.4.3}$$

and then compared to the yield stress σ_Y to determine if yield occurs. The variable κ is used to define the yield von Mises yield surface.

$$\kappa = \sqrt{\tfrac{2}{3}} \frac{\sigma_Y}{S^T} \tag{3.4.4}$$

The final deviatoric stress state S_{ij}^F is then calculated from this value of κ. If the value of κ is greater than 1, then the assumption of no plasticity is correct and the trial stress state is the final stress state; if κ is less than 1, then plastic deformation has occurred and the final stress state must be reduced.

$$S_{ij}^F = \begin{cases} S_{ij}^T & \text{if } \kappa \geq 1 \\ \kappa S_{ij}^T & \text{if } \kappa < 1 \end{cases} \tag{3.4.5}$$

This model is more appropriate than the elastic model because the yield stress σ_Y can be a function of density which more accurately models the stiffening behavior of crushed salt with increasing density. Like the elastic model, the elastic-plastic model is also very easily implemented. However, it does not accurately model the behavior of crushed salt in the limit as the density approaches intact salt density because it does not account for deviatoric creep.

3.4.3 Elastic–Creeping Model

Because intact salt creeps when subjected to a deviatoric stress state, crushed salt should logically be expected to creep deviatorically. This expectation becomes increasingly more reasonable as the density increases because, in the limit, the crushed salt becomes intact salt. The deviatoric crushed salt creep model presented here is based on a secondary creep model which has been used to describe the secondary creep behavior of intact WIPP salt [10].

The development proceeds by envisioning that the porous crushed salt uniaxial sample is composed of cylinders of salt, each of which has the intact salt secondary creep behavior separated by areas of open space. The local stress acting on the salt cylinders is then stated in terms of the average stress on the porous sample. The cross-sectional area of the porous sample is expressed in terms of the net cross-sectional area of the salt cylinders. This implied areal ratio is the inverse of the fractional density of the sample. The final resulting continuum model for the rate of the deviatoric stress of crushed salt is then

$$\dot{S}_{ij} = 2G_\rho \left(\dot{e}'_{ij} - A(\rho_\infty/\rho)^n \mathrm{e}^{(Q/RT)} \left|S_{pq}\right|^{n-1} S_{ij} \right) \tag{3.4.6}$$

where the material constants A, Q, n, and ρ_∞ refer to the values for intact salt [10]. This expression for the deviatoric stress rate is a stiff equation in the mathematical sense and must be implemented into a computer program with some care. A semi-analytical method developed for intact salt [9] and used in the structural analyses for the WIPP project [20] is used to integrate Equation (3.4.6). In the limit of no void volume, this model reduces to the elastic–secondary creep model for intact rock salt. The actual behavior is probably a unified combination of the creep and plasticity model with each behavior dominating the response in different density ranges.

3.5 Summary of the Constitutive Model

The volumetric behavior modeled by Equation (3.3.19) and the deviatoric behavior modeled by Equations (3.4.1), (3.4.5), and (3.4.6) have been implemented in the quasistatic, large deformation finite element program, SANCHO [20]. All three deviatoric models were implemented to aid in studies of the effect of the deviatoric behavior on the overall response of the material. Any of the three deviatoric models can be selected prior to the calculation. The instructions for using this model in SANCHO are documented in Appendix B.

The constitutive subroutine is entered with the current value of the total strain rate $\epsilon ij'$, the stress state from the end of the previous time step σ^0_{ij}, and the density

from the end of the previous time step ρ_0. The stress and strain rate are then decomposed into the volumetric and deviatoric parts using Equations (3.2.1)–(3.2.4). The volumetric response is then calculated using Equation (3.3.19) to calculate P_F and Equation (3.3.10) to calculate ρ_F. A subiteration scheme ensures that the approximations of Equation (3.3.20) are satisfied.

The deviatoric response is then calculated using the selected model. Although the shear modulus is a function of the density ρ which changes throughout the time step, all of the deviatoric models are currently written in terms of a G which is constant over the time step. This was done simply because the extra complexity required to have G vary over the time step was not judged to be warranted based on the scarcity of data describing the deviatoric behavior. The shear modulus used in the calculations is calculated using Equation (A.2) and the average density ρ_A which is defined to be $(\rho_0 + \rho_F)/2$. The final deviatoric stress state S_{ij}^F is calculated using this value of G and either Equation (3.4.1), (3.4.5), or (3.4.6).

The final total stress state is then obtained by recomposing the volumetric and deviatoric stresses.

$$\sigma_{ij}^F = S_{ij}^F - \delta_{ij} P_F \tag{3.5.1}$$

Several calculations performed using this model are documented in Chapter 4. Included in these are scoping calculations performed to determine the influence and importance of the deviatoric behavior to the overall response of the material. Only the elastic-plastic deviatoric model is used in these calculations because the material parameters for the elastic-creep model could not be easily determined.

4. Analyses using the Crushed Salt Constitutive Model

This chapter presents the results of several analyses performed using the crushed salt constitutive model in the finite element code SANCHO. Both single element analyses involving only crushed salt and analyses involving the interaction of intact and crushed salt in realistic configurations are presented. Several shaft calculations are performed to investigate the importance of the deviatoric behavior of crushed salt to the overall response of the closure of rooms and shafts. In these calculations, the deviatoric part of the model has been varied from the stiffest possible to the softest possible shear behavior and the differences in the closure of the analyzed shaft are compared. This chapter also includes a section describing a method used to artificially accelerate the creep of intact salt so that more realistic backfill-intact salt interactions can be obtained.

4.1 Single Element Analyses

Several single element calculations were performed to verify the implementation of the crushed salt constitutive model in SANCHO. These calculations involved the numerical simulation of the consolidation tests performed by Holcomb and Shields [4]. The finite element model consists of a single axisymmetric element loaded with a hydrostatic pressure. The hydrostatic pressure was held constant in all analyses except for the simulation of the 240C61 test where the actual pressure history shown in Figure 2.1 was used. The results from these analyses are identical to those calculated directly from the expressions in Chapter 2 and shown in Figures 2.5–2.8.

4.2 Shaft Analyses

Several calculations were performed to study the interaction between intact salt and crushed salt in realistic field configurations. The shaft configuration is the simplest configuration that can be used to study this interaction. The axisymmetric strip shown in Figure 4.1 is used to represent the shaft. The outer boundary of the strip is a distance of 200 radii from the inner boundary which is far enough to be considered an infinite boundary for the problem time span reported here. The inner radius of the shaft is 1.829 meters (6.0 feet). The borehole pressure is zero for the unbackfilled shaft. The crushed salt causes a changing borehole pressure in the backfilled shaft analyses. The elastic-secondary creep model with reduced elastic constants is used for the intact salt.

In calculations that simulate the interaction between intact salt and crushed salt, the deformation of the intact salt produces the loading in the crushed salt. To provide accurate information about the crushed salt response, the response of the intact salt must be calculated correctly. At the current time analyses of the closure rate of drift configurations at the WIPP underpredict the measured rate by approximately a factor of three [13]. A new constitutive model for intact salt may resolve the factor of three discrepancy, but such a model is, at best, in the development stage. A temporary method for increasing the creep rate of the intact salt was needed for these, and other, engineering calculations. This method is described below.

4.2.1 Accelerated Creep of Intact Salt

Morgan, *et al*, [13] investigated several possible causes for the discrepancy between the measured and computed responses of the South Drift. It was shown that reducing the elastic constants of the intact salt (halite) resulted in increased closure rates and hence closures. This study also showed that the closure histories resulting from calculations performed using the reduced elastic moduli had shapes very similar to the closure histories of data from the South Drift. Although reductions in the elastic constants of halite result in the desired increases in closure, the reason for these increased closures during the creep phase of the calculation is not readily apparent. Furthermore, reductions in the elastic constants are difficult to justify on physical grounds. The reference values of the elastic constants represent the unloading and reloading slopes of axial stress—axial strain curves obtained in laboratory tests on halite samples and are in good agreement with elastic constants determined from sound speeds measured in ultrasonic tests [23].

In Reference [13], physically based causes for the discrepancy between measured and calculated closures and closure rates were being explored. Therefore, because no physical basis for modifying the elastic constants existed, the subject was not pursued further in that study. In the current study, emphasis is placed on the behavior of crushed salt rather than intact salt so any method for computing closure rates of the same magnitude as the measurements is appropriate until the time that a more accurate material model is developed for the behavior of intact salt. Because reducing the elastic constants was shown to both increase the closure rate and to very closely match the shape of the closure history data from the South Drift, this approach was used for the crushed salt—intact salt interaction calculations presented here.

The factor by which the elastic constants were reduced was found by trial and error. A reference shaft closure history was calculated using the reference elastic constants. The elastic constants were then divided by a trial factor and the calculation repeated. This process was continued until closure rates computed with the reduced

moduli were approximately three times the closure rates computed with the reference moduli. The closure rates were compared at a time corresponding to approximately 1200 days after excavation which corresponds to the latest South Drift closure data available at that time. Measured closure rates for the South Drift were 3 times larger than the computed rates. Furthermore, the behavior of a shaft is similar to that of a drift. Hence, the procedure involved trying to increase shaft closure rates by a factor of 3 over the reference closure rates. Dividing both the elastic bulk and shear moduli by a factor of 12.5 resulted in the desired increase in closure rate. Figure 4.2 shows the closure rates for both the reference and reduced analyses, and Figure 4.3 shows the respective closure histories. Also shown in these figures are the data for the E140-S1246 closure station in the South Drift at the WIPP [15].

The 12.5 reduction factor has since been used in several calculations which have shown that the agreement between calculated and measured closures is fairly good; the method slightly underestimates the vertical closure and very closely estimates the horizontal closure when applied to drift configurations. Unless otherwise noted, all of the calculations described below use the reduced elastic moduli for the intact salt properties. The WIPP reference values [10] are used for the secondary creep parameters.

4.2.2 Baseline Shaft Analysis

A long term shaft analysis was performed to provide a baseline closure rate for comparison with the backfilled shaft calculations. In this analysis, which will be referred to as the baseline analysis, the shaft opening is not filled with crushed salt. The analysis simulates the closure of a 1.829 meter radius shaft at a depth of approximately 640 meters for a time of 4,000 years. Figure 4.4 is a plot of the normalized closure vs. time and Figure 4.5 shows the same curve on a logarithmic scale plot. The normalized closure is calculated by dividing the radial closure by the original shaft radius. The closure rate is plotted vs. time in Figure 4.6.

4.2.3 Backfilled Shaft Analyses

The crushed salt constitutive model was used in several calculations involving the simulation of the closure of a cylindrical shaft backfilled with wet crushed salt. The results of these calculations were compared with the closure of the baseline unbackfilled shaft to determine how much the consolidating backfill material slowed the closure rate of the intact salt.

The first pair of analyses was performed to determine the effect of the crushed salt on the closure rate and also to determine the importance of the deviatoric be-

havior of the crushed salt. The borehole contained wet crushed salt backfill material at an initial density of 1.70 g/cc (80% fractional density) in both of these analyses; the only difference was the modeling of the deviatoric behavior. In one case the crushed salt was modeled as having no shear strength by setting the shear modulus to a very low value. This is a lower bound on the shear behavior of the material. The upper bound on the shear strength for the borehole configuration occurs when the circumferential and axial stress in the backfill are both zero. The only non-zero stress component is the radial stress. This provides the maximum magnitude of the deviatoric stress for a given value of the mean stress. Both cases were run for a period of 100 years (3.156×10^9 seconds). Figure 4.7 shows the normalized closure computed for each case and the baseline analysis. These results show that the wet crushed salt backfill material does not significantly retard the closure rate of the intact salt. The results for the two deviatoric models are also nearly identical which indicates that at the slow closure rates seen in realistic configurations the volumetric behavior of the crushed salt dominates the overall response of the material. As the density of the crushed salt material increases to near intact densities, deviatoric behavior will become important. However, no materials test data are currently available to describe this transition from a consolidating material to an intact material and the constitutive model is not designed to model this behavior accurately. The maximum fractional density reached during the materials testing was approximately 90%; the material behavior above this value is extrapolated.

The second set of analyses was performed to determine the effect of the emplacement density of the crushed salt backfill on the closure rate of the intact salt. Five analyses were run with initial densities ranging from 1.70 g/cc to 1.95 g/cc in increments of 0.50 g/cc (80% to 91% fractional density). Figure 4.8 is a plot of the fractional density vs. time for each of the analyses and Table 4.1 shows the time required for the backfill material to reach 95% and 100% of intact density. Note that the consolidation rate is nonzero when the fractional density is equal to 1. This is caused by deriving the constitutive model from Equations (2.2.1) and (2.3.1) which are empirical equations based on a limited amount of data that did not approach intact density. This provides another indication that the constitutive model should not be used to predict the behavior of crushed salt at densities above approximately 95% until more relevant data are available.

Figure 4.9 shows the ratio of the current density to the initial density for each of the analyses. Also shown is an equivalent value for the baseline shaft based upon the volume change of the shaft. The ratio ρ/ρ_0 is equal to $(1 - e_v)^{-1}$ where e_v, the volume strain, is equal to the change of shaft area divided by the original shaft area. Figure 4.10 shows the time derivative of the density ratio. From this figure it can be seen that the crushed salt provides very little resistance to closure of the shaft until the density approaches intact density. The time required for consolidation of

the crushed salt material to various densities can be estimated fairly closely from the closure calculated from an unbackfilled shaft analysis.

4.3 Drift Analyses

In the previous section it was shown that the crushed salt provided very little resistance to the closure of the intact salt in the shaft configuration. In this section the interaction between the crushed salt and intact salt in a drift configuration will be investigated.

The initial drift configuration used in the interaction investigations is an array of drifts 5.03 m wide by 4.0 m high and spaced 40.54 m apart. The floor of the drifts are approximately 650 m below the surface. The finite element mesh used in the calculations is shown in Figure 4.11. Figure 4.12 shows a close-up view of the drift region. An all salt stratigraphy was used with the elastic moduli divided by 12.5 to provide the artificially accelerated creep rate. Reference [12] contains a full description of this configuration.

Figures 4.13 and 4.14 show the deformed shapes in the drift region at 20 and 50 years, respectively, for an unbackfilled drift. The horizontal and vertical closure are shown in Figure 4.15. The horizontal closure is equal to twice the horizontal displacement of point H in Figure 4.12 and the vertical closure is equal to the change in room height at the vertical centerline of the room.

The above analysis was then rerun with crushed salt in the drift. The crushed salt was emplaced with a density of 1.8 g/cc ($\approx$85% intact density). A close-up view of the finite element mesh around the drift is shown in Figure 4.16. Slidelines were used between the crushed salt and the intact salt to allow for separation of the two materials. There is a slight gap between the crushed salt and the intact salt at the wall and roof to allow for the initial elastic deformation of the intact salt. If this gap were not provided, the crushed salt would experience an instantaneous loading due rather than the more gradual loading due only to the creep of the intact salt. The size of the gap was determined from the elastic deformation calculated in the open drift calculation. A stiff elastic-plastic deviatoric behavior was used for this analysis. The yield strength of the crushed salt for each element at each timestep was chosen such that the maximum deviatoric stress was produced subject to the constraint that none of the stress components were tensile if the calculated pressure was compressive (see Appendix C). The analysis was run for a period of 20 years (6.312×10^8 seconds).

Figures 4.17 and 4.18 show the deformed shape at 10 and 20 years, respectively; the closure histories for the backfilled drift are compared to those of the open drift in Figure 4.19. The closure histories are very similar at early times. The closure

history of the backfilled drift begins to deviate from the unbackfilled closure history when the density in the backfill exceeds approximately 90–95% fractional density.

Contour plots of the crushed salt fractional density are shown at 10 and 20 years in Figures 4.20 and 4.21, respectively. At 20 years the majority of the crushed salt has consolidated to greater than 95% of intact density except for at the top and bottom corners of the drift. The salt at these locations has been squeezed out of the corners leaving areas of unconsolidated crushed salt. Since the area around the room is fairly coarsely meshed, one hypothesis was that these unconsolidated areas were artifacts of the modeling and would not appear in a more finely meshed analysis.

To test this hypothesis, a second drift analysis was run. A close-up of the finite element mesh around the room is shown in Figure 4.22. This mesh has rounded corners to more accurately model the actual configuration and is more finely meshed to hopefully smooth out the piece-wise linear deformation pattern apparent in the previous calculation. The room dimensions for this analysis were changed to a width of 3.2 m and a height of 4.3 m based on information about the actual field configuration that was obtained subsequent to the previous calculation. Figures 4.23 and 4.24 show the deformed shape of the unbackfilled drift at 20 and 49 years, respectively. Although the pinching at the corners is not nearly as pronounced as in the square corner analysis, it still exists. Another reason for the reduction of the pinching effect is the reduction of the horizontal span of the room which reduces the vertical deformation.

An analysis of a similar configuration with crushed salt backfill material in the room was unsuccessful due to problems with the slidelines near the corners of the room.

As was stated earlier, the deviatoric yield strength was chosen such that the maximum deviatoric stress was produced subject to the constraint that none of the stress components were tensile. This was done to maximize the shear stiffness of the backfill material and also to determine numerically the maximum theoretically possible value of the yield stress as a function of the density assuming that the crushed salt can be modeled with an elastic-plastic deviatoric model. The procedure used for these analyses is described in Appendix C.

Table 4.1. Consolidation Times for Backfilled Shaft Analyses

Initial Density	*Years to Density*	
(g/cc)	*95%*	*100%*
1.70	35	58
1.75	27	49
1.80	20	41
1.85	14	33
1.90	9	25
1.95	5	19

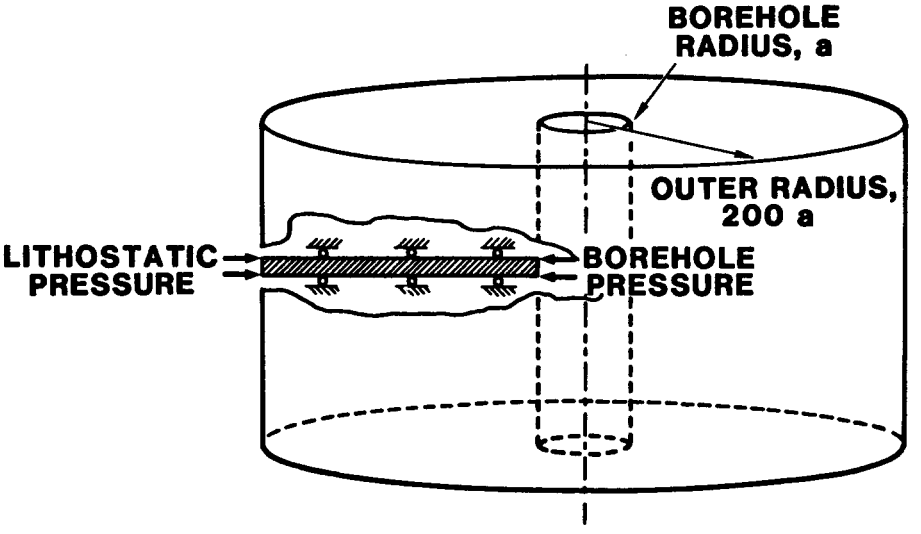

Figure 4.1. Shaft Configuration

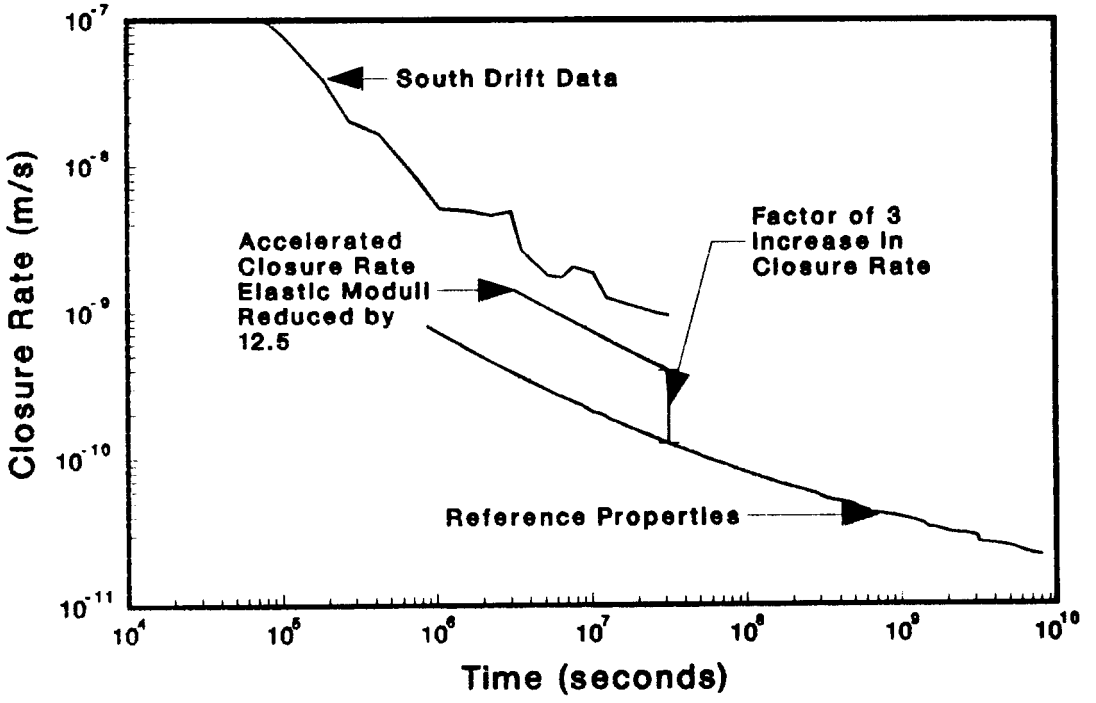

Figure 4.2. Comparison of Closure Rates for Reference and Reduced Moduli Shaft Analyses

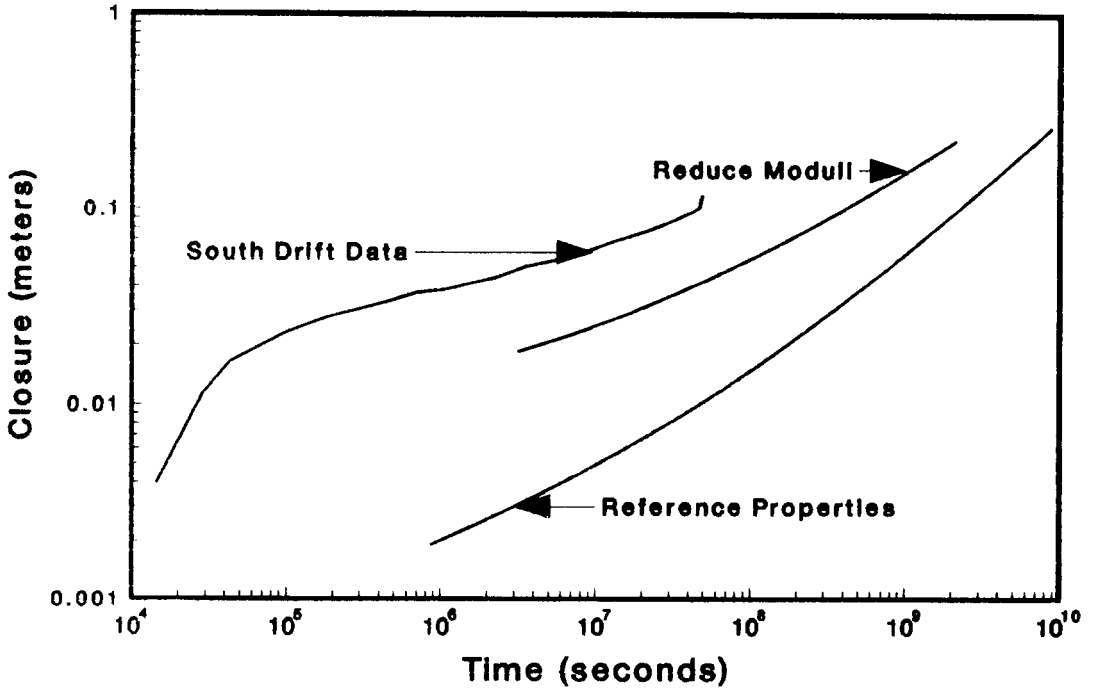

Figure 4.3. Comparison of Closure for Reference and Reduced Moduli Shaft Analyses

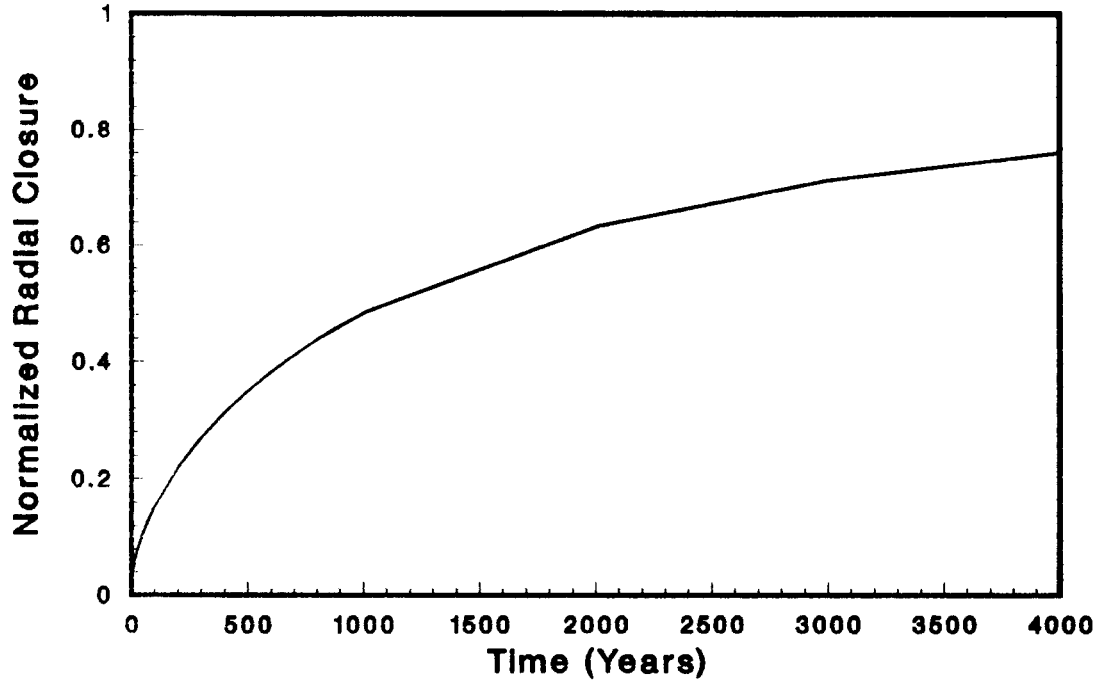

Figure 4.4. Normalized Closure History for Baseline Shaft

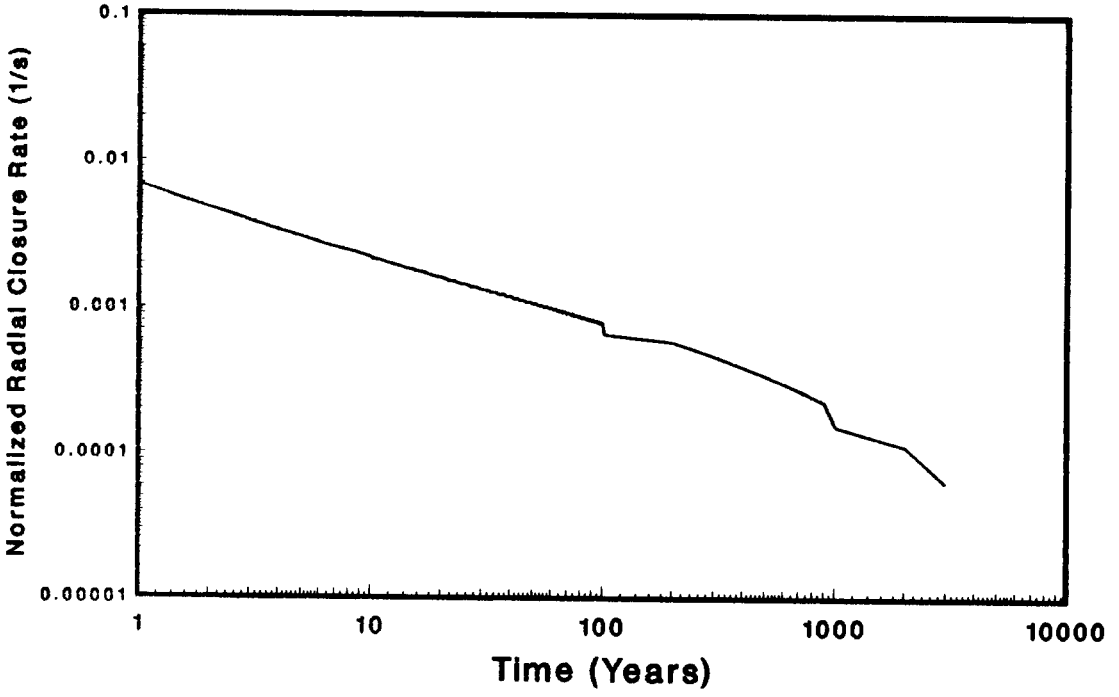

Figure 4.5. Logarithmic Normalized Closure History for Baseline Shaft

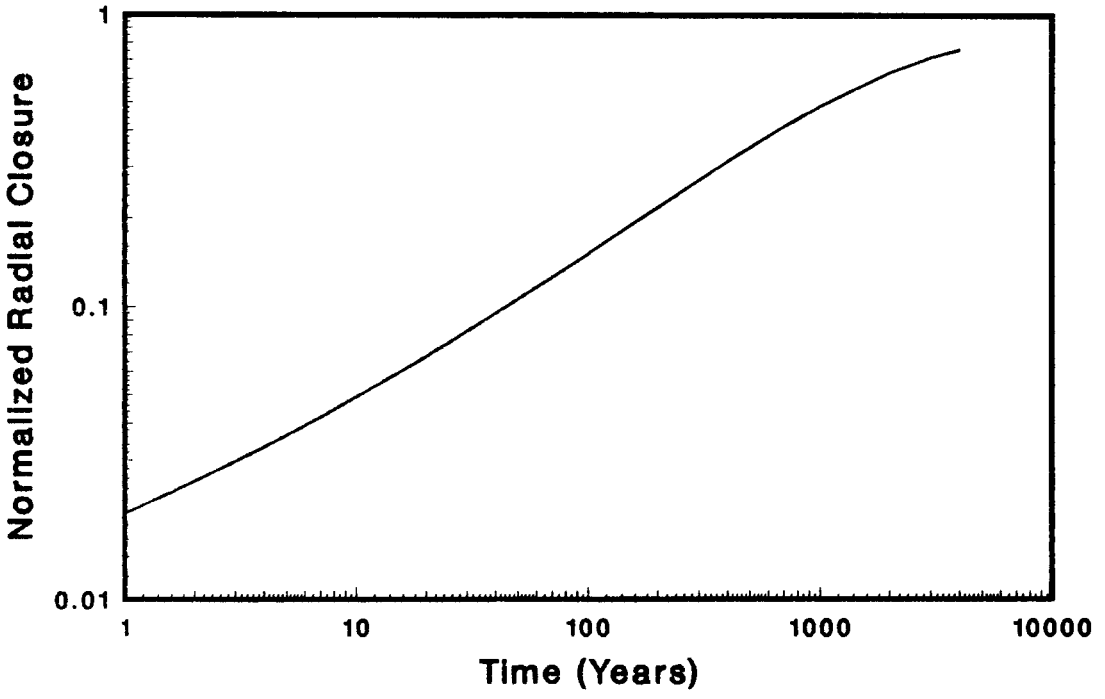

Figure 4.6. Logarithmic Normalized Closure Rate for Baseline Shaft

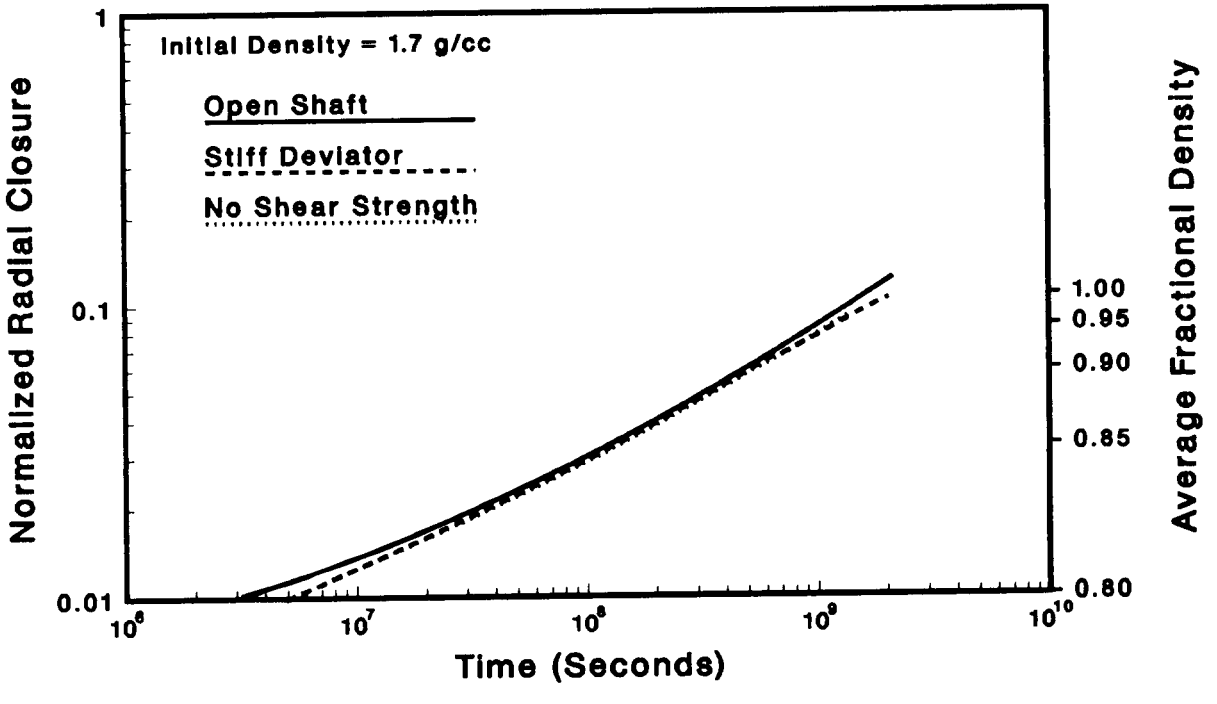

Figure 4.7. Normalized Shaft Closure for Deviatoric Behavior Analyses

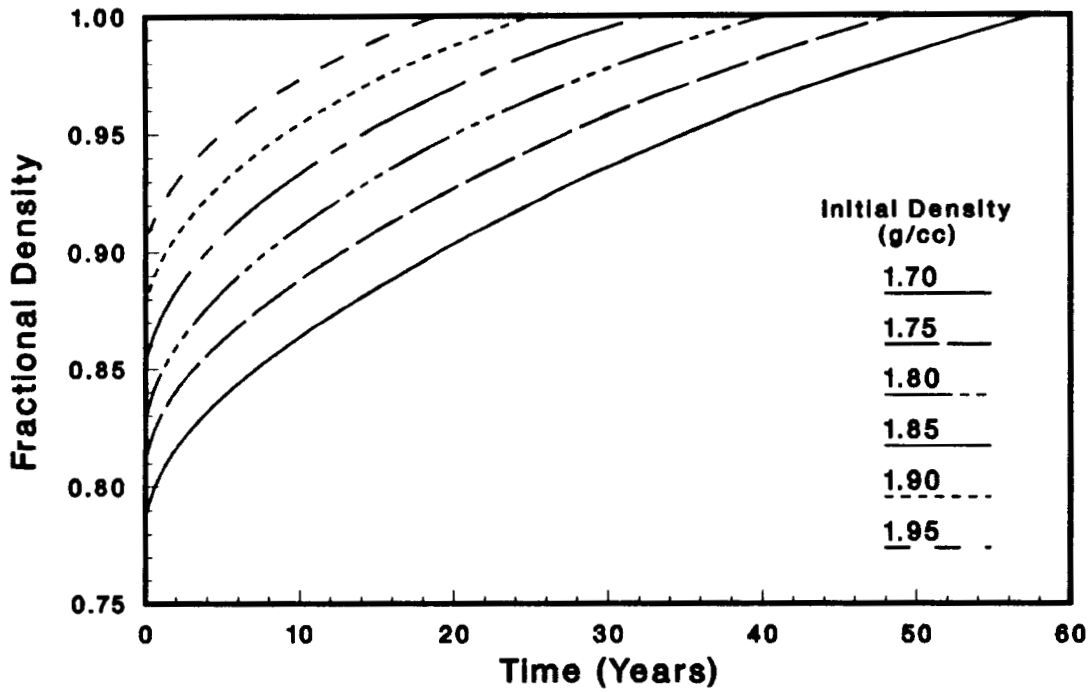

Figure 4.8. Fractional Density vs. Time for Emplacement Density Analyses

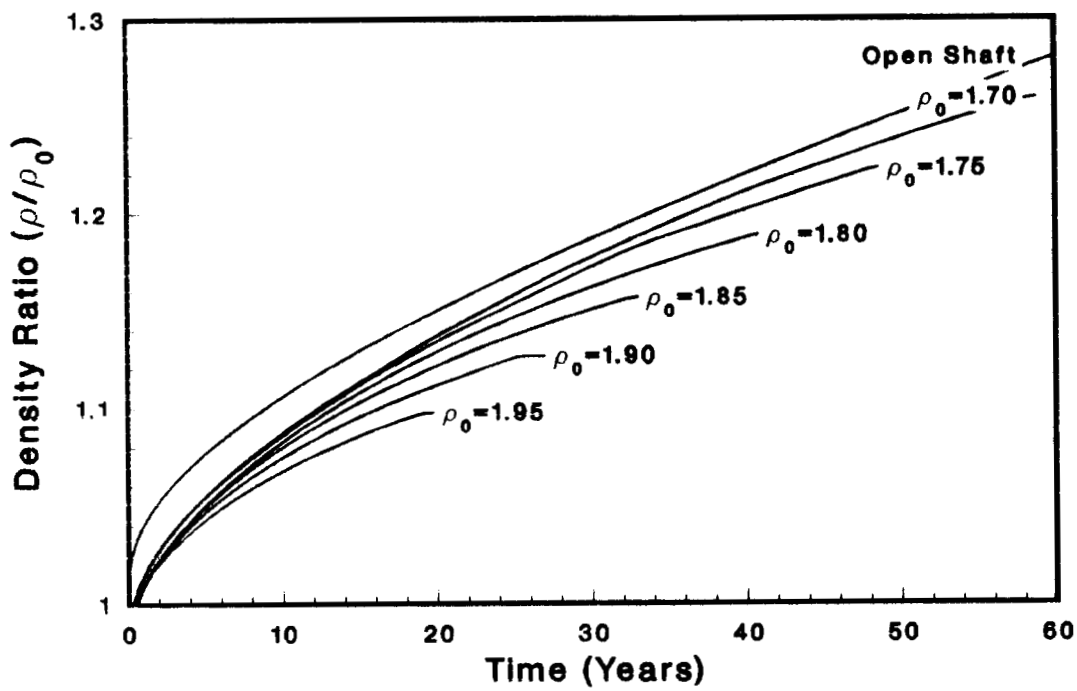

Figure 4.9. Density Ratio vs. Time for Emplacement Density Analyses

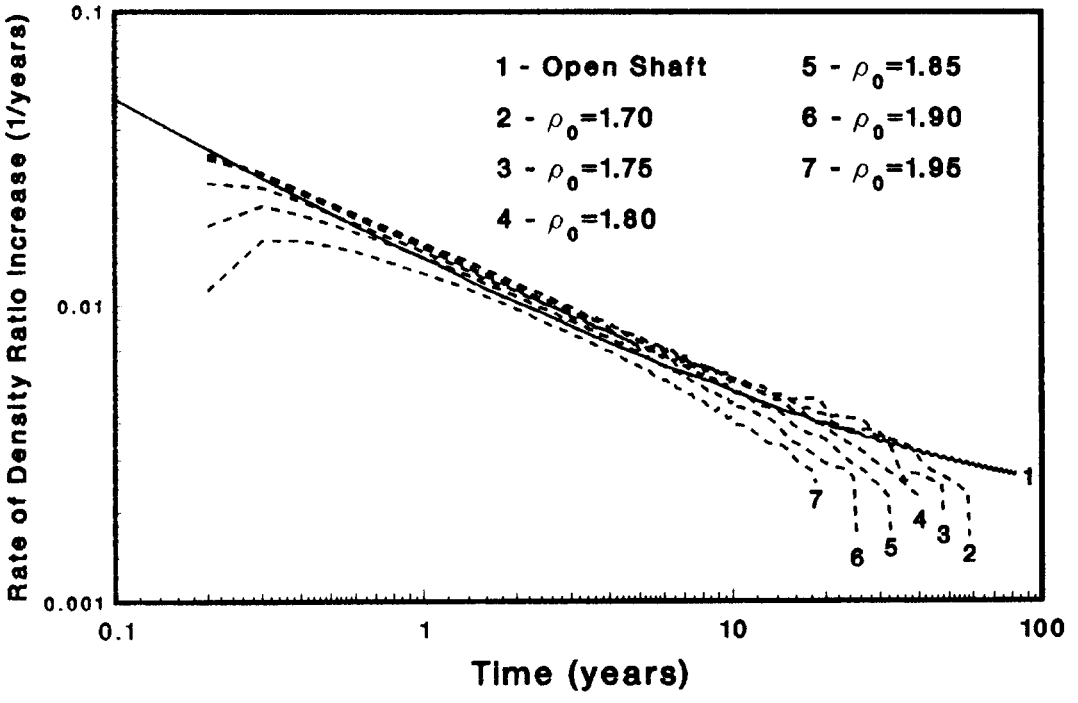

Figure 4.10. Time Rate of Change of Density Ratio for Emplacement Density Analyses

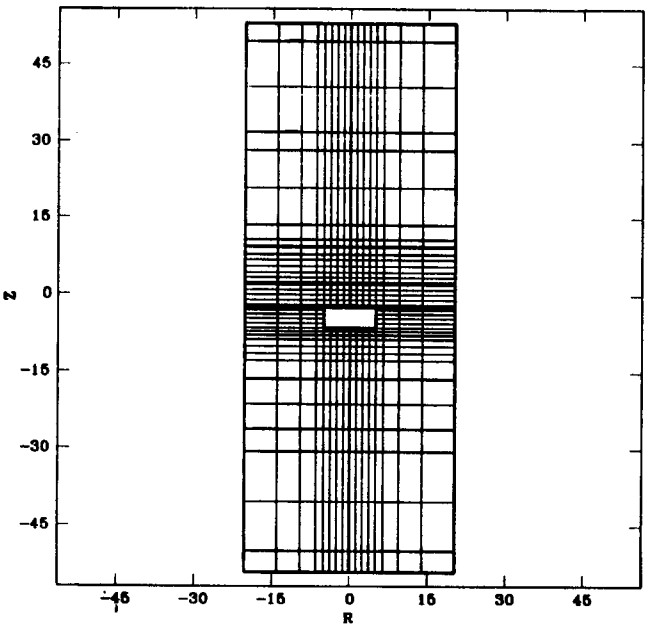

Figure 4.11. Finite Element Mesh for the Crushed Salt, Intact Salt Interaction Analyses—Unbackfilled Drift

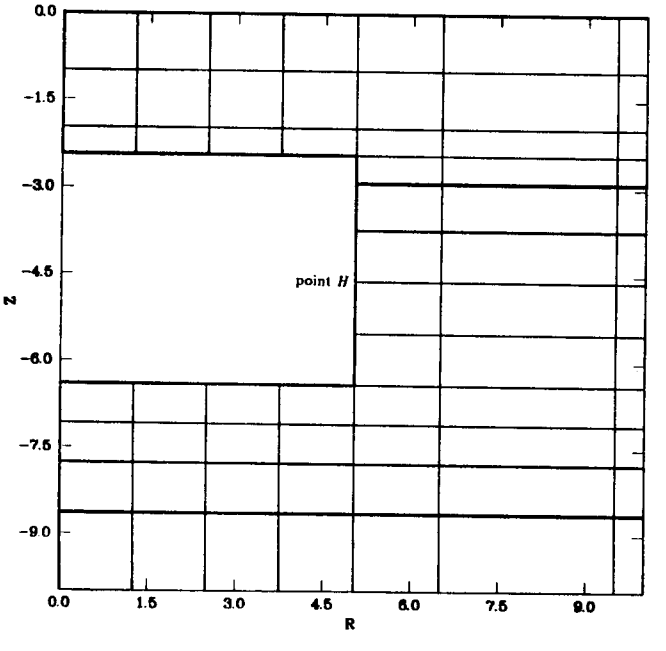

Figure 4.12. Closeup of the Drift Region Mesh for Crushed Salt, Intact Salt Interaction Analyses—Unbackfilled Drift

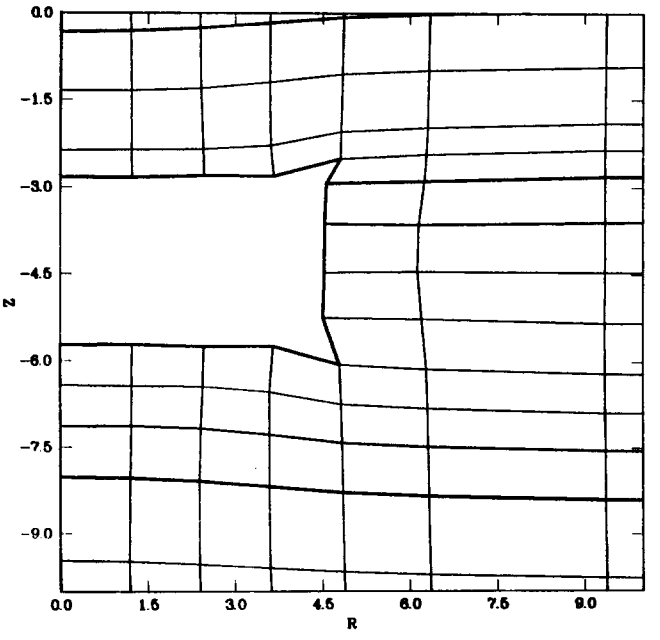

Figure 4.13. Deformed Shape of Square Corner Unbackfilled Drift at 20 Years

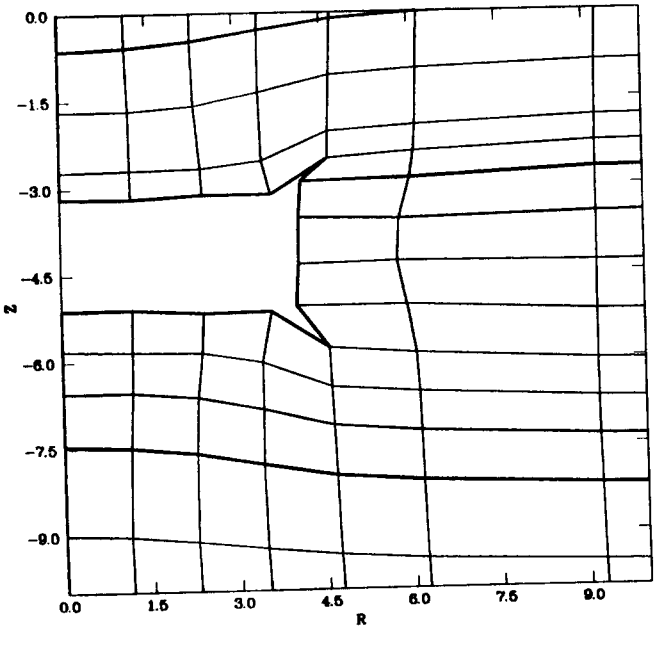

Figure 4.14. Deformed Shape of Square Corner Unbackfilled Drift at 50 Years

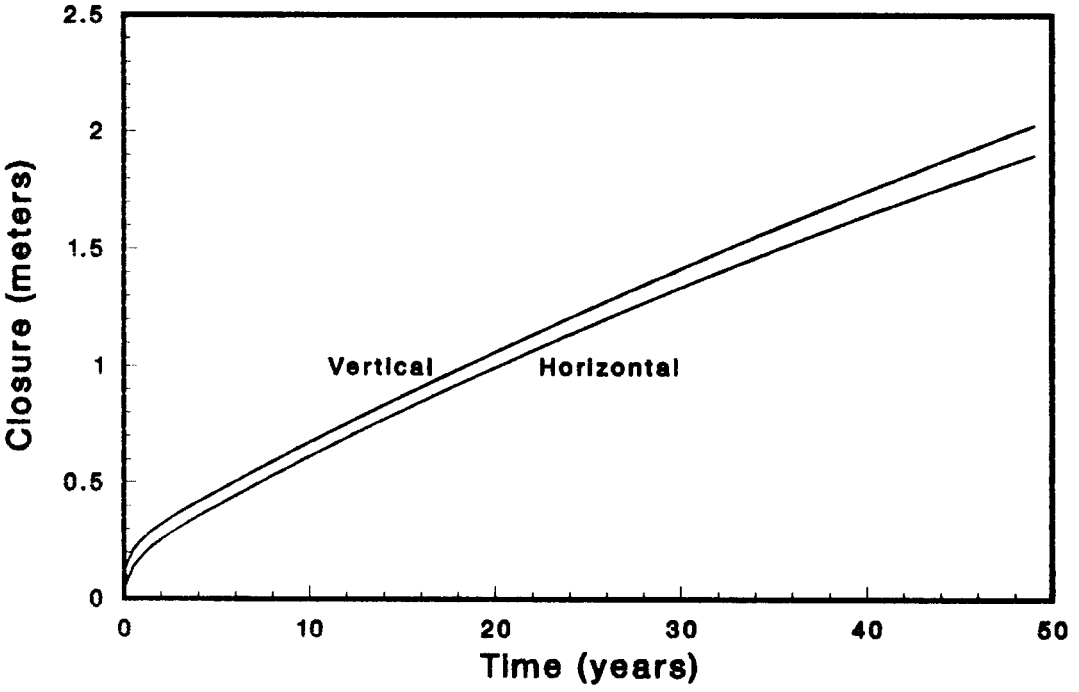

Figure 4.15. Closure Histories for Square Corner Unbackfilled Drift

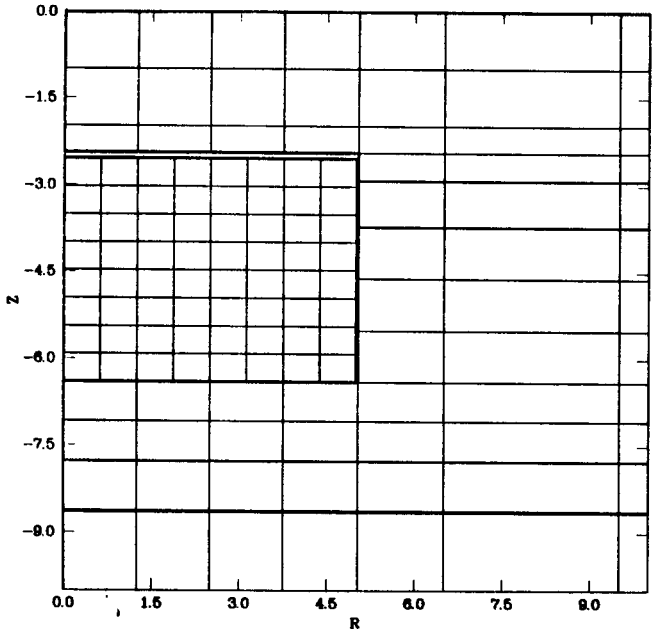

Figure 4.16. Closeup of the Drift Region Mesh for Crushed Salt, Intact Salt Interaction Analyses—Backfilled Drift

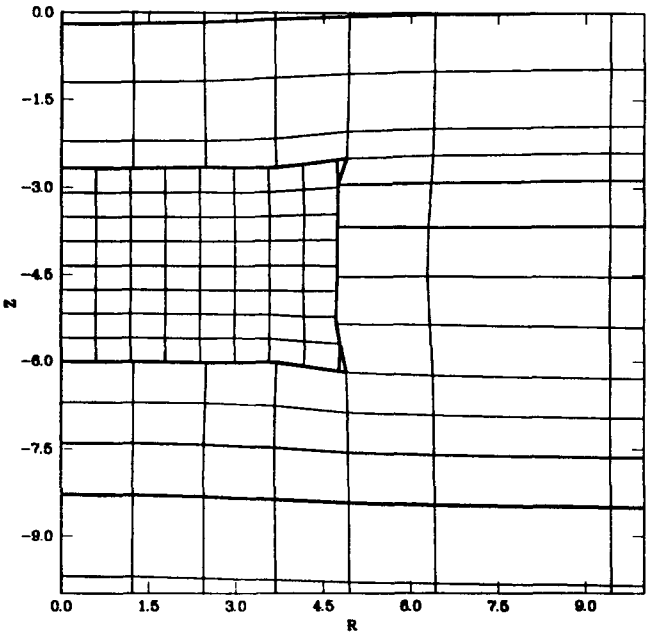

Figure 4.17. Deformed Shape of Square Corner Backfilled Drift at 10 Years

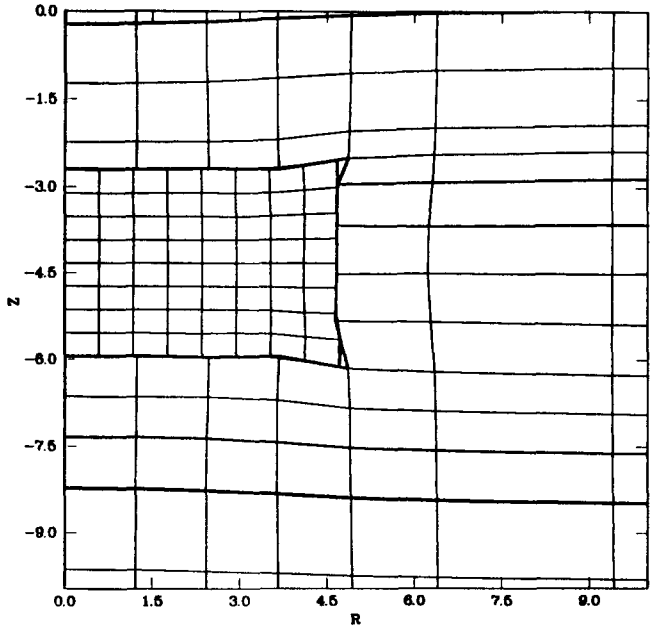

Figure 4.18. Deformed Shape of Square Corner Backfilled Drift at 20 Years

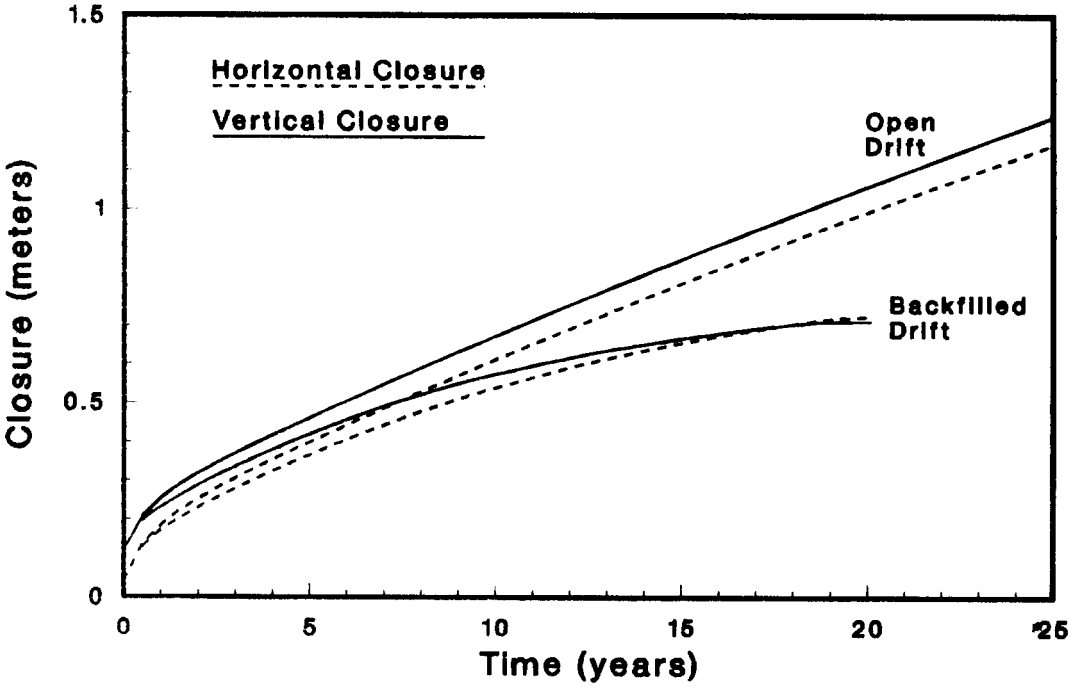

Figure 4.19. Comparison of Closure Histories for Backfilled and Unbackfilled Drift

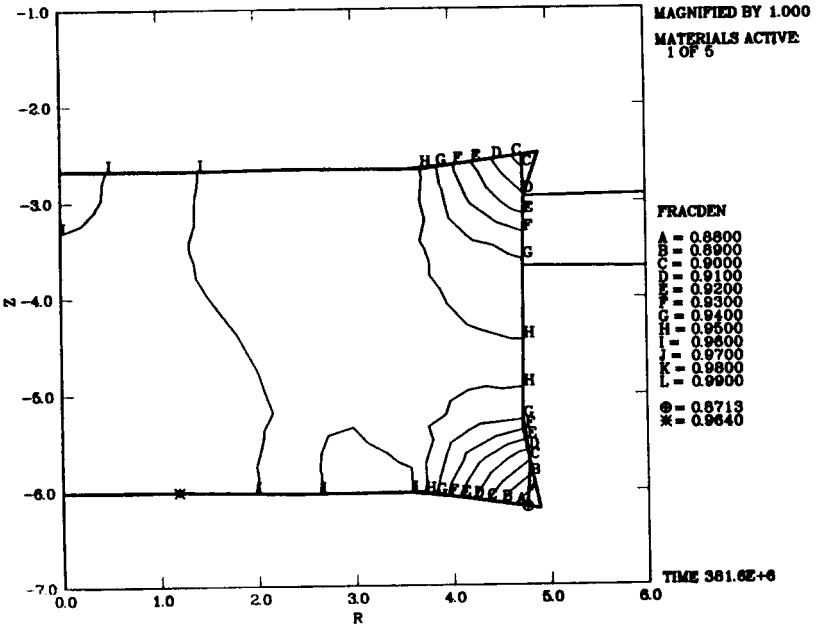

Figure 4.20. Density Contours for Square Corner Backfilled Drift at 10 Years

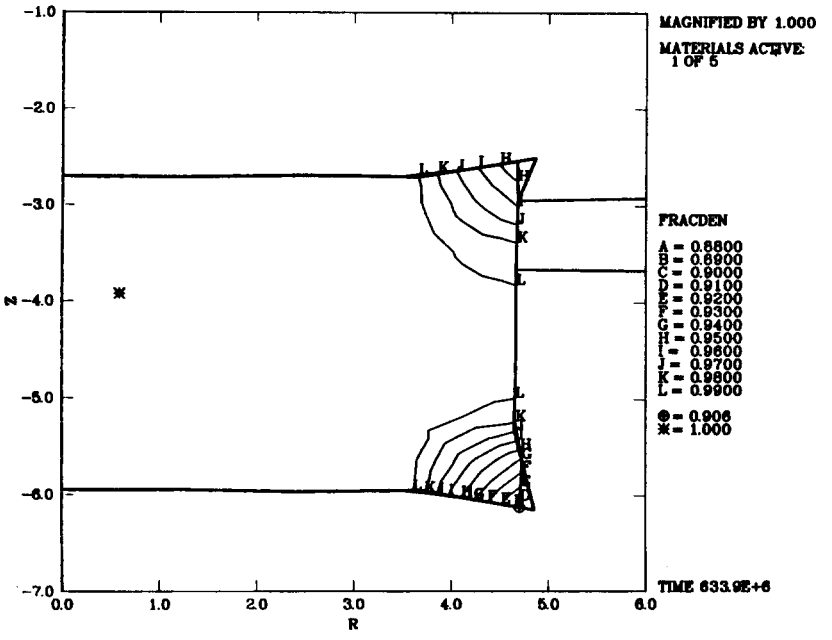

Figure 4.21. Density Contours for Square Corner Backfilled Drift at 20 Years

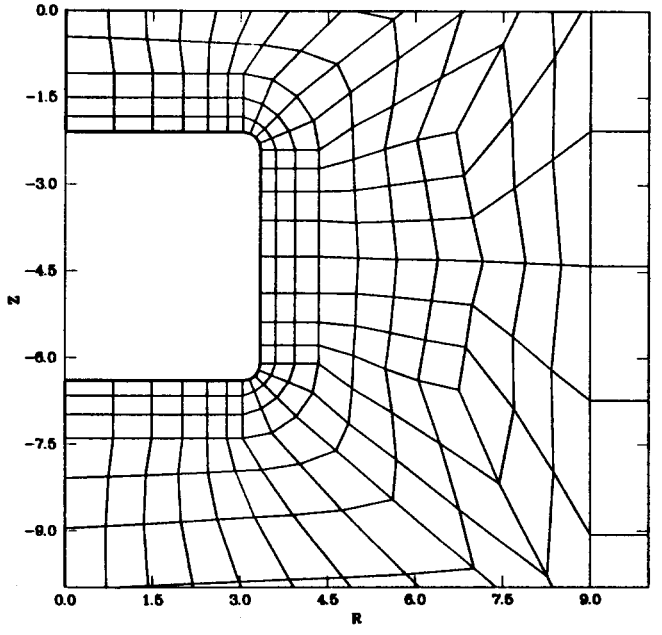

Figure 4.22. Closeup of the Drift Region for the Rounded Corner Drift

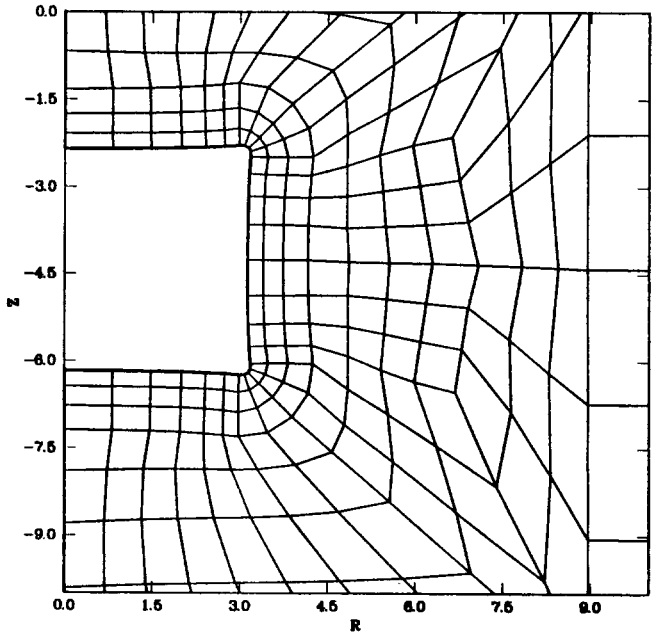

Figure 4.23. Deformed Shape of Rounded Corner Open Drift at 20 Years

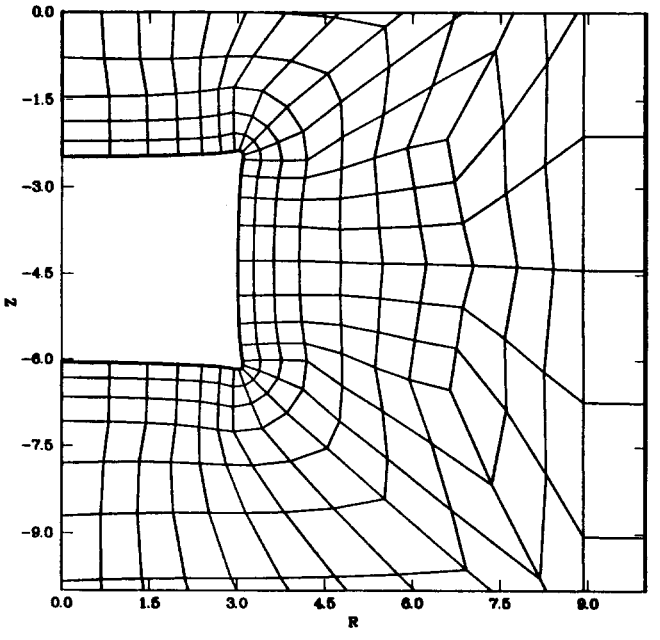

Figure 4.24. Deformed Shape of Rounded Corner Open Drift at 49 Years

5. Summary and Conclusions

The crushed salt constitutive model described in this report represents the current state of the art on the WIPP project in the modeling of crushed salt consolidation. Much research and experimental work remains to be done to more fully develop the model and improve the database upon which it is based. Although it has been shown that the choice of the deviatoric behavior does not significantly affect the volumetric behavior of the crushed salt and the creep behavior of the intact salt, a proper understanding of the deviatoric behavior is necessary to predict effects such as density gradients in the crushed salt. The proper deviatoric response is also necessary to improve the believability of the results predicted by the model. The accuracy of long-term predictions obtained with an *ad hoc* deviatoric model will be very difficult to justify.

More crushed salt consolidation data are needed especially at near intact densities and at lower confining pressures. Experiments are in progress to provide these data and the model will be updated as more data become available. The high density data should provide a more accurate view of the volumetric behavior as the material transitions from a void-dominated creeping material to a creeping solid.

The current model provides the basic capability needed to perform the scoping calculations necessary for support of the WIPP Plugging and Sealing Program. Future work will include:

- Updating the material parameters, and possibly modifying the form of the model, as more experimental data become available.
- Implementing the constitutive model in the two-dimensional, quasistatic, large deformation, inelastic response finite element code SANTOS [21] which is currently under development.
- Generalizing the crushed salt constitutive model and implementing it in the three-dimensional, quasistatic, large deformation, inelastic response finite element code JAC-3D [1] to provide the capability to more accurately analyze the inherently three-dimensional plugging and sealing configurations.
- Performing sensitivity studies to determine the sensitivity of both the model and the response predicted by the model to variations in the material parameters and the configurations analyzed with the model.

- Determining the material parameters to model the consolidation of the crushed salt and bentonite mixture, which is being considered for backfill, when experimental data become available.

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A. Functional Form of the Elastic Moduli

Table A.1 lists experimentally determined values of the elastic modulus as a function of the density of the crushed salt [8]. These were determined from a test on dry crushed salt in which the hydrostatic pressure was increased to 21 MPa, interrupted by eight depressurization-repressurization cycles. During these unload-reload cycles the response was nearly elastic with little hysteresis. A least squares fit was made to each cycle to determine the bulk modulus of the material at that density.

There are not enough data of this type to define a unique functional form for the bulk modulus; however, another necessary constraint is that the expression must predict the bulk modulus of intact (fully compacted) salt. Thus $K = 20.7$ GPa at a density of 2.14 g/cc [10] must be added to Table A.1. This additional point shows the necessity for a nonlinear function such as an exponential to describe the elastic bulk modulus as a function of the density. The data from Table A.1 together with the additional data point are shown on a semilog plot in Figure A.1. Also shown is a least square fit subject to the constraint that the equation must predict the correct value for intact salt. The equation for the elastic bulk modulus is then

$$K = 17.6\times10^3\, e^{6.53\rho} \qquad (A.1)$$

where K has units of Pascals and ρ is the density in g/cc. It appears that the fit is acceptable, but without the constraint that the crushed salt have the modulus of intact salt, the trend of the data is somewhat shallower than that predicted by the exponential fit. It is recommended that more tests of this type be made in the future.

Since there have been no experiments to determine the elastic shear modulus, the form of Equation (A.1) is also used to describe the shear modulus. The shear modulus for intact salt is equal to 12.4 GPa [10]. The constraint that the equation correctly predict the intact salt value gives

$$G = 10.6\times10^3\, e^{6.53\rho} \qquad (A.2)$$

where G has units of Pascals and ρ is the density in g/cc.

Equations (A.1) and (A.2) are also used to describe the elastic moduli of wet crushed salt. No test data are available to support this claim, but it is not expected that the addition of small amounts of water would significantly affect the elastic properties of the material.

Table A.1. Bulk Modulus Data for Dry Crushed Salt Material [8]

Density (g/cc)	*Bulk Modulus (GPa)*
1.54	0.562
1.62	0.855
1.67	1.269
1.72	1.381
1.76	1.823
1.79	1.557
1.83	1.938
1.87	2.290
1.90	2.700

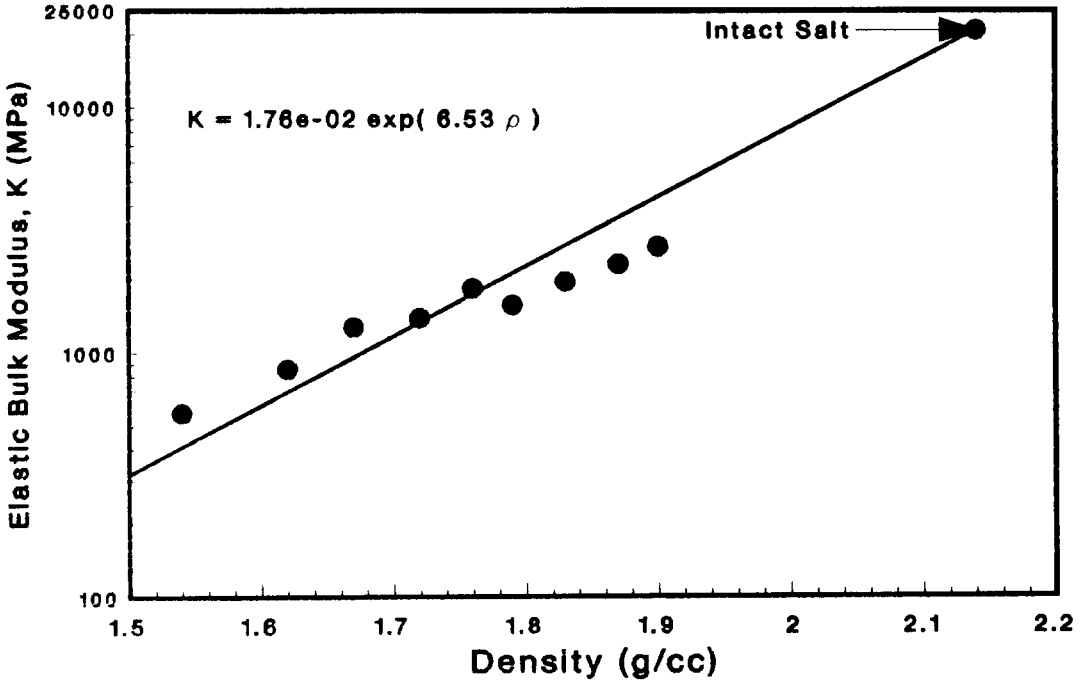

Figure A.1. Bulk Modulus Data for Dry Crushed Salt Material

B. User's Instructions for SANCHO

The crushed salt constitutive model is written as an update deck for SANCHO. The author of this report should be contacted for information concerning the location of this file and for instructions on how to use this model in SANCHO. The constitutive model is currently Material 7 and the information required for the material property specification cards is detailed below in the form used in Reference [20].

MATERIAL TYPE 7 — Crushed Salt Material

MATERIAL, 7, ro, gravx, gravy, omega	CARD 1
MATERIAL TITLE CARD	CARD 2
G_0, G_1, K_0, K_1, A_c, N, Q/R, A, A_1, B_0, B_1, T_0, T_1, Dev, θ	CARD 3

G = Shear Modulus $G = G_0 e^{G_1 \rho}$,
K = Bulk Modulus $K = K_0 e^{K_1 \rho}$,
A_c = Material Constant for deviatoric creep model, see Equation (3.4.6)
N = Stress Power Constant for deviatoric creep model,
Q/R = Exponential Constant for deviatoric creep model,
A = Parameter for Strain Decay, see Equation (2.5.2),
A_1 = 0.0 (Unused),
B = Stress Dependence $B = B_0 e^{B_1 \sigma}$,
T = Yield Stress $T = f(T_0, T_1)$, the values T_0 and T_1 are used in the function relating the yield stress to the density. The form of this function has not yet been determined.
Dev = Deviatoric Model Flag—
0 = Elastic-Plastic Deviatoric Model. If the yield strength is zero, the elastic deviatoric model is used 1 = Elastic-Creep Deviatoric Model
θ = Temperature, currently unused.

The current value of the density is output to the SEACO file as state variable `EPX(5)`; the other 4 variables are unused. A subroutine called `INTDEN` must be supplied to initialize the density of the crushed salt material. The calling syntax is

```
SUBROUTINE INTDEN (MX,I,EPX)
DIMENSION EPX(*)
```

where `MX` is the current material number and `I` is the element number. The array `EPX` is the state variable array. Elements 5, 10, 15, and 20 of this array must be initialized to the initial crushed salt density.

C. Determination of Crushed Salt Yield Strength

The choice of the proper deviatoric model for crushed salt is very difficult since few data are available. Another problem is the determination of the material parameters to be used in the chosen model. This section describes the method used for the deviatoric model in the backfilled drift analyses. The elastic-plastic deviatoric model was used since the yield strength of the material is the only unknown material parameter. The method described below was used to produce numerically the stiffest possible deviatoric behavior (maximum shear strength).

In the backfilled drift analyses, the yield strength for each element of the backfill and for each time step was chosen such that all of the stress components were compressive or zero if the deviatoric strain rate was compressive. This was done to produce the stiffest backfill material and also to determine numerically the maximum theoretically possible value for the yield stress as a function of the density assuming that the crushed salt can be modeled with an elastic-plastic deviatoric model. The procedure used to produce the stiff backfill model is described below.

For each element and at each time step, trial values of the quantity κ_i^T [see Equation (3.4.4)] for $i = 1,2,3$ were calculated for each of the three normal stress components using (no sum on i):

$$\kappa_i^T = \frac{-\sigma_F}{(S_{ii}^0 + 2G\dot{e}'_{ii}t)} \quad \text{if} \quad \dot{e}'_{ii} < 0 \tag{C.1}$$

where t is the load step size, S_{ii}^0 is evaluated at the start and σ_F at the end of the time step. The value of κ used in Equation (3.4.5) was chosen as the minimum of the κ_i^T. The maximum theoretical value of the yield stress at that time step and location was then calculated as

$$\sigma_Y = \sqrt{\tfrac{3}{2}}\,\kappa S^T \tag{C.2}$$

Figure C.1 is a plot showing the variation of the calculated yield stress as a function of the fractional density for the square-cornered backfilled drift calculation. Each point represents the calculated yield stress for an element at a time step during the calculation. The yield stress is seen to vary almost exponentially with the fractional density. A linear regression program [19] was used to find the best fit line relating the natural logarithm of the yield stress to the fractional density. The coefficient of correlation is 0.993 indicating a very good correlation. The t-test for statistical significance indicates that the calculated regression coefficients are significant at the 99.0% confidence level. The least squares best fit equation relating the yield stress

to the fractional density is

$$\begin{aligned} \ln \sigma_Y &= -4.10 + 19.21(\rho/\rho_\infty) \\ \sigma_Y &= 1.657 \times 10^{-2} \exp(19.21\rho/\rho_\infty) \end{aligned} \tag{C.3}$$

where σ_Y is the yield stress, ρ is the density, and ρ_∞ is the density of intact salt. This equation is plotted with the data in Figure C.1. Note that this is only a bound on σ_Y, not an actual value; tests will give a value less than this.

Although there are indications of a strong correlation between the yield stress and the fractional density, more research and experimentation are needed to gain a better understanding of the correct deviatoric behavior and the material constants that should be used in the deviatoric model.

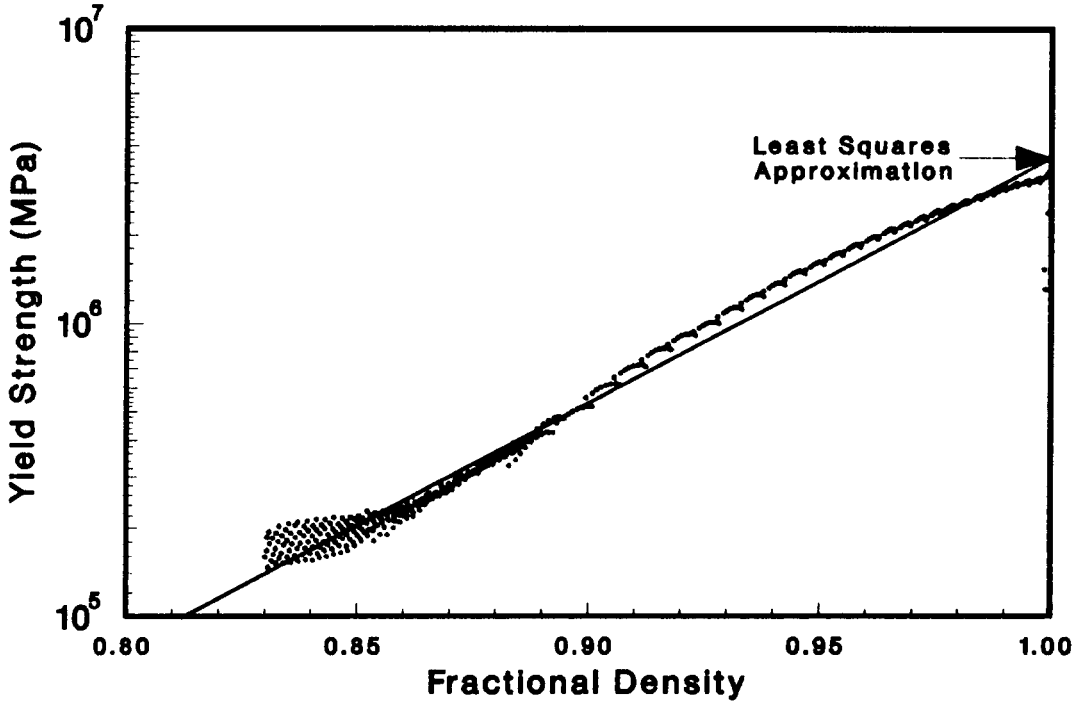

Figure C.1. Variation of Calculated Yield Stress with Fractional Density

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date: January 5, 1990

to: Darrell Mercer, Craig Fredrickson - DOE/SEIS Office

Scott E. Slezak Al Lappin

from: Scott Slezak - 6517, Al Lappin - 6345

subject: Potential for and Possible Impacts of Generation of Flammable and/or Detonable Gas Mixtures During the WIPP Transportation, Test, and Operational Phases

This revised memo summarizes our present thinking and preliminary calculations concerning the potential for flammable and/or detonable mixtures of hydrogen or methane (plus oxygen) at the WIPP. It is intended for your use in the very near future. The original memo was prepared on December 21 and December 22, 1989; internal referencing is not as complete as desirable, especially concerning the interim-storage and transportation phases of the WIPP. This revised form includes only editorial and typographical corrections that could not be made on the original schedule. Additional information concerning gas generation during the experimental phase is also contained in Molecke (1989c).

The objectives of the memo are to: 1) summarize the various conditions or situations of possible gas collection during the transportation, testing, and disposal/operational phases at the WIPP; 2) summarize the assumed gas-generation rates for CH TRU wastes; and 3) qualitatively assess the potential for collection of flammable and/or detonable gas mixtures under each of the conditions listed in 1) above. Emphasis is placed on the potential impact or consequence of gas detonation within the head space above a panel of emplaced waste and backfill, following emplacement of an effectively impermeable panel seal at the repository horizon.

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The study reaches the conclusions that:

1. The addition of carbon-composite or Kevlar particulate filters should effectively remove the potential for buildup of flammable/detonable concentrations of hydrogen within vented drums, so long as the drums are in a ventilated environment. There appears to be a credible potential, at longer times, for generation of flammable concentrations of methane, even within vented drums, if the highest laboratory-measured gas-generation rates should occur.

2. During the process of full-scale waste emplacement, there is not a credible potential for collection of flammable/detonable gas mixtures in the room head space, during the time interval before emplacement of the composite panel seal at the repository horizon.

3. There is a reasonable potential for collection of flammable and possibly detonable mixtures of hydrogen, methane, and oxygen in the room head space above backfilled waste after emplacement of the composite panel seal.

   Calculations have been completed to investigate the potential consequences of such a detonation. The results indicate that there should be no measurable displacement of the first grout component (nominally thirty feet in length). Thus, the health consequences of detonation of such a mixture appear to be nil.

4. There does not appear to be a credible potential for collection of flammable/detonable gas mixtures in any of the planned CH-TRU test alcoves during the WIPP test phase.

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The alcove atmosphere in four of the five waste-containing alcoves (TA3 - TA6) will be maintained in an anoxic condition by nitrogen circulation and catalytic oxygen removal. The atmosphere in the one alcove containing as-received waste (TA2) is not expected to reach potentially flammable limits. The ability to partially purge the room atmosphere with nitrogen gas will be present as a mitigative measure, should potentially flammable hydrogen or methane concentrations be approached in any of the test alcoves.

5. While collection of flammable or even nominally detonable gas concentrations in some of the bin-scale tests is credible, there is no risk of any methane-based detonation. Both the free volume and the ignition energy required to support such a detonation are not available.

   The tests in which the collection of flammable/detonable gas concentrations is most credible are those (approximately) three dozen bins in which the bin atmosphere is not purged with argon. Essentially all of the remaining bins, in which the atmosphere will be purged with argon, are expected to remain anoxic during the experimental time span. The one exception is bin tests containing process sludges, since there is evidence that radiolysis within process sludges can generate considerable concentrations of oxygen.

   All of the bin-scale tests will be closely monitored throughout their experimental life. The ability to partially purge the bin atmosphere will be maintained at all times. Possible mitigating actions have been identified, should they be required.

I. Possible Conditions Requiring Consideration of Gas Collection

In the present interim-storage, and planned transportation, testing, and operational life spans of CH-TRU wastes to be emplaced at the WIPP, the

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potential for generation and/or ignition of flammable and/or detonable gas mixtures generated by radiolysis and other waste-degradation processes be considered in several geometries and conditions. These include (listed in order of increasing time from the present and increasing geometric scale):

A. Within individual unvented drums presently in interim storage at waste-generator sites.

B. Within individual drums, fitted with carbon-composite filters for purposes of shipment within TRUPACT II.

C. Within the available void space within TRUPACT II containers (but outside individual drums) during shipment to the WIPP Site.

D. Within individual bin-scale tests at the WIPP, in the absence of atmospheric purging.

Individual bags of waste present in these tests will be removed from their original containers prior to being emplaced in bins. However, the bags will not be breached or slashed; their behavior is intended to simulate that during the operational phase of waste emplacement as closely as possible (Molecke, 1989a).

E. Within individual bin-scale tests at the WIPP, with atmospheric purging.

Individual drums of waste are either not present in the purged bin-scale tests, or (if the wastes being tested are sludges or compacted wastes) are specially penetrated to ensure free release of volatiles and access of brine to contained wastes) (Molecke, 1989a).

F. Within a CH-TRU test alcove at the WIPP, in the absence of atmospheric purging.

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Waste emplaced in one of the five planned waste-containing alcoves (TA2) will be emplaced without backfill, but will consist of drums vented (because they must be transported to the WIPP in TRUPACT II) with carbon-composite filters (Molecke, 1989b).

G. Within a CH-TRU test alcove at the WIPP, with atmospheric purging. As presently planned, waste emplaced in four of the five planned waste-containing alcoves (TA3-TA6) will be emplaced as individual drums (with non-VOC-sorbing Kevlar, instead of carbon-composite filters), combined with loose, granular salt, or salt-bentonite backfill (Molecke, 1989b).

H. Within the rooms within a CH-TRU waste-emplacement panel at the WIPP, after emplacement of temporary bulkheads, but prior to emplacement of a composite panel seal.

As presently designed, drums of as-received and/or supercompacted wastes will be emplaced and "surrounded" with granular salt or salt/bentonite backfill. The backfill will nominally be pneumatically or mechanically emplaced to within about 1 and 1/2 feet of the room ceiling; i.e., it will cover the drums. A "bulkhead" will be emplaced at the "ends" of each room after it is filled, for purposes of ventilation control. It is assumed that this bulkhead is not impermeable to gas, but allows displacement of head-space gas by gases generated by waste degradation.

I. Within a CH-TRU waste-emplacement panel at the WIPP, following emplacement of a composite panel seal. It is assumed here that, for reasons of safety (i.e., control of both ventilation and prevention of possible fire propagation), a composite panel seal will be emplaced two years after the beginning of waste/backfill emplacement in an individual waste panel. It is assumed that the grout component of the composite seal (as opposed to the crushed or block-salt component) is immediately effective in permeability reduction. It should be noted that the possibility of underground fire is considered in the WIPP

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Final Environmental Impact Statement (U.S. Department of Energy, 1980).

II. Assumed Gas-Generation Rates and Compositions

At present, there is considerable uncertainty in both gas-generation rates and gas compositions expected to result from emplacement of CH-TRU waste in the WIPP, with or without engineering modifications to waste and/or backfill. Better estimation of these rates and compositions is the central objective of the planned experiments with real CH-TRU wastes at the WIPP, although the effective concentrations of radionuclides in realistic Salado and Castile brines after interaction of these brines with CH-TRU wastes will also be determined. For purposes of the preliminary calculations summarized here, it has been assumed that: 1) hydrogen generation by radiolysis of a mix of CH-TRU wastes representative of the expected room inventory averages 0.05 moles/drum/year; 2) methane generation from biodegradation of the mix of CH-TRU wastes representative of the expected room inventory averages 0.25 moles/drum/year; and 3) oxygen dilution occurs only by generation of methane and hydrogen. Neither dilution by generation of other gases, such as CO_2, nor the expected oxygen depletion resulting from corrosion and/or microbial activity are factored into consideration. As a result, the fact that the expected long-term condition of WIPP waste-emplacement rooms and panels is strongly anoxic is ignored. Additional information concerning uncertainties in WIPP gas generation is contained in Lappin et al. (1989), Molecke (1979), and the WIPP Draft Supplemental Environmental Impact Statement (U.S. Department of Energy, 1989).

It should be noted that estimation of the rates at which anoxic conditions are achieved and of the degree to which anoxic conditions are stable are specific objectives of the WIPP Test Phase. These experiments specifically form an experimental linkage between short-term (sixty day) calculations performed for the WIPP transportation phase and long-term performance-assessment calculations, which: a) begin at 100 years after decommissioning of the WIPP repository; and b) assume anoxic conditions. Processes

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expected under the long-term anoxic conditions are being investigated in both laboratory (Brush, 1989) using simulated wastes and in larger-scale tests using real wastes (Molecke, 1989a; 1989b).

The gas-generation rates assumed here are intended to be representative on the room scale, rather than "bounding." They do not include consideration of such factors as possible segregation of waste types, but assume uniform mixing of wastes within each room. For example, hydrogen generation rates from radiolysis as high as 0.75 moles/drum/year have been reported by Molecke (1979) for process sludges, which are expected to make up approximately 15% of the WIPP inventory. Similarly, CO_2 generation rates as high as 5 moles/drum/year are reported by Molecke (1979) from microbial degradation of cellulosic wastes. It is assumed here (and in studies conducted by the British, e.g., Rees, 1989) that microbial methane generation is at a mole rate equal to that of CO_2 generation, or that methane production can occur instead of CO_2 generation. In the case where combustion/detonation is considered credible, the calculations have been performed on the basis of the worst-case gas mixture (stoichiometric mix of methane, hydrogen, and oxygen), not on the basis of time. Under these assumptions, the first-order consequence of more rapid or slower generation of hydrogen and methane would simply be to change the time of combustion/detonation, not to change its expected or possible impact.

III. Qualitative Evaluation of the Potential for Collection of Flammable/Detonable Gas Mixtures Under the Various Conditions Considered Here, and of Potential Mitigating Measures

A. Within individual unvented drums presently in interim storage at waste-generator sites.

The available information (e.g., Clements and Kudera, 1985) indicates a significant potential for generation of both flammable and detonable gas mixtures in the head spaces in unvented waste drums. While there appears

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to be some potential for flammable mixtures in head spaces of drums containing cellulosic wastes, the potential for generation and maintenance of detonable mixtures appears to be greatest for drums of process sludges.

The potential for generation of flammable/detonable gas mixtures in unvented drums is well known to the different waste generators, and is mentioned here only to point out that all of the waste drums to be shipped to the WIPP, as a result of criteria developed for the TRUPACT II container and/or experimental needs, will be fitted with carbon-composite or dual Kevlar/carbon-composite particulate filters. Therefore, information or interpretations based on the behavior of unvented drums is not directly applicable to the WIPP.

B. Within individual drums, fitted with particulate filters, for purposes of shipment within TRUPACT II.

The major objective of installing carbon-composite dual Kevlar/carbon-composite particulate filters on CH-TRU waste drums is to ensure that hydrogen buildup during a time interval twice the nominal transportation period to the WIPP (thirty days) does not reach the flammability limit of hydrogen in air (approximately 4%) (DeSoete, 1975). Calculations done in support of the TRUPACT Safety Analysis Report indicate that, for hydrogen generation rates of up to 2.5 moles/drum/year, the rate of hydrogen diffusion through the filter should exceed the internal gas-generation rate. Thus, there appears to be no risk of significant hydrogen buildup within any individual drum, so long as the vented drum has access to outside ventilation.

Similar calculations suggest that methane diffusion rates through the filter should be adequate to prevent internal pressurization at gas-generation rates below about 3.5 moles/drum/year. As noted above, however, there appears to be a credible potential for methane generation rates as high as 5 moles/drum/year. If this were to occur, there might be some

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potential for methane concentrations to reach the nominal flammable/detonable limits in air (5 and 6%, respectively).

Two arguments suggest, however, that the probability of either a methane-based deflagration or a methane-based detonation within an individual vented drum is extremely unlikely. First, the available information indicates that, if spontaneous combustion were "attempting" to occur, methane (in combination with oxygen) would be consumed by relatively low-temperature "cooking." The result of this process would be that both methane and oxygen would be depleted, at temperatures well below those required for combustion. Secondly, even if the temperature were increased very rapidly, such that "cooking" was not effective, available information indicates that the minimum, relatively spherical, free volume required for methane detonation is approximately 1/2 the volume of a 55-gallon drum. While the total void volume within a waste drum may reach or even exceed 50%, it must be noted that this is distributed volume, rather than occurring as a single relatively spherical void. In addition, the energy required to initiate a detonation in predominantly-methane mixtures is not available in individual drums, since the energy required is equivalent to "pounds" of high explosive (Matsui and Lee, 1978).

For these reasons, the present conclusions are that: 1) due to the effectiveness of venting, there is no potential for buildup of flammable amounts of hydrogen within vented drums, so long as the vent has access to ventilation air; 2) due to the credible possibility of high methane-generation rates, there is a slight potential for buildup of nominally flammable/detonable methane concentrations within individual vented drums, even if the venting has free access to ventilation; and 3) however, because of the large free volume required to support a methane-based detonation, and the large energy requirements for the initiation of detonation, there is no credible potential for methane detonation within an individual vented drum. Therefore, the worst-case individual drum scenario appears to be spontaneous combustion of a drum within which the head space contains a flammable concentration of methane.

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C. Within the available void space within TRUPACT II containers during shipment to the WIPP Site.

As we presently understand it, the calculations in support of TRUPACT certification have the objective of guaranteeing that hydrogen concentrations within the available void space within the container (and therefore within the individual drums) do not reach the nominal hydrogen flammability limit in air (4%) within 60 days. The calculations do not consider possible oxygen depletion.

The only point in mentioning these calculations here is to indicate that the TRUPACT criteria do not, in and of themselves, provide any long-term guarantee against flammable or detonable gas mixtures at the WIPP, nor were they intended to do so.

D. Within individual bin-scale tests at the WIPP, in the absence of atmospheric purging. The individual bags of waste used in these tests will be removed from their containers prior to being emplaced in bins, but the bags will not be breached or slashed. Their behavior is intended to simulate the operational phase of waste emplacement as closely as possible.

The planned bin-scale tests with real CH-TRU wastes (Molecke 1989a) consist of sealed bins nominally containing about six drum equivalents of waste. The bins are intended to be isolated from the environment, except for intermittent controlled gas venting (at app. 0.5 psi overpressure) and effective temperature control by the in situ environment 2150 feet underground. Because of the need to control possible gas venting and to sample gases within the drums, the capability will exist to purge any given bin with inert gas, nominally argon.

Approximately four dozen bins are intended to examine the behavior of "as-received" wastes, in the absence of: 1) atmospheric purging; 2) backfill;

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and 3) addition of either Salado or Castile brines. One specific objective of these tests is to investigate the rate and extent to which the atmosphere in waste-emplacement rooms can be expected to become effectively anoxic with time. In addition, these tests will examine whether, after gas release during vent installation prior to shipment, shipment, and handling, sufficient hydrogen and methane generation potentials remain for generation of flammable/detonable gas mixtures while conditions remain relatively oxygen rich. Note that these (nominally) four dozen tests form the only experimental link between the transportation time frame of 60 days and the time frame of long-term performance assessment, which begins 100 years after decommissioning.

The facts that these bins are to be sealed, but will not be at an overpressure of more than 0.5 psi above ambient, and that the atmosphere in these bins will not be purged with argon (see below) indicates that there is some potential for development of flammable and conceivably detonable gas mixtures in the void spaces within the bins during the planned five-year life span of these tests. This is, however, only of concern if there is adequate residual oxygen gas remaining in the bin(s).

However, there are several possible approaches to mitigating the risk. First, in order for deflagration to occur, there must be an ignition source. All electrical apparatus associated with the bin tests will be carefully grounded, to eliminate the potential for electrical ignition. Spontaneous combustion, which is being taken as the base-case or bounding accident scenario for single drums of waste emplaced at the WIPP, includes a precursor phase of temperature rise, to temperatures well in excess of 450 ^{o}C, the approximate temperature at which "cooking" and elimination of both methane and oxygen might occur (DeSoete, 1975; Sheldon, 1984)(see above). All of the bin tests will be equipped with thermocouples. While it is recognized that the extent of the area of increased temperature may be relatively small, the redundant thermocouples in each bin should monitor a significant temperature rise, well before the hottest point in the bin reached 450 ^{o}C. If not, and a local region within the drum reached a temperature of 450 degrees, a marked change in drum atmosphere (decrease in

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methane and oxygen, increase in CO_2) should be noted. Possible mitigations, based on ongoing monitoring of the individual bins, include: 1) partial purging with argon if either hydrogen or methane approaches the nominal flammability limit and a significant internal temperature excursion is identified and a change in gas composition is identified, indicative of "cooking," i.e., a marked increase in CO_2; 2) partial purging with argon if either hydrogen or methane approaches the nominal flammability limit and a significant internal temperature excursion is identified; or 3) partial purging with argon if either hydrogen or methane approaches the nominal flammability limit, independent of temperature. From an experimental point of view, the first option is much preferred.

Finally, as noted above, the potential for detonation is roughly proportional to the gas-filled void space, and is dependent on a minimum ignition energy being available. In addition, due to their low content of free brine, it is expected that reactions in the bin tests with "as received" wastes must occur through vapor-phase transport. Therefore, it appears that a possible mitigation measure for these bin tests would be to simply decrease the available void space with inert material, such as silica sand or alumina spheres.

In summary, in the absence of mitigating measures, there appears to be some potential for generation of nominally flammable mixtures of hydrogen, methane, and oxygen in the (nominally) four dozen bin tests investigating the gas-generation and oxidation-state behavior of as-received wastes. However, several possible mitigation measures have been identified for these experiments.

E. Within individual bin-scale tests at the WIPP, with atmospheric purging.

At present, planning calls for conducting at least 124 bin-scale tests, of which approximately four dozen, dealing with as-received waste, will not have their atmosphere purged with argon gas (see D above). The atmosphere

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in the rest of the bin tests will be purged of oxygen, since the intent is to examine the behavior under the expected long-term anoxic conditions. To ensure that anoxic conditions are not being artificially forced, the internal atmosphere will be allowed to "float" to its own oxygen content, after the initial purging. In essentially all cases, with the possible exception of process sludges (which can potentially generate appreciable oxygen from radiolysis), the in-bin oxygen level is expected to be negligible.

Note that individual drums of waste are either not present in the purged tests, or (if the contained wastes are either sludges or compacted wastes) are specially penetrated to ensure free release of volatiles and access of brine to contained wastes). In fact, to ensure free mixing, the waste generators have agreed to pierce or slash individual waste bags being used in these tests.

Therefore, we conclude that there is no credible risk of generation of flammable gas mixtures in the bin-scale tests in which the atmosphere has been purged and then allowed to "float,", except for those few tests with process-sludge wastes. However, the atmosphere in these tests will be routinely monitored, with the result that essentially the same range of potential mitigating actions will exist as already described (in D above) for the case of tests in which the atmosphere is not purged.

F. Within a CH-TRU test alcove at the WIPP, in the absence of atmospheric purging.

Present planning (Molecke, 1989b) calls for fielding of five alcoves filled with CH-TRU wastes at the WIPP. Four of the alcoves (TA3, TA4, TA5, and TA6) are intended to investigate waste/backfill behavior under expected long-term anoxic conditions (see G below). However, one alcove (TA2) is intended to simulate behavior during the later portions of the operational phase, as are bin tests with as-received wastes. Waste will be emplaced in TA2 without backfill or added brine. The alcove will nominally be "sealed"

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with a pneumatic seal, having a design-basis leak rate of 1% or less per week, and the alcove operated at a nominal positive differential pressure of 0.25 to 0.5 psi. Gases lost through leakage will be replaced by addition of nitrogen. In addition, this alcove, like alcoves TA3 through TA6, will be equipped with a gas circulation/purging system, so that the ability to partially purge the alcove atmosphere with nitrogen will be maintained at all times.

In the presence of "perfect" sealing (see I below), there might be some potential for the development of flammable gas mixtures in the general void space within TA2 during the anticipated 5-year span of the test. However, because of the anticipated gas-leakage rate of 1% per week, we do not believe this is credible. Gas leakage through the seal will be made up with nitrogen. Preliminary calculations indicate that the room atmosphere, even at the end of the expected 5-year test phase, will be well below flammable limits for both hydrogen and methane.

Waste emplaced in TA2 will be emplaced without backfill, but will consist of drums vented with carbon-composite filters, because the drums must be transported to the WIPP in TRUPACT. However, it must be recognized that even active venting of TA2 will not completely eliminate the potential for spontaneous combustion within an individual drum of waste in the alcove, since this potential appears to be limited by the effectiveness of the carbon-carbon composite filter on each drum.

G. Within a CH-TRU test alcove at the WIPP, <u>with atmospheric purging</u>.

As presently planned (Molecke, 1989b), waste emplaced in alcoves TA3 through TA6 will be emplaced as individual drums (with non-VOC-sorbing Kevlar particulate filters), combined with loose, granular salt, or salt-bentonite backfill. Because the objective of these alcoves is to examine behavior in the expected long-term anoxic conditions, the atmosphere in the alcoves will be: 1) initially purged with nitrogen; and 2) maintained in anoxic conditions by use of a continuous oxygen-"gettering" reactant

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system. Therefore, there will be no credible potential for generation of flammable gas mixtures within the general alcove atmosphere in alcoves TA3 through TA6.

However, the small potential for spontaneous combustion within individual vented drums (see B above) will remain. A possible mitigating action to eliminate the potential for propagation of deflagration within the backfill is presently being considered. Basically, the possibility of fire propagation through a granular material is proportional to the interconnected pore size. In the case of WIPP, the design-basis backfill of granular salt with a screen size of 1/4 inch or less, might have a similar maximum interconnected pore size, similar to the minimum pore size required for fire propagation. However, since all of the salt passing the 1/4-inch screen would be used, a large proportion of fines should be present, decreasing the effective pore size greatly. It appears that the expected presence of fines in the backfill mix should remove the possibility of fire propagation through the backfill.

H. Within the rooms within a CH-TRU waste-emplacement panel at the WIPP, after emplacement of temporary bulkheads, but prior to emplacement of a composite panel seal.

As presently designed, drums of as-received and/or supercompacted wastes will be emplaced and "surrounded" with granular salt or salt/bentonite backfill in waste-emplacement rooms. The backfill will nominally be pneumatically or mechanically emplaced to within about 1 and 1/2 feet of the room ceiling. In addition, it is assumed that a "bulkhead" will be emplaced at the "ends" of each room as it is filled, for purposes of ventilation control. However, it is assumed that this bulkhead is not impermeable to gas.

Preliminary calculations assume that the bulkheads allow simple displacement of initial atmosphere with gases resulting from waste degradation. These calculations indicate that, for the design-basis time

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period of two to two and one half years required for filling of an entire waste-emplacement panel, both hydrogen and methane levels within the head space above emplaced waste and backfill in the individual bulkheaded rooms will remain below nominally flammable concentrations. Calculated methane and hydrogen concentrations are 3.4% and 0.7% for the "oldest" room and 0.6% and 0.1% for the "newest" bulkheaded room, respectively. In fact, we expect the room bulkheads to be at least as "leaky" as the alcove seals, and that the concentrations of flammable gases in the room headspaces of bulkheaded room will, until the time of seal emplacement, actually be lower than estimated here.

If a notable rise in flammable-gas concentrations is measured, a small gap, e.g., 6 inches could be left between the top of the bulkhead and the roof to allow some ventilation. Since both hydrogen and methane are lighter than air, such a gap would allow the gases to creep along the ceiling and vent out of the room headspace. The same potential (if any) for spontaneous combustion within individual drums would persist as is present in all drums.

I. In the head space present within a CH-TRU waste-emplacement panel at the WIPP, <u>following emplacement of a composite panel seal</u>.

It is assumed here that a composite panel seal will nominally be emplaced two years after the beginning of waste/backfill emplacement in an individual waste panel. It is further assumed that the grout component of the composite seal (as opposed to the crushed or block-salt component) is immediately effective in permeability reduction. Finally, it is assumed that oxygen dilution occurs by generation of gases by waste degradation, i.e., the role of microbial activity and corrosion (under oxidizing conditions) in reducing oxygen concentrations is not considered.

Under these conditions, for the assumed gas-generation rates, preliminary calculations indicate that the "worst-case" or most potentially detonable mixture of methane, hydrogen, and oxygen would be present in the head space

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approximately five years after panel-seal emplacement. The "worst-case" mix is that containing a stoichiometric mix of hydrogen, methane, and oxygen for conversion to CO_2 and water. The calculations, summarized below, assume this gas mixture. Variations in total gas-generation rate would, so long as the relative rates of hydrogen and methane generation remained fixed, simply change the time at which the worst-case mix occurred, but would not change the consequences estimated here, under the assumptions used.

It appears that the nominal head space above the waste and backfill (1 1/2 feet) might be capable of propagating a methane-based "detonation." In order to estimate the resulting pressure loading on the panel seal, it is assumed here that: 1) a detonation is initiated in the head space at the corner furthest from the panel seal, and successfully propagates to the panel seal; and 2) the resulting pressure wave is applied uniformly over the area of the seal exposed in the 1 1/2-foot headspace.

The calculations, made using the Gordon-McBride code (available through COSMIC), indicate that a peak pressure of approximately 800 psi would be applied to the front face of the seal and immediately begins to decay in a linear fashion, to approximately 120 psi at 0.35 seconds after impact. The peak compressive pressure on the back face of the seal component is estimated to be only a few psi. The pressure-decay rate on the front face at longer times is somewhat uncertain, since it would depend on the thermal coupling of head-space gases to surrounding rock and waste/backfill. Because the high pressures decay so quickly, and the grout plug is so massive, and hence responds so slowly, dynamic calculations indicate that the effective pressures are much lower than the instantaneous pressures (Biggs, 1964).

Several factors in consideration of the probability of such an event occurring are inherently conservative. For example, the propagation of a detonation requires a certain minimum "duct" size. If the duct gets too small, a detonation will not successfully propagate. For the methane-dominated situated expected for the WIPP, it appears as if the nominal

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head-space gap may be marginally adequate, and then only for near-optimal (stoichiometric) mixtures. The duct is not capable of sustaining detonations in mixtures near the lean or rich flammability limits (Peraldi, et al., 1986; Slezak, 1990). Any significant amount of room closure prior to development of flammable gas mixtures would, in the absence of compensating waste/backfill settling, decrease the potential. In general, development of a detonation is enhanced by turbulent fluid flow; for purposes of considering gas dynamics, the walls and boundaries of the head space at WIPP are "rippling," but quite smooth. In addition, it was assumed that the "duct" was rigid, i.e. the elastic compliance of the waste and backfill below the headspace was not considered; in reality, the waste and backfill would be expected to compact in response to any pressure pulse within the headspace above, thereby greatly decreasing the likelihood of such a pressure pulse propagating.

The estimated consequences of the assumed detonation are negligible, largely because of the massive character of the grout component of the composite panel seal, which will have a mass of approximately 10^6 pounds, and a length of approximately 30 feet. It is estimated that there might be some fracturing within the salt and plug, to a depth of one or two feet. However, because the pressure is applied over a limited area, fracturing to greater depth is expected to be prevented by dissipation of the assumed shock wave. Similarly, there might be some slight spalling of grout on both ends of the first grout plug. No measurable movement of the first grout seal component is expected to occur. The assumed detonation event would be expected to have zero release consequence.

Even this preliminary calculation contains several conservative factors. For example, the calculation assumes that a detonation starts at the far corner of the waste-emplacement panel, and has 800 feet of free run to the panel seal. Further, only the first grout component of the composite seal is even considered. In fact, the present panel-seal design calls for emplacement of approximately 60 feet of tamped salt and block salt behind the first grout component, as well as for emplacement of a second grout component, equally massive as the first. Therefore, while there might be

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slight spallation on the back side of the first grout component, there is an additional 90 feet of salt and grout between the first grout component and any accessway within which people might be present during the operational phase. Both grout components of the composite seal will be "keyed" into the surrounding sale; no credit for this keying, or for any frictional forces on the grout, are considered here. In addition, creep in both the backfill and the tamped- and block-salt component of the composite seal will tend toward hydrostatic pressure on both faces of the grout plug. This also helps to lock in the plug. Finally, as noted above, no credit is taken for the low strength of design-basis waste and backfill prior to compaction (at which time no significant head space will remain); waste/backfill compaction in response to a pressure pulse within the head space would certainly tend to damp out propagation of such a pulse.

In summary, even if it is assumed that development of flammable/detonable gas mixtures in the head space above a panel of emplaced waste after emplacement of the panel seal is credible, and that this gas mixture in fact detonates, preliminary calculations indicate that the safety consequences to personnel would be negligible. The calculations contain several conservative assumptions.

Should experimental test results during the WIPP Test Phase indicate that the scenario considered here <u>is</u> credible, there are several mitigating actions that have been considered. For example, the available oxygen might be reduced by purging of the panel head space with inert gas just prior to panel-seal emplacement. The head space gases might be intentionally ignited well below their detonation limit, by use of Pt ignitors, which would require no maintenance of remote electrical power. Seal emplacement might be delayed, or the repository actively vented.

At any rate, the potential for and possible consequences of flammable and/or detonable gas mixtures will be considered in the final WIPP Safety Analysis Report, as appropriate on the basis of both experimental results during the test phase and further evaluation of the preliminary calculations summarized here.

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Public Law 108–447
108th Congress

An Act

Making appropriations for foreign operations, export financing, and related programs for the fiscal year ending September 30, 2005, and for other purposes.

Dec. 8, 2004
[H.R. 4818]

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

Consolidated Appropriations Act, 2005

SECTION 1. SHORT TITLE.

This Act may be cited as the "Consolidated Appropriations Act, 2005".

SEC. 2. TABLE OF CONTENTS.

The table of contents for this Act is as follows:

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Sec. 2. Table of contents.
Sec. 3. References.
Sec. 4. Statement of appropriations.

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DIVISION B—DEPARTMENTS OF COMMERCE, JUSTICE, AND STATE, THE JUDICIARY, AND RELATED AGENCIES APPROPRIATIONS ACT, 2005

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Title VII—Mississippi Gulf Coast National Heritage Area Act
Title VIII—Federal Lands Recreation Enhancement Act
Title IX—Satellite Home Viewer Extension and Reauthorization Act of 2004
Title X—Snake River Water Rights Act of 2004

DIVISION K—SMALL BUSINESS

1 USC 1 note.

SEC. 3. REFERENCES.

Except as expressly provided otherwise, any reference to "this Act" contained in any division of this Act shall be treated as referring only to the provisions of that division.

SEC. 4. STATEMENT OF APPROPRIATIONS.

The following sums in this Act are appropriated, out of any money in the Treasury not otherwise appropriated, for the fiscal year ending September 30, 2005.

SEC. 426. (a) WAIVER OF REQUIREMENTS.—Subject to subsection (b), the limitation on the release of funds in section 104(g)(2) of the Housing and Community Development Act of 1974 (42 U.S.C. 5304) shall not apply to the Village of Chickasaw Sewer Collection and Treatment System, located in the Village of Chickasaw, Mercer County, Ohio.

(b) APPLICABILITY.—Subsection (a) only applies to the grant that was awarded to the Village of Chickasaw (Ohio Small Cities CDBG Grant # C–W–03–283–1), for the period beginning September 1, 2003, and ending October 31, 2005, and in the amount of $600,000.

(c) ENVIRONMENTAL REVIEWS.—Notwithstanding the provisions of this section, the Village of Chickasaw must complete all appropriate environment reviews in a timely manner and to the satisfaction of the State of Ohio.

This division may be cited as the "Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Act, 2005".

DIVISION J—OTHER MATTERS

TITLE I—MISCELLANEOUS PROVISIONS AND OFFSETS

Miscellaneous Appropriations and Offsets Act, 2005.

SEC. 101. For an additional amount for the Department of Energy for the weatherization assistance program pursuant to 42 U.S.C. 6861 et seq. and notwithstanding section 3003(d)(2) of Public Law 99–509, $230,000,000, to remain available until expended.

SEC. 102. Section 1201(a) of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 (Public Law 108–375) is amended by striking "$300,000,000" in the matter preceding paragraph (1) and inserting "$500,000,000".

Ante, p. 2077.

SEC. 103. (a) The District of Columbia Appropriations Act, 2005 (Public Law 108–335) is amended as follows:

(1) The paragraph under the heading "CAPITAL OUTLAY" is amended by striking "For construction projects, an increase of $1,087,649,000, of which $839,898,000 shall be from local funds, $38,542,000 from Highway Trust funds, $37,000,000 from the Rights-of-way funds, $172,209,000 from Federal grant funds, and a rescission of $361,763,000 from local funds appropriated under this heading in prior fiscal years, for a net amount of $725,886,000, to remain available until expended;" and inserting "For construction projects, an increase of $1,102,039,000, of which $839,898,000 shall be from local funds, $38,542,000 from Highway Trust funds, $51,390,000 from the Rights-of-way funds, $172,209,000 from Federal grant funds, and a rescission of $361,763,000 from local funds appropriated under this heading in prior fiscal years, for a net amount of $740,276,000, to remain available until expended;".

Ante, p. 1338.

(2) Section 340(a) is amended to read as follows:

Ante, p. 1348.

"(a) Section 603(e)(3)(E) of the Student Loan Marketing Association Reorganization Act of 1996 (20 U.S.C. 1155(e)(3)(E)) is amended—

"(1) by striking 'and' at the end of subclause (II);

"(2) by striking the period at the end of subclause (III) and inserting '; and'; and

"(3) by adding at the end the following new subclause:

"'(IV) obtaining lease guarantees (in accordance with regulations promulgated by the Office of Public Charter School Financing).'.".

Ante, p. 1348.

(3) Section 342 is amended to read as follows:

"SEC. 342. PUBLIC SCHOOL SERVICES TO CHARTER SCHOOLS. Section 2209(b) of the District of Columbia School Reform Act of 1995 (sec. 38–1802.09(b), D.C. Official Code) is amended as follows:

"(1) In paragraph (1)—

"(A) by amending subparagraph (A) to read as follows:

"'(A) IN GENERAL.—Notwithstanding any other provision of law, regulation, or order relating to the disposition of a facility or property described in subparagraph (B), the Mayor and the District of Columbia government shall give a right of first offer with respect to any facility or property described in subparagraph (B) not previously purchased, leased, or transferred, or under contract to be purchased, leased, or transferred, or the subject of a previously proposed resolution submitted by the Mayor on or before December 1, 2004, to the Council of the District of Columbia seeking authority for disposition of such facility or property, or under an Exclusive Rights Agreement executed on or before December 1, 2004, to an eligible applicant whose petition to establish a public charter school has been conditionally approved under section 2203(d)(2), or a Board of Trustees, with respect to the purchase, lease, transfer, or use of a facility or property described in subparagraph (B).';

"(B) by amending subparagraph (B)(iii) to read as follows:

"'(iii) with respect to which—

"'(I) the Board of Education has transferred jurisdiction to the Mayor and over which the Mayor has jurisdiction on the effective date of this subclause; or

"'(II) over which the Mayor or any successor agency gains jurisdiction after the effective date of this subclause.'; and

"(C) by adding at the end the following new subparagraph:

"'(C) TERMS OF PURCHASE OR LEASE.—The terms of purchase or lease of a facility or property described in subparagraph (B) shall—

"'(i) be negotiated by the Mayor in accordance with written rules or regulations as determined by the Mayor, and published in the District of Columbia Register;

"'(ii) include rent or an acquisition price, as applicable, that is at the appraised value of the property based on use of the property for school purposes; and

"'(iii) include a lease period, if the property is to be leased, of not less than 25 years, and renewable for additional 25-year periods as long as the eligible applicant or Board of Trustees maintains its charter.'.

"(2) In paragraph (2)(A), by striking 'first preference' and inserting 'a right of first offer'.

"(3) By adding at the end the following new paragraph:

"'(3) CONVERSION PUBLIC CHARTER SCHOOLS.—Any District of Columbia public school that was approved to become a conversion public charter school under section 2201 before the effective date of this subsection or is approved to become a conversion public charter school after the effective date of this subsection, shall have the right to exclusively occupy the facilities the school occupied as a District of Columbia public school under a lease for a period of not less than 25 years, renewable for additional 25-year periods as long as the school maintains its charter at the appraised value of the property based on use of the property for school purposes.'.".

(4) Section 347 is amended by striking paragraphs (1) and (2) and inserting the following: *Ante,* p. 1352.

"(1) by striking subsection (f) and inserting the following:

"'(f) AUDIT.—The Board shall maintain its accounts according to Generally Accepted Accounting Principles. The Board shall provide for an audit of the financial statements of the Board by an independent certified public accountant in accordance with Government auditing standards for financial audits issued by the Comptroller General. The findings and recommendations of any such audit shall be forwarded to the Mayor, the Council of the District of Columbia, and the Office of the Chief Financial Officer of the District of Columbia.'; and

"(2) by adding at the end the following new subsection:

"'(h) CONTRACTING AND PROCUREMENT.—The Board shall have the authority to solicit, award, and execute contracts independently of the Office of Contracting and Procurement and the Chief Procurement Officer.'.".

(b) The amendments made by this section shall take effect as if included in the enactment of the District of Columbia Appropriations Act, 2005. Effective date. 20 USC 1155 note.

SEC. 104. The Secretary of the Department of Homeland Security shall transfer up to $40,000,000 from funds appropriated to the Coast Guard's "Acquisition, Construction, and Improvements" account in fiscal year 2005 from the Rescue 21 project to the HH–65 re-engining project, subject to 15-day advance notification to the House and Senate Committees on Appropriations.

SEC. 105. Section 203(m) of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (42 U.S.C 5133(m)) is amended by striking "December 31, 2004" and inserting "December 31, 2005". 42 USC 5133.

SEC. 106. Notwithstanding the amounts in the detailed funding table included in House Report 108–774, the appropriation for "Transportation Security Administration, Maritime and Land Security" shall include the following: "Credentialing, $5,000,000; TWIC, $15,000,000; Hazardous materials truck tracking, $2,000,000; Hazardous materials safety, $17,000,000; Enterprise staffing, $24,000,000; Rail security, $12,000,000; Offsetting collections, −$27,000,000".

SEC. 107. The matter under the heading "Military Construction, Navy and Marine Corps" in the Military Construction Appropriations Act, 2005 (division A of Public Law 108–324), is amended by striking "$1,069,947,000" and inserting "$1,065,597,000" and the matter under the heading "Military Construction, Naval Reserve" in such Act is amended by striking "$44,246,000" and inserting "$48,596,000". *Ante,* p. 1221. *Ante,* p. 1222.

SEC. 108. Notwithstanding any other provision of law, in addition to amounts otherwise made available in the Department of Defense Appropriations Act, 2005 (Public Law 108–287), an additional $2,000,000 is hereby appropriated and shall be made available under the heading "Shipbuilding and Conversion, Navy", only for the Secretary of the Navy for the purpose of acquiring a vessel with the Coast Guard registration number 225115: *Provided*, That the Secretary of the Navy shall provide for the transportation of the vessel from its present location: *Provided further*, That the Secretary of the Navy may lend, give, or otherwise dispose of the vessel at his election pursuant to 10 U.S.C. 2572, 7545, or 7306, or using such procedures as the Secretary deems appropriate, and to such recipient as the Secretary deems appropriate, without regard to these provisions.

SEC. 109. DESIGNATION OF NATIONAL TREE.

(a) DESIGNATION.—Chapter 3 of title 36, United States Code, is amended by adding at the end the following:

"§ 305. National tree

"The tree genus Quercus, commonly known as the oak tree, is the national tree.".

(b) CONFORMING AMENDMENTS.—Such title is amended—

(1) in the table of contents for part A of subtitle I, by striking "**, and March**" and inserting "**March, and Tree**";

(2) in the chapter heading for chapter 3, by striking ", AND MARCH" and inserting "MARCH, AND TREE"; and

(3) in the table of sections for chapter 3, by adding at the end the following:

"305. National tree.".

SEC. 110. Section 204(g) of the Employee Retirement Income Security Act of 1974, as amended (29 U.S.C. 1054(g)) shall not apply at any time, whether before or after the enactment of this section, to an amendment adopted prior to June 7, 2004, by a (multiemployer) pension plan covering primarily employees working in the State of Alaska, to the extent that such amendment—

(1) provides for the suspension of the payment of benefits, modifies the conditions under which the payment of benefits is suspended, or suspends actuarial adjustments in benefit payments in accordance with section 203(a)(3)(B) of said Act (29 U.S.C. 1053(a)(3)(B)) and applicable regulations; and

(2) applies to participants who have not retired before the adoption of such amendment.

Government employees.
36 USC 106 note.

SEC. 111. (a) The head of each Federal agency or department shall—

(1) provide each new employee of the agency or department with educational and training materials concerning the United States Constitution as part of the orientation materials provided to the new employee; and

(2) provide educational and training materials concerning the United States Constitution to each employee of the agency or department on September 17 of each year.

(b) Each educational institution that receives Federal funds for a fiscal year shall hold an educational program on the United States Constitution on September 17 of such year for the students served by the educational institution.

(c) Title 36 of the United States Code, is amended—

(1) in section 106—

(A) in the heading, by inserting "Constitution Day and" before "Citizenship Day";

(B) in subsection (a), by striking "is Citizenship Day." and inserting "is designated as Constitution Day and Citizenship Day.";

(C) in subsection (b)—

(i) by inserting "Constitution Day and" before "Citizenship Day";

(ii) by striking "commemorates" and inserting "commemorate"; and

(iii) by striking "recognizes" and inserting "recognize";

(D) in subsection (c), by inserting "Constitution Day and" before "Citizenship Day" both places such term appears; and

(E) in subsection (d), by inserting "Constitution Day and" before "Citizenship Day"; and

(2) in the item relating to section 106 of the table of contents, by inserting "Constitution Day and" before "Citizenship Day".

(d) This section shall be without fiscal year limitation.

Applicability. Deadline.

SEC. 112. (a) Notwithstanding any other provision of law or any contract: (1) the rates in effect on November 15, 2004, under the tariff (the "tariff") required by FCC 94–116 (reduced three percent annually starting January 1, 2006) shall apply beginning 45 days after the date of enactment of this Act through December 31, 2009, to the sale and purchase of interstate switched wholesale service elements offered by any provider originating or terminating anywhere in the area (the "market") described in section 4.7 of the tariff (collectively the "covered services"); (2) beginning April 1, 2005, through December 31, 2009, no provider of covered services may provide, and no purchaser of such services may obtain, covered services in the same contract with services other than those that originate or terminate in the market, if the covered services in the contract represent more than 5 percent of such contract's total value; and (3) revenues collected hereunder (less costs) for calendar years 2005 through 2009 shall be used to support and expand the network in the market.

Effective date.

(b) Effective on the date of enactment of this Act: (1) the conditions described in FCC 95–334 and the related conditions imposed in FCC 94–116, FCC 95–427, and FCC 96–485; and (2) all pending proceedings relating to the tariff, shall terminate. Thereafter, the State regulatory commission with jurisdiction over the market shall treat all interexchange carriers serving the market the same with respect to the provision of intrastate services, with the goal of reducing regulation, and shall not require such carriers to file reports based on the Uniform System of Accounts.

(c) Any provider may file to enforce this section (including damages and injunctive relief) before the FCC (whose final order may be appealed under 47 U.S.C. 402(a)) or under 47 U.S.C. 207 if the FCC fails to issue a final order within 90 days of a filing. Nothing herein shall affect rate integration, carrier-of-last-resort obligations of any carrier or its successor, or the purchase of covered services by any rural telephone company (as defined in 47 U.S.C. 153(37)), or an affiliate under its control, for its provision of retail interstate interexchange services originating in the market.

Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

Appendix DVR

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Design Validation Report

U.S. DEPARTMENT OF ENERGY

DOE-WIPP-86-010

WASTE ISOLATION PILOT PLANT

DESIGN VALIDATION
FINAL REPORT

JOB 12484

OCTOBER 1986

BECHTEL NATIONAL, INC.
SAN FRANCISCO, CALIFORNIA

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor its Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

FOREWORD

The reference design for the underground facilities at the Waste Isolation Pilot Plant was developed using the best criteria available at initiation of the detailed design effort. These design criteria are contained in the U.S. Department of Energy document titled Design Criteria, Waste Isolation Pilot Plant (WIPP), Revised Mission Concept-IIA (RMC-IIA), Rev. 4, dated February 1984. The validation process described in the Design Validation Final Report has resulted in validation of the reference design of the underground openings based on these criteria. Future changes may necessitate modification of the Design Criteria document and/or the reference design. Validation of the reference design as presented in this report permits the consideration of future design or design criteria modifications necessitated by these changes or by experience gained at the WIPP. Any future modifications to the design criteria and/or the reference design will be governed by a DOE Standard Operation Procedure (SOP) covering underground design changes. This procedure will explain the process to be followed in describing, evaluating and approving the change.

The Department of Energy wishes to acknowledge the following for their contributions to the design validation program:

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Peer Review Panel
- Neville G. W. Cook
- Francois E. Heuze
- Hamish D. S. Miller
- Robert L. Thoms

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WASTE ISOLATION PILOT PLANT
DESIGN VALIDATION
EXECUTIVE SUMMARY

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is being developed by the U.S. Department of Energy (DOE) as a research and development facility to demonstrate the safe disposal of radioactive waste from U.S. defense programs. The facility is located in southeastern New Mexico, about 25 miles east of the city of Carlsbad. Underground development is at a depth of about 2,150 feet in thick deposits of bedded salt. The facility operation will include in situ experiments addressing technical issues for defense waste programs and storage of defense related contact-handled (CH) and remote-handled (RH) transuranic (TRU) waste.

In 1979, the DOE established a Site and Preliminary Design Validation (SPDV) Program to provide additional confidence in the siting and design of the WIPP facility. On July 1, 1981, the DOE entered into an agreement with the State of New Mexico whereby the DOE would perform certain work to validate the reference design of the WIPP underground openings. The results of the site validation portion of the program are presented in the report titled Results of Site Validation Experiments, Volumes I and II, TME document 3177, dated March 1983. The results of the preliminary design validation portion of the program are presented in the report titled Waste Isolation Pilot Plant Preliminary Design Validation Report, dated March 30, 1983.

Design validation of the WIPP is defined as the process by which the reference design of the underground openings is confirmed by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. The design validation process consists of an assessment of the condition and behavior of shafts, drifts and a full-sized, four-room test panel

excavated during the SPDV Program and full WIPP construction. Based on this assessment of these excavations, and on predictions of their future behavior, any modifications to the design criteria, design bases or design configurations required to achieve a validated reference design will be developed. In addition, the validated reference design may be modified in the future as still more data and experience are gained during a 5-year demonstration period (period during which all waste must be retrievable) and permanent storage operations.

The WIPP Preliminary Design Validation Report was an interim report prepared as part of the overall validation of the WIPP underground opening reference design. The WIPP Design Validation Final Report contains additional information gathered after completion of the SPDV Program. This information has been analyzed and evaluated to complete the design validation process for the WIPP.

Four types of information were gathered for the WIPP Design Validation Final Report:

(1) observations of the behavior of the underground openings;

(2) descriptions of the geologic conditions encountered during underground construction;

(3) descriptions of core samples from instrumentation and other holes in the roof and floor of the underground openings; and

(4) data from installed geomechanical instrumentation.

The design validation process provides for the collection, analysis and evaluation of in situ data. This process is designed to permit determination of the need to modify elements of the underground opening reference design so that construction and operation of the full facility can proceed in a timely, safe, environmentally acceptable and cost effective manner. Observation and instrumentation data have been

collected and evaluated for each of the underground design elements. Tables I through VI at the end of this summary present the evaluation results for the design criteria, design bases and design configurations of the shafts and horizontal openings.

BACKGROUND OF UNDERGROUND DESIGN

Geologic characterization of the site began with a literature review and continued with the collection of field data. Special emphasis was placed on correlating data obtained from seismic reflection and resistivity surveys and borehole drilling. Design information regarding site stratigraphy from the ground surface to about 250 feet below the underground facility level was developed from geologic data obtained from drill holes ERDA-9, WIPP-12 and DOE-1, and from the SPDV exploratory and ventilation shafts.

The engineering designs for the WIPP surface and underground facilities began with the conceptual design, initiated in 1975 and completed in 1977. The conceptual design provided the basis for the development of the preliminary design of both the surface and underground facilities, which was completed in January 1980. The preliminary design incorporated the conventional room and pillar method for underground development.

Design of the WIPP provided for the access and storage openings to remain stable and provide minimum clearance for equipment during waste emplacement and the 5-year demonstration period, even though these openings will eventually close due to salt creep. Modeling techniques were used to estimate the geomechanical behavior and structural stability of the openings. The preliminary design included numerical modeling of the selected underground opening configurations. These models were used to predict opening closures and augmented other conventional mining industry methods of stability evaluation.

UNDERGROUND FACILITIES

Seven stratigraphic horizons were identified in 1979 as potential locations for the facility level. These horizons were chosen from examinations of available geotechnical data and on horizon selection criteria established by the WIPP project participants. Selection of the final underground development level was made by the DOE following the recommendation of WIPP project participants.

The WIPP facility is composed of three shafts connected to a single underground facility level. The C & SH shaft provides the principal means of access and also serves as the primary air intake opening. The waste shaft is designed to permit the transport of radioactive waste between the surface waste-handling facilities and the underground storage area. The exhaust shaft is the primary opening for exhaust air from the underground facility. All three shafts have three principle constituents: a lined section penetrating the rock overburden; an unlined section penetrating the salt; and a key at the rock/salt contact to act as a transition from the lined section to the unlined section.

The storage level contains all of the underground facilities for waste handling, waste storage, operations and maintenance. All of the underground horizontal openings are rectangular in cross section. The drift configurations range from 8 feet to 12 feet high and 12 feet to 25 feet wide.

Underground construction was accomplished in two phases. The initial (SPDV) phase was conducted from May 1981 through March 1983. The second phase, full construction, was accomplished from October 1983 through February 1985. Both phases included the excavation and outfitting of shafts, drifts and rooms.

SUPPORTING VALIDATION DOCUMENTS

The primary documents supporting design validation are the WIPP Preliminary Design Validation Report and quarterly geotechnical field data reports (GFDR).

The objective of preliminary design validation was to provide initial evaluation of the design criteria and design bases, and initial confirmation of the underground reference design. Geologic mapping, core drilling and logging, and geomechanical instrumentation data were assimilated to provide an early, short-term evaluation. The preliminary conclusions presented in the WIPP Preliminary Design Validation Report stated that the shafts and underground openings were performing as expected and were stable. In addition, gas had not been encountered in any significant quantity during excavation and no brine pockets had been encountered.

The GFDRs were initiated by the DOE to provide data from the SPDV Program and full construction in a timely manner. The GFDRs were intended to present in situ data on the geomechanical behavior of the strata surrounding the underground openings along with visual observations of opening behavior and analyses of selected underground design elements.

METHODOLOGY

Design validation is accomplished by determining the compatibility of the design criteria, design bases and reference design using site specific information. The design validation process consists of three major steps: data collection; analysis and evaluation; and prediction of future behavior.

The data collection program was designed to provide information on the geologic conditions encountered throughout the underground facility and on the structural behavior of the underground openings. The program

included geologic mapping, core drilling and logging, laboratory testing, visual inspections, and geomechanical instrumentation measurements. The data collected from these activities were analyzed and evaluated to determine the behavior of the various components of the underground facility and predict their future behavior by projecting the results of both finite element model and regression analyses.

The geomechanical instrumentation measurements provided in situ data on the behavior of the underground openings. These data were then used in empirical equations relating time and closure. Laboratory test results were used to calculate the salt creep and elastic parameters. Salt creep parameters were also determined by the regression analysis of in situ data. Long-term behavior of the underground openings was predicted by extrapolation of the results of the regression analysis.

GEOLOGIC CHARACTERIZATION

Geologic characterization of the WIPP underground openings began in June 1981. Data collection activities included geologic mapping, core drilling and logging, and fluid measurements. The SPDV exploratory shaft was mapped prior to selecting the storage horizon. The waste shaft was mapped, first as the SPDV ventilation shaft and again after it was enlarged to its final diameter. Geologic mapping was also conducted in the exhaust shaft.

Geologic mapping of the horizontal openings was conducted during design validation. This mapping was performed primarily to determine stratigraphic continuity. Mapping was conducted along one wall of the drifts to the northern extent of the facility and along the full length of the south exploratory drift. Geologic mapping was also conducted to the east and west facility boundaries in the experimental area and in the test rooms.

Geologic mapping confirmed the continuity of the stratigraphy within the horizontal openings to the facility boundaries. Core drilling and logging confirmed this stratigraphic continuity for a distance of 50 feet above and below the facility level. The geologic mapping and core logging did not detect any significant geologic structures. Data from the core holes were also used to establish the WIPP reference stratigraphy.

Fluid inflow measurements were obtained by various activities designed to characterize the two water-bearing dolomite members of the Rustler formation and the potential for the occurrence of gas and brine at the facility level. Measurements in the three shafts showed that water inflow from the Rustler formation is essentially negligible due to liner and seal performance.

Small amounts of pressurized gas have been encountered by some underground core holes. Brine has also been encountered in small quantities and is sometimes associated with gas occurrences. There has been no occurrence of gas or brine in quantities significant enough to jeopardize the stability or safety of the facility. Two programs, the brine testing program and the gas testing program, are being conducted to further characterize these occurrences. Neither program is associated with design validation.

Subsidence monuments have been installed on the surface over the shaft pillar area. The design criteria require that subsidence due to underground excavation not exceed 1 inch within a 500-foot radius of the waste shaft. It is not possible at this time to determine actual subsidence; this will occur over the next 25 years. Subsidence calculations used in the reference design indicate that the criteria limits will not be exceeded.

C & SH SHAFT

The C & SH shaft consists of a lined section, a shaft key, an unlined section and a shaft station. The shaft liner is made of structural steel that increases in thickness with depth to withstand increasing hydrostatic pressure. The reinforced concrete shaft key serves as a transition between the lined and unlined sections of the shaft. Chemical water seals behind the concrete key are designed to prevent ground water from flowing behind the key, into the unlined section of the shaft. The shaft station is excavated near the bottom of the unlined section.

Validation of the C & SH shaft reference design was accomplished by acquiring a variety of geotechnical data for analysis, evaluation and prediction of future behavior. The condition of the shaft liner and key are monitored by geomechanical instrumentation and visual inspections. Convergence points measure diametric closure; piezometers monitor ground-water pressures; strain gauges and pressure cells monitor the effect of salt creep on the concrete key. Telltale pipes in the shaft key provide information on the effectiveness of the chemical water seals. The unlined section of the shaft is monitored by extensometers and convergence points and is visually inspected for fracturing and rock slabbing. The shaft station has an extensive geomechanical instrumentation monitoring system and is inspected regularly.

The design basis hydrostatic pressure is suitable. Piezometer measurements indicate that the hydrostatic pressure is currently much less than the design pressure. Analysis of the shaft key indicates that lateral pressure on the key at the end of the operating period will be much less than the design basis lateral pressure requirement. Diametric closure of the key will be minimal. Computational analyses of stresses and strains indicate that the shaft will be stable and remain within the required safety limits during its operating life. Analysis of computed diametric closure near the bottom of the shaft

indicated that, while the closure will be within the design criteria and design basis limits, the lower buntons will be impacted.

The shaft design complies with the design criteria requirements for ground-water control. Regular inspections of shaft conditions show no signs of deterioration or instability.

The C & SH shaft station exhibits the highest degree of deterioration in the underground facility. The fracturing and separation observed has been stabilized, but will continue to develop. Closure during the 25-year operating life of the station will be on the order of 8 feet vertically and 5 feet horizontally. These conditions will require maintenance to ensure safety and to maintain the required minimum clearances for equipment and operations.

WASTE SHAFT

The waste shaft also consists of a lined section, a key, an unlined section and a shaft station. The shaft is lined with unreinforced concrete from the surface to the top of the Salado formation. The shaft liner terminates with a reinforced concrete key at the Rustler/Salado formation contact. The shaft is unlined, except for wire mesh, from the key to the bottom of the shaft.

Data collection activities in the waste shaft have consisted of geologic mapping, ground-water inflow measurements, geomechanical instrumentation measurements and periodic visual inspections. Except for convergence points, the geomechanical instruments are monitored remotely by the datalogger.

The waste shaft data was analyzed with respect to design parameters for each component of the shaft. As part of the engineering analysis, predictions of future behavior were made for each of the components.

Stability of the shaft liner has been confirmed. The water pressure exerted on it is significantly below the design hydrostatic pressure. If the pressure should reach the design hydrostatic pressure, the liner will still be stable. The shrinkage cracks in the liner do not present a structural problem.

The shaft key was designed to withstand a lateral pressure due to salt creep equivalent to 50 percent of the vertical overburden pressure. A numerical analysis was utilized to simulate the long-term effect of salt creep on the concrete key. It showed that the computed lateral pressure at the end of the operating period will be slightly higher than the design lateral pressure, but well below the total lateral pressure capacity of the key.

Observations of the waste shaft key have determined that only one minor seep occurs in the key and that no water seepage is occurring from the base of the key. This supports the conclusion that the water seals are functioning, that no water is seeping along the concrete/salt contact, and that salt dissolution is not occurring behind the key.

The design criteria require that no uncontrolled ground water reach the facility level through the shafts. Although minor amounts of fly water do reach the facility, this water has a negligible impact on operations and does not affect validation of this criterion.

The unlined section of the shaft was designed to be stable and maintain a diameter adequate for the operating life of the facility. The structural behavior of this section was analyzed using a finite element model and creep parameters determined from the C & SH shaft in situ data. The results indicate that the maximum stress occurred immediately after excavation and will decrease with time. Stress behavior will not cause a stability problem. Diametric closure due to salt creep will not exceed the design limits.

The design of the waste shaft station is based primarily on operational parameters. The closure and stability of the station was evaluated using in situ data from the C & SH shaft station. The estimated vertical closure rate will result in a total closure of over 7 feet during the 25 year operating life of the station. Actual closure may be less, but remedial work will still be required to maintain the proper clearances.

EXHAUST SHAFT

The exhaust shaft is constructed similarly to the waste shaft. It consists of a concrete lined section, a shaft key and an unlined section. The lined section is constructed of unreinforced concrete and the shaft key of reinforced concrete. The unlined section contains only rock bolts and wire mesh.

Data collection in the exhaust shaft has been on a much smaller scale than in the other two shafts. Geomechanical instrumentation was not required by the original shaft design because geologic and structural conditions were assumed to be similar to the other two nearby shafts. However, remotely monitored instrumentation has been installed to provide shaft-specific information for use in the sealing program. Geologic mapping and visual inspections have confirmed that the geologic and geohydrologic environment is similar to that of the other two shafts. Data from these two shafts have been used to predict the future performance of the exhaust shaft.

Geohydrologic and geomechanical data from the C & SH shaft and the waste shaft have been compared to model simulations for each section of the exhaust shaft. These models, field observations and instrumentation data confirm that the exhaust shaft reference design is suitable for its 25 year operating life.

The shaft liner is stable and has a water pressure against it that is less than the design basis hydrostatic pressure. If the pressure

increases, the liner will remain stable. Shrinkage cracks will not result in structural instability.

As with the waste shaft, an analysis of the exhaust shaft key indicates that the lateral pressure calculated for 25 years will slightly exceed the design lateral pressure, but will be well below the maximum allowable lateral pressure. Computational analyses of the stresses and strains indicate that the unlined section of the shaft will be stable and remain within safety limits during its operating life. The computed diametric closure will be within design criteria and design basis limits.

Water is entering the exhaust shaft through cracks and construction joints in the concrete liner. A small amount of water still reaches the shaft even after a remedial grouting program. When the exhaust fans are on, this water evaporates before reaching the facility. The water seals in the key appear to be functioning and there is no evidence of salt dissolution behind the key.

DRIFTS

The discussion of drifts contained in this section pertains to all horizontal underground openings except the shaft stations, test rooms, and storage area rooms and their associated drifts. The drifts were designed in accordance with the design criteria and design bases. The largest drifts were initially excavated 8 feet high and 25 feet wide. These drifts have been or will be enlarged to 12 feet high. This drift height is dictated by the minimum 11-foot operating clearance required for the waste storage equipment.

A variety of geotechnical activities were conducted to evaluate the behavior of the excavated drifts. These activities included geologic mapping, core drilling and logging, visual inspections, and geomechanical instrumentation measurements.

Visual inspections consisted of qualitative observations and documentation of various aspects of drift behavior. These observations are divided into four categories: roof and wall spalling; pillar fracturing; roof displacements and separations; and floor fracturing, displacements and separations.

Deformational behavior consisting of spalling from the roof and walls of the drifts and fracturing and spalling at pillar corners has occurred. Separations and lateral displacements have been detected in the halite above the roof, primarily at clay seams. These types of behavior are expected and will continue to occur, but can be controlled by scaling and rock bolting.

Fracturing has occurred in marker bed 139 (MB-139) and in the overlying halite beneath the floor of the drifts. The fracturing is not well developed and occurs primarily beneath large intersections. Based on experience in local potash mines, this fracturing is not expected to cause stability or operational problems.

The comparison of measured closure behavior in drifts with different dimensions indicates that the maximum closure and closure rate will occur in 12 x 25-foot drifts. The closure rates are affected by the presence of nearby parallel drifts and crosscuts as well as differences in salt properties. Based on available measurement data and the results of modeling analyses, the closure rate in the 13 x 25-foot storage area drifts may be 30 percent greater than that of a single, infinitely long drift with the same dimensions.

Analyses of salt behavior around the 25-foot wide drifts has determined both the redistribution of stresses due to creep and the locations of effective creep strain concentrations. The stresses which develop immediately after excavation relax with time due to creep behavior and will not cause future stability problems. The strain will remain within the limit required for structural stability with respect to catastrophic failure.

The evaluation of field observations and analytical results have shown that the design criteria were appropriate for design of the horizontal openings. The criteria identified as requiring specific evaluation were determined to be suitable. The reference design for the horizontal openings is therefore validated.

Based on the results of design validation of the drifts, it is recommended that all drifts be inspected frequently for operational clearance and safety. If the clearance is insufficient, the drifts must be trimmed to the required dimensions. Scaling and rock bolting should be performed where necessary for safety purposes.

TEST ROOMS

The test rooms comprise a panel of four rooms having a similar configuration as the planned storage rooms. They have been instrumented, observed and analyzed to evaluate the behavior of the future storage rooms. Data collection activities have consisted of geologic mapping, core drilling and logging, visual inspections and geomechanical instrumentation measurements. The instrumentation includes borehole extensometers, inclinometers, convergence points, convergence meters and rigid-inclusion, vibrating-wire stressmeters.

Room deterioration has been minimal and consists of spalling from the roof and walls, vertical fracturing in the pillars, minor displacements and separations above the roof and beneath the floor, and fracturing beneath the floor. Areas of drummy rock detected by roof and wall inspections immediately following excavation were scaled and rock bolted. These areas have not increased noticeably in size since the test rooms were excavated, over 3 years ago.

Subhorizontal fracturing has developed beneath the test room floors. Separations and fractures are on a small scale except for one isolated location beneath Test Room 3. Fracturing in this area is well developed and occurs in two distinct zones. Studies have not shown

fracturing of this magnitude to occur anywhere else within the underground WIPP facility.

The analysis of closure of the test rooms using creep constants derived from laboratory data underestimate actual closure. The design criteria closure of 12 inches in 5 years has been exceeded within 3 years. Strains measured in the test rooms compare well with strains computed by numerical modeling.

STORAGE AREA

The storage area rooms and drifts are designed to permit the permanent storage of defense-related CH and RH TRU waste. The storage area is composed of eight panels consisting of seven rooms each. Each room is 13 feet high, 33 feet wide and 300 feet long. The storage area, including all rooms and drifts, is designed to provide storage space for 6,330,000 cubic feet of CH TRU waste and 1,000 canisters of RH TRU waste.

Validation of the storage room reference design depends primarily on the analysis of data from the four test rooms. Evaluation of the storage rooms was based on the results of a finite element model analysis using creep parameters determined from the test room analyses. The results of this analysis provided determinations of horizontal and vertical stresses, effective stresses, effective creep strains, principal stresses, room deformation and closure, and intersection closure.

The analyses show that the stress arch around the opening migrates away with time. The maximum stress occurs immediately after excavation and is reduced as the opening deforms over time due to salt creep. These stresses will therefore not cause a stability problem in the future. However, MB-139, the anhydrite bed approximately 4 feet below the floor, is expected to be subjected to gradually increasing stress and may exhibit local failure.

Effective creep strains will intensify and concentrate at some locations around the opening. While minor spalls and failures are expected to occur on the excavation surfaces, the rooms will remain structurally stable.

The storage room reference design of 13 feet high and 33 feet wide was based on calculations using laboratory-derived average creep parameters. This design allowed for 12 inches of vertical closure and 9 inches of horizontal closure 5 years after excavation. This accommodates the design bases requirements for a minimum of 16 inches of ventilation space above the stored waste and a 12-foot minimum height for storage equipment. The current predicted vertical closure at 5 years is about 22 inches. For permanent storage, the additional 10 inches of closure can be accommodated by excavating the storage rooms to a height of 13 feet 10 inches.

If a decision is made to retrieve the stored waste, the design criteria assumed, using a one-shift-per-day basis, that a room may be as much as 15 years old before removal of all of the waste is completed. A 15-year old room has a predicted vertical closure of 54 inches. This closure is 14 inches greater than the maximum acceptable closure and would result in crushing and possible breaching of the waste containers. Because this is not in compliance with the design criteria, other alternatives must be considered.

A 10 year maximum for retrieval is conservative. If three shifts per day were utilized, no room would be older than 7 years by the time its waste was removed. A 7 year old room would have 28 inches of vertical closure. Additional closure benefits can be gained by excavating a room to is maximum dimensions and then trimming the room to those maximum dimensions after 1 year of closure. This will allow the room to close at the rate determined by secondary creep and will result in 21 inches of vertical closure 7 years after trimming. This will meet the design criteria requirements.

The design bases provide for 9 inches of horizontal closure in the first 5 years after room excavation. The current prediction, based on in situ data, is 15 inches of closure in the 33- to 34-foot wide rooms. If the rooms are excavated 34-feet wide and backfilled with loose salt, this closure will be suitable for permanent storage.

For retrieval, the horizontal closure 15 years after excavation will be approximately 36 inches. This closure will result in some crushing and possible breaching of the waste containers. Even if retrieval is effected within 7 years, some containers may still be crushed and breached.

The timing of retrieval operations and two-stage excavation can be used to reduce wall-to-wall closure. Using a three-shift-per-day basis, a 7 year old room would close approximately 20 inches. If a first in/first out storage and retrieval operations is utilized, and waste is removed before a room reaches an age of 6 years, horizontal closure will be reduced to 18 inches. Both these changes would decrease the possiblity of crushing or breaching the containers. If a 34-foot wide room is trimmed after 1 year to its initial full dimensions, the horizontal closure at 7 years will be about 14 inches. This will further minimize crushing or breaching of the containers. The extent to which crushing will be minimized is unknown. This is because the space between the waste canisters and the room wall will be filled with loose salt. The load transferring capabilities of the backfill is not known at the present time.

The reference design also provides for permanent waste storage in all of the storage area drifts. Fifteen years after excavation a 13 x 25-foot drift is predicted to have a vertical closure of about 25 inches and a horizontal closure of about 20 inches. This is suitable for waste storage but trimming will be required for equipment clearance.

The storage area entry drifts will contain plugs for the isolation of the storage panels. The final design of these plugs is not yet

complete. However, the conceptual design envisions a multiple-component plug approximately 100 feet long.

The reference design for the storage rooms will be considered to be validated when any of the following recommended alternative modifications, or combination of these modifications, are incorporated:

(1) Maintain the reference design storage room dimensions of 13 to 14 feet high and 33 to 34 feet wide and maintain the salt backfill, but reduce the volume of waste to be stored and modify the container stacking configuration for the 5-year demonstration period. Revise the design criteria to require that waste be retrieved before a room exceeds an age of 7 years. This will meet the criteria that the waste containers not be crushed or breached, but it will require a significant number of additional storage rooms.

(2) Maintain the reference design storage room dimensions and maintain the planned waste volume. Revise the design criteria to delete the requirement for salt backfill and to require that waste be retrieved before a room exceeds an age of 7 years. This will meet the criteria that the waste containers not be crushed or breached without requiring additional storage rooms.

(3) Maintain the reference design storage room dimensions, planned waste volume, and salt backfill requirement. Revise the storage operations so that the first-emplaced waste is the first-retrieved waste with retrieval effected before the room exceeds 6 years of age. Excavate the room to 14 x 34 feet, then, 1 year later, trim the room to its initial 14 X 34 foot dimensions. This will minimize container crushing and breaching. More storage rooms will be utilized during the 5-year demonstration period, but the total number of rooms will remain the same as provided by the reference

design. This modification will require changing the design criteria to allow crushing and breaching of the CH waste containers prior to retrieval and to require a demonstration of the retrieval and handling of crushed and breached containers.

(4) Reduce the reference design storage room width from 33 feet to 28 feet, maintain the room height at 13 to 14 feet, and reduce the pillar width to 84 feet. Maintain the first room for RH waste emplacement at the original reference design dimensions. Reduce the planned waste volume and maintain the salt backfill requirement. Excavate the rooms to 14 x 28 feet, then trim them to this dimension after 1 year. Use a first-in/first-out storage operation. This will reduce the creep to approximately that of a 13 x 25-foot drift. Stability will be enhanced and crushing and breaching will be minimized. The volume of excavation will be approximately the same as for the reference design storage rooms, but with the advantage of a lower creep rate. If this alternative is selected, additional engineering evaluation will be required.

(5) Maintain the reference design storage room dimensions, the planned waste volume, the salt backfill requirement, and the reference design optimized excavation and storage plan. Revise the design criteria, as in alternative number 3, to allow crushing and breaching of the CH waste containers prior to their retrieval. Require a demonstration of the retrieval and handling of crushed and breached containers prior to the receipt of waste. This will not only demonstrate the safe retrieval of waste during the 5-year demonstration period, but also during permanent storage.

In addition to these recommended alternative modifications, the following modifications are recommended:

(6) The drifts used for storage will require maintenance and trimming to accommodate the required equipment and storage clearances. Their closure rates are not critical for storage because they will be used only for permanent storage near the end of the permanent storage period.

(7) Add additional rooms to compensate for the space occupied by the plugs in the storage area entry drifts.

(8) Install instrumentation in the storage rooms to obtain in situ data to monitor storage room behavior.

Table I

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Facility design	
a. Designed for an operating life of 25 years.	*
b. Underground facilities and equipmentshall be designed to be compatible with retrieval operations for all contact-handled (CH) and remote-handled (RH) TRU waste, with a retrieval decision to be made within 5 years after the intial emplacement of each species.	Suitable 12.3.3
c. The facility will be decommissioned after it has fulfilled its intended purposes. This will include backfilling the underground facilities, sealing the shafts and decommissioning the surface facilities.	*
(2) CH TRU waste **	
a. Estimated annual volume is 500,000 cubic feet.	*
b. Estimated volume at the end of the 5 year retrieval decision period is 1,410,000 cubic feet.	*
c. Estimated total storage capacity is 6,330,000 cubic feet.	*
d. Heat generated from the waste is negligible; it will be less than 10 milliwatts for average drums, less than 20 milliwatts for average boxes, and 10 watts for few drums containing heat source plutonium.	*

* Indicates element for which evaluation is not required.
** See Foreword.

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
e. Estimated annual quantities are 9,616 six-packs and 2,404 modular steel boxes.	*
f. Estimated total quantities are 121,700 six-packs and 30,430 modular steel boxes.	*
g. Underground facilities and equipment shall be designed to provide for a determination to effect retrieval of waste stored for a period up to 5 years after the initial emplacement and for a target of 5 to 10 years to reach the waste and retrieve it after the decision is made.	Suitable 12.6.1 12.6.2
(3) RH TRU waste **	
a. Assumed total receipt of 1,000 cansisters.	*
b. Assumed maximum receipt rate of two canisters per day and 250 canisters per year.	*
c. If assumed quantities are insufficient, additional RH waste storage will be accommodated within existing storage rooms.	*
d. Heat generated from the waste is on the order of 60 watts per canister.	*
e. Access shall be available to all emplacement positions throughout the retrievability period.	Suitable 12.3.3

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
f. When both CH and RH waste are scheduled for the same room, the RH waste shall be emplaced first. After the 5 year retrievability period has terminated, CH waste may be emplaced in that room.	*
(4) Shaft design	
a. Shafts shall be designed to be structurally stable throughout the operating life of the underground facility and the decommissioning period.	Suitable 7.4.1 8.4.1 9.4.1
b. Time-dependent closure of shafts due to salt creep shall be considered. Shafts shall be designed so that minimum dimensions required for shaft functions are maintained during design life.	Suitable 7.4.1 8.4.1 9.4.1
c. Ground-water flow into the shafts shall be controlled so that no uncontrolled ground water reaches the storage horizon via the shafts.	Suitable 7.4.1 8.4.1 9.4.1
(5) Shaft liner design	
a. Help ensure that dimensions remain within limits required for shaft functions.	*
b. Prevent ground-water flow into the shaft.	Suitable 7.4.1 8.4.1 9.4.1
c. Protect wall rock from deterioration.	*

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
d. Preclude risk of rock fall from shaft wall.	*
(6) Mine design	
a. The underground openings shall be designed so that deformation of excavations and pillars will remain within limits required for structural function, ventilation and safety.	Suitable 7.4.1 8.4.1 10.4.1
b. Rock bolts shall be used where necessary to provide positive support of roof and walls.	*
c. Surface subsidence resulting from underground excavation shall not exceed 1 inch within a 500-foot radius of the waste shaft.	Suitable 6.5
d. Excavations and pillars shall be located and dimensioned to avoid geologic discontinuities. If discontinuities are encountered, remedial action shall be engineered to correct the problem.	Suitable 3.4 6.3.1.2 6.3.3
e. Design shall be based on established mining procedures.	*
f. Predicted behavior of the salt shall be verified by in situ testing (SPDV) before proceeding with construction of the storage area.	*
g. Designed to accommodate creep closure and maintain the minimum dimensions required for the operating life of the opening.	Suitable 10.4.1 12.6.1

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
h. Creep closure rates used for design shall be confirmed by instrument observations in the excavations.	Suitable 11.3.2 12.3.2
i. Excavation dimensions shall include allowance for creep closure sufficient to prevent container breaching by creep-induced stresses during the retrievability period.	Suitable 12.6.1 12.6.2
j. Minimize the potential for repository rock fracturing.	Suitable 11.4.1
k. Underground waste storage procedures shall include a designed backfill plan for fire protection. The backfill thickness shall be 1 to 2 feet.	Suitable 12.6.1
l. Permit isolation of panels of rooms with plugs after storage and backfilling are completed.	Suitable 12.6.1
m. Air locks, dampers, regulators and doors shall be designed and installed in such a manner that they can accommodate creep without impairment to their ability to maintain ventilation separation.	*
(7) Emplacement criteria	
a. The underground storage rooms and access drifts shall be designed to be compatible with the waste transport vehicle, with waste container sizes, shapes, weights and stacking configurations, and with waste emplacement equipment.	Suitable 12.6.1

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
b. Provisions shall be made to accommodate backfilling over and around CH waste containers.	Suitable 12.6.1
c. Each storage panel shall have provisions for being isolated from other panels upon completion of storage operations in that panel.	Suitable 12.6.1
(8) Retrievability	
a. All wastes placed into the WIPP are retrievable, with retrievability to be demonstrated, until such time as the pilot plant is converted to an operational repository for permanent disposal of wastes.	Suitable 12.6.1 12.6.2
b. Each storage room shall allow for salt creep and shall be sized to minimize breaching of the CH waste containers for a period of 10 years.	Suitable 12.6.1 12.6.2
(9) Underground excavation and haulage	
a. Mining shall be performed with continuous miners or equivalent machine type devices. Drill and blast-type mining shall be prohibited except where authorized.	*
b. Underground design shall provide maximum stability for excavated rooms and entries.	Suitable 7.4.1 8.4.1 10.4.1 11.4.1 12.6.1

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
c. Meet or exceed the intent of the applicable requirements of the MSHA in 30 CFR 57.9 and the New Mexico Mine Safety Code for All Mines.	*

Table II

EVALUATION RESULTS FOR C & SH SHAFT DESIGN BASES

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Shaft liner	
a. Hydrostatic pressure is considered to start 250 feet below the ground surface and extend to the top of the key.	Suitable 7.4.1
b. Water shall be prevented from flowing down the unlined shaft from behind the liner.	Suitable 7.4.1
(2) Shaft key	
a. Key shall be designed to resist the lateral pressure from the salt. (Assumed to be 75 percent of the overburden pressure.)	Suitable 7.4.1
b. Key shall be designed to resist the hydrostatic pressure from above the salt.	Suitable 7.4.1
(3) Unlined section	
Provide 11-foot 8-inch diameter to allow for future salt creep deformation.	Suitable 7.4.1

Table III

EVALUATION RESULTS FOR WASTE SHAFT DESIGN BASES

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Shaft liner	
Hydrostatic pressure is considered to start 250 feet below the ground surface and extend to the top of the key.	Suitable 8.4.1
(2) Shaft key	
Design lateral pressure shall be 50 percent of the vertical pressure due to soil, rock and salt overburden.	Suitable 8.4.1
(3) Unlined section	
Provide 20-foot diameter to allow for future salt creep deformation.	Suitable 8.4.1

Table IV

EVALUATION RESULTS FOR EXHAUST SHAFT DESIGN BASES

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Shaft liner	
Hydrostatic pressure is considered to start 250 feet below the ground surface and extend to the top of the key.	Suitable 9.4.1
(2) Shaft key	
Design lateral pressure shall be 50 percent of the vertical pressure due to soil, rock and salt overburden.	Suitable 9.4.1
(3) Unlined section	
Provide 15-foot diameter to allow for future salt creep deformation.	Suitable 9.4.1

Table V

EVALUATION RESULTS FOR STORAGE AREA DESIGN BASES

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Operational requirements	
a. The storage area rooms, drifts and crosscuts shall be designed to allow for retrieval of all CH and RH waste stored for a period of up to 5 years after the initial emplacement of each waste species.	Suitable 12.6.1 12.6.2
b. Excavation dimensions in the waste storage area shall be to a uniform height of 13 feet.	Suitable 12.6.1 12.6.2
(2) Essential features	
Provide 1 foot vertical and 9 inches horizontal allowance for creep closure to maintain the minimum design dimensions up to 5 years after initial emplacement.	Suitable 12.6.1 12.6.2
(3) Safety design requirements	
A minimum opening of 16 inches shall be left at the top of the rooms and drifts for air passage above the waste and backfill.	Suitable 12.6.1 12.6.2

Table VI

EVALUATION RESULTS FOR DESIGN CONFIGURATIONS

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) C & SH shaft	
a. Provide 5/8 to 1 1/2-inch thick and 10-foot I.D. stiffened steel liner in upper 846 feet.	Suitable 7.3.2.1 7.3.3.1
b. Provide 30-inch thick, 10-foot I.D. and 39-foot long concrete key at rock/salt interface.	Suitable 7.3.2.2 7.3.3.2
c. Provide 11-foot 10-inch diameter unlined shaft below the key.	Suitable 7.3.2.3 7.3.3.3
d. Provide 17-foot high and 32-foot wide station.	Suitable 7.3.2.4 7.3.3.4
(2) Waste shaft	
a. Provide 10 to 20-inch thick and 19-foot I.D. concrete liner in upper 837 feet.	Suitable 8.3.2.1 8.3.3.1
b. Provide 51-inch thick, 19-foot I.D. and 63-foot long concrete key at rock/salt interface.	Suitable 8.3.2.2 8.3.3.2
c. Provide 20-foot diameter unlined shaft below the key.	Suitable 8.3.2.3 8.3.3.3
d. Provide 17-foot high and 30-foot wide station.	Suitable 8.3.2.4 8.3.3.4
(3) Exhaust shaft	
a. Provide 10 to 16-inch thick and 14-foot I.D. concrete liner in upper 844 feet.	Suitable 9.3.2.1 9.3.3.1

Table VI (continued)

EVALUATION RESULTS FOR DESIGN CONFIGURATIONS

ELEMENT	RESULT AND CHAPTER REFERENCE
b. Provide 42-inch thick, 14-foot I.D. and 63-foot long concrete key at rock/salt interface.	Suitable 9.3.2.2 9.3.3.2
c. Provide 15-foot diameter unlined shaft below the key.	Suitable 9.3.2.3 9.3.3.3
(4) Storage area	
a. Provide 13-foot high and 25-foot wide or smaller drifts.	Suitable 12.6.1 12.6.2
b. Provide 13-foot high and 33-foot wide storage rooms.	Suitable 12.6.1 12.6.2

CHAPTER 1
INTRODUCTION

1.1 PURPOSE

This report presents the results of validation of the underground opening reference design for the Waste Isolation Pilot Plant (WIPP). The basis for the report is defined in the Design Validation Plan (ref. 1-1) which, in part, includes certain data requirements defined in the Stipulated Agreement (ref. 1-2) reached between the U.S. Department of Energy (DOE) and the State of New Mexico on July 1, 1981.

Design validation of the WIPP is defined as the process by which the reference design of the underground openings is confirmed by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. The design validation process consists of an assessment of the condition and behavior of shafts, drifts and a full-sized, four-room test panel excavated during an initial stage known as the Site and Preliminary Design Validation (SPDV) Program and during full WIPP construction. Based on this assessment of these excavations, and on predictions of their future behavior, any modifications to the design criteria, design bases or design configurations required to achieve a validated reference design will be developed. In addition, the validated reference design may be modified in the future as still more data and experience are gained during a 5-year demonstration period (period during which all waste must be retrievable) and permanent storage operations.

In fulfilling the data requirements for design validation, this report provides documentation of actual underground conditions encountered as they relate to the design criteria, design bases and design configurations for the reference design of the underground openings. The contents of this report include all relevant data and field observations acquired for design validation. The underground openings excavated to date provide a firm basis for evaluation of the current and expected future behavior of the underground development.

The purpose of design validation is to:

- o validate the underground reference design, thus providing confidence in the safety and stability of the WIPP underground openings;

- o confirm the suitability of the design criteria, design bases and design configurations established specifically for the reference design of the underground openings;

- o re-confirm and expand upon the conclusions of the SPDV Program; and

- o comply with the DOE agreement with the State of New Mexico to validate the reference design of the WIPP underground openings.

This process was initially described in the WIPP Preliminary Design Validation Report (ref. 1-3) issued in March 1983. That report presented the results of a preliminary evaluation of the underground opening reference design based on activities conducted during the SPDV phase of underground development. That initial report was prepared in response to conditions contained in the Stipulated Agreement (Appendix A) between the DOE and the State of New Mexico which permitted a preliminary evaluation of design considerations at an early stage in underground development and allowed for any reference design modifications deemed necessary for full WIPP construction. The WIPP Design Validation Final Report (this report) is an extension of the preliminary report and presents further confirmation of the reference design based on additional data collected since completion of the SPDV Program in both old and new areas of underground excavation.

The WIPP Design Validation Final Report presents:

- o a summary of the background and development of the WIPP reference design;

- the design criteria and design bases used to develop the reference design for the underground openings;

- geologic characterizations of the shafts, drifts and test rooms;

- the methodology used for data collection, its analysis and evaluation, and the predictions of future behavior of the underground openings;

- the description of data collection activities in the shafts, drifts and test rooms;

- analyses and evaluations of the geologic behavior of the rock strata surrounding the shafts, drifts and test rooms based on visual inspections and geomechanical instrumentation measurements;

- predictions of expected future conditions of the underground openings based on model simulations using in situ data;

- an assessment of the suitability of the design criteria and design bases and validation of the reference design configurations, with recommendations for design modifications, if any;

- recommendations for operation and maintenance of the underground facility as they pertain to design validation; and

- all data and reference sources that support design validation.

1.2 SCOPE

Design validation of the WIPP underground openings has been accomplished through an assessment of their safety, stability and predicted future behavior. Observation and instrumentation data consistent with the Design Validation Plan objectives have been

collected and evaluated for each of the major design elements: shafts, drifts and test rooms.

Initial analyses and evaluations of the underground data obtained for design validation were provided in the WIPP Preliminary Design Validation Report. The WIPP Design Validation Final Report presents the results of activities whose objectives are outlined in the Design Validation Plan. These activities included field data collection and analyses of these data to determine the validity of the reference design.

Basically, four types of information were gathered for design validation. These are:

(1) observations of the behavior of the underground openings;

(2) descriptions of the geologic conditions encountered during underground construction;

(3) descriptions of core samples from instrumentation and other holes in the roof and floor of the underground openings; and

(4) data from installed geomechanical instrumentation.

Field tasks performed to gather this information included the following:

- establishment of survey control for underground excavations and reference points for geologic mapping;

- development of procedures and standards for activities such as geologic mapping/logging of underground excavations;

- geologic mapping in the shafts and horizontal openings;

- examination and logging of rock cores from boreholes to obtain geologic information;

- observation and measurement of ground-water flow into the shafts;

- measurement of hydrostatic and lateral pressures on the shaft liner and shaft key;

- monitoring the floor height of horizontal openings above the top of marker bed 139 (MB-139) and the height of clay seams above the roofs using core hole data;

- measurement of closure in the shafts and horizontal openings;

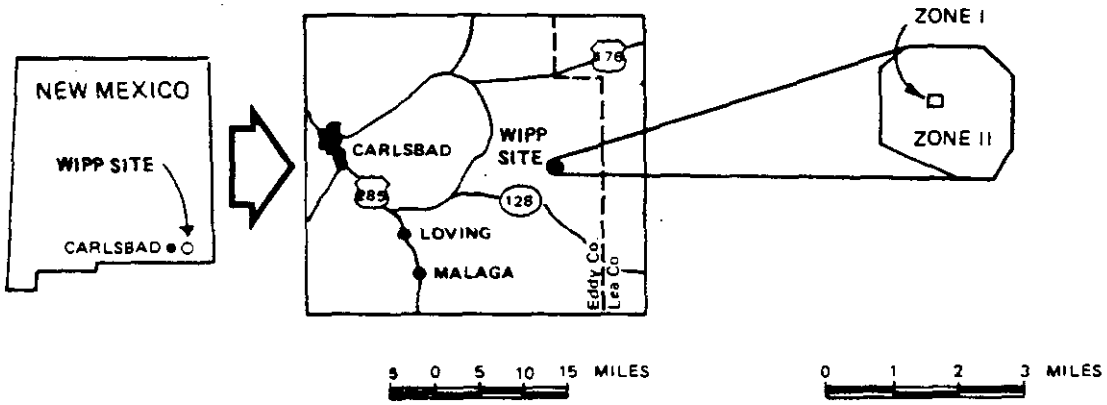
- determination of the presence of gases and fluids;

- survey of shaft verticality; and

- examination of all surfaces of underground openings for displacement of clay seams, fracturing, roof sagging, floor heaving, or other occurrences that may indicate unstable conditions.

1.3 HISTORICAL BACKGROUND

The WIPP is being developed by the DOE as a research and development (R & D) facility to demonstrate the safe disposal of radioactive waste from U.S. defense programs. The facility is located in southeastern New Mexico, about 25 miles east of the city of Carlsbad (Figure 1-1). The underground development level is at a depth of approximately 2,150 feet in thick deposits of bedded salt. The facility will include space for the permanent storage of defense related transuranic (TRU) waste and for in situ experiments addressing technical issues for high-level defense waste programs. The WIPP's phased design and construction resulted in initial confirmation of the underground opening reference design through the SPDV Program. Design



ZONE DESCRIPTION

ZONE I Surface Facilities Area
ZONE II Underground Storage Limits

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Figure 1-1

LOCATION OF THE WIPP

validation will provide confirmation of the decision to continue facility construction with subsequent in situ experiments and defense TRU waste storage.

The WIPP project is the result of waste management program efforts that were started by the U.S. government as long ago as 1955 when the U.S. Atomic Energy Commission (AEC) requested that the National Academy of Sciences (NAS) evaluate methods for disposing of radioactive waste in geologic formations. The NAS recommended bedded salt as the geologic formation providing the highest confidence for long-term isolation of waste from the biosphere. As a result of these efforts, the DOE (formerly the AEC) initiated the WIPP program in 1975. The major accomplishments of the program are listed in Table 1-1.

Assessments that pertain to design of the WIPP include extensive analyses of the impact of the facility on present and future environments. A Final Environmental Impact Statement (FEIS) (ref. 1-4) was prepared which provides information about the environmental and safety consequences of the WIPP project. A Safety Analysis Report (SAR) (ref. 1-5) was also prepared to support construction and operation of the WIPP. The SAR addresses all aspects of industrial and nuclear safety of the project and is updated periodically.

The WIPP is being developed in phases. At the time this report was prepared, most of the site characterization, design and supporting technological development had been done. The engineering design of the underground openings began with a conceptual design followed by a preliminary design and finally a detailed reference design. Facility development at the site began with the SPDV Program which allowed direct observation of the underground facility geology through two shafts and associated underground drifts. This program provided data for preliminary evaluation and confirmation of the reference design of the proposed underground excavations. Design and construction of the surface facilities have proceeded virtually independent of the underground opening design validation and are not addressed in this report.

Table 1-1

MAJOR ACCOMPLISHMENTS OF THE WIPP PROGRAM

	ITEM	DATE STARTED	DATE COMPLETED
(1)	National Academy of Sciences recommends salt as best geologic formation for disposal of nuclear waste.	-	1957
(2)	Salt deposit studies conducted in New Mexico by U.S. Geological Survey and Sandia National Laboratories.	1972	1975
(3)	Conceptual design of the WIPP.	1975	1977
(4)	Characterization of the WIPP site.	1975	1983
(5)	Public law authorizes capital funding for the WIPP.	-	1977
(6)	Title I - Preliminary design of the WIPP.	1/78	1/80
(7)	Safety Analysis Report issued for the WIPP.	-	2/80
(8)	Final Environmental Impact Statement issued for the WIPP.	-	10/80
(9)	SPDV Preliminary Design Validation Program.	7/79	3/83
(10)	Detailed design for Site and Preliminary Design Validation (SPDV).	7/79	10/80
(11)	SPDV Site Validation Experiments Program.	8/80	3/83
(12)	Title II - Detailed design of the WIPP.	2/81	2/84
(13)	Construction of SPDV shafts.	5/81	3/82
(14)	Design validation.	4/81	10/86
(15)	SPDV shaft outfitting and test room development.	10/81	7/83
(16)	Authorization for full WIPP construction.	-	7/83

1.4 THE WIPP MISSION

The authorized mission for the WIPP emphasizes its role as an R & D facility to demonstrate safe disposal of radioactive waste from U.S. defense programs. Its mission is also to provide information from site characterization, laboratory experiments, geomechanical instrumentation and in situ tests which can be used to develop performance-assessment models for technological applications. Figure 1-2 shows the underground layout of the three R & D areas at the WIPP.

The WIPP R & D Program consists of three major program areas:

(1) site characterization and evaluation;

(2) repository development and operation; and

(3) waste package interactions.

In addition to providing for the permanent storage of defense related TRU waste, these program areas include technology development in waste isolation, in situ tests without radioactive material, and in situ tests with radioactive material. The WIPP will also serve as a laboratory for experiments with high-level defense waste. All high-level wastes will be removed from the WIPP at the conclusion of the testing period. These in situ waste experiments and associated activities are not part of design validation and, therefore, are not discussed in this report. An initial description of the in situ testing plan for the WIPP R & D Program was provided in Sandia National Laboratories' (SNL) Report 2628 (ref. 1-6).

1.5 DESIGN VALIDATION PROGRAM

Validation of the WIPP facility underground reference design is based on a strategy consisting of a detailed plan and approach for validating major reference design elements. A description of this strategy is

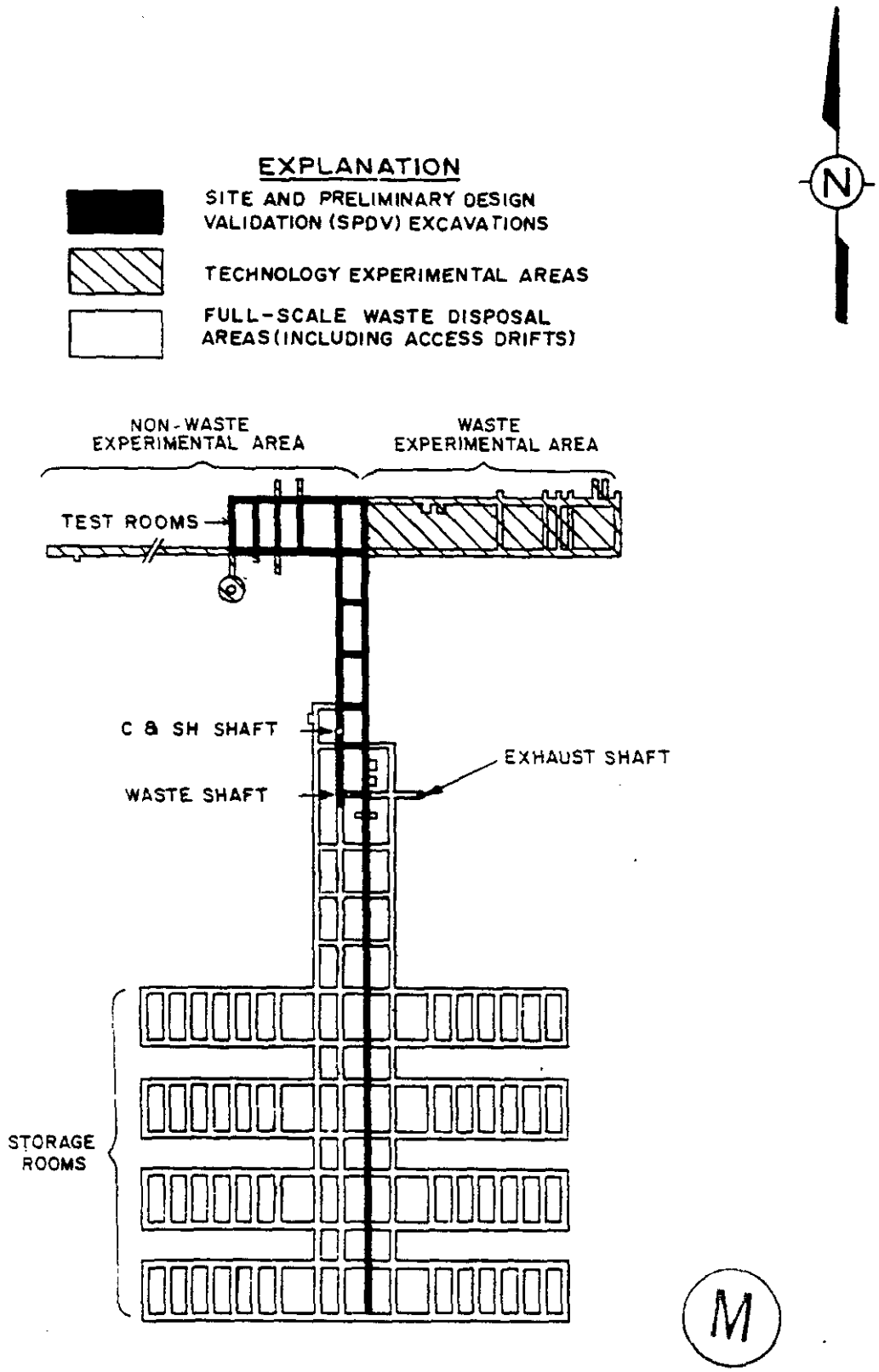

Figure 1-2

PLAN VIEW OF UNDERGROUND FACILITY

contained in the document titled Design Validation Strategy (ref. 1-7). The elements comprising the strategy for design validation are:

(1) Identify the design approaches and construction activities for the underground openings.

(2) Identify the design criteria, design bases and design configurations to be validated.

(3) Develop the methodology for validation.

(4) Acquire data on the underground development level from core samples, geologic mapping, laboratory tests, in situ tests, visual observations and mines in similar geologic formations.

(5) Synthesize the data obtained from the activities in element 4 to define the geologic environment of the facility level.

(6) Evaluate in situ geomechanical instrument measurements and visual observations to determine the response of the geologic materials to changes resulting from excavation or other disturbances.

(7) Predict the future behavior of the underground openings and salt surrounding the openings based on current in situ measurements, visual observations and computational analyses.

(8) Provide for comparisons of predicted and existing conditions at regular time intervals.

(9) Document design validation results and conclusions.

(10) Provide recommended design modifications as required.

(11) Provide data and reference sources to support the performance of the above activities.

Design validation efforts for the WIPP began with the SPDV Program. This program involved the excavation of underground openings, shafts, drifts and test rooms, representative of the full WIPP facility. These underground openings permitted the direct examination of geologic features and material behavior at the facility level. Additional observations and geomechanical instrumentation measurements were obtained following completion of the SPDV Program to complete the design validation program. A brief description of the design validation program is presented in the following subsections.

1.5.1 Site and Preliminary Design Validation (SPDV)

The SPDV Program was designed to further characterize and validate the WIPP site geology and provide preliminary validation of the underground opening reference design. The SPDV Program was composed of two integrated parts:

(1) site validation (ref. 1-8) to increase confidence in the process of site characterization and qualification; and

(2) preliminary design validation to assess the condition and behavior of excavated shafts, drifts and a full-sized, four-room test panel similar to those planned for the waste storage area.

The general SPDV underground layout is shown on Figure 1-3. The underground development level is located in Zone II, a WIPP site control zone that delineates the limits of underground storage. A preliminary design validation report was issued on March 30, 1983. This report presented the results of early observations and analyses of the condition and behavior of the SPDV excavations and is discussed in Chapter 4.

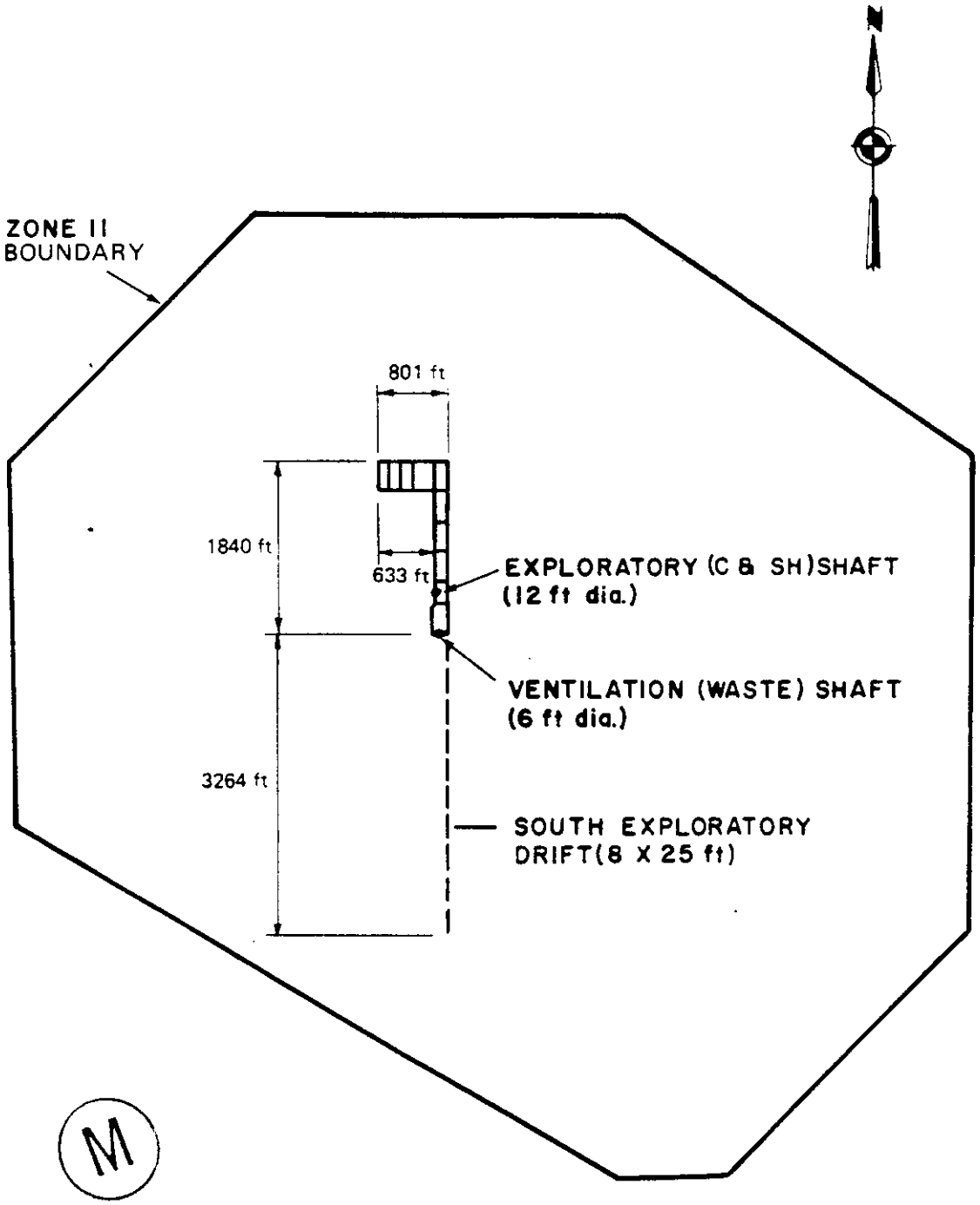

Figure 1-3

THE SPDV UNDERGROUND LAYOUT

1.5.2 Design Validation

Major activities related to design validation are cited in Table 1-2. As indicated by this table, field data collection activities that began with the SPDV Program were continued beyond the end of the program to provide additional data for design validation. The design validation process includes the evaluation and analysis of data obtained by these activities. The results of these evaluations and analyses have been presented in quarterly geotechnical field data reports (GFDR), each of which presents a discussion of different selected elements of the WIPP underground development. These reports provide supporting documentation for the WIPP Design Validation Final Report and are discussed in Chapter 4.

Some of the field data collection activities shown in Table 1-2 will continue after submittal of the WIPP Design Validation Final Report and beyond the completion of full WIPP construction. Collection of this data will provide additional information on the behavior of the underground openings through the 5-year demonstration period and through permanent storage operations. The data will also permit continuous monitoring of the safety of the openings. Underground facility reference design modifications will be made as required by an evaluation and analysis of these data. The data obtained will be periodically distributed to the project participants, the State of New Mexico, and will be placed in WIPP public reading rooms.

Table 1-2

DESIGN VALIDATION ACTIVITY SCHEDULE

	ACTIVITY	RESPONSIBILITY	SCHEDULE
(1)	Prepare and issue Design Validation Plan	B/DOE	7/82 - 1/83
(2)	Field data collection:		
	a. Geologic mapping of vertical and horizontal underground excavations	TSC/B	3/82 - 3/83
	b. Geomechanical instrumentation measurements and visual observations in shafts, drifts, and test rooms	TSC/B	4/82 - 3/83
	c. Log core from holes in horizontal underground openings	TSC/B	10/82 - 3/83
	d. Fluid inflow measurements	TSC/B	9/81 - 3/83
	e. Shaft verticality surveys	DOE/TSC	1/82 - 3/83
(3)	Evaluate field data; prepare Preliminary Design Validation Report	B	10/82 - 3/83
(4)	Issue Preliminary Design Validation Report	DOE	3/83
(5)	Continue with (2a), (2b), (2c), and (2d) above	TSC/B	3/83 - 7/86
(6)	Evaluate/analyze field data; prepare Design Validation Final Report	B	3/83 - 5/86
(7)	Design Validation Final Report review by Peer Review Panel	B	5/86 - 6/86
(8)	Issue Design Validation Final Report	DOE	10/86

B = Bechtel National, Inc.; DOE = U.S. Department of Energy; TSC = Technical Support Contractor (Westinghouse Electric Corp.)

CHAPTER 2
BACKGROUND OF UNDERGROUND DESIGN

2.1 SITE CHARACTERIZATION AND EVALUATION

WIPP site characterization programs have consisted of geologic and hydrologic studies as well as biologic, meteorologic and economic studies. Geologic and geohydrologic characterization of the site, which started with surveys of literature and existing data, continued with the collection of new data and had the greatest degree of influence on design of the underground facility. Special emphasis was placed on correlating data obtained by geophysical techniques and borehole drilling. The geophysical techniques most widely used were seismic reflection and resistivity. Borehole drilling programs included holes drilled primarily for stratigraphic information on or near the site and holes drilled at the edge of, or away from, the site to study salt dissolution. Three holes, WIPP-11, WIPP-12 and DOE-1, were drilled through the Salado formation to acquire geologic data on deeper strata outside the Zone II boundaries of the site (refs. 2-1, 2-2 and 2-3). Within Zone II, the drilling of deep exploratory holes, i.e., to the depth of the WIPP facility level, was restricted by siting criteria. Prior to the drilling of the SPDV exploratory and ventilation shafts (subsequently known as the C & SH and waste shafts, respectively), ERDA-9 was the only borehole within Zone II that extended below the facility level.

The generalized stratigraphic relationship of the geologic formations of interest beneath the WIPP site is shown on Figure 2-1. Siltstone and fine-grained sandstone are the main rock types forming the Dewey Lake red beds. The Rustler formation, composed primarily of anhydrite and fine-grained sandstone, siltstone and mudstone, contains two water-bearing dolomite beds. Saline water is found in these beds, the Magenta and Culebra members, and at the contact between the Rustler and Salado formations. The Salado formation consists largely of halite containing thin beds of anhydrite and polyhalite with occassional thin clay seams. The Castile is a thick anhydrite and halite formation

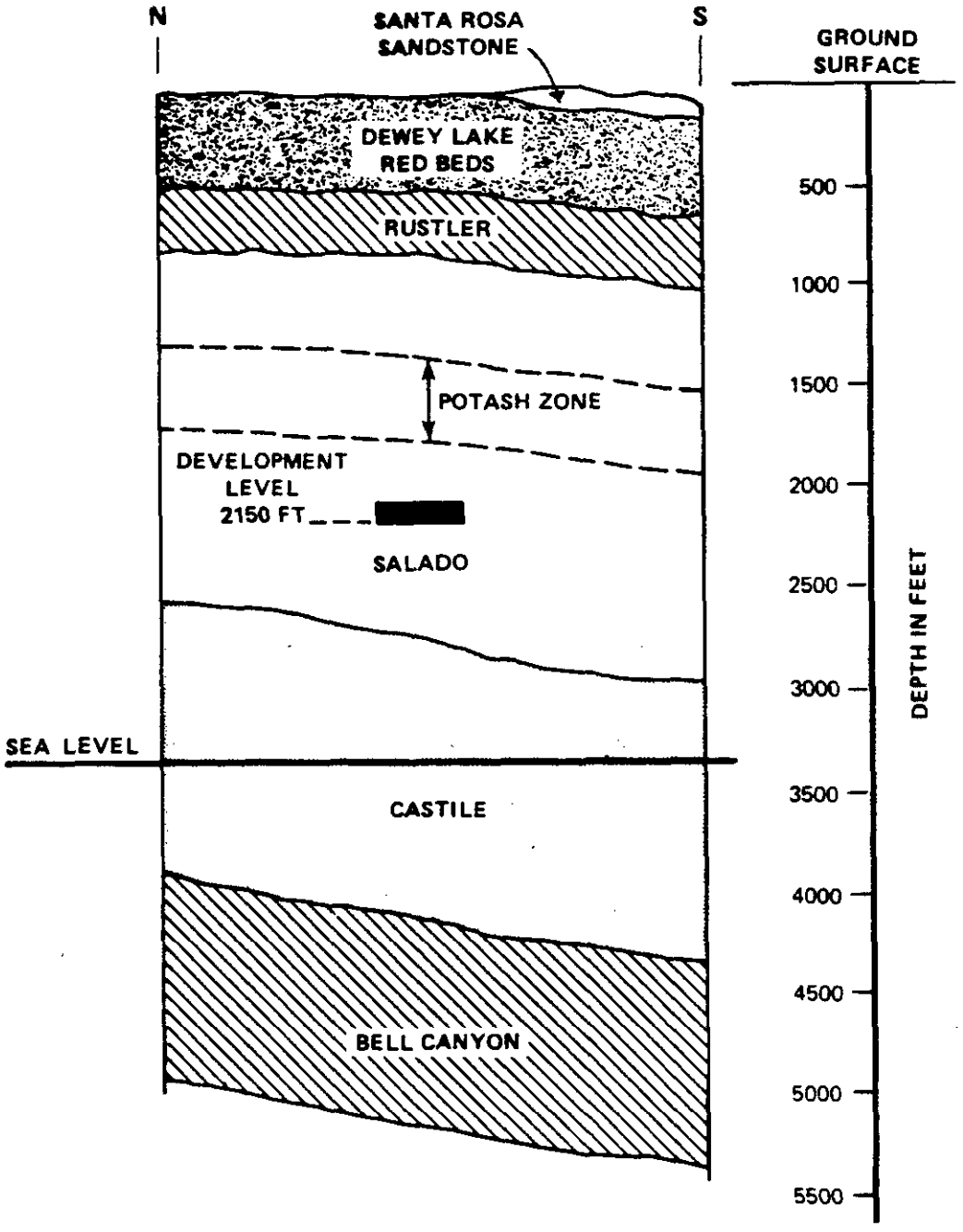

Figure 2-1

GENERAL SITE STRATIGRAPHY

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underlying the Salado. The Bell Canyon formation consists primarily of sandstone, limestone and shale. No aquifers are present in the Salado or Castile formations beneath the site.

Site stratigraphy from the ground surface to about 250 feet below the underground facility level is presented in Appendix B, Figure B-1, Sheets 1 through 5. The stratigraphy shown is based on geologic data obtained from boreholes WIPP-12, ERDA-9 and DOE-1, and from the C & SH and waste shafts. An analysis of these data shows a strong correlation of the stratigraphy between the boreholes and shafts from the ground surface to below the underground facility level. This correlation is based primarily on the geophysical logs because core sample logging or "hands-on" mapping was not always carried out through the entire interval. Where possible, graphic lithologic descriptions based on logging or mapping of the rock strata have been included on Figure B-1 in Appendix B. This helps to more fully define the stratigraphic relationships shown by the geophysical logs.

The analysis between boreholes WIPP-12 to the north and DOE-1 to the south resulted in correlation of the major formation contacts and most marker beds in the Salado formation. Due to a lack of distinctive stratigraphic changes, the Dewey Lake red beds exhibit a relatively uniform profile in both the lithologic and geophysical logs. The Rustler formation, however, exhibits a much greater fluctuation in its geophysical profile as a result of the anhydrite, dolomite and fine-grained clastic beds it contains. Figure B-1 in Appendix B shows that the Rustler thickens slightly to the north with a slight rise in formation contacts occurring in the area of the WIPP facility.

Correlation of the Salado formation stratigraphy between WIPP-12 and DOE-1 verifies the consistency of most of the marker beds. The geophysical logs shows distinct breaks where polyhalite and anhydrite beds occur in the largely halitic rock strata. The major stratigraphic occurrence, in that portion of the Salado formation shown on Figure B-1 in Appendix B, is a thinning of strata to the north. This thinning

becomes apparent below marker bed 124 (MB-124) and is relatively well pronounced in the underground facility horizon. The effect of this thinning is to produce a reversal in the direction of dip of the strata above and below MB-124 between WIPP-12 and DOE-1. Above this marker bed the strata dip to the north, while below the marker bed the strata dip to the south. This thinning of strata controls the slope of the facility level excavation because the excavation must avoid encroachment on any stratigraphic horizons that could affect the stability or safety of the underground openings.

The figures in Appendix B show the continuity of rock strata across the WIPP site and in the area of underground excavation. These figures are intended to show that the major design assumptions which were made based on data from boreholes ERDA-9 and WIPP-12 remain valid, based on additional data obtained from geologic mapping of the underground openings and logging of underground core holes. Therefore, correlation of the site stratigraphy from the ground surface to below the underground facility level confirms the macroscopic continuity of stratigraphy beneath the WIPP site. Geologic characterization at the WIPP underground facility level is presented in Chapter 6.

Geohydrologic data pertaining to the site were obtained from conventional and special-purpose tests in many boreholes (ref. 1-5). Geophysical logging of these holes provided hydrogeologic information on the rock strata encountered. Pressure measurements, fluid samples and ranges of rock permeability were obtained for selected formations. Also, potentiometric surfaces of major aquifer systems were contoured by using measured water level elevations in boreholes.

Evaluation of data obtained from early site selection studies indicated that the current WIPP site was a suitable candidate for the establishment of a facility to demonstrate the safe disposal of radioactive waste. Additional studies have resulted in the issuance of numerous reports regarding the suitability of the WIPP site, including the Geological Characterization Report, Waste Isolation Pilot Plant

(WIPP) Site, Southeastern New Mexico (ref. 2-4), Final Environmental Impact Statement: Waste Isolation Pilot Plant (ref. 1-4), and the Waste Isolation Pilot Plant Safety Analysis Report (ref. 1-5). Final site validation was achieved in 1983 by an evaluation of the data contained in a report titled Results of Site Validation Experiments, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico (ref. 2-5) which presented the results of studies performed to fully satisfy all site qualification criteria. This report was followed by a confirmation of overall site suitability in a report titled Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability (ref. 2-6).

2.2 DESIGN CRITERIA

The Design Criteria, Waste Isolation Pilot Plant (WIPP), Site and Preliminary Design Validation (SPDV) (ref. 2-7), and the Design Criteria, Waste Isolation Pilot Plant (WIPP), Revised Mission Concept-IIA (RMC-IIA) (ref. 2-8) were used as guides by the Architect-Engineer (Bechtel National, Inc.) in developing the reference design for the WIPP underground openings. The documents contain general requirements which were addressed in the reference design. The Design Criteria, RMC-IIA, is the highest level design document for the project. All other design documents, such as design bases, drawings and specifications, were required to be in compliance with this document.

The design criteria also stipulate the type and estimated or assumed rate of waste to be received at the WIPP. The majority of the criteria presented in the RMC-IIA document are requirements which do not need evaluation as to their suitability and have no impact on validation considerations for the underground opening reference design. The major criteria that governed development of the reference design are presented in Table 2-1. Although some of the criteria in this table are elements which cannot be evaluated, they are included because of their influence on the reference design configurations. Those criteria that can be evaluated are discussed in later chapters of this report as

Table 2-1

ABRIDGED WIPP DESIGN CRITERIA

(1) Facility design

a. Designed for an operating life of 25 years.

b. Underground facilities and equipment shall be designed to be compatible with retrieval operations for all contact-handled (CH) and remote-handled (RH) TRU waste, with a retrieval decision to be made within 5 years after the initial emplacement of each species. (Chapter 12)

c. The facility will be decommissioned after it has fulfilled its intended purposes. This will include backfilling the underground facilities, sealing the shafts and decommissioning the surface facilities.

(2) CH TRU waste *

a. Estimated annual volume is 500,000 cubic feet.

b. Estimated volume at the end of the 5 year retrieval decision period is 1,410,000 cubic feet.

c. Estimated total storage capacity is 6,330,000 cubic feet.

d. Heat generated from the waste is negligible; it will be less than 10 milliwatts for average drums, less than 20 milliwatts for average boxes, and 10 watts for few drums containing heat source plutonium.

e. Estimated annual quantities are 9,616 six-packs and 2,404 modular steel boxes.

f. Estimated total quantities are 121,700 six-packs and 30,430 modular steel boxes.

g. Underground facilities and equipment shall be designed to provide for a determination to effect retrieval of waste stored for a period up to 5 years after the initial emplacement and for a target of 5 to 10 years to reach the waste and retrieve it after the decision is made. (Chapter 12)

(3) RH TRU waste *

a. Assumed total receipt of 1,000 canisters.

b. Assumed maximum receipt rate of two canisters per day and 250 canisters per year.

* See Foreword.

Table 2-1 (continued)

ABRIDGED WIPP DESIGN CRITERIA

c. If assumed quantities are insufficient, additional RH waste storage will be accommodated within existing storage rooms.

d. Heat generated from the waste is on the order of 60 watts per canister.

e. Access shall be available to all emplacement positions throughout the retrievability period. (Chapter 12)

f. When both CH and RH waste are scheduled for the same room, the RH waste shall be emplaced first. After the 5 year retrievability period has terminated, CH waste may be emplaced in that room.

(4) Shaft design (Chapters 7, 8 and 9)

a. Shafts shall be designed to be structurally stable throughout the operating life of the underground facility and the decommissioning period.

b. Time-dependent closure of shafts due to salt creep shall be considered. Shafts shall be designed so that minimum dimensions required for shaft functions are maintained during design life.

c. Ground-water flow into the shafts shall be controlled so that no uncontrolled ground water reaches the storage horizon via the shafts.

(5) Shaft liner design

a. Help ensure that dimensions remain within limits required for shaft functions.

b. Prevent ground-water flow into the shaft. (Chapters 7, 8 and 9)

c. Protect wall rock from deterioration.

d. Preclude risk of rock fall from shaft wall.

(6) Mine design

a. The underground openings shall be designed so that deformation of excavations and pillars will remain within limits required for structural function, ventilation and safety. (Chapters 7, 8 and 10)

Table 2-1 (continued)

ABRIDGED WIPP DESIGN CRITERIA

b. Rock bolts shall be used where necessary to provide positive support of roofs and walls.

c. Surface subsidence resulting from underground excavation shall not exceed 1 inch within a 500-foot radius of the waste shaft. (Chapter 6)

d. Excavations and pillars shall be located and dimensioned to avoid geologic discontinuities. If discontinuities are encountered, remedial action shall be engineered to correct the problem. (Chapters 3 and 6)

e. Design shall be based on established mining procedures.

f. Predicted behavior of the salt shall be verified by in situ testing (SPDV) before proceeding with construction of the storage area.

g. Designed to accommodate creep closure and maintain the minimum dimensions required for the operating life of the opening. (Chapters 10 and 12)

h. Creep closure rates used for design shall be confirmed by instrument observations in the excavations. (Chapters 11 and 12)

i. Excavation dimensions shall include allowance for creep closure sufficient to prevent container breaching by creep-induced stresses during the retrievability period. (Chapter 12)

j. Minimize the potential for repository rock fracturing. (Chapter 11)

k. Underground waste storage procedures shall include a designed backfill plan for fire protection. The backfill thickness shall be 1 to 2 feet. (Chapter 12)

l. Permit isolation of panels of rooms with plugs after storage and backfilling are completed. (Chapter 12)

m. Air locks, dampers, regulators and doors shall be designed and installed in such a manner that they can accommodate creep without impairment to their ability to maintain ventilation separation.

Table 2-1 (continued)

ABRIDGED WIPP DESIGN CRITERIA

(7) Emplacement criteria

a. The underground storage rooms and access drifts shall be designed to be compatible with the waste transport vehicle, with waste container sizes, shapes, weights and stacking configurations, and with waste emplacement equipment. (Chapter 12)

b. Provisions shall be made to accommodate backfilling over and around CH waste containers. (Chapter 12)

c. Each storage panel shall have provisions for being isolated from other panels upon completion of storage operations in that panel. (Chapter 12)

(8) Retrievability

a. All wastes placed into the WIPP are retrievable, with retrievability to be demonstrated, until such time as the pilot plant is converted to an operational repository for permanent disposal of wastes. (Chapter 12)

b. Each storage room shall allow for salt creep and shall be sized to minimize breaching of the CH waste containers for a period of 10 years. (Chapter 12)

(9) Underground excavation and haulage

a. Mining shall be performed with continuous miners or equivalent machine type devices. Drill and blast-type mining shall be prohibited except where authorized.

b. Underground design shall provide maximum stability for excavated rooms and entries. (Chapters 7, 8, 10, 11 and 12)

c. Meet or exceed the intent of the applicable requirements of the MSHA in 30 CFR 57.9 and the New Mexico Mine Safety Code for All Mines.

indicated in the table.

2.3 DESIGN BASES

The design bases identify the detailed design requirements for the WIPP underground facilities. They are derived from the more general concepts presented in the design criteria. The design bases cover all aspects of the design and facility operations. Design bases applicable to design validation are listed in references 2-9 through 2-20. The essential elements of the design bases pertaining to design validation of the C & SH shaft, waste shaft, exhaust shaft, drifts and storage area are discussed in Chapters 7 through 10 and Chapter 12. The discussions cover only those bases that require evaluation. All other bases are requirements determined during design reviews and need not be evaluated for their suitability.

2.4 DESIGN CONFIGURATIONS

The reference design configurations are the engineered facilities designed to comply with the design criteria and design bases. They are described in various contract drawings and specifications. The essential elements of the design configurations are discussed in Chapters 3 and 12.

2.5 DESIGN DEVELOPMENT

Design of the WIPP surface and underground facilities consisted of three stages:

(1) the conceptual design;

(2) the preliminary design; and

(3) the detailed design, including the underground opening reference design.

At both the conceptual and preliminary design stages, an extensive, independent review of the underground layout and design was made by the

DOE and its consultants, SNL and Westinghouse Electric Corporation. The review included assessment of the underground design concept and consultation with Carlsbad area potash mine operators to obtain information from their experience. The preliminary design was also reviewed by other Federal agencies, the State of New Mexico and the NAS.

From these reviews and consultations, the DOE concluded that the detailed design, based on the current state of the art, was sound. However, for further confirmation, it was decided that the impact of site-specific geologic conditions on the underground opening reference design should be verified by direct observation. Consequently, the DOE initiated the SPDV Program described in Chapter 1. The SPDV Program provided in situ data on the local geology and on the geomechanical response of the strata to the underground openings.

2.5.1 Conceptual Design

Design of the WIPP surface and underground facilities began with the conceptual design, initiated in 1975 and completed in 1977 (ref. 2-21). The conceptual design provided the basis for development of the preliminary design of both the surface and underground facilities.

2.5.2 Preliminary Design

The WIPP preliminary design was begun in 1978 and completed in 1980 (ref. 2-22). The preliminary design (Figure 2-2) was based on empirical methods and local mining practices, incorporating the conventional room and pillar method for underground development. It included analytical evaluations of underground openings in bedded salt using the finite element method and laboratory test data (refs. 2-23 and 2-24). The roof and floor of the rooms and entries were checked for stability by methods described in the SME Mining Engineering Handbook (ref. 2-25). In addition to Bechtel, SNL performed confirming numerical analyses (refs. 2-26 and 2-27). These analyses predicted short- and long-term stress distributions around the selected openings as well as elastic and creep deformations.

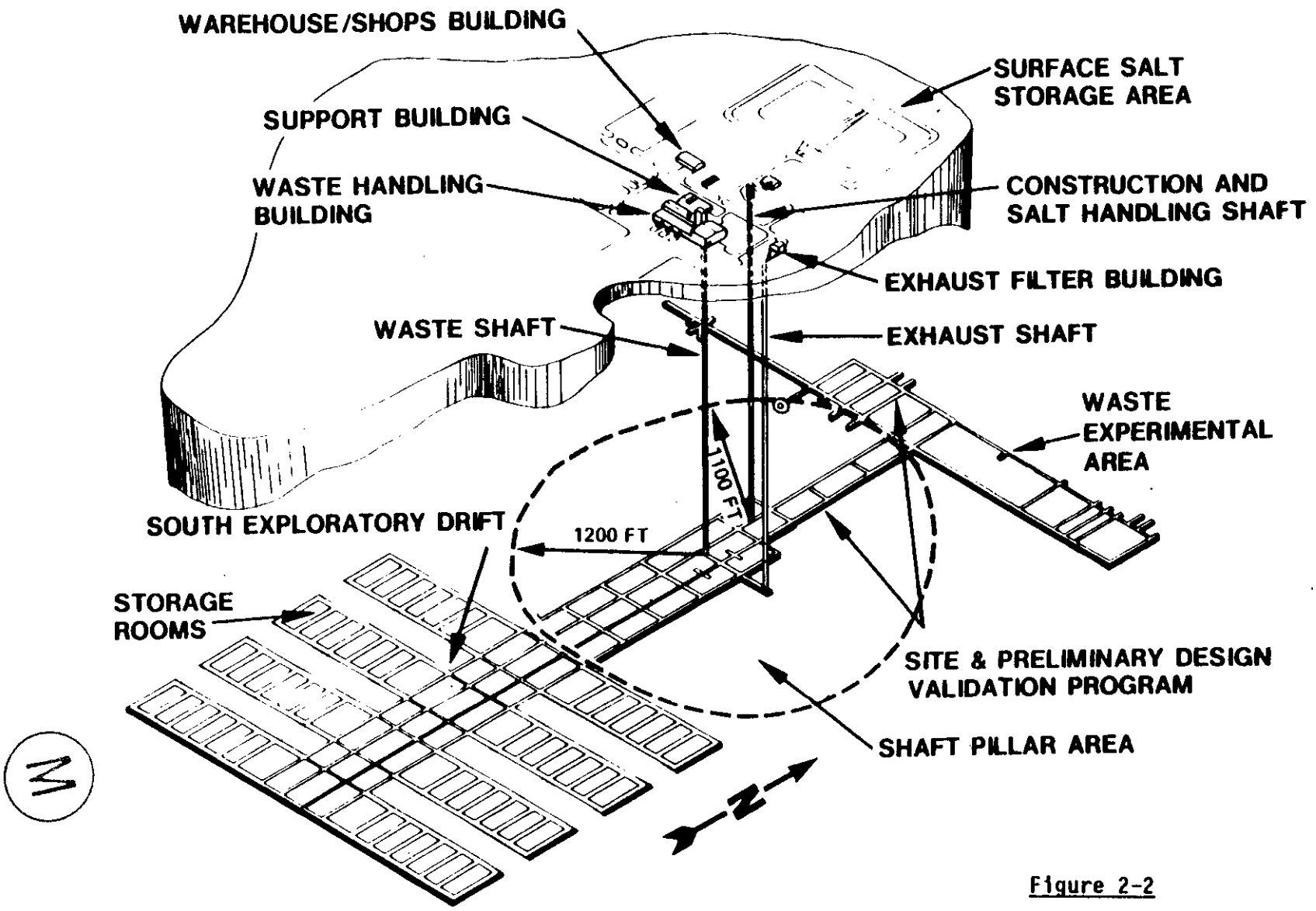


Figure 2-2

PERSPECTIVE VIEW OF THE WIPP

2.5.3 Detailed Design

Detailed design of the WIPP, begun in 1981 and completed in 1984, included design of the surface and underground facilities and the reference design for the underground openings. This was based on an extensive amount of data derived from the site characterization, including information from boreholes, surface geophysical measurements and laboratory tests. These data were used to establish the facility level and the design parameters. The number of holes drilled to the proposed facility level was restricted in order to retain its isolation from the surface. The layout and configuration of the underground openings were based mainly on empirical data which incorporates the room and pillar concept utilized in existing potash mines in Carlsbad and other mining areas, and on storage efficiency. The design was also based on mining and engineering standards universally applied to underground projects.

Analyses were performed to evaluate the stability of underground openings using material properties obtained from laboratory tests of core samples (ref. 2-28). Validation of the underground opening reference design with respect to the actual underground environment requires direct observation of geologic conditions at the facility level and the behavior of the underground openings. This interaction between observation of underground excavation and development of design is consistent with engineering practice for underground construction and with achieving the most cost-effective facility configuration.

Detailed design of the WIPP had sufficient flexibility to allow the incorporation of initial information obtained from excavation during the SPDV Program. This design flexibility was necessary for construction of the underground facilities. Calculations that applied material properties and analytical models developed from laboratory tests were performed to evaluate the behavior of the underground openings. Information obtained from the design validation program was used to confirm, refine, or alter the underground opening reference design as required to accommodate in situ conditions. The detailed

design included the development of construction details for the experimental areas and the full-scale waste storage area. It also included design of the surface facilities but this is not included in the design validation program.

2.6 DESIGN METHODS

Practical experience in the safe construction of salt and potash mines extends over many years. Empirical knowledge on the safe sizes of openings and pillars has been documented (ref. 2-29) and performance records of openings in salt are available. Different methods of analysis are required to determine the stability of openings in salt for different conditions of potential failure. The normal safety concepts of engineering, which relate a factor of safety to loads or stresses, cannot be transferred directly to the analysis of underground openings in salt. Therefore, postulated failure conditions were analyzed by other appropriate methods. In general, an opening in salt can be considered stable when the following two basic requirements are satisfied:

(1) the deformation of the opening conforms to the clearance envelope allowed for safe operation of the workings during design life; and

(2) the load bearing capacity of the salt around the opening is adequate to prevent sudden structural failure of the opening.

Subsections 2.6.1 through 2.6.3 discuss the empirical methods, closed form solutions and model simulations used for the reference design of the WIPP underground openings.

2.6.1 Empirical Method

Most of the seven potash mines in the Carlsbad area were visited by project participants on several occasions as the design evolved. The preliminary room and pillar configurations, including the width and

spacing of the rooms, drifts and pillars, were based primarily on experiences gained from general mining practices in those mines in areas with similar geology. The extraction ratio at the WIPP facility horizon is significantly less than that used in potash mines of similar depth in the Carlsbad area and in other parts of North America.

2.6.2 Closed Form Solutions

Closed form solutions in the SME Mining Engineering Handbook were used to check the design of the room-and-pillar system, including room dimensions, room spacing, pillar stresses and pillar width-to-height ratios. These types of solutions were also used to check room stability, including the stresses on the roof beams, and to estimate surface subsidence (ref. 2-30). Closed form solutions for steel and concrete structural design were used for design of the shaft liners and keys.

2.6.3 Model Simulation

To determine the geomechanical and structural behavior around the underground openings, mathematical models of the openings were generated and preliminary finite element analyses were performed to simulate this behavior. These analyses used material properties obtained from laboratory tests of drill core samples to estimate closure of the openings. In order to maintain the operational capability of the underground facility during its design life, allowances for roof, floor and wall closures were added to the operational clearance envelope of the underground openings. The design criteria require confirmation or modification of the estimated closure based on geomechanical instrument measurements obtained in the excavations.

Preliminary analyses were only considered parametric studies since important feedback from the design validation program observations and geomechanical instrument measurements was required to complete the understanding of the mechanism of creep deformation in the salt at the WIPP site.

CHAPTER 3
UNDERGROUND FACILITIES

3.1 INTRODUCTION

This chapter presents a brief history of the underground development level selection process. It also describes the configurations of the WIPP shafts, drifts and rooms, and summarizes their excavation history. The discussion of excavation history includes those details pertaining to the "as-built" openings which are considered significant with respect to the reference design. The reference design of the underground openings was based on requirements contained in the Design Criteria (refs. 2-7 and 2-8) and Design Bases (refs. 2-9 through 2-20) documents.

The WIPP underground facility is divided into three general areas (Figure 3-1). The northern portion is the experimental area containing the design validation test rooms and technology experiments. The central area is the shaft pillar. The number of drifts in this area is restricted to minimize subsidence around the shafts. This portion of the facility will primarily contain shops and personnel areas. The southern portion of the facility is the waste storage area. Although some mining has been conducted in this area, it remains largely unexcavated at the time of publication of this report.

3.2 SELECTION OF THE UNDERGROUND DEVELOPMENT LEVEL

Selection of the WIPP underground development level evolved over several years and various facility design concepts. Seven stratigraphic horizons were identified in 1979 as potential locations for the facility level and ranked in order of their preference. These seven horizons were chosen based on an examination of available borehole data, primarily geologic and geophysical logs from borehole ERDA-9, and on horizon selection criteria established by the WIPP project participants. The selection criteria consisted of recommended distances between the underground opening surfaces and the nearest overlying or underlying clay seams or partings.

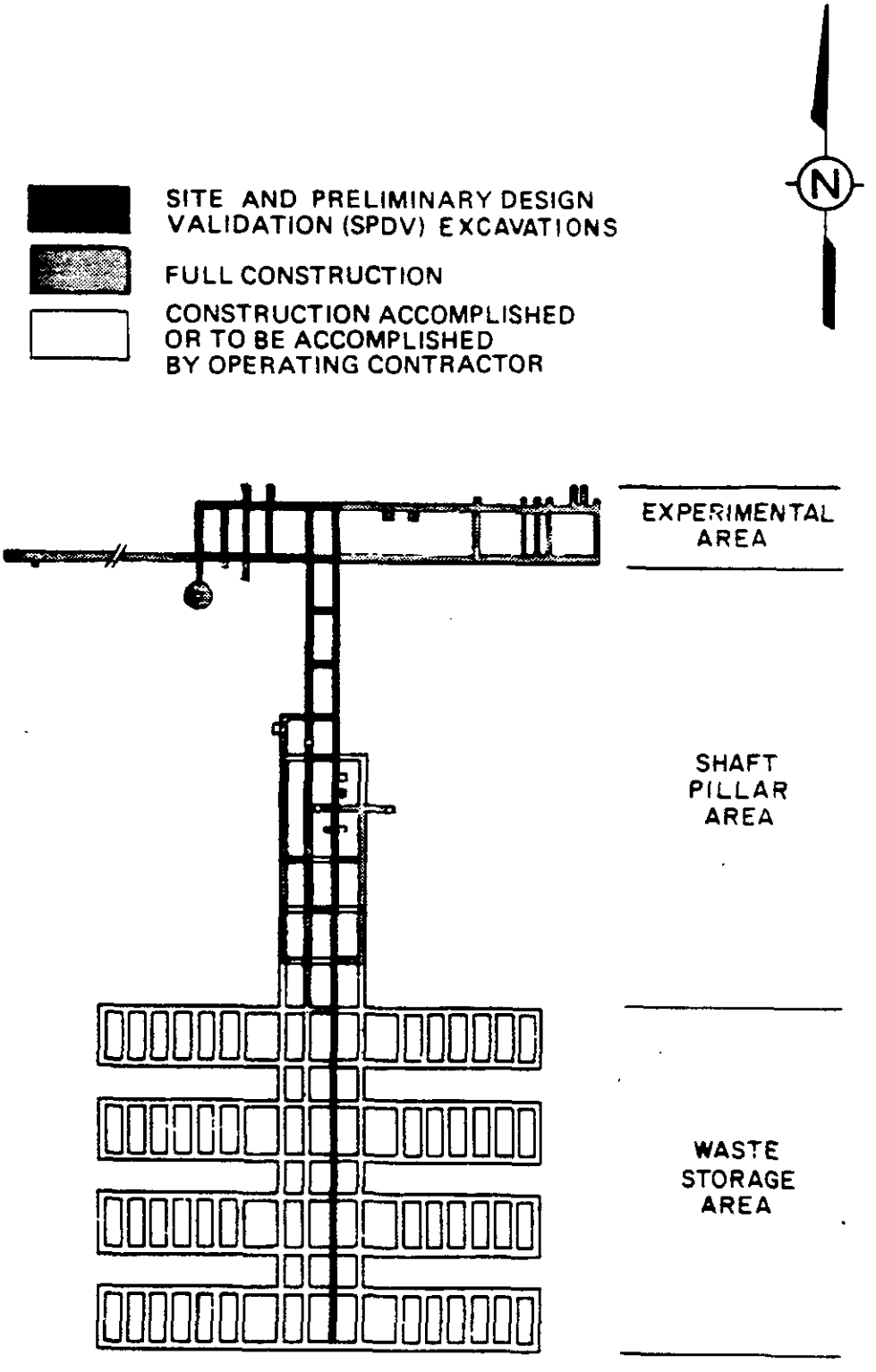


Figure 3-1

FUNCTIONAL AREAS OF THE UNDERGROUND FACILITY

Geologic mapping of the SPDV exploratory shaft in April and May 1982 permitted an assessment of the suitability of those intervals in the area of MB-139 preferred for the location of the facility level. This assessment included an evaluation of the intervals of interest against a modified version of the 1979 horizon selection criteria. These modified criteria were a result of changes to the initial WIPP facility concept, consisting of a reduction from two levels to one and alterations in the room size. The modified criteria were as follows:

(1) The rock comprising the underground facility horizon should contain no significant dissolution features, faults, or fractures. If any such features are noted, a detailed investigation must be conducted. (This element was not explicitly stated in the 1979 criteria.)

(2) There should be a minimum 4-foot thickness of halite between the top of MB-139 and the facility floor. The undulatory upper contact of MB-139 shall be considered in the selection of the facility floor level. (The 1979 criteria required a 5-foot thickness between the facility floor and the first underlying clay seam or parting.)

(3) There should be a minimum 14 1/2-foot section of halite for construction of nominal 13-foot high rooms. Minor impurities, such as argillaceous halite and polyhalite, may be acceptable. (The facility design in 1979 called for 12-foot high rooms.)

(4) There should be a minimum of 5 feet of halite between the facility roof and the first overlying clay seam (defined as 1/4 inch thick or greater) for purposes of roof stability. (This criterion was adjusted at the site to a 5- to 10-foot thickness at the verbal request of SNL personnel.)

(5) Horizons containing substantial amounts of polyhalite should be avoided. The minimum thickness of halite defined in the

third criterion listed above was increased from 14 1/2 feet to 17 feet or more to accommodate the 17-foot high SPDV exploratory shaft station.

Selection of the final underground development level was made following a series of meetings in which the interval ranked first was evaluated for its ability to satisfy these criteria. The selection was based primarily on the results of detailed geologic shaft mapping from a depth of 2,080 feet to 2,185 feet. A meeting, attended by representatives from the DOE, Westinghouse, SNL and Bechtel, was held on May 2, 1982, to discuss the results of the selection process and to present a recommendation for the facility level location to the DOE. The final level selected for the facility floor was at a preliminary depth of 2,149 feet (elev. 1258.4 feet). The recommendation was accepted by the DOE and later reviewed and concurred in by a representative of the New Mexico Environmental Evaluation Group (EEG).

Geologic mapping of the SPDV exploratory shaft and subsequent evaluation by the project participants showed that, as anticipated, the geology was similar to that encountered in borehole ERDA-9. One exception was the discovery of an additional anhydrite bed, anhydrite "b", and its underlying clay seam. Figures 3-2 and 3-3 show the preliminary design (pre-SPDV) of the shaft station and storage rooms. This preliminary design was based on the stratigraphy at the first-ranked alternative horizon. Figures 3-2 and 3-3 show that only one anhydrite layer and clay seam were expected above the facility level at this horizon, based on the interpretation of ERDA-9 core. This would have produced 12 feet of uninterrupted halite above the shaft station and 16 feet above the storage rooms. However, shaft mapping revealed an intermediate bed, anhydrite "b", approximately 7 feet below the known bed, anhydrite "a". This reduced the uninterrupted halite thickness above the facility level roof to 3.5 to 5 feet at the shaft station and 7 to 8.5 feet in the waste storage area. Despite this finding, the underground facility horizon chosen was judged to adequately meet all of the established criteria.

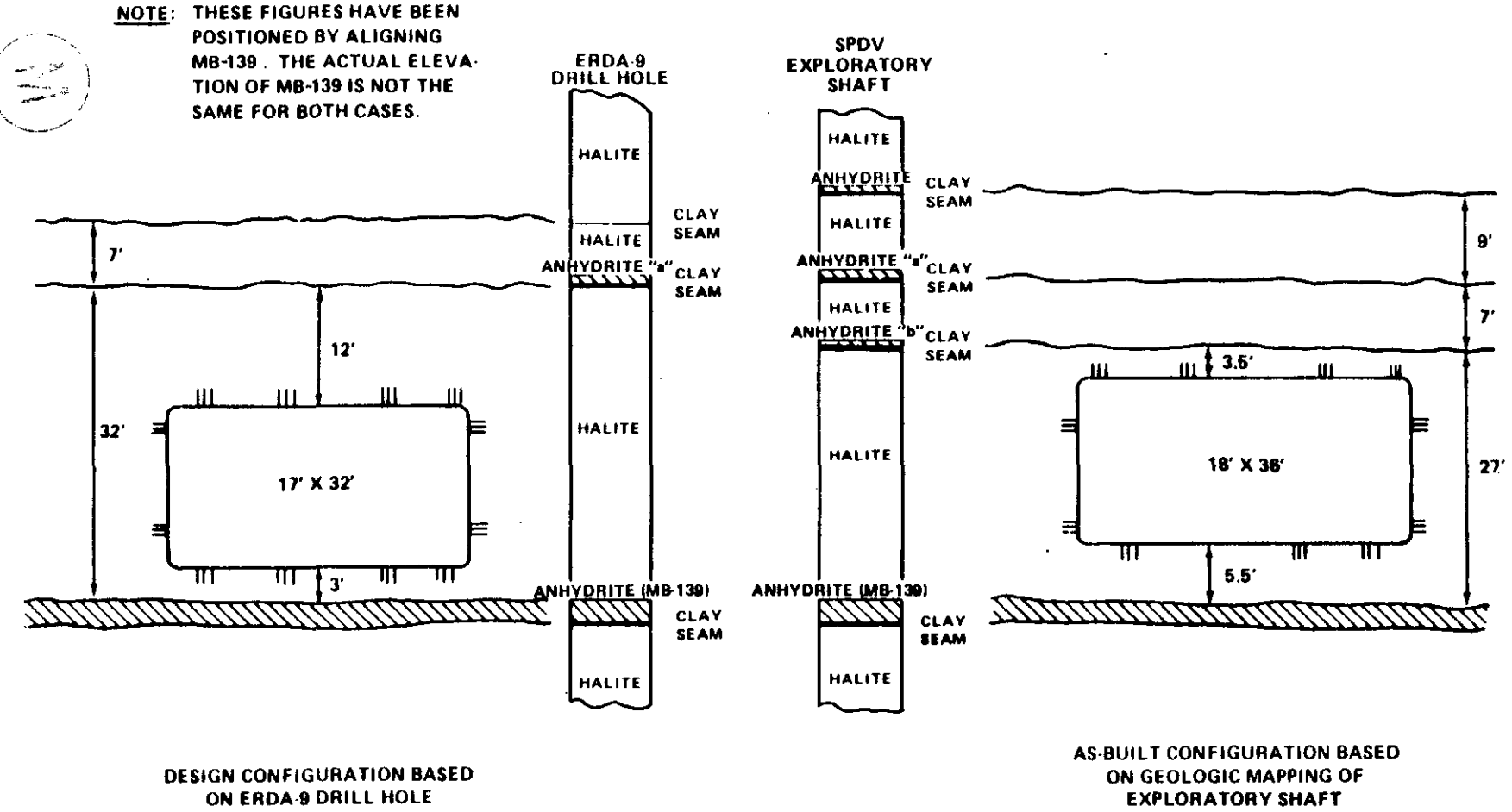
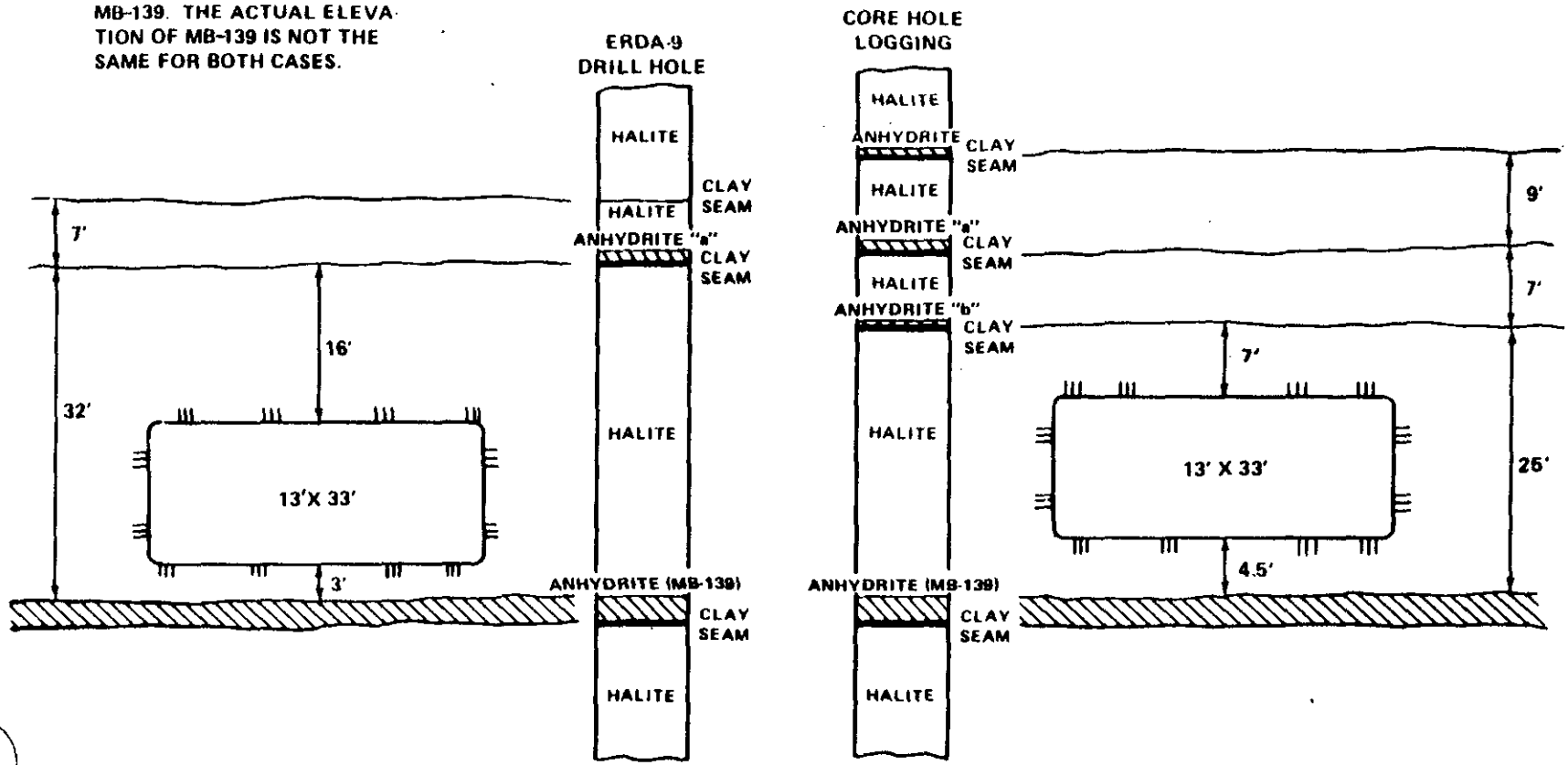


Figure 3-2

SPDV EXPLORATORY SHAFT STATION
DESIGN VERSUS AS-BUILT CONFIGURATION

NOTE: THESE FIGURES HAVE BEEN POSITIONED BY ALIGNING MB-139. THE ACTUAL ELEVATION OF MB-139 IS NOT THE SAME FOR BOTH CASES.



DESIGN CONFIGURATION BASED ON ERDA-9 DRILL HOLE

REVISED CONFIGURATION BASED ON CORE HOLE DATA

Figure 3-3

STORAGE ROOM
DESIGN VERSUS REVISED CONFIGURATION

At a meeting held on February 13, 1986, consideration was given to the desirability of relocating the facility level to a different stratigraphic horizon (ref. 3-2). The discussion was prompted by the following observations of the behavior of the underground openings:

(1) The effect of excavation on the strata surrounding the underground openings are being investigated by gas permeability testing. These tests indicate that zones of increased permeability due to fracturing, and proportional to the size of the opening, have developed between the floor of the openings and the base of MB-139 in the test rooms. These zones have also developed at intersections and other locations in the N1420 drift. Increased permeability has also been detected within anhydrite "b" above the roof of the test rooms. (Additional permeability testing is being conducted by SNL. The final results from this program are not yet available.)

(2) Fracturing has been encountered both within and above MB-139. It is especially well developed in the southern half of Test Room 3 (Room T). This fracturing is discussed in Chapter 10, subsection 10.3.2.1, and in Chapter 11, subsection 11.3.2.1.

(3) Both horizontal displacements and vertical separations have been observed above the roof of the underground openings. These occur primarily at anhydrite "b" and are associated with the underlying clay seam. This is discussed in Chapter 10, subsection 10.3.2.1, and in Chapter 11, subsection 11.3.2.1.

(4) In situ closure rates are almost three times greater than the rates originally predicted from laboratory test data. This is discussed in Chapters 10, 11 and 12.

The underground opening behavior occurring at the WIPP is similar to that of other openings excavated in areas with similar geologic formations. The conditions are understood and any problems encountered can be adequately mitigated using standard mining engineering procedures. The behavior experienced at the present facility level is likely to occur to some extent at any alternate horizon selected. These conclusions, and the fact that the behavioral characteristics and geologic environment at the existing level are known, resulted in a decision by the WIPP project participants to keep the facility level at its present location. Studies of the behavior of the rooms and drifts will continue beyond design validation as discussed in Chapter 1, subsection 1.5.2.

3.3 DESCRIPTION OF UNDERGROUND FACILITIES

3.3.1 C & SH Shaft

The construction and salt handling (C & SH) shaft is the principal means of access to the underground WIPP facility and is the primary fresh-air intake for the underground ventilation system. It was originally designated the exploratory shaft during the SPDV Program. The shaft provides a means of access for personnel and materials to and from the facility, and for the removal of excavated salt. Geomechanical instrumentation installed in the shaft provides important data for monitoring the behavior of the liner and key, the salt strata surrounding the shaft. and ground-water pressures.

The shaft is lined with steel casing having a 10-foot inside diameter from the ground surface to a depth of 846 feet. The 10-foot diameter extends through the concrete shaft key to a depth of 880 feet. From the key to the bottom of the shaft at 2,298 feet the shaft is a nominal 12 feet in diameter and is unlined.

The steel liner was designed to retain the rock formations above the salt and to prevent water seepage into the shaft. The liner was designed for both construction and permanent loads. The construction load was considered to be the hydrostatic pressure exerted on the liner

by the fluid used to "float" it into place for installation. The permanent load is the hydrostatic pressure exerted on the liner by ground water under artesian conditions in the water-bearing zones. Rock pressure was not used in design due to the controlling influence of the hydrostatic pressure. Since hydrostatic pressure increased with depth, the steel liner thickness was also increased. The liner is 5/8 inch thick at the top and increases to 1 1/2 inches thick at the bottom. The liner is held in place with cement grout.

The C & SH shaft key is a 37 1/2-foot long reinforced-concrete structure at the base of the steel liner. The key serves two important functions. First, it provides a transition from the lined to the unlined sections of the shaft. Second, as an integral part of the liner, it prevents ground water from the upper water-bearing members from dissolving the salt around and beneath the key. This water movement is obstructed primarily by two water seals installed behind the concrete. A third seal, installed at the interface of the steel liner and concrete key, prevents water from flowing out at the interface and down the inner surface of the key. A gravel-filled trench was constructed behind the concrete above the lower of the two seals to intercept water migration past the upper seal. This water is drained through four pipes, called "telltales", to the key surface and into a water collection ring at the base of the key.

The shaft is unlined below the concrete key. Excavation by the rotary drilling method has resulted in shaft walls that are smooth and undamaged. No support or protective wire mesh was required.

3.3.2 Waste Shaft

The waste shaft serves to connect the waste handling building on the ground surface with the WIPP underground facility. The shaft's primary function is to permit the transfer of radioactive waste from the surface to the underground storage area. It will also serve as an intake shaft for small volumes of air during storage operations and as an emergency escape route. The waste shaft was initially excavated as

a 6-foot diameter ventilation shaft, which was the primary exhaust route during the SPDV phase of construction. As in the C & SH shaft, geomechanical instruments installed in the waste shaft provide important geotechnical data with which to monitor the behavior of the shaft and its surrounding geologic environment.

The waste shaft is lined with unreinforced concrete from the ground surface to the top of the key at a depth of 837 feet. The purpose of the liner is to retain the surrounding rock and to prevent ground water from entering the shaft. The lined section of the shaft has a finished inside diameter of 19 feet. The liner thickness increases with depth from 10 inches at the surface to 20 inches at the key. A water collection ring was incorporated into the liner immediately beneath both the Magenta and Culebra water-bearing members. These rings are connected to another ring at the base of the key.

The waste shaft key is similar in construction to the C & SH shaft key. It serves as a transition from the concrete-lined section to the exposed salt section of the shaft and it prevents ground water from reaching the salt via the shaft opening. The key is 63 feet long, 4 1/4 feet thick and constructed of reinforced concrete. The bottom of the key is at a depth of 900 feet. In contrast to the C & SH shaft key, the waste shaft key has only two water seals.

A water collection ring at the base of the key collects water trickling down the surface of the key and conducts it, as well as water from the two upper rings, to the shaft station via a 2-inch diameter PVC pipe. Two guide pipes, consisting of 2-inch diameter polyvinyl chloride (PVC) pipe, were also installed in the concrete key at a depth of 843 feet at the request of SNL to serve as guides for drilling test holes across the contact of the Rustler formation with the Salado formation.

The section of the shaft below the key is 20 feet in diameter and consists of exposed salt lined with wire mesh anchored by rock bolts. The 20-foot diameter shaft enlarges to 23 feet just above the waste

shaft station. This 23-foot diameter extends to the bottom of the shaft, approximately 122 feet below the facility level.

3.3.3 Exhaust Shaft

The exhaust shaft is the primary ventilation exhaust for the underground facilities. It is designed as a duct to remove air from the underground areas up through the exhaust filter building at the ground surface. In addition, the exhaust shaft will serve as a backup escape route during emergencies. This shaft is also used to carry an auxiliary 15 kV power cable and signal cables underground. These redundant cables serve as emergency alternates should the primary cables in the C & SH shaft become inoperative. The exhaust shaft, like the C & SH and waste shafts, contains a suite of geomechanical instruments.

The exhaust shaft is lined with unreinforced concrete from the ground surface to the top of the shaft key at a depth of 844 feet. The purpose of the liner is the same as that in the other two shafts. The liner has an inside diameter of 14 feet. The liner thickness increases from 10 to 16 inches with depth.

The exhaust shaft key serves the same function as the keys in the other two shafts. It is a transition element between the concrete liner in the upper section of the shaft and the exposed salt in the lower section. It is also designed to prevent ground water in the upper water-bearing members from reaching the salt section of the shaft. The key is 63 feet long and 3 1/2 feet thick. The key contains eight telltale drains at a depth of 857 feet and nine drains each at 855 feet and 870 ft. The key also contains two water seals, a water collection ring, and two guide pipes for drilling test holes. The bottom of the key is at a depth of 907 feet.

The exhaust shaft below the key is 15 feet in diameter. It is lined with wire mesh anchored by rock bolts. The exhaust shaft terminates at the facility level; there is no shaft sump.

3.3.4 Drifts

The underground shaft stations and drifts have been designed to facilitate the handling and transport of radioactive waste. They also provide access for construction operations and experimental activities. The drifts are designed to provide adequate ventilation supply and exhaust for all areas of the underground facility.

All drifts are rectangular in cross section with typical dimensions that range from about 8 to 12 feet high and 14 to 25 feet wide. Access drifts serve as the main haulageways between the shafts and the experimental and waste storage areas. Cross-cut drifts (crosscuts) are designed to accommodate equipment, shops and traffic flow. The crosscuts are generally smaller in cross-sectional dimensions than the access drifts. The excavated dimensions of major drifts and rooms are presented in Table 3-1. The horizontal underground openings are oriented either north-south or east-west and are labeled based on a grid system having the centerline of the C & SH shaft as its origin. For example, the E0 drift runs north-south in line with the C & SH shaft and the N1100 drift is an east-west drift 1100 feet north of the C & SH shaft.

The northern part of the facility contains the experimental areas. Four test rooms were excavated west of the E0 drift as part of the SPDV Program. These rooms are discussed in subsection 3.3.5. The remaining experimental areas have been excavated for long-term experimental programs to be conducted under the direction of SNL. These experiments are not part of design validation and are addressed in this report only when necessary to clarify the discussion.

The shaft pillar area (Figure 3-1) is designed to protect the surface structures and shafts from settlement resulting from the natural closure of underground openings. The shaft pillar dimensions were derived in accordance with standard analyses developed by the U.S. Bureau of Mines (ref. 2-30). Excavation within the shaft pillar area was designed to maintain an extraction ratio of less than 15 percent.

Table 3-1

FACILITY LEVEL CONFIGURATIONS
NOMINAL EXCAVATED DIMENSIONS OF MAJOR DRIFTS AND ROOMS

Drift or Room					Width (ft)	Height (ft)
E0	From	N35	To	N1420	25	12
E140	From	N140	To	N1420	14	8
E140	From	N140	To	S2210	25	12
E140	From	S2210	To	S3264 (Exploratory Drift)	25	8
E300	From	S90	To	S1980	14	12
W30	From	S90	To	S700	20	12
W30	From	S700	To	S1950	14	12
W170	From	N140	To	S1300	14	12
N140	From	E0	To	E140	12	12/19
N140	From	E0	To	W170	12	12/19
N460	From	E0	To	E140 (Conference Room)	20	8
N780	From	E0	To	E140	12	12
N1100	From	E0	To	E1546	14	9
N1100	From	E0	To	W667	20	12
N1100	From	W667	To	W1800 (Room G Entry Drift)	20	9
N1100	From	W1800	To	W2990 (Room G)	20	10
N1420	From	E140	To	E1546	14	12
N1420	From	E140	To	W647	20	12
S90	From	E0	To	E140	12	12
S90	From	E140	To	E300	14	12
S400	From	E60	To	E140	20	12
S400	From	E140	To	E300	14/18	12/17
S400	From	E300	To	E500	20	12
S700	From	W170	To	W30	20/25	12
S700	From	W30	To	E140	20	12
S700	From	E140	To	E300	20/35	12
S1000	From	W170	To	W30	20	12
S1000	From	W30	To	E140	25	12
S1000	From	E140	To	E300	20	12
S1300	From	W170	To	W30	20	12
S1300	From	W30	To	E140	20	12
S1300	From	E140	To	E300	20	12
S1600	From	W170	To	W30	20	12
S1600	From	W30	To	E140	20	12
S1600	From	E140	To	E300	20	12
S1600	From	E300	To	E520	14	12
S1950	From	W30	To	E140	14	12
S1950	From	E140	To	E300	20	12
S2180	From	E140	To	E300	14	12

Table 3-1 (continued)

FACILITY LEVEL CONFIGURATIONS
NOMINAL EXCAVATED DIMENSIONS OF MAJOR DRIFTS AND ROOMS

Drift or Room	Width (ft)	Height (ft)
Test Rooms 1, 2, 3 & 4 (300 feet long)	33	13
Experimental Rooms A1, A2, A3, B & D (306 feet long)	18	18
Alcove I1 (43 feet long)	24	12
Alcoves I2, I3, I4, I5, I6 & I7 (33 feet long)	33	12
Rooms C1 & C2 (98 and 102 feet long)	18	18
Room J (98 feet long)	33	12
Rooms L1 & L2 (98 feet long)	33	12
Room H Entry	12	10
Room H (outside radius = 54 feet)	36	10

A geomechanical instrumentation program was implemented to gather geotechnical data from the underground drifts. The program was designed to monitor the stability of the openings, to assess deformational characteristics of the salt, and to measure closure rates of typical drifts, rooms and intersections. In addition, an extensive program of geologic mapping, core drilling, laboratory testing and visual observations has been conducted. The methodology used and the results of these programs are discussed in other chapters of this report.

3.3.5 Test Rooms

Four test rooms were excavated in the northern section of the facility during the SPDV phase of construction. These rooms represent full-scale models of the future waste storage rooms and have the same dimensions, 13 feet high, 33 feet wide and 300 feet long, as the planned storage rooms.

The test rooms are designed to permit an assessment of deformation and closure rates due to salt creep as well as the stability of the future storage rooms. This has been accomplished by evaluations and analyses of geotechnical data gathered from geomechanical instruments installed in each room and the results of geologic mapping, core drilling, laboratory testing of samples from the surrounding strata, and qualitative visual observations by project geotechnical personnel. The results of these evaluations and analyses are presented in Chapters 11 and 12.

3.3.6 Waste Storage Area

The waste storage area will be developed in the southern portion of the facility (Figure 3-1). The reference design for this area includes a series of eight panels with seven storage rooms in each panel. The room dimensions are 13 feet high, 33 feet wide and 300 feet long. The width of the pillars between rooms is 100 feet. This configuration results in a storage area extraction ratio of less than 25 percent based on a line 100 feet beyond the storage area excavation neat line.

Full development of the waste storage area will eventually encompass about 140 acres. The reference design is based on the assumption that the storage rooms and panels will be excavated in stages coordinated with the scheduled arrival of waste. Waste storage is designed not only for the rooms but also for all drifts and crosscuts in the waste storage area (south of the S1600 drift).

3.4 UNDERGROUND CONSTRUCTION

The existing WIPP underground facility was constructed in two phases. The first phase, SPDV (Figure 3-1), was conducted from 1981 to 1983 and consisted of the excavation of the exploratory and ventilation shafts as well as several drifts and a panel of four test rooms. SPDV accomplished two objectives: (1) it permitted the completion of experiments and geotechnical activities required for the Site Validation Program (ref. 2-5); and (2) it provided for the initial in situ confirmation of the underground facility reference design. This allowed construction of the underground facility to proceed in a timely and cost-effective manner.

Excavation associated with the second phase of underground construction was accomplished from October 1983 through February 1985 and is designated as full construction on Figure 3-1. This excavation included enlarging the ventilation shaft for its conversion to the waste handling shaft, constructing the exhaust shaft, and mining additional underground drifts and test rooms for conducting R & D experiments. The operational name of the exploratory shaft changed to the C & SH shaft during this period. Design validation has been an integral part of this construction activity.

A third phase of underground construction is currently in progress. This is the initial operations phase during which excavation of the storage rooms will occur concurrently with waste emplacement. Mining for this phase started in June 1985 with the excavation of crosscuts for the installation of shops in the shaft piller area. Partial excavation of some storage rooms will follow. However, initial waste

emplacement is currently not scheduled to begin until late 1988. No discussion of the operations phase is presented in this report, although it will be strongly affected by the design validation results presented herein.

3.4.1 C & SH Shaft

C & SH shaft construction was performed during 1981 and 1982. Construction started in May 1981 with the excavation of a 98-foot deep pilot hole. The pilot hole was augered using a crane-mounted drilling unit. Steel surface casing with an interior diameter of 12 feet was grouted into place to a depth of 93.4 feet.

Shaft drilling started on July 4, 1981, and was completed 112 days later. The drilling was performed using a jacknife derrick with draw works capable of supporting a suspended load of 500 tons. The drilling method used consisted of air-lifted reverse circulation performed through double-walled drill pipe. The drilling fluid (brine) was maintained at a relatively constant level above the drill bit. The drill bit consisted of a 142-inch diameter full-face rolling cutter head. Shaft drilling was completed to a depth of 2,298 feet on October 24, 1981. Table 3-2 contains an abridged history of the C & SH shaft drilling program.

Liner installation began on November 12, 1981, and was completed on December 3, 1981. A steel liner was installed in 20- and 40-foot sections in the shaft above the salt formation. The steel sections were connected during installation using full-penetration bevel welds. Nondestructive radiographic examination was performed on each welded section. The liner was partially floated into place by filling the shaft with brine and adding brine to the inside of the liner to overcome the effect of buoyancy. Additional support for installation was provided by the drilling derrick and draw works. After the liner was in place, the annular space was grouted by the tremmie method. The grouting was completed on December 8, 1981.

Table 3-2

C & SH SHAFT - ABRIDGED DRILLING HISTORY

Location:		Eddy County, New Mexico; New Mexico Grid Coordinates X 666894.89, Y 499687.23
Elevation:		Ground Surface = 3410.5 ft MSL
Drilling Contractors/Rig Types:		Meredith Drilling Company/Auger (11.0 ft to 97.5 ft*); Challenger Drilling Company/ National 125 Jacknife Rotary (97.5 ft to 2,298 ft)
Drilling Data	Augered:	May 18 to June 17, 1981
	Spudded:	July 4, 1981
	Completed:	October 24, 1981
	Casing:	180-in. corrugated metal pipe, ground surface to 11 ft; 144-in. steel casing, ground surface to 93.4 ft; 120-in. steel liner, ground surface to 846 ft
	Drill Hole:	142-in. (nominal) diameter uncased borehole to a total depth of 2,298 ft
	Drilling Fluid:	Brine
Directional Survey Contractor:		Sperry-Sun (Gyroscopic Multishot Surveys)
Bottom Hole Coordinates:		X 666893.45, Y 499686.56 at 2,276 ft
Horizontal Displacement:		1.59 ft S 65.03° W at 2,276 ft

Table 3-2 (continued)

C & SH SHAFT - ABRIDGED DRILLING HISTORY

Geophysical Logging Contractors:	Birdwell(B) and Dresser Atlas(D)
Geophysical Logs:	October 16 to December 17, 1981
Fluid Density (D)	1,200 ft to 550 ft
Fluid Density (B)	750 ft to 20 ft
Density (B)	2,294 ft to 50 ft
Caliper (3-diameter/aver.) (B)	2,294 ft to 50 ft
Epithermal Neutron (B)	2,294 ft to 50 ft
Gamma Ray (B)	2,300 ft to 0 ft
Fluid Density (B)	400 ft to 100 ft
Nuclear Cement Top Locator (NCTL) (B)	827 ft to 0 ft
Nuclear Annulus Investigation Log (NAIL) (B)	839 ft to 0 ft
Fluid Density (D)	2,250 ft to 2,003 ft

* All depths measured from ground surface.

A key was constructed at the base of the steel liner during March and April 1982. The key is 37 1/2 feet long and constructed of reinforced concrete. Key construction required additional excavation in the salt below the liner to enlarge the shaft diameter. After the installation of reinforcing steel, drains, geomechanical instruments, grout pipes and block-outs for the injection of chemical seals, concrete was placed in several lifts from the bottom of the key to the bottom of the liner. Finally, the chemical seals were placed by injection.

3.4.2 Waste Shaft

Drilling of the SPDV ventilation shaft started on December 24, 1981, and was completed to a depth of 2,196 feet on March 10, 1982. The drilling operation was performed with the same drill rig used to drill the C & SH shaft. The drill bit was a 72-inch diameter full-face rolling cutter head. An abridged history of the shaft drilling is presented in Table 3-3. Except for a 97-foot long surface casing, the ventilation shaft was unlined. The ventilation shaft, and later the waste shaft, served as the exhaust for the underground facility until excavation of the permanent exhaust shaft was completed.

Enlargement of the SPDV ventilation shaft to become the waste shaft began in October 1983 (Table 3-3). This enlargement was performed from the top to the bottom of the shaft using the smooth-wall drill and blast method. The blasting was accomplished in 10-foot rounds that permitted the muck to fall down the 6-foot diameter shaft to the facility level. The muck was removed from the waste shaft station and hauled to the surface via the salt-handling skip in the C & SH shaft.

Construction of the unreinforced concrete liner closely followed this excavation. Typically, the shaft crew would take out three rounds (30 feet) of rock before placing one 24-foot section of concrete. This arrangement normally left no more than 6 feet of unlined shaft below the concrete.

Table 3-3

WASTE SHAFT - ABRIDGED CONSTRUCTION HISTORY

Location:		Eddy County, New Mexico; New Mexico Grid Coordinates X 666920.76, Y 499286.92
Elevation:		Ground Surface = 3407.5 ft MSL Shaft Collar = 3407.9 ft MSL (ventilation shaft) Shaft Collar = 3409.0 ft MSL (waste shaft)
Ventilation Shaft		
Drilling Contractors/Rig Types:		Meredith Drilling Company/Auger (8.0 ft to 98.2 ft*); Challenger Drilling Company/ National 125 Jacknife Rotary (98.2 ft to 2,196 ft)
Drilling Data	Augered:	June 13 to 17, 1981
	Spudded:	December 24, 1981
	Completed:	March 10, 1982
	Casing:	108-in. corrugated metal pipe, ground surface to 8 ft; 74-in. steel casing, 0.5 ft above ground surface to 96.9 ft
	Drill Hole:	72-in. (nominal) diameter uncased borehole to a total depth of 2,196 ft
	Drilling Fluid:	Brine
Directional Survey Contractor:		Sperry-Sun (Gyroscopic Multishot Surveys)
	Bottom Hole Coordinates:	X 666918.81, Y 499285.81 at 2,177 ft
	Horizontal Displacement:	2.25 ft S 60.2° W at 2,177 ft

Table 3-3 (continued)

WASTE SHAFT - ABRIDGED CONSTRUCTION HISTORY

Shaft Survey Contractor:	Cementation West, Inc.
Horizontal Displacement:	1.37 ft SW at 2,150 ft
Geophysical Logging Contractor:	Birdwell
Geophysical Logs:	March 8 to 10, 1982
Caliper (3-diameter/aver.)	2,190 ft to 0 ft
Epithermal Neutron	2,190 ft to 0 ft
Density	2,190 ft to 0 ft
Gamma Ray	2,100 ft to 0 ft
Fluid Density	2,191 ft to 1,800 ft

Waste Shaft

Excavation Contractor:	Ohbayashi Corporation
Excavation Method:	Smooth-wall drill and blast
Finished Shaft Diameter:	Lined = 19 ft Unlined = 20 ft minimum
Shaft Collar Excavation Began:	October 11, 1983
Liner Plate and Concrete Backfill Completed:	November 12, 1983
Collar Pads and Sinking Headframe Foundations Poured:	November 14, 1983
Concrete Liner Constructed: (including key)	November 30, 1983, to April 3, 1984
Liner Plate at Magenta Dolomite Grouted:	March 8 to 10, 1984
Liner Plate at Culebra Dolomite Grouted:	April 3 to 5, 1984
Salt Section Excavated:	April 7 to June 11, 1984
Sump Excavated:	June 20 to August 8, 1984
Liner Grouted:	August 11 to 25, 1984

* All depths measured from ground surface.

As part of the shaft design, both the Magenta and Culebra dolomite members of the Rustler formation were overexcavated and covered with steel liner plate prior to concrete placement. The space between the liner plate and the rock provided room for water from these water-bearing zones to accumulate. This allowed the concrete liner to reach full strength without damage from hydrostatic pressure buildup. After the concrete liner had reached full strength, this annular space was grouted with Portland cement grout at a 1:1 cement-to-water ratio.

Construction of the waste shaft key was nearly identical with that of the C & SH shaft key. The key is 63-feet long and composed of reinforced concrete. The shaft was overexcavated and the reinforcing steel, drainpipes, geomechanical instruments and chemical seal blockouts were installed. Unlike in the C & SH shaft, the chemical seals were placed between lifts of concrete. Concrete was placed from the bottom of the key to the top in several lifts, with construction joints at the top of each lift and at each chemical seal blockout. At the chemical seal locations the seal material was placed into the blockout prior to placing the next lift of concrete. Construction of the shaft liner and key was completed on April 3, 1984.

Excavation of the shaft to its 20-foot finished diameter below the key began on April 7, 1984. This section of the shaft is lined with wire mesh anchored by 3-foot long rock bolts. Mesh installation, like liner installation, was accomplished concurrently with excavation. The shaft enlargement reached the facility level on June 11, 1984. The shaft sump was excavated between June 30 and August 8, 1984. The sump extends approximately 122 feet below the facility level.

The concrete liner and grouting at both water-bearing zones did not completely prevent water from entering the shaft. Water seeped through the liner at construction joints and some cracks from a depth of about 560 feet to 835 feet. A grouting program was undertaken to seal these leaks in August 1984. A total of 628 bags of Portland Type V cement, 103 bags of MC-500 microfine cement, and 76 gallons of Scotch-brand

5600 foam chemical grout were injected into 293 drilled holes (ref. 3-3). The grouting significantly reduced, but did not eliminate, water seepage through the concrete liner.

3.4.3 Exhaust Shaft

The exhaust shaft was constructed in two phases over a 16 month period. The first phase was the excavation of a 6-foot diameter pilot shaft using upreaming techniques. The second phase consisted of enlargement of this shaft by conventional drill and blast methods and lining of the upper 907 feet. The construction history is summarized in Table 3-4.

Shaft excavation began on September 22, 1983, with the drilling of a pilot hole. The pilot hole was a 7 7/8-inch diameter hole drilled from the ground surface to intersect with the S400 drift at a depth of about 2,150 feet. Therefore, directional control of the hole was critical. The upper 80 feet of the pilot hole was augered, then lined with a surface casing. Drilling progressed to a depth of 744 feet using a tri-cone roller bit and compressed air. A "Dynadrill" was then used to correct hole alignment from 735 to 1,183 feet based on the results of gyroscopic hole surveys. The circulating medium was also changed at this time from air to brine. The tri-cone bit was used to complete the pilot hole. The hole diameter was then reamed to 11 inches from the surface to the facility level, again using a tri-cone roller bit. Pilot hole drilling was completed on December 16, 1983.

Excavation of the pilot shaft was performed by reaming the 11-inch diameter pilot hole to a diameter of 6 feet. This was accomplished by the raise-bore method. Reaming was performed from the facility level to the ground surface. The raise-boring operation was conducted from December 31, 1983, to February 10, 1984, using a Robbins series 61R1131 raise-bore machine. This machine utilizes a full-face rolling cutter head pulled to the surface with hydraulic jacks. Drill cuttings fell to the facility level and were hauled to the surface via the C & SH shaft.

Table 3-4

EXHAUST SHAFT - ABRIDGED CONSTRUCTION HISTORY

Location:	Eddy County, New Mexico; New Mexico Grid Coordinates X 667370.39, Y 499287.23
Elevation:	Shaft Collar = 3411.5 ft MSL Shaft Reference = 3409.0 ft MSL
Excavation Contractor:	Ohbayashi Corporation
Excavation Method:	Raise-bore 6-ft diameter pilot shaft; smooth-wall drill and blast to final dimensions
Subcontractors for Raise-Bore Excavation:	Raisebore, Inc., and J. S. Redpath Co.
Finished Shaft Diameter:	Lined = 14 ft Unlined = 15 ft
Pilot Hole Drilled:	September 22 to December 16, 1983
Raise-Bore Excavation:	December 31, 1983, to February 10, 1984
Shaft Collar Excavation Began:	July 15, 1984
Liner Plate and Concrete Backfill Completed:	July 17, 1984
Concrete Liner Constructed: (including key)	July 18 to November 29, 1984
Liner Plate at Culebra Dolomite Grouted:	December 2 to 4, 1984
Liner Plate at Magenta Dolomite Grouted:	December 4 to 5, 1984
Salt Section Excavated:	December 7, 1984, to January 17, 1985
Liner Grouted:	June 1 to July 31, 1985

Enlargement of the pilot shaft from 6 feet to the final exhaust shaft diameter of 15 feet began on July 15, 1984, and was accomplished by drilling and blasting in 10-foot rounds. Excavation was performed from the ground surface to the facility level. The rock was blasted into the open pilot shaft so that it fell to the facility level where it could be removed and hauled to the surface via the C & SH shaft.

The upper 844 feet of the exhaust shaft is lined with unreinforced concrete. As in the waste shaft, construction of the exhaust shaft liner occurred concurrent with the drill and blast excavation. Concrete placement for the liner was completed on November 29, 1984. The two water-bearing zones in the Rustler formation, the Magenta and Culebra dolomites, received the same special treatment that was performed in the waste shaft. Each zone was overexcavated and covered with steel liner plate prior to placing the concrete liner. After the liner had cured, grout was injected behind the liner plates.

Exhaust shaft key construction, similar to that in the waste shaft, was performed in November 1984. The key consists of reinforced concrete and extends from a depth of 844 to 907 feet. It initially contained 2 chemical seals, 8 telltale drains, 2 guide pipes for test hole drilling, and geomechanical instrumentation. Placement of the concrete and chemical seal material was identical to that performed in the waste shaft. Two additional sets of telltale drains were installed in the key by drilling after its construction. Each set contains nine drains. One set was installed above and one set below the initial eight-drain set.

The exhaust shaft is 15 feet in diameter from the bottom of the key to the facility level. For safety, the walls are covered with wire mesh anchored by rock bolts. Excavation of the shaft to its final dimensions was completed on January 17, 1985.

As in the waste shaft, water began seeping through the exhaust shaft liner at construction joints and small cracks. Total water inflow

through the liner was measured at 0.35 gallons per minute in January 1985. A grouting program, using Portland cement and chemical grout, was conducted from June 1 through July 31, 1985, to seal these leaks and to ensure that the integrity of the shaft key was maintained. A total of 164 bags of Class C cement and 826.9 gallons of Terragel 5531 chemical grout were used. The total water inflow was reduced by this grouting to an essentially non-measureable quantity.

3.4.4 Drifts

The exploratory (C & SH) shaft station was the first underground horizontal opening excavated after completion of the SPDV exploratory and ventilation shafts. The initial shaft station excavation was performed from May 2 to June 3, 1982, using the drill and blast method. The station was trimmed to its final dimensions using the Dosco continuous mining machine discussed later in this subsection. The station area north of the shaft is 32 feet long, 32 to 35 feet wide and 12 feet high. South of the shaft, the station is 90 feet long and 32 to 38 feet wide. The height of the station south of the shaft is 18 feet for a distance of 54 feet and 14 feet for the remaining 36 feet. Cartridge water-gel explosives detonated by electric detonators were used for the drill and blast excavation. A detailed description of the SPDV exploratory shaft station excavation is presented in the WIPP Preliminary Design Validation Report (ref. 1-3).

Following the initial excavation of this station, the drill and blast method was used to excavate a drift southward to provide a connection between the two shafts so ventilation could be established. This drift was approximately 310 feet long, 18 feet wide and 9 feet high. Excavation of the drift was accomplished from June 3 to June 13, 1982.

The only other major use of the drill and blast method at the facility level was for construction of the loading pocket in the SPDV exploratory shaft. This pocket was constructed from June 1 through 30, 1982, on the north side of the shaft below the facility floor level.

It was later outfitted with a steel hopper and other equipment associated with the salt handling system.

The initial (SPDV) underground construction phase was conducted by Cementation West, Inc., of Tucson, Arizona. A British-made Dosco LH 1300, boom-type continuous mining machine was mobilized underground to the SPDV exploratory shaft station during late summer of 1982. This machine was used to excavate the remaining horizontal underground openings during the SPDV Program. The Dosco was capable of excavation rates of 1,000 to 1,200 tons per 24 hours (excavation was conducted on a three-shifts-per-day, seven-days-per-week basis). However, the excavation rate was often much less due to numerous construction and engineering related constraints. The mining machine was demobilized in May 1983 at the completion of the SPDV Program.

A second underground construction contract for full WIPP construction was awarded to Ohbayashi Corporation of South San Franicsco, California. During this phase of construction, two Japanese Mitsui Miike, boom-type continuous mining machines were used for excavation of the underground horizontal openings. Each of these machines excavated at a rate of 300 to 400 tons per 24 hours. These machines were mobilized to the underground facility in October 1983 and demobilized in April 1985.

A summary of the excavation sequence for the underground horizontal openings is presented on Figure 3-4. This figure shows the mining progress on a daily basis from October 14, 1982, through March 31, 1986. The underground mining operation was performed in the same manner during both construction phases regardless of the type of mining machine being used. The rotating head on the boom of the mining machine cut the salt away from the working face. The "muck" was pulled through the machine on a conveyor and deposited in one of several types of haul vehicles. Typically, the haul vehicles were underground trucks capable of carrying about 5 tons of muck. Other vehicles used included LHDs (Load-Haul-Dump, a type of front-end loader) and a telescoping-bed haul truck. The trucks carried the muck to the C & SH shaft station

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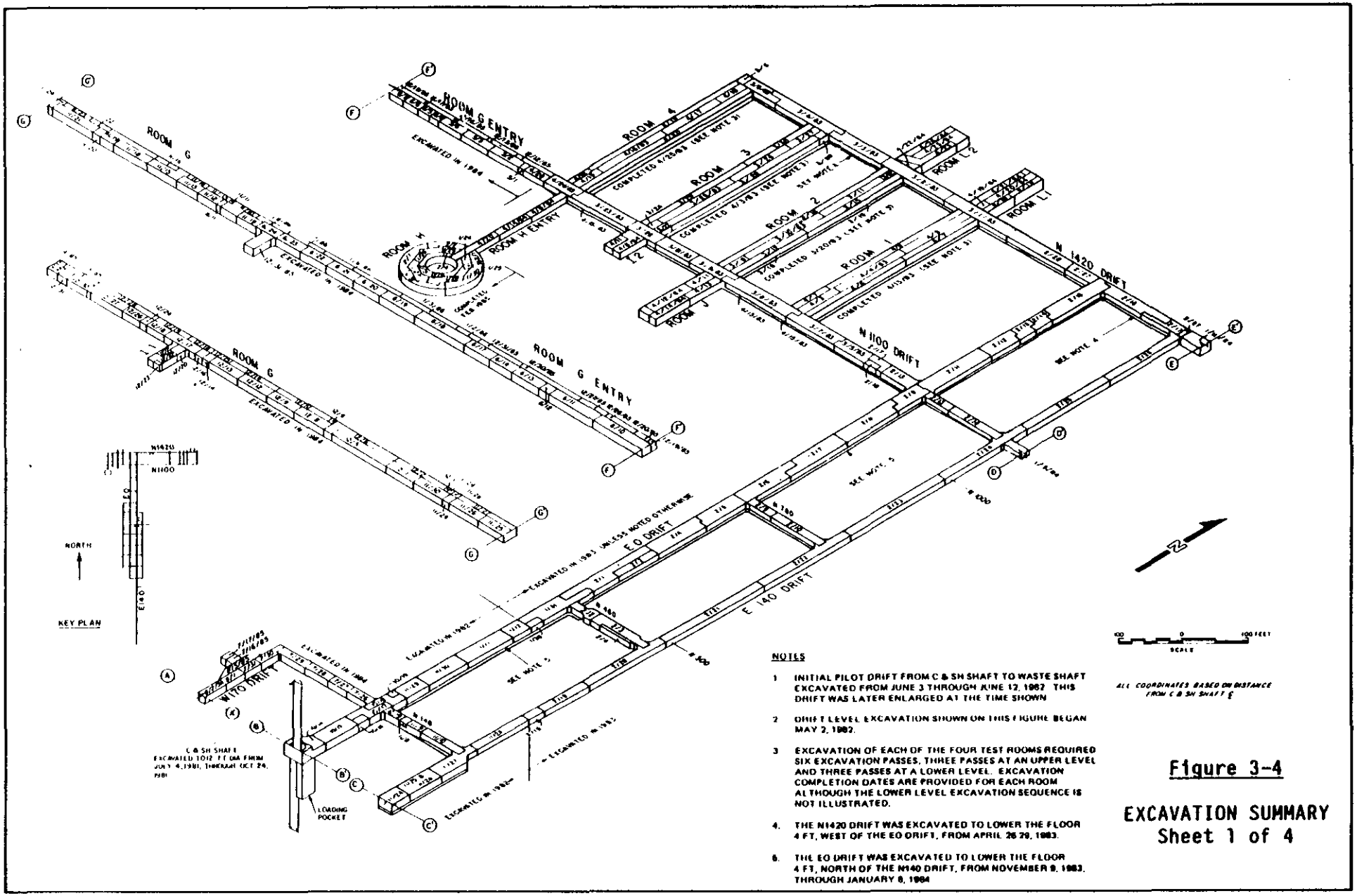


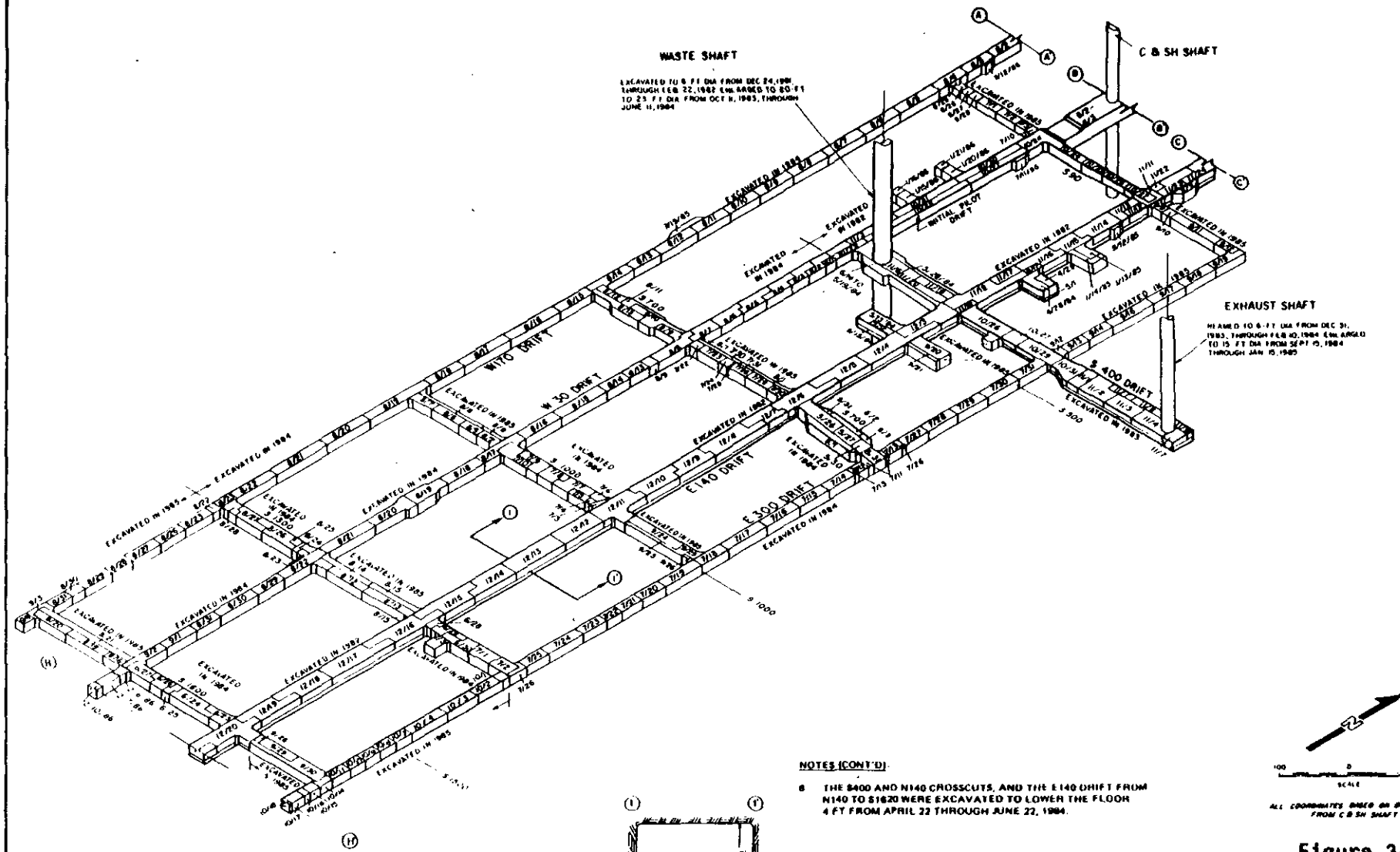
NOTES

1. INITIAL PILOT DRIFT FROM C & SH SHAFT TO WASTE SHAFT EXCAVATED FROM JUNE 3 THROUGH JUNE 12, 1982. THIS DRIFT WAS LATER ENLARGED AT THE TIME SHOWN.
2. DRIFT LEVEL EXCAVATION SHOWN ON THIS FIGURE BEGAN MAY 2, 1982.
3. EXCAVATION OF EACH OF THE FOUR TEST ROOMS REQUIRED SIX EXCAVATION PASSES, THREE PASSES AT AN UPPER LEVEL AND THREE PASSES AT A LOWER LEVEL. EXCAVATION COMPLETION DATES ARE PROVIDED FOR EACH ROOM ALTHOUGH THE LOWER LEVEL EXCAVATION SEQUENCE IS NOT ILLUSTRATED.
4. THE N1420 DRIFT WAS EXCAVATED TO LOWER THE FLOOR 4 FT, WEST OF THE E0 DRIFT, FROM APRIL 26 TO 29, 1983.
5. THE E0 DRIFT WAS EXCAVATED TO LOWER THE FLOOR 4 FT, NORTH OF THE N140 DRIFT, FROM NOVEMBER 9, 1983, THROUGH JANUARY 6, 1984.

ALL COORDINATES BASED ON DISTANCE FROM C & SH SHAFT ℄

Figure 3-4

EXCAVATION SUMMARY
Sheet 1 of 4



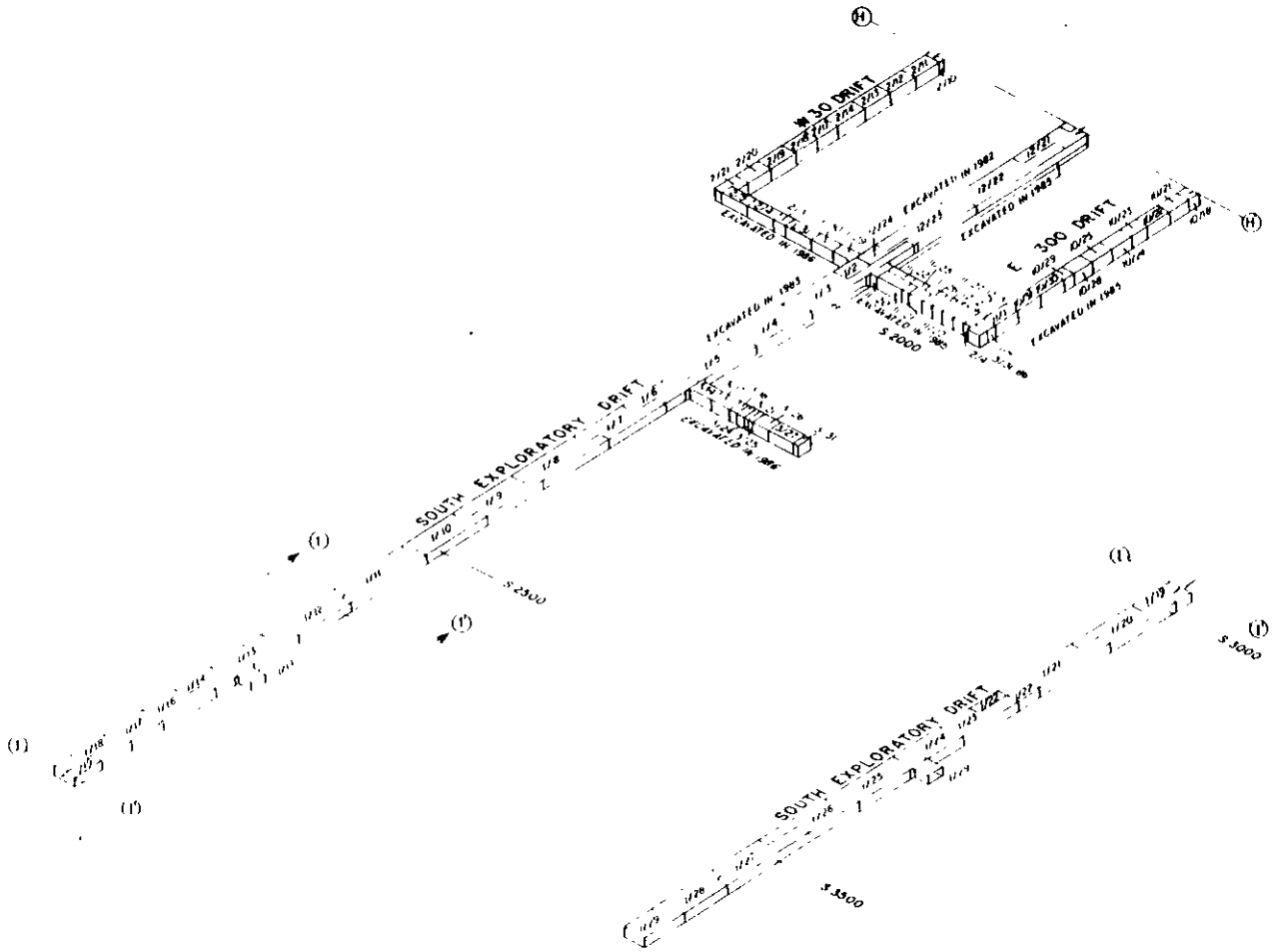
SOUTH EXPLORATORY DRIFT
SECTION 1-1'

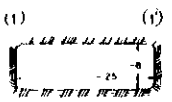
NOTES (CONT'D):

8. THE S400 AND N140 CROSSCUTS, AND THE E140 DRIFT FROM N140 TO S1620 WERE EXCAVATED TO LOWER THE FLOOR 4 FT FROM APRIL 22 THROUGH JUNE 22, 1984.

Figure 3-4

EXCAVATION SUMMARY
Sheet 2 of 4





SOUTH EXPLORATORY DRIFT
SECTION I-I'

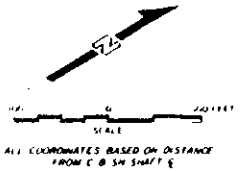
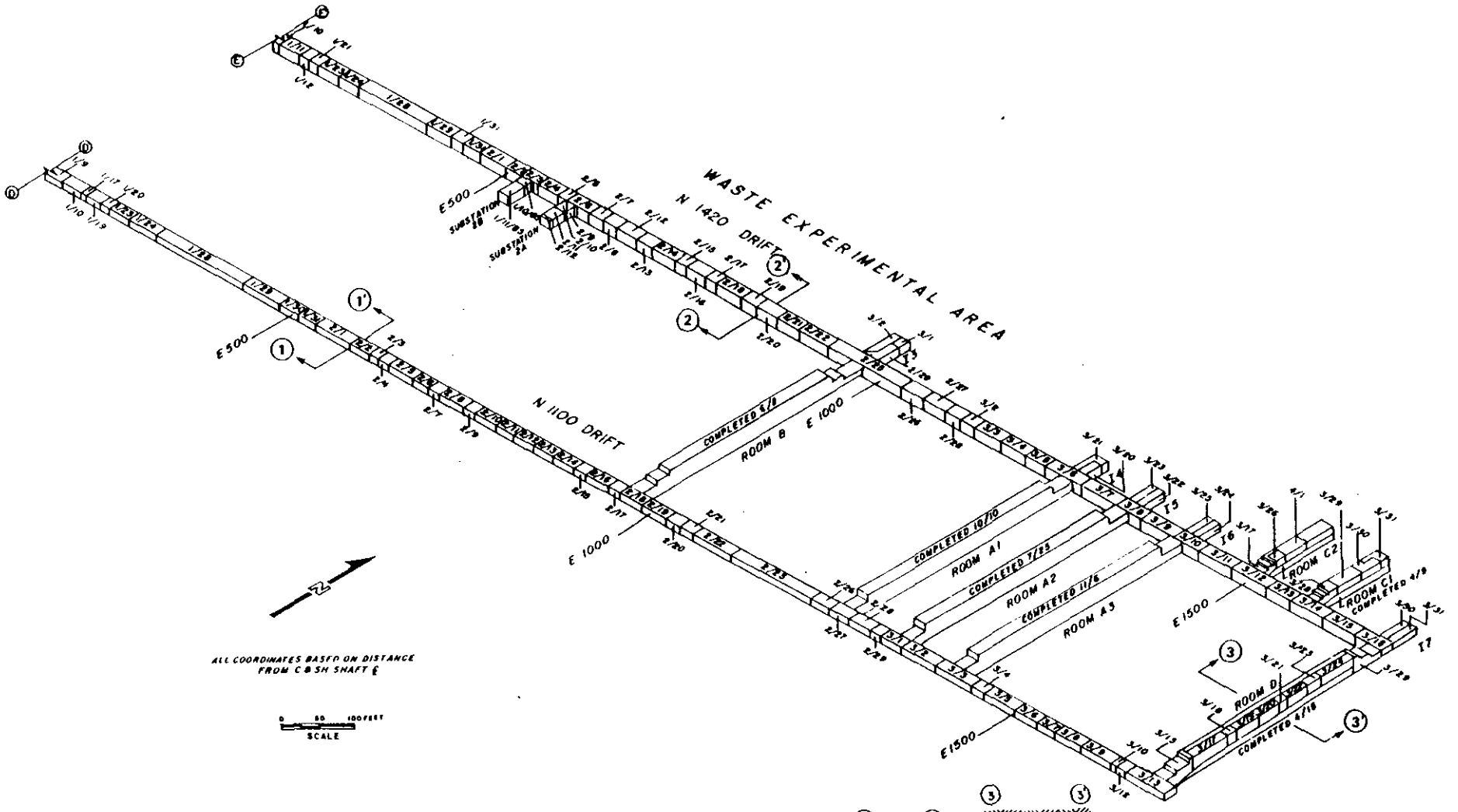


Figure 3-4

EXCAVATION SUMMARY
Sheet 3 of 4



NOTES:

1. EXCAVATION SUMMARY FOR ROOMS A1, A2, A3, AND B ARE NOT PRESENTED
2. ALL EXCAVATIONS SHOWN ON THIS SHEET WERE MADE IN 1984, EXCEPT FOR SUBSTATION 2B

Figure 3-4

EXCAVATION SUMMARY
Sheet 4 of 4

and dumped it into the loading pocket. From there, the muck was carried to the surface in 7- to 8-ton loads in the skip. The skip dumped the muck at the surface into 50-ton Caterpillar or Euclid haul trucks which then carried the muck to the surface salt storage area.

During and immediately after excavation, a sounding survey of the roofs in the horizontal openings was made using a scaling bar to identify areas of drummy or slabby rock which could pose safety or stability problems. Remedial work was performed immediately after sounding in any areas identified as potentially unstable. This work consisted of hand-scaling thin drummy areas, removing larger drummy areas up to 18 inches thick with the mining machine, or rock bolting. In addition, two follow-up surveys were made of the roofs in all of the horizontal openings excavated at the time of the survey. The first survey was completed in July 1983 and the second in November 1984. Remedial work was performed on problem areas identified during these surveys. This work consisted of scaling, excavation, or rock bolting. It should be noted that the drummy areas identified during the July 1983 survey were sounded again in the November 1984 survey and did not show any noticeable enlargement.

Rock bolts are used selectively throughout the underground drifts for both remedial work and safety. The roofs of many high-traffic personnel areas are pattern bolted and covered with wire mesh as an additional safety precaution.

The C & SH shaft station has presented the majority of problems associated with roof stability. Due to its initial excavation by the drill and blast method, and the proximity of overlying clay seams, the roof in the station has required support by a large number of rock bolts. The method of rock bolting has evolved through several phases due to the effect of salt creep on roof separation along the clay seams.

Rock bolts were initially installed in the C & SH shaft station roof

from May 9 to June 20, 1982. These bolts were 1 inch in diameter, 8, 10 or 12 feet in length, and made of grade 60 steel. They were anchored using resin cartridges.

These resin-anchor bolts began failing at the head assemblies shortly after their installation was completed. The failed bolts were replaced with 8-foot long, 5/8-inch diameter mechanical-anchor bolts with 2 x 12 x 12-inch wooden blocks installed between the steel head assembly plate and the salt. A total of over 400 resin-anchor and mechanical-anchor bolts were installed in the shaft station roof through April 1983.

During December 1983 and January 1984, 146 additional mechanical-anchor bolts, 5/8 inch in diameter and 8 feet long, were installed in the C & SH shaft station roof. In May 1984, another 91 similar anchor bolts were installed. After the mechanical-anchor bolts were installed, the nut and head assembly plate were cut off those older resin-anchor bolts showing evidence of excessive deformation. This was to prevent injury to personnel from falling nuts and plates should these resin-anchor bolts fail.

From mid-April through early August 1985, approximately 133 3/4-inch diameter mechanical-anchor bolts, 6 and 8 feet long, were installed in the station roof on approximately 3 1/2-foot centers. In addition, 245 resin-anchor bolts, 1 inch in diameter, were anchored above anhydrite "b" and across anhydrite "a". These bolts were 12 and 14 feet in length. The entire station roof was covered at this time with wire mesh secured with 2-foot long, 5/8-inch diameter mechanical-anchor bolts. Approximately 750 of the 2-foot long bolts were installed.

Although some resin-anchor bolts were used in the SPDV drifts and test rooms excavated in 1982 and 1983, mechanical-anchor bolts have been used in all subsequently excavated areas. Bolt lengths vary from 2 to 8 feet in the drifts and rooms. Wire mesh secured by 2-foot long mechanical-anchor bolts has been installed on the roofs of all high-traffic personnel areas. This includes instrument-shed and

electrical alcoves, many of the shop areas, and some of the brows above the entries to the waste experimental rooms. Rock bolts and wire mesh have also been installed in the roof of the N140 crosscut.

Rock bolts and wire mesh have been installed for roof support in the waste shaft station waste transfer area. The bolts, 3/4 inch in diameter and 12 feet long, are mechanical-anchor steel bolts set on nominal 4-foot centers.

3.4.5 Test Rooms

As part of the SPDV Program, four test rooms were excavated at the north end of the underground facility (Figure 3-4) by Cementation West, Inc., using the Dosco mining machine. The test room excavation was conducted from March 9 to April 25, 1983. Test Room 2 was excavated first, followed by Test Rooms 3, 1 and 4, in that order. Each room was excavated in a series of six passes along its longitudual axis (Figure 3-5). The first pass was the largest in cross section and was conducted down the center of the planned room along its roof. This pass was approximately 15 feet wide and 8 feet high. The second and third passes were conducted on either side of the first pass. Each of these passes were about 9 feet wide and 8 feet high. The last three passes lowered the floor 5 feet to complete the room excavation to its design height and width of 13 x 33 feet.

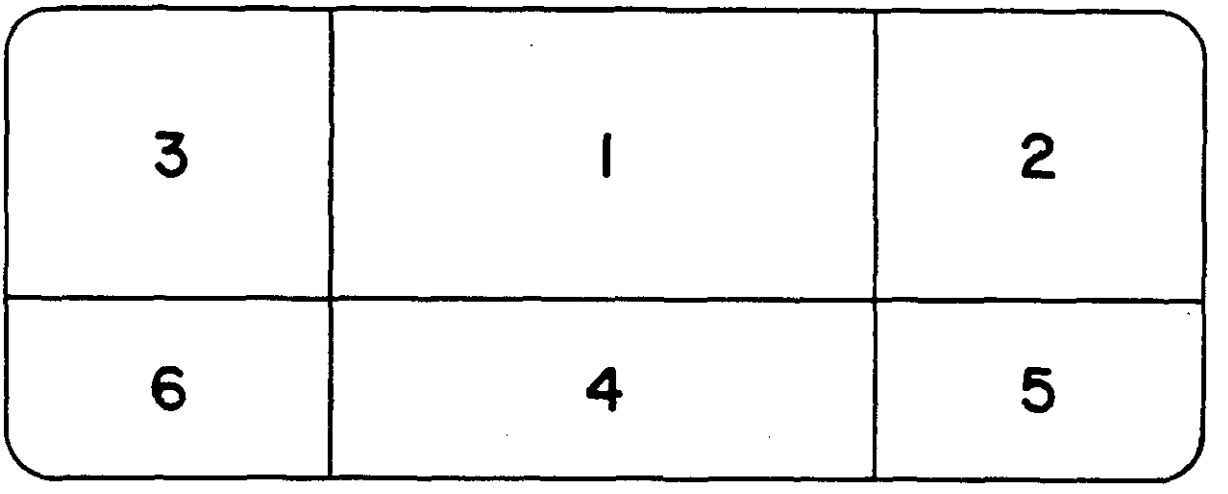


Figure 3-5

TEST ROOM EXCAVATION SEQUENCE

CHAPTER 4
SUPPORTING VALIDATION DOCUMENTS

4.1 INTRODUCTION

This chapter discusses the principle documents containing information used to support design validation. These documents are the Waste Isolation Pilot Plant Preliminary Design Validation Report (ref. 1-3) and geotechnical field data reports (refs. 4-1 thru 4-19). These documents contain all of the data which has been collected, analyzed and evaluated for design validation since site construction activities began in July 1981. Other documents pertaining to design and site characterization are referenced throughout this report. However, they are considered peripheral documents not directly related to the design validation process and, therefore, are not described in this report. Because these other reports are public documents, they are available to anyone interested in obtaining additional background information or detailed data on the WIPP project.

4.2 PRELIMINARY DESIGN VALIDATION REPORT

The following subsections present a summary of the WIPP Preliminary Design Validation Report produced for the SPDV Program described in Chapter 1.

4.2.1 Purpose and Objectives

The purpose of the WIPP Preliminary Design Validation Report was to provide documentation on the behavior of the initial underground openings. Four types of information were gathered for this purpose:

(1) observations of the behavior of the underground openings;

(2) descriptions of the geologic conditions encountered during SPDV underground construction;

(3) descriptions of core samples from instrumentation and exploratory holes in the roof and floor of the underground openings; and

(4) data from installed geomechanical instrumentation.

The objective of the report was to provide initial evaluations of the suitability of the design criteria and design bases and initial confirmation of the underground opening reference design in order to permit full facility construction. This initial confirmation was based on data obtained from geologic field activities and geomechanical instrumentation which were subjected to preliminary analysis and evaluation.

4.2.2 Data Acquisition Program

The preliminary design validation data acquisition program consisted of geologic field activities which provided information for initial validation of the WIPP underground opening reference design. Data was obtained from three principal activities:

(1) geologic mapping;

(2) vertical core hole logging; and

(3) geomechanical instrument measurements.

All of the data collected was verified at the site field office, then sent to the DOE/Technical Support Contractor (TSC) offices in Albuquerque, New Mexico, for preparation and inclusion into the GFDRs and other reports. Due to the qualitative nature of the geologic mapping and core hole data, efforts for preparation of this material generally required only limited evaluation, editing and drafting. The geomechanical instrumentation data, however, required more extensive preparation and analysis due to its applications to various aspects of underground opening behavior and the calculation of in situ salt properties.

4.2.3 Geomechanical Instrumentation

The SPDV geomechanical instrumentation program for the WIPP was designed to provide empirical data on the behavior of the salt around the underground openings and on the pressure developed behind the exploratory shaft liner and key by ground water and salt creep. The objective of the geomechanical instrumentation program for SPDV was to provide:

(1) short-term in situ measurements for assessment of the preliminary design performance of the underground openings;

(2) early detection of conditions that could affect the safety of personnel during construction; and

(3) data on adverse ground conditions that may be developing, in order to identify potential problems and plan and implement remedial measures.

Instruments were initially installed in the SPDV exploratory shaft, exploratory shaft station, ventilation shaft station, the E0, E140 and N1100 drifts, and the S90 crosscut to provide data input for the WIPP Preliminary Design Validation Report. The exploratory drift extending south of the ventilation shaft was added to the SPDV Program to provide additional information on the geology in the area proposed for excavation of the waste storage rooms. Geomechanical instruments were installed at several locations in this drift.

For the WIPP Preliminary Design Validation Report, borehole extensometer and convergence point data from the SPDV exploratory shaft, as well as data from the ventilation shaft station and drifts, were insufficient to estimate long-term closure rates. Most drift extensometers and convergence points had been installed only a relatively short time before the report was prepared. A period of 1 year or more was thought to be required before a relatively steady closure rate could be established. The data were useful in

demonstrating short-term stability of the excavations and for developing cumulative closure amounts. Instruments with the most extensive data typically showed a maximum of only 3 or 4 months of regular monitoring since installation.

4.2.4 Preliminary Conclusions

Preliminary conclusions presented in the WIPP Preliminary Design Validation Report were:

(1) The walls of the finished shafts are stable, both in the overburden and salt formations. The mapped shaft stratigraphy is generally comparable to the stratigraphy used in the design. Ground-water control is satisfactory. The shaft liner and shaft key are performing as expected. No major revision of design elements or parameters is foreseen for future WIPP shafts as a result of the findings of preliminary design validation.

(2) The underground horizontal openings are also stable. After excavation, repeated inspections of the exploratory and ventilation shaft stations, entry drifts, crosscuts and the south exploratory drift revealed essentially no deterioration in rock stability. The underground drifts and shaft stations are stable and provide safe working conditions.

(3) Encounters of gas were expected and are typical of nearby potash mines. The small amount of gas encountered is well below the limit permitted in the underground facility by MSHA regulations. No brine pockets have been encountered or detected during excavation of the shafts and underground openings.

4.3 GEOTECHNICAL FIELD DATA REPORTS

4.3.1 Background

The compilation of GFDRs was initiated by the DOE to provide geotechnical and related information from the WIPP underground activities to interested persons or groups in a timely manner. These reports provided data from the two major phases of WIPP development: SPDV and full construction. As discussed previously, SPDV was established as an early construction phase to permit validation of the WIPP site and preliminary validation of the reference design of the underground openings. The full construction phase following SPDV was utilized to continue visual inspections of the underground openings, monitoring and interpretation of data from geomechanical instruments, and evaluations and computational analyses of the behavior of the underground openings for design validation.

The GFDRs were eventually produced on a quarterly basis. These quarterly reports contain an evaluation of selected aspects of the WIPP underground environment based on preliminary interpretation and analyses of data collected from the above activities. The analyses and evaluations contained in the GFDRs provide the supporting documentation required for design validation.

4.3.2 Objectives

As stated in the GFDRs, the geomechanical instrumentation program for SPDV and design validation was designed and implemented to provide in situ data on the behavior of the rock (primarily salt) around the shafts and horizontal underground openings. More specifically, the instrumentation program was designed to provide:

(1) early detection of conditions that could affect operational safety;

(2) monitoring of closure rates to allow evaluation of waste storage and retrievability;

(3) a greater understanding of the in situ behavior of bedded salt by comparison of observed response with current facility reference design calculations; and

(4) measurements of salt deformation and stresses to confirm or indicate the necessity for revisions to the opening configuration and the parameters used in underground facility design based on clearance requirements.

4.3.3 Geomechanical Instrumentation

An extensive geomechanical instrumentation program was implemented to provide in situ data on the shafts and horizontal underground openings as part of the investigations performed at the WIPP site. These instruments have been providing data on deformation, pressure, loads and stress on a regular basis for analysis and evaluation. Instruments for measuring the geomechanical response of the shafts and horizontal underground openings include convergence points, convergence meters, multiple-point and single-point borehole extensometers, load cells, pressure cells, stressmeters, strain gauges, inclinometers, piezometers and lateral movement gauges.

Data from these geomechanical instruments are read remotely by an automatic datalogger system and/or collected manually. All data obtained are entered on magnetic tape for data reduction, tabulation, analysis and archiving. Data collected from the geomechanical instruments have been documented in the GFDRs. These data are the basis for analysis and evaluation by the project participants and other interested groups. The geomechanical instruments provide data for the analysis and evaluation of several phenomena at various locations, including strain in the C & SH shaft key, water pressure behind the C & SH and waste shaft liners, radial closure of shafts, pressures between shaft keys and wall rock, roof-to-floor and wall-to-wall closure in the shaft stations, drifts and rooms, and displacements at depth into the walls, roof and floor of shaft stations, drifts and rooms.

The frequency of data collection is determined on a per instrument basis and is dependent upon instrument location, method of instrument reading (manual or datalogger), and the number of days elapsed since excavation at the instrument location. After installation, the instrument is read frequently, but with time this reading frequency is decreased since the rate at which the salt mass responds following excavation also decreases with time.

The geomechanical instrumentation data are presented graphically in the GFDRs and represent readings collected from the WIPP site since April 1982. The data plots in the reports are grouped by areas within the underground facility and also by instrument type. The data plots are updated as new data become available. Summary tables of the instruments, with the latest readings and the operating histories, are also presented in the reports.

4.3.4 Geologic Data

Geologic data presented in the GFDRs have included the results of geologic mapping activities, core hole logging, and observations of the condition and behavior of underground opening surfaces. Geologic maps of the shafts and representative horizontal opening surfaces have been presented periodically in the GFDRs or in topical reports issued separately. Geologic logs containing descriptions of core samples obtained from core holes in the underground openings were presented in the GFDRs as they became available.

Frequent observations by project geotechnical personnel have provided qualitative determinations of the condition of the underground openings. These assessments were presented in the GFDRs to document changes in the condition of the underground openings and in salt behavior on a regular basis. Observations such as the condition of the roof and rock bolts in shaft stations, fractures in pillar corners at drift intersections and in the salt surrounding the drifts and rooms, behavior of the roof and walls of the drifts and rooms, and horizontal displacements, vertical separations and fracturing detected in open

boreholes were documented. This information has provided important input for design evaluation and safety assessments.

4.3.5 Geomechanical/Structural Analyses

The quarterly GFDRs contain sections on both geotechnical and computational analyses. These sections present analyses of various elements of the underground excavations. The analyses are updated periodically to include the most current data available at the time the reports are published. They have provided a significant amount of information related to the geomechanical and structural behavior of the underground openings.

CHAPTER 5
METHODOLOGY

5.1 INTRODUCTION

Design validation of the WIPP underground openings is accomplished by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. Design validation also allows for the development of recommendations to improve or optimize the reference design. The methods used to validate the reference design may also be used to validate any recommended design modifications. Mathematical models containing the modifications can be generated and analyses performed to predict the future behavior of the modified reference design.

The design validation process consists of three major steps:

(1) data collection;

(2) analysis and evaluation; and

(3) prediction of future behavior.

Sections 5.2 through 5.4 present the methods used for data collection, analysis and evaluation, and prediction of future behavior.

5.2 DATA COLLECTION

One of the principal areas of effort in support of design validation was the compilation of geotechnical data. This data formed the basis for later analysis and evaluation and for predictive modeling. Data collected from geologic mapping, core drilling and logging, laboratory testing, geomechanical instrumentation and field observations have provided information for validation of the underground opening reference design. These data can be categorized based on their relationship to observations of geologic conditions or to structural behavior. Geologic observations include an assessment of the rock

characteristics; stability of the openings in rock; reaction of the rock to excavation; and movements along clay seams. Structural behavior is the development or modification of stresses and strains in the salt created by excavation of the underground openings, and the pressures occurring at rock/structure interfaces.

5.2.1 Geologic Mapping

Geologic mapping of the shafts, drifts and test rooms was conducted by site geologists. The objectives of the mapping were:

(1) provide confirmation and documentation of the continuity of the stratigraphy, lithology and structure above and below the facility horizon;

(2) evaluate any geologic conditions which may affect the excavation, stability, or safety of the horizontal openings;

(3) support field adjustments and modifications to the reference design based on the geologic conditions encountered; and

(4) finalize geomechanical instrument locations.

5.2.2 Core Drilling and Logging

Information on stratigraphy and lithology was obtained from core holes drilled into the floor and roof of the underground openings. The objectives of the core drilling program were:

(1) confirm the thickness, lateral extent, mineralogy and stratigraphic continuity of the host rock beyond the limits of the excavations;

(2) confirm the continuity of the geologic structure and the absence of any unusual features within the immediate zone of influence of the excavations; and

(3) obtain stratigraphic information in order to determine extensometer anchor depths.

Details of the core drilling program are discussed in Chapter 6.

5.2.3 Laboratory Testing

Initial laboratory tests were performed on core samples of evaporite minerals and clay from exploratory boreholes AEC-7 and ERDA-9. These tests were performed by RE/SPEC, Inc., of Rapid City, South Dakota, and by SNL (refs. 5-1 and 5-2). The evaporite samples were tested in triaxial vessels at both room and elevated temperatures. Quasi-static compression tests were performed under different constant confining pressures and variable axial loads in steps, each load step being maintained for about 10 minutes. Quasi-static compression tests were considered as constant stress-rate tests for all practical purposes. Direct shear tests were performed on samples of clay to determine the coefficient of sliding friction.

5.2.4 Geomechanical Instrumentation

Geomechanical instruments in the WIPP underground facility provide data on deformation, pressure, loads and stress. Instruments for measuring the geomechanical response of the shafts and other underground openings include convergence points, convergence meters, multiple-point and single-point borehole extensometers, load cells, pressure cells, stressmeters, strain gauges, inclinometers, piezometers and lateral movement gauges. Data from the geomechanical instruments are collected manually as well as read remotely by an automatic datalogger system at the surface. All data are entered on magnetic tape for data reduction, tabulation, analysis and archiving. These data are a basis for the analysis and evaluation of underground opening behavior.

The geomechanical instrumentation program for design validation was designed and implemented to provide in situ data on the behavior of the

rock (primarily salt) around the shafts and underground openings. More specifically, the instrumentation program was designed to provide:

(1) early detection of conditions that could affect construction and operational safety;

(2) closure monitoring for evaluation of the ability of the underground openings to permit waste storage and retrieval;

(3) a greater understanding of the in situ behavior of bedded salt by a comparison of the observed responses with underground opening reference design calculations; and

(4) measurements of salt deformation to permit confirmation or revision of the opening configurations and the parameters used in the underground opening reference design based on clearance requirements.

Tables 5-1 through 5-5 present information on the distribution of geomechanical instruments installed at the WIPP. The instruments provide data for the evaluation and analyses of several phenomena at various locations, including strain in the C & SH shaft key, water pressure behind the C & SH and waste shaft liners, radial closure of the shafts, pressures between the concrete shaft keys and wall rock, roof-to-floor and wall-to-wall closure in the shaft stations, drifts and rooms, and displacements at depth into the walls, roof and floor of shaft stations, drifts and rooms.

Data from the geomechanical instruments are collected manually or read remotely by an automatic datalogger system. The datalogger is a computer system that automatically collects and records output from instruments at specified polling times. The signals from the instruments are first sent to local termination cabinets (LTC) where the signal is digitized and then transmitted to the datalogger for disk storage. Manual readings are manually entered into the computer system. Changes from initial readings and rates of change are

Table 5-1

C & SH SHAFT
INSTRUMENTS

Location and Type	Purpose
Lined Section	
Convergence points	Measure wall-to-wall closure of shaft
Piezometer	Measures fluid pressure buildup behind liner due to water accumulation
Key	
Piezometer	Measures fluid pressure buildup behind key due to water accumulation
Pressure cell	Measures contact pressure buildup between concrete key and wall rock
Welded strain gauge	Measures strain in reinforcing steel of shaft key
Embedment strain gauge	Measures strain in concrete of shaft key
Unlined Section	
Multiple-point extensometer	Measures salt creep deformation
Convergence points	Measure wall-to-wall closure of shaft
Station	
Convergence points (includes permanent and temporary convergence points and wall shortening points)	Measure roof-to-floor and wall-to-wall closure of openings and pillar shortening
Extensometer (single-point and multiple-point)	Measures salt creep deformation in roof, floor and walls
Rock bolt load cell	Measures tensile loads on rock bolts
Lateral movement gauge	Measures lateral movement in roof

Table 5-2

WASTE SHAFT
INSTRUMENTS

Location and Type	Purpose
Lined Section	
Piezometer	Measures fluid pressure buildup behind liner due to water accumulation
Key	
Piezometer	Measures fluid pressure buildup behind key due to water accumulation
Pressure cell	Measures contact pressure buildup between concrete key and wall rock
Unlined Section	
Convergence points	Measure wall-to-wall closure of shaft
Multiple-point extensometer	Measures salt creep deformation
Station	
Convergence points (includes permanent and temporary points)	Measure roof-to-floor and wall-to-wall closure of openings
Multiple-point extensometer	Measures salt creep deformation in roof, floor and walls

Table 5-3

EXHAUST SHAFT
INSTRUMENTS

Location and Type	Purpose
Lined Section	
Piezometer	Measures fluid pressure buildup behind liner due to water accumulation
Key	
Piezometer	Measures fluid pressure buildup behind key due to water accumulation
Pressure cell	Measures contact pressure buildup between concrete key and wall rock
Unlined Section	
Multiple-point extensometer	Measures salt creep deformation

Table 5-4

DRIFTS
INSTRUMENTS

Location and Type	Purpose
Convergence points (includes permanent and temporary convergence points and wall shortening points)	Measure roof-to-floor and wall-to-wall closure of openings and pillar shortening
Extensometer (single- and multiple-point)	Measures salt creep deformation in roof, floor and walls of openings

Table 5-5

TEST ROOMS
INSTRUMENTS

Location and Type	Purpose
Convergence points	Measure roof-to-floor and wall-to-wall closure
Multiple-point extensometer	Measures salt creep deformation in roof, floor and walls
Inclinometer	Measures direction and amount of salt movement above the roof, below the floor, and in the walls
Rigid-inclusion stressmeter	Monitors changes in stress within anhydrite
Convergence meter	Measures vertical closure

calculated and stored in the computer. The data is transferred monthly to magnetic tapes which are made available to project participants.

Instruments connected to the datalogger include extensometers, piezometers, strain gauges, pressure cells, convergence meters and stressmeters. All convergence points, inclinometers, rock bolt load cells, lateral movement gauges and some extensometers must be read manually. Strain gauges, piezometers and pressure cells have been read manually at times.

The frequency of data collection is determined on a per instrument basis and is dependent upon instrument location, method of instrument reading (manual or datalogger). and the number of days elapsed since excavation at the instrument location. After installation the instrument is read frequently, but with time this reading frequency is decreased since the rate at which the salt mass responds following excavation also decreases with time.

The frequency of readings has been influenced by access limitations caused by construction operations and by the volume of data to be collected. At a few convergence point stations in newly excavated areas, readings were taken frequently to record the early rock response. Monitoring periods in these instances were typically every 4 to 12 hours for 24 hours, then once daily. Most manually read instruments were initially read weekly, then once every 2 weeks, and then once every month. Instruments connected to the datalogger were initially read at 24-hour intervals, then several times per week, and then once every 2 weeks. The current schedule for obtaining readings is shown in Table 5-6. Each instrument's range, sensitivity, resolution and precision are also presented in this table. These parameters are important when interpreting and evaluating the data, especially those readings which reflect changes that are close to the resolution, sensitivity, or precision limits of the instrument.

Table 5-6

GEOMECHANICAL INSTRUMENTATION SPECIFICATION SUMMARY

Location	Instrument Type	Phenomenon Monitored	Parameters to be Evaluated	Scheduled Frequency of Readings as of this Report	Instrument Specifications: Range (R), Sensitivity (S) Resolution (E), Precision (P)
C&SH shaft	Borehole extensometers	Deformation	$\Sigma\delta^*$, $\frac{\Delta L^{**}}{\Delta t}$	Weekly (D)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.
C&SH shaft key	Strain gauges	Strain	Σ Strain*	As accessible (M)	(R): 0-3000 μin./in.-embedded (R): 0-2500 μin./in.-spot welded (S): 1 μin./in.
C&SH shaft key	Pressure cells	Pressure	Σ Pressure*	As accessible (M)	(R): 0-1000 psi (S): 1 psi
C&SH shaft liner & key	Piezometers	Water pressure	Σ Pressure*	Monthly (M)	(R): 0-500 psig (E): ±0.5 psi
C&SH shaft	Convergence points	Deformation	$\Sigma\delta^*$, $\frac{\Delta L^{**}}{\Delta t}$	As accessible (M)	(R): 2-50 ft (P): ±0.005 in.
Waste shaft	Borehole extensometers	Deformation	$\Sigma\delta^*$, $\frac{\Delta L^{**}}{\Delta t}$	As accessible (D)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.
Waste shaft Key	Pressure cells	Pressure	Σ Pressure*	Weekly (D)	(R): 0-1000 psi (S): 1 psi
Waste shaft liner & key	Piezometers	Water Pressure	Σ Pressure*	Weekly (D)	(R): 0-500 psig (E): ±0.5 psi
Waste shaft	Convergence points	Deformation	$\Sigma\delta^*$, $\frac{\Delta L^{**}}{\Delta t}$	As accessible (M)	(R): 2-50 ft (P): ±0.005 in.
Exhaust shaft	Borehole extensometers	Deformation	$\Sigma\delta^*$, $\frac{\Delta L^{**}}{\Delta t}$	Weekly (D)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.
Exhaust shaft liner & key	Piezometers	Water pressure	Σ Pressure*	Monthly (M)	(R): 0-500 psig (E): ±0.5 psi
Exhaust shaft key	Pressure cells	Pressure	Σ Pressure*	As accessible (M)	(R): 0-1000 psi (S): 1 psi
Drifts	Rockbolt load cells	Load	Σ Load*, $\frac{\Delta p^{**}}{\Delta t}$	Monthly (M)	(R): 0-300 kips (S): 16 lb
Drifts	Borehole extensometers	Deformation	$\Sigma\delta^*$, $\frac{\Delta L^{**}}{\Delta t}$	Weekly (D)/ Monthly (M)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.
Drifts	Convergence points	Deformation	$\Sigma\delta^*$, $\frac{\Delta L^{**}}{\Delta t}$	Monthly to every 2 months (M)(1)	(R): 2-50 ft (P): ±0.005 in.
Drifts	Lateral movement gauges	Deformation	$\Sigma\delta$	No longer read	(R): 0-5 in. (E): 1/64 in. (P): ±1/64 in.
Test rooms	Vertical inclinometers	ϕ_x, ϕ_y	$\Sigma\delta_x^*$, $\Sigma\delta_y^*$, $\Sigma\delta_{xy}^*$, Azimuth*, $\frac{\Delta\Sigma w_x}{\Delta t}$, $\frac{\Delta\Sigma w_y}{\Delta t}$, $\frac{\Delta\Sigma\delta_{xy}}{\Delta t}$	Every 2 months (M)	(R): 0-30° (P): ±0.3 in./100 ft of casing (E): ±0.001 in./2 ft of casing (S): ±0.001 ft/2 ft of casing
Test rooms	Horizontal inclinometers	ϕ_z	$\Sigma\delta w_z^*$, $\frac{\Delta\Sigma w_z}{\Delta t}$	Every 2 months (M)	(R): 0-30° (P): ±0.3 in./100 ft of casing (E): ±0.001 in./2 ft of casing (S): ±0.001 ft/2 ft of casing
Test rooms	Vibrating wire stressmeters	Stress	ΣS^*, $\frac{\Delta S^*}{\Delta t}$	Weekly (D, M)	(R): 12,000-44,000 psi wire stress
Test rooms	Convergence meters	Deformation	$\Sigma\delta^*$, $\frac{\Delta L^{**}}{\Delta t}$	Weekly (D)	(R): Approximately 2.5 ft (S): ±0.001 in.
Test rooms	Convergence points	Deformation	$\Sigma\delta^*$, $\frac{\Delta L^{**}}{\Delta t}$	Monthly (M)	(R): 2-50 ft (P): 0.005 in.
Test rooms	Borehole extensometers	Deformation	$\Sigma\delta^*$, $\frac{\Delta L^{*}}{\Delta t}$	Weekly (D)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.

Notes:

(D) = read through datalogger
(M) = read manually
$\Sigma\delta$ = total change from t = 0
ϕ = angle
ΔL = change from last reading
Δt = elapsed time since last reading

(1) New convergence points are read weekly for the first month after installation.
*Design/validation parameter
**Safety/operational parameter

M

5.2.5 Field Observations

The determination of underground conditions includes a qualitative assessment based on frequent observations by WIPP site geotechnical personnel. Changes in rock conditions and in the behavior of the underground openings have been observed and documented on a regular basis in the GFDRs. In addition, quarterly inspections have been made by Bechtel home office design engineering personnel. These inspections augmented the site geologists' observations and helped highlight those changes which occurred so slowly that they were difficult to detect on a daily basis.

Periodic inspections of the C & SH shaft have been made since the shaft was completed. Conditions of the shaft walls, liner and key have been observed in addition to any water flow into the shaft. Similar inspections of the waste and exhaust shafts have also been made but less frequently due to limited accessibility.

Observations of the horizontal openings include such items as the condition of their roofs and walls; fracturing in pillar corners at drift and room intersections and in roofs and floors; and horizontal displacements and vertical separations measured in open boreholes. This information has provided important input for design and safety evaluations.

5.3 ANALYSIS AND EVALUATION

Data collected at the WIPP site have been analyzed and evaluated by qualified engineers and scientists. Engineering experience and judgement were used in the evaluation of field observed conditions. Laboratory tests were performed on core samples to determine the constitutive equations for the host rocks. Theoretical and applied aspects of measurements, statistics and physics were utilized to analyze and evaluate geomechanical instrument data.

5.3.1 Observations

The observations of geologic conditions documented during visual inspections are used to evaluate the performance of the underground openings. These evaluations are made in conjunction with the analytical techniques. The evaluations are qualitative, however, and are subjective assessments of the behavior of the salt surrounding the excavations.

5.3.2 Laboratory Tests

The results of the laboratory testing described in subsection 5.2.3 on samples of halite, argillaceous halite, anhydrite, polyhalite and clay from the facility level were evaluated and statistically analyzed to determine elastic and creep constants. Constitutive equations for each of these materials were established and their material property constants were determined (ref. 5-3). The material property constants based on the laboratory test results are presented in Chapter 6.

5.3.3 In Situ Measurements

Statistical and numerical methods were used to analyze in situ data and to evaluate the physical behavior of salt. Numerical models were used to compute creep parameters from the in situ data.

In situ measurement data from selected geomechanical instruments in the drifts and test rooms were fitted with analytical equations using regression procedures. Since early data are lacking for most of the instruments, one approach was to calculate the closure rates and fit an equation to the closure rate versus elapsed time relationship. An estimate of the early closure not measured by the instruments was independently derived.

5.4 PREDICTION OF FUTURE BEHAVIOR

Validation of the underground opening reference design requires predicting the future behavior of the openings. This was achieved by collecting in situ data consisting of field observations and

geomechanical instrument measurements. Statistical methods were then used to extrapolate the data obtained from the geomechanical instruments. Selected in situ data were fitted to analytical curves and predictions were made based on the extrapolated results. Closed form solutions and engineering experience were also utilized to substantiate the adequacy of the facility. A model simulation method was used to verify the creep model of salt based on creep constants derived from data obtained from laboratory material tests. After the determination of creep parameters using a statistical technique, the numerical model for simulating the facility was also utilized to predict and evaluate future behavior. This includes the closures, strain distributions and stress distributions over the operating life of the facility.

Design reviews were performed as required during design of the WIPP underground facility. Experience and judgment were an important adjunct in predicting the future behavior of the underground openings. More than 3 years of continuous data collection and analysis and evaluation have provided an adequate data base for predicting future behavior.

Subsections 5.4.1 through 5.4.3 describe the methods used for predicting the future behavior of the underground openings.

5.4.1 Extrapolation of In Situ Data

Selected in situ closure data were analyzed and fitted by analytical curves for extrapolation of future responses. Regression analyses by the Gauss-Newton or Marquardt compromise techniques were performed to determine the regression parameters. These regression parameters were assumed to be valid for the future behavior of the opening, and the equations were used to predict the future closure rate. To estimate the additional closure that could occur, the equation was integrated over the required time interval.

5.4.2 Closed Form Solutions

Closed form solutions provided in the SME Mining Engineering Handbook (ref. 2-25) were used to evaluate the selected room and pillar sizes and their stability. Closed form solutions for steel and concrete structural design were also used to substantiate the adequacy of the shaft liners and keys (refs. 5-4 thru 5-7).

5.4.3 Model Simulations

Numerical analyses were performed to compute the predicted responses of the underground openings. The constitutive laws discussed in Appendix C were used in these analyses. However, yield or failure criteria developed for halite and non-halitic materials based on the results of laboratory tests were not incorporated in the numerical modeling. Due to the idealization of the real system in a mathematical model, the uncertainty of in situ auxiliary conditions corresponding to the mathematical model, and deviations in the material properties obtained from the laboratory tests, analyses using laboratory test data did not provide suitable results for design validation. Therefore, an engineering approach using curve fitting methods was employed. Creep parameters computed by the following procedure were used for the analyses. Additional information pertaining to material property deviations based on laboratory tests is presented in Chapter 6.

Numerical models were generated for the locations of specific instruments to simulate the instrument response and compute the creep parameters.

After generating the numerical models for these locations, their creep parameters were computed and the structural behavior was simulated by performing an analysis using the statistical method presented in Appendix C and the following procedures:

(1) At the initial stage, the surface of the openings were restrained to simulate the unexcavated condition.

(2) An internal stress was applied at each element to represent the initial lithostatic stress state, which is defined as:

$$\delta_{xx} = \delta_{yy} = \delta_{zz} = -\int_0^y pgdy \qquad (5\text{-}1)$$

where: p is the rock mass per unit volume;
g is the gravitational constant; and
y is the depth.

(3) The overburden and support pressures at the boundaries and the weight of the rock were applied to compute the static solution.

(4) The restraints at the surface of the openings were then removed to simulate the excavation.

(5) The structural responses were computed using a time step integration scheme. Normalized time steps were used throughout the analysis. At the first time step, the time increment was calculated by an iterative scheme using a predetermined initial time increment.

(6) In subsequent time steps, the time increment for each time step was calculated based upon the previous time steps and the specified maximum tolerances of stress and strain increments at the previous and current time steps. The structural responses were computed at each normalized time step.

CHAPTER 6
GEOLOGIC CHARACTERIZATION

6.1 INTRODUCTION

Geologic characterization of the underground excavations for design validation of the WIPP began in June 1981. Initial characterization activities consisted of monitoring the drilling and geophysical logging of the SPDV exploratory shaft. As shaft outfitting and underground excavation progressed, the geologic work evolved into mapping of the shafts and underground horizontal openings, performing ground-water inflow tests, monitoring geomechanical instrumentation installations and taking subsequent readings or measurements, logging underground core hole samples, and performing other tasks related to defining the geologic integrity of the WIPP site. Data from these activities were evaluated in conjunction with information from previous site studies to more accurately define site geologic conditions as they related to design validation of the WIPP underground facility.

6.2 DATA COLLECTION ACTIVITIES

6.2.1 Geologic Mapping

An important aspect of validating the WIPP underground opening reference design included geologic mapping of the shafts and drifts. The objectives of this mapping were discussed in Chapter 5.

6.2.1.1 C & SH Shaft

Geologic characterization of the C & SH shaft began in late June 1981 with the drilling of the SPDV exploratory shaft (see Chapter 3, subsection 3.3.1, for an explanation of the two shaft names). The initial activity conducted to develop this characterization consisted of logging the drill cuttings at periodic intervals to permit a determination of rock types and to provide a description of the geologic formations penetrated (Appendix D, Figure D-1). These formations included, in descending order, the Dewey Lake red beds, the Rustler formation and the Salado formation.

After completion of the drilling operation, geophysical logging was performed in the shaft to determine the condition of the shaft wall and to more accurately define the stratigraphy penetrated. These logs were the caliper, gamma ray, density and epithermal neutron. The logs were analyzed to better determine the depths to various stratigraphic horizons and correlate them with those found in holes drilled during previous site investigation phases (Appendix B, Figure B-1).

Reconnaissance and detailed geologic mapping of the C & SH shaft was performed between March 31, 1982, and May 2, 1982, from a depth of about 846 feet (elev. 2564 feet) near the Rustler/Salado formation contact to a depth of 2,193 feet (elev. 1217 feet). Mapping above the 846-foot depth could not be performed due to the presence of the permanent steel liner, while drilling fluid and muck prevented mapping below the 2,193-foot depth. The results of this mapping, combined with criteria established as a result of previous site investigations, were used to select the final depth for the underground development level (Chapter 3, Section 3.2). The mapping results are shown in Appendix D, Figures D-2 through D-4. A detailed discussion of the mapping is contained in reference 3-1.

Vertical control for the shaft mapping was established by tape measure from a known elevation provided by the SPDV underground excavation contractor at the shaft collar. The scope of work and methodology for the shaft geotechnical activities are contained in reference 6-1.

Reconnaissance geologic mapping of the shaft from a depth of about 920 feet (elev. 2490 feet) to 2,083 feet (elev. 1327 feet) was accomplished after construction of the shaft key. The mapped area was limited to a strip 1 to 5 feet wide along the south side of the shaft. One interval from about 1,832 feet (elev. 1578 feet) to 1,892 feet (elev. 1518 feet) was not mapped due to the interference of shaft outfitting activities.

Detailed circumferential geologic mapping was performed in the key area from the base of the steel liner to a depth of about 920 feet.

Detailed mapping was also performed from a depth of about 2,083 feet to about 2,193 feet. Detailed mapping was carried out through this interval to obtain sufficient geologic information for use in making the final facility level selection. The facility level selection mapping was performed by several teams of geologists working over a 3-day period from April 30 to May 2, 1982. The detailed mapping was generally performed independently of shaft outfitting activities to permit better observation and interpretation of the shaft geologic characteristics.

Representative samples of the geologic strata surrounding the shaft were obtained during mapping for later, more detailed classification. Photographs were taken at various locations along the shaft wall for verification of the mapping results and record-keeping purposes. As mapping progressed, observations of the shaft wall were also made to determine the condition of the salt as a result of its behavior following excavation.

Based on the data obtained from the above activities, characterizations were made of the geologic formations penetrated by the C & SH shaft. The characterizations consisted primarily of descriptions of the stratigraphy, lithology and structure of the formations. Other detailed data were included, where relevant, to more accurately characterize the salt strata in areas of primary concern to the design of the WIPP underground facility.

The C & SH shaft geologic activities served to further refine and confirm the data obtained from previous site investigations. The geologic conditions observed in the C & SH shaft within the mapped interval corresponded to the conditions expected from previous investigations. Borehole ERDA-9, in particular, showed conditions similar to the C & SH shaft. Although some variation was observed, it was attributed to core loss in ERDA-9 which prevented the early detection of these conditions.

Only minor modifications to the reference design of the C & SH shaft key structure and the geomechanical instrumentation levels were made to accommodate the observed geology.

6.2.1.2 Waste Shaft

Drilling of the initial 6-foot diameter SPDV ventilation shaft (later to be enlarged to the waste shaft) was conducted from December 1981 to February 1982. Samples of the drill cuttings were obtained at periodic intervals from the drilling fluid to permit monitoring of the stratigraphy being penetrated. After the drilling was completed, a set of geophysical logs was run to determine the shaft wall conditions and to further define the boundaries of the rock strata penetrated.

Geologic mapping of the 6-foot diameter shaft began in July 1982 in conjunction with the initiation of shaft outfitting. Initially, five areas of weaker rock which had been washed out by the drilling operation were mapped between July and September 1982 before steel liner plate was placed over these areas for safety purposes. Geologic mapping of the SPDV ventilation shaft from the bottom of the steel surface casing at 97 feet (elev. 3312 feet) to the bottom of MB-139 was conducted during September and October 1982.

Both reconnaissance and detailed geologic mapping were performed in the 6-foot diameter shaft. The mapping extended from a depth of 97 feet below the ground surface to a depth of about 2,170 feet (elev. 1239 feet). The results of this mapping are shown in Appendix E, Figures E-1 through E-6. In addition, a lithologic log, based on the geologic mapping, and a geophysical density log are shown in Appendix B, Figure B-1, for correlation with the C & SH shaft and boreholes WIPP-12, ERDA-9 and DOE-1. A detailed description of the SPDV ventilation shaft geotechnical activities is contained in reference 4-3.

Mapping of the SPDV ventilation shaft was generally performed by a team of two geologists. Depth control was maintained by hanging a tape down the shaft wall at 100- to 200-foot intervals from the top of the

surface casing. Orientation in the shaft was maintained by following a steel guide installed on the southwest wall to control movement of the work platform used in the shaft. Most of the shaft was mapped in a strip about 2 to 3 feet wide along the steel guide. Although only a portion of the shaft wall was mapped, visual examination was made of the entire wall to determine if any geologic abnormalities existed. Below a depth of about 1,180 feet (elev. 2229 feet), mapping was performed on a limited basis due to salt incrustation on the shaft wall. This crust was apparently the result of dust from the facility level that was exhausting through the shaft and depositing on the wet shaft wall. Representative samples of the rock strata were collected to permit a more detailed description. Photographs were taken at various locations along the shaft wall for verification of the mapping results and record-keeping purposes. In addition to providing a description of the rock strata, observations of the shaft wall were made to determine, where possible, the reaction of the rock to excavation.

Detailed mapping around the full circumference of the 6-foot diameter shaft was performed at the following five intervals:

(1) Magenta dolomite member,
(2) Culebra dolomite member,
(3) Rustler formation fracture zone;
(4) Rustler/Salado formation contact; and
(5) MB-139.

Because of salt incrustation on the shaft wall immediately above the facility level, detailed circumferential mapping could not be performed in this area. However, two opposing strips about 1 foot wide were cut through the crust to permit mapping of the shaft wall for a distance of about 50 feet above the facility level. Depths in the facility level area were verified by a separate survey utilizing elevation points established in the C & SH shaft station.

The enlargement of the SPDV ventilation shaft into the waste shaft began in October 1983 and was completed in August 1984. Additional geologic mapping and visual inspections were conducted concurrently with this excavation. Mapping was conducted from December 9, 1983, to August 10, 1984. Visual inspections of the shaft surface were performed throughout the shaft enlargement operations. The lithology of the exposed shaft stratigraphy was described and compared with the description of the same stratigraphic interval mapped in the SPDV ventilation shaft. Any differences or additional detail were noted and the SPDV ventilation shaft geologic map was modified accordingly.

In the lined section of the waste shaft, the depth to the base of each successive concrete segment was provided by the shaft excavation contractor. Vertical control for mapping was then established from the base of the previous segment. During enlargement of the unlined section of the shaft, vertical control was established from occasional survey control points installed by the contractor and from the previously mapped SPDV ventilation shaft geology. In the shaft sump, vertical control was based on a contractor survey point installed at a depth of 2,167 feet (elev. 1242 feet).

Detailed, full circumference geologic mapping was performed in areas of specific geologic interest. These areas were selected because of their poor exposure in the SPDV ventilation shaft, the possible occurrence of dissolutioning, or their hydrologic significance. These areas of detailed mapping were:

(1) the Forty-niner member claystone;
(2) the Magenta dolomite member;
(3) the Tamarisk member claystone;
(4) the Culebra dolomite member;
(5) the upper portion of the unnamed lower member of the Rustler formation; and
(6) the Rustler/Salado formation contact and key area.

The detailed mapping in the waste shaft was generally conducted as outlined in reference 6-1. Mapping was conducted by teams of four to six people. Once vertical control was established by the contractor from the base of the previous concrete segment, a 5 x 5-foot grid was painted on the shaft surface around its circumference to permit the accurate location of any lithologic contacts and geologic features.

Reconnaissance geologic mapping was performed in the waste shaft sump. A vertical strip, approximately 5 feet wide, was cleaned and mapped along the entire length of the sump.

A detailed description of the geotechnical activities conducted in the waste shaft is contained in reference 6-2. The results of the mapping are shown in Appendix E, Figure E-1.

The geologic mapping and visual inspections of the SPDV ventilation/waste shaft has provided additional documentation of the strata above and below the WIPP underground development level. Based on the data obtained from the shaft mapping activities, a general characterization of the stratigraphy, lithology and structure of the geologic formations penetrated by the waste shaft was made.

The waste shaft penetrates five formations. In descending order, they are the Gatuna formation of Quaternary age, the Santa Rosa sandstone of Triassic age, and the Dewey Lake redbeds, Rustler formation and Salado formation, all of Permian age. In addition, the waste shaft also penetrates thin surficial Quaternary dune sands and the Mescalero caliche. In the WIPP site area, the Santa Rosa sandstone and the Gatuna formation are represented by thin layers of sandstone (ref. 6-3). They were not mapped in the waste shaft due to installation of the shaft collar facilities.

The results of the geologic mapping of the waste shaft correlate well with the SPDV ventilation shaft mapping results. The stratigraphic units penetrated by the waste shaft are the same as those encountered by the C & SH shaft.

Post-depositional dissolution features were not observed in any stratigraphic horizons in the waste shaft. Several zones previously identified as containing dissolution residues in borehole ERDA-9 are now considered to contain pronounced primary sedimentary features.

6.2.1.3 Exhaust Shaft

The exhaust shaft was enlarged from a 6-foot diameter raise-bored shaft to its finished 14- to 15-foot diameter using conventional drill and blast methods from July 1984 to January 1985. Geologic mapping of the shaft wall was conducted concurrently with excavation and construction activities.

Reconnaissance geologic mapping was performed along the entire length of the shaft with the exception of selected areas where detailed mapping was performed. A vertical strip, approximately 5 feet wide, was cleaned and mapped. The procedures used for the reconnaissance mapping are contained in reference 6-1.

Detailed circumferential mapping of specific areas of geologic interest was also performed. These areas included those previously described in the C & SH and waste shafts and four additional areas within the Dewey Lake redbeds, three of which contain gypsum filled fractures. The areas of detailed mapping in the exhaust shaft were:

(1) gypsum-filled fractures at a depth of 195.0 to 210.0 feet;
(2) gypsum-filled fractures at a depth of 269.0 to 280.5 feet;
(3) gypsum-filled fractures at a depth of 353.5 to 375.0 feet;
(4) the Dewey Lake/Rustler formation contact (546.4 feet);
(5) the Forty-niner member claystone (575.5 to 586.5 feet);
(6) the Magenta dolomite member (602.5 to 627.0 feet);
(7) the Tamarisk member claystone (689.0 to 695.5 feet);
(8) the Culebra dolomite member (713.5 to 736.0 feet);
(9) the upper portion of the unnamed lower member (736.0 to 800.0 feet); and
(10) the Rustler/Salado formation contact and key (845.0 to 912.0 feet).

The detailed geologic mapping was performed in a manner similar to that in the waste shaft, using a 5 x 5-foot grid. Vertical survey control was provided by the shaft excavation contractor. As the shaft liner was constructed, the depth to the base of each successive concrete segment was provided by the contractor. Vertical control for mapping was then established from the base of the previous segment. During excavation of the unlined section of the shaft, vertical control was established with survey chains suspended from contractor-installed survey control points.

The results of the exhaust shaft mapping are shown in Appendix F, Figure F-1. A detailed description of the geotechnical activities in the exhaust shaft are included in the report titled Geotechnical Activities in the Exhaust Shaft (ref. 6-4).

In general, the exhaust shaft mapping results correlate well with the results from the waste shaft. Slight lateral variations in the geology produce minor exceptions. The exhaust shaft geologic mapping activities have produced additional confirmation of data obtained from previous site investigations. This mapping confirms the suitability of the shaft reference design, with some minor modifications, based on the original design parameters.

6.2.1.4 Drifts and Test Rooms

Geologic mapping of the drifts and test rooms was performed to characterize the facility level geology, demonstrate its continuity, and provide permanent documentation of the geology exposed in the underground excavations. Those drifts and rooms that were not mapped were visually inspected by site geologists to verify that the stratigraphy is laterally continuous and similar to that exposed in the mapped areas of the facility. No unusual geologic features were observed.

Geologic mapping was conducted in accordance with the procedures established in reference 6-1. A horizontal level-line referenced to

the C & SH shaft station floor elevation was established in the drifts and rooms using an engineer's tripod level. All stratigraphic contacts and geologic features were referenced to this level-line datum. Horizontal distances were measured with an engineer's tape using the C & SH shaft centerline as the zero reference point. Detailed mapping was performed at 10-foot intervals along one wall of the drifts. Between these intervals, the continuity of the stratigraphic contacts and the nature of the individual units were observed and noted on the map. The mapped drifts were the E140 drift, the E0 drift, the N1100 drift and the N1420 drift. Selected figures showing the megascopic results of this mapping are contained in Appendix B.

Geologic Mapping in the test rooms consisted of describing a 6- to 10-foot wide strip surrounding the instrument array in the center of each room. Both walls and the roof in each room were mapped. The remainder of the room was carefully inspected to confirm lateral continuity of the stratigraphic units. The strip maps from the test rooms are presented in Appendix G, Figures G-1 through G-4.

6.2.2 Core Drilling

6.2.2.1 Purpose

Vertical core holes were drilled into the floor and roof of the underground openings to provide geologic information for design validation. The objectives of the vertical core holes are described in Supporting Document 3 of reference 2-5. The purpose of the program was discussed in Chapter 5 of this report.

6.2.2.2 Summary of Drilling

A total of 124 vertical core holes have been drilled and logged in the underground drifts and in the SPDV test rooms, excluding those drilled as part of SNL's in situ tests. This number includes 16 holes drilled to replace holes that had poor core recovery and four holes drilled to obtain information on non-cored sections in the original holes. The

holes were generally drilled in pairs, one hole drilled vertically into the roof and one hole drilled vertically into the floor. Core was obtained in each hole to a nominal depth of 50 feet. Table 6-1 presents a summary of the core hole data. A map showing the core hole locations is presented on Figure 6-1. Geologic cross sections at selected core hole locations in the drifts are contained in Appendix H. Geologic drill logs of all of the core holes are contained in Appendix I.

Drilling was performed by the underground excavation contractor. The drill rig was set up by the driller and the attitude of the core hole was checked by site geotechnical personnel. Logging and handling of the core were performed by geotechnical personnel in conformance with the procedures outlined in Supporting Document 3 of reference 2-5.

All core holes were drilled using rotary equipment and compressed air or saturated brine as the circulating medium. The holes were drilled with a diamond impregnated bit which produced 2-inch or 2 3/8-inch diameter core. A 5-foot long double-tube or split double-tube core barrel was used to retain the core.

The core was logged underground as it was removed from the core barrel or after the drilling of the hole was completed. Logging was generally performed by the same geologist to maintain consistency in the descriptions of the geologic materials. The following data are recorded on each log:

(1) location of core hole and direction of drilling (up or down);
(2) beginning and completion dates of drilling;
(3) length and number of core run;
(4) amount and percentage of core recovery;
(5) stratigraphic and lithologic descriptions (color descriptions are based on the Geological Society of America (GSA) Rock-Color Chart);
(6) graphic lithologic profile; and

Table 6-1

SUMMARY OF CORE HOLE DATA

Core Hole No.	Direction	Collar Elevation (ft-MSL)	Approximate Station (ft)		Facility Coordinates (ft)		Depth/ Penetration (ft)	Instrument Designation
MB-139-1	Down	1264.1	N79	W6	N9766	E6888	10.0	None
MB-139-2	Down	1251.2	S410	E150	N9277	E7044	15.7	None
MB-139-3	Down	1260.5	S101	E157	N9586	E7051	16.0	None
MB-139-4	Down	1258.7	S99	W17	N9588	E6877	16.2	None
DH-01	Up	1318.2	N1424	E439.5	N11110.9	E7335.5	50.8	None
DH-02(1)	Down		N1424	E440	N11110.9	E7336.06	50.2	None
DH-02A(1)	Down		N1424	E435	N11110.9	E7331.29	49.2	None
DH-02B	Down	1306.3	N1424	E442	N11110.9	E7331.29	53.0	None
DH-03	Up	1318.1	N1112	E444	N10799.2	E7335.4	48.8	None
DH-03A	Up	1317.4	N1112	E450.5	N10779.2	E7341.92	49.9	None
DH-04	Down	1309.6	N1112.5	E444	N10799.2	E7335.4	45.8	None
DH-04A(1)	Down	1309.6	N1113	E446			11.2	None
DH-04B	Down	1309.7	N1112	E450.5	N10799.70	E7341.85	51.4	None
DH-05	Up	1329.9	N1463	E972	N11149.6	E7865.0	51.0	None
DH-06	Down	1317.9	N1463	E972	N11149.7	E7864.9	49.75	None
DH-07	Up	1326.7	N1112	E976.5	N10799.3	E7870.8	49.8	None
DH-08	Down	1318.8	N1112	E976.5	N10799.4	E7870.9	38.3	None
DH-08A(1)	Down	1318.7	N1112	E975			50.7	None
DH-08B	Down	1318.0	N1112	E979.5	N10799.47	E7866.66	51.4	None
DH-09	Up	1324.5	N1432	E1332.5	N11108.71	E8227.11	51.1	None
DH-10	Down	1312.1	N1432	E1332.5	N11106.70	E8227.09	52.0	None
DH-11	Up	1320.5	N1112	E1332.5	N10799.8	E8227.3	50.9	None
DH-12	Down	1311.1	N1112	E1332.5	N10799.4	E8227.2	51.3	None
DH-13	Up	1311.4	N1424	E1690	N11112	E8585	13.8	None
DH-13A	Up	1311.5	N1424.5	E1691	N11112	E8586	49.0	None
DH-13B	Up	1311.4	N1425	E1695	N11112.6	E8590.1	21.0	None
DH-14	Down	1299.5	N1425	E1695	N11112.6	E8590.1	49.1	None
DH-15	Up	1308.9	N1104	E1688.5	N10793.26	E8589.96	51.0	None
DH-16	Down	1300.3	N1104	E1688	N10792.89	E8589.39	51.0	None
DH-17	Up	1316.5	N1427	E178	N11114.2	E7071.8	52.0	None
DH-18	Down	1305.1	N1429	E181	N11114.2	E7071.8	50.8	None
DH-19	Up	1314.7	N1107	E206.5	N10794.2	E7101.7	51.6	None
DH-20	Down	1306.2	N1109	E206	N10794.2	E7101.7	51.1	None
DH-21	Up	1331.0	N1421	E786	N11109.1	E7680.9	50.4	None
DH-22	Down	1318.8	N1421.5	E785.5	N11109.2	E7680.9	51.0	None
DH-23	Up	1328.0	N1112	E781	N10799.2	E7679.9	51.0	None
DH-24	Down	1319.5	N1112	E781	N10799.2	E7679.8	49.4	None
DH-24A	Down	1319.5	N1112	E780	N10799.08	E7678.59	50.4	None
DH-25	Up	1318.8	N1422	E1510	N11109.7	E8403.8	51.8	None
DH-26	Down	1307.2	N1427	E1510	N11114.3	E8403.8	53.0	None
DH-27	Up	1300.8	N1107	W682	N10793.7	E6218.4	50.5	None
DH-28	Down	1289.9	N1107	W682	N10793.8	E6218.3	50.5	None
DH-29	Up	1298.3	N1099	W982	N10785.4	E5932.4	50.4	None
DH-29A	Up	1298.1	N1099	W987	N10786.1	E5927.3	35.0	None
DH-30	Down	1289.2	N1099	W982	N10785.5	E5932.2	50.1	None
DH-31	Up	1298.5	N1099	W1282	N10784.9	E5632.3	50.5	None
DH-31A	Up	1298.5	N1099	W1280	N10784.8	E5630.5	49.2	None
DH-31B	Up	1298.5±	N1099	W1261	N10786.7	E5652.2	4.9	None
DH-32	Down	1289.6	N1099	W1282	N10784.9	E5632.2	50.0	None
DH-32A	Down	1289.5	N1099	W1261	N10786.7	E5652.2	5.5	None
DH-33	Up	1298.6	N1099	W1582	N10786.0	E5331.1	50.5	None
DH-33A	Up	1297.4	N1099	W1570	N10786.8	E5342.0	4.1	None
DH-34	Down	1289.4	N1099	W1582	N10786.5	E5331.7	51.5	None
DH-34A	Down	1289.2	N1099	W1570	N10786.8	E5341.9	3.6	None
DH-35	Up	1294.4	N1102	W1882	N10789.4	E5032.2	52.0	None
DH-36	Down	1284.6	N1102	W1882	N10789.4	E5032.2	51.5	None
DH-37	Up	1297.4	N1101	W2182	N10788.9	E4732.0	51.5	None
DH-38	Down	1287.0	N1101	W2182	N10788.8	E4731.9	47.5	None
DH-39	Up	1296.0	N1101	W2482	N10789.2	E4430.7	50.7	None
DH-40	Down	1286.1	N1101	W2482	N10789.2	E4431.0	51.0	None
DH-41	Up	1295.8	N1101	W2782	N10789.0	E4132.6	49.9	None
DH-42	Down	1285.9	N1101	W2782	N10789.0	E4132.4	51.2	None
DH-42A	Down	1285.7	N1101	W2789	N10789.2	E4125.5	40.5	None

(1) Survey data not available.

Table 6-1 (continued)

SUMMARY OF CORE HOLE DATA

Core Hole No.	Direction	Collar Elevation (ft-MSL)	Approximate Station (ft)		Facility Coordinates (ft)		Depth/ Penetration (ft)	Instrument Designation
DH-207	Up	1259.8	S697	E155	N8989.7	E7049.1	53.0	GE-246
DH-208	Down	1251.6	S698	E150	N8988.8	E7044.0	49.2	None
DH-211	Up	1270.5	S1320	E163	N8366.5	E7057.1	50.0	None
DH-212	Down	1261.7	S1320	E163	N8366.5	E7057.1	52.1	None
DH-215	Up	1272.0	S1960	E153	N7727.2	E7046.9	52.0	GE-247
DH-216	Down	1262.6	S1960	E153	N7727.2	E7046.9	54.2	GE-248
DH-219	Up	1266.3	S2422	E162	N7264.9	E7056.6	51.0	None
DH-219A	Up	1266.1	S2418	E162	N7268.5	E7056.2	11.3	None
DH-220	Down	1257.4	S2421	E162	N7265.5	E7055.9	51.8	None
DH-223	Up	1255.1	S3079	E154	N6607.2	E7048.5	52.6	GE-249
DH-224	Down	1246.6	S3079	E154	N6607.5	E7048.5	52.5	None
DH-227	Up	1247.0	S3656	E147	N6030.7	E7041.2	51.7	None
DH-228	Down	1237.8	S3656	E147	N6030.7	E7041.2	50.4	None
DH-301	Up	1276.9	N150	W170	N9830.5	E6724.5	50.75	None
DH-302	Down	1264.9	N150	W170	N9830.5	E6724.5	50.6	None
DH-303	Up	1267.2	S400	W170	N9282.3	E6726.1	51.4	None
DH-304	Down	1254.3	S400	W170	N9282.5	E6726.1	50.5	None
DH-306	Down	1244.1	S400	E140	N9287.3	E7049.9	52.0	None
DH-306A	Down	1244.0	S400	E125	N9287.9	E7034.6	8.5	None
DH-307	Up	1262.6	S400	E300	N9286.7	E7194.2	52.0	GE-263
DH-309	Up	1259.8	S700	E220	N8987.1	E7123.0	52.3	GE-265
DH-311	Up	1264.4	S1000	E300	N8686.3	E7194.9	52.0	GE-264
DH-313	Up	1270.6	S1300	E300	N8385.9	E7190.6	19.6	None
DH-313A	Up	1270.9	S1300	E299	N8386.6	E7189.5	50.2	None
DH-314	Down	1258.3	S1300	E300	N8386.5	E7189.5	50.75	None
DH-315	Up	1272.1	S1300	W170	N8387.3	E6725.5	50.3	None
DH-316	Down	1259.9	S1300	W170	N8387.2	E6725.3	50.1	None
DH-317	Up	1271.3	S1600	W33	N8077.4	E6875.9	50.1	None
DH-317A	Up	1271.2	S1600	W30	N8077.5	E6879.5	5.0	None
DH-317B	Up	1271.2	S1597	W30	N8080.3	E6881.0	51.0	None
DH-318	Down	1258.5	S1600	W30	N8077.3	E6876.1	50.0	None
DH-319	Up	1260.0	S700	E300	N8988.1	E7191.6	51.05	None
DH-321	Up	1261.4	S400	E0	N9792.0	E6891.8	52.0	GE-268
DH-323	Up	1261.2	S400	E55	N9291.7	E6952.5	52.5	GE-267
DO-45	Up	1285.5	N254	E147	N9941.0	E7041.3	52.4	GE-230
DO-46	Down	1276.5±	N254	E147	N9941.0	E7041.3	51.5	None
DO-52	Up	1280.4	N146	W4	N9832.5	E6890.5	51.6	GE-226
DO-53	Down	1266.6	N146	W4	N9832.5	E6890.5	49.2	None
DO-56	Up	1296.8	N621	E0	N10311.8	E6892.3	52.1	GE-234
DO-57	Down	1288.1	N621	E0	N10311.8	E6892.4	52.1	None
DO-63	Up	1310.6	N1110	E0	N10796.0	E6891.9	52.8	GE-243
DO-64	Down	1301.5	N1110	E0	N10796.0	E6891.6	52.8	GE-221
DO-67	Down	1296.8	N1265	W231.5	N10952.1	E6662.9	51.7	GE-220
DO-69	Up	1310.1	N1265	W231.5	N10951.9	E6662.5	51.4	GE-218
DO-77	Down	1294.6	N1270	W364.5	N10962.5	E6529.6	53.4	GE-216
DO-79	Up	1307.7	N1270	W364.5	N10962.6	E6529.5	51.8	GE-214
DO-88	Up	1305.9	N1265	W497.5	N10952.8	E6396.5	52.7	GE-212
DO-90	Down	1292.1	N1265	W497.5	N10952.6	E6396.4	53.6	GE-210
DO-91	Down	1292.1	N1275	W630.5	N10961.5	E6263.9	51.8	GE-209
DO-93	Up	1304.9	N1275	W630.5	N10961.1	E6263.9	52.0	GE-207
DO-201	Up	1262.2	S406	W19	N9280.6	E6874.9	51.7	None
DO-202	Down	1248.6	S406	W19	N9280.6	E6874.9	51.4	None
DO-203	Up	1298.2	N624	E140	N10308.6	E7041.7	52.0	GE-235
DO-204	Down	1290.5	N640	E140	N10308.5	E7041.5	51.6	None
DO-205	Up	1316.5	N1410	E0	N11095	E6892	50.7	None
DO-206	Down	1308.0	N1410	E0	N11095	E6892	50.6	None
DO-229	Up	1259.8	S401	E153	N9287	E7049	50.6	None
OH-9	Up	1310	N1433	W231.5	N11125.6	E6662.9	15.4	None
OH-11	Up	1308	N1433	W364.5	N11125.6	E6529.6	19.7	None
OH-13	Down	1298	N1433	W231.5	N11125.6	E6662.9	9.5	None
OH-14	Down	1296	N1433	W364.5	N11125.6	E6529.6	9.7	None

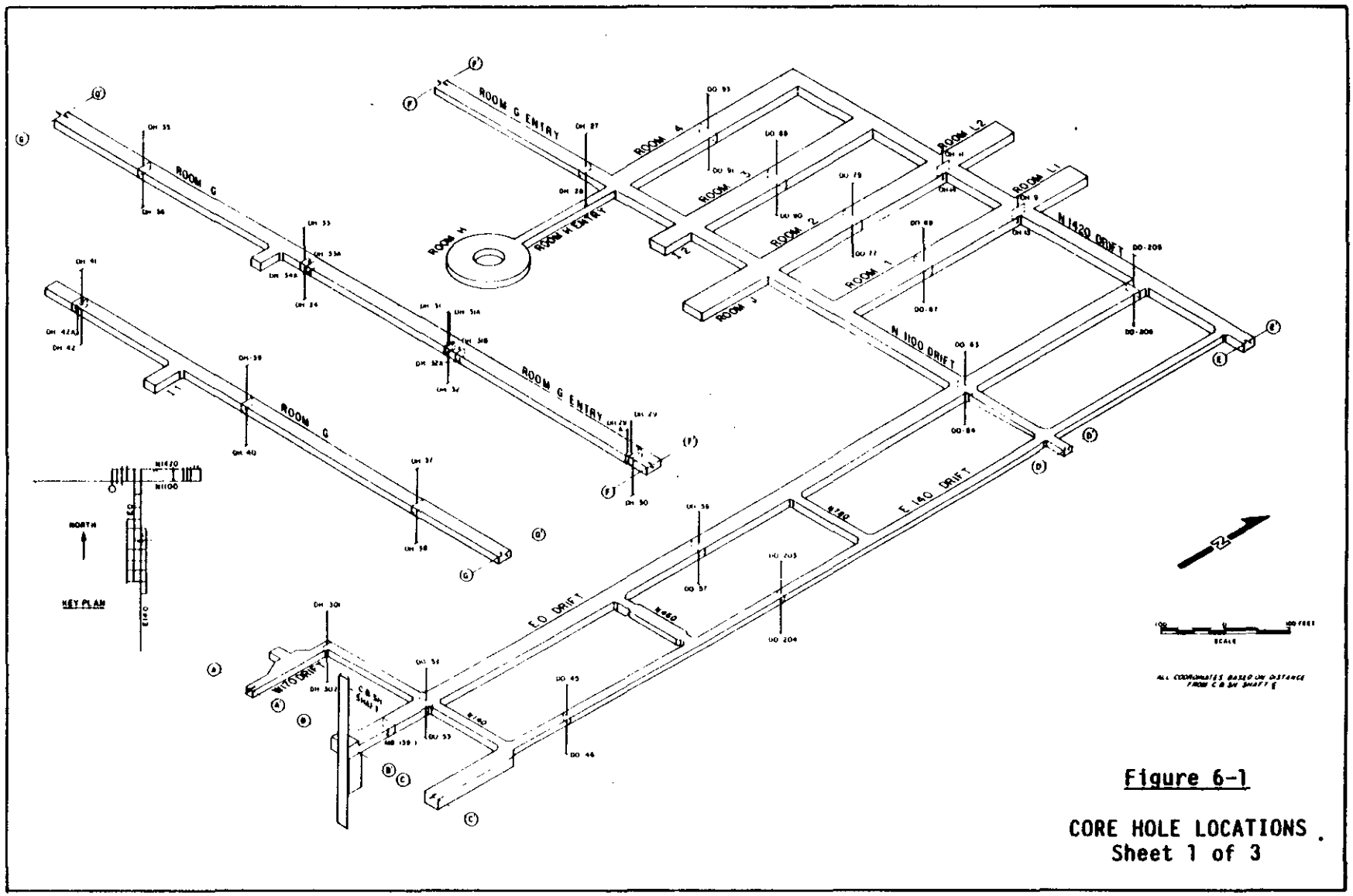


Figure 6-1

CORE HOLE LOCATIONS
Sheet 1 of 3

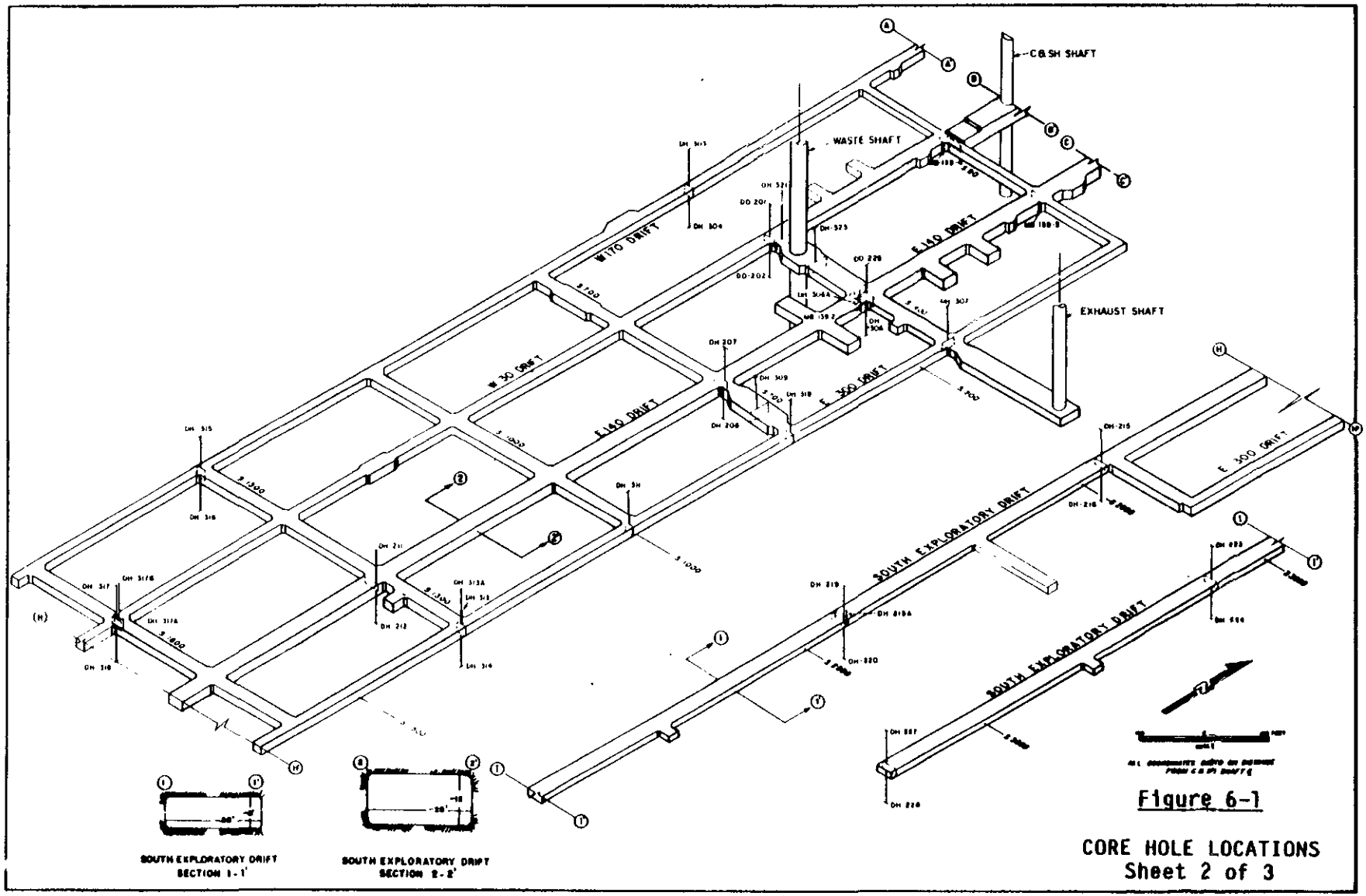


Figure 6-1

CORE HOLE LOCATIONS
Sheet 2 of 3

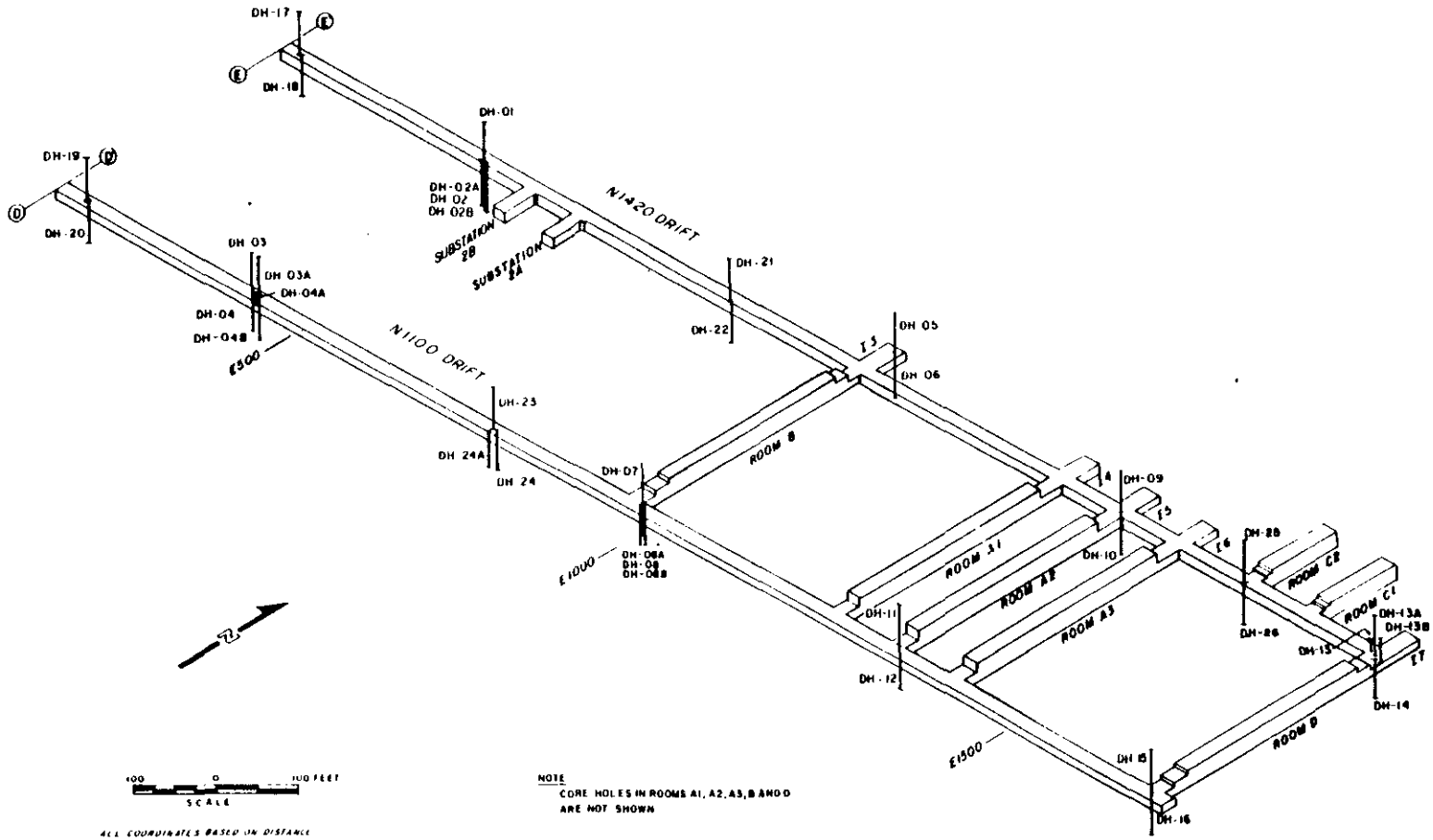


Figure 6-1

CORE HOLE LOCATIONS
Sheet 3 of 3

(7) other pertinent information related to core conditions and observations made during drilling.

Included on the logs of many of the core holes is a core sample reference number for each distinguishable stratigraphic unit (except anhydrite). This number (in some cases several numbers) is shown in brackets at the end of the unit description. The number identifies a specific core sample that has undergone a laboratory analysis to determine its percentage of insolubles (clay/polyhalite). A listing of the reference core samples and their laboratory test results for insoluble residues are presented in Table 6-2. The reference sample system was used to provide uniformity in the logging of the core and to facilitate the comparison of unit descriptions with samples having a known insoluble content. The sample number or numbers which appear on the log are those which are visually most similar to the overall unit. The crystal size in the reference samples may not be the same as in the units with which they are correlated.

Each box of core was photographed and then stored in the WIPP core library. After data from several of the core holes was collected, correlations between the holes were developed.

6.2.2.3 Summary of Results

The underground core drilling program has demonstrated the lateral continuity of stratigraphy throughout the underground facility horizon. Three anhydrite units were identified in the upholes and two anhydrite units were identified in the downholes. These units are consistently underlain by clay seams. In addition, a clay seam designated clay I was found in most of the upholes and a clay seam designated clay D was found in many of the downholes. Anhydrite is commonly associated with these two seams. The remaining units consist of halite with varying amounts of argillaceous material and polyhalite. Individual units vary slightly from hole to hole in thickness, crystal size, and the percentage of accessory constituents such as argillaceous material and polyhalite. The stratigraphy

Table 6-2

INSOLUBLE RESIDUES OF REFERENCE CORE SAMPLES
SANDIA NATIONAL LABORATORIES

Reference Sample Number	Hole Number	Depth Interval (feet)	Water-Insoluble			EDTA-Insoluble (1)		
			Sample Weight (grams)	Residue Weight (grams)	Percent Weight	Sample Weight (grams)	Residue Weight (grams)	Percent Weight
1	DO-52	9.0 - 9.7	451.09	0.03	0.01			
2	DO-52	39.4 - 40.0	336.10	0.11	0.03			
3	DO-52	14.3 - 15.0	415.57	2.15	0.52	1.61	0.72	44.72
4	DO-53	14.1 - 14.5	251.72	0.40	0.16	0.36	0.14	38.89(2)
5	DO-53	4.0 - 4.3	206.53	1.28	0.62	0.80	0.28	35.00(2)
6	DO-53	23.7 - 24.1	155.36	1.26	0.81	0.96	0.59	61.46
7(3)	DH-48	18.0 - 18.35			0.22			
8	DO-52	2.0 - 2.75	436.67	2.16	0.49	1.32	0.91	68.94
9(3)	DH-12	28.15- 28.6			0.75			57.1
10(3)	DH-11	46.5 - 46.9			3.85			39.2
11(3)	DH-12	50.05- 50.4						
12(3)	DH-11	32.8 - 33.35			2.36			50.0
13	DO-53	36.1 - 36.7	364.13	1.89	0.52	1.47	1.17	79.59
14	DO-52	42.6 - 43.5	543.62	17.97	3.31	5.13	4.58	89.28
15	DO-52	33.8 - 34.7	538.73	20.28	3.76	5.05	3.98	78.81
16	DO-52	48.7 - 49.2	315.06	16.59	5.27	5.31	4.33	81.54
17(3)	DH-10	43.3 - 43.6			0.52			49.2

Notes:

(1) For description of sample preparation see Results of Site Validation Experiments, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico, Section 5.4 (ref. 2-5).

(2) Small sample volume may have produced inaccurate result.

(3) Reference sample used for visual comparison is identical to the sample tested in the laboratory, but is from different interval within the same unit.

encountered in the core holes was used to prepare the reference stratigraphic column discussed in subsection 6.3.1.3.

The presence of any gas or brine detected during drilling is recorded on the drill logs. Usually within 2 weeks of completing an air-drilled uphole, brine weeps or moisture halos appear at the collar of the hole. Brine has also collected in some downholes which were dry during drilling. Observations of gas and brine occurrences are discussed in the following subsection.

6.2.3 Fluid Measurements

6.2.3.1 General Description

Ground-water inflow measurements were taken in both the SPDV exploratory and ventilation shafts as part of the geologic field activities for the SPDV Program. In addition, measurements in the waste shaft and exhaust shaft were taken as part of design validation. Gas and brine have been encountered in boreholes and at excavation faces in the facility level drifts and rooms. Studies are being performed by other WIPP project participants to further investigate and evaluate these occurrences.

6.2.3.2 C & SH Shaft

Measurements of fluid inflow were taken during the SPDV exploratory shaft drilling operation when the drill tools were out of the hole for a bit change. The measurements were taken by monitoring changes in the drilling fluid level over a period of several hours. These data were then used to estimate approximate ground-water flow rates into the shaft.

6.2.3.3 Waste Shaft

Ground-water inflow measurements were taken in the 6-foot diameter SPDV ventilation shaft during shaft outfitting. These measurements were taken in the shaft sump and at the base of the Rustler formation. The measurements in the shaft sump were used to determine total flow into

the shaft from all ground-water sources penetrated. Periodic measurements to determine water level rise with respect to a known point at the top of the sump were obtained during test intervals ranging from about 1.5 to 90 hours. The data obtained from these measurements were used to calculate approximate ground-water flow rates into the shaft ranging from 0.3 to 0.9 gallons per minute (gpm). The average flow rate was determined to be about 0.6 gpm.

An attempt to measure ground-water inflow from the rock strata above the Salado formation was only partially successful. A collection system to retain ground-water inflow was constructed at the base of the Rustler formation by placing plastic sheeting across the shaft and attaching it to the wall. The quantity of water collected in the sheeting and drained into a graduated container was calculated to accumulate at a rate of approximately 0.3 to 0.4 gpm from all sources above the Salado formation.

No direct inflow from the Magenta or Culebra dolomite members or at the Rustler/Salado formation contact was measured. The Magenta dolomite did not exhibit measurable flow. Ground water from this member resulted in the wetting of the wall below the dolomite for a distance of about 20 feet. Below this distance the shaft wall was essentially dry. Therefore, it was concluded that the Magenta was making no contribution to the collection system at the base of the Rustler formation. Visual inspection of the Rustler/Salado formation contact, and shaft wall conditions immediately above and below this contact, suggested that the zone was making little, if any, contribution to the water accumulating in the sump. Based on these results, it was concluded that the Culebra dolomite member was contributing the majority of ground water reaching the SPDV ventilation shaft sump.

The 6-foot diameter SPDV ventilation shaft was later enlarged to become the waste shaft for the WIPP facility. Of the three formations observed during geologic mapping activities in the enlarged shaft, only the Magenta and Culebra dolomite members of the Rustler formation were

obvious fluid-bearing zones. The Magenta exhibited only a few weeps and generally produced very little water. The entire Culebra section, however, was wet, but no obvious local concentrations of water inflow were observed. Wherever a ledge was present, a steady dripping of water occurred. The Rustler/Salado formation contact, often considered a fluid-producing zone, did not contain any observable fluid except for some dampness around rock bolts.

After the waste shaft liner was constructed, ground water was observed seeping through cracks and construction joints in it. These observations are discussed in Chapter 8, subsection 8.3.1.1.

6.2.3.4 Exhaust Shaft

A water inflow measurement of approximately 0.4 gpm into the 7 7/8-inch diameter pilot hole for the exhaust shaft was taken on December 1, 1983. On December 21, 1983, a water inflow of 0.47 gpm was measured after the pilot hole was enlarged to 11 inches in diameter.

After the shaft was excavated to its finished dimensions, water inflow through cracks and construction joints in the liner was measured. Measurement was made from the 2-inch drainpipe that connects the three water collection rings in the shaft. The measured flow was 0.35 gpm in January 1985. A grouting program, conducted in June and July 1985 within the lined section of the shaft, reduced this inflow to a non-measurable quantity.

6.2.3.5 Drifts and Test Rooms

Small amounts of gas under pressure have been encountered by some underground boreholes and at the working face of underground horizontal excavations. Brine is observed to weep locally from walls and into some boreholes. The brine occurrences are visible during or immediately after excavation or drilling and remain moist or produce fluid for a period of from several weeks to more than 3 years. The formation of salt blisters on walls and salt straws and precipitate at

hole collars are common. Salt incrustations forming on the roof are being monitored at three locations: W30/S1600, E140/S2190 and E140/S2740.

The gas occurrences encounterd by boreholes are indicated on the geologic drill logs. Pressure transient testing and gas sampling were performed in several holes in the roof and floor of the facility as reported in reference 4-11. Only two occurrences of gas at the working face were documented prior to the end of December 1985. In both cases, degassing could be heard at the face for short periods of time.

The locations of major weeps occurring on walls that were geologically mapped are indicated on the maps and a discussion of their occurrence and structure is presented in reference 4-10. Sampling of brine from weeps for chemical analysis is currently being conducted. A preliminary inventory of brine occurrences at accessible locations is presented in reference 4-15.

The flow of gas from monitored holes has been low and erratic. It appears to be associated with clay seams or a result of fracture permeability in anhydrite beds. The spatial distribution of brine occurrences is also undefined. Although very few weeps have been observed on the roof surface, boreholes in the roof sometimes weep brine. The amount and duration of flow from boreholes and wall areas varies considerably. Based on observations made during preliminary gas testing, the brine appears to be associated primarily with anhydrite beds and their underlying clay seams. However, brine can also weep directly from halitic units, as observed on the walls and roof of drifts and in the drum durability test pit in Room J.

Two program plans have been developed to investigate gas and brine occurrences in the WIPP underground facility. The programs will investigate the origin, migration, volume and composition of the occurrences. Work on the Brine Testing Program (BTP) is presently

being conducted and will continue through 1987. The Gas Testing Program (GTP) is also currently in progress.

As part of the BTP, 36 accessible boreholes containing brine have been monitored. These holes include the shallow holes for the Material Interface-Interactions Test (MIIT) in Room J, inclinometer holes in Test Rooms 1 and 2 (51X-IG-00201 and 51X-IG-00202), an abandoned stressmeter hole (51X-NG-00252) in Test Room 2, hole L1-X00 in Room L1, nine stratigraphic core holes in Room G (DH-35 through DH-42A), and eight stratigraphic core holes in experimental Rooms A1, A2, A3 and B (A1X01, A1X02, A2X01, A2X02, A3X01, A3X02, BX01 and BX02). The static level of any brine in the holes is measured and recorded on a regular basis. The brine is then evacuated from the hole and its volume measured.

The BTP monitoring of brine occurrences in the MIIT holes in Room J was suspended at the end of April 1985 due to interference with experimental activities in the room. Monitoring of the remainder of the boreholes listed above continues. As new monitoring locations for the BTP are identified, they will be added to the program.

An inventory of all boreholes drilled in the underground facility has been assembled. Data contained in the inventory include hole location, diameter, depth, present status, drilling fluid used, and any observations on the occurrence of gas or brine. Over 1400 holes are presently listed, most of which contain geomechanical instruments or are otherwise inaccessible. The list will be used to locate accessible boreholes that may be suitable for use in the gas and brine testing programs.

6.3 DESCRIPTION OF FACILITY GEOLOGY

6.3.1 Stratigraphy

The stratigraphy within the WIPP underground facility horizon has been determined through vertical core hole drilling and geologic mapping of

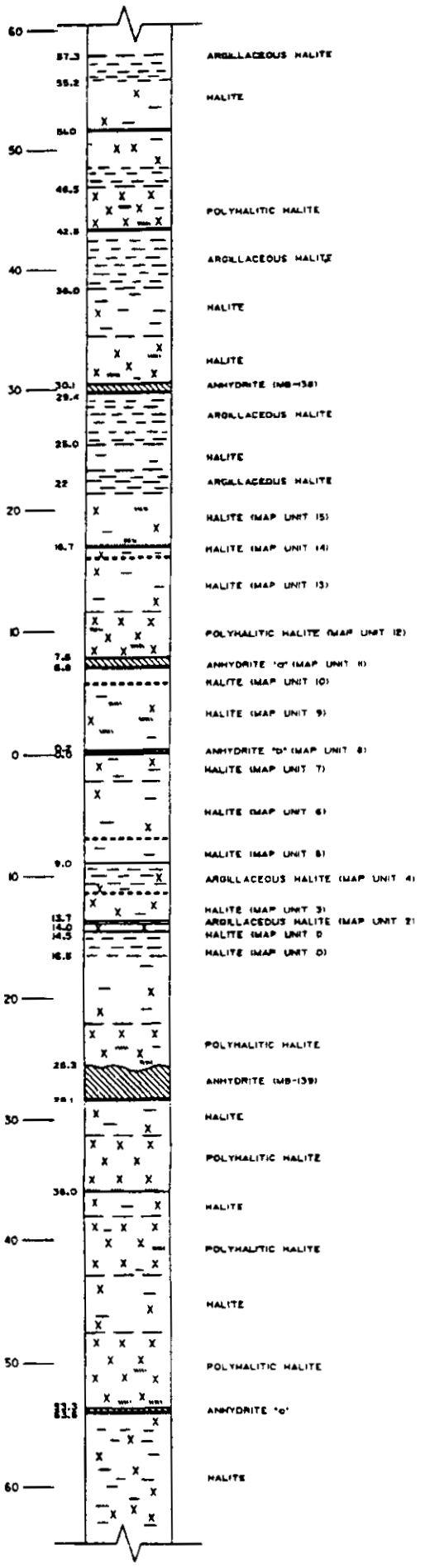
the excavation walls. A description of the generalized stratigraphy and evidence for stratigraphic continuity is presented in the following subsections. Figures showing the stratigraphy within the WIPP underground facility horizon are presented in Appendix B.

6.3.1.1 Generalized Stratigraphy

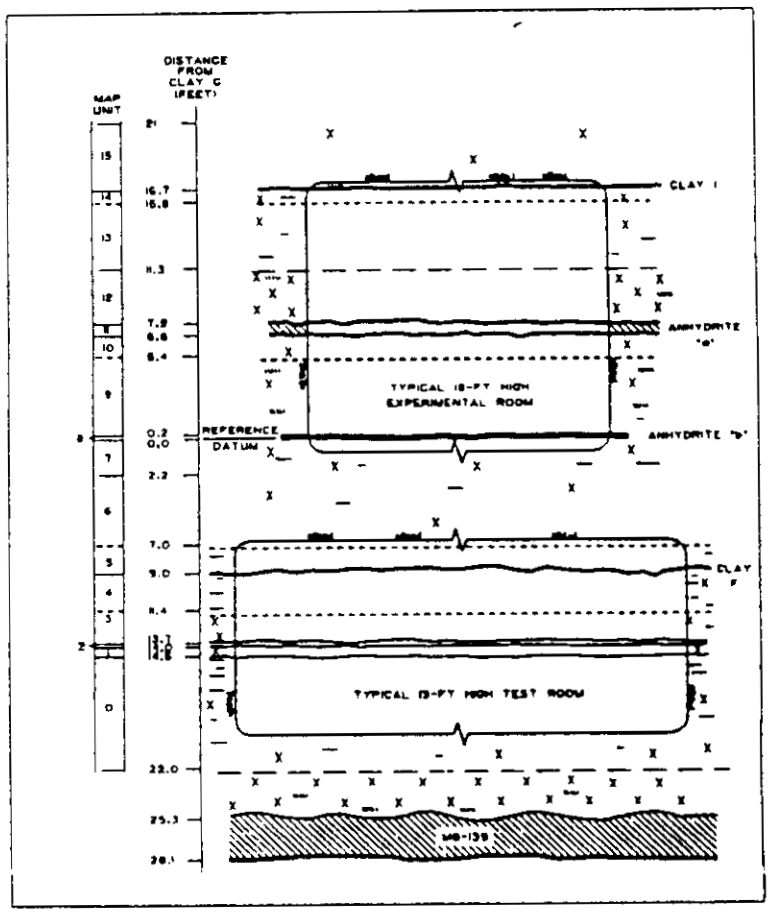
The WIPP underground facility horizon consists primarily of halite containing varying amounts of polyhalite and clay. This halite is interrupted by 5 anhydrite beds, 12 clay seams and 6 argillaceous layers. Figure 6-2 contains a generalized stratigraphic column showing the relationship of these materials. Detailed descriptions of the individual units (except clay seams) are presented in Table 6-3. Figure 6-3 shows the individual clay seams and their descriptions.

Because of the difference in the behavior of halite and anhydrite, the five anhydrite beds represent significant boundaries above and below the horizontal underground openings. Three of the beds, abouth 1 1/2 to 12 inches thick, occur approximately 7, 14 and 35 feet above the roof of the storage level drifts and rooms. The remaining two beds occur beneath the floor of the drifts and rooms. The most significant of these two beds is MB-139 which occurs approximately 3 1/2 to 4 1/2 feet below the floor of the storage level and varies from 2.5 to 4 feet in thickness. The remaining bed occurs about 32 feet below the storage level and is approximately 4 inches thick. Thin clay seams underlie all of the anhydrite beds.

Fifteen lithologic units have been identified during geologic mapping within the facility level drifts, rooms and waste experimental area. The majority of these units are halite containing varying amounts of polyhalite and argillaceous material, usually less than 2 percent. The remaining units consist of 2 anhydrite beds, 2 argillaceious halite units and 1 polyhalitic halite unit. Each of the 15 mapped units has been assigned a numerical designation as shown on Figure 6-2 and contained in Table 6-3.



(SEE TABLE 6-3 FOR DETAILED DESCRIPTIONS OF UNITS)



EXPLANATION

ROCK TYPE

HALITE | ANHYDRITE | POLYHALITIC HALITE | ARGILLACEOUS HALITE

ACCESSORY CONSTITUENTS

LAMINAR FEATURES

POLYHALITE | CLAY SEAM

ARGILLACEOUS MATERIAL

ANHYDRITE STRINGERS

LITHOLOGIC CONTACTS

SHARP (IDENTIFIABLE WITHIN 0.05 FT.) | GRADATIONAL (IDENTIFIABLE WITHIN 0.05 TO 0.2 FT.) | DIFFUSE (IDENTIFIABLE WITHIN 0.2 TO 0.6 FT.)

NOTES:

1. DISTANCES ARE MEASURED FROM THE BASE OF ANHYDRITE 'b' (CLAY G) AND ARE AVERAGED FROM REPRESENTATIVE CORE HOLE LOGS, SHAFT AND TEST ROOM MAPPING. ACTUAL DISTANCES AND UNIT THICKNESSES MAY VARY LOCALLY FROM THOSE SHOWN.
2. DESCRIPTIONS OF UNITS ARE BASED ON CORE HOLE DATA, SHAFT MAPPING AND VISUAL INSPECTION OF EXPOSURES IN UNDERGROUND DRIFTS AND ROOMS.
3. DETAILED DESCRIPTIONS OF CLAY SEAMS ARE PRESENTED ON FIGURE 6-4.
4. PERCENTAGES OF ARGILLACEOUS MATERIAL AND POLYHALITE ARE BASED ON VISUAL ESTIMATES FROM EXAMINATION OF DRILL CORE AND EXPOSURES IN THE UNDERGROUND EXCAVATIONS. SANDIA NATIONAL LABORATORIES' MEASUREMENTS OF INSOLUBLES FROM SELECTED CORE WERE USED AS A POINT OF REFERENCE.

Figure 6-2

WIPP GENERALIZED STRATIGRAPHIC COLUMN

Table 6-3

DESCRIPTION OF GENERALIZED STRATIGRAPHY

Approximate Distance From Clay G (Ft)	Stratigraphic Unit	Description*
55.2 to 57.3	Argillaceous halite	Clear to moderate brown, medium to coarsely crystalline. <1 to 3% brown clay. Intercrystalline and discontinuous breaks. In one core hole, consists of a 1 in. thick clay seam. Unit can vary up to 4 ft thickness. Contact with lower unit is gradational.
46.5 to 55.2	Halite	Clear to moderate reddish orange and moderate brown, coarsely crystalline, some medium. ≤1% brown clay, locally argillaceous (clays M-1 and M-2). Scattered anhydrite stringers locally.
42.8 to 46.5	Polyhalitic halite	Clear to moderate reddish orange, some moderate brown, coarsely crystalline. <1 to 3% polyhalite. None to 1% brown and some gray clay. Scattered anhydrite locally. Contact with unit below is fairly sharp.
38.0 to 42.8	Argillaceous halite	Clear to moderate brown, medium to coarsely crystalline, some fine. <1 to 5% brown clay. Locally contains 10% clay. Intercrystalline and scattered breaks. Locally contains partings and seams. Contact with lower unit is gradational based on increased clay content. Average range of unit is 38.0 to 42.8 ft above clay G but does vary from 33.8 to 46 ft.
34.0 to 38.0	Halite	Clear to moderate brown, some moderate reddish brown, coarsely crystalline, some fine and medium. ≤1% brown clay, trace gray clay locally. Scattered breaks. Locally argillaceous. <1% polyhalite. Contact with unit below is gradational based on clay and polyhalite content.
30.1 to 34.0	Halite	Clear to moderate reddish orange, coarsely crystalline. <1 to 3% polyhalite. Commonly polyhalitic. Scattered anhydrite stringers with anhydrite layers up to 1/2 in. thick locally. Scattered brown clay locally. Contact with MB-138 below is sharp.
29.4 to 30.1	Anhydrite (MB-138)	Light to medium gray, microcrystalline. Partly laminated. Scattered halite growths. Clays seam K found at base of unit.
25.0 to 29.4	Argillaceous halite	Clear to moderate brown, some light moderate reddish orange. Medium to coarsely crystalline. <1 to 3% brown clay, some gray. Locally up to 5% clay. Clay is intercrystalline with scattered breaks and partings present. < 1/2% dispersed polyhalite. Contact with lower unit is gradational based on clay content. Upper contact is sharp with clay K.
23.0 to 25.0	Halite	Clear, some light moderate brown, coarsely crystalline. <1/2% brown clay. Contact with clay J below varies from sharp to gradational depending if clay J is a distinct seam or merely an argillaceous zone.
21.0 to 23.0	Argillaceous halite	Usually consists of scattered breaks or argillaceous zone containing <1 to 3% brown clay. In C & SH shaft, it is a 1/2 in. thick brown clay seam.
16.7 to 21.0	Halite (Map Unit 15)	Clear, coarsely crystalline, scattered medium. None to <1% dispersed polyhalite and brown clay. Scattered anhydrite. Lower contact is sharp with clay I.
15.8 to 16.7	Halite (Map Unit 14)	Clear to grayish orange-pink, coarsely crystalline, some medium. <1/2% dispersed polyhalite. Scattered discontinuous gray clay stringers. Clay I is along upper contact. Contact with lower unit is diffuse.
11.5 to 15.8	Halite (Map Unit 13)	Clear to moderate reddish orange and moderate brown, medium to coarsely crystalline, some fine. ≤1% brown clay, locally up to 3%. Trace of gray clay. Scattered discontinuous breaks. <1% dispersed polyhalite and polyhalite blebs. Contact with unit below is gradational based on clay and polyhalite content.

Table 6-3 (continued)

DESCRIPTION OF GENERALIZED STRATIGRAPHY

Approximate Distance From Clay G (Ft)	Stratigraphic Unit	Description*
7.5 to 11.5	Polyhalitic halite (Map Unit 12)	Clear to moderate reddish orange, coarsely crystalline. <1 to 3% dispersed polyhalite and polyhalite blebs. Scattered anhydrite stringers. Contact is sharp with unit below.
6.8 to 7.5	Anhydrite "a" (Map Unit 11)	Light to medium gray, light brownish gray and sometimes light moderate reddish orange. Microcrystalline. Halite growths within. Partly laminated. Clear, coarsely crystalline halite layer, up to 2 in. wide, found within exposures in waste experimental area. Thin gray clay seam H at base of unit.
5.5 to 6.8	Halite (Map Unit 10)	Clear to moderate reddish orange/brown, fine to coarsely crystalline. <1% brown and/or gray clay and dispersed polyhalite. Discontinuous clay stringers locally. Contact with lower unit is diffuse based on crystal size and varying amounts of clay and polyhalite.
0.2 to 5.5	Halite (Map Unit 9)	Clear to light moderately reddish orange, coarsely crystalline, some medium. None to <1% polyhalite. Trace of gray clay locally. Scattered anhydrite stringers. Contact with unit below is sharp.
0.0 to 0.2	Anhydrite "b" (Map Unit 8)	Light to medium gray, microcrystalline anhydrite. Scattered halite growths. Thin gray clay seam G at base of unit.
0.0 to -2.2	Halite (Map Unit 7)	Clean to light/medium gray, some moderate reddish orange/brown. Coarsely crystalline, some fine and medium. <1 brown and gray clay. Locally up to 2% clay. <1% dispersed polyhalite. Upper contact is sharp with clay G. Contact with lower unit is gradational.
-2.2 to -7.0	Halite (Map Unit 6)	Clear, some moderate reddish orange, coarsely crystalline, some fine to medium locally. <1/2% gray clay and polyhalite. Contact with lower unit gradational and/or diffuse.
-7.0 to -9.0	Halite (Map Unit 5)	Clear coarsely crystalline. <1/2% gray clay. Contact with lower unit is usually sharp with clay F.
-9.0 to -11.4	Argillaceous halite (Map Unit 4)	Clear to moderate brown and moderate reddish brown, coarsely crystalline. <1% polyhalite. <1 to 5% argillaceous material; predominantly brown, some gray, locally. Intercrystalline and discontinuous breaks and partings common in upper part of unit. Decreasing argillaceous content downward. Contact with lower unit is gradational.
-11.4 to -13.7	Halite (Map Unit 3)	Clear to moderate reddish orange, coarsely crystalline. <1% dispersed polyhalite and polyhalite blebs. Locally polyhalitic. Scattered gray clay locally. Contact with lower unit is sharp.
-13.7 to -14.0	Argillaceous halite (Map Unit 2)	Moderate reddish brown to medium gray, medium to coarsely crystalline. <1 to 3% argillaceous material. Contact with lower unit is usually sharp.
-14.0 to -14.5	Halite (Map Unit 1)	Light reddish orange to moderate reddish orange, medium to coarsely crystalline. <1% dispersed polyhalite. Contact with lower unit is sharp.
-14.5 to -22.0	Halite (Map Unit 0)	Clear to moderate reddish orange/brown, moderate brown and grayish brown. Medium to coarsely crystalline. <1 to 5% argillaceous material. Predominantly brown, some gray, intercrystalline argillaceous material and discontinuous breaks and partings. Upper two feet of unit is argillaceous halite decreasing in argillaceous material content downward. None to <1% polyhalite. Contact with lower unit is gradational based on polyhalite content.

Table 6-3 (continued)

DESCRIPTION OF GENERALIZED STRATIGRAPHY

Approximate Distance From Clay G (Ft)	Stratigraphic Unit	Description*
-22.0 to -25.3	Polyhalitic halite	Clear to moderate reddish orange. Coarsely crystalline, some medium locally. <1 to 3% polyhalite. Scattered anhydrite. Scattered gray clay locally. Contact with lower unit (MB-139) is sharp, but commonly irregular and undulating. Trace of gray locally present along this contact.
-25.3 to -28.1	Anhydrite (MB-139)	Moderate reddish orange/brown to light and medium gray, microcrystalline anhydrite. "Swallowtail" pattern, consisting of halite growths within anhydrite, common in upper part of unit. Locally, hairline, clay-filled, low-angle fractures found in lower part of unit. Thin halite layer common close to lower contact. Clay seam E found at base of unit. Upper contact is irregular, undulating and sometimes contains <1/16 in. gray clay.
-28.1 to -31.2	Halite	Clear to moderate reddish orange, and light gray. Coarsely crystalline, some fine and medium. ≤1% polyhalite and intercrystalline gray clay. Contact with lower unit is gradational based on increased polyhalite content.
-31.2 to -36.0	Polyhalitic halite	Clear to moderate reddish orange, coarsely crystalline. < 1 to 3% polyhalite. Contact with lower unit is usually sharp along clay D.
-36.0 to -37.8	Halite	Clear to moderate reddish orange, some light gray. Medium to coarsely crystalline. ≤1% polyhalite and gray clay. Contact with lower unit is gradational based on increased polyhalite content.
-37.8 to -42.7	Polyhalitic halite	Clear to moderate reddish orange/brown, coarsely crystalline. < 1 to 3% polyhalite. Trace of clay locally. Scattered anhydrite locally. Contact with lower unit is gradational, based on decreased polyhalite content.
-42.7 to -47.3	Halite	Clear to moderate reddish orange, medium to coarsely crystalline. < 1% dispersed polyhalite. < 1% brown and/or gray clay. Contact with lower init is gradational and/or diffuse.
-47.3 to -53.3	Polyhalitic halite	Clear to moderate reddish orange. Coarsely crystalline with some medium sometimes present close to lower contact. <1 to 3% polyhalite. Scattered anhydrite especially common close to anhydrite "c". Lower contact is sharp with anhydrite "c".
-53.3 to -53.5	Anhydrite "c"	Light to medium gray, microcrystalline anhydrite. Scattered halite growths. Faintly laminated locally. Clay seam B found at base of unit.
-53.5 to -65.7	Halite	Clear to medium gray and moderate brown. Medium to coarsely crystalline, some fine locally. ≤1% polyhalite, locally polyhalitic. <1 to 3% clay, both brown and gray. Intercrystalline clay with discontinuous breaks and partings. Zones of argillaceous halite found within unit. Seams of clay mixed with halite crystals present locally. Upper contact of this unit is sharp with clay B.

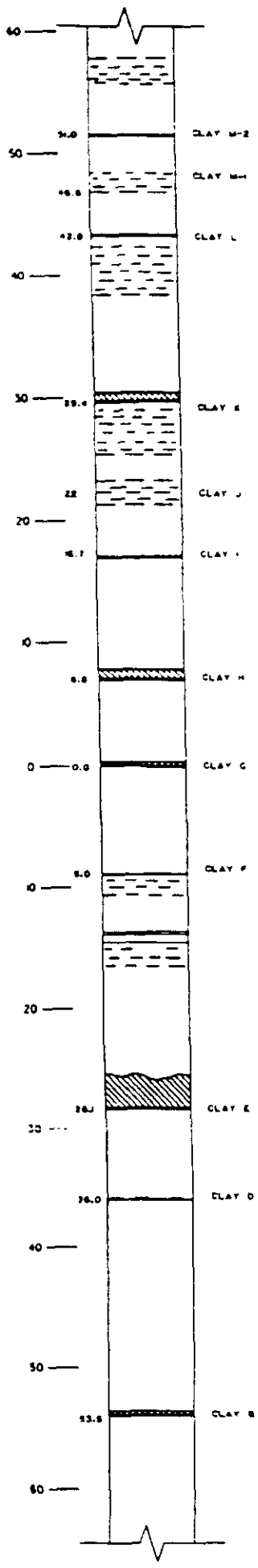
* Descriptions are based on examination of drill core and exposures of units in shafts and other underground openings.

Map units 1 through 6 occur within the storage level drifts and rooms. Unit 1 is a distinct, relatively thin, orange-colored unit commonly referred to as the "orange marker bed". This unit is continuous throughout the facility level excavations. During excavation, it was used as a marker to help keep the underground openings within the proper stratigraphy. The descriptions for map units 7 through 15 represent the lithology most frequently encountered in the drifts and rooms in the waste experimental area. Minor variations in these lithologies occur at various locations but they are not of sufficient difference to justify their inclusion in the generalized descriptions.

6.3.1.2 Stratigraphic Continuity

The results of geologic mapping and core hole drilling in the underground facility have confirmed the lateral extent and stratigraphic continuity of the geologic units within the underground facility horizon. Strata exposed in the drifts have been traced continuously for 4,500 feet in an east-west direction and more than 5,000 feet in a north-south direction. North-south and east-west correlations between the vertical core holes have also demonstrated the continuity of the stratigraphic units above and below the facility level. Figures B-4 through B-9 in Appendix B show the correlations of stratigraphic horizons that have been made based on core hole data. These figures also demonstrate the slight southern dip of the units. Figure B-5 shows a slight thinning of units to the south by about 5 percent. Figures B-1 and B-2 show a larger correlation of stratigraphic horizons between boreholes WIPP-12 to the north and DOE-1 to the south. The five anhydrite beds shown on Figure 6-2 are laterally continuous across the WIPP site.

Although the general character of each stratigraphic unit remains constant throughout the underground facility horizon, minor variations occur. Some thin clay seams are discontinuous and some halite units thin locally or pinch out. The disruptions of some of these units are localized phenomena thought to result from syndepositional processes. Both lateral and vertical variations in the argillaceous and polyhalite



VARIES FROM AN ARGILLACEOUS HALITE ZONE CONTAINING <1 TO 3% BROWN CLAY TO A CLAY/HALITE SEAM UP TO 3 1/2 INCHES THICK.

COMMONLY FOUND AS AN ARGILLACEOUS HALITE ZONE CONTAINING <1 TO 3% BROWN CLAY OR MERELY A BROWN, SOMETIMES GRAY, CLAY PARTING. LOCALLY FOUND AS A SEAM UP TO 1/2-INCH THICK.

IN C & SH SHAFT, IT IS A 2-INCH THICK BROWN CLAY SEAM. MOST COMMONLY IT IS FOUND AS THE UPPER CONTACT OF THE ARGILLACEOUS ZONE BELOW.

USUALLY BROWN CLAY BUT SOMETIMES GRAY TO GRAY-BROWN. IN CORE, MOST COMMONLY FOUND AS 1/4 TO 1 1/4-INCH HARD, BROWN CLAY SEAM. IN THE C & SH SHAFT, IT IS UP TO 1 1/2 INCHES THICK. USUALLY IT IS A LOW ANGLE CONTACT.

IN C & SH SHAFT, CONSISTS OF A REDDISH BROWN CLAY SEAM UP TO 1/2-INCH THICK. IN CORE HOLES, FOUND AS SCATTERED BREAKS OR ARGILLACEOUS HALITE CONTAINING <1 TO 3% CLAY.

1/4 TO 5/8-INCH THICK CLAY. COMMONLY BROWN OR BROWNISH GRAY IN CORE BUT GRAY WHERE EXPOSED IN EXPERIMENTAL TEST ROOMS. COMMONLY ASSOCIATED WITH THIN ANHYDRITE ABOVE. EXPOSURES IN EXPERIMENTAL TEST ROOMS SHOW IT TO BE FAIRLY REGULAR WITH UNDULATIONS USUALLY LESS THAN 1 INCH AMPLITUDE. SOME SCATTERED HALITE GROWTHS LOCALLY WITHIN CLAY.

AVERAGES <1/4-INCH THICK CLAY BUT VARIES FROM TRACE UP TO 1/2 INCH. USUALLY GRAY COLOR BUT BROWN IN SEVERAL CORE HOLES. CLAY H IS EXPOSED IN THE WASTE EXPERIMENTAL AREA. HERE IT IS A GRAY, IRREGULAR SEAM WITH UNDULATIONS OF 1 TO 3 INCHES AMPLITUDE.

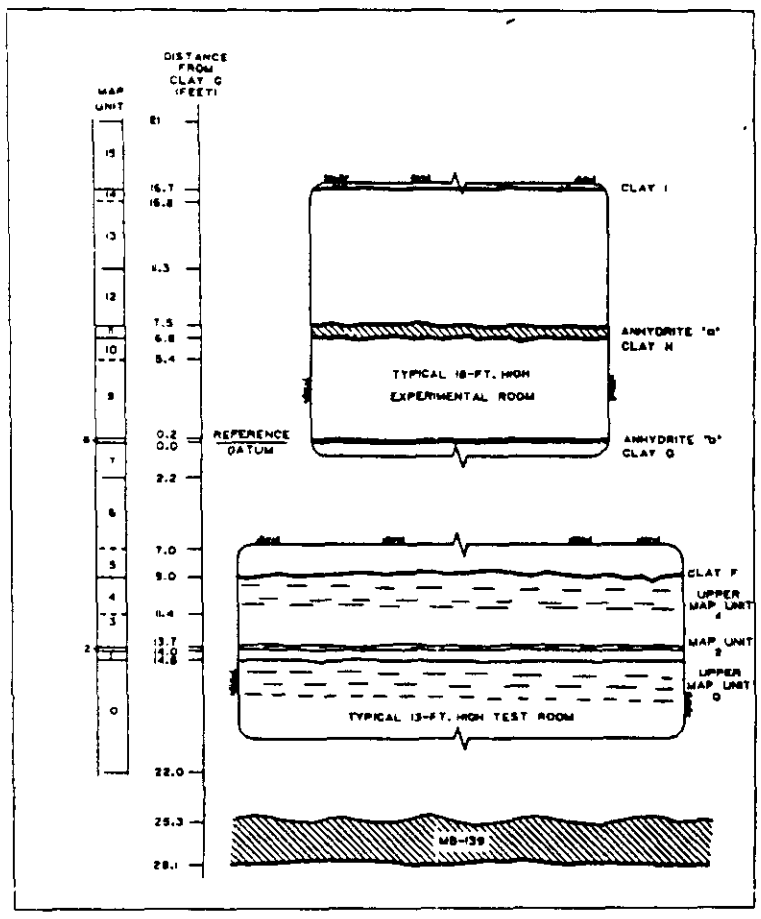
TRACE UP TO 3/8-INCH THICK GRAY CLAY. USUALLY A LOW ANGLE CONTACT IN CORE. EXPOSED IN WASTE EXPERIMENTAL AREA WHERE IT IS A GRAY, FAIRLY REGULAR SEAM WITH UNDULATIONS AVERAGING <2 INCHES AMPLITUDE. LOCALLY, MOISTURE IS NOTED ALONG THIS SEAM. EXPOSED ALONG THE WALLS OF MANY OF THE FACILITY LEVEL DRIFTS AND ROOMS ALONG THE UPPER CONTACT OF MAPPING UNIT 4, VERY IRREGULAR.

GRAY TO BROWN SEAM 1/8 TO 1/2-INCH THICK. HALITE IS COMMONLY MIXED WITH CLAY AND SILT. SOMETIMES BIFURCATES INTO TWO SEAMS. LOCALLY DISCONTINUOUS. UNDULATIONS OF 2 TO 8 INCHES AMPLITUDE.

1/8 TO 1 1/2-INCH GRAY CLAY SEAM. MOISTURE PRESENT IN SOME LOCATIONS. LOCALLY IRREGULAR WITH UNDULATIONS UP TO 4 INCHES AMPLITUDE.

VARIES FROM A ZONE OF CLAY BREAKS UP TO A 3/4-INCH, GRAY CLAY SEAM. SOMETIMES THIN ANHYDRITE IS ASSOCIATED ABOVE. NEAR HORIZONTAL IN CORE.

GENERALLY 1/8 TO 1/4-INCH GRAY CLAY SEAM BUT LOCALLY UP TO 1 1/4 INCHES. USUALLY LOW ANGLE AND SLIGHTLY IRREGULAR IN CORE.



EXPLANATION

ROCK TYPE

ANHYDRITE

ARGILLACEOUS HALITE

ACCESSORY CONSTITUENTS

LAMINAR FEATURES

ANHYDRITE STRINGERS

CLAY SEAM X/4 IN. THICK

LITHOLOGIC CONTACTS

SHARP

IDENTIFIABLE WITHIN 0.05 FT.

NOTES:

1. DISTANCES ARE MEASURED FROM CLAY G AND ARE AVERAGED FROM REPRESENTATIVE CORE HOLE LOGS AND SHAFT MAPPING.
2. DESCRIPTIONS OF CLAY SEAMS ARE BASED ON CORE HOLE DATA, SHAFT MAPPING AND VISUAL INSPECTION OF EXPOSURES IN UNDERGROUND DRIFTS AND ROOMS.
3. ONLY CLAY SEAMS ARE SHOWN ON THIS FIGURE. ALL OTHER UNITS ARE SHOWN ON FIGURE 6-2 AND DESCRIBED IN TABLE 6-3.

Figure 6-3

CLAY SEAMS

content of the halite units are common. The size of halite crystals varies from fine to coarse both laterally and vertically within inidvidual units. Although the anhydrite is microcrystalline, the beds vary laterally in color, thickness and polyhalite or halite content. The upper surface of MB-139 is undulatory with amplitudes of up to 12 inches.

The halite around the underground openings exhibits slightly varied behavior in response to excavation at different locations. This may be due to minor variations in crystal size or clay content. The clear halite in the roof of the E140 drift south of the waste shaft exhibits more spalling than is apparent in similar halite in other areas of the underground openings. Spalling along the upper portion of map unit 4 occurs in many of the facility level drifts and rooms. In the locations where this unit contains abundant argillaceous material, the spalling appears to be more pronounced. This behavior is discussed in Chapters 10 and 11.

6.3.1.3 Reference Stratigraphy

A meeting was held on November 15, 1979, to determine a reference stratigraphy for the WIPP site. This was titled the "November '79 Reference Stratigraphy" and was based on data obtained from exploratory boreholes. The purpose of the reference stratigraphy was to provide input data for thermal/structural analyses of shafts, drifts and rooms at the WIPP that could be referenced by all structural analysts and updated as more data became available.

The "November '79 Reference Stratigraphy" was revised in July 1981 and again in September 1983 as more data were collected from construction activities and underground core holes. The 1983 revision was titled "September '83 Reference Stratigraphy". This revision was based on the evaluation of 39 core hole logs and the geologic mapping performed in the SPDV exploratory and ventilation shafts.

The evaluation determined that the strata are fairly horizontal but dip slightly to the south. Based on a statistical analysis, the entire stratigraphic section was found to vary in elevation in a regular manner, but individual unit thicknesses and the relative separation between units were found to have no statistically significant variation between the northern and southern limits of the underground facility horizon (ref. 5-3).

Figure 6-4 shows the reference stratigraphy developed by this statistical analysis. This stratigraphy consists of 1 polyhalite bed, 2 argillaceous halite units, 7 anhydrite beds, 12 clay seams, and halite as the remaining constituent. This reference stratigraphy extends approximately 165 feet above and below the facility level. The location and thickness of the various units were adjusted by averaging values determined from the core holes. Geologic maps of the SPDV exploratory and ventilation shafts and the log of borehole ERDA-9 were used for units outside the WIPP underground facility horizon. The uniformity of the rock in the core holes and shafts, the lack of a statistically significant variation in unit thicknesses and elevation, and the expected small influence of any differences on structural behavior resulted in a decision to use the same reference stratigraphy throughout the site.

Subsequent to the development of the September 1983 reference stratigraphy, additional core holes were drilled and logged, the ventilation shaft was enlarged to the waste shaft, the exhaust shaft was completed, and both of these shafts were geologically mapped. Based on additional data from these activities, a generalized stratigraphic column of the underground facility horizon was developed (Figure 6-2 and Table 6-3). This stratigraphic column does not vary significantly from the earlier 1983 reference stratigraphy. Therefore, the 1983 reference stratigraphy continued to be used for model calculations.

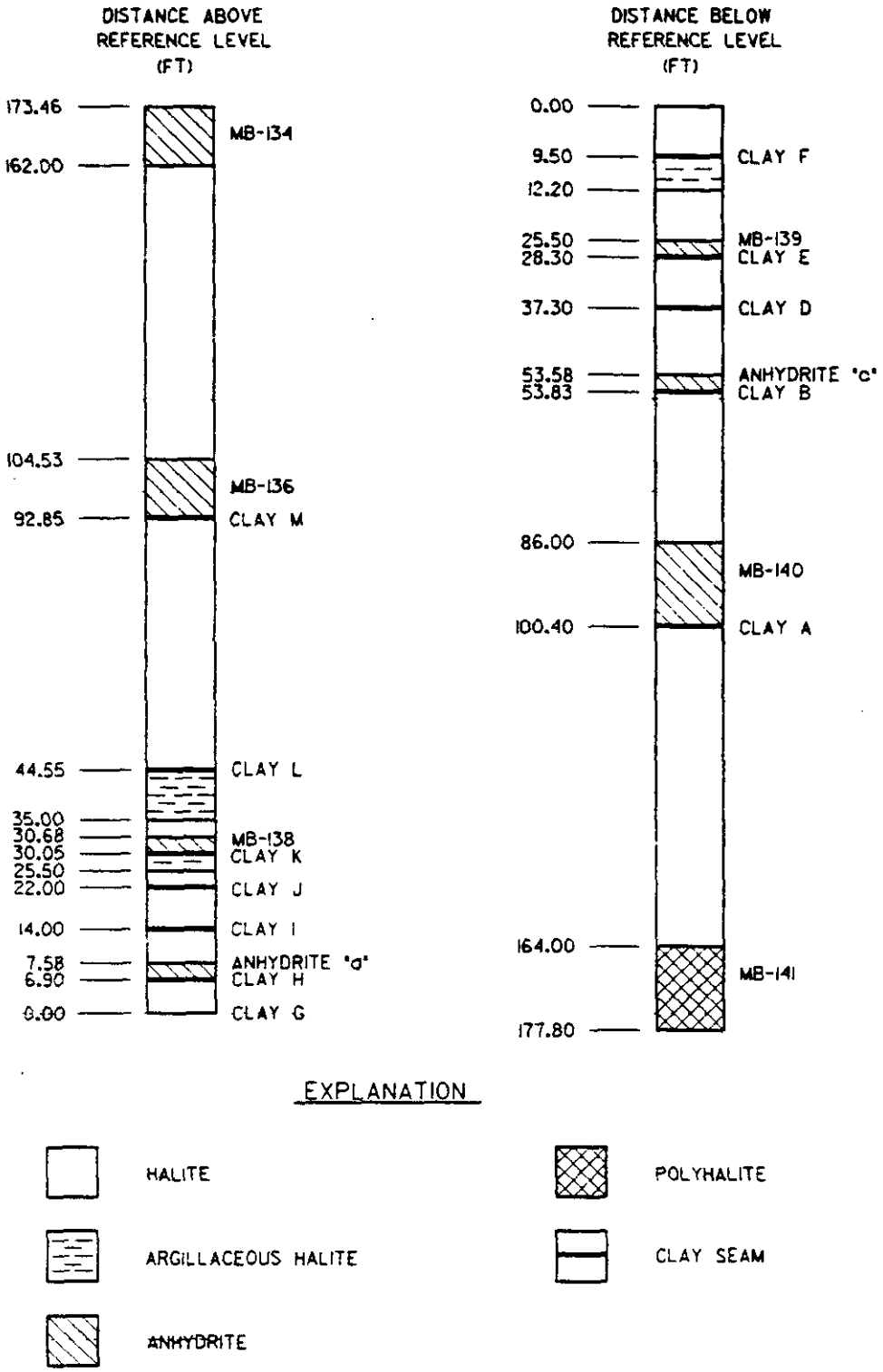


Figure 6-4

REFERENCE STRATIGRAPHY

6.3.2 Lithology

The Salado formation is predominantly halite, but other evaporite minerals and argillaceous materials are present that may locally compose up to 50 percent of the salt. Anhydrite, an early-precipitated evaporite mineral, is found in beds (usually less than 5 feet thick) which are typically underlain by a clay seam (1/16 to 3/4 inch thick). Polyhalite, a late-forming evaporite mineral, is commonly found as an accessory mineral in the Salado formation. Clay and silt may be found disseminated through the halite or in thin seams, partings, or breaks. Following is a description of the major lithologies occurring within the underground facility horizon.

Clear Halite. These units consist of halite with only trace amounts of impurities. The halite is predominantly medium to coarsely crystalline and clear to very light gray or moderate reddish orange. Less commonly, it occurs as finely crystalline, opaque, very light gray halite with a sucrose texture. Trace impurities of clay and/or polyhalite are generally dispersed in the halite. Scattered very light gray to white anhydrite or magnesite stringers may be present.

Polyhalitic Halite. These units are composed mainly of medium to coarsely crystalline halite with accessory amounts of polyhalite. As the polyhalite content increases, the color of the rock changes from transparent light orange-pink to translucent moderately reddish orange/brown or dark reddish brown. The polyhalite occurs primarily as interstitial blebs or patches and, less commonly, in stringers about 1/4 to 3/4 inch thick.

Argillaceous Halite. Six argillaceous halite units, three above and three below clay G, occur within the underground facility horizon. Generally, these units consist of medium to coarsely crystalline and some finely crystalline halite with from less than 1 to as much as 5 percent silty clay. The clay is predominantly brown in color with some gray. It is commonly intercrystalline or forms scattered breaks or partings. Discontinuous clay seams are present locally. The percent

of clay is a visual estimate; laboratory measurements of insolubles (ref. 6-5) were used as a reference.

The contacts between these units and the surrounding materials vary from gradational to distinct. Clays F, K and L occur at the upper contact of three of these argillaceous units. The three units below clay G are exposed in the underground drifts and rooms. These are geologic map units 2 and 4 and the upper portion of map unit O (Figure 6-2). They are exposed continuously throughout the openings except in the waste experimental area which is stratigraphically higher. Map unit 2 is very thin and absent in places.

No significant moisture is associated with these argillaceous halite layers. Commonly, they are slightly moist immediately after excavation and locally develop brine blisters on the walls of the underground openings.

Anhydrite. These beds range in thickness from a few inches to a few feet. Because they are readily identified, the anhydrite beds in the vicinity of the facility level have served as reference units.

Three anhydrite beds, 0.15 to 1.05 feet thick, are present above and two beds, 0.3 and 2.5 to 4 feet thick, are present below the facility level (Figure 6-2). All of the beds are laterally continuous and each is underlain by a thin clay seam. Locally, very thin anhydrite seams are associated with identified clay seams and scattered anhydrite stringers are common in several of the halite units. The anhydrite is microcrystalline and commonly ranges from a very light gray to medium gray-green color, although it is sometimes a moderate reddish to pinkish color. Halite growths are common, especially within MB-139. Anhydrite "a" commonly contains a clear halite seam up to 1 1/2 inches thick.

MB-139 is the thickest anhydrite unit within the underground facility horizon and is the most variable in color and composition. It is

described here in detail because of its importance in the deformational behavior of the underground openings, particularly the test rooms (Chapter 11).

MB-139 ranges from 2.5 to 4 feet thick. For mapping purposes, it has been divided into two subunits (Appendix G, Figures G-10 through G-34). Subunit A corresponds to Zones I, II and III described in reference 6-6. This subunit consists predominantly of reddish polyhalitic anhydrite and anhydrite mixed with light to medium gray anhydrite. Pods, lenses and seams of light to very light gray anhydrite are commonly scattered throughout the subunit. Irregular halite growths, ranging from less than 1/16 to more than 25 square inches, are common, especially in the upper half of subunit A. Commonly, a 1- to 2-inch thick seam of moderately reddish-orange to gray polyhalitic anhydrite with scattered halite and polyhalitic halite growths occurs along the upper contact. This corresponds to Zone I described in reference 6-6. Swallowtail growth patterns and hopper crystals are occasionally present in the upper 12 inches of subunit A, commonly within an upward undulation of the marker bed. Halite-filled fractures are found in places within the undulations. Scattered within the reddish polyhalitic anhydrite is an irregular and sometimes discontinuous layering of light gray anhydrite, which varies from less than 1/8 inch to 1/2 inch thick. Pods and lenses of gray anhydrite are often faintly aligned, although discontinuously, with the general trend of the layering. These pods and lenses are most prevalent in the lower half of subunit A.

Subunit B corresponds to Zones IV and V in reference 6-6. Its contact with subunit A is diffuse and based mainly on a change in color. Subunit B consists of light to medium gray anhydrite. Some core samples exhibit layering which faintly follows the general trend of the layering in subunit A. Halite growths are present, but to a much lesser degree than in subunit A. Usually the lower 4 to 8 inches of the subunit is faintly laminated and contains a few halite growths. A subhorizontal halite layer, usually less than 1/8 inch thick, is occassionally present close to the lower contact.

The upper contact of MB-139 is undulatory. The lower contact is underlain by clay E. This clay ranges from 1/4 inch to 1 1/2 inches thick. It is often slightly moist and sometimes wet.

Clay Seams. Characteristics of the clay seams within the underground facility horizon are shown on Figure 6-3 and summarized in Table 6-4. These include qualitative and/or quantitative characterizations and descriptions of the clay seams in terms of the following:

(1) color;
(2) thickness;
(3) moisture;
(4) grain size;
(5) consistency/plasticity;
(6) planar trend; and
(7) continuity/uniformity.

This information has been gathered through a review of core hole logs, geologic mapping and inspection of existing exposures.

The clay seams underlying anhydrite beds usually vary from less than 1/8 inch to 3/4 inch in thickness but may range up to 1 1/2 inches thick, as is common for clay E. The other, less continuous seams are usually less than 3/4 inch thick but may be as much as 2 inches thick, as is clay L in the C & SH shaft. Clay M-1 was as much as 3 1/2 inches thick in one hole but it consisted of a mixture of clay and halite crystals at this location.

Generally, the seams consist of clay with some silt. The clay varies from gray to brown in color. Only field classifications of the clay in core and underground exposures have been performed. These classifications indicate that the seams generally consist of soft to hard, medium plastic material. Locally, fine to coarse halite crystals are present in some of the seams. Clays F and M-1 commonly contain

Table 6-4

CLAY SEAM CHARACTERISTICS

Seam	Rating[1]	Color	Thickness	Moisture	Grain Size	Consistency/ Plasticity	Planar Trend	Continuity/ Uniformity	Occurrence
B	1	Gray	< 1/8 to 1/4 in. average; locally up to 1 1/4 in.	Dry to slightly moist.	Passes #200 sieve.	Generally hard.	Slightly irregular; generally low angle in core but locally up to 35°.	Continuous.	Present in core holes and C & SH and waste shaft mapping.
D	2	Gray	≤3/4 in.	Dry except hole DD-57 where clay is moist; hole drilled with fluid.	Passes #200 sieve.	Hard to medium soft; medium to highly plastic.	Near horizontal in core.	Varies from zone of breaks to seam with associated anhydrite.	Present in many core holes and in C & SH shaft mapping
E	1	Gray	1/4 to 1 1/2 in.	Locally moist to wet.	Passes #200 sieve.	Soft to hard; medium plastic	---	Continuous.	Present in many core holes and in C & SH and waste shaft mapping.
F	2	Gray, sometimes brown.	<1/8 to 1/2 in.	Slight.	Passes #200 sieve. Commonly mixed with halite crystals.	Slightly plastic.	Very irregular; undulations of 2-in. to 8-in. amplitude.	This is at the upper contact of map unit 4; locally discontinuous; sometimes bifurcates into two seams.	Exposed along walls of many of the facility level drifts and rooms.
G	1	Gray	Trace up to 3/8 in.	Slightly to moderately moist; weeps along exposures in underground excavations.	Passes #200 sieve.	Soft to hard; medium plastic.	Fairly regular; undulations average <2-in. amplitude.	Continuous.	Found in most core holes, shaft mapping and underground waste experimental area excavation.
H	1	Gray; brown in several core holes.	Average ≤1/4 in. but ranges from trace up to 1/2 in.	Slightly to moderately moist.	Passes #200 sieve.	Medium plastic.	Fairly irregular; undulations of 1-in. to 3-in. amplitude.	Continuous.	Found in most core holes, shaft mapping and underground waste experimental area excavation.

Table 6-4 (continued)

CLAY SEAM CHARACTERISTICS

Seam	Rating (1)	Color	Thickness	Moisture	Grain Size	Consistency/ Plasticity	Planar Trend	Continuity/ Uniformity	Occurrence
I	1	Brown-brownish gray in core; gray where exposed in waste experimental rooms.	<1/4 to 5/8 in.	Slightly moist.	Passes #200 sieve; some scattered halite crystals locally.	Hard in some core holes; medium plastic.	Regular; undulations generally <1-in. amplitude.	Fairly continuous.	Commonly found in core holes, C & SH and exhaust shafts; also exposed in waste experimental room excavation.
J	3	Reddish-brown	1/2 in. in C & SH Shaft only.	---	Passes #200 sieve; trace silt, trace to some halite crystals.	---	---	Generally found as scattered breaks or localized argillaceous zone.	Found in C & SH shaft as 1/2 in. seam; not found in other shafts; in core holes, found as scattered breaks or localized argillaceous zone; absent in many core holes.
K	1	Brown, sometimes gray to gray-brown.	3/4 to 1 1/2 in.	Dry to moist; locally wet.	Passes #200 sieve; claystone in exhaust shaft.	Hard to medium hard; medium plastic.	Generally low angle contact in core; fairly regular.	Continuous.	Present in many core holes and shafts.
L	3	Brown	Up to 2 in. in C & SH shaft; usually found only as top of argillaceous unit.	---	Passes #200 sieve; some halite crystals.	---	---	Not a continuous seam; it is found generally as the top of argillaceous zone throughout core holes and shafts.	Exposed in C & SH shaft as seam; otherwise only noted as top of argillaceous unit.

Table 6-4 (continued)

CLAY SEAM CHARACTERISTICS

Seam	Rating[1]	Color	Thickness	Moisture	Grain Size	Consistency/ Plasticity	Planar Trend	Continuity/ Uniformity	Occurrence
M-1	4	Brown	<1/16 to 1/2 in.	Dry	Passes #200 sieve.	---	---	Unknown.	These two layers found in core holes in waste experimental area; not noted in shaft mapping.
M-2	4	Brown	Up to 3 1/2 in.	Dry	Clay mixed with halite crystals.	---	---	Unknown.	

Notes:

(1) Key to "Rating": 1 - continuous throughout facility level;
2 - generally continuous, but varies in character and regularity;
3 - discontinuous and not always well developed;
4 - continuity unknown.

(2) Clays B, E, G, H and K are sometimes noted as only a trace or not at all on core logs. This is usually because core grinding or washing during drilling removed evidence of clay.

(3) Some core logs note clay layers are moist. In holes drilled with brine, this may be due to drilling fluid. Many layers are dry in holes drilled with air. These may actually be slightly moist in the in situ state, but dried out by the drilling process.

(4) Clays B, E, G, H and K always underly continuous anhydrite layers. Clays I and D are commonly associated with thin anhydrite layers.

(5) Plasticity and consistency based on evaluation of in situ condition.

more halite mixed with the clay/silt fraction. Clay F also appears to be more silty and less plastic than the other seams.

Generally, the clay seams are slightly moist in their in situ state. However, some of the seams are wet and exhibit some brine weeping in places. This was observed for clays E, G, H and K in some core holes. The clay seams in some of the holes where brine was used as a drilling fluid were observed to be moist. This was probably due in part to the drilling fluid. In contrast, clay seams were observed to be dry in many of the core holes drilled using air circulation. It is expected that, in the in situ state, these seams contain a slight amount of moisture which was evaporated as a result of the drilling method. Some moisture can be seen along exposures of clay H and clay G in the waste experimental area. More moisture is evident along clay G and some salt blisters have accumulated locally along this seam. The clay seams exposed in the underground openings are generally slightly moist during and immediately after excavation. Some seams have continued to expel moisture long after excavation. Often, however, they dry out at the surface within a few days after their exposure.

Clays G, H and I, exposed in the waste experimental area, commonly contain white specks which may be salt resulting from the air drying of the clay. The clay usually has a slightly salty taste. These white specks are soft, can be easily crushed between the fingers, and have a slightly bitter taste.

The consistency of the clay encountered in the core holes and excavations is related to its moisture content. When wet or moist, the clay is generally soft to medium stiff and can be picked out with the fingers and molded into a ball in the hand. When the clay is only slightly moist or dry, it is stiff to hard and is difficult to work in the hand.

6.3.3 Structure

Geologic mapping of the underground openings has not identified any faults, joints, significant folds, or other structural disruptions that could affect the suitability of the WIPP facility for storing radioactive waste. Very small scale (approximately 1 foot), localized disruptions of the bedding have been encountered. These are attributed to penecontemporaneous processes.

Detailed correlations between vertical core holes, combined with the results of geologic mapping in the drifts and test rooms, indicate that the strata within the underground facility horizon are deformed slightly into a sinusoidal shape. Figure B-4 in Appendix B depicts this shape, but greatly exaggerates the amplitude of the deformation. The amplitude of the fold is approximately 10 to 15 feet and its wavelength is approximately 2,000 to 3,000 feet. The fold is superimposed on a gentle southward dip.

The deformation of the strata is post-depositional in origin. While undulations of depositional surfaces are common, all of the strata in the interval from 50 feet above to 50 feet below the facility level exhibit parallel undulations. This consistency in folding over a relatively large interval containing numerous depositional sequences suggests that the beds were deformed after deposition. The folding is a minor feature which does not adversely affect the suitability of the facility for waste storage.

6.4 PROPERTIES OF HOST ROCKS

As discussed in subsection 6.3.2, the underground facility horizon is composed of halite containing beds of argillaceous halite, anhydrite, polyhalite and thin clay seams. Laboratory tests were performed to determine the constitutive equations and material property constants for these host rocks (ref. 5-3). Subsections 6.4.1 and 6.4.2 present the properties of the host rocks based on laboratory and in situ data. In situ closure measurments were also used to "back calculate" the creep parameters for halite.

6.4.1 Laboratory Tests

Laboratory tests were performed on core samples from surface boreholes at the WIPP site prior to the initiation of underground excavation (ref. 5-3). Material property constants determined from the laboratory tests are presented in Tables 6-5 through 6-7. Table 6-5 shows the elastic constants for halite, argillaceous halite, anhydrite and polyhalite.

The failure criteria for both anhydrite and polyhalite were defined based on the results of the laboratory tests. One such criterion is Mohr-Coulomb, which defines failure in terms of friction and cohesion. Failure means that the material is unable to hold a deviatoric stress beyond a certain value. Once this value is reached, the material starts yielding. However, the Mohr-Coulomb criterion ignores the effect of intermediate principal stress on failure. In terms of principal stresses at failure,

$$(\sigma_3 - \sigma_1) = 2\Theta_o \cos\beta - (\sigma_3 + \sigma_1) \sin\beta \qquad (6\text{-}1)$$

where: Θ_o and β are Mohr-Coulomb parameters; and

σ_1 and σ_3 are principal stresses that are positive in tension.

Because the process of yield must be independent of the choice of axes, the failure criterion must be independent of the choice of axes and should be expressed in terms of stress invariants. The Drucker-Prager yield criterion is expressed as follows:

$$\sqrt{J_2'} = c - aJ_1 \qquad (6\text{-}2)$$

where: $\sqrt{J_2'}$ is the second stress invariant and is equal to $\bar{\sigma}/\sqrt{3}$; and

J_1 is the first stress invariant:

$$J_1 = \sigma_1 + \sigma_2 + \sigma_3 \qquad (6\text{-}3)$$

$$\bar{\sigma} = \frac{1}{\sqrt{2}} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2} \qquad (6\text{-}4)$$

Table 6-5

ELASTIC CONSTANTS DETERMINED FROM LABORATORY TESTS

MATERIAL	E (ksf)	υ
Halite	647,450.	0.25
Argillaceous halite	647,450.	0.25
Anhydrite	1,568,500.	0.35
Polyhalite	1,155,000.	0.36

Note:

E = elastic modulus

υ = Poisson's ratio

Table 6-6

FAILURE CONSTANTS DETERMINED FROM LABORATORY TESTS

	ULTIMATE				YIELD			
MATERIAL	Θ_o (ksf)	β (^{o})	a	c (ksf)	Θ_o (ksf)	β (^{o})	a	c (ksf)
Anhydrite	627.	37.0	0.279	752.	564.	29.0	0.226	689.
Polyhalite	395.	51.0	0.395	414.	359.	46.5	0.361	403.

Table 6-7

CREEP CONSTANTS DETERMINED FROM LABORATORY TESTS

MATERIAL	PRIMARY CONSTANTS A	B	$\dot{\varepsilon}^*$ (sec^{-1})	SECONDARY CONSTANTS D ($ksf^{-4.9}$ sec^{-1})	n	Q (kcal/mole)
Halite	4.56	127	5.39×10^{-8}	4.96×10^{-13}	4.9	12.0
Standard Error				1.05×10^{-13}	0.27	0.65
Argillaceous Halite	4.56	127	5.39×10^{-8}	1.49×10^{-12}	4.9	12.0

For anhydrite, however, the ultimate strength decreases somewhat with the change in strain rate. That is, a 10 percent decrease occurs as the strain rate is decreased from 10^{-4} sec^{-1} to 10^{-6} sec^{-1}. For polyhalite, the ultimate strength is assumed to be independent of the strain rate. Table 6-6 shows the failure constants for anhydrite and polyhalite.

Table 6-7 shows the creep constants for halite and argillaceous halite. Although the data for most individual creep tests are internally consistent, steady-state creep rates obtained from different specimens tested under the nominally same conditions may scatter by an order of magnitude. Nevertheless, statistical analysis has resulted in a "best fit" to the data. Table 6-7 also shows the deviation of the secondary creep constants for halite. It was concluded that when such large deviations or uncertainty exist, calculations using mean values are apt to be meaningless and the design process requires considerable judgement (ref. 6-7).

Based on laboratory tests, the failure criterion of halite can be described using a failure function ø, such that when ø becomes positive, halite no longer supports any deviatoric stress. The function ø is assumed to be:

$$\phi = \bar{\varepsilon} - 0.023 - f(p) \qquad (6\text{-}5)$$

where: $\bar{\varepsilon}$ is the effective creep strain (see Appendix C) and the function f(p) is expressed as:

$$f(p) = \begin{cases} 0.132 & \text{for } p \geq 125.26 \text{ ksf} \\ p(a - bp) & \text{for } p \leq 125.26 \text{ ksf} \end{cases} \qquad (6\text{-}6)$$

where: p, the pressure in ksf, is expressed as

$$p = - \frac{\sigma_1 + \sigma_2 + \sigma_3}{3} \qquad (6\text{-}7)$$

and is positive in compression; and

a and b are equal to 2.122×10^{-3} ksf^{-1} and 8.487×10^{-6} ksf^{-2}, respectively (ref. 5-3).

Equation 6-5 indicates that if $\bar{\epsilon} \geq 0.023 + f(p)$ at any point in the halite, yielding will be initiated at that point. For p greater than 120 ksf, the failure effective strain is about 0.16.

Laboratory test results have also shown that a clay seam will be active for a frictional coefficient of 0.4, and that clay seam separation is unlikely unless the seam is very near the opening.

The average unit weight of the salt within the reference stratigraphy interval was determined to be 143.6 pounds per cubic foot (pcf) (ref. 5-3).

6.4.2 In Situ Data

In situ data was gathered from geomechanical instruments at various underground locations. The creep law shown by equation C.4-1 in Appendix C was used to fit the in situ data and to determine the creep parameters. The MARC General Purpose Finite Element Program (ref. 6-8) was used for the numerical computation based on the theory discussed in Appendix C. Table 6-8 shows the primary and secondary creep parameters determined from test room in situ data. Chapter 11 presents a more detailed discussion of the procedures used for computing these parameters.

Secondary creep parameters were also computed using in situ data from the C & SH shaft. The secondary creep parameters computed from horizontal deformations in the C & SH shaft and in the test rooms are reasonably close. The parameter based on test room wall-to-wall

Table 6-8

CREEP PARAMETERS DETERMINED FROM IN SITU DATA

MATERIAL	PRIMARY PARAMETERS A	PRIMARY PARAMETERS z (sec^{-1})	SECONDARY PARAMETER C ($ksf^{-4.9}$ sec^{-1})
Halite			
Roof-to-Floor	1.774	5.573×10^{-8}	2.588×10^{-21}
Wall-to-Wall	1.618	4.757×10^{-8}	1.361×10^{-21}

closure is 1.36×10^{-21} $ksf^{-4.9}$ sec^{-1} while the parameter based on extensometer measurements in the C & SH shaft is 1.30×10^{-21} $ksf^{-4.9}$ sec^{-1}.

6.5 SURFACE SUBSIDENCE MONITORING

The design criteria state that subsidence due to underground excavation shall not exceed 1 inch within a 500-foot radius of the waste shaft. The layout of the underground excavation and the extraction ratio requirements were established to comply with this criteria. Subsidence monuments have been installed on the ground surface above the shaft pillar area (Chapter 2, Figure 2-2). Additional subsidence monuments are scheduled to be installed above the storage area in mid-1986. These monuments will be used to determine surface subsidence during the 25-year facility operating life.

Because the storage area has not yet been excavated, actual subsidence cannot be measured. This subsidence will occur over the next 25 years. The calculations used for the reference design indicate that subsidence is not likely to exceed the criteria limit. Therefore, the reference design subsidence criteria is considered validated on a computational basis rather than on actual measurement data. A review of this conclusion may be required later when a history of actual subsidence is available.

CHAPTER 7
C & SH SHAFT

7.1 INTRODUCTION

This chapter presents the results of the design validation program for the C & SH shaft. Included are discussions of the design criteria, design bases and design configurations pertaining to the C & SH shaft. This is followed by information and data from the design validation process including the data collected, its analysis and evaluation, and predictions regarding future behavior of the shaft liner and key and the rock strata surrounding the shaft. Conclusions and recommendations are presented based on a comparison of the results of the design validation process with the reference design.

7.2 DESIGN

This section presents the design criteria and design bases used to develop the reference design for the C & SH shaft. The configuration of the shaft is discussed in Chapter 3, subsection 3.3.1.

7.2.1 Design Criteria

The Design Criteria document (ref. 2-8) contains the general concepts that were used as a guide for design of the WIPP underground openings. Table 2-1 summarizes those design criteria elements that are to be evaluated by the design validation process. The following discussion provides a summary of the elements that pertain to validation of the C & SH shaft reference design.

The design criteria specify that all shafts shall be designed for structural stability over an operating life of 25 years. The design shall also consider the requirements for shaft decommissioning and sealing. Shaft design shall prevent wall deformations which would interfere with shaft functions or affect the safety of operations within the shafts. Rock support shall be used as required to limit rock deformations and to prevent loosening and fallout of wall rock.

The time-dependent diametric closure of the shafts due to creep shall be considered in their design. The shafts shall be designed so that the minimum dimensions required for shaft functions are maintained throughout the operating life of the facility. Provisions for instruments to measure closure shall be included in the design.

Ground-water flow into the shafts shall be controlled so that no uncontrolled ground water reaches the facility level via the shafts. Ground-water pressures and inflows shall be measured throughout the construction period and operating life of the shaft.

Shaft design shall consider the requirements of decommissioning and backfilling upon termination of operations. The design shall accommodate the need to ultimately seal potential pathways between the storage facility and the biosphere.

The shaft liner shall be designed to help ensure that the shaft dimensions remain within the limits required for shaft functions, prevent ground-water flow into the shaft, protect wall rock from deterioration, and preclude the risk of rockfall from the shaft walls.

The shaft stations shall be designed to provide structurally stable excavations and pillars. Deformations of excavations and pillars shall remain within the limits required for structural functions, ventilation and safety. The excavation design shall maintain the minimum dimensions required for the operating life of the opening by accommodating closure. Closure rates used for design shall be confirmed or modified by instrument observations in the excavations. Rock bolts shall be used where necessary to provide support of the roof and walls.

7.2.2 Design Bases

The Design Basis, Exploratory Shaft (ref. 2-10) and the Design Basis, Exploratory Shaft Geomechanical Instrumentation (ref. 2-12) were the primary documents used as a basis for design of the C & SH shaft. These documents, described in Chapter 2, provided the detailed design

requirements for the C & SH shaft. Table 7-1 summarizes those design basis elements which are to be evaluated by the design validation process. The following discussion provides a summary of the major design bases for the C & SH shaft. Not all of these bases require evaluation as seen by comparing the discussion with Table 7-1.

The design bases specify that the C & SH shaft shall be designed to provide access for personnel and equipment to excavate and operate the underground facility and to provide a means by which the excavated salt can be transported to the surface. It shall also serve as the ventilation intake shaft.

The shaft liner shall be made of structural steel and have an inside diameter of 10 feet. The remainder of the shaft shall be unlined and have an approximate diameter of 11 feet 8 inches. The steel liner shall extend from 1 foot above the ground surface to the top of the salt formation at a depth of approximately 850 feet. The primary materials used to line the shaft shall be cement grout, steel casing, corrugated metal pipe, structural steel and reinforced concrete.

The liner shall protect against sloughing, fallout and deterioration of the rock formations and shall prevent water seepage into the shaft. It shall have a smooth inner surface to reduce air friction. The liner shall be designed for temporary installation loads and permanent loads. The permanent load shall consist of a hydrostatic lateral pressure starting 250 feet below the ground surface and extending to approximately 837 feet below the surface. Rock pressure shall not be used as a factor in the design analysis. Installation loads to be considered shall be the compressive and tensile forces resulting from lateral pressure due to unequal heights of drilling fluid during the various stages of installation.

During shaft drilling, ground-water flow into the shaft shall be determined. If the amount of ground water entering the shaft is determined to be unacceptable by the DOE Contracting Officer, approved

Table 7-1

VALIDATION ELEMENTS OF C & SH SHAFT DESIGN BASES

(1) Shaft Liner

a. Hydrostatic pressure is considered to start 250 feet below the ground surface and extend to the top of the key.

b. Water shall be prevented from flowing down the unlined shaft from behind the liner.

(2) Shaft Key

a. Key shall be designed to resist the lateral pressure from the salt. (Assumed to be 75 percent of the overburden pressure.)

b. Key shall be designed to resist the hydrostatic pressure from above the salt.

(3) Unlined Section

Provide 11-foot 8-inch diameter to allow for future salt creep deformation.

corrective action shall be taken to control the water inflow. The basis for determining if the amount of ground water flowing into the shaft is unacceptable shall be if the inflow exceeds an amount which can be tolerated without appreciably altering the drilling fluid characteristics as approved by the DOE Contracting Officer.

The shaft key shall be constructed using reinforced concrete and will serve as the transition element between the lined and the unlined sections of the shaft. It shall retain the rock formation and shall be provided with chemical water seals and a water collection ring with drains to prevent water from flowing from behind the liner down the unlined shaft. The key shall be designed to resist lateral pressure generated by salt creep, rock and soil overburden, and by hydrostatic pressure from above the salt. The design lateral pressure was selected as 75 percent of the overburden pressure based on the configuration of mine shafts in the vicinity of the WIPP. These shafts generally have a concrete liner that is thinner and that extends to a greater depth than the shaft key at the WIPP. Most of these shafts are at least 25 years old and show no significant deterioration or structural instability.

No liner or wire mesh is planned for the section of the shaft in the Salado formation. However, if field conditions require, rock bolts and wire mesh may be installed in zones of fractured salt.

The shaft station excavation shall be the minimum required to meet the operational and safety requirements in the shaft pillar area of the waste storage level. Supports of underground workings shall comply with Federal and New Mexico codes. The use of rock bolts and wire mesh in specific areas shall be determined by excavation conditions and code requirements. The roof, walls and floor shall be checked periodically for loose salt in accordance with applicable codes.

The bottom of the shaft shall extend below the facility level to accommodate the salt handling equipment and a sump to collect water that might enter the shaft. Should the stratigraphy of the facility

level be unsuitable for waste storage, the shaft bottom may be lowered to reach a more suitable stratigraphy.

Geomechanical instruments shall be provided to measure radial convergence (closure) of the shaft, water pressure behind the liner, salt creep, forces on the concrete key, and the variation of load on rock bolts. The type of instruments installed shall be strain gauges, pressure cells, piezometers, stressmeters, extensometers, load cells and radial convergence points.

The shaft liner, key, unlined section and furnishings shall be inspected at approximately 1 month intervals, or lesser intervals as required, to detect cracking, corrosion, deterioration and water intrusion.

7.3 DESIGN VALIDATION PROCESS

The design validation process for the C & SH shaft consists of data collection, analysis and evaluation, and predictions of future behavior. The following discussions of each of these activities have been divided into four sections: the lined section of the shaft; the shaft key; the unlined section; and the shaft station. This division is based on the different in situ and design conditions in each of these areas.

7.3.1 Data Collection

Data collection in the C & SH shaft has consisted of geologic mapping, visual inspections and geomechanical instrument measurements. The results of shaft mapping have been discussed in Chapter 6. Field observations and the geomechanical instrumentation program are discussed in the following subsections.

7.3.1.1 Lined Section

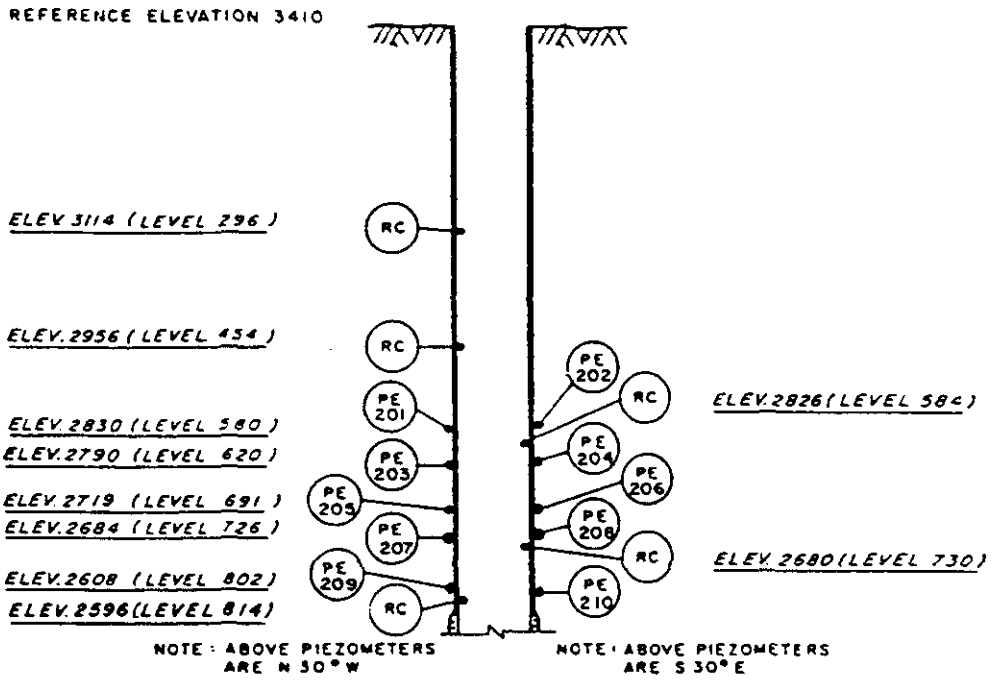
Field Observations. The C & SH shaft has been inspected on a regular basis since its construction. During the facility level construction

phase, the mining contractors conducted weekly shaft inspections for safety and shaft maintenance. These weekly inspections are being continued by the facility operator.

Site geologists inspect the shaft at approximately 6-month intervals. These inspections provide geotechnical evaluations of the condition of the shaft, and of instrument conditions and their performance. Shaft inspections were performed on the following dates: August 29, October 1, October 5, October 22, November 19 and December 3, 1983; June 2, June 21, October 13 and November 12, 1984; and April 9 and December 9, 1985. The results of these inspections are presented in the GFDRs.

Geomechanical Instrumentation. Nine sets of radial convergence points were installed in the C & SH shaft between July 7 and 17, 1982. Two additional sets were installed on October 8, 1982. Five of these 11 sets were installed in the lined section of the shaft (Figure 7-1). Plots of the convergence point data from the lined section are presented in Appendix J, Figures J-205 through J-209.

Ten piezometers were installed in the lined section of the C & SH shaft above the shaft key between July 10 and 17, 1982 (Figure 7-1). Two piezometers each are at elevations of 2830, 2790, 2719, 2684 and 2608 feet. All of these piezometers are in the Rustler formation. The piezometers at elevations of 2790 and 2684 feet are in the water-bearing dolomite members, the Magenta and Culebra, respectively. Graphic plots of piezometer data are presented in Appendix J, Figures J-34 through J-44. The piezometers are dual-component instruments containing a vibrating-wire gauge and a pneumatic gauge. The vibrating-wire gauge is the principal instrument used to measure water pressure. The pneumatic gauge is used for initial calibration and periodic performance checks on the vibrating-wire units. The vibrating-wire piezometers were connected to the datalogger on October 30, 1982. The pneumatic units can only be read manually at the instrument location; however, most of the pneumatic units are no longer functioning.



LEGEND

- PE — PIEZOMETER
- RC — RADIAL CONVERGENCE POINTS
- GE — EXTENSOMETER

NOT TO SCALE

NOTES

1. RC'S AT EACH LEVEL CONSIST OF FOUR POINTS.
2. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH IN FEET FROM THE TOP OF THE SHAFT BUNTON AT ELEVATION OF 3410.0 FT MSL. ELEVATIONS ARE FROM CEMENTATION WEST, INC., 1983, WIPP SHAFT AND STATION SURVEY.

Figure 7-1

C & SH SHAFT LINER INSTRUMENTATION

The shaft instrumentation has had a history of damage. Convergence points and especially piezometers are susceptible to damage from falling objects and construction activities. Damage in the lined section of the shaft has generally consisted of sheared data cables, sheared or bent convergence points, broken junction boxes and water damage.

Water intrusion has been a major problem with most of the shaft instruments and control systems. One water source has been the holes drilled into the steel liner for piezometer installation. The bushing in the liner through which the piezometer was installed did not have tapered threads, making it difficult to seal the hole in the liner. Leakage through these holes has generally occurred at some time in their history. It was especially difficult to effect a seal when a piezometer was reinstalled after being repaired due to other damage.

Water trickling down the liner from around these bushings has sometimes entered damaged fiberglass junction boxes and terminal boxes through cracks. Water has also seeped into the conduit connecting piezometers with the nearest junction box. This water has corroded terminal blocks and seeped down cables connecting lower terminal boxes.

A second water source has been rainfall. During periods of heavy rain, water runs down the shaft along the surface of the liner. This water can enter terminal boxes broken by impact or construction activities. Once in the boxes, it causes corrosion and cable damage.

A great deal of effort has been exerted correcting these problems. Shields were placed over boxes, cables were replaced and rerouted, and piezometers were repaired and sealed as well as possible. These measures improved performance somewhat, but problems still exist. The data acquired from the instruments is considered valid, but must be interpreted in light of the various interruptions in data monitoring. The specific details of instrument damage are updated in every GFDR, particularly in the tables of operating histories.

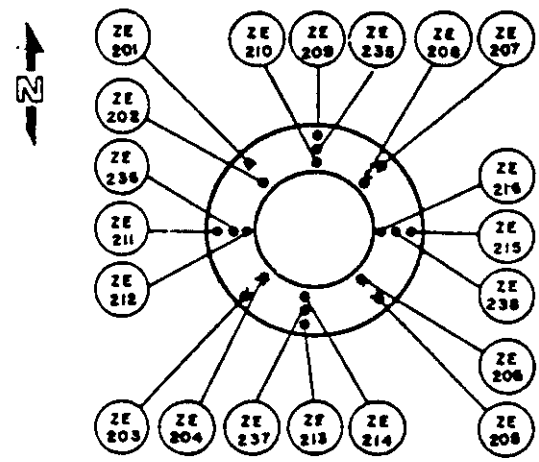
7.3.1.2 Shaft Key

Field Observations. The shaft inspections conducted on October 1 and November 19, 1983, June 2 and October 13, 1984, and April 3 and December 9, 1985, paid particular attention to the shaft key. The design of the key provides a means to determine if any water from the water-bearing zones in the Rustler formation is flowing behind the key. This situation, if it existed, could cause dissolution of the salt around the key resulting in eventual structural instability.

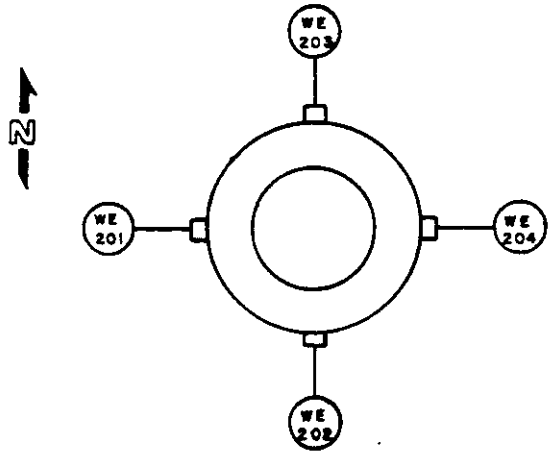
During inspection of the shaft key, the condition of four telltale drains that connect to a French drain behind the key is observed. Any moisture in the drains is noted. Similarly, other capped pipes (those for possible future injection of grout and those originally used for chemical seal injection) are checked for accumulated water. The interface between the salt and the bottom of the key receives particular attention.

The latest geotechnical inspection of the shaft key was made on December 9, 1985. The four telltale drains at the key were inspected and cleaned. Only the hole on the northwest side of the shaft was weeping, resulting in salt accumulation on the terminal box below. After chipping off this salt, a small amount of liquified chemical seal material began oozing out of the telltale. Inspection of the bottom of the key showed no evidence of seepage below the concrete.

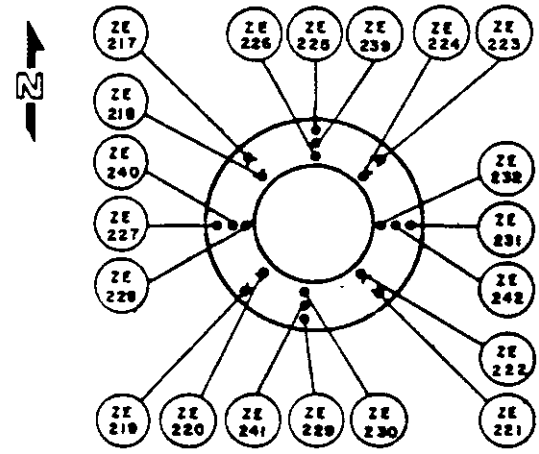
Geomechanical Instrumentation. Twenty-four embedment strain gauges, 16 spot-welded strain gauges, and 4 pressure cells were installed in the C & SH shaft key from April 11 to 17, 1982. Two piezometers were installed in the shaft key on July 10, 1982. The locations of these instruments are shown on Figure 7-2. All instruments were read manually until they were connected to the datalogger system on October 30, 1982. Appendix J contains plots of the data from these instruments. Piezometer data are presented on Figures J-44 and J-45. Figures J-54 through J-57 present pressure cell data. The strain gauge data are presented on Figures J-58 through J-97.



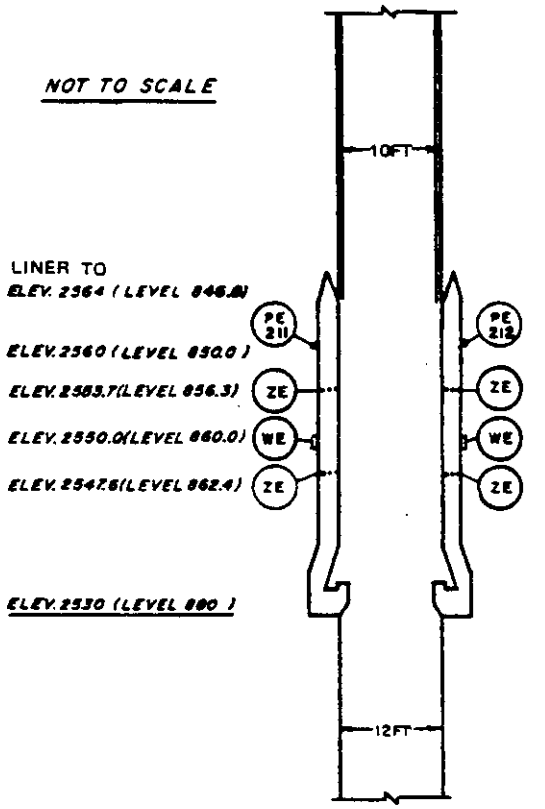
STRAIN GAUGE LOCATIONS
AT ELEV. 2553.7 FT (LEVEL 856.3 FT)



PRESSURE CELL LOCATIONS
AT ELEV. 2550.0 FT (LEVEL 860.0 FT)



STRAIN GAUGE LOCATIONS
AT ELEV. 2547.6 FT (LEVEL 862.4 FT)



SHAFT KEY (PROFILE)

LEGEND

- ZE STRAIN GAUGE
- WE PRESSURE CELL
- PE PIEZOMETER

NOTES:

1. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH FROM THE TOP OF THE SHAFT BUNTON AT AN ELEVATION OF 3410.0 FT MSL. ELEVATIONS ARE FROM CEMENTATION WEST, INC., 1983, WIPP SHAFT AND STATION SURVEY.
2. STRAIN GAUGES ARE ORIENTED HORIZONTALLY AND TANGENTIAL TO SHAFT CIRCUMFERENCE.
3. STRAIN GAUGES SHOWN AS ⊕ ARE SPOT WELDED TO REINFORCING STEEL.

M

Figure 7-2

C & SH SHAFT KEY
INSTRUMENTATION

The instruments for monitoring the shaft key, and especially their electrical boxes and cables, have had the same performance problems as the piezometers and convergence points in the lined section above. The two key piezometers have been damaged and repaired repeatedly.

The major problem in the key has been water damage inside the various electrical boxes. The worst damage was in termination cabinet LTC-1. Water seeping down inside cables connected to water-damaged boxes in the lined section of the shaft corroded the terminals in the LTC. LTC-1 links the piezometers, strain gauges and pressure cells to the surface datalogger. Several attempts were made to repair the LTC components. The components were permanently removed in October 1984 in order to avoid further damage. The shaft instrumentation system is scheduled for an overhaul during a future construction contract. Meanwhile, all LTC-1-controlled instruments are read manually during shaft inspections.

The terminal boxes for the pressure cells and strain gauges have also been damaged. Initial damage was to the fiberglass boxes and data cables as they were struck by falling objects and construction materials traveling on the shaft conveyance. Subsequent damage was by water seeping into the boxes. The boxes and cables have been repaired numerous times.

Detailed accounts of instrument damage are presented in the GFDRs, particularly in the tables of operating histories. The GFDRs also discuss data collection, data plots and interpretative problems with the C & SH shaft key instruments.

7.3.1.3 Unlined Section

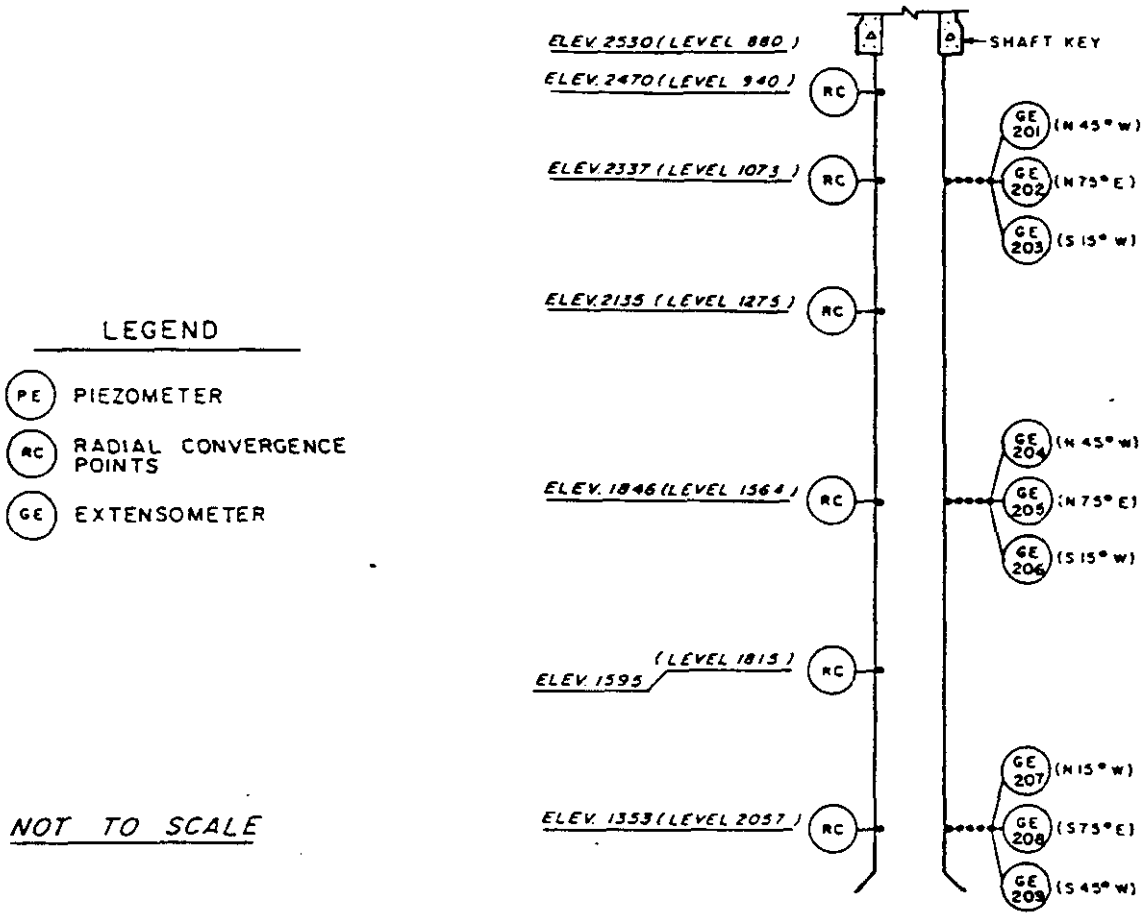
Field Observations. Shaft inspections include observations of the unlined section of the C & SH shaft. This section of the shaft consists of exposed salt forming a smooth wall. The inspections consist primarily of determining if any spalling or fracturing of the salt is occurring.

The unlined section was inspected to a depth of 2,057 feet (elev. 1353 feet) on December 9, 1985. One near-vertical fracture was observed on the west side of the shaft between a depth of 1,021 feet and 1,043 feet (elev. 2389 feet and 2367 feet). It ranged from closed to less than 1/4-inch wide at the wall surface and extended about 10 feet in length. It did not appear on the east side of the shaft. Previous shaft mapping showed the presence of halite-filled vertical fractures in anhydrite from a depth of approximately 1,023 feet to 1,038 feet (elev. 2387 feet to 2372 feet). The fracture observed appears to be one of those previously mapped. Salt blisters and precipitate were noted in various areas commonly associated with clay layers. The most notable area was a 4-foot zone around the entire shaft circumference from a depth of approximately 1,038 feet to 1,042 feet (elev. 2372 feet to 2368 feet).

Geomechanical Instrumentation. Nine borehole extensometers were installed in the unlined section of the C & SH shaft between July 6 and 8, 1982. These extensometers are arranged in three-instrument arrays at elevations of 2337 feet, 1846 feet and 1353 feet (Figure 7-3). Readings were taken manually until the extensometers were connected to the datalogger system in October 1982.

The extensometers are the multiple-point, sonic-probe type consisting of four anchors. The anchors for each extensometer were set at depths of 4, 9, 18 and 36 feet. The collar of the extensometers was recessed 1 foot into the salt. Data plots for the extensometers are presented in Appendix J, Figures J-116 through J-124.

The extensometers have not been damaged as much as the other instruments in the shaft. Their operating histories rarely show any interruption in the data. This lack of damage is a result of several factors. The diameter of the unlined shaft is 2 feet greater than that of the key or lined section. The instruments are recessed and therefore not susceptible to damage from falling objects. The extensometers are connected to LTC-2 and LTC-3, which are not directly



NOTES

1. RC'S AT EACH LEVEL CONSIST OF FOUR POINTS.
2. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH IN FEET FROM THE TOP OF THE SHAFT BUNTON AT ELEVATION OF 3410.0 FT MSL. ELEVATIONS ARE FROM CEMENTATION WEST, INC., 1983, WIPP SHAFT AND STATION SURVEY.

M

Figure 7-3

C & SH SHAFT UNLINED SECTION
INSTRUMENTATION

linked to LTC-1 and the piezometers. Thus, water damage has not been a problem.

Six sets of radial convergence points are located in the unlined section of the shaft. These points have a history of damage and replacement similar to that of the other convergence points. This history is discussed in the GFDRs. Plots of the convergence point data from the unlined section are presented in Appendix J, Figures J-210 through J-214. Only five plots are presented since damage to the set of points at elevation 1595 feet prevented the obtaining of reliable readings.

7.3.1.4 Shaft Station

Field Observations. Site geologists monitor the deformational behavior of the C & SH shaft station on a regular basis. Particular attention is given to four aspects of movement or failure: roof and wall spalling; fracturing at pillar corners; roof displacements and separations; and floor displacements, separations and fracturing. The observations are recorded at least every 3 months and have been published in each GFDR since the February 1984 issue.

A description of the C & SH shaft station excavation and roof support methods were presented in Chapter 3. The failure of resin-anchored rock bolts installed initially in the shaft station roof has been attributed to a combination of the following factors:

(1) the resin firmly held the bolt shank in place and salt creep caused failure at the first weak point;

(2) improper bolt installation resulted in damage to the threaded section of the bolt (improper torque and lack of beveled or spherical washers); and

(3) contributing factors such as corrosion and hydrogen embrittlement.

Rock bolts installed to replace the failed bolts, and subsequent bolt installations, used mechanical anchors. As the load on these bolts increases due to salt creep, the anchor yields by slipping in the hole. Although this slipping is not desirable for the roof support of underground openings in hard rock, it provides more control than rigid anchors that do not yield but instead produce sudden bolt failure as a result of the stress created by creeping salt. The slipping reduces the load on the bolt, thus reducing the potential for bolt failure, but allows continued roof support and prevents sudden roof falls. Each mechanical-anchor rock bolt supports a load that is less than its capacity, but the aggregate support provided by all of the rock bolts in a pattern is more than adequate for positive ground control. The experience at WIPP shows that the mechanical-anchor rock bolts perform well in creeping salt if periodically inspected and maintained.

The station roof and walls have exhibited continual slabbing and spalling which has required periodic scaling. Wire mesh has been installed over the entire station roof to contain any small, loose salt fragments.

Vertical fractures have developed in the pillar corners at the S90 crosscut. The condition of these fractures has been monitored and the results reported on a regular basis in the GFDRs. A discussion of fracturing at pillar corners is presented in Chapters 10 and 11.

Displacements, separations and fractures have been detected in boreholes drilled into the station roof and minor separations have been detected in some holes drilled into the station floor. Separations and fracturing at clay G and in the underlying halite were detected shortly after the initial station excavation. Horizontal displacements have been observed in various boreholes during the past 2 years.

In May and June 1986, 20 boreholes were drilled in four arrays in the shaft station to further investigate the extent of separations and fracturing in the roof and floor. This drilling was conducted as part

of a program to characterize excavation effects in the salt surrounding the openings and particularly in MB-139. This program is discussed more fully in Chapters 10 and 11.

The new boreholes were inspected for the existence of separations and fractures. Existing holes were inspected for horizontal displacements. The probe used for this inspection consisted of an aluminum rod with a 1/16-inch thick nail attached perpendicular to one end. When applying moderate pressure, the nail snags on the borehole wall if a separation, fracture, or clay seam is encountered. The separation is considered to be less than 1/16 inch wide if the nail catches on, but does not penetrate the hole wall. If the separation at the wall surface is at least the nail width (approximately 1/16 inch) there will be a slight penetration. If the separation is larger, the nail penetrates its entire 1/2-inch length into the wall. When the probe catches on the hole wall, the feature is probed on all sides of the hole. This ensures that it is a continuous feature and not a clay pocket or an imperfection caused by the drilling.

Fracture zones, anhydrite beds, or clay seams were sometimes identified by picking out pieces of the material with the probe nail. An estimate of their vertical dimension was made by moving the probe rod up and down within the limits of the feature. Occassionally a slight penetration occurred at the clay seams due to a very small separation or penetration into the softer clay.

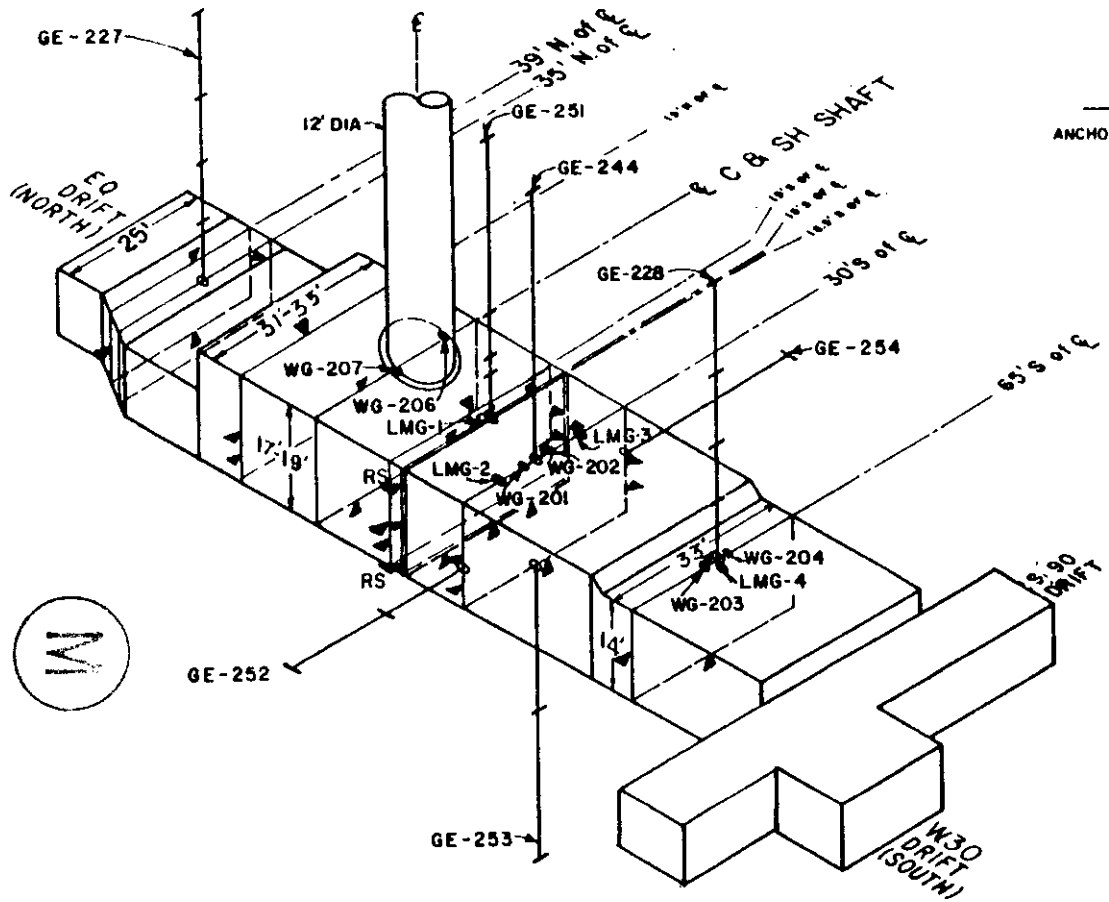
In the array of holes drilled north of the shaft, no separations or fractures were detected in the roof. In the two arrays drilled south of the shaft, multiple separations and fractures, ranging from approximately 1/16 inch to 4 inches wide, were found in most of the roof holes within the halite below clay G. Many of the fractures occur within 3 feet of the roof. Some separation and fracturing appears to be associated with clay G based on data from other holes in the station area and from the central roof holes in the two arrays, but no significant occurrence appears to have developed in the holes closest

to the station walls. A separation, less than 1/16 inch wide was detected in only one roof hole beyond a depth of 4 feet.

Only a few separations or fractures, less than 1/8 inch wide, were detected in the central floor hole of the hole array drilled north of the shaft. Some separations and fractures, less than 1/16 inch to 1 inch wide, were detected in the two floor hole arrays drilled south of the shaft. These occurrences were in MB-139 and the overlying halite. Essentially no separation was encountered at clay E at the base of MB-139. Holes drilled around the edge of the electrical substation concrete base slab foundation to investigate a potential source of its tilting encountered only small scattered separations. The total accumulated vertical separation is estimated to be less than 1/2 inch.

Geomechanical Instrumentation. As in other areas of the underground facility, a suite of geomechanical instruments was installed in the C & SH shaft station (Figure 7-4). The original instrumentation design consisted of 6 rock bolt load cells, 3 borehole extensometers, and 2 sets of convergence points. These instruments were installed between June 30 and November 16, 1982. Subsequently, 4 extensometers, 4 lateral movement gauges, 3 convergence point sets, and 1 set of wall shortening points were installed between January 8 and February 3, 1983. The purpose of this second suite of instruments was primarily to monitor any vertical or lateral movement of the immediate roof in the C & SH shaft station. The immediate station roof consists of a "beam" of salt resulting from separation along the thin clay seam beneath anhydrite "a". South of the shaft this beam is about 3 to 4 1/2 feet thick, while north of the shaft it is about 7 feet thick. Chapter 3, Section 3.2, presents a brief discussion of the underground facility horizon selection and the resulting location of the station with respect to overlying and underlying clay seams and anhydrite layers.

The data plots for the C & SH shaft station are presented in Appendix J. Figures J-146, J-147, J-163, and J-170 through J-173 show



LEGEND

ANCHOR COLLAR

GE EXTENSOMETER

RC CONVERGENCE POINT

RS WALL SHORTENING POINT

WG ROCKBOLT LOAD CELL

LMG LATERAL MOVEMENT GAUGE

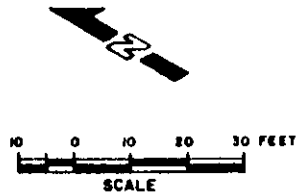


Figure 7-4

C & SH SHAFT STATION INSTRUMENTATION

the extensometer data. Convergence point data are presented on Figures J-188 through J-194 and rock bolt load cell data are shown on Figures J-192 through J-197.

Four lateral movement gauges were installed in the roof of the station. These were intended to measure lateral displacement of the salt above anhydrite "b". However, the lateral movement measurements were distorted by the vertical movement of the roof and a meaningful trend or pattern in the relative direction of horizontal movement did not develop. Therefore, reading of the lateral movement gauges was discontinued and the data are not presented in this report.

7.3.2 Analysis and Evaluation

The data collected from the C & SH shaft have been reviewed and subjected to statistical analysis, closed form solution and model simulation techniques for evaluation against the reference design parameters. The following subsections present discussions of these analyses and evaluations for the four sections of the shaft.

7.3.2.1 Lined Section

Observed Conditions. Observations of the steel liner during shaft inspections have detected no signs of deterioration. There is no indication of any liner instability due to shaft deformation. Water seepage has occurred only through the previously discussed piezometer bushings.

Structural Analysis. As a result of increasing hydrostatic pressure with depth, the thickness of the C & SH shaft steel liner and the size and spacing of its stiffener rings vary accordingly. The stiffener rings are 3-inch thick steel rings welded to the outer face of the liner. The thickness of the liner and the width and spacing of the stiffener rings for various depths are:

Depth (feet)	Plate Thickness (inches)	Stiffener Width (inches)	Stiffener Spacing (feet)
0.00 to 182.45	5/8	7-1/2	10
182.45 to 362.45	1	12	10
362.45 to 542.45	1	11	5
542.45 to 642.45	1-1/4	10-1/2	5
642.45 to 742.45	1-3/8	9	4
742.45 to 842.45	1-1/2	10-1/2	4

A structural analysis was performed for the shaft liner based on these depths and dimensions. The liner and stiffeners were made of A-441 steel fabricated into 20-foot sections by full penetration bevel welds between the liner sections and by fillet welds between the liner and the stiffeners. Radiographic acceptance examinations were performed on all welds in accordance with the American Welding Society (AWS) (ref. 7-1) and the ASME Boiler and Pressure Vessel Code, Sections VIII and IX (ref. 7-2).

A computer program was used to design the steel liner against elastic buckling between the stiffeners, elastic buckling of the combined liner and stiffener, and the yielding of the liner. This program was developed jointly by Fenix & Scisson and Southwest Research Institute and was based on Theory of Plates and Shells by S. P. Timoshenko and S. Woinowsky-Krieger (ref. 7-3).

The computational results of the analysis of the liner, based on the depths and dimensions presented above, show that the external pressure capacities and corresponding closure limits (maximum diametric changes) at the midpoint of a stiffener and at the midpoint between stiffeners are:

Depth (feet)	Pressure Capacity (psi)	Closure Limit at Stiffener (inches)	Closure Limit Between Stiffeners (inches)
0.00 to 182.45	139	0.007	0.054
182.45 to 362.45	281	0.010	0.069
362.45 to 542.45	434	0.019	0.108
542.45 to 642.45	518	0.030	0.104
642.45 to 742.45	595	0.043	0.112
742.45 to 842.45	684	0.043	0.118

In situ hydrostatic pressures determined from piezometer readings at elevations of 2830, 2790, 2719, 2684 and 2608 feet (Figure 7-1) were compared with design pressures and the pressure capacity of the liner as discussed below.

Measured Water Pressure. Piezometers are used to monitor the hydrostatic pressure exerted on the steel liner by water from the two water-bearing zones in the Rustler formation. Selected water pressure measurements are presented in Table 7-2. Because of the piezometer history of damage and leakage, the data must be used with caution. However, as expected, the data show a general trend of increasing pressure (Figure 7-5). The exceptions, 37X-PE-00211 and 37X-PE-00212, are discussed in the next subsection.

As indicated in Table 7-1, the design basis hydrostatic pressure is assumed to begin at a depth of 250 feet below ground level. This corresponds to the potentiometric surface of the water-bearing members in the Rustler formation. The hydrostatic design pressure gradient of the liner in the Rustler formation is shown on Figure 7-5. Piezometer reading data from June 1986 indicate pressures significantly less than the design hydrostatic pressure. This can be explained by a combination of the following conditions:

(1) drawdown of the potentiometric surface in the vicinity of the shafts;

Table 7-2

C & SH SHAFT LINER AND KEY
SUMMARY OF MEASURED WATER PRESSURES (psi)

Date of Reading	PIEZOMETER NO. 37X-PE-00											
	201	202	203	204	205	206	207	208	209	210	211	212
	Elev. 2830		Elev. 2790		Elev. 2719		Elev. 2684		Elev. 2608		Elev. 2560	
Pressure capacity of liner	518		518		595		595		684			
Jun. 20,'83	112	111	108	108	86	86	110	104	140	142	6	12
Dec. 3,'83	96	96	100	101	84	84	98	100	137	139	13	9
Jun. 5,'84	90	93	-	-	79	-	90	96	127	129	5	1
Dec. 27,'84	93	95	119	119	102	100	105	116	-	152	3	0
Feb. 8,'85	98	100	131	130	109	105	107	117	-	157	10	7
May 21,'85	90	93	84	81	61	44*	105	-**	146*	137*	5	6
Jun. 29,'85	89	92	91	-**	97	-**	104	-**	-**	-**	4	7
Dec. 9,'85	90	91	108	104	100	-**	108	-**	-**	-**	-1	-1
Mar. 24, '86	101	102	-	134	107	-**	104	-**	-**	-**	-2	-4
Jun. 02, '86	89	91	104	-	100	-**	108	-**	-**	-**	-	-2

NOTE: All piezometers have leaked or suffered damage at one time or another.

* Piezometer leaking.

** Piezometer removed for repair.

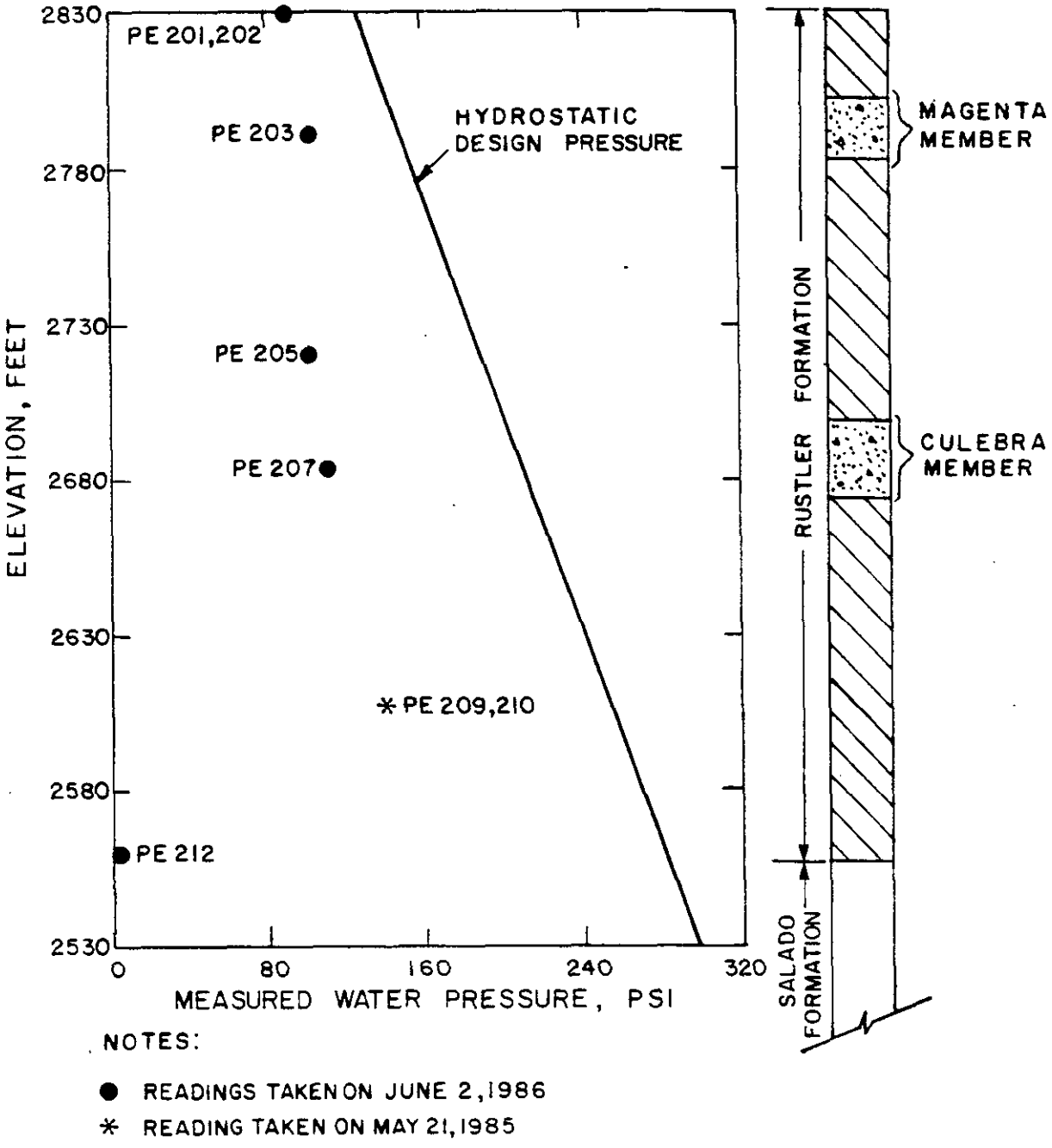


Figure 7-5

C & SH SHAFT LINER AND KEY
WATER PRESSURE DISTRIBUTION

(2) incomplete hydraulic continuity behind the liner;

(3) water leakage through the piezometer bushings and telltales; and

(4) partial plugging of the piezometer filters.

Lowering of the potentiometric surface is primarily the result of water flowing into the unlined SPDV ventilation shaft and later through cracks in both the waste and exhaust shaft liners. Hydrologic testing at the site by SNL has also contributed to lowering the potentiometric surface.

The annular space between the steel liner and the rock was filled with grout during liner installation (Chapter 3). In addition to supporting the liner, the grout was intended to help prevent water in the water-bearing zones from contacting the salt in the key area. The variations in water pressure at the different piezometer elevations, and especially the lack of a linear increase with depth, suggests that this objective has been at least partially achieved. The absence of hydraulic continuity along the rock/liner interface could prevent the water at individual piezometer elevations from achieving the anticipated pressures.

Most of the piezometers have developed leaks at some time in their history. This leakage would result in a drop in water pressure at the affected piezometer. The piezometer would then measure a water pressure that is lower than anticipated. The influence of the leaks on piezometer readings is considered to be minor because, as individual piezometers are repaired or bushings are sealed, the data plots do not show a significant change from the normal variation within the data.

The fourth cause of variation in the pressure readings could be a result of partially-plugged filters. Each piezometer contains a stainless steel, porous stone filter. It has been noted during their

repair that some filters are partially covered with salt deposits and corrosion. It is not clear how much of an effect this may have on the piezometer readings. It is possible that there is no effect if the corrosion and salt deposition occurred after the filter was exposed to the atmosphere during piezometer removal.

Closure. Closure data show the in situ diametric changes in the liner based on radial convergence point measurements at elevations of 3114, 2956, 2826 and 2680 feet (Figure 7-1). These data are considered a lower bound because the in situ readings represent only relative closures since the first readings were taken 329 days after excavation. In addition to the effect of hydrostatic pressure, the closure data are also affected by variables such as temperature and lithostatic pressure.

Radial convergence point measurements in the lined section of the shaft indicate that the maximum diametric closure is less than 0.10 inch. Since the shaft is used for ventilation purposes and is open to the atmosphere, changes in ambient temperature from around 0°F in the winter to over 100°F in the summer may affect the diametric closure by approximately 0.075 inch. Consequently, only closure data recorded at approximately the same temperature should be used for analysis.

7.3.2.2 Shaft Key

Observed Conditions. Shaft key inspections indicate that the key is stable. Certain observations, however, dictate that continuous monitoring of the key will be required. The telltale drains, connected to a French drain behind the key, drip intermittently. Several other capped pipes typically produce small amounts of water when opened after being closed for several weeks.

No water has been observed bypassing the lower chemical water seal. During the June 2, 1984, inspection, liquified chemical seal material was observed in two chemical seal injection pipes. It is likely that chemical seal material is migrating behind the key since small amounts

were observed dripping from the northwest telltale drain and from piezometer 37X-PE-00211. These fluid observations do not present any immediate cause for concern. However, the key should be monitored on a regular basis and appropriate actions taken if required to mitigate any significant increase in fluid discharge.

Inspection of the bottom of the key has revealed no evidence of seepage below the concrete. Some salt stalactites have been observed hanging from the concrete but these originate from brine dripping from the leaking piezometers or telltale drains above.

Model Simulation. The long-term impact of C & SH shaft salt creep on the concrete key was evaluated by a nonlinear computational analysis using the finite element method (ref. 7-4). The objective of the analysis was to determine the structural adequacy of the shaft key based on the appropriate ACI Codes (ref. 7-5). Site stratigraphy was considered in the analysis. The creep behavior of the salt was incorporated into the material properties used in the finite element model. The shrinkage of the concrete during initial curing was also simulated in the computation (ref. 7-6).

From the shaft geologic mapping, it was determined that the stratigraphy in the shaft key area consists of horizontal layers of halite, argillaceous halite, anhydrite and siltstone, with clay seams between some of these layers (Figure 7-6). This stratigraphy was used as the basis in modeling.

The properties for the host rock are based on laboratory test results (refs. 5-3 and 7-7) as described in Appendix C. Because the analysis was performed early in design validation, before the methods of computing primary creep and using in situ material properties were developed (ref. 5-1), the analysis included only the secondary creep of salt based on laboratory test data.

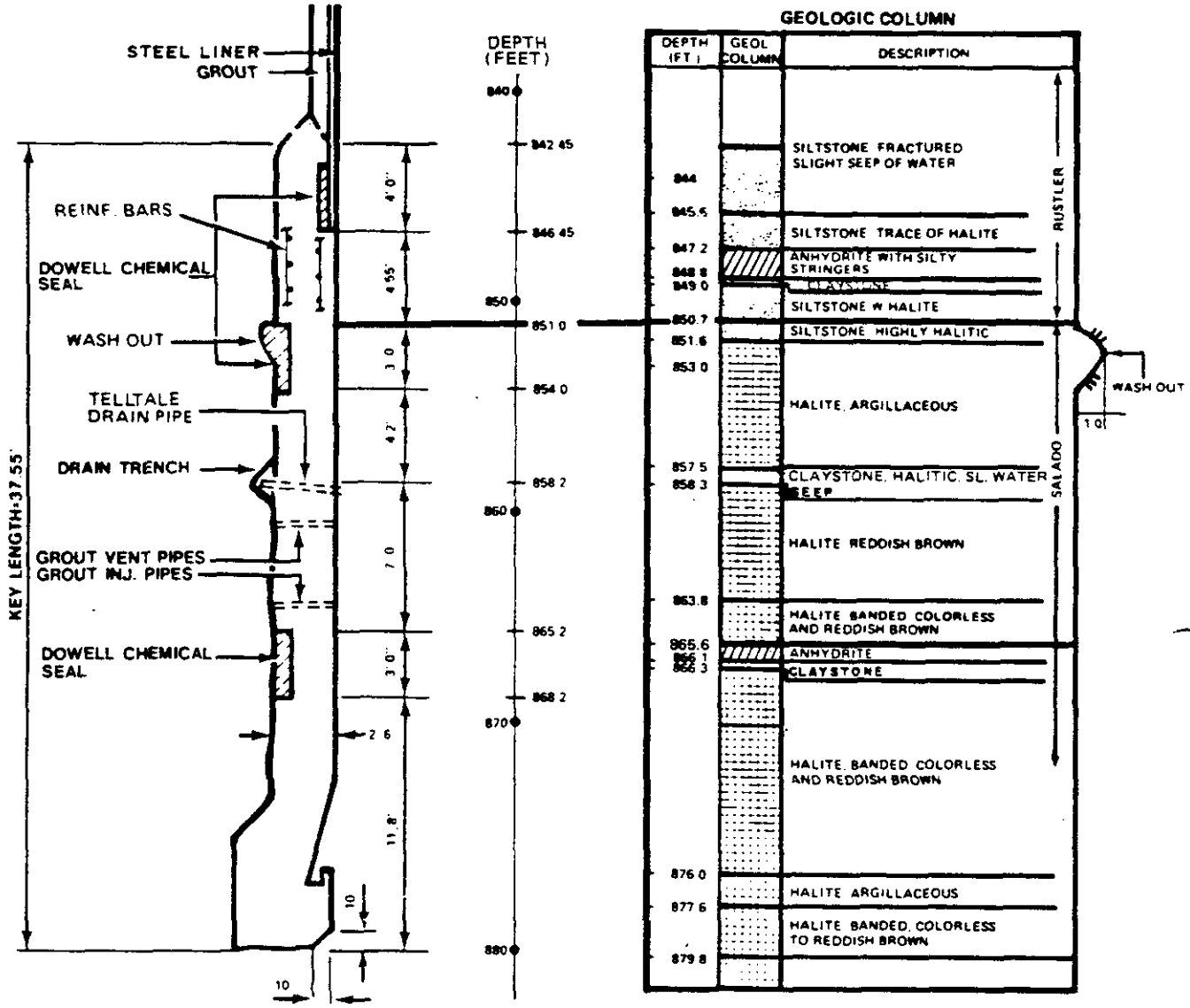


Figure 7-6

C & SH SHAFT KEY
STRATIGRAPHY

The relationship for concrete shrinkage (ref. 7-8) can be expressed as:

$$\varepsilon_{sh} = \frac{t}{35 + t} \varepsilon_{shu} C_{the} C_h C_s C_{cem} C_{fa} \quad (7\text{-}1)$$

for t in days, or:

$$\varepsilon_{sh} = \frac{t}{3{,}024{,}000 + t} \varepsilon_{shu} C_{the} C_h C_s C_{cem} C_{fa} \quad (7\text{-}2)$$

where: t is the shrinkage time in seconds;

ε_{shu} is the ultimate shrinkage strain, taken to be 0.0008;

C_{the} is the correction factor for thickness (1.17 - 0.029T);

C_h is the correction factor for humidity (1.40 - 0.010H);

C_s is the correction factor for slump (0.89 + 0.041S);

C_{cem} is the correction factor for cement content (0.75 + 0.034B); and

C_{fa} is the correction factor for percent fines and air content, taken to be 1.0.

The thickness T of the key wall is 30 inches; the humidity H is very low in the region of the key and is assumed to be 50 percent; the slump S of 4 inches is taken as the average value for 5,000 psi concrete; and B is the number of sacks of cement per cubic yard of concrete, considered to be equal to seven. The values of the correction factors C_{the}, C_h, C_s and C_{cem}, as calculated from the equations above, are 0.3, 0.90, 1.05 and 0.99, respectively.

Figure 7-7 shows the finite element model for the creep analysis. Since the structure is symmetrical about the centerline of the shaft, the shaft key and the area around it were modeled using 196 quadrilateral ring finite elements representing 18 distinct geologic layers. The MARC General Purpose Finite Element Analysis Program (ref. 6-8) was used for the analysis. To reduce the computation time, the stress and strain were computed at the centroid of each element. Four clay seams, at depths of 848.9, 857.9, 866.2 and 900.9 feet, were considered as active slip planes, represented by 25 friction and gap link elements with a coefficient of friction equal to 0.4. The outside

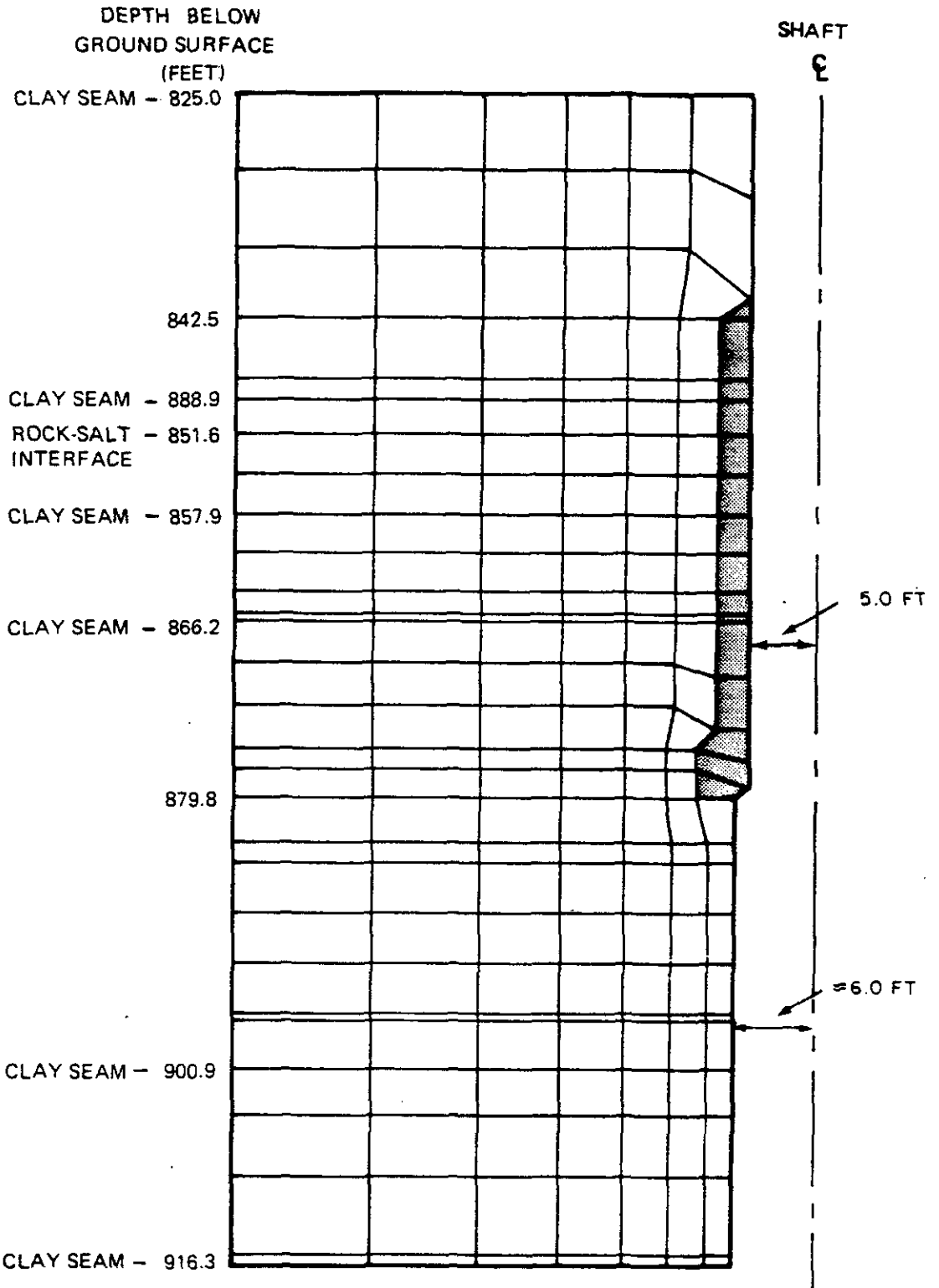


Figure 7-7

C & SH SHAFT KEY
FINITE ELEMENT MODEL

M

vertical boundary had zero horizontal displacement and the bottom boundary had zero vertical displacement. The boundary conditions at the top of the model were uniform calculated pressures based on the mass density of the geologic formation from the ground surface to the elevation of the boundaries. The lithostatic stress state was defined as described in Chapter 5, equation 5-1.

Creep analysis was performed on the mathematical model by using the procedures described in Chapter 5. The analysis was carried out for a 5-year interval without the key and a comparison was made of the corresponding radial deformations to determine the time when creeping salt would come into contact with the shrinking concrete key. The times computed for various layers behind the key were between 1.6 and 3.9 years with an average value of 2.7 years after excavation of the shaft (or 2 years after construction of the shaft key). To simulate contact of the shaft wall with the concrete key, the elements of the key were tied to the proper locations on the shaft wall and the analysis was continued for a total of 27 years (refs. 7-4 and 7-6).

Deformation. Readings from the strain gauges embedded in the concrete key show a range of strains from approximately 0.00014 in compression to 0.00021 in tension with an average compressive strain of 0.00004 through December 9, 1985. The readings from the strain gauges welded to the reinforcing steel show a range of approximately 0.00031 in compression to 0.00054 in tension with an average tensile strain of 0.00006.

Table 7-3 summarizes the changes in readings of the embedment and welded gauges at a depth of 856 feet (elev. 2554 feet) since April 22, 1982, immediately after concrete was placed for the shaft key. The trend of the change in strain readings indicates that the salt had not made contact with the key by June 1985.

Water Pressure. Figure 7-5 shows water pressure readings from piezometers 37X-PE-00211 and 37X-PE-00212. These piezometers have

Table 7-3

C & SH SHAFT KEY
SUMMARY OF STRAIN GAUGE READINGS AT ELEVATION 2554 FEET

Strain Gauge No.	Change in strain x 10^{-6} since April 22, 1982 Jun. 5, 1984	Feb. 8, 1985	Jun. 29, 1985	Dec. 9, 1985	Remarks
37X-ZE-209	-63	-59	-81	-9.5	Embedment
211	-23	-16	-34	-51	strain gauges
213	-133	-104	-139	-144	14.5 inches
215	-82	-67	-99	-111	from inner surface
235	-12	16	-23	-47	Embedment
236	56	88	37	16	strain gauges
237	-18	35	-23	-8	9 inches from
238	-63	-23	-81	-99	inner surface
210	-110	-71	-123	-154	Embedment
212	178	272	201	215	strain gauges
214	58	128	65	79	3.5 inches
216	-53*	-7	-61	-76	from inner surface
201	-93	-100	-102	-138	Strain gauges
203	-	-	444*	-	welded to the
205	-235	-286	-352	-371	outer rein-
207	-102	-127	-142	-95	forcing bar
202	-43	-	-61	-58	Strain gauges
204	443	2066	1056	541	welded to the
206	-193	-147	-230	-246	inner rein-
208	-	-	-1659**	-	forcing bar

NOTE: Negative strain change indicates compression.

• Reading taken on May 3, 1984.
** Reading taken on Dec 30, 1982.

shown a range of readings from a maximum of 30 psi in 1982 to a current reading of 2 psi. As shown on the figure and in Table 7-2, the readings of these two piezometers are consistently lower than the readings from the upper piezometers. These lower piezometers are at a depth of 850 feet (elev. of 2560 feet), just above the chemical water seal at a depth of 851 feet (elev. 2559 feet). It appears that this seal may be breached and that water is able to bypass it and exit through the French drain and telltales. Piezometers 37X-PE-00211 and 37X-PE-00212 may also be isolated from the upper piezometers by the grout that was injected behind the steel liner at a depth of 843 feet (elev. 2567 feet).

The assumption that the chemical water seal just below the piezometers may be breached is based on observations of piezometer behavior during the October 1983 inspection. As discussed in subsection 7.3.1.2, several capped pipes in the key were found to contain small amounts of water during this inspection and were drained. Prior to this, piezometers 37X-PE-00211 and 37X-PE-00212 indicated pressures of around 6 to 8 psi. After draining the pipes, both piezometers showed a drop to 2 psi within 2 days. This indicates a hydraulic connection across the water seal.

It is unlikely that water in the key originates from higher in the shaft. Detailed mapping in the shaft key noted weeps from claystone and siltstone beds at depths of 842. 846 and 858 feet. This is probably the source of the water seen in the French drain telltales and other pipes in the key. The fact that the key piezometers have had consistently lower readings than the upper piezometers indicates that there is probably no hydraulic connection with the water-bearing members higher in the shaft. The draining of water from the grout pipes influenced only those piezometers in the key; none of the upper piezometers showed any pressure drop. The existence of a source of water in the key area provides a better explanation of the dripping from the telltales and the performance of the key piezometers than does the migration of water from the water-bearing members higher in the shaft.

Salt Pressure. The four earth pressure cells installed between the concrete of the shaft key and the salt have a combined average reading of less than 10 psi in compression. These four cells, located 90 degrees apart at elevation 2550 feet (Figure 7-2), are intended to register changes in lateral pressures on the shaft key exerted by the creeping salt. Table 7-4 shows that the pressure cells have not registered any significant change in readings for a period of over 3 years since construction of the concrete key.

If we assume that the pressure cells are functioning properly, then the halite between a depth of 858 feet and 863 feet (elev. 2552 feet and 2547 feet) had not made contact with the pressure cell diaphragms as of December 9, 1985. According to the results of computational analyses, the contact between the salt and concrete will be reestablished at different elevations at different times between 1984 and 1986.

7.3.2.3 Unlined Section

Observed Conditions. The unlined section of the shaft appears to be stable with no evidence of rock spalling, wall deterioration, or dissolution by water.

Closure. Figure 7-8 compares average diametric closure readings at six elevations on December 9, 1985. The readings reflect only relative closure since the initial readings were taken nearly 1 year after completion of shaft excavation. Thus, the maximum diametric closure at a depth of 2,057 feet (elev. 1353 feet), near the bottom of the shaft, will be more than 1.0 inch. At higher elevations in the shaft, the actual diametric closure over the same period will, likewise, be higher than those shown on the figure.

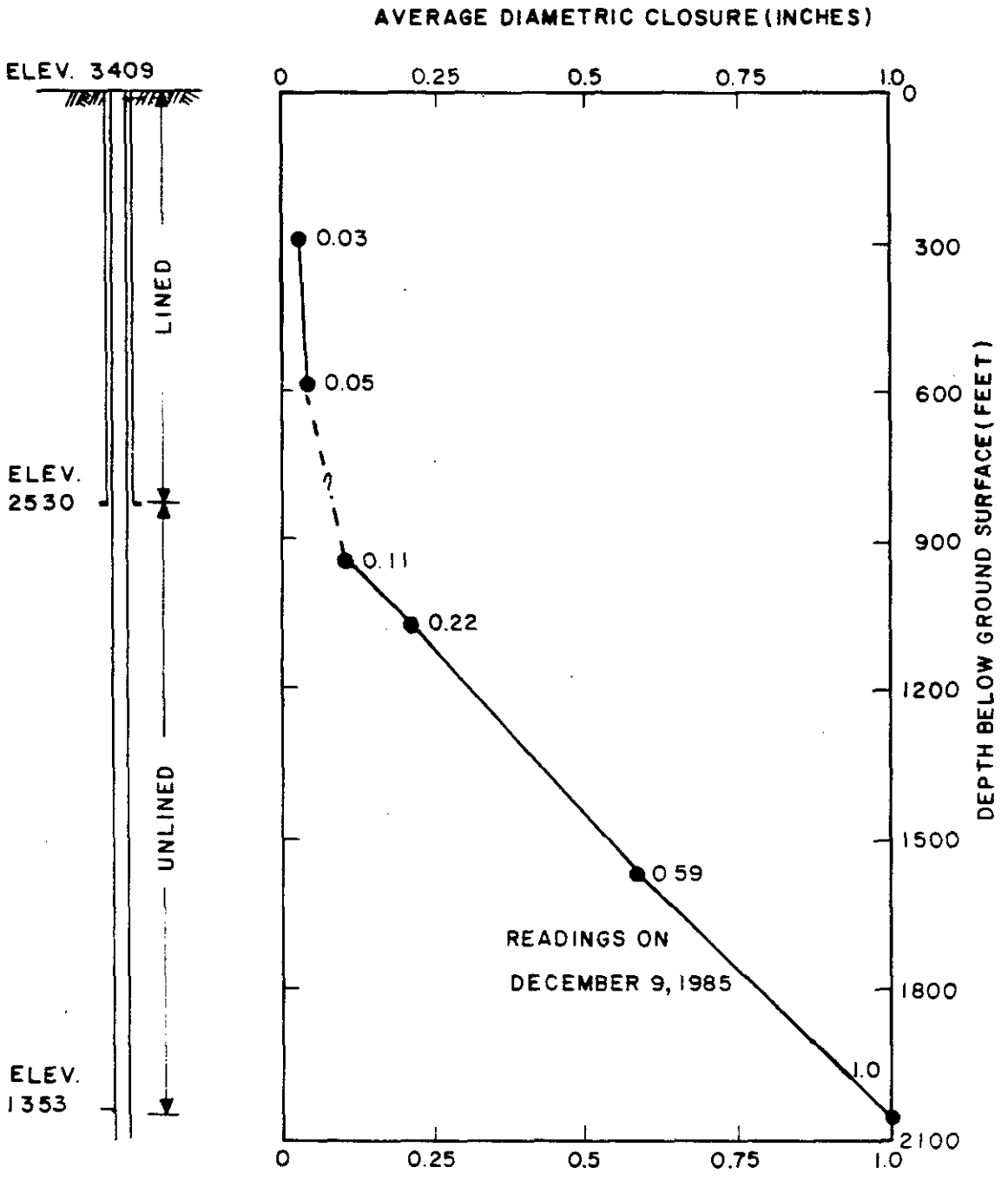
Deformation. The radial deformation of salt behind an opening can be determined from the measurements of movements of borehole extensometers with multiple anchor points.

Table 7-4

C & SH SHAFT KEY
PERFORMANCE HISTORY OF PRESSURE CELLS

Description	Pressure Cell Reading (psi) WE-201	WE-202	WE-203	WE-204	Date of Reading
Initial Irad Gage Co calibration	+1	+2	+6	+13	Feb. 3,'82
Initial SRI calibration	+8	+7	+8	+8	Feb. 16,'82
Site received, inspection	-1	+1	0	-2	Mar. 30,'82
Pre-installation, surface	-1	+1	-5	-2	Apr. 4,'82
Pre-installation, in shaft	0	-1	-2	-2	Apr. 15,'82
After plaster of paris	-2	-2	0	-2	Apr. 15,'82
After concrete placement	0	0	0	0	Apr. 15,'82
Initial installed reading	0	0	0	0	Apr. 16,'82
Time after installation:					
7 days	+2	-1	+2	+17	Apr. 22,'82
107 days	-1	-3	-2	0	Jul. 31,'82
529 days	-2	-5	-31	+1	Sep. 26,'83
530 days	+1	-3	0	-2	Sep. 27,'83
544 days	-4	-8	-32	-3	Oct. 11,'83
597 days	-4	-7	-	0	Dec. 3,'83
797 days	-1	-7	-38	0	Jun. 20,'84
938 days	-12	-11	-27	0	Nov. 8,'84
1030 days	-12	-30	-	-2	Feb. 8,'85
1140 days	-6	-10	-25	+3	May 21,'85
1179 days	-6	-11	-25	+5	Jun. 29,'85
1342 days	-14	-10	-25	-2	Dec. 9,'85

NOTE: Negative sign indicates tension.



NOTES:

1. SHAFT WAS EXCAVATED FROM JULY THROUGH OCTOBER 1981
2. CONVERGENCE POINTS WERE INSTALLED FROM JULY THROUGH OCTOBER 1982.

Figure 7-8

C & SH SHAFT UNLINED SECTION
AVERAGE DIAMETRIC CLOSURE

According to extensometer readings on September 16, 1985, the total average collar displacements at elevations 1846 feet and 1353 feet (Figure 7-3) were 0.19 inches and 0.235 inches, respectively. However, the extensometers were installed nearly 7 1/2 months after the completion of shaft excavation.

Figure 7-9 shows the collar movement time histories for multiple-point borehole extensometers 37X-GE-00202, 37X-GE-00205 and 37X-GE-00208 relative to their deepest anchor. The undulating shape of the curves appears to reflect the influence of seasonal temperature changes on the extensometers. The effect of temperature changes is more pronounced on the instrument behavior than on the salt surrounding the instrument. Figure 7-10 shows the change in calculated rates of collar movement with time for the extensometer time histories on Figure 7-9. The maximum rates coincide with the hottest months while during mid-winter the rates are close to, or slightly less than, zero. Because the time interval chosen for calculating the rate of collar movement is much less than the total observation period of 2 years, these rates are probably very close to the actual rates.

Comparison of the extensometer collar movements with convergence point readings suggests that the salt in the vicinity of the deepest anchor may also be moving. Thus collar movement does not reflect the true radial closure of the shaft. The amount of movement of the deepest anchor for any extensometer of given length can be estimated so that the collar displacement provides absolute radial closure. The diametric closure can be computed by model simulation as described below, by curve fitting as described in reference 4-19, or by closed form solution, also described in reference 4-19. Based on this analysis, the absolute movements of the collar and intermediate anchors for the 36-foot long shaft extensometers will deviate from the measured values by only 0.03 inch.

Model Simulation. The structural behavior of the unlined section of the C & SH shaft was analyzed by a nonlinear creep analysis using the

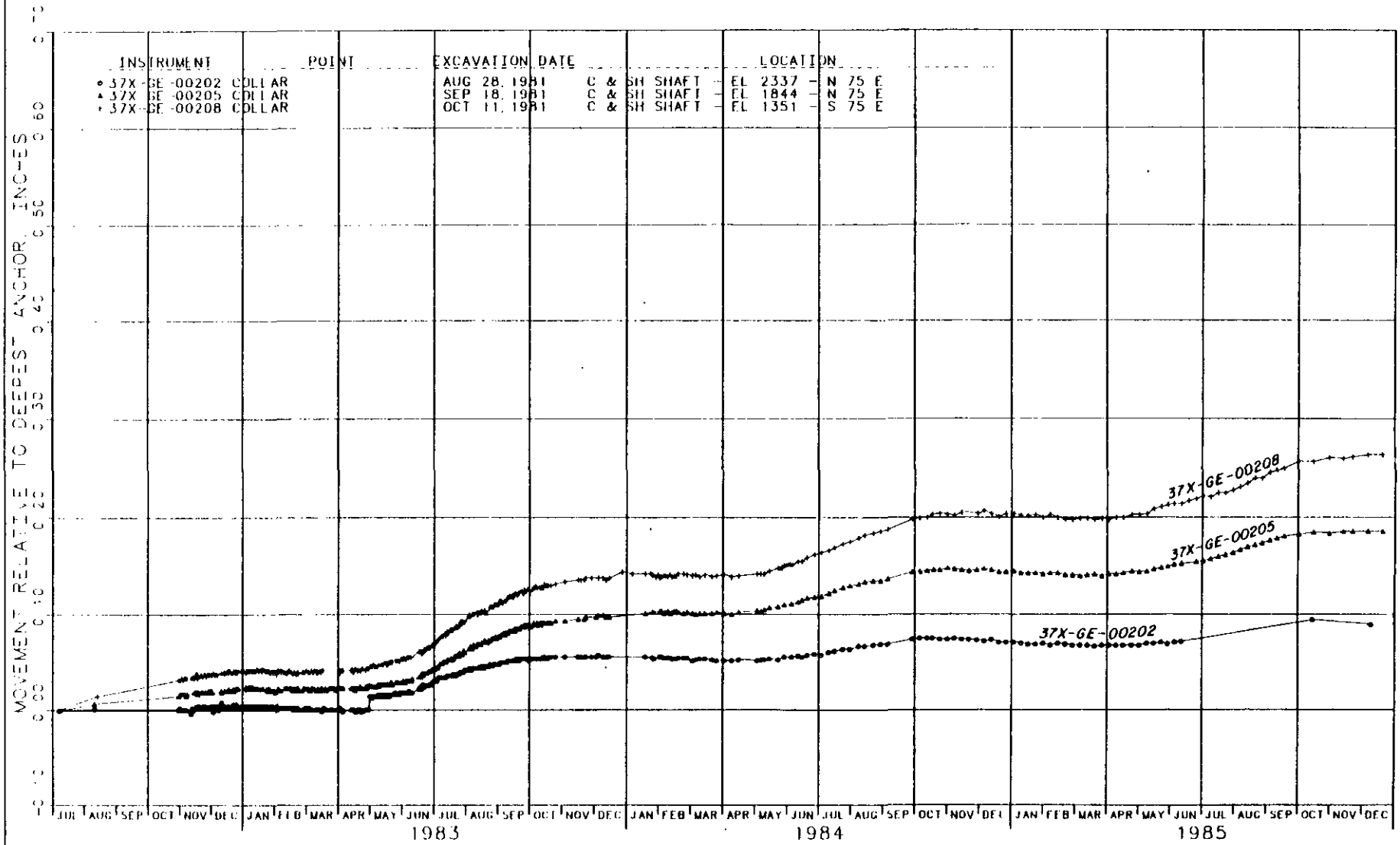
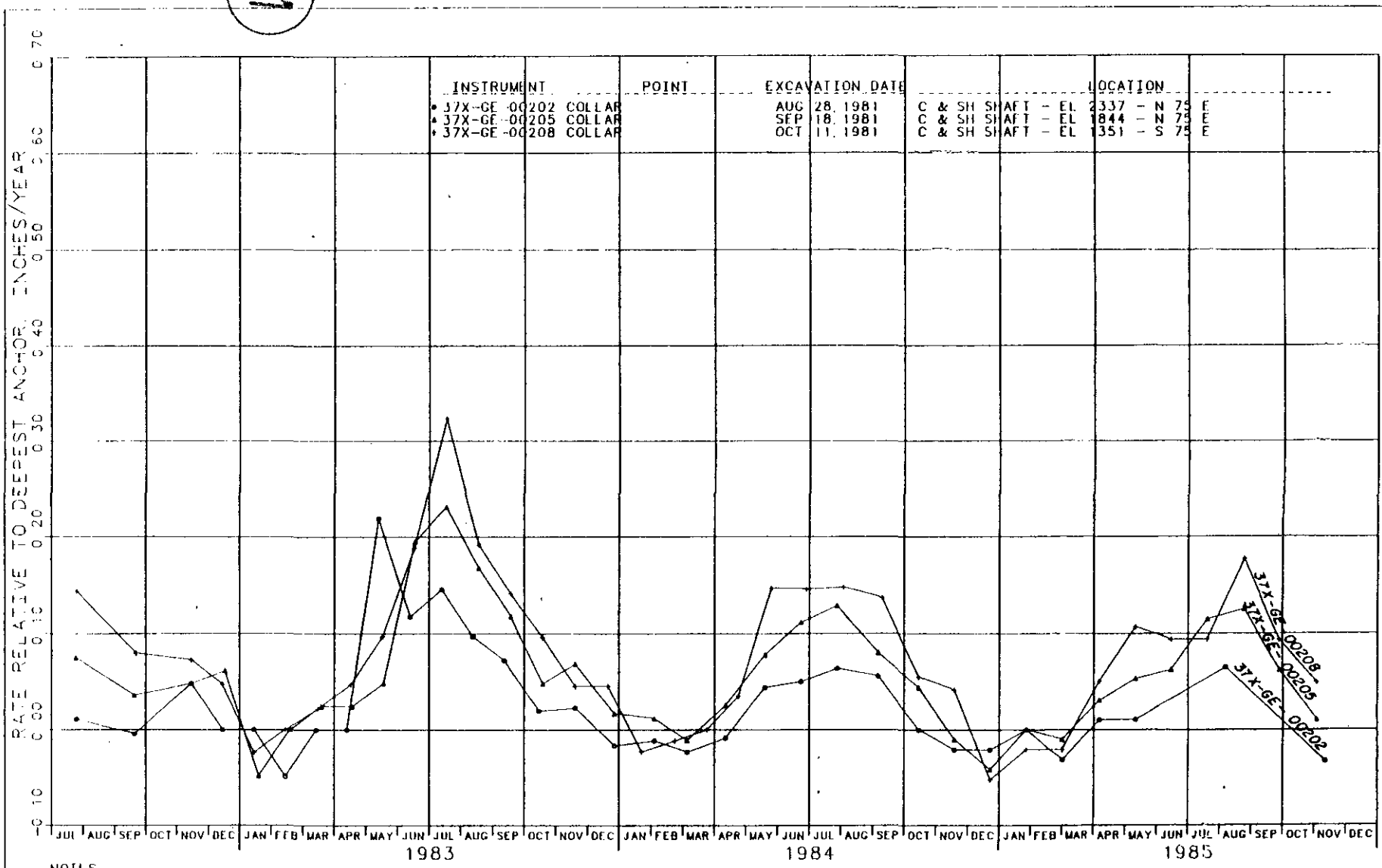


Figure 7-9

C & SH SHAFT UNLINED SECTION
COLLAR MOVEMENT TIME HISTORY



NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

Figure 7-10

C & SH SHAFT UNLINED SECTION
RATE OF COLLAR MOVEMENT VERSUS TIME

MARC General Purpose Finite Element Program (ref. 6-8). The objective of the analysis was to compute actual structural behavior by utilizing available in situ data, thereby verifying the design adequacy of the unlined section of the shaft.

The finite element model used for the analysis utilizes a single horizontal plane of quadrilateral ring elements with the upper and lower horizontal boundaries restrained against vertical displacement. This model is shown on Figure 7-11. The outside vertical boundary was given a constant uniform pressure based upon the lithostatic stress state defined in Chapter 5, equation 5-1. The inside boundary was also given a uniform pressure based upon the same lithostatic stress assumption; however, the pressure was removed in a step-wise fashion over a period of approximately 1 day. This was done to simulate the excavation of the drilled shaft, which results in a gradual relief of overburden pressure on the shaft interior and affects structural behavior in the early stage of excavation.

The secondary creep parameter C in Chapter 6, Table 6-8, was determined based on extensometer data at a depth of 2,057 feet (elev. 1353 feet). The value of C can be computed for each extensometer location using the analytical results and in situ data from the extensometer. Because C, determined from each extensometer, may vary, predicted diametric closures along each extensometer will vary accordingly. Using the diametric closures predicted at different directions on the horizontal plane, the principal directions of the strain on the horizontal plane can be determined. Consequently, closure along two horizontal principal directions can be predicted. Based on the predicted diametric closures at a depth of 2,057 feet in the N15°W, S75°E and S45°W directions, the major axis was found to be N17°40'W and the minor axis N72°20'E.

Closure predictions were made for two principal directions on the horizontal plane. Because the stress and strain distributions are not sensitive to the value of the secondary creep parameter, except during

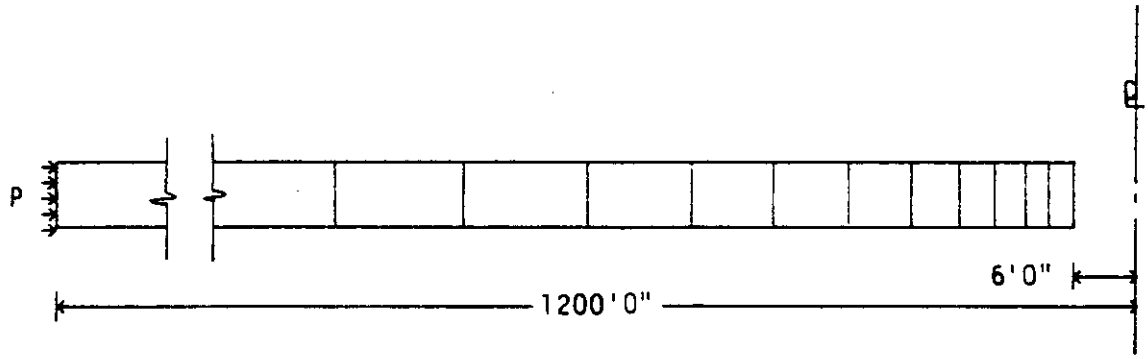


Figure 7-11

C & SH SHAFT UNLINED SECTION
FINITE ELEMENT MODEL

the initial stages of creep, the stress and strain distributions were computed based on the average values of the creep parameter C determined from three different directions.

7.3.2.4 Shaft Station

Observed Conditions. The C & SH shaft station exhibits spalling from both the roof and wall surfaces that requires continual routine maintenance. Displacements, separations and fracturing occuring above the roof at clay G and in the underlying halite were expected.

Data from the Excavation Effects Program indicate that the halite from 4 to 10 feet above the roof contains essentially no separations or fracturing. Floor heave is evident at the electrical substation where the concrete base slab has tilted several degrees, but holes drilled into the station floor encountered only minor separations and fracturing. Extensometer 51X-GE-00253, in the station floor, does not show any significant increase in collar movement that would be expected if floor heave and fracturing is occurring. Although the C & SH shaft station is the oldest and largest horizontal opening, the extent of separations and fracturing beneath the floor is very small relative to the fracturing found in the floor beneath Test Room 3 (Chapter 11).

The observed behavior in the station is apparently due in large part to its initial excavation by blasting. No other underground area has exhibited the degree of spalling that has occurred in the station. The blasting is thought to have accelerated separations at clay G and in the underlying halite in the main station area south of the shaft. However, the extensive rock bolting in the roof appears to have effectively controlled these separations.

Fracturing in the pillar corners at the S90 crosscut has continued to evolve as the salt responds to stresses produced by the station excavation. Changes in the fracturing are exhibited primarily by the appearance of new vertical fractures and by the elongation and widening of existing fractures. Minor spalling has also occurred, particularly

at the roof and wall intersection in the upper portion of geologic map unit 4.

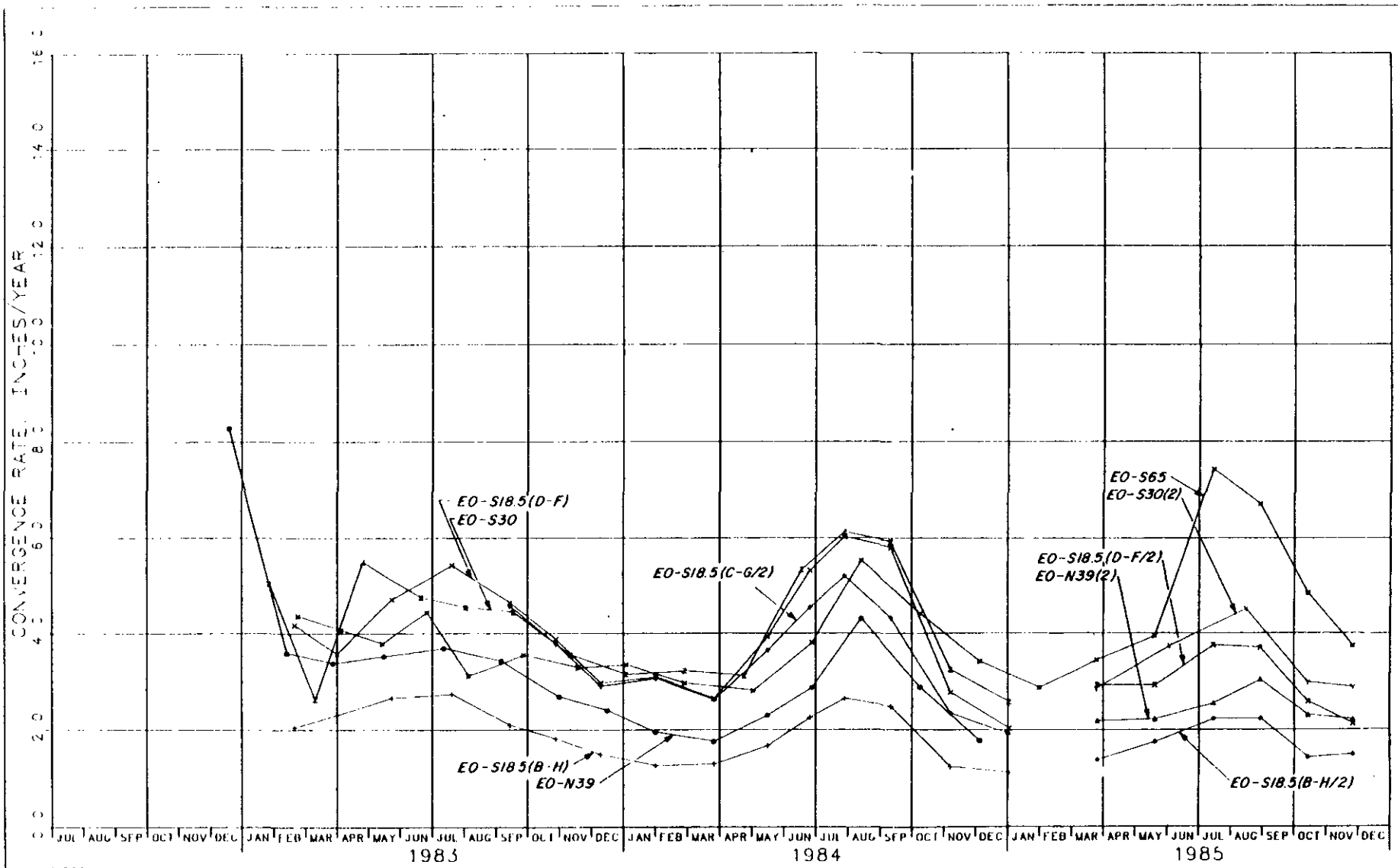
Closure. Figure 7-12 shows closure rates calculated from the readings of roof-to-floor convergence points. The maximum rate appears to have occurred during the early part of August 1984.

The closure rates shown on Figure 7-12 cannot be directly compared without considering the differences in dimensions at the locations shown, as well as differences in the thickness of the roof beam below clay G, and the number of rock bolts in the vicinity of the respective convergence measurement stations.

Figure 7-13 compares the central vertical closure readings at stations S18.5 and N39. Although the closure measurements are very close at both stations, actual total closure at the S18.5 station will be greater since the initial reading at this station was taken nearly 261 days after the completion of excavation, compared to only 35 days at the N39 station. In addition, the larger opening dimensions at the S18.5 station will also result in more rapid closure. Even though the density of rock bolts is greater south of the C & SH shaft than north of it, the roof-to-floor closure is greater to the south. This is probably because the roof beam below clay G is thinner and longer to the south.

Figure 7-14 shows the collar movements of multiple-point borehole extensometers 51X-GE-00227 and 51X-GE-00228 in the station roof, 35 feet north and 65 feet south of the C & SH shaft, respectively. The average collar movement rate of 51X-GE-00228 is higher than that of 51X-GE-00227, as determined from Figure 7-14. The roof closure rate south of the shaft is currently more than the rate north of the shaft.

A double-point borehole extensometer (51X-GE-00253) was installed in the floor of the C & SH shaft station. The initial reading from this extensometer was taken nearly 238 days after the completion of

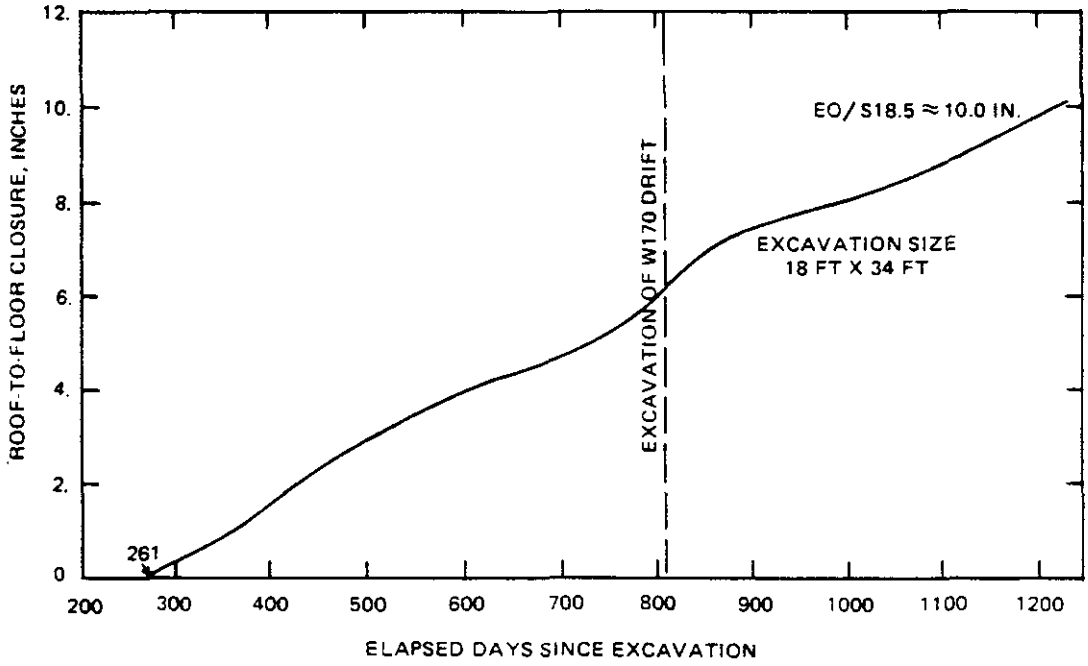


NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

Figure 7-12

C & SH SHAFT STATION
CALCULATED ROOF-TO-FLOOR CLOSURE RATES



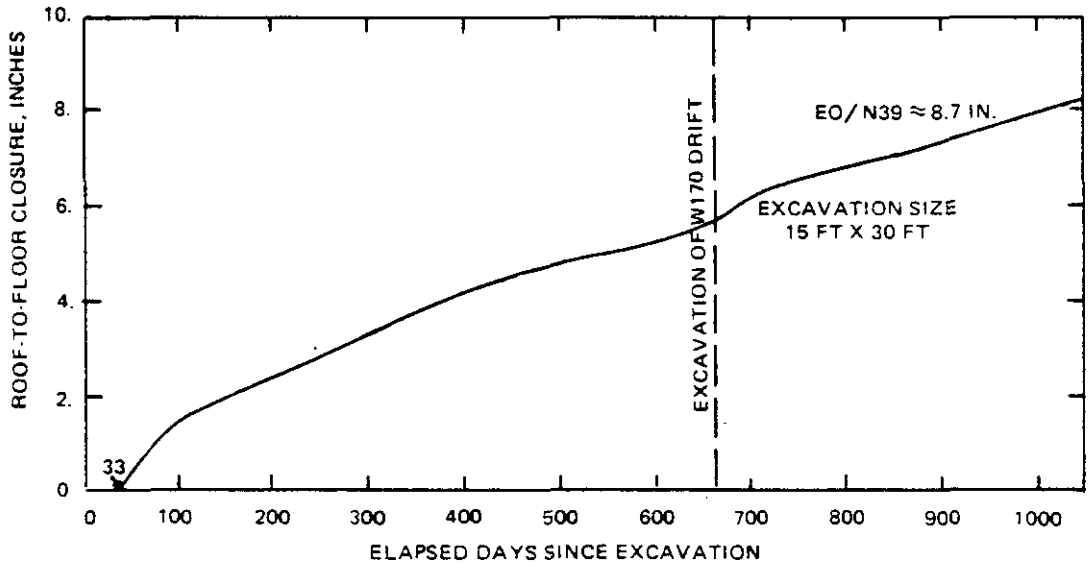


Figure 7-13

C & SH SHAFT STATION
TYPICAL ROOF-TO-FLOOR CLOSURE HISTORY

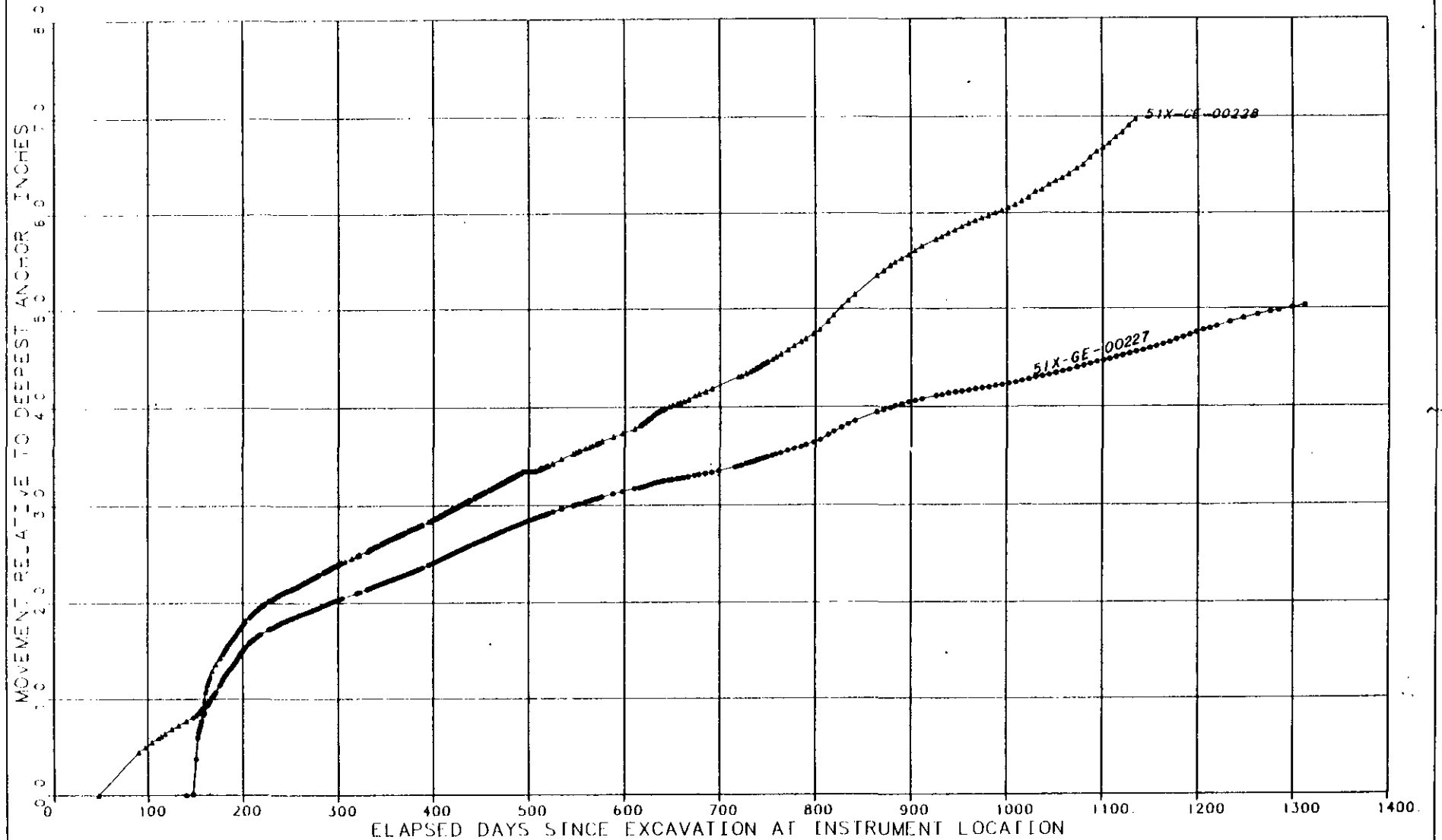


Figure 7-14

C & SH SHAFT STATION
HISTORY OF COLLAR MOVEMENTS - ROOF EXTENSOMETERS

excavation at the instrument location (Appendix J, Figure J-172). The measured collar movement relative to the deepest anchor was 3.26 inches on December 20, 1985. Actual floor heave will be higher as a result of the time-lag between the end of excavation and the initial reading date. There was a slight increase in the collar movement rate due to excavation of the nearby W170 drift, but the rate has since become steady.

Roof Stability. Figure 7-15 shows the distribution of measured movements along roof extensometer 51X-GE-00251, 18 1/2 feet south of the C & SH shaft, for the readings taken on September 18, 1985. The magnitudes shown are cumulative between the initial reading date of January 11, 1983, and September 18, 1985. The movements are also expressed as percentages of the collar reading. Sixty-one percent of the relative movement has taken place between the collar and anchor A. This has remained practically constant since December 1983 and is an indirect indication that there is no accelerating trend in the rate of opening at clay G in the vicinity of this extensometer. For comparison, the distribution of measured movement along roof extensometer 51X-GE-00227, 35 feet north of the C & SH shaft, is shown on Figure 7-16. The relative movement between the collar and anchor A has remained constant at 52 percent through December 1985. Based on these measurements, there is no indication that clay G is parting at an accelerating rate either north or south of the shaft.

7.3.3 Prediction of Future Behavior

This subsection presents the results of the analysis and evaluation of the finite element modeling and the data collected in the C & SH shaft. These results are presented in the form of predictions for future behavior of the constructed shaft elements (liner and key) and of the salt surrounding the unlined section of the shaft and the shaft station.

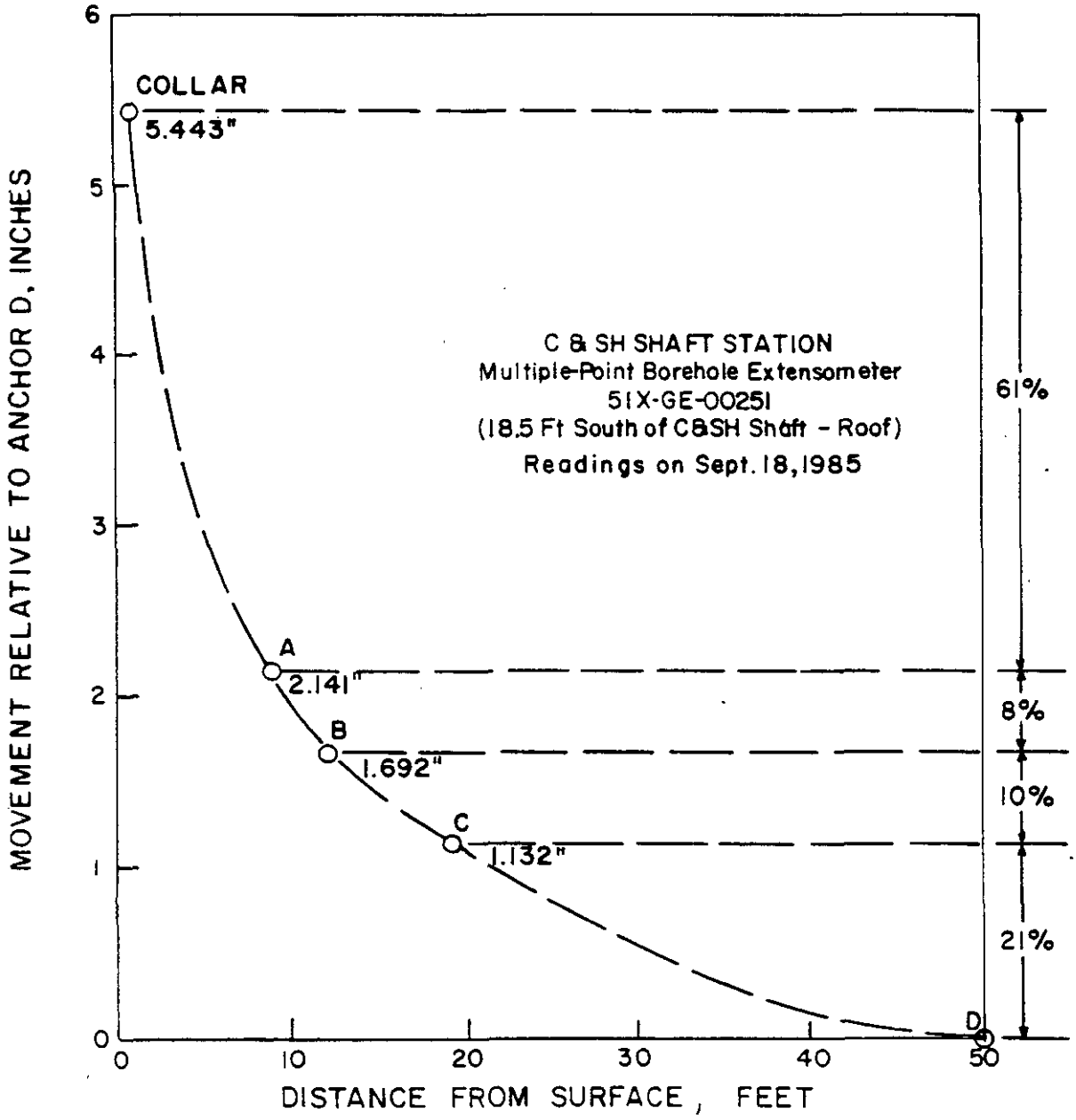


Figure 7-15

C & SH SHAFT STATION
MOVEMENT DISTRIBUTION ALONG ROOF EXTENSOMETER 51X-GE-00251

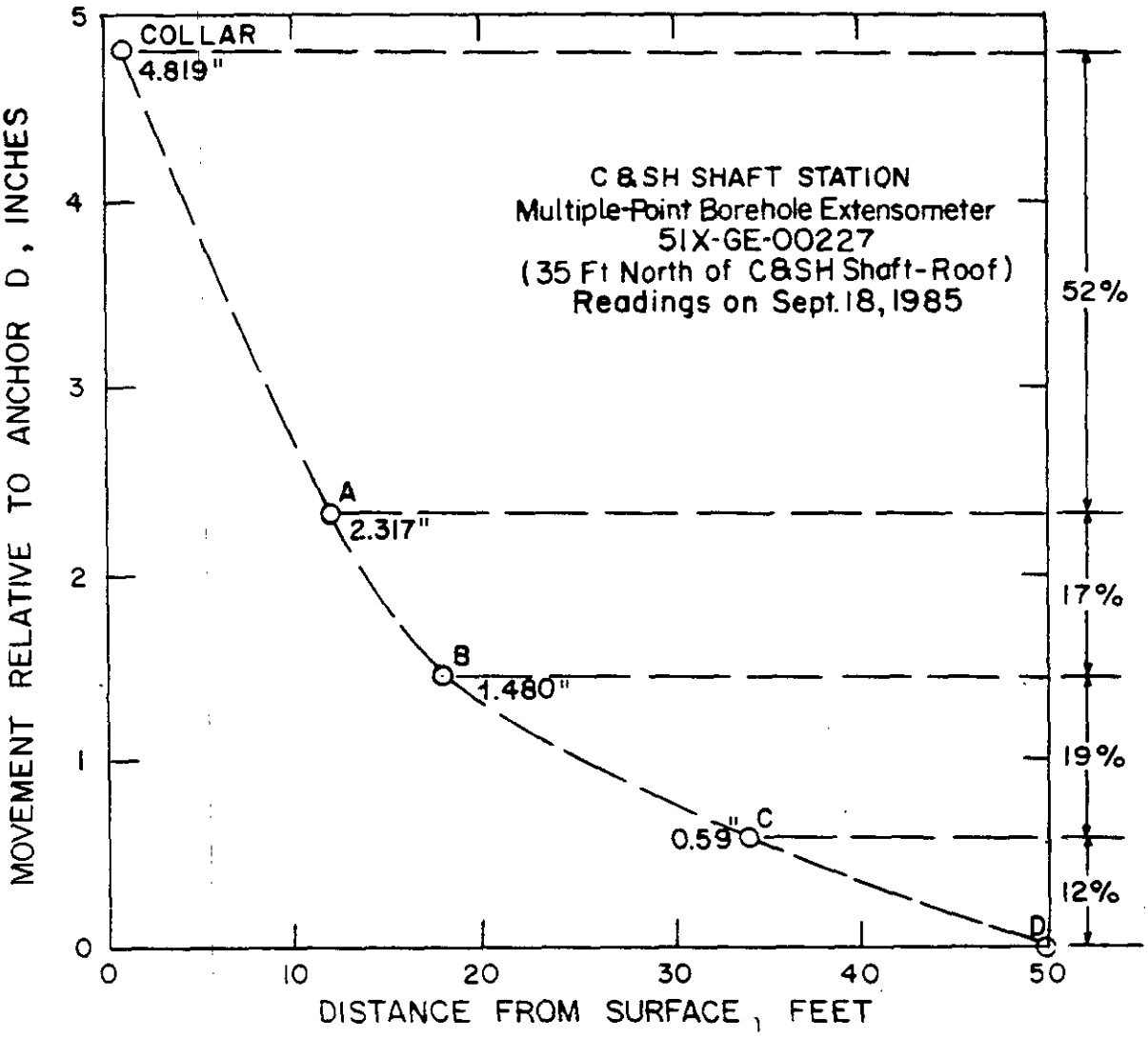


Figure 7-16

C & SH SHAFT STATION
MOVEMENT DISTRIBUTION ALONG ROOF EXTENSOMETER 51X-GE-00227

7.3.3.1 Lined Section

The water pressure on the shaft liner to date has been less than the hydrostatic design pressure. The prediction of future water pressures behind the liner is difficult due to the reasons discussed in subsection 7.3.2.1. The lower potentiometric surface and lack of hydraulic continuity along the rock/liner interface may prevent the ground water from reaching the design hydrostatic head. In addition, leaks around the piezometers and possibly obstructed filters may cause the measurements to be somewhat less than the actual pressure conditions.

Figure 7-17 shows that if the water pressure does reach the design hydrostatic pressure, the liner will remain stable based on its design factor of safety. The figure shows that the pressure capacity of the liner far exceeds the design hydrostatic pressure. This pressure was determined based on water level data obtained at the site during preliminary design activities. The data indicated that the highest potentiometric surface in the Rustler formation beneath the site occurred at a depth of approximately 250 feet below the ground surface. This data was later confirmed by investigations conducted in the site vicinity by the U.S. Geological Survey (USGS) (ref. 7-9). It is not expected that this potentiometric surface will be exceeded during the 25-year operating life of the facility. If any external water were to infiltrate along the rock/liner interface to form a column of water that would exceed the hydrostatic head contained in the design bases, the stability and safety of the steel liner would still not be compromised based on the design factor of safety.

7.3.3.2 Shaft Key

The results of the shaft key analysis indicate that after concrete is placed against the shaft wall it shrinks away from the wall at a rate greater than the rate of salt creep, resulting in a separation between the concrete and the salt. The rate of concrete shrinkage decreases with time and continuous salt creep eventually results in the salt

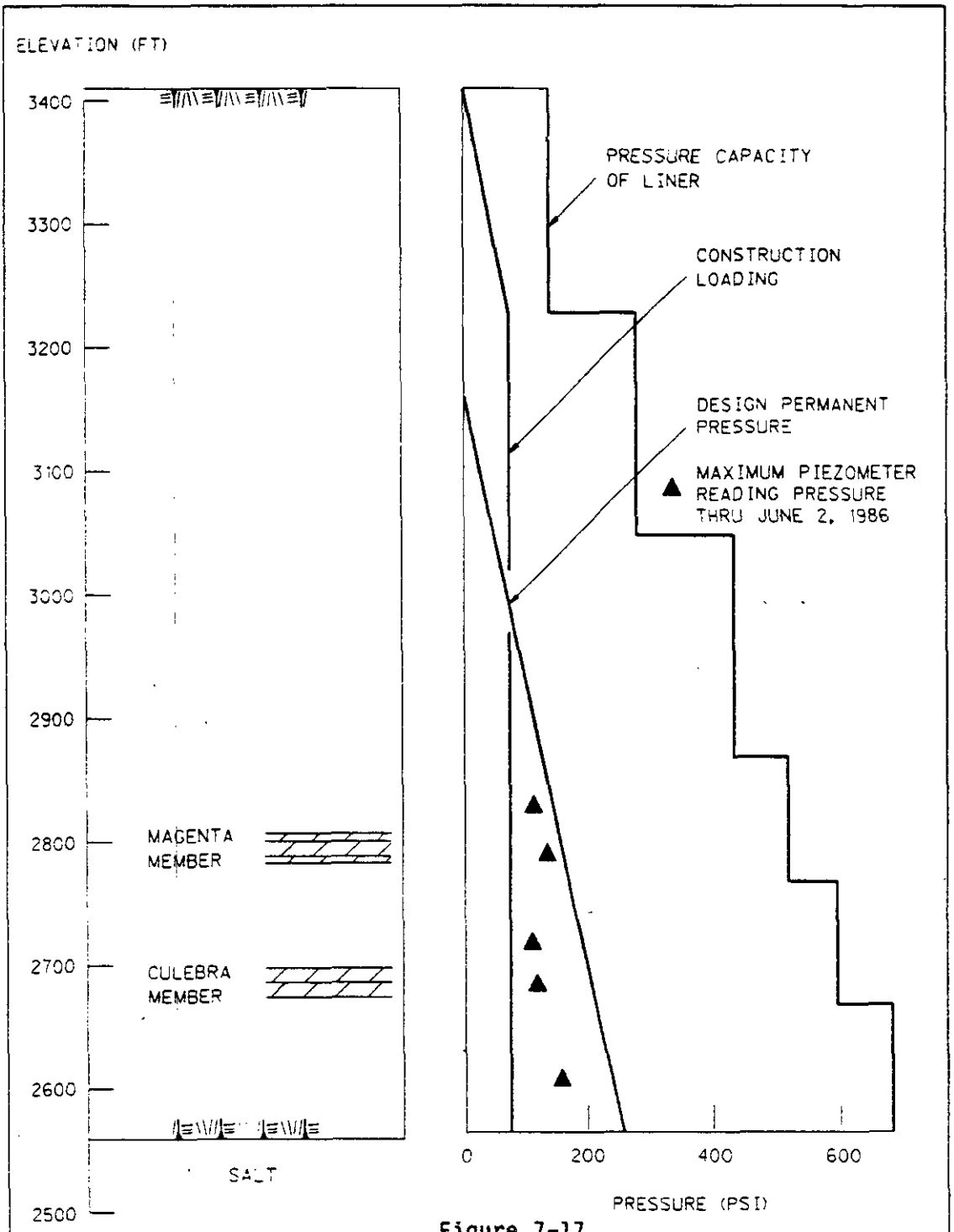


Figure 7-17

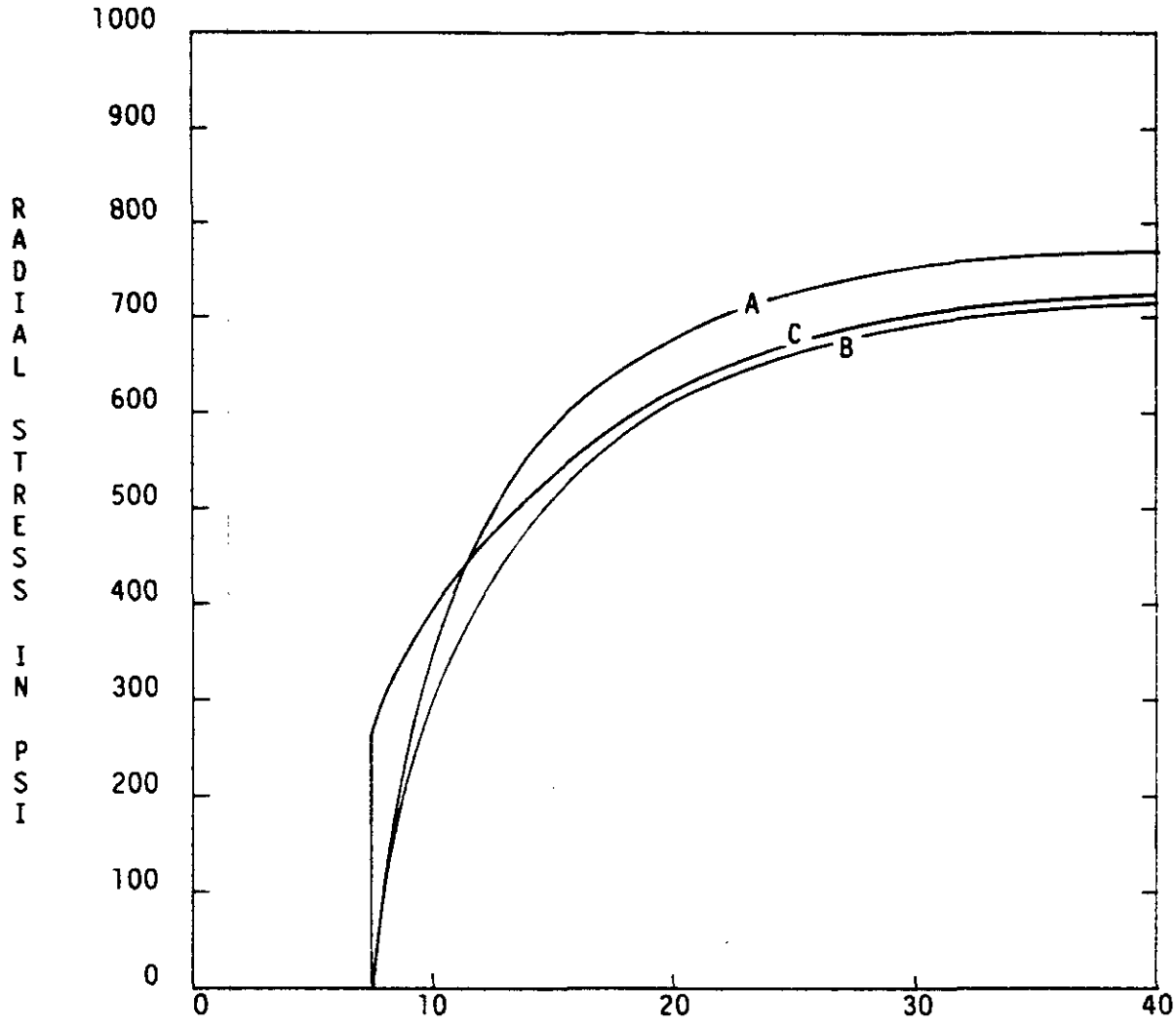
C & SH SHAFT LINER
LATERAL PRESSURE COMPARISON

contacting the concrete again. The interactive pressure between the concrete and the salt will then gradually increase due to continuous salt creep.

In the key area, the shaft wall radial and tangential stresses (Figures 7-18 and 7-19, respectively) were plotted as a function of distance from the centerline of the shaft for a typical section immediately after excavation of the shaft and for 1 year and 25 years after concrete placement. As expected, the radial stresses in the salt are initially relieved near the opening but begin increasing after the salt comes in contact with the concrete. Further away from the opening, the stresses trend toward the overburden pressure.

The tangential stresses in the salt 3 days after excavation show an elastic response which gives very high values near the opening. The stresses are relieved near the opening from the time the salt starts to creep until it contacts the concrete. After contact is made, and for the remainder of the 25 year analysis period, the stresses in the salt and concrete key increase. There exists a discontinuity of stress at the concrete/salt interface which is primarily due to differences in their material properties. Like the radial stresses, the tangential stresses approach the overburden pressure with increasing distance from the opening.

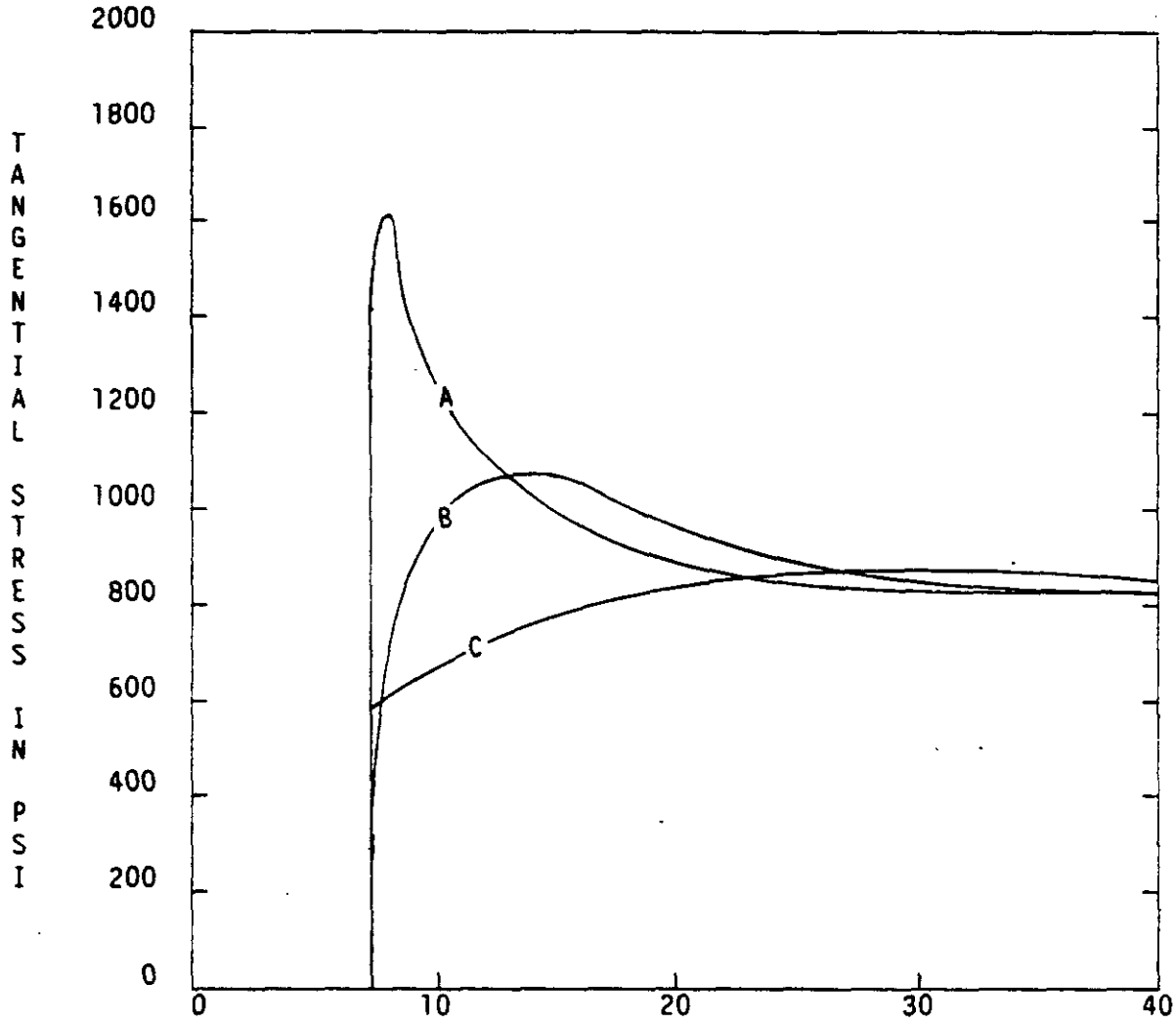
At 25 years, the radial stresses, which are equal to the lateral pressures on the salt face of the key, will increase to an average value of 275 psi. At the same time, the maximum hoop stress at the inside face of the concrete key has an approximate value of 1,000 psi, with an average value across the key of about 825 psi. Figures 7-20 and 7-21 show the predictions for average lateral pressures and average hoop stresses, respectively. A lateral pressure capacity in the key of 833 psi, based on an allowable hoop stress controlled by a concrete compression of 3,000 psi, results in a factor of safety of approximately three.



A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER CONCRETE PLACEMENT
C – 25 YEARS AFTER CONCRETE PLACEMENT

Figure 7-18

C & SH SHAFT KEY
RADIAL STRESS DISTRIBUTION



A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER CONCRETE PLACEMENT
C – 25 YEARS AFTER CONCRETE PLACEMENT

Figure 7-19

C & SH SHAFT KEY
TANGENTIAL STRESS DISTRIBUTION

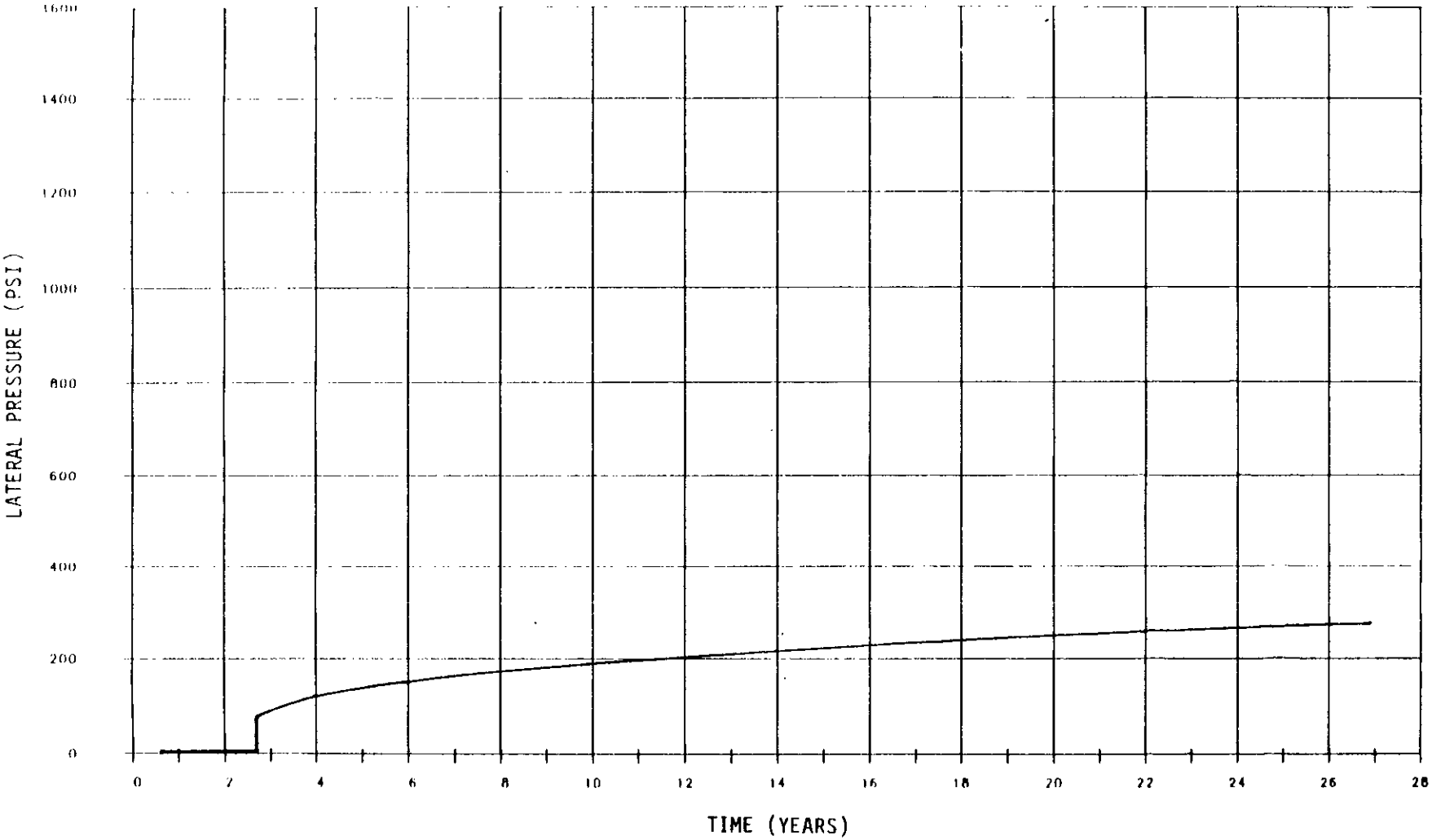


Figure 7-20

C & SH SHAFT KEY
LATERAL PRESSURE PREDICTION

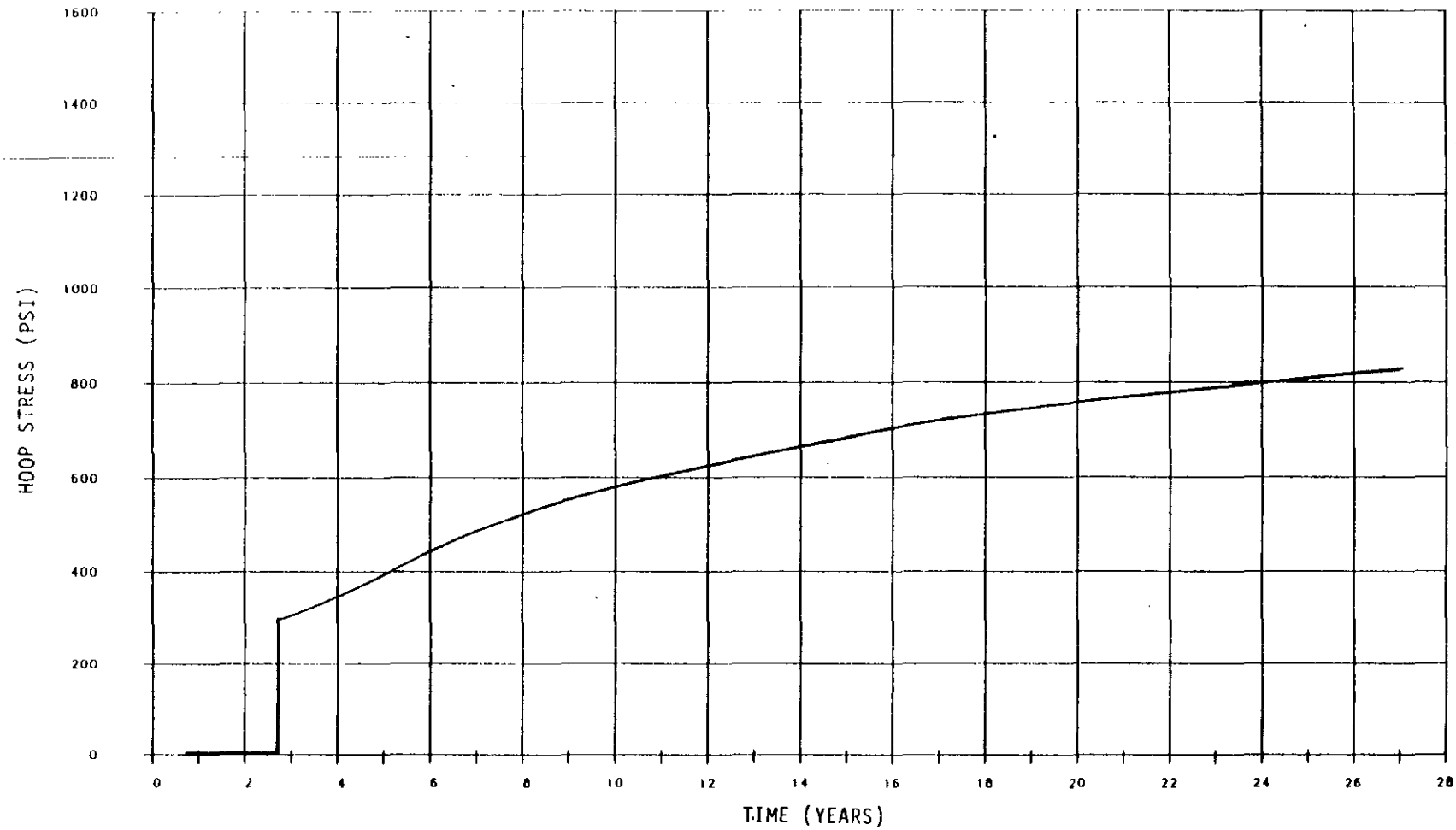


Figure 7-21

C & SH SHAFT KEY
HOOP STRESS PREDICTION

The average diametric closure of the key at 27 years is expected to be about 0.1 inch with a maximum value of 0.175 inch, or about half the predicted value for the salt in the unlined section immediately below the key (Figure 7-22). The average diametric closure of the unlined section immediately below the key at 27 years varies from 0.03 inch for the anhydrite bed to 0.38 inch for the argillaceous halite layer. Figure 7-23 shows the diametric closure predictions for both the concrete key and the salt in the adjacent shaft wall.

7.3.3.3 Unlined Section

Extrapolation of In Situ Responses. Convergence point measurements are too few to be used for the extrapolation of future in situ responses in the unlined section of the shaft. Thus, the readings of collar movements of multiple-point borehole extensometers must be used for this extrapolation. Because the extensometer collars are recessed 1 foot into the wall, and the readings are referenced to the deepest anchor which is also moving, extrapolation of collar movement will not produce an exact estimate of the movement of the shaft surface.

The maximum collar movement occurs at multiple-point borehole extensometer 37X-GE-00208 at a depth of 2,057 feet (elev. 1353 feet) (Figure 7-3). As discussed earlier, and as shown on Figure 7-9, the collar movement is affected by seasonal temperature fluctuations. However, if we consider only the later portion of the curve, its slope is approximately 0.125 inch/year between June 1984 and June 1985. Assuming this rate to be constant for another 22 years, the additional radial movement of the collar will be nearly 3 inches. Thus, the effective diameter of the unlined shaft will be reduced by nearly 6 inches.

Replication of In Situ Responses. Figures 7-24 and 7-25 show the radial and tangential stress distributions relative to the overburden stress at different times. Figure 7-24 indicates that the zone where radial stresses are affected increases in size with time while Figure 7-25 indicates that tangential stresses are only affected within an approximately constant radius of 60 feet.

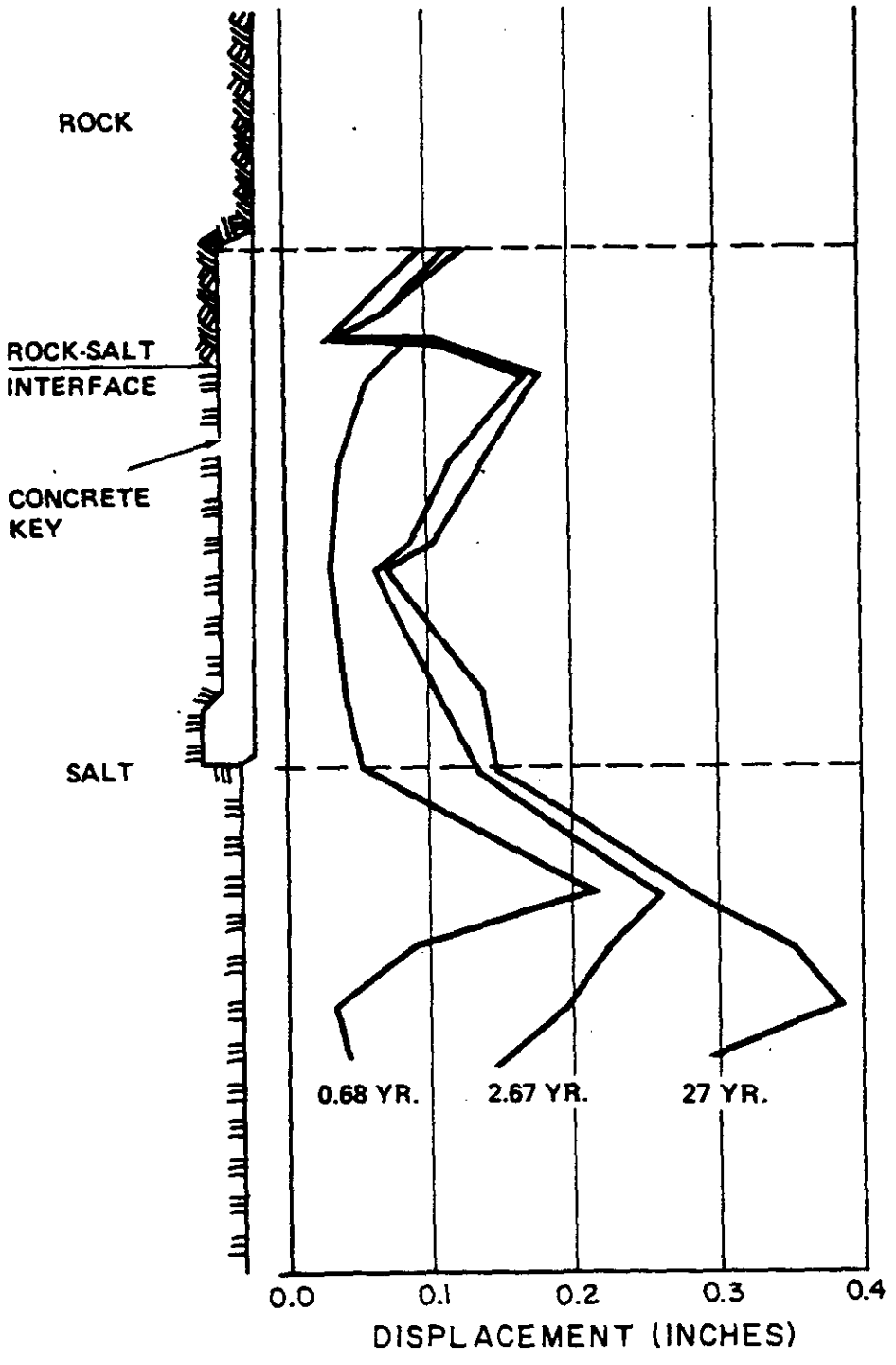


Figure 7-22

C & SH SHAFT KEY
DIAMETRIC CLOSURE

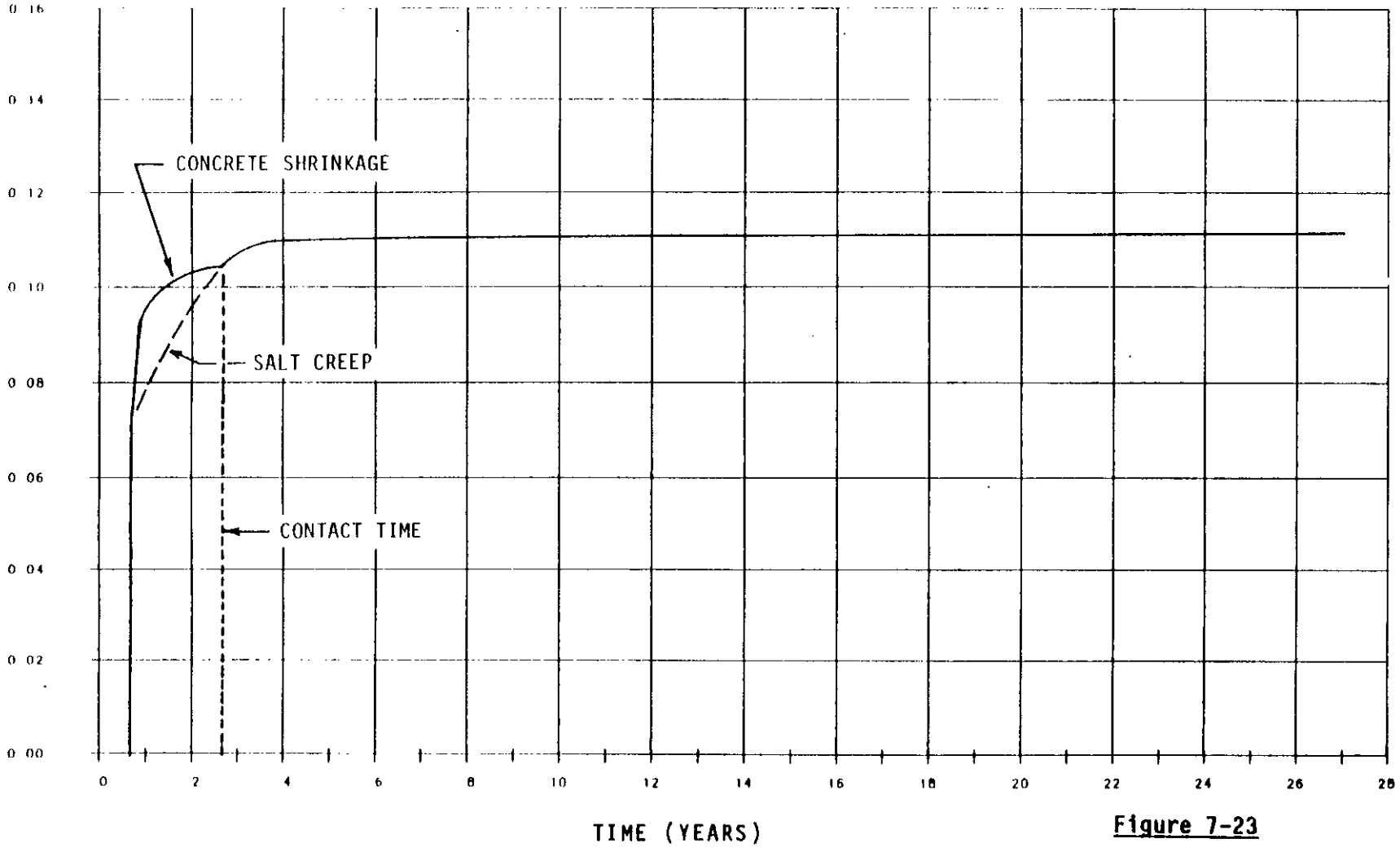
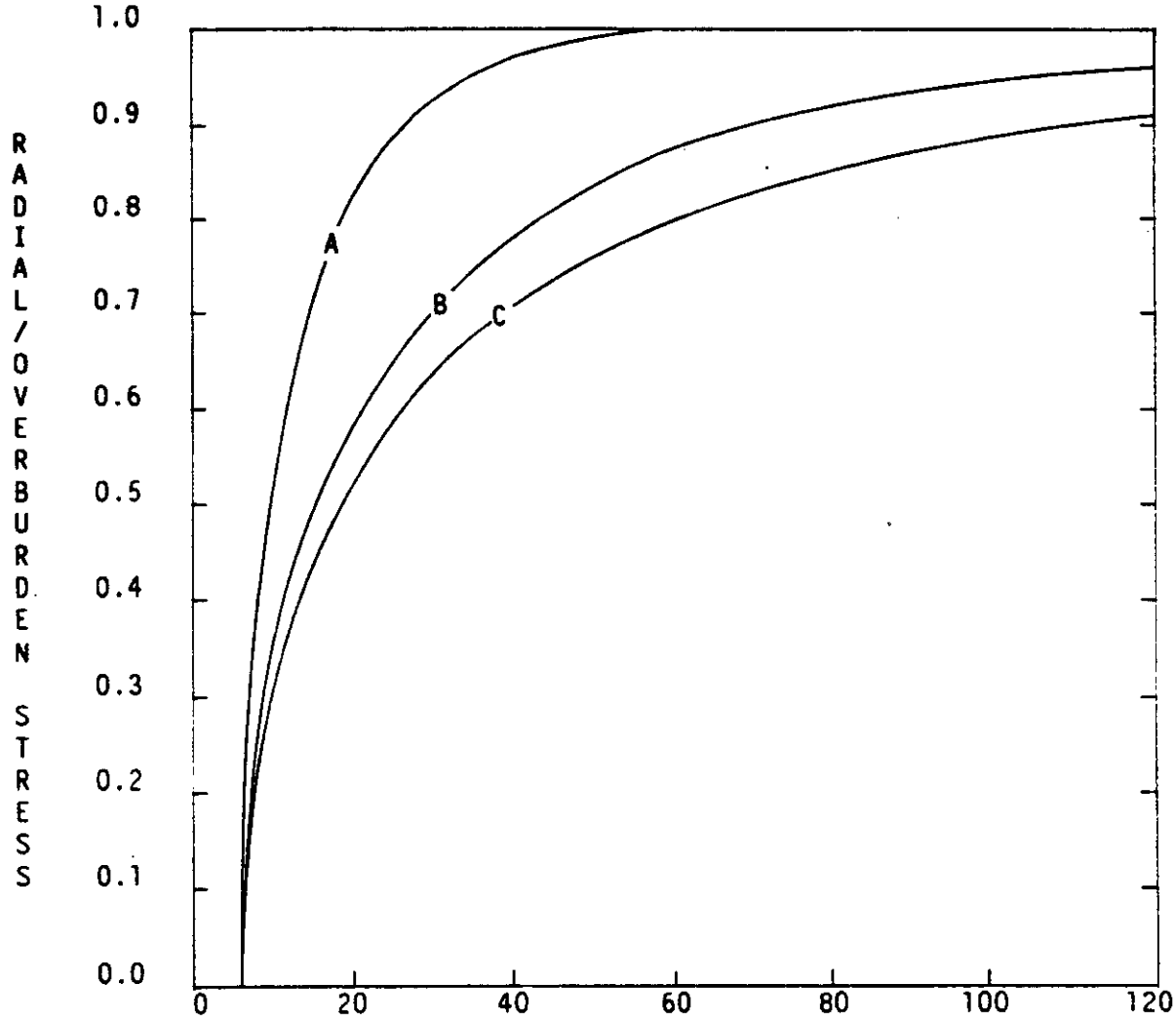


Figure 7-23

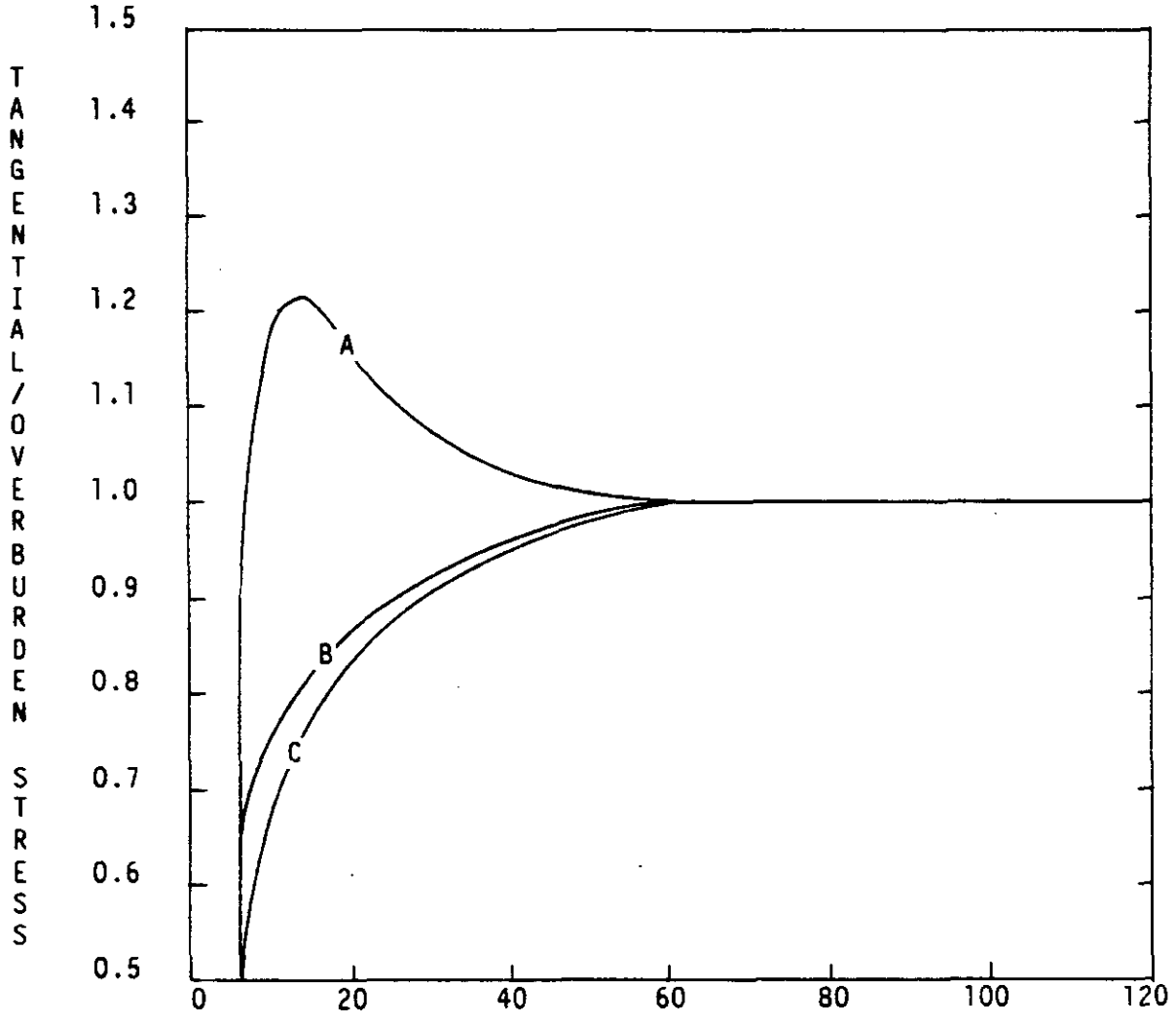
C & SH SHAFT KEY
DIAMETRIC CLOSURE PREDICTION



A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER EXCAVATION
C – 15 YEARS AFTER EXCAVATION

Figure 7-24

C & SH SHAFT UNLINED SECTION
RADIAL STRESS DISTRIBUTION AT ELEVATION 1353



A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER EXCAVATION
C – 15 YEARS AFTER EXCAVATION

Figure 7-25

C & SH SHAFT UNLINED SECTION
TANGENTIAL STRESS DISTRIBUTION AT ELEVATION 1353

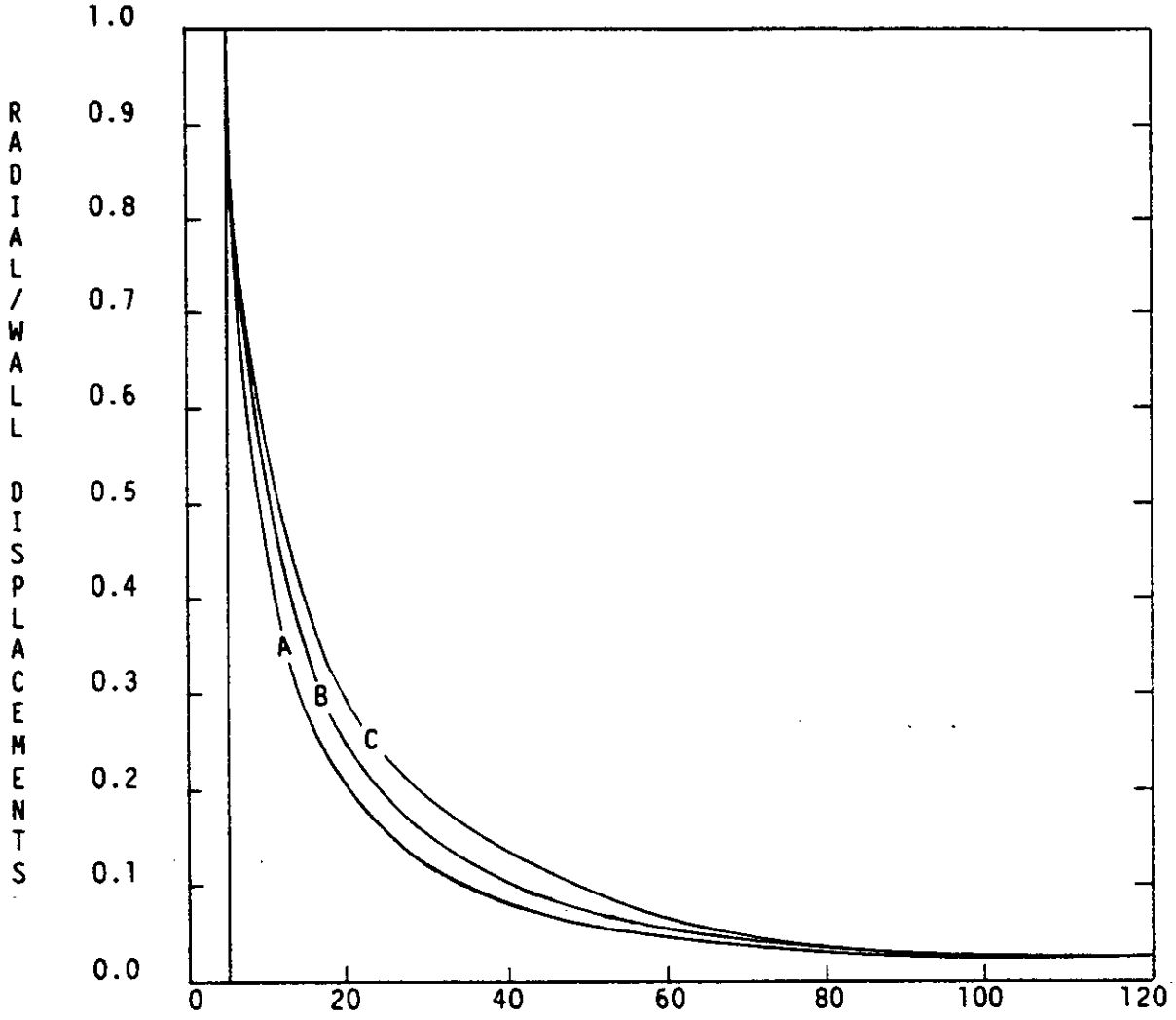
Figure 7-26 shows the ratio of radial displacements at various distances from the shaft centerline relative to the radial displacement of the shaft wall at different times. Based on this figure, the ratio of the displacements between each extensometer anchor point and the shaft wall can be determined. This figure indicates that the extensometer collar readings relative to the deepest anchor will reach about 84 percent of the actual radial displacement of the shaft wall 15 years after excavation.

Figure 7-27 illustrates the effective creep strain distribution in the shaft at a depth of 2,057 feet (elev. 1353 feet) at selected times after excavation. The magnitude of effective strain at the shaft wall at 15 years approaches a value of approximately 0.03.

Figure 7-28 shows diametric closure versus depth at different times. The response curves are drawn relative to the time the initial instrument readings were made. The response indicated by the curve to the left of the vertical axis corresponds to the computed response which took place between excavation and the initial instrument reading. The relative response between October 1982 and June 1984 is correct regardless of the time offset. Varying the time offset in effect shifts the position of all other response curves relative to the vertical axis. The diametric closure prediction at a depth of 2,057 feet is shown on Figure 7-29.

7.3.3.4 Shaft Station

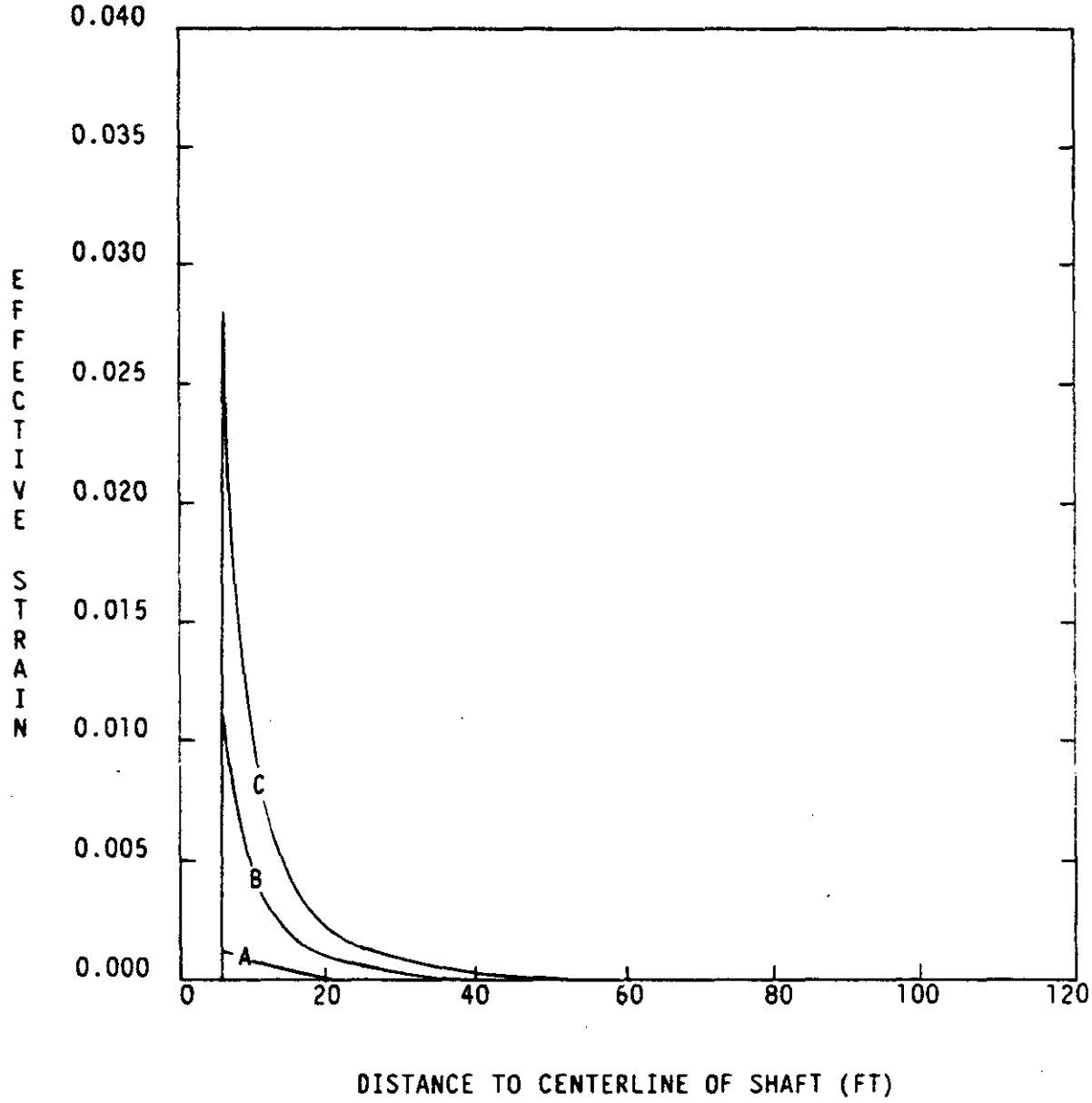
Figure 7-15 shows that, for roof extensometer 51X-GE-00251 in the C & SH shaft station, the relative movement between the collar and anchor A, expressed as a percentage of the collar reading, has remained practically constant for the last 2 years. Thus, provided that no failure of the mechanical-anchor rock bolts occurs, the closure rate of the roof is expected to stabilize. It is assumed that no new excavation will occur close to the station. If additional excavation is performed, the rate of closure between the roof and floor and between the walls may be accelerated.



A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER EXCAVATION
C – 15 YEARS AFTER EXCAVATION

Figure 7-26

C & SH SHAFT UNLINED SECTION
RADIAL DISPLACEMENT DISTRIBUTION AT ELEVATION 1353



A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER EXCAVATION
C – 15 YEARS AFTER EXCAVATION

Figure 7-27

C & SH SHAFT UNLINED SECTION
EFFECTIVE CREEP STRAIN DISTRIBUTION AT ELEVATION 1353

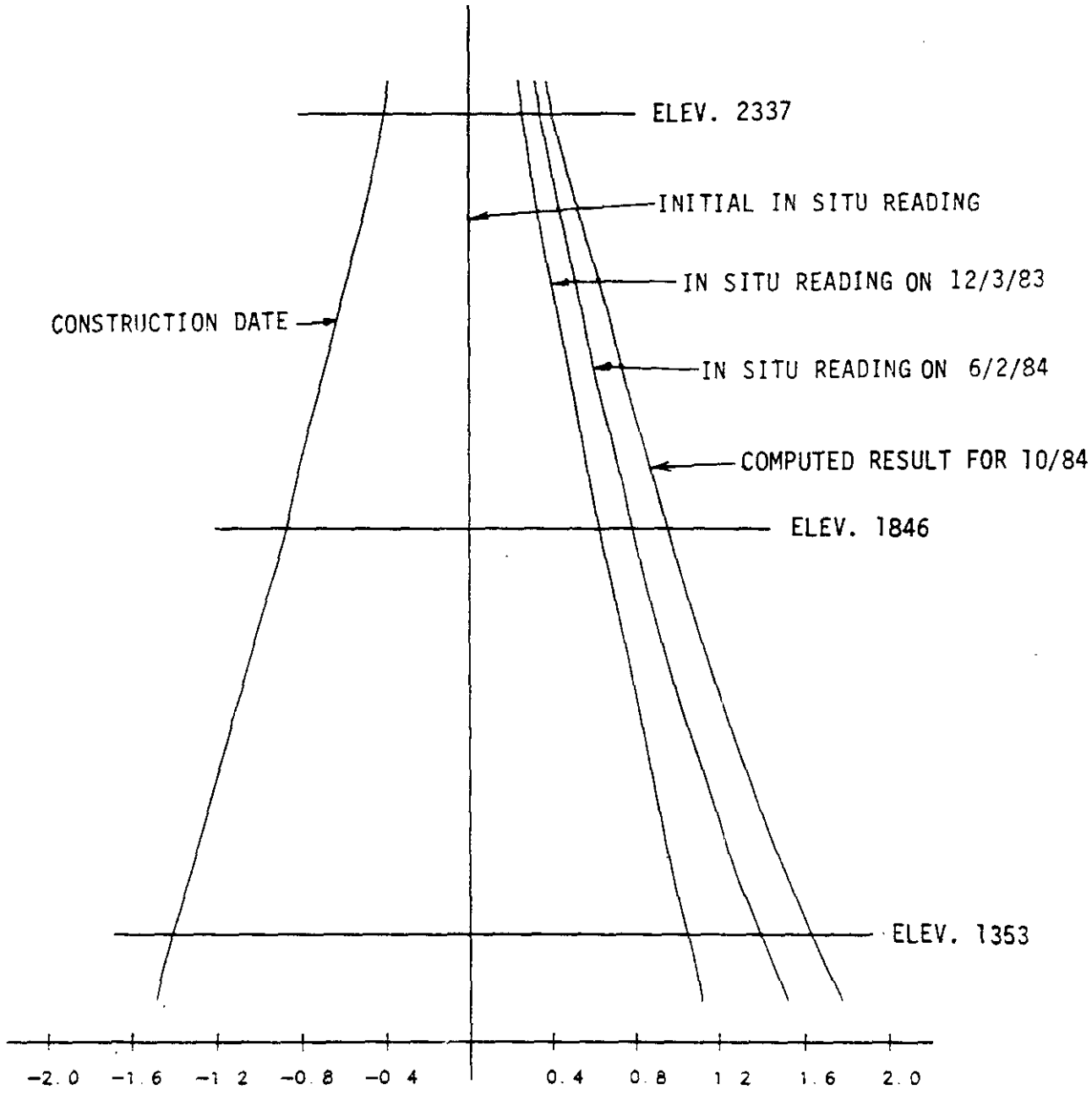
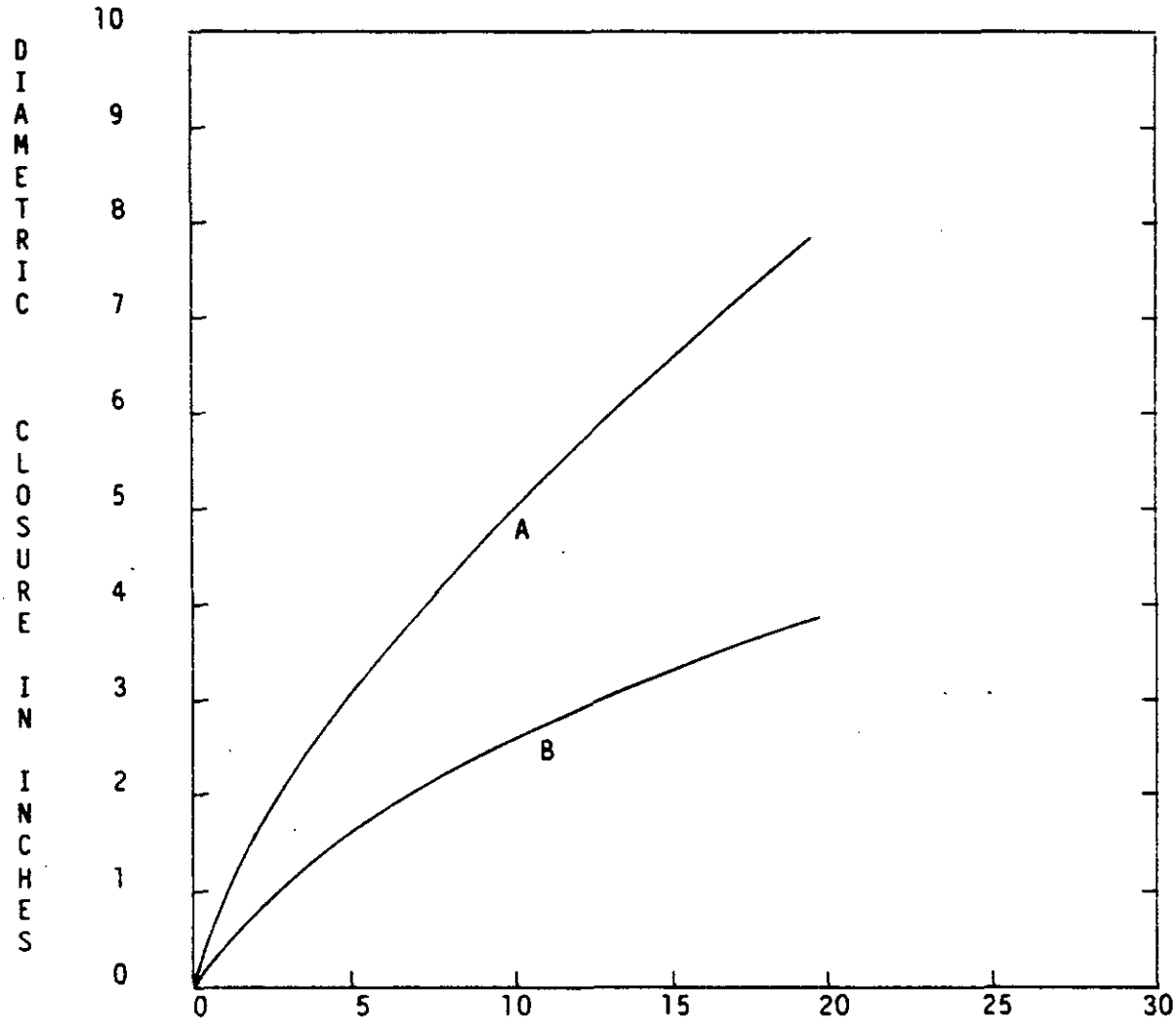


Figure 7-28

C & SH SHAFT UNLINED SECTION
RELATIVE DIAMETRIC CLOSURE



A – NORTH 17°40' WEST- MAJOR AXIS
B – NORTH 72°20' EAST- MINOR AXIS

Figure 7-29

C & SH SHAFT UNLINED SECTION
CLOSURE PREDICTION AT ELEVATION 1353

The rock bolts and wire mesh in the station roof will control spalling and stabilize the roof to provide a safe working environment but will not control salt creep. Although separations and fracturing have developed in the salt surrounding the shaft station, they exist on a much smaller scale than those observed in Test Room 3. They are expected to continue to develop throughout the operating life of the facility.

The total measured roof-to-floor closure in the C & SH shaft station was approximately 10 inches on September 16, 1985, nearly 3 1/4 years after the completion of excavation. The measured wall-to-wall closure over the same period was about 6 inches. Actual closure values are higher because the initial readings were taken nearly 260 days after the station was excavated. The average rate of roof-to-floor closure over the measurement period is approximately 3.89 inches/year. Assuming this rate will be constant throughout the operating life of 25 years, an additional roof-to-floor closure of about 8 feet is expected. Since the wall-to-wall closure is approximately 60 percent of the roof-to-floor closure, the additional wall-to-wall closure is expected to be nearly 5 feet.

7.4 CONCLUSIONS AND RECOMMENDATIONS

Design validation requires a determination of the compatibility of the design criteria, design bases and design configurations used in the reference design. Therefore, the following conclusions and recommendations address those criteria identified as applicable to the C & SH shaft in Chapter 2, Table 2-1, and the design basis elements presented in this chapter, Table 7-1. Other conclusions and recommendations that are a product of the design validation process are also presented.

7.4.1 Conclusions

Validation of the C & SH shaft reference design is based on a comparison of the applicable elements contained in the Design Criteria

and Design Bases documents with in situ conditions. These documents contain the requirements that the C & SH shaft must meet in terms of shaft stability, deformation, water pressure, water control, and shaft station stability and deformation.

Observations made during shaft inspections have not detected any signs of deterioration or instability. Due to its design pressure capacity, the liner is expected to remain stable even if the water pressure exceeds the design hydrostatic pressure.

The design basis assumption that the hydrostatic pressure begins 250 feet below the ground surface is suitable. Piezometer measurements indicate that the hydrostatic pressure is currently much less than the design basis pressure. These measurements are of sufficient accuracy to indicate that an anomalously high hydrostatic condition does not exist.

The design basis requirement that the key be designed to resist lateral pressure from the salt equal to 75 percent of the overburden pressure, approximately 640 psi, is suitable. The shaft key analysis indicates that the lateral pressure on the key at the end of 25 years will be approximately 275 psi. The lateral pressure capacity of the key is 833 psi. This provides for a factor of safety of about three. The analysis further shows that the maximum diametric closure expected for the key at the end of the operating period is only 0.175 inch. If the plastic flow or creep properties of the concrete were included in the analysis, the results would indicate that the design pressure would not be reached until after the 25-year operating life of the facility.

Based on the computed vertical, horizontal and effective stresses in the unlined section, the magnitude of stresses immediately adjacent to the opening decreases with time as the stress arch around the opening migrates away. The maximum stress occurs immediately after excavation and is followed by relaxation due to creep behavior. The stresses will, therefore, not cause a future stability problem in the unlined section of the C & SH shaft.

The analyses show the locations of effective creep strain concentrations in the unlined section of the shaft at different times. It is predicted that the maximum effective creep strain will not exceed 0.05 at the end of the operating life of the shaft. Based on the effective creep strain limit discussed in Chapter 6, the structural stability of the C & SH shaft will remain within required safety limits during its operating life.

The analyses also predict that the diametric closure near the bottom of the shaft at the end of its operating life will be approximately 10 inches along the major axis of principal strain, approximately 18 degrees from the longitudinal direction of the shaft tubular steel supports (buntons). Based on the predicted deformations and closures, the unlined section of the shaft will meet the requirements stated in the design criteria. The diameter of approximately 12 feet in the unlined section will allow for salt creep over the operating life, as required by the design bases. However, based on the design configuration of the C & SH shaft, the connections at both ends of some buntons do not provide sufficient allowance for longitudinal adjustment.

The C & SH shaft reference design complies with the criteria that require control of ground-water flow. This conclusion is made despite the fact that considerable instrumentation damage has been caused by water flow. This water has seeped into the shaft through holes cut in the liner for piezometer installation or is a result of direct rainfall. The piezometer leakage problem has been addressed and will receive additional corrective attention during a future shaft renovation. The rainwater does not reach the facility level in any significant or measureable quantity.

The chemical water seal just below the key piezometers is probably breached. The lowest water seal in the key is functioning properly. The water draining from the telltale drains has a local source. Therefore, it is concluded that there is no solutioning of the salt behind the key.

The C & SH shaft station exhibits the highest degree of deterioration in the underground facility. This is considered to be the result of the effects of blasting for initial excavation of the station. The station roof has been stabilized by rock bolting and no further significant deterioration is expected. However, removal of the 3-foot thick salt beam between the roof and clay G may be required for safety reasons in the future. Closure will continue at a rate of 3.89 inches/year vertically and 2.33 inches/year horizontally. Total closure after 25 years will be on the order of 8 feet vertically and 5 feet horizontally. This closure will require that the station roof or floor, and walls be trimmed periodically to maintain the design dimensions.

Separation and fracturing in the salt is expected to continue in the station roof and beneath the floor. Both closure and fracturing in the station will necessitate periodic maintenance during its operating life in order to maintain safety as well as the required clearances for equipment and operations.

The reference design for the C & SH shaft is validated based on the preceding discussions. The reference design complies with the design criteria and design bases. Except for instrument repair and maintenance, no modifications are required to the shaft reference design. The C & SH shaft will perform its functions as required during the operating life of the facility.

7.4.2 Recommendations

Based on the results of design validation, the following recommendations are made with respect to the C & SH shaft:

(1) Water behind the shaft key is undesirable and should be monitored carefully. If the volume of water behind the key increases, or if water starts flowing from beneath the key, past the lower water seal, it may become necessary to inject grout above the top water seal in the key. Grout should not

be placed behind the key (below the top seal) unless absolutely necessary. If this cannot be avoided, the grout must be a chemical gel (or other non-rigid grout) and must be compatible with both the existing water seal material and with the Plugging and Sealing Program requirements.

(2) Based on the results of design validation of the C & SH shaft, it is recommended that, during inspection of the shaft furnishings, the bunton connections should be inspected for closure allowance. If the allowance is insufficient, corrective action should be taken to provide for additional closure.

(3) The observation holes drilled in the roof of the shaft station to monitor displacements and separations, and in the floor to monitor fracturing, should be maintained. Continued observations of conditions in these holes will be valuable in assessing the safety and stability of the station.

CHAPTER 8
WASTE SHAFT

8.1 INTRODUCTION

The waste shaft provides the connection between the surface waste handling facilities and the underground storage level. A discussion of shaft construction was presented in Chapter 3 and geologic characterization of the shaft stratigraphy was presented in Chapter 6. This chapter presents discussions of the design criteria and design bases pertaining to the waste shaft. It documents the collection of waste shaft geotechnical data, its analysis and evaluation, and presents predictions of future shaft behavior. Conclusions and recommendations are presented based on a comparison of the results of the design validation process with the shaft reference design.

8.2 DESIGN

This section presents the design criteria and design bases used to develop the reference design for the waste shaft. The design configuration of the shaft is discussed in Chapter 3, subsection 3.3.2.

8.2.1 Design Criteria

The design criteria for the waste shaft are the same as those for the C & SH shaft. The criteria requiring validation are indicated in the listing of abridged criteria presented in Chapter 2, Table 2-1, and are discussed in Chapter 7.

The design criteria requiring evaluation for design validation of the waste shaft are:

(1) shaft shall be designed to be structurally stable;

(2) shaft shall be designed to accommodate salt creep;

(3) ground-water flow into the shaft shall be controlled;

(4) underground openings (i.e. waste shaft station) shall be designed to accommodate deformation; and

(5) underground openings shall be stable.

8.2.2 Design Bases

The Design Basis, Waste Shaft (ref. 2-15) was the primary document used as a guide for waste shaft design. The major elements of this basis are summarized in this subsection. Only a few of these elements must be evaluated or have a direct impact on design validation. These particular elements are presented in Table 8-1.

The design bases specify that the waste shaft shall be designed to transport personnel, materials and radioactive waste. It shall also serve as an intake shaft for a small volume of air during normal operations and as an escape route during emergency operations.

The shaft shall be lined with unreinforced concrete from the bottom of its collar in the waste handling building to the top of the shaft key at the rock/salt interface. The liner shall be permanent and shall protect against spalling, fallout and deterioration of the rock in the shaft wall. It shall also prevent water seepage into the shaft.

The shaft liner shall be designed in compliance with applicable ACI Codes. A load factor of 1.4 shall be used for designing the concrete liner. The specified concrete compressive strength shall be 5,000 psi. No lateral rock pressure shall be assumed for design of the shaft liner. Hydrostatic pressure shall be considered to start at 250 feet below the ground surface and extend to the rock/salt interface at the top of the key. The water pressure shall be considered to increase 0.437 pounds per square inch (psi) for each foot of depth.

At water-bearing zones, the shaft shall be enlarged and liner plate installed to provide pressure relief and drainage space behind the liner during concrete placement and curing. Drainage pipes and

Table 8-1

VALIDATION ELEMENTS OF WASTE SHAFT DESIGN BASES

(1)	Shaft liner Hydrostatic pressure is considered to start at 250 feet below the ground surface and extend to the top of the key.
(2)	Shaft key Design lateral pressure shall be 50 percent of the vertical pressure due to soil, rock and salt overburden.
(3)	Unlined section Provide 20-foot diameter to allow for future salt creep deformation.

temporary hoses shall be installed to control water inflow prior to placement of the concrete liner. When the concrete liner has attained adequate strength, the area behind the liner plate shall be grouted to preclude deterioration of the dolomite and mudstone in the water-bearing zones.

The shaft key at the bottom of the concrete liner shall be constructed of reinforced concrete keyed into the rock and salt strata. A chemical water seal shall be placed behind the top and bottom of the key to prevent the migration of water. After the completion of shaft excavation and construction of the concrete liner and key, permanent piping from water collection rings to the shaft station shall be installed. Water from the collection rings shall be piped to a tank in the shaft station and then transported to the surface. The piping shall include inspection and clean-out fittings. Inspection and cleaning of the water collection rings and drainage piping shall be performed as necessary.

A load factor of 1.7 shall be applied to the design loading used for the concrete in the shaft key. The key shall be designed to resist lateral pressure generated by salt creep. The design lateral pressure shall be 50 percent of the total vertical pressure due to the soil, rock and salt overburden.

Below the key, the shaft shall be excavated 20 feet in diameter to allow for future salt creep deformation. Rock bolts and wire mesh shall be installed in this unlined section of the shaft in order to provide a structurally stable salt surface.

A shaft station shall be excavated at the storage level. The shaft shall extend below the storage level to such a depth as required by the hoisting equipment and sump. The use of rock bolts and wire mesh shall be dictated by the condition of excavated surfaces as well as code requirements. The roof, walls and floor shall be checked periodically for loose salt in accordance with applicable codes. The tolerance for

excavation of roof, floor and wall surfaces shall be no greater than plus 6 inches. In no case shall the finished cross section dimensions be less than the design dimensions.

Geomechanical instruments shall be installed to measure water pressure behind the shaft liner, salt creep pressure behind the key, and radial convergence in the unlined section of the shaft. The types of instruments installed shall be piezometers, pressure cells, radial convergence points and extensometers.

The shaft, including the liner, key, unlined section, station and furnishings, shall be inspected at 1 month intervals, or as required by applicable codes, to detect cracking, corrosion, deterioration and water intrusion.

8.3 DESIGN VALIDATION PROCESS

The design validation process for the waste shaft consists of analytical calculations, finite element modeling, and the analysis of data collected from geomechanical instruments installed in the C & SH and waste shafts. The in situ material parameters of salt determined from C & SH shaft instrumentation data were used to analyze the closure behavior of the waste shaft. For the shaft station, the in situ measurement data obtained from the C & SH shaft station were used to predict future closure behavior. The following subsections present information pertaining to validation of the waste shaft reference design.

8.3.1 Data Collection

Data collection in the waste shaft has consisted of geologic mapping, visual observations and geomechanical instrumentation measurements. Data obtained from the geologic mapping were presented in Chapter 6. The following subsections discuss the field observations and the geomechanical instrumentation in the shaft.

8.3.1.1 Field Observations

Waste shaft inspections have been concerned primarily with water seepage through the concrete liner, salt incrustation on the surface of the liner, dissolution in the shaft sump and the results of the liner grouting program.

Water seepage through the waste shaft liner has occurred since construction. As discussed in Chapter 3, subsection 3.4.2, grouting during construction behind the steel liner plate at both the Magenta and Culebra members did not completely prevent water from entering the shaft. It was estimated that the total water seepage through the liner was approximately 0.5 gallons per minute (gpm). A remedial grouting program (ref. 3-3), conducted from August 11 through August 25, 1984, reduced the seepage to about 0.015 gpm as measured in October 1984. Subsequent inspections in February and June 1985 determined that fresh water had begun seeping through cracks and construction joints in the liner from zones within and above the grouted area. The highest level of water seepage was occurring at a depth of only 60 feet below the shaft collar. Because this is higher than the potentiometric surface of ground water in the Magenta and Culebra members, the source of the seepage was probably rainwater and construction water contained in the backfill around the shaft collar and in the underlying Gatuna sandstone. This is based on the fact that heavy rains in the late summer of 1984 left substantial quantities of water ponded in the waste-handling building excavations and in the remnant of the SPDV ventilation shaft drilling fluid reserve pit.

The initial rate of this renewed seepage could not be measured because the PVC drainpipe had been broken in several places. Subsequent repair of the drainpipe has permitted the rate of water inflow to be measured on a regular basis. The measurements are obtained by timing the flow of water from the drainpipe into a calibrated bucket. These measurements do not consider the small amount of uncontrolled "fly water" that falls down the inside of the shaft. The initial measurement, in January 1986, was 0.47 gpm. The measurements, are

plotted on Figure 8-1 and show a generally decreasing trend in the flow rate. This trend may be influenced by three factors. First, the water contained in the backfill and sandstone has slowly drained into the shaft. Second, the rate of evaporation increases as the outside air temperature increases, thus reducing the amount of water reaching the drains. Both of these conditions are temporary. A series of rainstorms could recharge the backfill and sandstone, and evaporation will decrease with cooler winter temperatures. Heavy rains in June 1986 may have been responsible for the increased flow detected by the late June reading. The third factor influencing the flow trend is the possibility that the water collection rings and the drainpipe may be partially blocked by debris. This would result in reduced water flow through the drainpipe and an increase in the amount of unmeasureable fly water.

Although there has been limited access to the waste shaft since August 1984, several inspections of the shaft and sump have been made. One inspection was made on February 21, 1985, at which time some instrumentation damage was observed. In addition, the PVC drainpipe was observed to have been broken in several locations. Appreciable salt incrustation was noted on the surface of the concrete liner and on many of the instrumentation boxes and cables. This incrustation was primarily attributed to salt dust from the underground excavation adhering to the damp shaft walls during the period since September 1984 when the waste shaft was used as an exhaust shaft. A small percentage of this salt incrustation was also attributed to water seepage through the liner.

On June 16, 1985, another inspection of the waste shaft was made to within 60 feet of the shaft station. The shaft ventilation had been changed from upcast to downcast after the February inspection. Very little salt incrustation was present on the concrete liner and only a small amount was present in places on the wire mesh. Fresh water entering the shaft through the liner, from approximately 60 feet below the collar, was running down the liner. Although much of the liner was

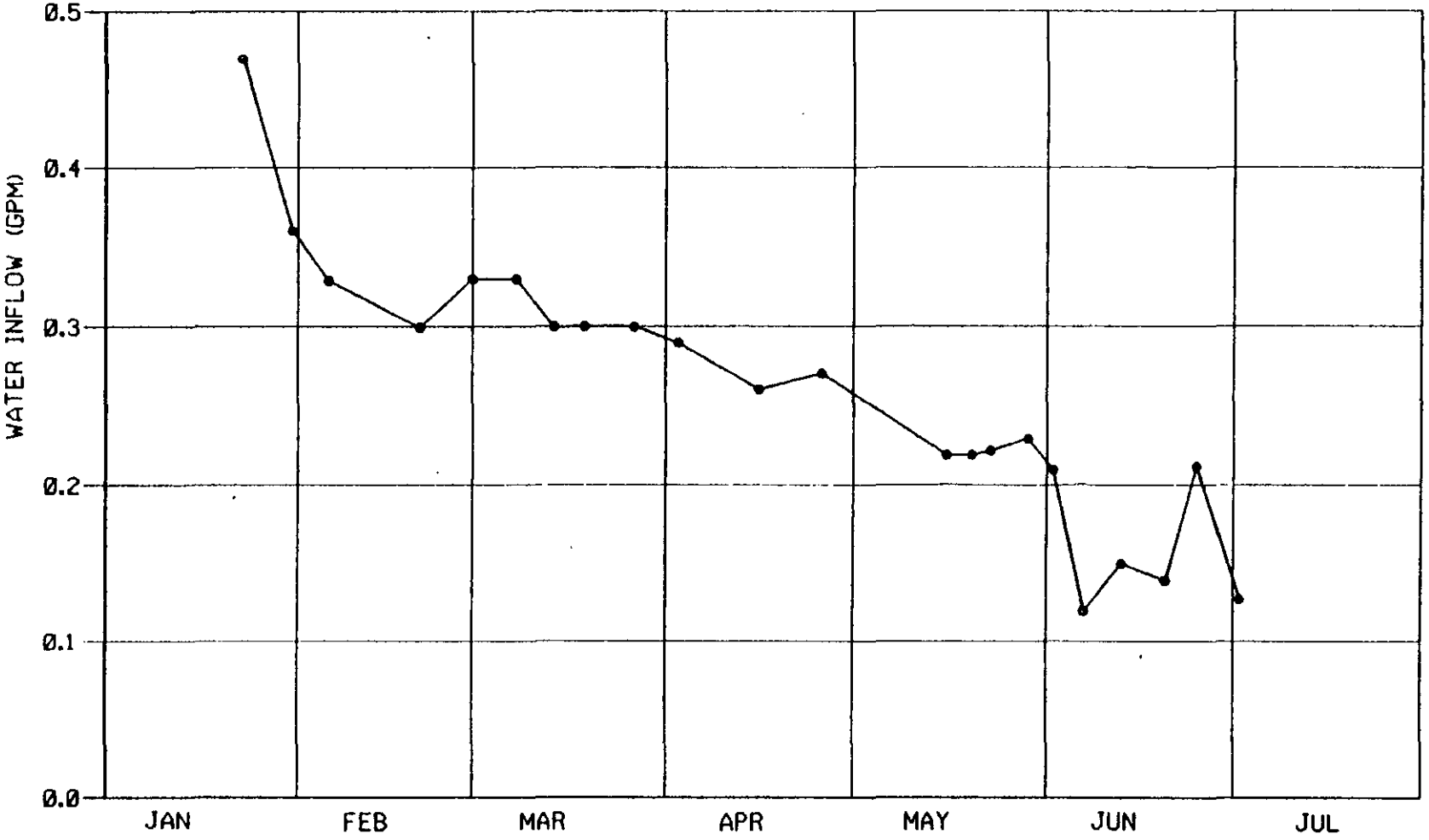


Figure 8-1

WASTE SHAFT
WATER INFLOW MEASUREMENTS

observed to be wet, the water rings were not full. This water appeared to have dissolved the salt incrustation observed in the February 1985 inspection. Cracks were common in the liner to within 60 feet of the collar. The PVC drainpipe damage had not been repaired. No water was seen draining from below the concrete key. The shaft sump contained water to within 60 feet of the shaft station floor. This water was a combination of rainwater, construction water and ground water. It was pumped out in September 1985.

On December 1, 1985, another inspection of the waste shaft was made. The PVC drainpipe was still broken or disconnected at several levels. The water rings were plugged and overflowing. There appeared to be an increase in water flow into the shaft, most noticeably at the Culebra member. An approximately 1/8- to 1/4-inch thickness of salt had been deposited on the liner below the Culebra.

On December 11, 1985, an inspection of the waste shaft sump was made. During this inspection, and a subsequent inspection on December 12, 1985, MB-139 was observed closely. The clay along the lower contact was distinct and no separations were noted. Although the upper contact could not be distinguished behind a covering of wire mesh, MB-139 could be seen quite well and appeared to be intact and undisturbed. One small fracture, approximately 2 feet long and 1/2 inch wide was observed on the west side of the shaft approximately 1 foot above the lower contact.

An anhydrite bed 61 to 66 feet below the station floor was also observed during this inspection. A zone of dissolution was present along the upper contact of this layer in the northwest to southeast half of the shaft. The dissolution occurred partially within the anhydrite bed. The maximum void width of approximately 0.7 foot occurred on the south-southwest side of the shaft and extended approximately 18 feet south into the salt. The zone of dissolution pinched out going around the shaft in either direction away from the area of maximum opening. There did not appear to be any disturbance of

the strata overlying or underlying this zone anywhere around the shaft and no voids or disturbance of the anhydrite existed on the opposite side of the shaft. The upper contact of the anhydrite with the overlying halite did not exhibit any irregularities. From the physical evidence available, it appeared that this feature was the result of localized dissolution. No dissolution of the anhydrite was observed. The dissolved material was probably a soluble evaporite mineral representing a facies change within the Salado formation. The dissolution appeared to have resulted from the previously discussed water which had been standing in the sump. The level of this water was measured at 60 feet from the shaft station floor prior to its being pumped out in September 1985. The shaft wall below the water line exhibited no significant deterioration due to the standing water. However, some sloughing of an anhydrite layer 71 to 75 feet below the shaft station floor and widening of the shaft near the bottom of the sump was evident. The shaft wall exhibited a glazed surface which probably resulted from minor dissolution of the salt surface.

A shaft inspection was conducted on July 24, 1986. The inspection team mapped the location of cracks in the concrete liner and any associated seepage. They also mapped the location of leaking construction joints. This mapping indicates that additional cracks have developed in the liner since mapping was conducted prior to the August 1984 grouting program. The shaft was found to be considerably drier than during the 1984 mapping program. Many of the new cracks mapped may have existed in 1984 but were masked by the water on the shaft walls. Also, salt precipitates now enhance the outline of the cracks. The inspection also revealed that recent construction work inside the shaft has resulted in some instrument cable and junction box damage and in breakage of the previously repaired PVC drainpipe.

The waste shaft station has shown little deterioration since it was enlarged from the SPDV ventilation shaft station dimensions. Visual surveys are performed approximately every 3 months by site geologists. The results of these inspections are documented in the GFDRs. Only

minor spalling along the station walls has occurred. Vertical fractures similar to those found in the drifts and test rooms have developed at intersection corners. The roof, although showing no visible evidence of deterioration, has been covered by wire mesh and rock bolts for safety purposes. During the July 1986 shaft inspection, some separation at clay G was observed on the east and west sides of the shaft. The separation was a maximum of 3/4 inch wide at the shaft surface and decreased away from the shaft. No separation was observed at clay H.

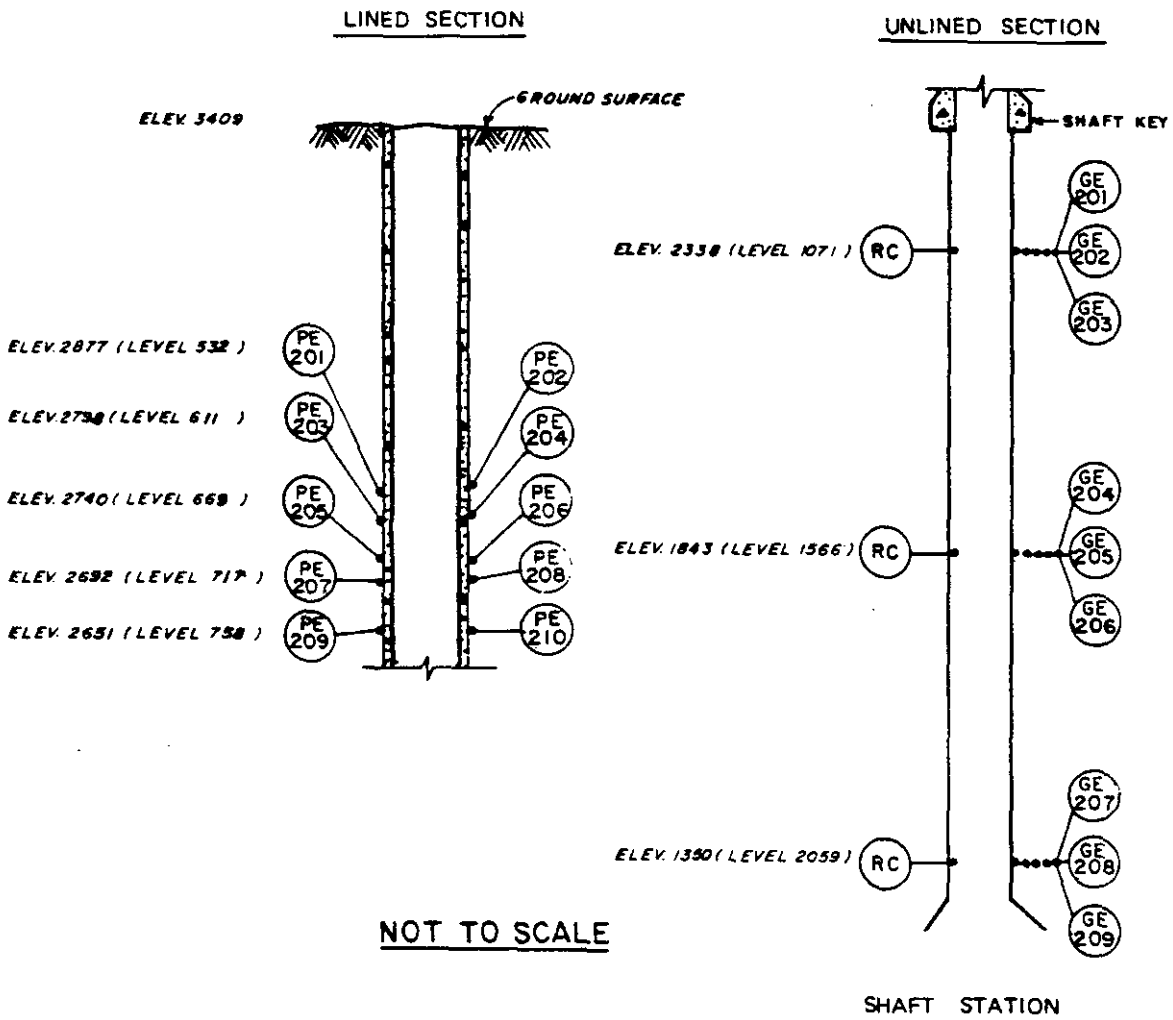
Minor separations and fracturing in MB-139 and in the overlying halite have been observed in the station floor. A dish-like fracture zone similar to that found in Test Room 2 is present, but has developed on a much smaller scale. Inspection of MB-139 in the shaft sump, and evidence from boreholes drilled in the station floor, show that the marker bed and the overlying halite are, for the most part, intact.

8.3.1.2 Geomechanical Instrumentation

The waste shaft geomechanical instrumentation is similar in design to that of the C & SH shaft. The shaft contains 12 vibrating-wire piezometers, 4 pressure cells, 9 multiple-point borehole extensometers, and 3 sets of radial convergence points. Figure 8-2 shows the instrument locations in the waste shaft and Figure 8-3 shows details of the key instrumentation.

As in the C & SH shaft, all of the geomechanical instruments, except the convergence points, are monitored remotely. The instruments are connected to the surface datalogger that polls all of the remotely-read underground instruments on a scheduled basis.

The 12 piezometers were installed on September 7 and 8, 1984, after the 6-foot diameter SPDV ventilation shaft had been enlarged to become the 20-foot to 23-foot diameter waste shaft. The water that could exert pressure on the liner is expected to come from the two water-bearing members in the Rustler formation. The Magenta dolomite member occurs



LEGEND

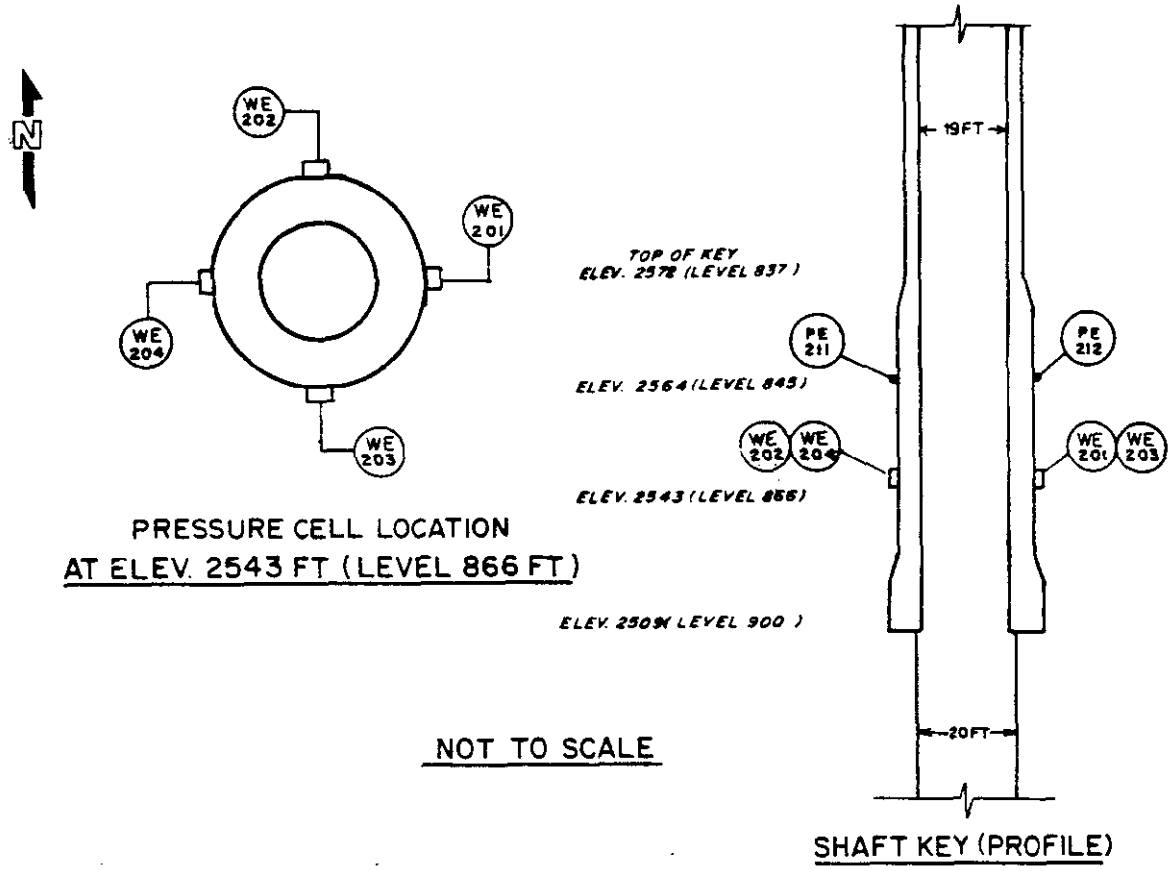
- (PE) PIEZOMETER
- (RC) CONVERGENCE POINTS
- (GE) EXTENSOMETER

NOTES

1. PC'S AT EACH LEVEL CONSIST OF FOUR POINTS.
2. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH IN FEET FROM THE SHAFT COLLAR AT ELEVATION 3409 FT MSL
3. SEE FIGURE 8-2 FOR DETAILS OF SHAFT KEY INSTRUMENTATION.

Figure 8-2

WASTE SHAFT
INSTRUMENTATION



LEGEND

(WE) - PRESSURE CELL

(PE) - PIEZOMETER

NOTES:

1. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH IN FEET FROM THE SHAFT COLLAR AT ELEVATION 3409 FT MSL
2. PRESSURE CELLS LOCATED AT CONCRETE-ROCK INTERFACE.

Figure 8-3

WASTE SHAFT KEY
INSTRUMENTATION

from a depth of 596 feet to 621 feet (elev. 2813 to 2788 feet) and the Culebra dolomite member from a depth of 706.5 feet to 728.5 feet (elev. 2702.5 to 2680.5 feet). Two piezometers are at each of the following elevations: 2877, 2798, 2740, 2692, 2651 and 2564 feet (Figures 8-2 and 8-3). The piezometers are located on opposite sides of the shaft, one at N60°E and the other at S60°W. Piezometer readings are shown on the data plots in Appendix J.

The four pressure cells are located in the waste shaft key between the salt of the shaft wall and the concrete comprising the key. The pressure cells were installed at a depth of 866 feet (elev. 2543 feet). The four cells are spaced 90 degrees apart around the shaft at the north, east, south, and west positions (Figure 8-3). Initial pressure cell readings were taken on April 6, 1984. The waste shaft key concrete was placed between March 23 and April 3, 1984. Pressure cell data plots are also presented in Appendix J.

The extensometers and convergence points were installed only in the unlined section of the shaft below the key. These instruments, whose locations are shown on Figure 8-2, were installed after enlargement of the shaft to its final dimensions.

The nine multiple-point borehole extensometers were installed between August 31 and September 5, 1984, 3 to 5 months after the completion of shaft enlargement. Three extensometers each are located at three elevations in the unlined section of the shaft: 2338, 1843 and 1350 feet (Figure 8-2). The extensometers are spaced 120 degrees apart around the shaft. Plots of the readings are presented in Appendix J.

A set of radial convergence points, consisting of four points each, is located at each of the same elevations as the extensometers. The convergence points were installed immediately after enlargement of the shaft. Due to interference by shaft furnishings, it was not possible to set the convergence points at 90 degrees from each other. The set of convergence points at a depth of 1,071 feet consists of two points

on each side of the shaft conveyance furnishings. The two points were set 44 degrees apart. At the other two depths the two points on each side of the shaft are set 53 degrees apart. Convergence point readings were obtained from April through June 1984 and are plotted in Appendix J. However, their performance is considered poor and erratic. The readings have been affected by salt incrustation on the convergence point eyebolts and extensions. Convergence point readings were discontinued when the temporary waste shaft hoist was decommissioned on September 12, 1984. The convergence points will be inaccessible until approximately December 1986, when the permanent waste shaft hoist is installed.

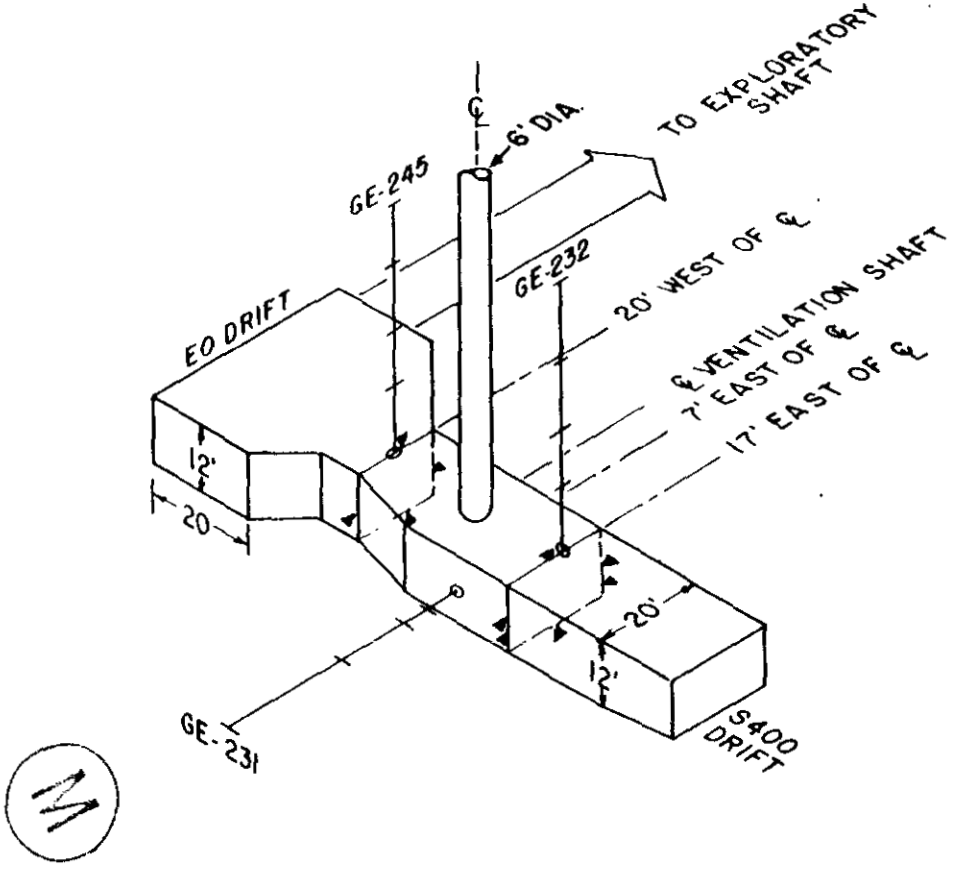
Geomechanical instruments were installed in the SPDV ventilation shaft station in late 1982. The instrumentation consisted of three multiple-point borehole extensometers and two sets of convergence points as shown on Figure 8-4. When the shaft was enlarged to become the waste shaft, the station was also enlarged and the original instruments were destroyed. Two extensometers were then installed in the enlarged shaft station. Both of these extensometers are in the roof, one on either side of the waste shaft (Figure 8-5).

8.3.2 Analysis and Evaluation

Analysis of the waste shaft data and its evaluation against reference design parameters has been divided into four elements: the concrete-lined section of the shaft; the shaft key; the unlined section; and the shaft station. This division is based on the different in situ and design conditions in each of these areas.

8.3.2.1 Lined Section

Engineering mechanics principles were used to design the concrete liner against elastic buckling. Both axial and flexural stresses were considered in the design. Permissible stress values were those used for structural plain concrete (ref. 8-1) utilizing the ultimate strength design method. Since there are no significant salt strata in



EXPLANATION

ANCHOR — COLLAR

GE EXTENSOMETER

RC RADIAL CONVERGENCE POINT

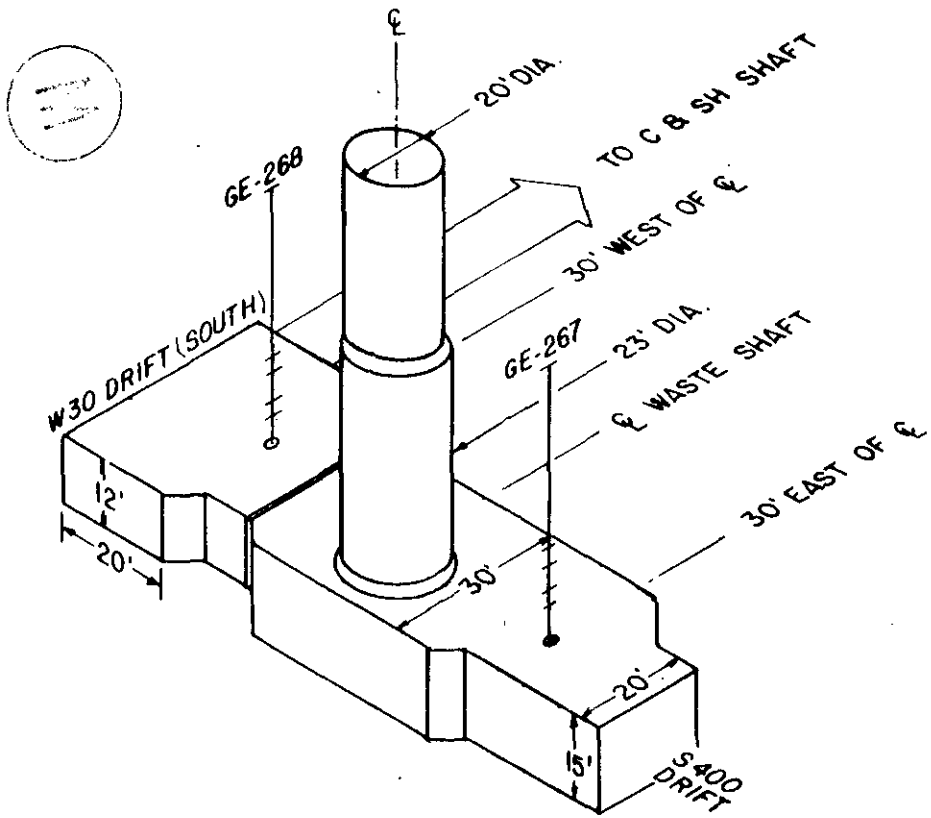
N

10 0 10 20 30 FEET

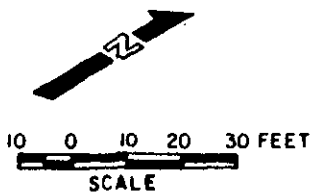
SCALE

Figure 8-4

SPDV VENTILATION SHAFT STATION
INSTRUMENTATION



EXPLANATION



NOTES:

1. PREVIOUSLY IDENTIFIED AS THE SPDV VENTILATION SHAFT STATION.
2. INITIAL INSTRUMENTATION WAS DESTROYED IN JUNE 1984. EXTENSOMETERS GE-267 AND GE-268 WERE INSTALLED AFTER STATION ENLARGEMENT.

Figure 8-5

WASTE SHAFT STATION INSTRUMENTATION

the rock surrounding the liner, rock creep and the resulting rock pressure against the liner were assumed to be negligible. Hydrostatic pressure acting from a depth of 250 to 844 feet was used in the design based on the applicable design basis element (Table 8-1).

Additional stresses in the liner due to initial imperfections in roundness and grouting pressures were also considered. For stress calculations, an initial imperfection of 1 inch was assumed in the roundness of the liner. In place of the local water pressures, grouting pressures 1.3 times the ground-water pressure were assumed to act over one-sixth of the circumference of the liner. Due to localized effects, a 20 percent increase in the allowable concrete stress was assumed due to the short-term loading of the grouting pressure.

The external pressure capacities and corresponding closure limits (maximum diametric changes) for different thicknesses of the liner are:

Depth (feet)	Liner Thickness (inches)	Pressure Capacity (psi)	Closure Limit (inches)
27 to 462	10	216	0.165
462 to 580	14	370	0.215
580 to 762	18	523	0.251
762 to 837	20	598	0.266

The intent of the shaft piezometers is to monitor the pressure exerted on the liner by water from the Rustler formation. These data would indicate if the design hydrostatic pressure from the design basis was suitable.

Table 8-2 summarizes the variation in measured water pressures behind the liner at different times. Figure 8-6 shows the average reading on September 18, 1985, for each piezometer pair plotted against shaft depth. For comparison, the hydrostatic design pressure for the liner through this interval is also shown.

The measured pressures at this time are lower than the design pressure for two apparent reasons. First, water seepage through cracks and

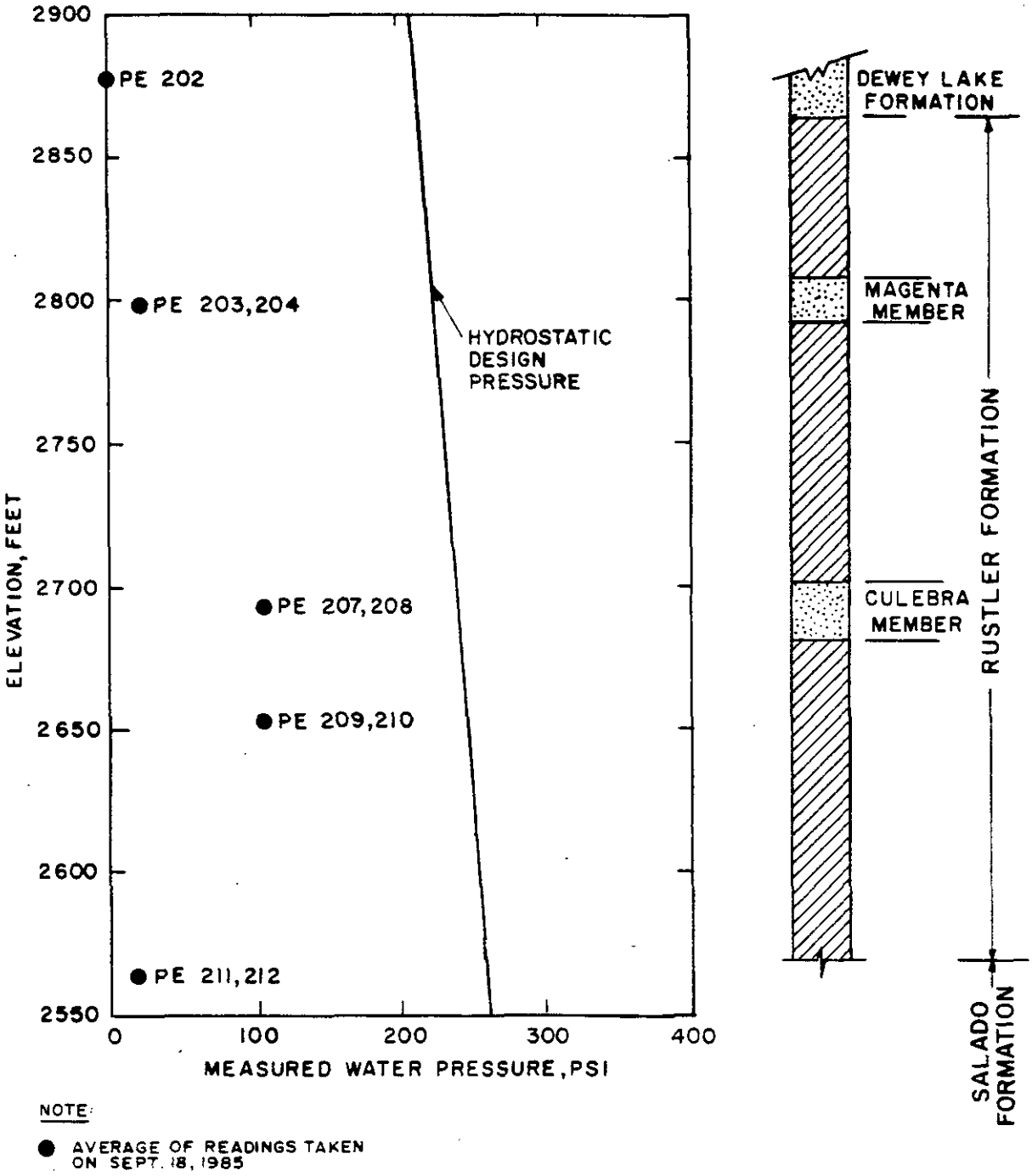
Table 8-2

WASTE SHAFT LINER AND KEY
SUMMARY OF MEASURED WATER PRESSURES (psi)

PIEZOMETER NO. 31X-PE-00

Date of Reading	201	202	203	204	205	206	207	208	209	210	211	212
	Elev. 2879		Elev. 2798		Elev. 2740		Elev. 2692		Elev. 2651		Elev. 2564	
Dec. 26, 1984	-1	0	16	20	-7	-8	77	93	65	76	13	11
May 16, 1985	-2	0	11	16	12	-15	79	95	58	84	8	10
June 27, 1985	*	0	13	19	*	-16	78	95	*	91	11	12
Sep. 18, 1985	*	1	17	26	*	-14	99	115	*	107	19	22
Dec. 18, 1985	*	-3	-3	-2	*	-3	47	51	*	27	4	8
Mar. 16, 1986	*	-3	2	6	*	-13	*	63	*	47	5	12
June 13, 1986	*	0	10	15	*	-20	*	85	*	74	18	19

* Piezometer not functioning.



M

Figure 8-6

WASTE SHAFT LINER
WATER PRESSURE MEASUREMENTS

construction joints in the liner has not allowed the water to build up to its full hydrostatic head. This means that the piezometers are not measuring the full pressure that might be expected against the liner if the leaks were sealed. Second, the low pressure readings, and especially the variation in readings, suggest that hydraulic continuity is incomplete along the rock/liner interface. It is possible that water from the Culebra has been isolated, or at least restricted, in its vertical extent. This is suggested by the distribution of pressures shown on Figure 8-6.

The pressure distribution of the piezometers is also shown on Figure 8-7. These readings, however, are the maximum pressure values measured for each piezometer elevation. The figure also shows the design hydrostatic pressure distribution for the entire liner and its pressure capacity. The pressure capacity provides a significant factor of safety over the design hydrostatic pressure.

8.3.2.2 Shaft Key

Due to lithostatic pressure, the salt formation behind the shaft key tends to creep over time. The result is a buildup of inward pressure against the concrete key. The concrete key was designed to withstand a lateral pressure equal to 50 percent of the vertical overburden pressure (approximately 60 ksf) for at least 25 years after its construction. This reduction in lateral pressure from 75 percent of the overburden pressure for the C & SH shaft to 50 percent for the waste shaft was based on the results of the analysis of data obtained from the C & SH shaft (Chapter 7).

A nonlinear finite element analysis was utilized to simulate the long-term creep interaction of the salt and the concrete key. The analysis was performed using the MARC Finite Element Program discussed in Chapter 6. The material properties of the finite element model simulated the creep behavior of the salt via a power law (equation C.4-6 in Appendix C) provided in the analysis.

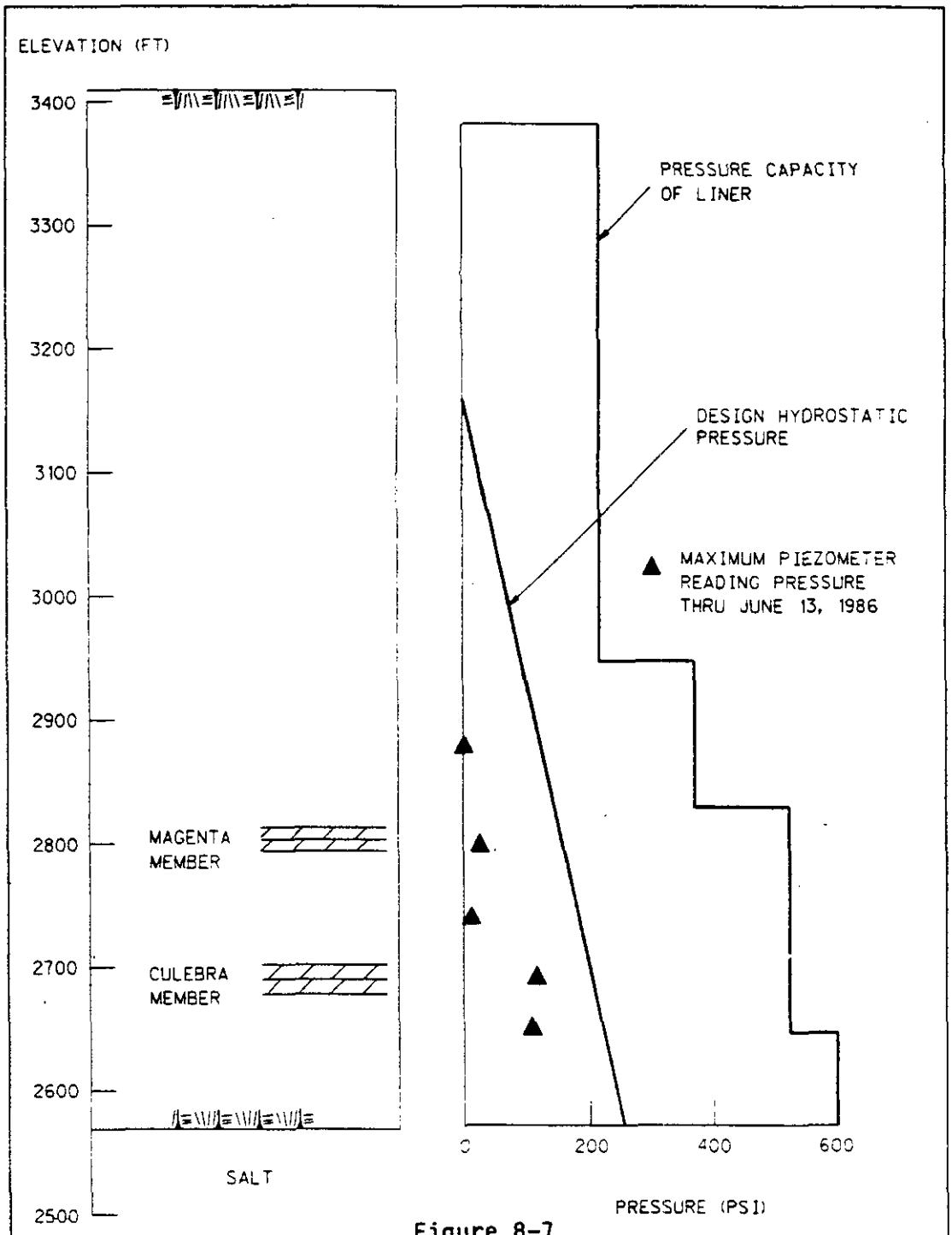
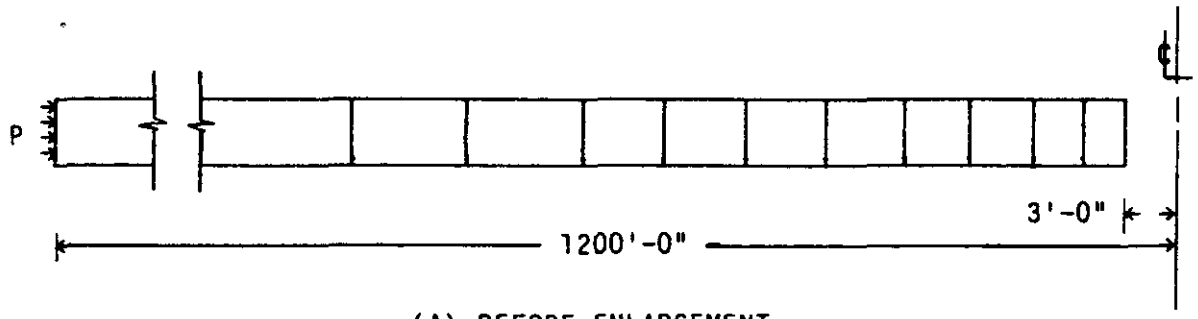
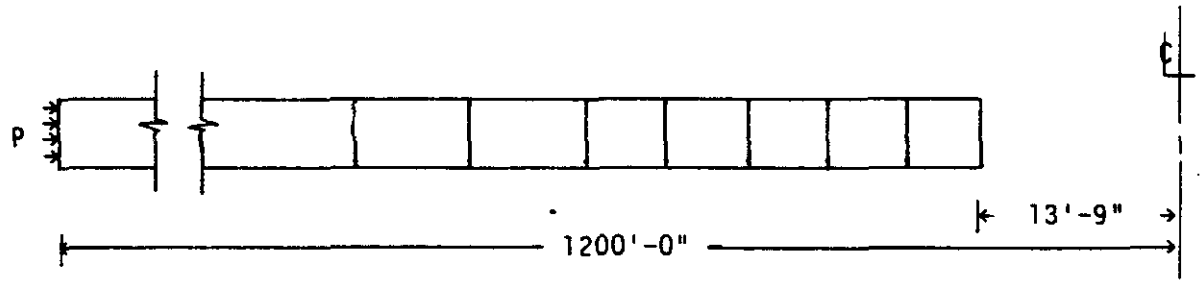


Figure 8-7

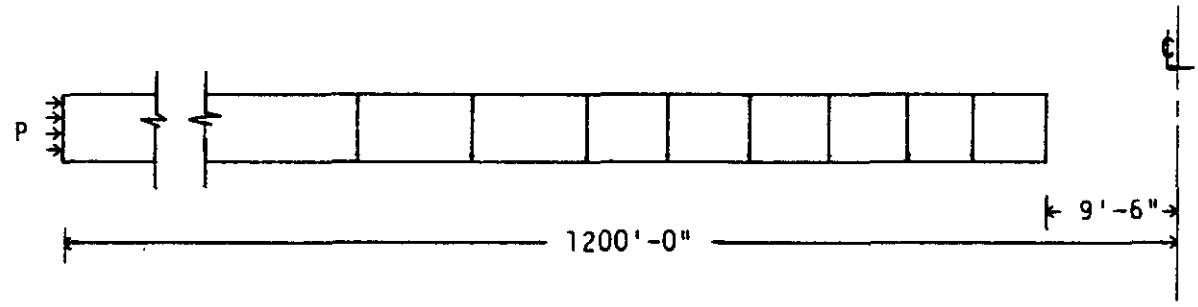
WASTE SHAFT LINER
LATERAL PRESSURE COMPARISON



(A) BEFORE ENLARGEMENT



(B) AFTER ENLARGEMENT



(C) AFTER CONCRETE CONSTRUCTION

Figure 8-8

WASTE SHAFT KEY
FINITE ELEMENT MODEL

Model Simulation. Unlike the more sophisticated analysis of the C & SH shaft key (which employed a multi-layered, axisymmetric finite element model), the finite element model for the waste shaft key and surrounding salt consists of a single layer of quadrilateral, axisymmetric ring elements as shown on Figure 8-8. Because only the lateral flexural stiffness of the shaft key was considered in the finite element model, and not its longitudinal flexural stiffness, the analysis provides conservative results. Also for conservatism, the shrinkage effect of the concrete was not taken into account in this analysis.

An inner element of the model, shown on Figure 8-8, represents a segment of the concrete key. In order to simulate the time interval between shaft excavation and concrete placement for the key, this element was not tied to the surrounding salt deposits. All depth-dependent input values, such as overburden stresses, were computed for a depth of 892 feet, low in the key, where such values are at a maximum. Because halite is the most dominant material in the rock around the shaft key, its properties were used for the model elements. Halite is also the material at the base of the shaft key where lateral pressure is at a maximum.

The following analytical procedure was used to perform a creep analysis of the waste shaft key:

(1) Initially, lateral forces were applied outwardly against the inside surface of the shaft. This simulates the condition prior to excavation of the original 6-foot diameter shaft.

(2) Lateral forces were applied inwardly against the outer vertical boundary of the model. The magnitude of these forces were based on the lateral earth pressure, equal to 892 feet of overburden, computed for the key elevation of 2517 feet.

(3) Internal stresses were applied in each element to represent the initial lithostatic stress state.

(4) All nodes of the model were restrained against vertical displacement.

(5) Subsequently, outward lateral forces against the inside surface of the shaft were removed to simulate excavation of the original 6-foot diameter shaft.

(6) A creep analysis was performed on the salt deposits surrounding the 6-foot diameter shaft until that time when the shaft diameter was enlarged and the concrete for the key was placed (795 days).

(7) The three innermost ring elements were detached (tie constraints removed) from the model to represent the enlargement of the shaft. A concrete ring element (tie constraints added to the model) then replaced the three salt elements just removed to model the concrete key.

(8) A second creep analysis was performed using this new model and a creep time representing 28 years after placement of the concrete key.

The stratigraphy in the upper section of the waste shaft is similar to that in the C & SH shaft. The creep parameters determined from in situ salt behavior in the C & SH shaft were, therefore, assumed to be valid for correlating analytical results of the waste shaft from normalized time to real time. The secondary creep parameter C was found to equal 5.70×10^{-21} $ksf^{-4.9}$ sec^{-1}. Because early in situ measurements were not available for the C & SH shaft, the primary creep parameters A and z were determined from in situ data from the horizontal drifts and were found to be 3.2 and 1.1×10^{-7} sec^{-1}, respectively.

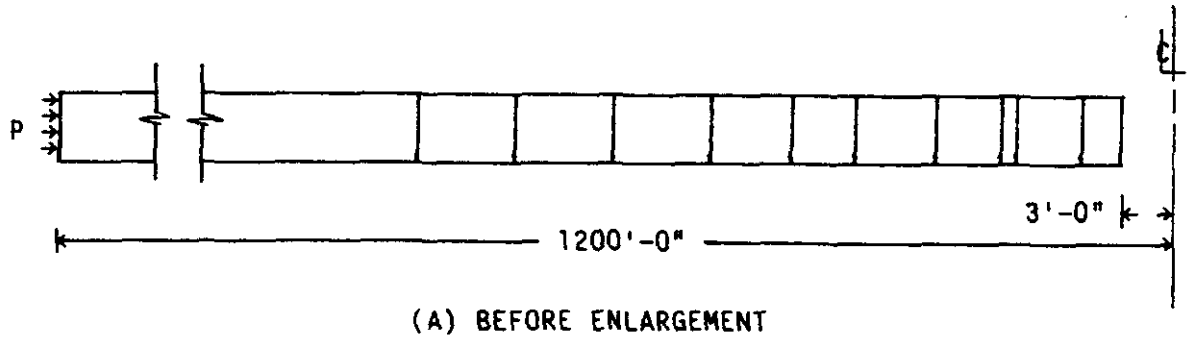
Seepage Evaluation. The structural integrity of the shaft key is not totally dependent upon salt creep. The stability of the key, and consequently the shaft liner, can be compromised by water dissolving the salt surrounding the key. Water is prevented from seeping from the upper water-bearing zones down into the salt around the key primarily by two chemical water seals. The key configuration, including the seals, is described in Chapter 3.

The number of piezometers in the key are not sufficient to conclusively support an evaluation of seepage. However, the distribution of water pressure behind the liner and key provides an indication that there is probably no hydraulic continuity along the rock/liner interface. This is especially evident at the lowermost water-bearing zone at a depth of 717 feet (elev. 2692 feet). Here, water pressures are over 100 psi. The next lower level of piezometers, at a depth of 758 feet (elev. 2651 feet), also indicate pressures of about 100 psi. However, the lowest level of piezometers, in the shaft key, reflect pressures of less than 25 psi.

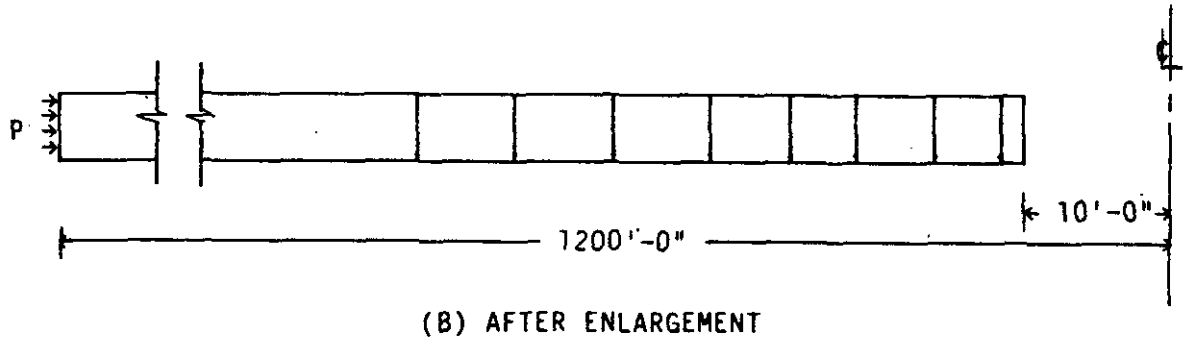
The telltale drains in the waste shaft key could not be located during the July 1986 inspection. Assuming they were constructed as designed, they may be covered by a thin veneer of concrete formed during concrete placement. A seep was noted on one side of the shaft at the approximate design level of the telltales. Inspection of the base of the key determined that no water was seeping from behind the key. This indicates that ground water is not bypassing the lower water seal between the key and the surrounding halite.

8.3.2.3 Unlined Section

The structural behavior of the unlined section of the waste shaft was also computed by a nonlinear creep analysis using the MARC Finite Element Program (ref. 6-8). The objective of the analysis was to compute the actual structural behavior by utilizing applicable in situ data from the C & SH shaft and the horizontal drifts, and to verify the design adequacy of the unlined section of the shaft.



(A) BEFORE ENLARGEMENT



(B) AFTER ENLARGEMENT

Figure 8-9

WASTE SHAFT UNLINED SECTION
FINITE ELEMENT MODEL

Model Simulation. The finite element model used for the unlined section of the waste shaft utilizes a single horizontal row of 70 quadrilateral axisymmetric ring elements. The model, shown on Figure 8-9, has its upper and lower horizontal boundaries restrained against vertical movement and a constant uniform lithostatic pressure, equal to 2,059 feet of overburden, applied to its outside vertical boundary. The same lithostatic pressure was initially applied to the inside vertical boundary as well; however, that pressure was later removed from the inside boundary to simulate the drilling of the original 6-foot diameter shaft.

The analysis simulates the salt creep until that time when the 6-foot diameter shaft was enlarged to its present 20-foot diameter. The shaft enlargement was simulated in the model by removing those ring elements that were located within the 20-foot diameter shaft opening. With the enlarged shaft configuration, simulated salt creep for another 28 years was analyzed.

Determination of Creep Parameters. Because the stratigraphy beneath the WIPP site is fairly uniform, the values of the creep parameters for the unlined section of the waste shaft were assumed to be identical to those values calculated at the corresponding elevations of the C & SH shaft. In addition, the C & SH shaft was drilled at a much earlier date than was the waste shaft; therefore, more in situ geomechanical instrument measurements were available for the C & SH shaft. The values of the creep parameters for the C & SH shaft were determined by correlating analytical results with extensometer readings obtained from a depth of 2,057 feet (elev. 1353 feet) in the shaft. The creep parameters C, A and z for the C & SH shaft were found to be 1.30×10^{-21} $ksf^{-4.9}$ sec^{-1}, 3.2 and 1.1×10^{-7} sec^{-1}, respectively. Chapter 7 presents specific details on how the creep parameters were evaluated for the C & SH shaft.

8.3.2.4 Shaft Station

The analysis of closure and stability of the waste shaft station is based upon closure measurements in the C & SH shaft station. This is due to the limited amount of geomechanical instrumentation data available from the waste shaft station for the reasons discussed in subsection 8.3.1. The following discussion presents a brief comparison of the two shaft stations.

The waste shaft station cross-section dimensions are 15 feet high and 30 feet wide. These dimensions are comparable to those of the C & SH shaft station. However, the C & SH shaft station was excavated by drilling and blasting while the waste shaft station was excavated using a mining machine. The density of rock bolts in the roof of the C & SH shaft station is much greater than that in the waste shaft station. Also, the roof of the C & SH shaft station close to the shaft is approximately 3 feet below clay G, while clay G at the waste shaft station is nearly 8 feet above the roof. Thus, closure analysis of the waste shaft station using measurement data from the C & SH shaft station will be conservative.

The dimensions of the waste shaft station are also comparable to those of the test rooms and storage rooms. Computational analysis of the storage rooms (Chapter 12) predicts that failure will occur in MB-139, below the floor, due to gradual stress buildup. Similar behavior is expected to occur in MB-139 beneath the waste shaft station.

8.3.3 Prediction of Future Behavior

This subsection presents predictions of future behavior for the various elements of the waste shaft including the lined section, the shaft key, the unlined section and the shaft station.

8.3.3.1 Lined Section

The cracks in the concrete-lined section of the shaft are primarily the result of normal tension cracking occurring during the restrained

shrinkage of plain concrete. The cracks are not detrimental to the liner's structural integrity but sealing by grouting will be required to meet the design criteria regarding ground-water control.

Although the rate of water flowing into the waste shaft has been minor, the total volume of flow has resulted in the lowering of the potentiometric surface around the shaft. Other activities have also affected the potentiometric level in the vicinity of the shafts. Most notably, SNL pumping tests in borehole H-3 in late 1985 lowered the potentiometric surface approximately 40 feet (A.R. Lappin, SNL, personal communication). Due to the unknown effect of current and future hydrologic studies at the WIPP, it is difficult to predict the magnitude of future water pressure on the liner. However, two statements can be made concerning this water pressure:

(1) The piezometer data present a valid indication of water pressures behind the liner. Although this data cannot be used for predicting future pressures, continuous monitoring of these instruments will reflect current pressures and indicate short-term trends. This information can be compared with the design basis pressure distribution (Figures 8-6 and 8-7) to evaluate liner stability.

(2) Following the next grouting program in the waste shaft, if all water seepage through the liner has been stopped, it is possible that the potentiometric surface could return to its highest level determined during preliminary design activities. Assuming complete hydraulic continuity behind the liner, this condition would result in a pressure distribution equal to that of the hydrostatic pressure used for liner design. This condition would be within the design limits.

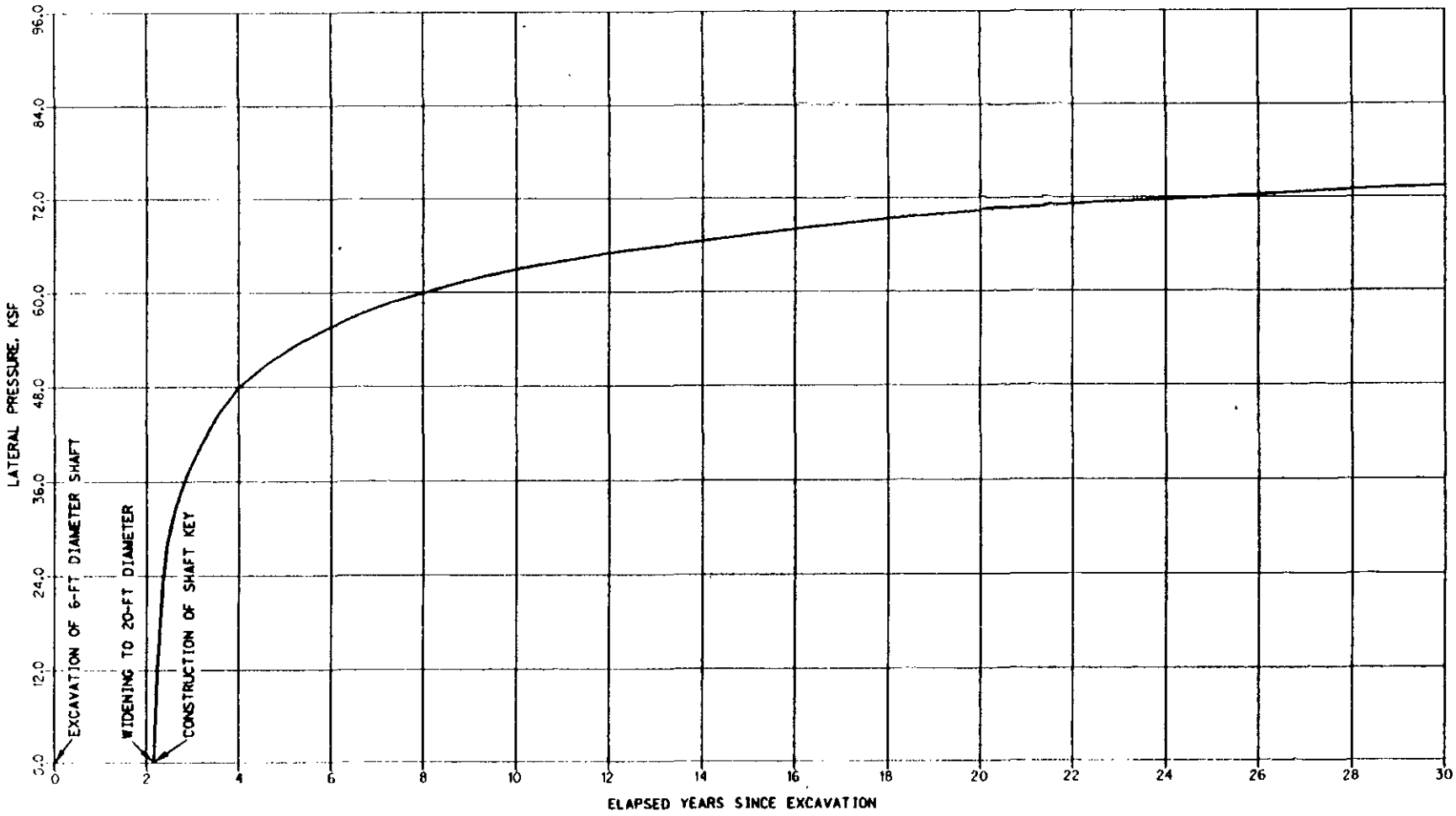


Figure 8-10

WASTE SHAFT KEY
LATERAL PRESSURE PREDICTION

8.3.3.2 Shaft Key

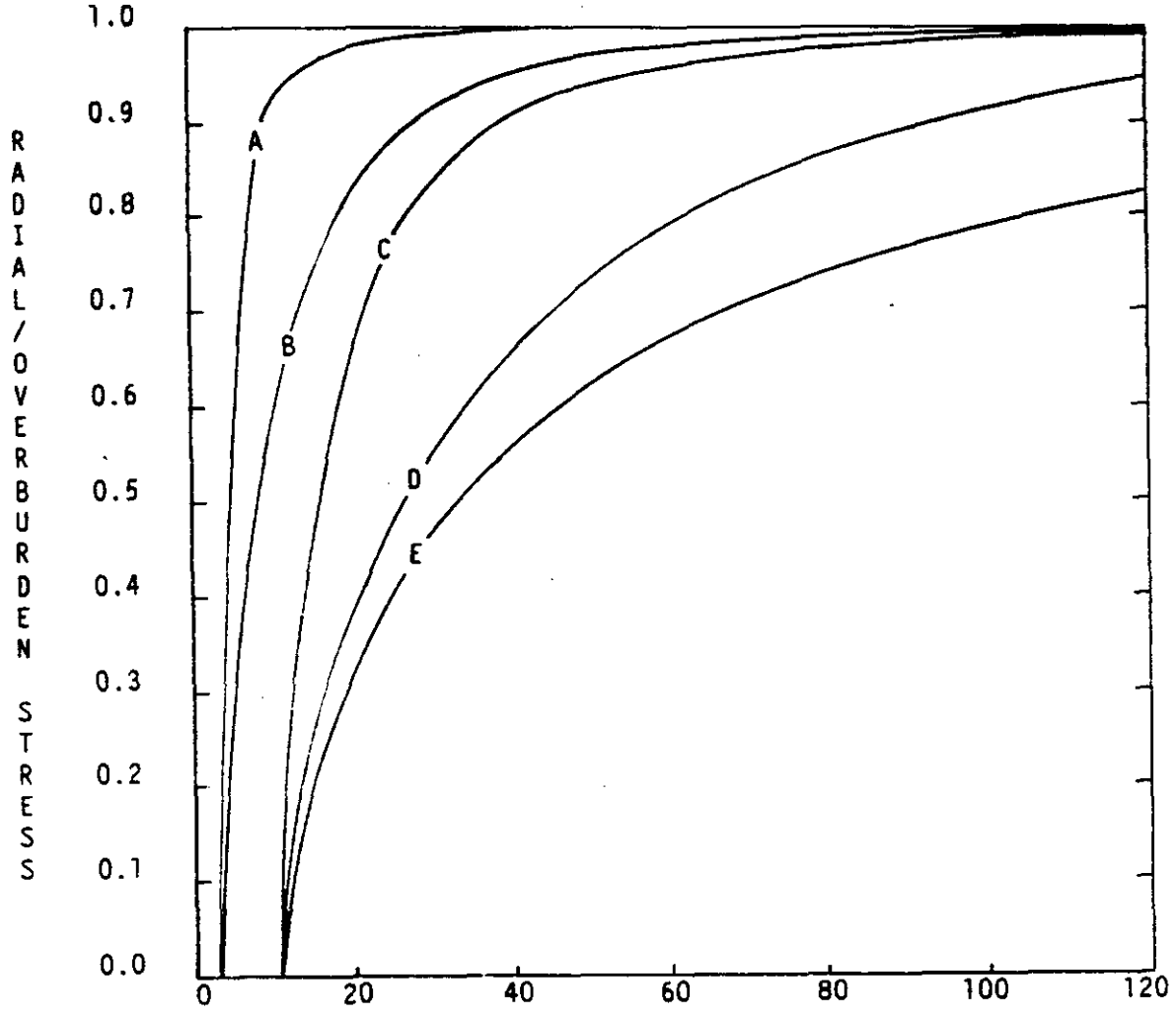
Figure 8-10 shows the predicted lateral pressure curve for the concrete key based on the finite element analysis. The key was designed as a compression cylinder in accordance with the strength design method for reinforced concrete (ref. 7-5) using an ultimate hoop stress of 4.25 ksi (0.85 f'_c). Using the design basis load factor of 1.7 for lateral loads, the maximum allowable hoop stress in the concrete key is 2.50 ksi, which results in an allowable lateral rock pressure of 148 ksf based on the diameter of the key. The design basis lateral pressure design requirement is approximately 60 ksf. Figure 8-10 shows a lateral pressure on the shaft key of approximately 72 ksf at the end of the 25-year shaft operating life. If the shrinkage and creep properties of the concrete were taken into account in the finite element analysis, the lateral pressure would actually be less than 72 ksf at 25 years.

The reinforced concrete of the shaft key is expected to exhibit cracks due to shrinkage. These are tensile cracks due to the reinforcement restraining the concrete from shrinking. The cracks are not considered significant because they are common to most reinforced concrete structures.

8.3.3.3 Unlined Section

Figures 8-11 and 8-12 show the radial and tangential (hoop) stress distributions relative to the overburden stress for different times in the unlined section of the waste shaft. Figure 8-11 shows the zone around the shaft opening where radial stresses are affected and indicates a decrease in magnitude over time. The computational results depicted on Figure 8-12 indicate that tangential stresses are only affected within a radius of approximately 120 feet.

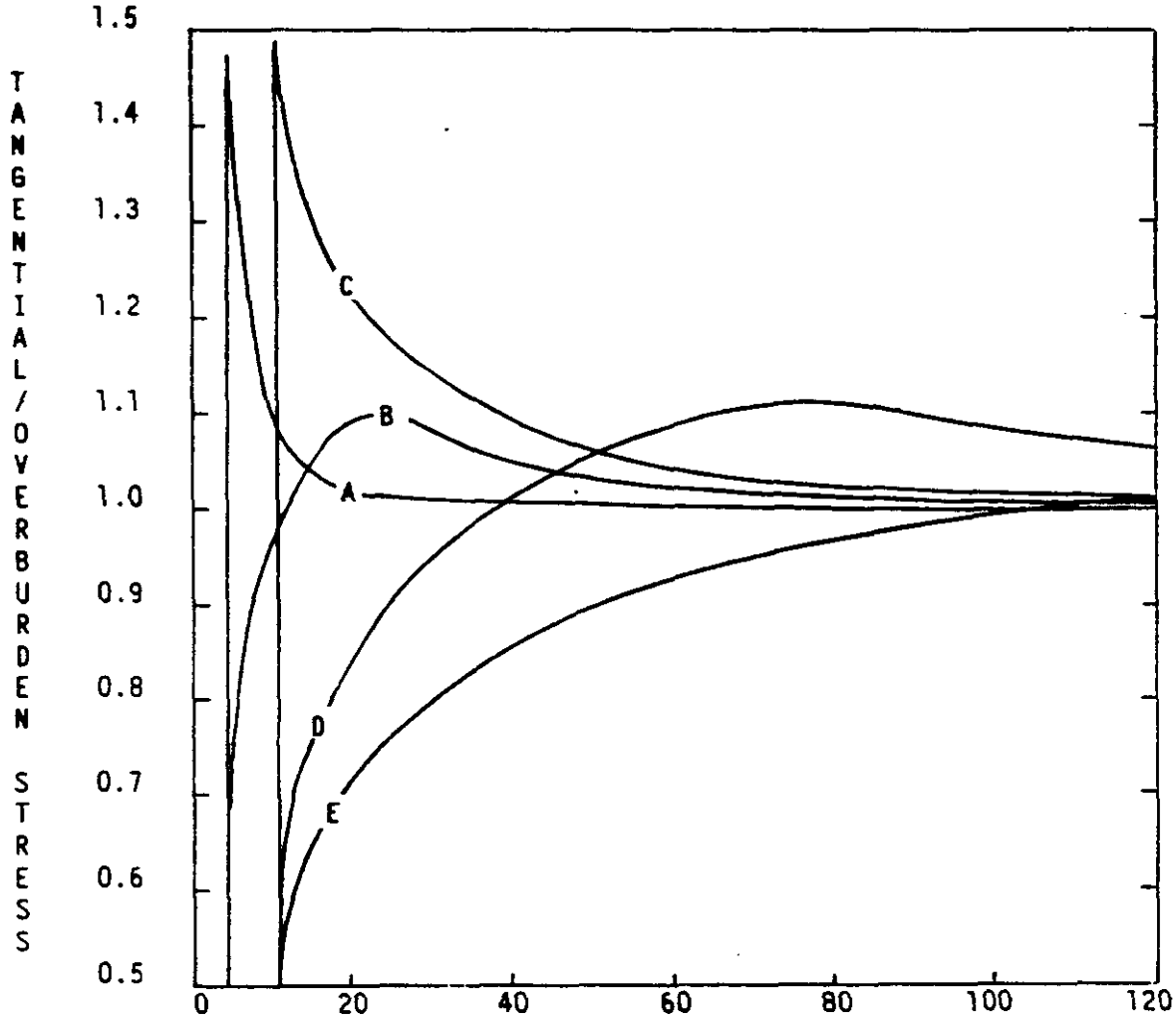
Figures 8-13 and 8-14 show the effective stress and effective creep strain distributions in the unlined section of the waste shaft. The effective stress in the shaft wall at 25 years is approximately 140 ksf



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 20-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 20-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 8-11

WASTE SHAFT UNLINED SECTION
RADIAL STRESS DISTRIBUTION AT ELEVATION 1350 FEET

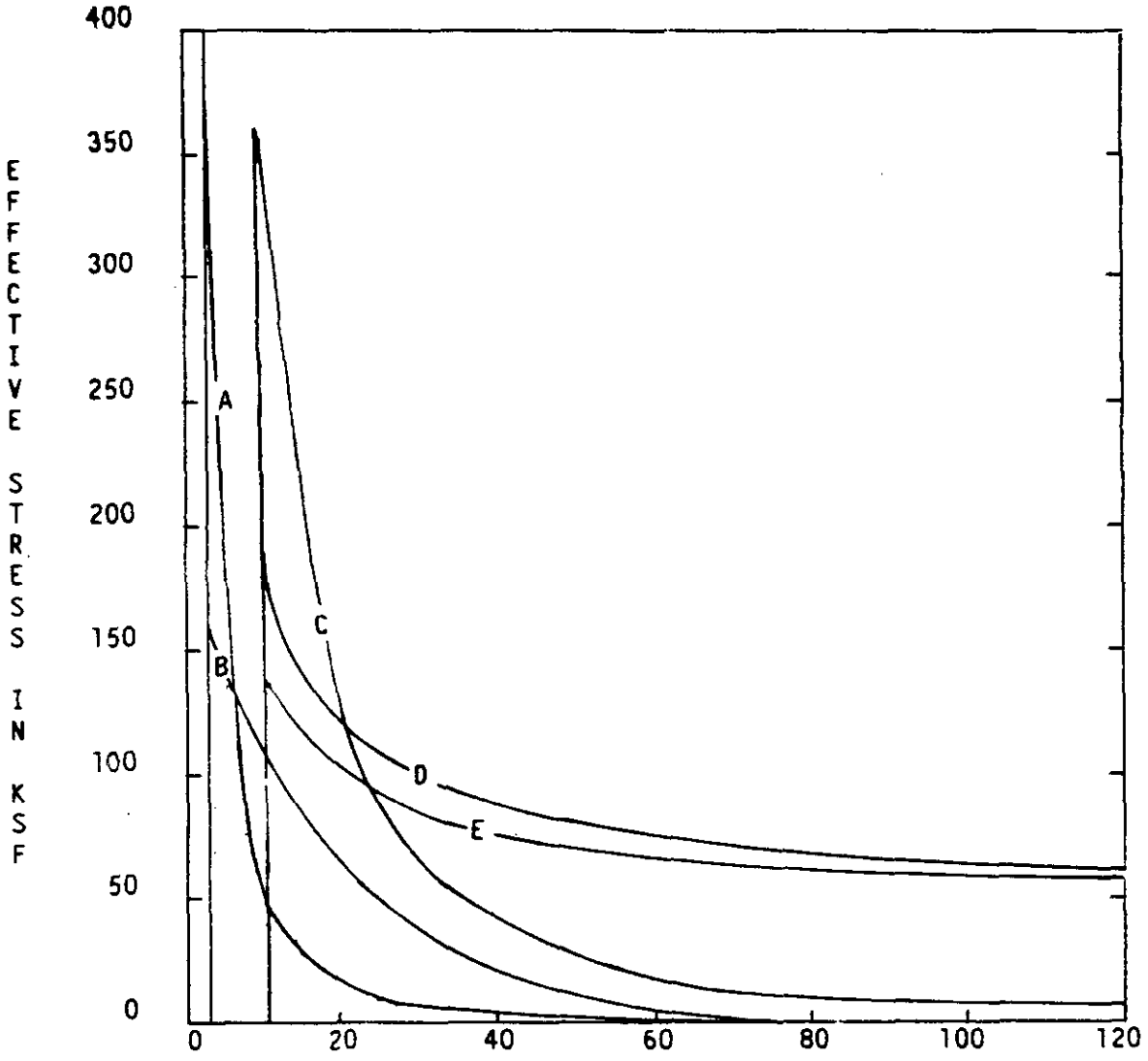


A - IMMEDIATELY AFTER EXCAVATION OF 6 FT-DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 20 FT-DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 20 FT-DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

M

Figure 8-12

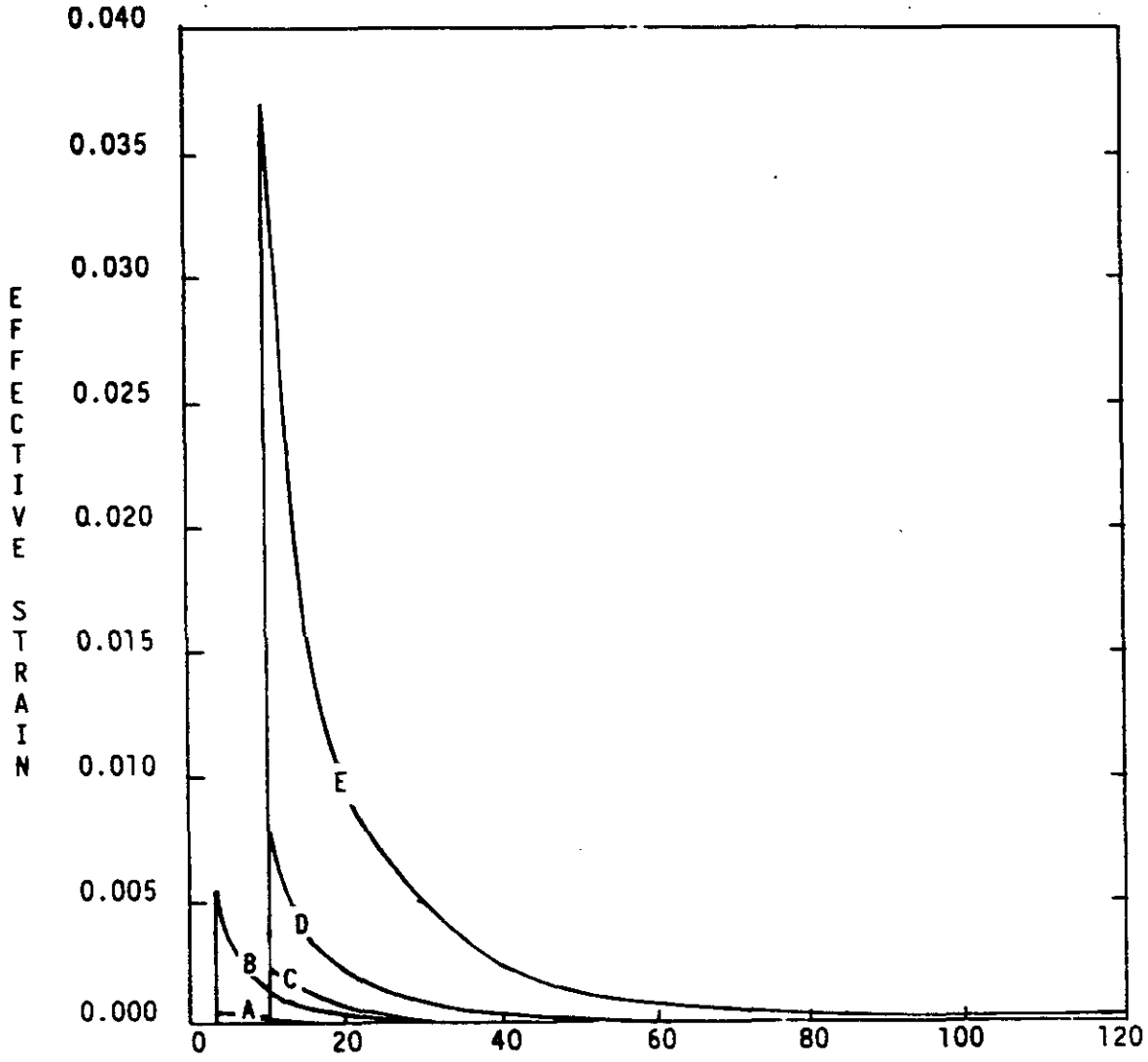
WASTE SHAFT UNLINED SECTION
TANGENTIAL STRESS DISTRIBUTION AT ELEVATION 1350 FEET



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 20-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 20-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 8-13

WASTE SHAFT UNLINED SECTION
EFFECTIVE STRESS DISTRIBUTION AT ELEVATION 1350 FEET



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 20-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 20-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

M

Figure 8-14

WASTE SHAFT UNLINED SECTION
EFFECTIVE CREEP STRAIN DISTRIBUTION AT ELEVATION 1350 FEET

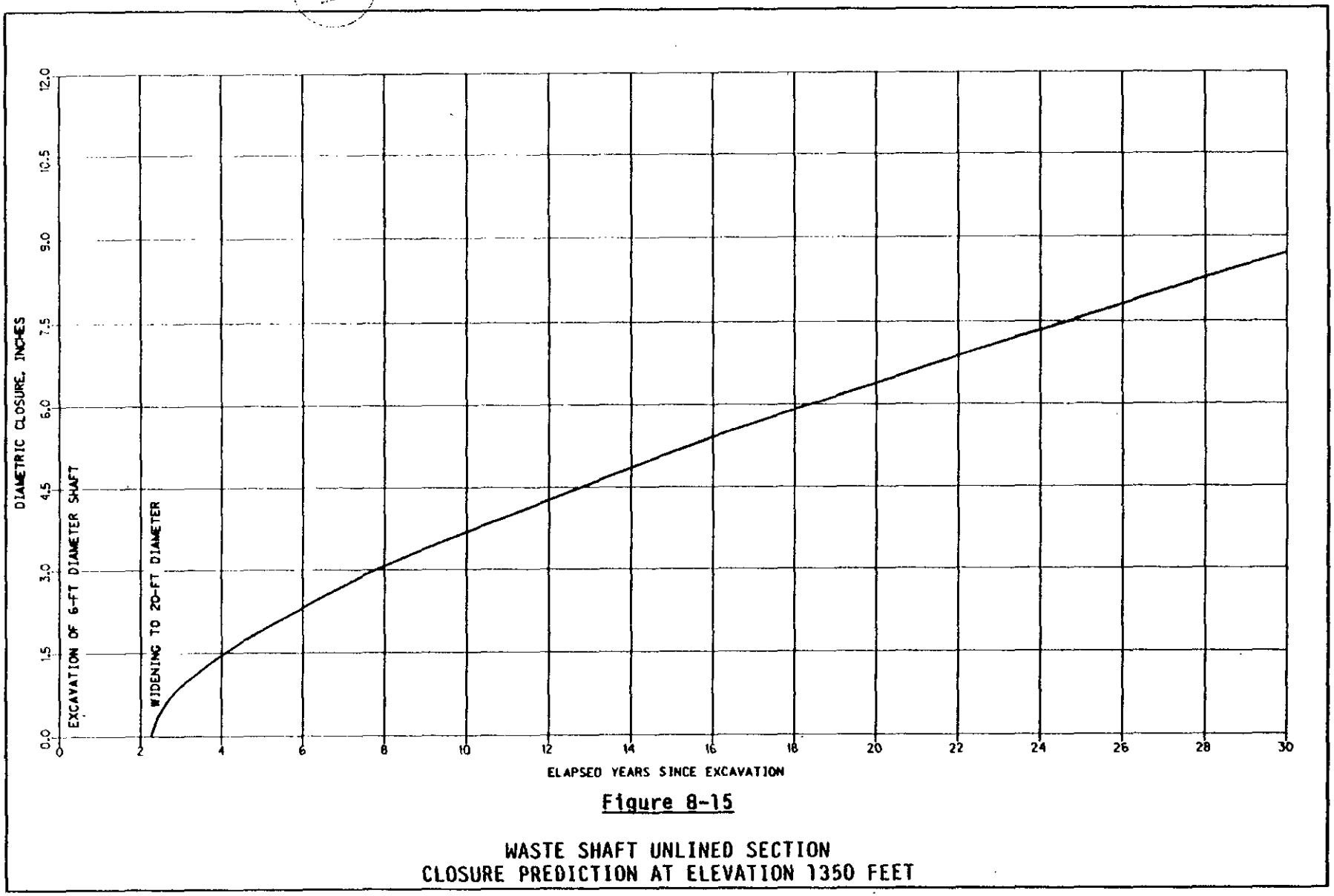


Figure 8-15

WASTE SHAFT UNLINED SECTION
CLOSURE PREDICTION AT ELEVATION 1350 FEET

while the effective creep strain in the shaft wall at 25 years reaches a value of approximately 0.037.

Figure 8-15 contains the prediction of diametric closure for the unlined section of the waste shaft at a depth of 2,059 feet (elev. 1350 feet). This figure shows a diametric closure of approximately 7 1/2 inches over the 25-year operating life of the shaft.

8.3.3.4 Shaft Station

Closure in the waste shaft station is predicted using measurement data from the C & SH shaft station. The measured roof-to-floor closure in the C & SH shaft station was approximately 10 inches on September 16, 1985, over 3 years after the completion of excavation. The measured wall-to-wall closure is greater than 6 inches over the same time period. However, the initial readings were taken nearly 260 days after the station was excavated; therefore, the actual closure magnitudes will be higher. The average rate of roof-to-floor closure over the measurement period was approximately 3.89 inches/year. Using this value as a constant closure rate over the plant operating life of 25 years, an additional roof-to-floor closure of about 8 feet is expected to occur. The wall-to-wall closure over the same period is expected to be approximately 60 percent of the roof-to-floor closure, or about 5 feet. Actual closure may be lower as discussed in subsection 8.3.2.4.

8.4 CONCLUSIONS AND RECOMMENDATIONS

Design validation requires an assessment of the compatibility of the design criteria, design bases and design configurations used for the reference design. The following conclusions and recommendations address those design elements identified in Section 8.2. Other conclusions and recommendations resulting from the design validation process are also presented.

8.4.1 Conclusions

The design criteria require that all of the shafts are to be stable. Shaft stability has been evaluated using analytical calculations,

finite element modeling and in situ data analysis. The shaft liner is considered stable because the water pressure exerted on it has remained significantly below the design hydrostatic pressure. If the water pressure increases to the design hydrostatic pressure, as may be expected if the leaks are sealed by additional grouting, liner stability will not be compromised. The pressure capacity of the liner sufficiently exceeds the design hydrostatic pressure.

Based on existing evidence, the cracks in the liner and key do not present a structural problem. The unreinforced concrete liner is expected to function as intended, provided that the existing cracks and construction joints are grouted and contact grouting is performed at the rock/liner interface. Consolidation grouting of the surrounding rock may also be necessary to achieve a dry shaft.

The shaft key was designed to withstand a design basis lateral pressure equal to 50 percent of the overburden pressure (approximately 60 ksf). The finite element analysis determined that the lateral pressure on the key at the end of the facility operating life will be approximately 72 ksf. Although this value is higher than the design lateral pressure, the key is expected to remain stable throughout its operating life because the allowable lateral rock pressure is 148 ksf. This is twice the lateral pressure predicted and provides a sufficient margin of safety. Furthermore, if the shrinkage and creep properties of the concrete were taken into account in the analysis, the lateral pressure would be less than 72 ksf.

The analytical results for the waste shaft, presented in Section 8.3, show the calculated redistribution of stresses around the shaft due to the effects of creep. Based on the computed vertical, horizontal and effective stresses in the unlined section, the magnitude of stresses immediately adjacent to the opening decreases with time as the stress arch around the opening migrates away. The maximum stress occurs immediately after excavation and is followed by relaxation due to creep behavior. Therefore, the stresses will not cause a future stability

problem in the waste shaft except in the anhydrite bed (MB-139) below the floor of the shaft station. Gradual buildup of stress in this bed may result in floor heave and fracturing.

The analysis shows the locations of effective creep strain concentrations for selected times in the unlined section. Based on these predicted values of effective creep strain and the strain limit discussed in Chapter 6, the waste shaft will remain structurally stable over its planned 25-year operating life.

The analysis predicts that diametric closure in the unlined section of the waste shaft will be approximately 7 1/2 inches over its 25-year operating life. Based on the predicted deformations and closures, the waste shaft will meet the requirements stated in the design criteria and the 20-foot diameter unlined section will provide sufficient operating clearance to allow for salt creep.

The design criteria requires that no uncontrolled ground water reach the facility level via the shafts. The majority of water seeping through cracks and construction joints in the liner is collected in three water-collection rings and directed to the underground facility where it is disposed. Only minor amounts of uncontrolled fly water reach the facility level. This water has a negligible impact and does not affect validation of the criterion regarding ground water reaching the facility level.

Shaft inspections have determined that only one minor seep occurs in the key and that no water seepage occurrs from the base of the key. This supports the conclusion that the water seals are functioning, that no water is seeping along the concrete/salt interface, and that no salt dissolution is occurring behind the concrete key. The installation technique for the waste shaft water seals was improved over that used for the C & SH shaft water seals (Chapter 3).

The zone of dissolution observed in the shaft sump wall is not considered to be detrimental to the operation of the facility. The

material was dissolved differentially by standing water in the sump resulting from construction activities. It is not the result of any geologic discontinuity or process. This zone will not produce any structural problems in construction of the waste shaft facilities.

The waste shaft station is expected to undergo roof-to-floor closure at a rate of 3.89 inches/year. However, this rate has been obtained by using the C & SH shaft station instrument data. The actual closure rate may be lower. Additional heave and fracturing in the salt beneath the floor, as well as in MB-139, is expected to occur. Some remedial work will be required to maintain the required roof-to-floor clearance for operational equipment and activities.

The reference design for the waste shaft is considered to be validated in accordance with the objectives of the design validation program based on the analyses, evaluations and predictions of future behavior presented in this chapter. With one exception, the waste shaft reference design complies with the design criteria and the design bases. The criterion that stipulates that shaft liner design shall prevent ground-water flow into the shaft has not been met. The rate of water currently seeping into the waste shaft is not considered to be detrimental to the stability of the shaft or to its functional purpose. However, the criteria will be satisfied when additional remedial grouting has been performed. No modifications to the shaft reference design will be required.

8.4.2 Recommendations

Based on the results of design validation, the following recommendations with respect to the waste shaft are made:

(1) Due to the limited in situ data base, validation of the waste shaft key and unlined section relies on numerical modeling utilizing creep parameters derived from the C & SH shaft in situ data. It is recommended that the modeling be repeated, prior to the first receipt of waste, using the latest in situ

data from the waste shaft. This analysis should be repeated periodically for comparison and verification of in situ data against design parameters.

(2) Grouting should be performed to completely seal the waste shaft liner. This should include contact grouting behind the liner and grouting of shrinkage cracks and construction joints. Consolidation grouting may also be required. Qualified personnel should inspect the shaft at regularly scheduled intervals. The liner should be checked for leaks after grouting has been completed. The key should be checked for water seeping from behind the key at its base. If any seepage is detected it may become necessary to grout the area above the upper water seal. If possible, grout should not be placed behind the key below the upper seal. However, should grouting behind the key become necessary, the grout must be a chemical gel (or other non-rigid grout) and must be compatible with both the existing water seal material and with the requirements of the Plugging and Sealing Program.

(3) The dissolution zone in the waste shaft sump should be filled with a salt-compatible cement mortar.

(4) Because waste shaft station closure is based on C & SH shaft station data, and because of the importance of the waste shaft station in general, vertical convergence points or meters should be installed at selected locations and measurements taken periodically. These data should then be analyzed to obtain better estimates of station closure.

CHAPTER 9
EXHAUST SHAFT

9.1 INTRODUCTION

This chapter presents information on design validation of the exhaust shaft. Included are discussions of its design, the design validation process, and conclusions and recommendations pertaining to validation of the reference design.

9.2 DESIGN

This section presents the design criteria and design bases used to develop the reference design for the exhaust shaft. The design configuration of the shaft is discussed in Chapter 3, subsection 3.3.3.

9.2.1 Design Criteria

The design criteria for the exhaust shaft are identical to those for the other two shafts. The criteria requiring validation are indicated in the listing of abridged criteria presented in Chapter 2, Table 2-1, and are discussed in Chapter 7.

The design criteria requiring evaluation for design validation of the exhaust shaft are:

(1) shaft shall be designed to be structurally stable;

(2) shaft shall be designed to accommodate salt creep; and

(3) ground-water flow into the shaft shall be controlled.

9.2.2 Design Bases

The design bases are the detailed design requirements developed from the design criteria. The primary design basis document for the exhaust shaft is the Design Basis, Exhaust Shaft (ref. 2-16). The major elements of the design bases are the same as those for the waste shaft,

except for the items discussed in the next paragraph. The elements that require evaluation or that have a direct impact on design validation are presented in Table 9-1.

In addition to adhering to the design basis elements discussed previously for the waste shaft, the exhaust shaft shall be designed to connect the facility level with the exhaust filter building at the ground surface. The exhaust shaft shall be used to remove air from the underground development level during construction and storage operations. The entire shaft shall be inspected utilizing a closed-circuit television camera that shall be lowered from the top of the shaft. Unlike the design bases for the other two shafts, the exhaust shaft design basis does not require the installation of geomechanical instrumentation.

9.3 DESIGN VALIDATION PROCESS

As discussed in Chapter 5, design validation of the exhaust shaft has been achieved by data collection, its analysis and evaluation, and the prediction of future behavior. Data collection activities have included geologic mapping and visual observations of the exhaust shaft wall. Although geomechanical instruments have been installed in the shaft, no data was available for design validation due to the late date of installation.

Computational analyses for the exhaust shaft were performed in the same manner as those for the waste shaft. The finite element analyses of the shaft key and unlined section used the material parameters for salt obtained from the C & SH shaft and horizontal drift analyses. The results of the analyses were then used to predict future behavior.

9.3.1 Data Collection

Data collection in the exhaust shaft was on a much smaller scale than in the other two shafts. Geologic mapping was conducted in the shaft to verify the stratigraphy. This mapping is discussed in detail in Chapter 6. Visual inspections and observations in the shaft were

Table 9-1

VALIDATION ELEMENTS OF EXHAUST SHAFT DESIGN BASES

(1)	Shaft liner Hydrostatic pressure should be considered to start at 250 feet below the ground surface and extend to the top of the key.
(2)	Shaft key Design lateral pressure shall be 50 percent of the vertical pressure due to soil, rock and salt overburden.
(3)	Unlined section Provide 15-foot diameter to allow for future salt creep deformation.

sporadic due to limited access. The following discussion presents those observations which affect design validation.

9.3.1.1 Field Observations

Exhaust shaft construction was completed on January 15, 1985. Initial of the lined section of the shaft was performed on January 30, 1985. At that time water seepage through cracks and construction joints in the liner was observed. Seepage into the shaft was measured at 0.35 gallons per minute (gpm).

Subsequent inspections of the exhaust shaft liner were made in February and May 1985 to observe its condition and to evaluate the need for grouting to reduce water seepage. The first occurrence of moisture on the liner was observed 25 feet below the shaft collar. The majority of water seepage was occurring between approximate depths of 569 feet and 759 feet (elev. 2840 feet and 2650 feet). Below a depth of 759 feet the entire shaft liner was wet, making it difficult to determine the exact source of seepage. Some salt accumulation was observed on the liner below the Culebra water-bearing member. The May 1985 inspection generally revealed a 1/4- to 3/8-inch thickness of salt incrustation in this area with some local accumulation up to 4 inches in thickness.

Salt accumulation at two telltale drain holes, at a depth of 857 feet (elev. 2552 feet) on the northeast and east sides of the shaft key, had resulted in the almost complete plugging of these holes. The six other drain holes had minor salt accumulation. The bottom of the key had salt stalactites hanging from the concrete but no flow of water under the concrete was observed. There was no evidence of any dissolution of salt at the concrete/salt contact.

A cement/chemical grouting program was conducted in the exhaust shaft from June 1 through July 31, 1985. An inspection of the exhaust shaft liner was made on July 30, 1985. The liner was appreciably drier than it had been prior to grouting, especially below the Culebra member. One collar pipe, for future piezometer installation at a depth of 616

feet (elev. 2793 feet), was weeping and one pipe, at a depth of 722 feet (elev. 2687 feet), was dripping. This water constituted the majority of the total seepage into the shaft. Weeping from random cracks above a depth of 617 feet appeared to be of the same magnitude as before grouting. The water ring at the base of the shaft key was relatively dry. New telltale drain holes at a depth of 870 feet (elev. 2539 feet) were all dry. Several of the original drain holes, at 857 feet, and several new holes, at a depth of 855 feet (elev. 2554 feet), were weeping slightly. No evidence of seepage at the concrete key/salt contact was observed. The grouting program reduced water seepage into the exhaust shaft to an essentially non-measurable quantity.

Cursory inspections of the exhaust shaft made during the installation of geomechanical instruments in November and December 1985 indicated no appreciable change in the condition of the shaft liner since the July 1985 inspection.

A second grouting program was conducted in the exhaust shaft during August, September and October, 1986. The program was performed at this time to reduce the possible need for grouting in the future when shaft access will be limited. The grouting was conducted on a smaller scale than in the earlier program. It consisted of injecting grout through existing sleeves from the top of the salt in the key are to the top of the Magenta member. Grouting was also performed, as required, above the Magenta through sleeves in the liner. The results of the grouting were not available at the time of publication of this report.

9.3.1.2 Geomechanical Instrumentation

The original exhaust shaft design contained no provision for the installation of geomechanical instrumentation based on the assumption that rock behavior would be similar to that in the waste shaft. However, it was subsequently decided that geomechanical instrumentation should be installed to obtain shaft-specific behavior information for later use in the shaft sealing program.

Instrument locations in the exhaust shaft were based on waste shaft instrument locations. Twenty-one piezometers, 4 pressure cells and 9 extensometers have been installed in the exhaust shaft. The instrument installation was completed on December 27, 1985, 385 days after the completion of shaft excavation. All exhaust shaft instruments are monitored remotely by the datalogger.

9.3.2 Analysis and Evaluation

The analysis and evaluation of the constructed exhaust shaft has been performed using direct observation data and geomechanical instrumentation readings from the C & SH and waste shafts. This analysis and its evaluation against reference design parameters was performed for the three major sections of the shaft: the lined section; the shaft key; and the unlined section.

The adequacy of the exhaust shaft reference design was evaluated based on a complete spectrum of geomechanical behavior including stress, strain and deformation over the planned operating life of 25 years. The analyses used creep parameters computed from the C & SH shaft and the 8 x 25-foot drifts as well as hydrostatic pressures from the waste shaft.

9.3.2.1 Lined Section

Analyses were performed for the unreinforced concrete liner in the exhaust shaft. However, because no instrumentation data from this shaft were available, the analyses were based on data obtained from the C & SH and waste shafts.

The structural analysis and design of the exhaust shaft were performed using engineering mechanics principles and design bases similar to those used for the waste shaft as described in Chapter 8. For example, both axial and flexural stresses were considered in the design of the concrete liner, with permissible stress values taken as those used for structural unreinforced concrete (ref. 8-1) utilizing the ultimate

strength design method. Loads considered in the design of the concrete liner included a hydrostatic pressure assumed to act from a depth of 250 to 844 feet; a grouting pressure equal to 1.3 times the ground-water pressure acting over one-sixth of the circumference of the liner; and stresses due to an initial imperfection of 1 inch in the roundness of the liner. Since there is no major salt strata surrounding the liner, no significant creep will occur and rock pressures against the liner were assumed to be negligible.

Based on its finished dimensions, the computational results show that the external pressure capacities and corresponding closure limits (maximum diametric changes) for different thicknesses of the exhaust shaft liner are:

Depth (feet)	Liner Thickness (inches)	Pressure Capacity (psi)	Closure Limit (inches)
15 to 500	10	320	0.140
500 to 740	14	513	0.175
740 to 844	16	611	0.190

Since no measurements of the finished liner diameter were taken during construction, the actual closure is not available for comparison.

Figure 9-1 shows the relationship between the hydrostatic design pressure and the pressure capacity of the liner. The hydrostatic pressure is identical to that used for design of the waste shaft. Because the exhaust shaft liner also has water seeping through cracks and construction joints, the hydrostatic pressure is expected to behave in the same manner as discussed for the waste shaft in Chapter 8. That is, the design hydrostatic pressure is not expected to be reached until the shaft liner is completely sealed. When the design hydrostatic pressure is reached, the liner will have a factor of safety greater than two, based on the liner pressure capacity.

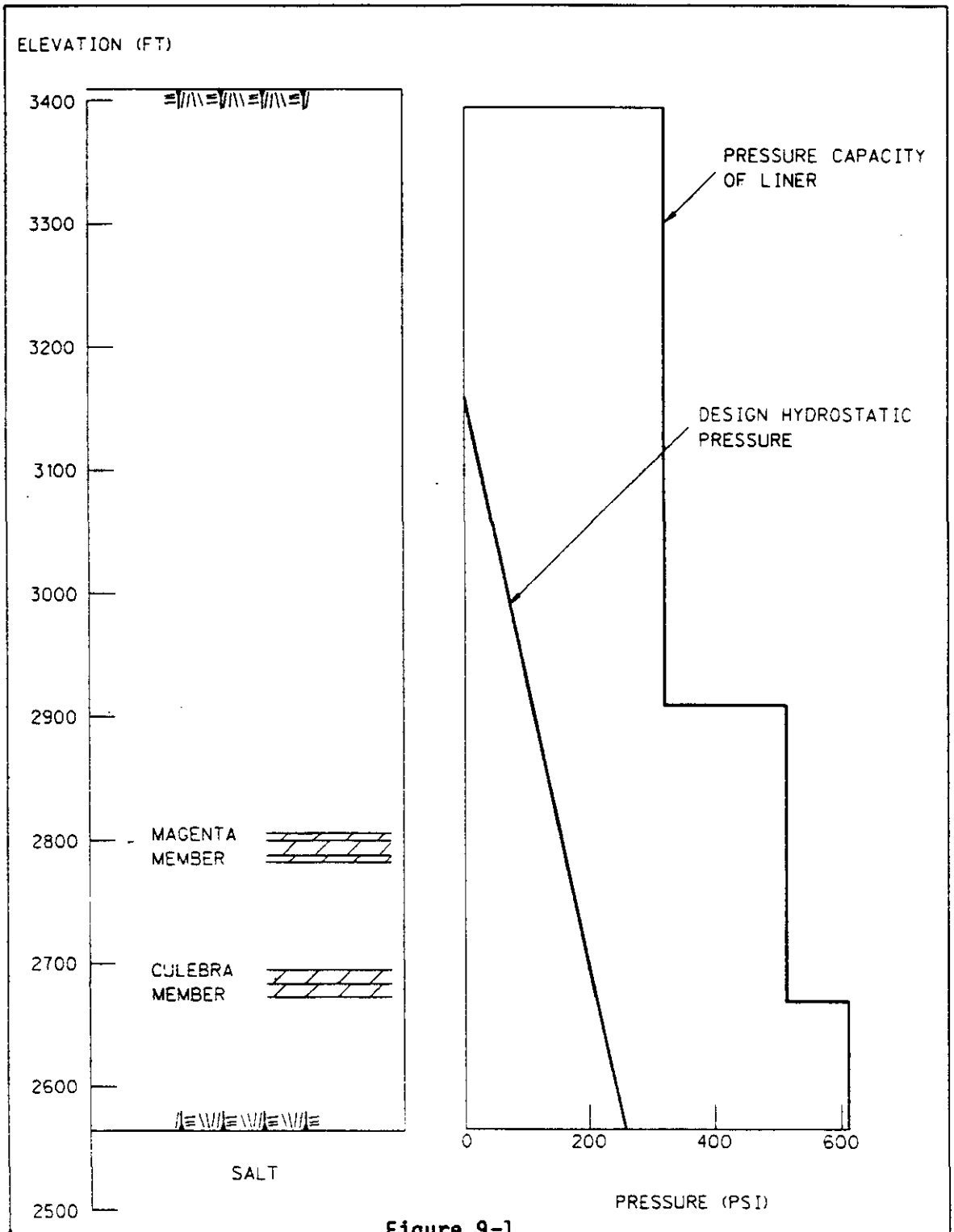


Figure 9-1

EXHAUST SHAFT LINER
LATERAL PRESSURE COMPARISON

9.3.2.2 Shaft Key

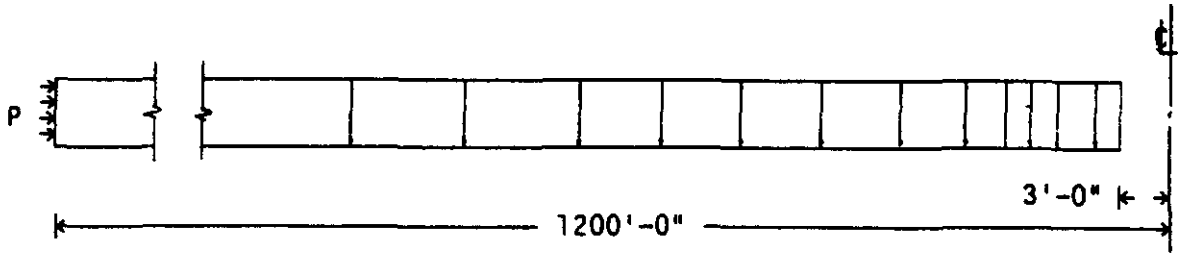
The exhaust shaft key was designed to withstand a lateral pressure equal to 50 percent of the vertical overburden pressure or about 60 ksf. A nonlinear finite element analysis, similar to that performed for the waste shaft key described in Chapter 8, was used to simulate the long-term creep interaction of the salt and the concrete key. The creep behavior of the salt was simulated using a power law (equation C.4-6 in Appendix C). For conservatism, the shrinkage effects and creep of the concrete were not taken into account in the analysis.

Model Simulation. The finite element model for the exhaust shaft key and surrounding salt consists of a single layer of quadrilateral axisymmetric ring elements as shown on Figure 9-2. An inner element of the model represents a segment of the concrete key; however, this element is not tied to the surrounding salt deposits until that time when the concrete for the shaft key is actually placed. All depth dependent input values, such as overburden stresses, initial lithostatic state, etc., were computed based on a depth of 891.5 feet, low in the key, where such values are at a maximum. Halite is the prevalent material present at the base of the shaft key and its properties were used for the parameters modeling the salt deposits surrounding the key.

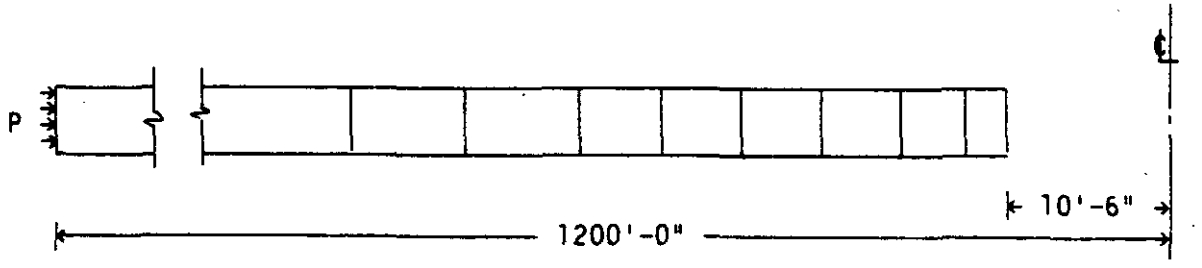
The analytical procedure used to perform the creep analysis for the exhaust shaft key was similar to that used for the waste shaft key analysis described in Chapter 8. However, in the finite element model for the exhaust shaft, the key diameter was enlarged to 21 feet with a finished inside diameter of 14 feet.

9.3.2.3 Unlined Section

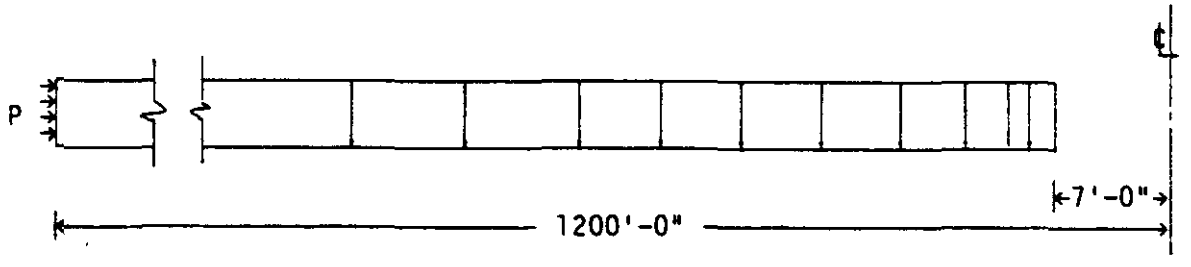
The structural behavior of the unlined section of the exhaust shaft was also computed using the MARC Finite Element Program discussed in Chapter 6. The analysis computed the actual structural behavior by utilizing applicable in situ data from the C & SH shaft and the horizontal drifts.



(A) BEFORE ENLARGEMENT



(B) AFTER ENLARGEMENT



(C) AFTER KEY PLACEMENT

Figure 9-2

EXHAUST SHAFT KEY
FINITE ELEMENT MODEL

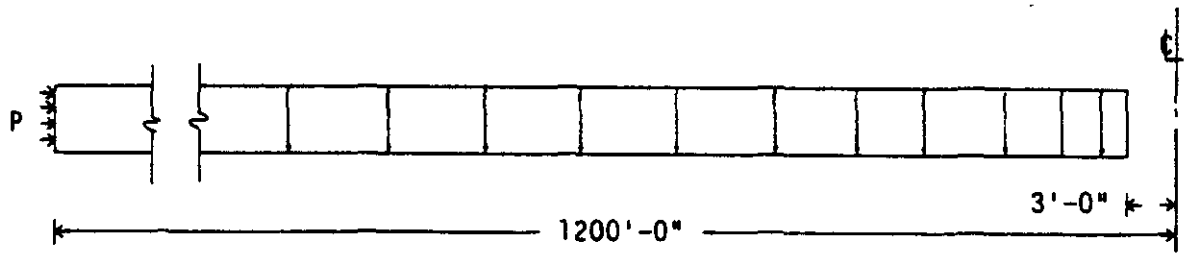
M

Model Simulation. The finite element model used for the unlined section of the exhaust shaft utilizes a single horizontal row of 70 quadrilateral axisymmetric ring elements. The model, shown on Figure 9-3, has its upper and lower horizontal boundaries restrained against vertical movement and has a constant lithostatic uniform pressure, equal to 2,066 feet of overburden, applied to its outside vertical boundary. The same lithostatic pressure was initially applied to the inside vertical boundary; however, that pressure was later removed from the inside boundary to simulate the drilling of the 6-foot diameter pilot bore.

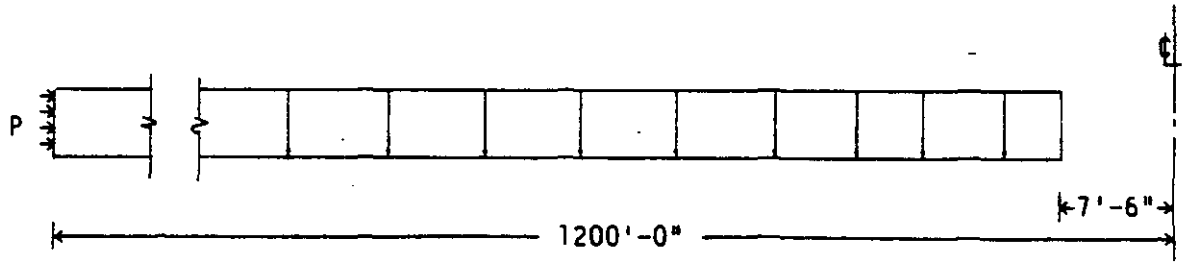
The analysis simulates the salt creep until that time when the 6-foot diameter hole was enlarged to its present 15-foot diameter. The shaft enlargement is simulated in the model by removing those ring elements which are located within the newly-excavated 15-foot diameter. With the enlarged shaft configuration, simulated salt creep for another 25 years was analyzed.

Determination of Creep Parameters. Since the stratigraphy surrounding the C & SH shaft is similar to that surrounding the exhaust shaft, the creep parameters determined from the in situ salt behavior in the C & SH shaft were assumed to be valid for correlating analytical results for the exhaust shaft from normalized time to real time. The secondary creep parameter C for the C & SH shaft was found to equal 5.70×10^{-21} $ksf^{-4.9}$ sec^{-1}. Since early in situ measurements were not available for the C & SH shaft, the primary creep parameters A and z were determined from in situ data from the horizontal drifts and were found to be 3.2 and 1.1×10^{-7} sec^{-1}, respectively.

Chapter 7 presents specific details on the computation of the secondary creep parameter C from the C & SH shaft. Chapter 10 presents the computation of the primary creep parameters A and z from the drifts.



(A) BEFORE ENLARGEMENT



(B) AFTER ENLARGEMENT

Figure 9-3

EXHAUST SHAFT UNLINED SECTION
FINITE ELEMENT MODEL

9.3.3 Prediction of Future Behavior

This subsection presents the results of the analysis and evaluation of the exhaust shaft. Predictions of future behavior for the lined section, key and unlined section are discussed.

9.3.3.1 Lined Section

The cracks in the concrete liner of the exhaust shaft are primarily tension cracks formed during restrained shrinkage we described in Chapter 8 with respect to the waste shift liner. These are neither unusual nor unexpected. Grouting of the cracks, as well as the leaking construction joints, will be required to meet the design criteria regarding ground-water control.

As discussed in Chapter 7, subsection 7.3.3.1, there is no reason to expect that the potentiometric surface at the WIPP site will exceed the design basis depth of 250 feet below the ground surface over the operating life of the facility. In the future, the recently installed piezometers will permit monitoring of the actual water pressure on the liner. Even if the water pressure rises to the design pressure, the pressure capacity of the liner will provide a sufficient margin of safety.

9.3.3.2 Shaft Key

The elapsed time from the drilling of the 6-foot diameter pilot bore to its widening to 21 feet in the key area and construction of the concrete key was approximately 316 days. Figure 9-4 shows the predicted lateral pressure curve for the concrete key based on the finite element analysis. The key was designed as a compression cylinder in accordance with the strength design method for reinforced concrete (ref. 7-5) using an ultimate hoop stress of 4.25 ksi. Using a load factor of 1.7 for lateral loads, the maximum allowable hoop stress in the key is 2.50 ksi. This hoop stress results in an allowable lateral rock pressure of 154 ksf based on the diameter of the key. Figure 9-4 shows a lateral pressure on the key of approximately 72 ksf

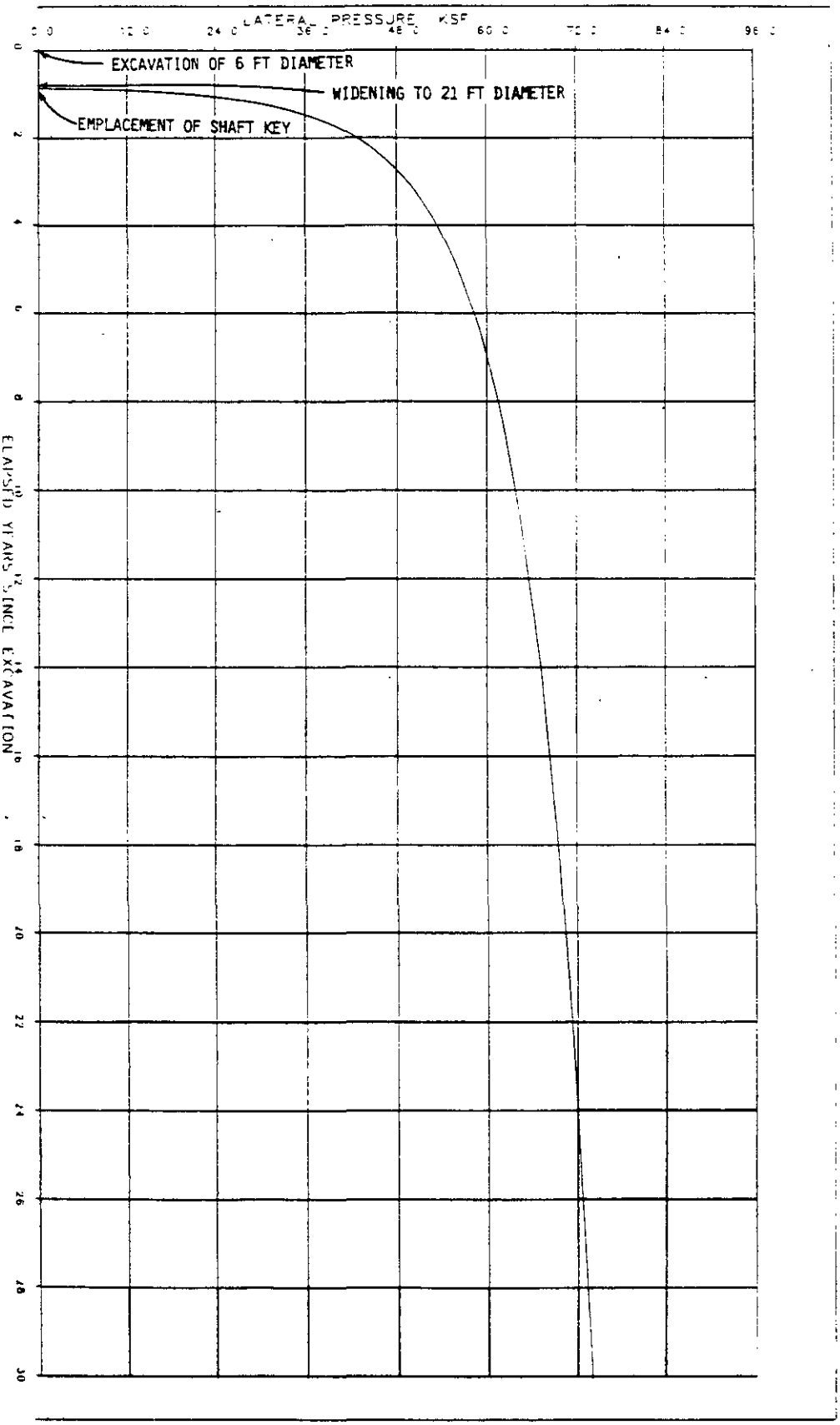


Figure 9-4

EXHAUST SHAFT KEY
LATERAL PRESSURE PREDICTION

at 25 years. Although higher than the design basis lateral pressure of 60 ksf, this value is about 50 percent of the allowable lateral pressure. In addition, the lateral pressure would actually be less than 72 ksf if concrete shrinkage and creep were taken into account in the finite element analysis.

Although no shrinkage cracks have been found in the reinforced concrete in the key, their presence would not be unexpected. They are common to most reinforced concrete structures and should not be of major concern.

9.3.3.3 Unlined Section

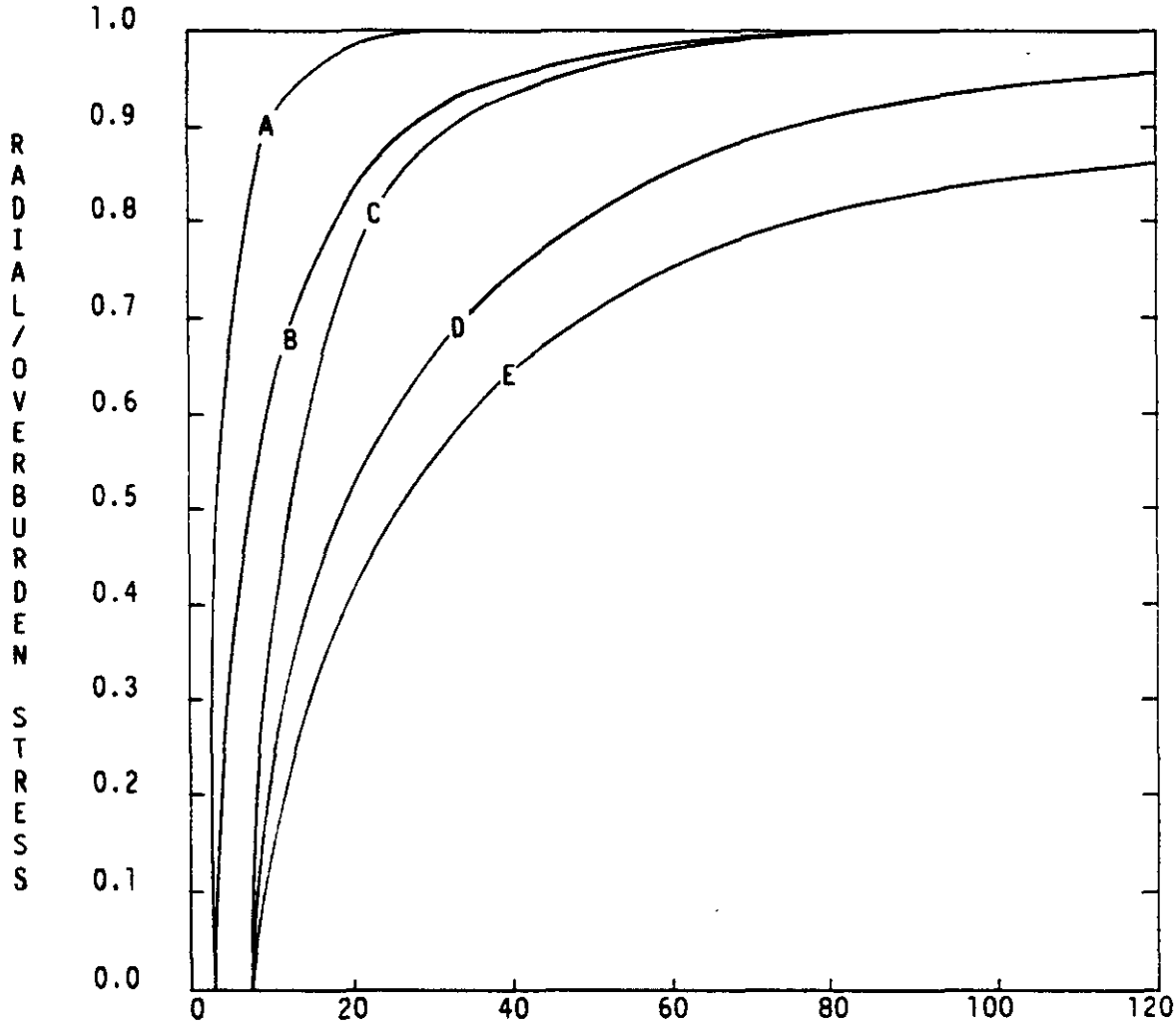
Figures 9-5 and 9-6 show predictions for radial and tangential (hoop) stress distributions relative to the overburden stress at different times for the unlined section of the exhaust shaft. Figure 9-5 shows the zone around the shaft opening where radial stresses are affected and their decrease in magnitude over time. The computational results indicate that tangential stresses are affected only within a radius of approximately 120 feet.

Figures 9-7 and 9-8 show predictions of the effective stress and effective creep strain distributions in the unlined section of the exhaust shaft. The magnitude of the effective stress in the shaft wall at 25 years approaches 140 ksf while the effective creep strain reaches a value of approximately 0.037.

Figure 9-9 shows approximately 6 inches of diametric closure in the unlined section of the exhaust shaft at a depth of 2,066 feet (elev. 1343 feet) over the 25-year operating life of the shaft.

9.4 CONCLUSIONS AND RECOMMENDATIONS

Design validation of the exhaust shaft requires an assessment of the compatibility of the design criteria, design bases and design configurations used for the reference design. The following discussion presents conclusions and recommendations regarding validation of the



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 15-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 15-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

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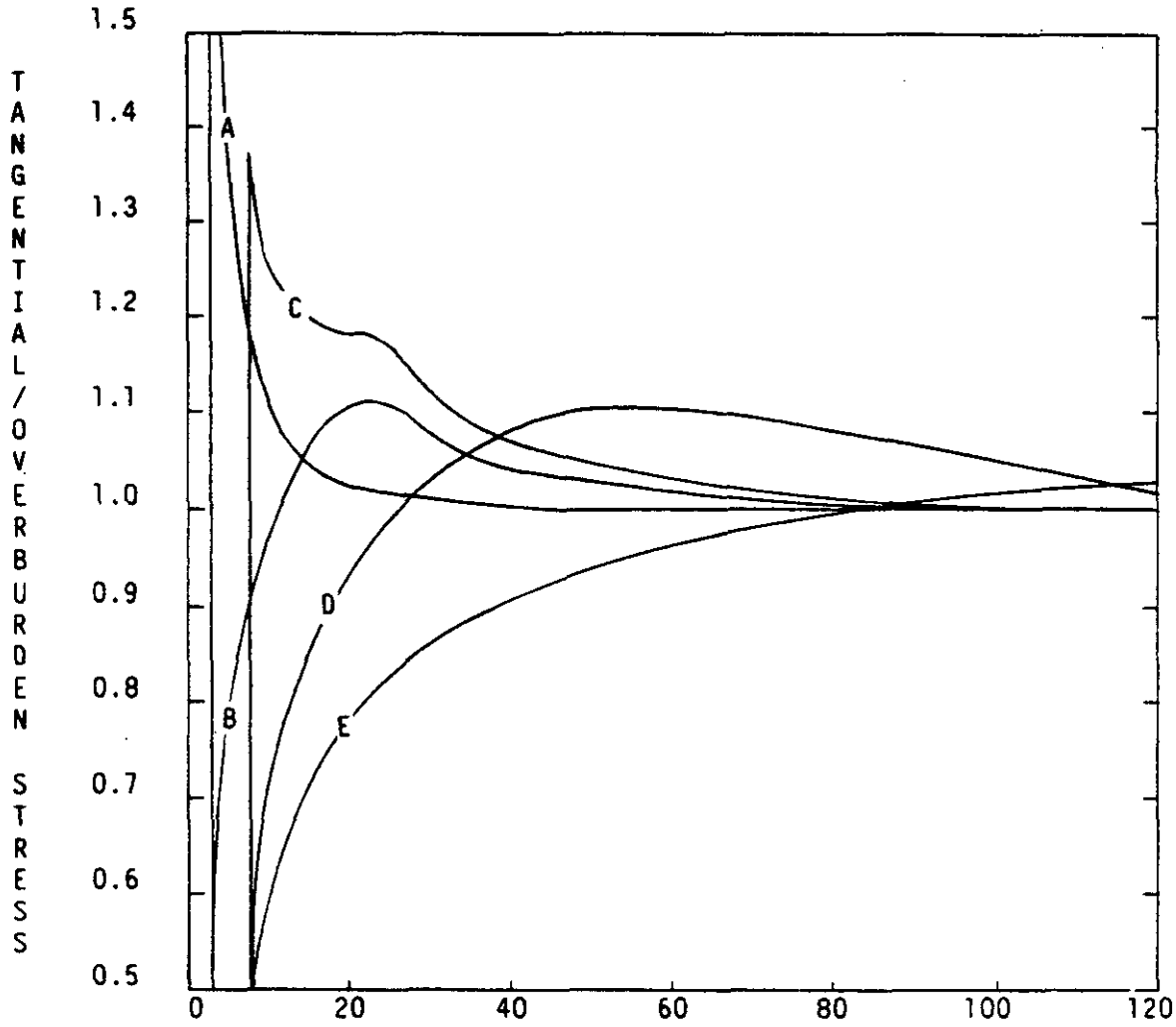
Figure 9-5

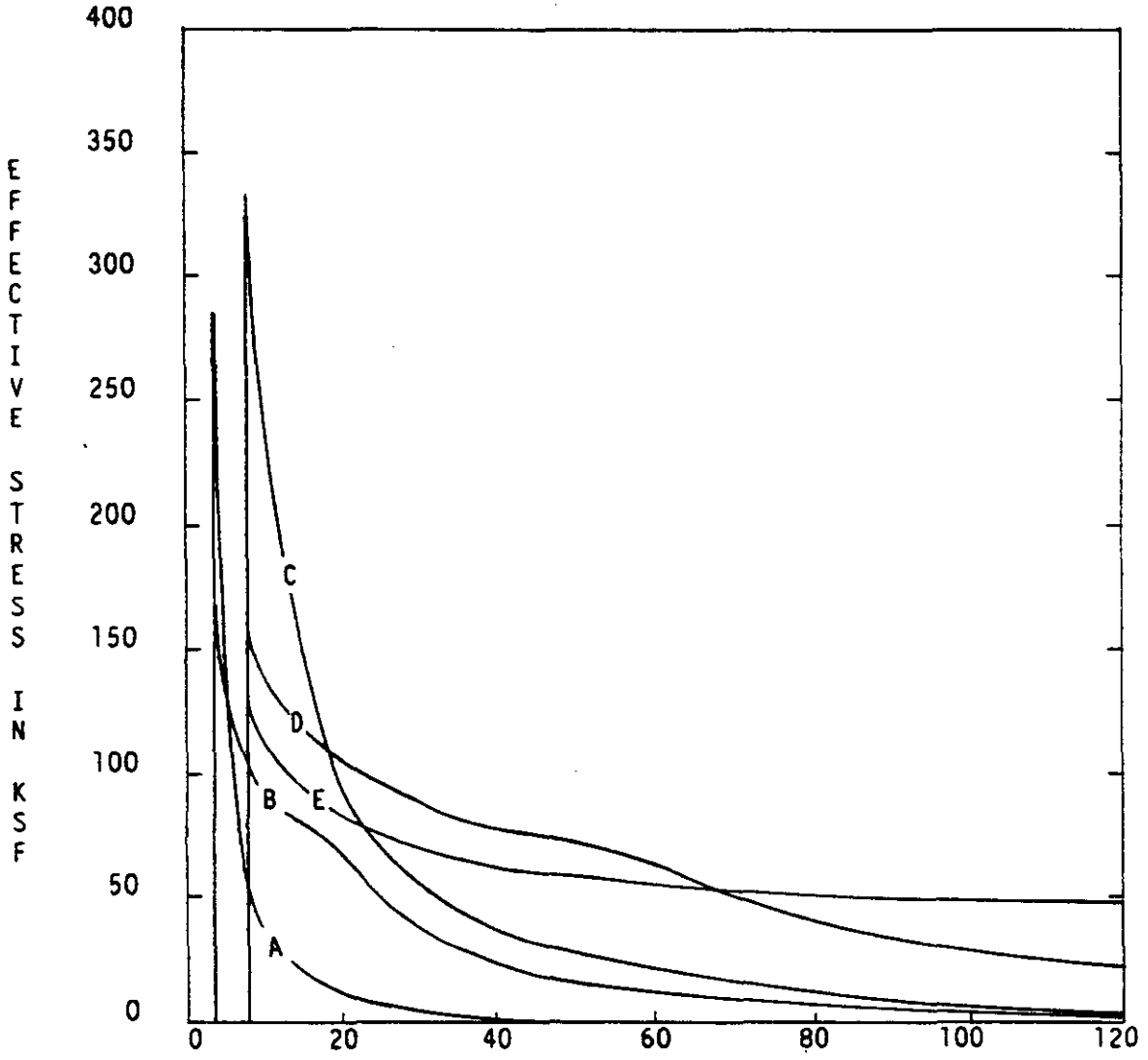
EXHAUST SHAFT UNLINED SECTION
RADIAL STRESS DISTRIBUTION AT ELEVATION 1343 FEET



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 15-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 15-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 9-6

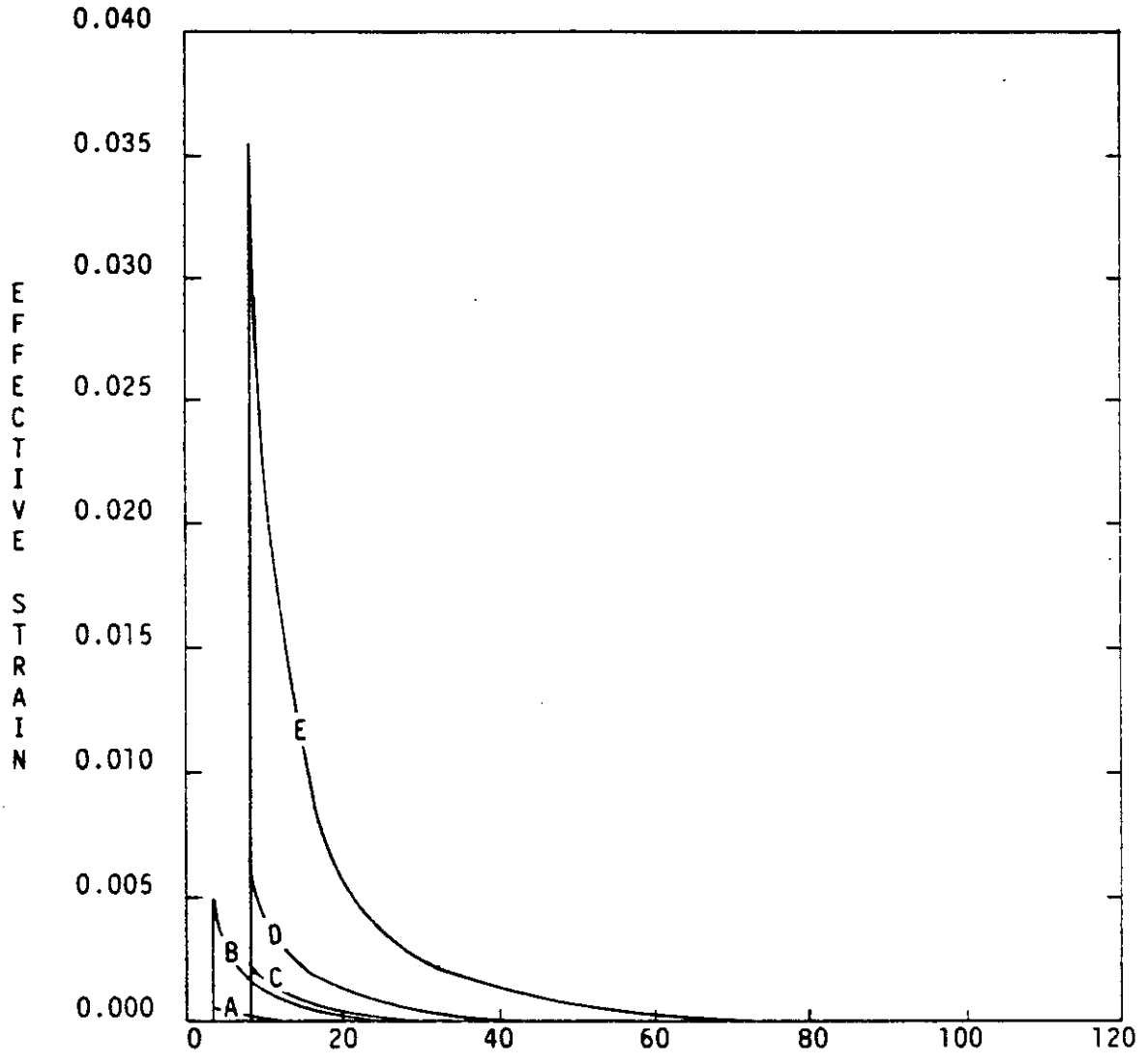
EXHAUST SHAFT UNLINED SECTION
TANGENTIAL STRESS DISTRIBUTION AT ELEVATION 1343 FEET



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 15-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 15-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 9-7

EXHAUST SHAFT UNLINED SECTION
EFFECTIVE STRESS DISTRIBUTION AT ELEVATION 1343 FEET



A – IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B – IMMEDIATELY BEFORE WIDENING TO 15-FT DIAMETER
C – IMMEDIATELY AFTER WIDENING TO 15-FT DIAMETER
D – ONE YEAR AFTER WIDENING OF SHAFT
E – 25 YEARS AFTER WIDENING OF SHAFT

Figure 9-8

EXHAUST SHAFT UNLINED SECTION
EFFECTIVE CREEP STRAIN DISTRIBUTION AT ELEVATION 1343 FEET

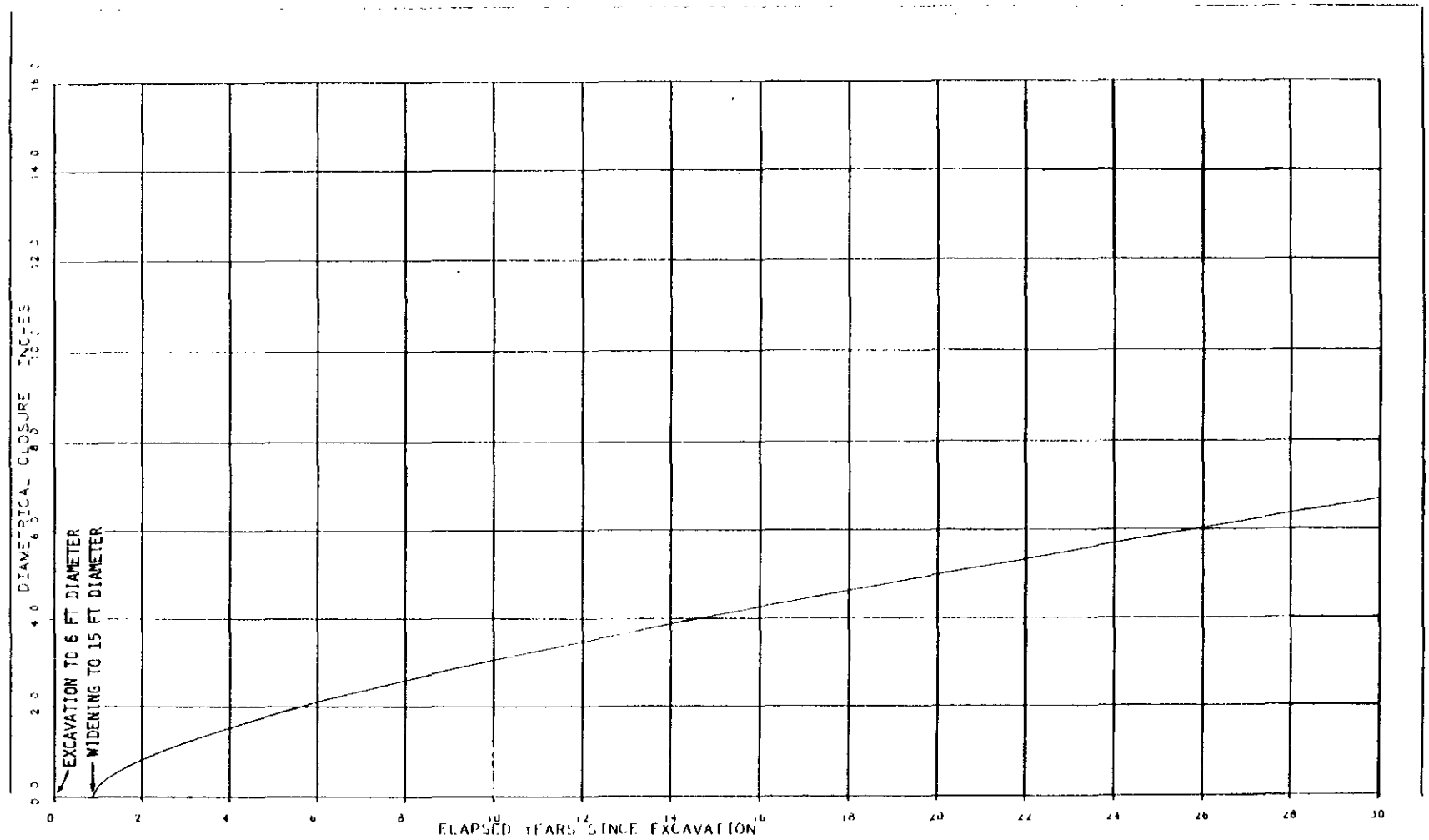


Figure 9-9

EXHAUST SHAFT UNLINED SECTION
CLOSURE PREDICTION AT ELEVATION 1343 FEET

exhaust shaft design as they pertain to the design elements identified in Section 9.2. These design elements stipulate the requirements that the exhaust shaft must meet in terms of shaft stability, deformation, water pressure and water control. Other conclusions and recommendations that are a product of the design validation process are also presented.

9.4.1 Conclusions

The stability of the exhaust shaft has been evaluated using analytical calculations, finite element modeling and analysis of data from the C & SH and waste shafts. The conclusions regarding shaft stability are the same as those for the waste shaft. The water pressure exerted on the shaft liner is currently less than the design hydrostatic pressure. If the hydrostatic pressure increases to its design limit, the liner will remain stable because its pressure capacity exceeds the design hydrostatic pressure by a factor greater than two. The cracks in the liner are not expected to result in any structural instability.

Analytical results show that the lateral pressure on the shaft key at the end of the 25-year operating life will be approximately 72 ksf. Although this pressure exceeds the design basis lateral pressure of 60 ksf, the allowable lateral pressure on the key is 154 ksf, or more than twice the predicted lateral pressure at 25 years. This provides a sufficient margin of safety against failure. If concrete shrinkage and creep were taken into account in the analysis, the margin of safety would be even greater.

The analytical results also show the redistribution of stresses around the unlined section of the shaft due to the effects of salt creep. Based on the computed vertical, horizontal and effective stresses in the unlined section, the magnitude of stresses immediately adjacent to the opening decreases and the stress arch around the opening migrates away with time. The maximum stress occurs immediately after excavation and is followed by relaxation due to creep behavior. Therefore, the stresses will not cause a future stability problem in the unlined

section of the shaft. The analysis shows the locations of effective creep strain concentrations at different times around the opening in the unlined section. Based on the predicted values of effective creep strain and the strain limit discussed in Chapter 6, the exhaust shaft will remain structurally stable within the limits required for safety during its operating life.

The analysis also predicts that the maximum diametric closure in the unlined section at the end of the operating period will be approximately 6 inches. Based on the predicted deformations and closures, the exhaust shaft will meet the requirements stated in the design criteria. The design basis requirement that the 15-foot diameter unlined section allow for salt creep over its operating life will be met.

As in the waste shaft, water is entering the exhaust shaft through cracks and construction joints in the concrete liner. The amount of water seepage was greatly reduced by grouting conducted after construction. The small amount of water still reaching the open shaft quickly evaporates in the upcast flow of exhaust air. While the exhaust fans are operating, no water reaches the underground facility level. The water seals behind the shaft concrete key appear to be functioning as intended at the bottom of the key. No water is seeping from the concrete/salt interface. There is no evidence of salt dissolution behind the key.

The reference design for the exhaust shaft has been validated in accordance with the objectives of the design validation program, based on the analyses, evaluations and predictions of future behavior presented in this chapter. With one exception, the exhaust shaft reference design complies with the design criteria and the design bases. The criterion that the liner shall prevent ground-water flow into the shaft has not been met. However, the water currently seeping into the shaft is not considered to be detrimental to shaft stability or function. No modifications to the exhaust shaft reference design are required.

9.4.2 Recommendations

Based on the results of design validation, recommendations similar to those for the waste shaft are made for the exhaust shaft:

(1) Validation of the exhaust shaft key and unlined section relied on analysis and modeling using in situ data from the C & SH and waste shafts. It is recommended that the numerical modeling be repeated, prior to the first receipt of waste, using in situ data from the exhaust shaft instruments. This analysis should be repeated periodically for the comparison of in situ data against design parameters.

(2) The exhaust shaft should be inspected by qualified personnel at regularly scheduled intervals. The liner should be inspected for renewed seepage and grouting performed if an amount of water considered sufficient to affect the liner's stability or functional purpose is observed. The key should be inspected for water seeping from behind the key at its base. If any is detected, grout should be injected above the top water seal. Grout should not be placed behind the key below the top seal. If this cannot be avoided, the grout must be a chemical gel (or other non-rigid grout) and must be compatible with both the existing water seal material and with the requirements of the Plugging and Sealing Program.

CHAPTER 10
DRIFTS

10.1 INTRODUCTION

This chapter presents the results of validation of the reference design for the underground drifts. Discussions are presented on the reference design, data collected from the openings, its analysis and evaluation, and predictions of future behavior. Conclusions and recommendations pertaining to the reference design are presented based on the results of the validation process.

The term drifts includes all horizontal underground openings except the shaft stations, test rooms, and storage area rooms and their associated drifts. Discussions of the shaft stations are presented in Chapters 7 and 8. Discussions of the test rooms, storage rooms and storage area drifts are presented in Chapters 11 and 12.

The largest drifts planned for the underground facility were initially excavated 8 feet high and 25 feet wide. These drifts have been or will be enlarged to 12 feet high. The present 12-foot high, 25-foot wide drifts were excavated earlier than most of the smaller drifts and, therefore, have the longest history of in situ data collection. Because these 12 x 25-foot drifts are the largest to be excavated, they also have the most critical dimensions. Consequently, the analyses, evaluations and predictions are based primarily on these larger drifts. The smaller drifts and rooms are, therefore, considered to be validated as a result of the validation of the larger 12 x 25-foot drift reference design.

10.2 DESIGN

This section presents the design criteria and design bases used to develop the reference design of the drifts.

10.2.1 Design Criteria

The design criteria established for the design of the WIPP underground facility are discussed in Chapter 2 and summarized in Table 2-1. Table 2-1 presents the major criteria affecting underground design, including such items as waste receipt rate, type of waste, backfill requirement, etc. Those criteria requiring evaluation of their suitability for design validation are indicated in Table 2-1. The remaining criteria contained in the Design Criteria document (ref. 2-7) do not require evaluation.

Three of the indicated criteria pertain directly to the drift reference design. The first criterion states that the underground openings shall be designed to provide structurally stable excavations and pillars. "Stable" is defined in the criteria document to mean that deformations of excavations and pillars are to remain within the limits required for structural function, ventilation and safety. The second criterion states that the underground opening reference design shall provide maximum stability for the excavated rooms and drifts. The third criterion stipulates that the underground excavation shall be designed to accommodate creep closure and maintain the minimum dimensions required for the operating life of the opening. Not only are these criteria to be evaluated for their suitability, but the reference design configurations based on them must also be evaluated. These reference design configurations were discussed in Chapter 3.

10.2.2 Design Bases

The design bases comprise the second level of the design documents. They outline specific design requirements that were followed in designing the final drift configurations. Only those design bases that apply directly to the underground drift configurations are discussed in this subsection. The Design Basis, Underground Excavations (refs. 2-9 and 2-18), Design Basis, Underground Shops and Facilities (ref. 2-20), and Design Basis, Geomechanical Instrumentation (ref. 2-17) should be referred to for details of the appropriate design bases used for the underground drifts. None of these design bases contained elements

pertaining specifically to the drifts that required evaluation during the validation program. Those bases that required evaluation for validation pertain only to the storage area drifts and are discussed in Chapter 12.

The design bases specify that excavation within the shaft pillar area shall be the minimum required to meet the operational and safety requirements of the waste storage level. The area extraction ratio was, therefore, kept below 15 percent in this area.

The maximum tolerance for excavation of the roof, floor and walls shall be plus six inches. In no case shall the finished dimensions be less than those specified by the design. The minimum vertical dimension for equipment clearances used to meet this basis was 11 feet.

Supports for underground workings shall comply with Federal and New Mexico codes. The use of rock bolts and wire mesh in specific areas shall be determined by mine conditions and code requirements. Entry roofs, walls and floors shall be checked periodically for loose salt in accordance with applicable codes. Methods of locating gas or brine accumulations shall be implemented, such as drilling holes ahead of the excavation and testing for the presence of gas.

A geomechanical instrumentation system shall be installed to provide in situ measurement data for design verification or modification and for subsequent operational planning. In addition, the instrumentation system shall monitor stress change, closure and creep to provide a record of the structural stability of the drifts and to provide early warning of abnormal conditions for operational safety.

Deformation measurements in the drifts shall be measured as a function of horizontal and vertical closure. Salt creep and stress distributions around the drifts and at intersections shall also be measured.

The instrumentation shall provide the primary detection of changes in structural behavior. Visual observations shall follow any detected abnormal strain, pressure or deformation for evaluation of the safety of the underground working places. In addition, a program shall be provided for periodic visual inspection of all underground working places.

10.3 DESIGN VALIDATION PROCESS

Validation of the reference design of the underground drifts includes the collection of data and the presentation of results based on its analysis and evaluation. The results of the design validation process are used to present conclusions regarding the compatibility of the design criteria, design bases and design configurations, and recommendations for modifications, if any. This section presents the data collected and predictions of future drift behavior based on analysis and evaluation of the data.

10.3.1 Data Collection

Data pertaining to the underground drifts was collected from various sources. Geologic data was acquired from geologic mapping and core drilling. These data verified the stratigraphic continuity at the facility level and are discussed in detail in Chapter 6. Data were also acquired from periodic visual inspections and from geomechanical instrumentation. Collection of these data are described in the following subsections.

10.3.1.1 Field Observations

Various aspects of underground behavior are evaluated by qualitative observations and documentation. Visual inspections of the drifts include observations of their general surface conditions in response to stress redistribution and creep. These conditions include shallow spalls from the roof and walls, especially at their intersection; and vertical fracturing in the pillars, both at corners and parallel to the walls. In addition to visual inspections, other techniques are used. Boreholes are surveyed using video cameras and displacements,

separations and fracturing of geologic strata surrounding the boreholes are detected using a simple probe. Surveys of underground conditions have been performed at least once every 3 months. Each survey is documented in a GFDR beginning with the February 1984 edition (refs. 4-12 through 4-19).

Recently, a special program was conducted to determine the effect of excavation induced deformation on the salt strata surrounding the facility level. An array of boreholes was drilled into the roof and floor at 30 locations in the drifts and test rooms during May through July 1986. These arrays are shown on Figure 10-1. These boreholes were used to locate separations and fractures in the halite and anhydrite near the horizontal underground openings. This Excavation Effects Program was instigated after the discovery of significant fracturing beneath the southern half of Test Room 3 (Room T). The objectives of this excavation effects study were to determine if fracturing of this magnitude has occurred anywhere else and to investigate existing conditions at selected localities throughout the facility.

The documented field observations can be separated into four categories: roof and wall spalling; pillar fracturing; roof displacements and separations; and floor displacements, separations and fracturing.

Roof and Wall Spalling. During and immediately after excavation, a sounding survey of the roofs of all drifts was performed. Each survey identified areas of potential instability, such as drummy or slabby salt. Remedial work was accomplished immediately and included scaling, additional excavation, or rock bolting. Comprehensive sounding surveys were also performed in every underground opening in July 1983 and November 1984. The behavior of the roof and walls is documented in the table entitled "Condition of Roof and Walls" in each GFDR.

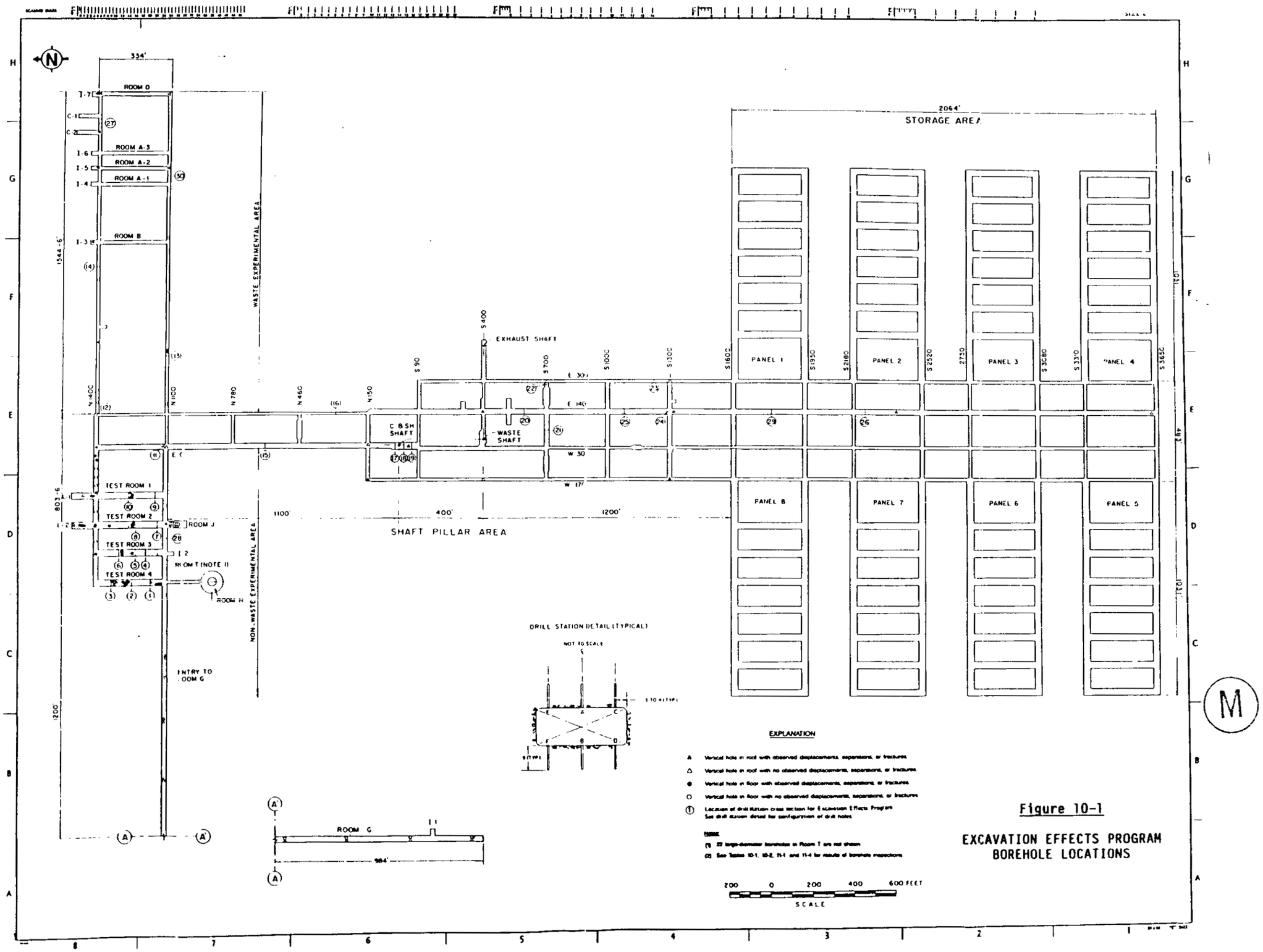


Figure 10-1

EXCAVATION EFFECTS PROGRAM
BOREHOLE LOCATIONS

Pillar Fracturing. Vertical fractures have developed in the corners formed by drift intersections. These fractures began appearing about 3 to 6 months after excavation. Site geologists have monitored the growth of these fractures and have included their observations in the GFDRs.

Vertical fractures parallel to the drift walls have been detected in several horizontal boreholes. These fractures were not present at the time of drilling. They were first observed in May 1986 and occur within 1 to 2 feet of the wall surface.

Roof Displacements and Separations. Horizontal displacements and vertical separations have been detected in some open boreholes in the drifts during the past 2 years. Periodic inspections of all accessible boreholes in the drifts have been made since September 1985. The results of these inspections in the roof holes are presented in Table 10-1.

Visual inspections were conducted directly or remotely using a video camera and/or probe. The probe used was described in Chapter 7, subsection 7.3.1.4. Depths to displacements and separations were measured with a tape measure. Relative horizontal displacements were measured where possible or estimated.

The recently conducted Excavation Effects Program consisted of drilling numerous arrays of 1 7/8-inch and 3-inch diameter holes at selected locations along the drifts (Figure 10-1). The holes were drilled approximately 9 feet into the roof and floor and inspected using a probe. The results of the inspection of these holes are presented in Table 10-2.

The N1100 and N1420 drifts were excavated eastward to E1680 in early 1984. These drifts incline upward to the experimental area. The roofs of both drifts intersect anhydrite beds "a" and "b". Slabby rock at the intersection was removed by the mining machine and rock bolts

Table 10-1

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN ROOFS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
DH-01	2-10-84	3	50.8	N1424/E439.5	None
DH-03	2-7-84	3	48.8	N1112/E444	D
DH-03A	3-12-84	3	49.9	N1112/E450.5	D
DH-05	3-9-84	3	51.0	N1463/E972	D
DH-07	2-22-84	3	49.8	N1112/E976.5	None
DH-09	3-14-84	3	51.1	N1432/E1332.5	None
DH-11	3-6-84	3	50.9	N1112/E1332.5	None
DH-13	3-28-84	3	13.8	N1424/E1690	D, S
DH-13A	3-29-84	3	49.0	N1425/E1691	D, S
DH-13B	4-5-84	3	21.0	N1425/E1695	D, S
DH-15	3-21-84	3	51.0	N1104/E1688.5	None
DH-17	1-19-84	3	52.0	N1104/E1688	None
DH-19	1-21-84	3	51.6	N1107/E206.5	None
DH-21	2-27-84	3	50.4	N1421/E786	None
DH-23	2-15-84	3	51.0	N1112/E781	None
DH-25	3-30-84	3	51.8	N1422/E1510	D, S
DH-27	7-27-84	3.5	50.5	N1107/W682	None
DH-29	7-25-84	3.5	50.4	N1099/W982	None
DH-29A	9-12-84	3.5	35.0	N1099/W987	None
DH-31	7-19-84	3.5	50.5	N1099/W1282	None

* D = displacement; S = separation; F = fracturing

Table 10-1 (continued)

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN ROOFS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
DH-31A	7-24-84	3.5	49.2	N1099/W1280	None
DH-31B	9-12-84	3.5	4.9	N1099/W1261	None
DH-33	7-18-84	3.5	50.5	N1099/W1582	None
DH-33A	9-13-84	3.5	4.1	N1099/W1570	None
DH-35	1-27-85	3.5	52.0	N1102/W1882	None
DH-37	1-26-85	3.5	51.5	N1101/W2182	None
DH-39	1-24-85	3.5	50.7	N1101/W2482	None
DH-41	1-24-85	3.5	49.9	N1101/W2782	None
DH-205	2-18-83	3	50.7	N1410/E0	None
DH-211	12-19-82	3	50.0	S1320/E163	None
DH-219	1-14-83	3	51.0	S2422/E162	None
DH-227	1-28-83	3	51.7	S3656/E147	None
DH-301	8-30-84	3.5	50.8	N150/W170	D
DH-303	9-4-84	3.5	51.4	S400/W170	None
DH-313	7-10-84	3	19.6	S1300/E300	None
DH-313A	7-12-84	3	50.2	S1300/E299	None
DH-315	9-6-84	3.5	50.3	S1300/W170	D
DH-317	7-6-84	3	50.1	S1600/W33	None
DH-317A	7-6-84	3	5.0	S1600/W30	None
DH-317B	9-7-84	3.5	51.0	S1597/W30	None
DH-319	9-10-85	3.5	51.1	S700/E300	None

Table 10-1 (continued)

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN ROOFS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
OH-2	8-83	4	20	S410/E147	None
OH-3	8-83	4	20	Room 2 centerline	S, F
OH-4	8-83	4	20	N1110/W365	S
OH-6	8-83	4	20	N1110/W5	None
OH-7	8-83	4	20	S70/E0	D, S, F
OH-8	8-83	4	20	N140/E0	None
OH-9	2-84	4	15.4	N1433/W232	S, F
OH-10	2-84	4	21.0	N1420/W218	D
OH-11	2-84	4	19.7	N1433/W365	None
-	-	5	10	Room L1 centerline	None
L2PU-02	-	5	9.2	Room L2 centerline	None

Table 10-2

EXCAVATION EFFECTS PROGRAM

BOREHOLE INSPECTION SUMMARY

SECTION	OPENING DIMENSIONS (HxW-FT)	EXCAVATION - DATE	LOCATION	DATE DRILLED	DATE INSPECTED	OBSERVED CONDITIONS					
						ROOF HOLES			FLOOR HOLES		
						E	A	C	F	B	D
11	12x25	2/83 (FLOOR LOWERED 4 FT 12/83)	N110, W02	5/30/86	6/02/86	C	NONE	C (POSSIBLY CLAY G)	C	S, C	C
12	12x14	2/83	N1430, E140	6/05/86	6/10/86	S, C	C	C	S, C	S	S(?), C
13	8x14	1/84	N810, E439	6/20/86	6/30/86	D *	NONE	NONE	NONE	NONE	NONE
14	12x14	2/84	N1430, E875	6/06/86	6/10/86	S	S(?)	S	S(?)	C	S(?)
15	12x25	2/83 (FLOOR LOWERED 4 FT 12/83)	N626, W02	6/20/86	6/30/86	NONE	C	S, C	C	S, C	C
16	8x14	2/83	N305, E147	7/15/86	7/18/86	NO ROOF HOLES			NONE	C	C
17	12x32	10/82	C&SH SHAFT STATION - N028	5/30/86	6/02/86	C	NONE	F	NONE	S, F	NONE
18	17x35	6/82	C&SH SHAFT STATION - S024	6/04/86	6/04/86	C	S, F	F	S	NONE	S
19	15x35	6/82	C&SH SHAFT STATION - S056	6/03/86	6/04/86	F, C	F	F	F, C	C	C
20	14x25	12/82 (FLOOR LOWERED 5/84)	S592, E155	7/10/86	7/11/86	NONE	NONE	NONE	S, C	NONE	NONE
---	15x35	6/82	C&SH SHAFT STATION - ELECTRICAL SUBSTATION	6/05/86	6/06/86					X	Y
										S, C	S, C
21	12x20	7/85	S700, E66	7/08/86	7/09/86	NONE	NONE	NONE	NONE	S	C (POSSIBLY CLAY E)
22	12x14	5/84; 7/84	S700, E300	7/08/86	7/09/86	NONE	NONE	NONE	C	NONE	NONE
23	12x14	7/84	S890, E229	7/09/86	7/10/86	NONE	NONE	C	NONE	C	C
24	12x20	12/82; 6/85; 6/84	S1300, E155	7/09/86	7/10/86	NONE	NONE	NONE	NONE	NONE	NONE

Table 10-2 (continued)

EXCAVATION EFFECTS PROGRAM
BOREHOLE INSPECTION SUMMARY

SECTION	OPENING DIMENSIONS (HxW-FT)	EXCAVATION DATE	LOCATION	DATE DRILLED	DATE INSPECTED	OBSERVED CONDITIONS					
						ROOF HOLES			FLOOR HOLES		
						E	A	C	F	B	D
25	12x25	12/82 (FLOOR LOWERED 5/84)	S829, E155	7/9/86	7/10/86	NONE	NONE	NONE	C	C	C
26	8x25	1/83	** S2205, E154	7/16/86	7/18/86	NO ROOF HOLES			NONE	NONE	C
27	12x14	3/84	** N430, E555	7/17/86	7/18/86	NO ROOF HOLES			NONE	NONE	C
28	12x20	3/83 (FLOOR LOWERED 4/83)	** N110, W432	7/16/86	7/18/86	NONE	NO HOLE	NONE	NONE	NO HOLE	C
29	12x25	12/82 (FLOOR LOWERED 8/85)	** S1700, E155	7/10/86	7/17/86	C	NONE	NONE	NO FLOOR HOLES		
30	8x14	2/84	** N110, E1303	7/17/86	7/18/86	C	NO HOLE	NONE	C	NO HOLE	NONE

* EXISTING HOLE.
** LOCATION APPROXIMATE. NOT SURVEYED.

EXPLANATION

D = HORIZONTAL DISPLACEMENT. FOUND ONLY IN PREVIOUSLY DRILLED HOLES. DISPLACEMENT APPEARS TO DEVELOP WITH TIME FOLLOWING HOLE DRILLING.

S = VERTICAL SEPARATION. PROBE NAIL PENETRATES HOLE WALL SURFACE. VERTICAL SEPARATIONS RANGE FROM APPROXIMATELY 1/16 INCH TO 6 INCHES.

F = FRACTURE ZONE. PIECES OF HALITE COMMONLY PICKED OUT OF ZONE BY PROBE NAIL.

C = PROBE NAIL CATCHES ON HOLE WALL SURFACE BUT DOES NOT PENETRATE. INDICATES POSSIBLE SEPARATION OF LESS THAN 1/16 INCH. OCCURENCES AT KNOWN CLAY LAYERS ARE NOT INDICATIVE OF SEPARATION AND ARE NOT INCLUDED IN THIS TABLE.

NOTES:

1. SECTION LOCATIONS AND HOLE CONFIGURATIONS ARE SHOWN ON FIGURE 10-1.
2. HOLES WERE DRILLED VERTICALLY USING A JACK-LEG DRILL.
3. NOMINAL HOLE DEPTH IS 9 FEET BUT SOME HOLES ARE SHORTER DUE TO LOW DRIFT ROOF OR DRILLING DIFFICULTIES.
4. ONE ROOF AND ONE FLOOR HOLE OF EACH ARRAY WERE GENERALLY DRILLED 3 INCHES IN DIAMETER TO ACCOMODATE USE OF BOREHOLE CAMERA IF DESIRED. OTHER HOLES WERE DRILLED 1-7/8 INCHES IN DIAMETER. EXISTING HOLES WERE USED WHERE POSSIBLE.
5. OBSERVATIONS WERE MADE USING A PROBE CONSISTING OF A NAIL ATTACHED PERPENDICULAR TO THE END OF A ROD.
6. HOLES AT SECTION 13 WERE DRILLED TO ONLY 6- OR 6.5-FT DEPTH DUE TO LOW DRIFT ROOF. NO ROOF HOLES WERE DRILLED AT SECTIONS 16 OR 26 DUE TO LOW DRIFT ROOF.
7. POSSIBLE SEPARATIONS IN FLOOR HOLES AT SECTION 25 ARE PROBABLY AT CLAY E.

and wire mesh were installed. Several fractures in the roof brow at these anhydrites have been observed.

A portion of the N140 crosscut between W170 and E140 has been excavated above clay G. An inspection of this area in June 1986 showed some minor vertical separation, on the order of 1/8 inch, as well as some squeezing out of clay G. No fractures in the underlying halite were observed.

Floor Displacements, Separations and Fracturing. Fracturing has developed beneath the floor in some locations. These fractures occur in the halite above MB-139 and sometimes extend into MB-139. The most prominent fracturing at present is beneath Test Room 3, as discussed in Chapter 11.

As with the roof boreholes, observations were accomplished using both video equipment and a probe. The results of floor hole inspections conducted through July 1986 in accessible boreholes are presented in Table 10-3. Results of the Excavation Effects Program are included in Table 10-2.

10.3.1.2 Geomechanical Instrumentation

An extensive system of geomechanical instruments has been installed in the underground drifts (Figure 10-2) to provide in situ data on the deformational behavior of these openings. The majority of the instruments were installed during the SPDV Program and therefore have been monitored for over three years. Additional instrumentation was installed after the SPDV program was completed.

Instrumentation in the drifts consists of radial convergence points and multiple-point borehole extensometers. The convergence points consist of pairs of eyebolts anchored in the salt of the roof, floor and walls of the drifts as well as at corners of intersections. The closure of the opening is measured between a pair of convergence points using a tape extensometer. The borehole extensometers are the sonic-probe type

Table 10-3

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN FLOORS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
DH-36	1-26-85	3.5	51.5	N1102/W1882	None
DH-38	1-26-85	3.5	47.5	N1101/W2182	None
DH-40	1-25-85	3.5	51.0	N1101/W2482	None
DH-42	1-23-85	3.5	51.2	N1101/W2782	None
DH-42A	1-25-85	3.5	40.5	N1101/W2789	None
DH-228	1-28-83	3	50.4	S3656/E147	None
OH-13	2-84	4	9.5	N1433/W232	S, F
OH-14	2-84	4	9.7	N1433/W365	D, S, F
JV-01	9-85	36	8	Room J	None
JV-02	9-85	36	8	Room J	None
JV-03	9-85	36	8	Room J	None
JV-04	9-85	36	8	Room J	None
JV-05	9-85	36	8	Room J	None
JV-06	9-85	36	8	Room J	None
JV-07	9-85	36	8	Room J	None
JV-08	9-85	36	8	Room J	F
JV-09	9-85	36	8	Room J	None
L2X-01	1-85	30	12	Room L2	None
L2PD-01	-	5	13.0	Room L2 centerline	D, S, F
-	-	5	11.3	Room L2 centerline	S, F

* D = displacement; S = separation; F = fracturing

Table 10-3 (continued)

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN FLOORS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
-	-	16	10.3	Room L2 centerline	D, S
NPD-03	1-86	5	9.3	N1420, east of Test Room 1	None
NPD-04	1-86	5	9.5	N1420, east of Test Room 1	None
NPD-05	1-86	5	9.6	N1420/Room L1	None
NPD-06	1-86	5	9.5	N1420/Room L1	None
NPD-07	1-86	5	9.0	N1420/Room L2	S, F
NPD-08	1-86	5	12.0	N1420, east of Test Room 1	S
NPD-11	1-86	5	8.9	N1420, between Test Rooms 2 and 3	None
NPD-12	1-86	5	9.0	N1420, between Rooms L1 and L2	None

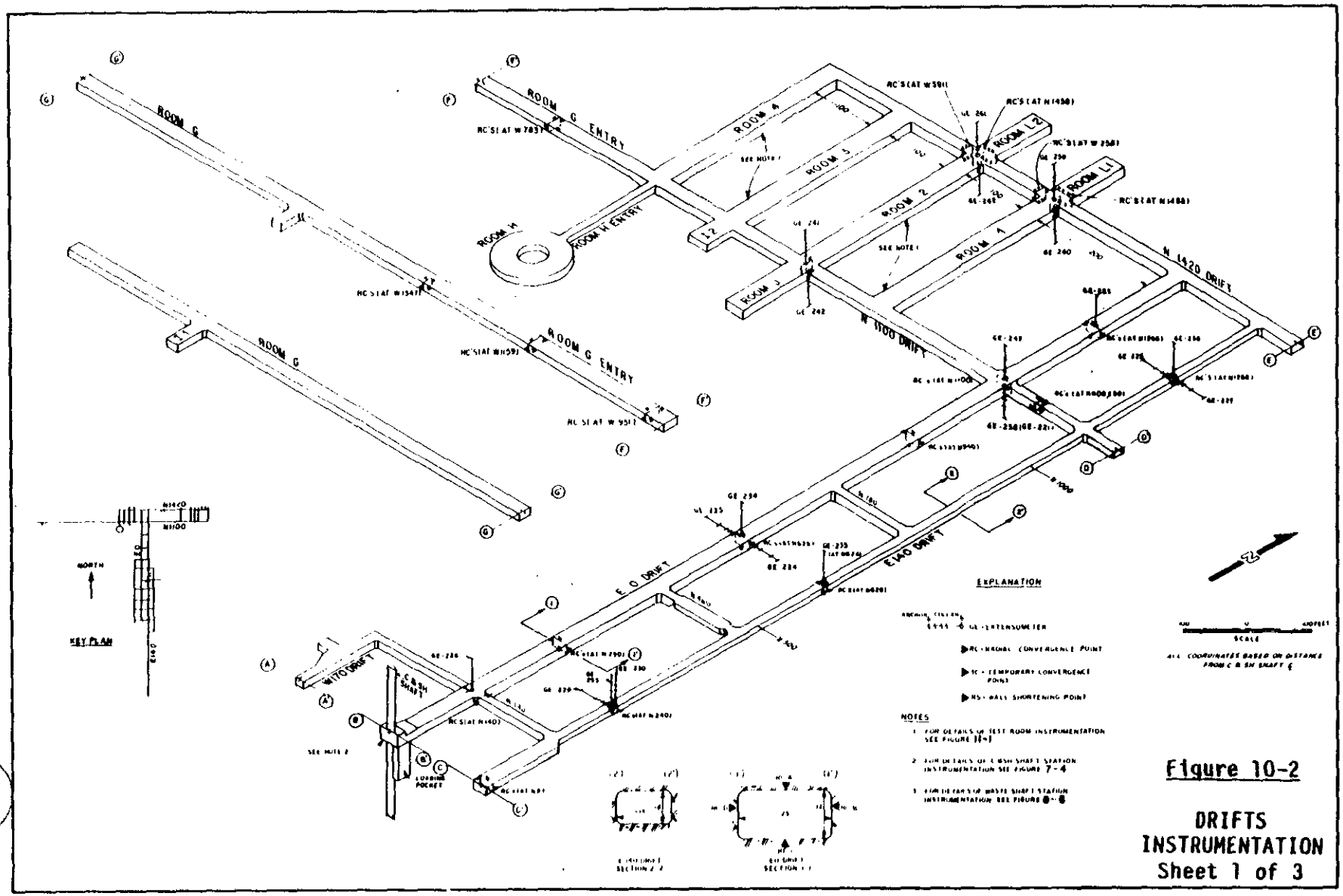


Figure 10-2

DRIFTS INSTRUMENTATION
Sheet 1 of 3

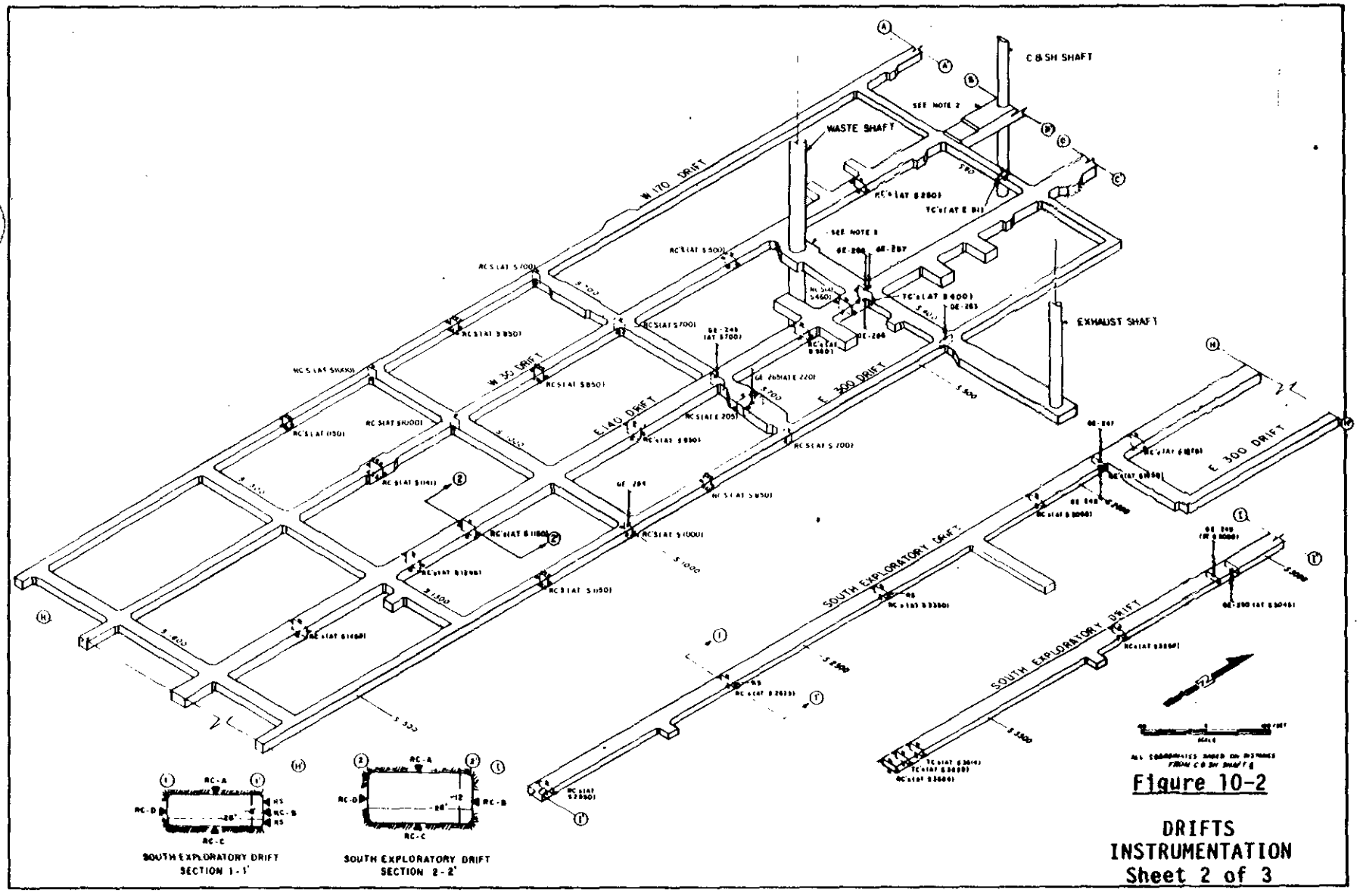


Figure 10-2

DRIFTS
INSTRUMENTATION
Sheet 2 of 3

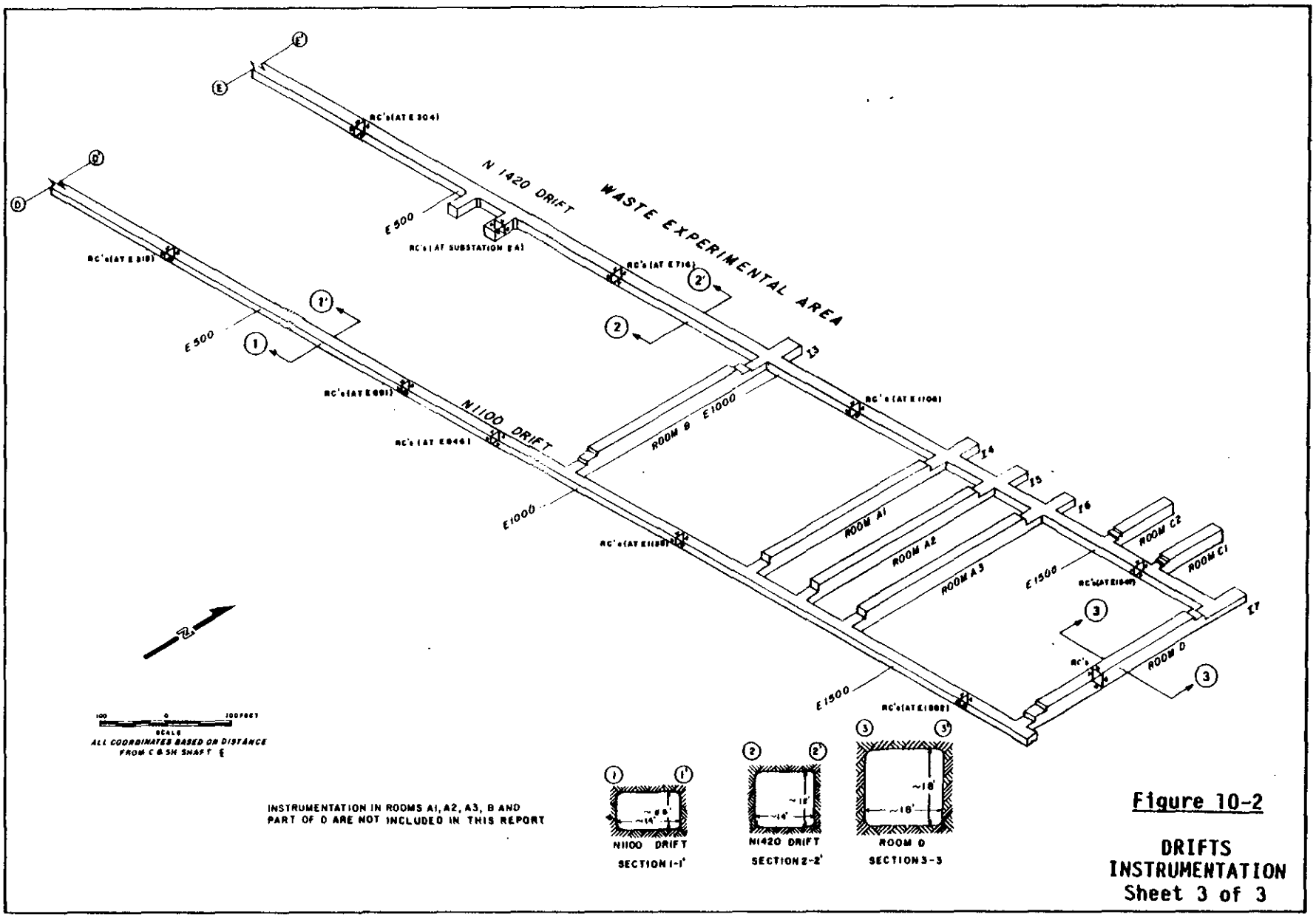


Figure 10-2

DRIFTS INSTRUMENTATION Sheet 3 of 3

with stainless steel anchor rods and expansion-ring anchors. Two-anchor, four-anchor and five-anchor extensometers have been installed. Anchor depths vary with locality and site-specific stratigraphy. Recent data plots for the drift instruments are presented in Appendix J.

No stressmeters were installed in either the halite or anhydrite surrounding the drift openings. A program to develop reliable stressmeters for use in halite was begun but abandoned when other WIPP participants initiated similar programs. The results of their programs indicate that measurements using modified stressmeters are not yet sufficiently reliable to be considered for design validation. Therefore, numerical modeling was relied upon to analyze stress changes with time in the halite and anhydrite around the openings. The reliability of the readings from the two stressmeters installed in MB-139 beneath Test Room 2 is discussed in Chapter 11.

The underground instrumentation system has had a complex history. All extensometers have been reset at least once because salt creep moved the anchor-rod magnets beyond the initial 2-inch measurement limit. Convergence points were frequently damaged by construction activities and were regularly replaced. Extensometers were also damaged during construction; some were replaced and others were abandoned. The operational history of the instruments is presented in each issue of the GFDRs.

10.3.2 Analysis and Evaluation

The in situ data collected and observations made during the design validation process were analyzed and evaluated to determine the effects of salt behavior on the drift excavations. Closure data were analyzed and a model simulation was performed for a typical 8 x 25-foot wide drift. An option for lowering the floor 5 feet was incorporated into the model for subsequent analysis of the drifts in the storage area. The results of the analysis of the larger drifts are presented in Chapter 12.

10.3.2.1 Observed Conditions

Evaluation of observed conditions is a qualitative process. It represents the assessment of qualified geologists and engineers and is an important component of the analysis and evaluation of measured responses and structural calculations.

Roof and Wall Spalling. Changes in roof and wall conditions occur slowly. Drummy areas detected during the original soundings have not enlarged significantly. These drummy areas occur in clear halite and are not associated with any noticeable clay deposits. Separations occur along planes of weakness, probably created by the orientation of crystal faces. Few new slabby areas have developed. For an unknown reason, more slabby areas developed in the roof of the E140 drift south of the waste shaft during excavation than in any other underground area. These areas have shown little, if any, growth.

Wall spalling is even more subdued. The most noticeable spalling occurs in the argillaceous halite unit and associated clay seam (geologic map unit 4 and clay F) near the intersection of the wall and roof. This area has exhibited slowly deteriorating conditions and requires occasional scaling. This spalling of map unit 4 and the squeezing out of associated clay F is most noticeable in the N1420 drift north of the test rooms and along the E140 drift south of the waste shaft. Spalling results from room closure and is related to the percentage of argillaceous material in the halite and to the proximity of the roof intersection. Similar behavior associated with anhydrite "b", anhydrite "a" and clay I has been observed in the walls of the drifts and test rooms in the waste experimental area. Some minor squeezing of clay G, clay H and clay I has occurred where these clays are exposed along drift walls. Relative motion along these clays similar to clay F is exhibited by the lower section of the wall moving into the excavation relative to the upper section. Some spalling of map unit 0 has also been noted along the E140 drift south of approximately S2500.

Pillar Fracturing. The vertical fractures that have developed in the pillar corners occur throughout the underground facility. They are particularly prominent in corners that were not beveled during excavation. The fractures range in width from closed to about 2 inches and extend into the salt essentially perpendicular to the surface.

The fractures grow steadily with time as the halite responds to deformation around the opening. Pillar corner fractures are the most obvious manifestation of pillar shortening in the drifts and rooms. These fractures will continue to grow and the corners will continue to deteriorate, with increasing spalling as a result. This behavior is expected and poses no stability problems, but it will require monitoring and maintenance throughout the operating life of the facility.

Vertical fractures have developed in the walls of the drifts parallel to the longitudinal drift axis. The fracture openings range from closed to 1/16 inch in width. The fractures have been detected in some boreholes where they occur within 2 feet of the wall surface. This type of fracturing is typical of underground excavations and probably represents tension fractures developed due to stress relief.

Roof Displacements and Separations. Clay G and clay H, above the roof of the facility level drifts, and clay I, above the roof of the drifts in the experimental area, have exhibited displacements and separations. Table 10-1 presents the results of observations made through July 1986 in 58 open boreholes. Twenty of these holes exhibited positive evidence of the occurrence of displacements and/or separations. Sixteen of these holes are at intersections. The vertical separations range from closed to 1/4 inch in width, and the horizontal displacements are up to 1 inch wide.

An additional 32 holes in 11 arrays were drilled in the roof at various facility level drift locations during the Excavation Effects Program (Figure 10-1). Of these, four arrays were drilled at intersections. Three additional arrays were drilled in the roof of drifts in the waste experimental area.

Inspection of the recently drilled holes using a probe indicate that minimal separation has occurred at the intersections and along the drifts. The size of the opening as well as the elapsed time since its excavation do not appear to have a significant effect on this phenomenon. Although the E140 drift south of the waste shaft was excavated early in construction and has the largest opening dimensions (12 x 25 feet), only minimal separations, less than 1/16 inch wide, were detected.

No separations were detected at clay G in the drift hole arrays, and the separations in the halite were usually less than 1/16 inch. There appears to be about 1/8 inch of separation at clay I in the array at E875 in the N1420 drift. This is consistent with observations made in previously drilled holes in the waste experimental area.

The observed displacements and separations immediately above the facility drifts appear to be normal deformational behavior. As the deviatoric stress around the underground openings increases following excavation, the surrounding salt will deform. The clay seams are zones of weakness that provide slip planes for salt movement during lateral loading. Movement is generally represented by the halite section below the clay seams moving into the excavation relative to the section above.

Floor Displacements, Separations and Fracturing. Minor displacements, separations and fracturing have occurred beneath the floor of the drifts. Table 10-3 presents the results of observations made in 34 open boreholes through July 1986. Ten of these holes exhibited displacements, separations or fracturing. Displacements up to 3/4 inch wide and separations up to 1/2 inch wide have been observed in boreholes at the intersection of Test Room 1 and Room L1, as well as at the intersection of Test Room 2 and Room L2. These are large, four-way intersections with 20 x 33-foot dimensions. Some displacements, separations and fracturing were also detected in three open boreholes in Room L2. Only two holes in the N1420 drift east of Test Room 1 exhibited separations, less than 1/8 inch wide. No other separations

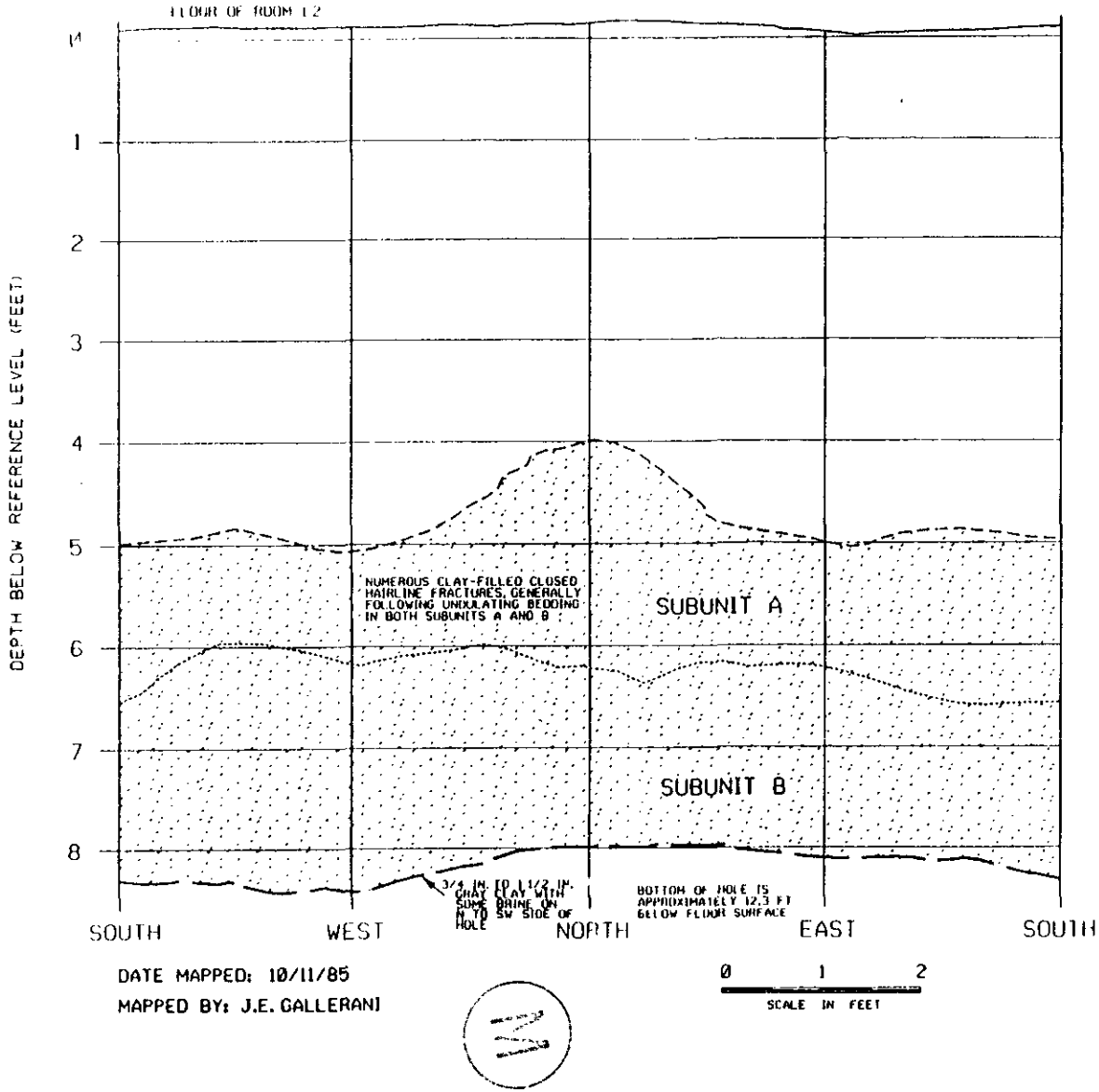
have been detected in any other open boreholes in the N1420 drift or Room G. Only closed fractures were observed in the 30-inch diameter hole (L2X-01) in Room L2 (Figure 10-3). These fractures, many coated with clay, appeared to have originated prior to room excavation.

Nine small-diameter holes were drilled in the floor of the 35-foot wide S700 crosscut and inspected using a probe. These holes were drilled to determine the depth to MB-139 as well as to determine if any fractures were present. Fracture zones up to 1 inch wide were encountered in two locations in the halite above MB-139. Only one borehole contained a hairline fracture within MB-139.

During September 1985, nine 36-inch diameter holes were drilled in the floor of Room J, a 33-foot wide room, to accommodate structural steel columns. Only one near-horizontal fracture, less than 1/32 inch wide, was encountered in the halite above MB-139 in hole JV-8. No fractures were found in the other holes in Room J.

One fracture has been detected in the floor of the E140 drift south of the waste shaft. This fracture was observed while the drift was being enlarged from 8 feet to 12 feet high from April through June 1984. The fracture was about 18 inches below the original floor in halite and extended from approximately S1859 to S1871. Separation ranged from 1/16 inch to 1/2 inch and was associated with some clay. It curved upwards toward the floor at its northern and southern limits.

The results of the Excavation Effects Program indicate that minimal separations occur beneath the floor of the drifts and intersections. As determined from the roof holes, the size of the opening and elapsed time since excavation do not appear to have any effect on the occurrence of separations in the salt beneath the floor. No fracture zones were detected in any of the holes and separations where encountered, ranged from less than 1/16 inch to 1/8 inch wide. As with the older open boreholes, the Excavation Effects Program holes show evidence of separations within MB-139, at clay E and in the overlying halite.



EXPLANATION

- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE BOREHOLE WALL.
- FRACTURE ZONE
  ZONE OF FRACTURED SALT BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE WIDTH OF SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE OPENING, 12 INCHES FROM BOREHOLE WALL.

NOTES:

1. BOREHOLE IS 30 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM AN UNSURVEYED REFERENCE LINE.
3. MAPPING WAS PERFORMED AT A SCALE OF 1 INCH EQUALS 1 FOOT.

Figure 10-3

DRIFTS
GEOLOGIC LOG OF HOLE L2X-01

The floor hole array in the N1420 drift at E875 encountered a slight separation of approximately 1/16 inch, coincident with a clay seam at a depth of about 8 1/2 feet. MB-139 at this location is about 22 feet below the floor.

Brine was encountered during the drilling of the central hole in the array at S700/E66 and continued to flow from the hole for several days after the completion of drilling. The hole encountered several separations up to 1/16 inch wide between a depth of 7.4 and 7.7 feet. No separations were detected in the other holes of this array. Brine has been encountered at several other hole array locations but no significant separations were detected in the holes.

The observations made to date indicate that fracturing in the drift floors is minimal. This includes observations of the E140 drift, which was one of the earliest excavations made during the SPDV Program. No fractures of the magnitude found in Test Room 3 (Chapter 11) have been detected in any of the drifts. Displacements, separations and fracturing beneath the floor is expected to continue in the future.

10.3.2.2 Closure Behavior at Selected Stations

Analyses were performed at selected stations to study roof-to-floor and wall-to-wall closure. Analysis was also performed to study the effect of floor lowering on closure.

Roof-to-Floor Closure. Until May 1984, the E140 drift south of the waste shaft was unique in that there were neither crosscuts nor nearby parallel drifts. However, in May and June 1984 the floor of the drift was lowered by 4 feet and new drifts and crosscuts were added between stations N140 and S1620. These two operations have resulted in an increase in closure rates for this portion of the drift. Since both operations occurred concurrently, it is difficult to isolate their effects on closure. However, it has generally been observed that any far field disturbance has only a short-term effect on the closure, and

that the closure rate, after a momentary increase, decays to its pre-perturbation rate pattern.

If we assume that the closure at station E140/S1879 is not measurably affected by the additional excavations performed north of station S1620, this station can then represent the closure of an infinitely long opening in a geologically uniform formation. However, because the convergence points were installed nearly 4 days after the completion of excavation, the roof-to-floor closure versus elapsed time curve was extrapolated backwards by fitting an equation in the form of

$$t = t_1 \, (1 + R(t)/R_1)^3 \qquad (10\text{-}1)$$

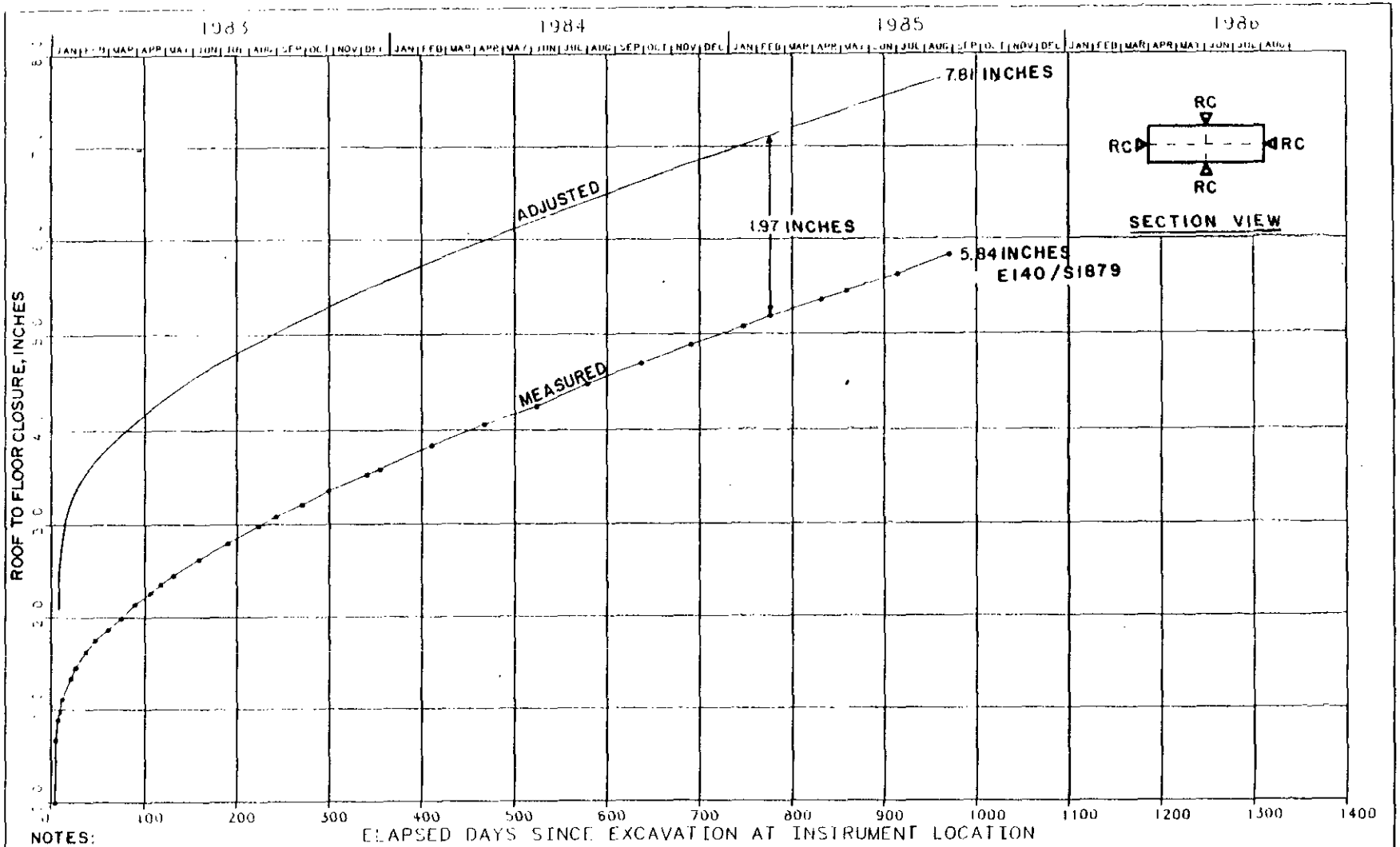
where: R(t) is the instrument reading at elapsed time t since the end of excavation; and

R_1 is the regression parameter, equal to total closure at elapsed time t_1 since the end of excavation.

This equation indicates that at t equal to 0, the slope of the closure curve is infinite. This is not true because the slope at t equal to 0 is finite but large.

Based on the results of the regression analysis, the value of R_1 was determined to be 1.97 inches. However, the curve-fitting was not very good, probably because excavation at the instrument location was done in two stages making it difficult to assign the value for t_1. Because the shape of the early part of the closure versus time curve is not smooth, the estimated value of t_1 is approximate.

Figure 10-4 compares the measured closure with the adjusted curve at station E140/S1879 using the results of the regression analysis. The reading of roof-to-floor closure on August 26, 1985, was 5.84 inches and the adjusted value is 7.81 inches. Note that this station is nearly 230 feet from the boundary location north of which the floor was lowered 4 feet. It is likely that the excavation had some effect on



NOTES:

1. EXCAVATION DIMENSIONS = 8FT X 25FT
2. ADJUSTED CURVE OBTAINED USING THE RESULTS OF REGRESSION ANALYSIS

Figure 10-4

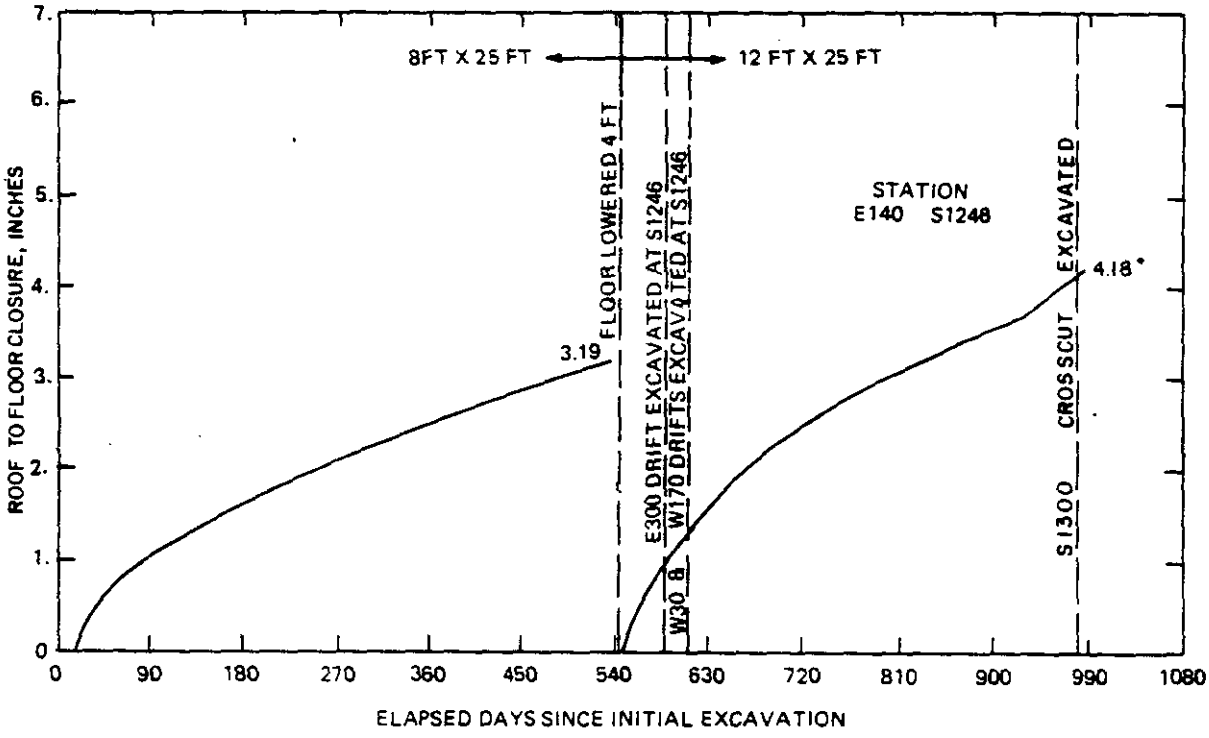
DRIFTS
COMPARISON OF MEASURED CLOSURE WITH REGRESSION CURVE AT E140/S1879

the closure at this station, although Figure 10-4 does not clearly show such an effect. The convergence points at this location have since been destroyed.

Figure 10-5 shows the central roof-to-floor closure at E140/S1246. The roof-to-floor convergence points were installed nearly 14 days after excavation at this location. This figure shows the effect that lowering the floor 4 feet has on the closure. In addition, the E300 drift excavation passed this location on August 21 and 22, 1984. The effect of lowering the floor, though, masks the effects of the adjacent excavation. As of August 26, 1985, the roof-to-floor closure of the 12 x 25-foot drift was 4.18 inches. The initial reading was taken on July 11, 1985, 1 day after the floor was lowered. Because the closure rate is very high at the early stages, actual roof-to-floor closure is greater than 4.18 inches.

Relationship Between Roof-to-Floor Closure and Drift Dimensions. Convergence points have been installed at various stations in underground drifts having different cross section dimensions. Some of the drifts, especially the E140 drift south of S1600, are isolated, while most of the other drifts have nearby parallel drifts and crosscuts. The closure behavior of these drifts is affected not only by the opening dimensions but also by the presence of adjacent openings. Differences in creep properties of the salt may also be responsible for differences in creep behavior. In addition, the closure behavior is affected by the 4- to 5-foot lowering of the drift floor.

Figure 10-6 shows measured roof-to-floor closure at selected stations in drifts with different cross section dimensions. Because measurements were not made immediately after the opening was excavated, the closure values were normalized to the values at approximately 10 days after the completion of excavation at the respective instrument station. As shown on this figure, the maximum closure and closure rate occur in drifts with opening dimensions of 12 x 25-feet. Because the



*MEASUREMENT ON AUGUST 26, 1985.

Figure 10-5

DRIFTS
EFFECT OF FLOOR LOWERING AND ADJACENT EXCAVATIONS
ON CLOSURE AT E140/S1246

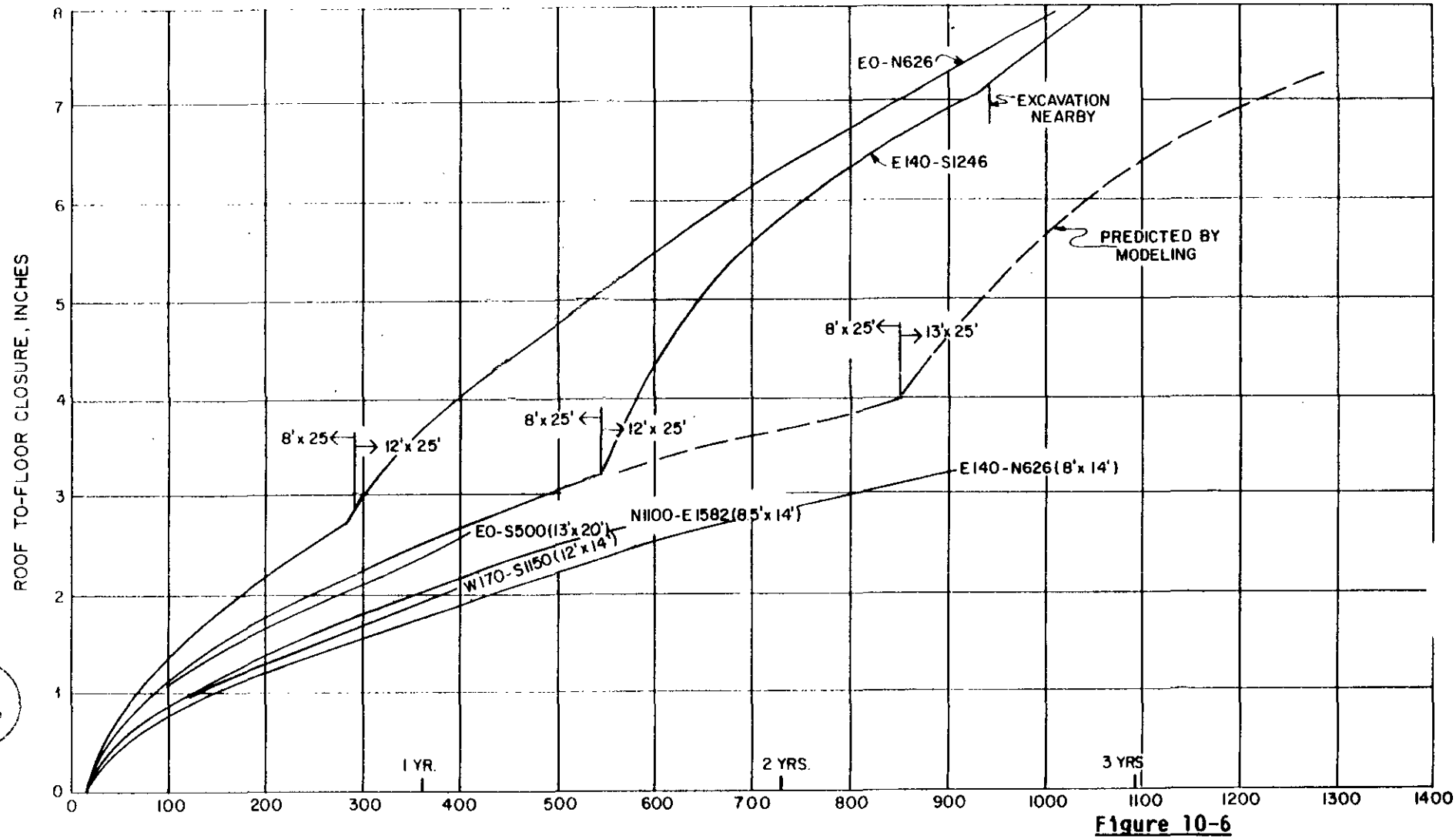


Figure 10-6

DRIFTS
COMPARISON OF ROOF-TO-FLOOR CLOSURE IN DRIFTS WI
DIFFERENT DIMENSIONS

drifts in the storage area will have cross section dimensions of 13 x 25 feet, the modeling analysis discussed in this chapter and in Chapter 12 focuses on predicting the behavior of the 13 x 25-foot drift opening for the operating life of 25 years.

The effect of lowering the floor 4 feet at instrument stations E0/N626 and E140/S1246 is to increase the closure rate permanently. Although the floor lowering was performed at different times at these stations, the steady state rate after excavation appears to be nearly the same. However, if the floor lowering is performed at a much later date following the initial excavation, it is likely that the total closure may be somewhat decreased. The closure behavior at these two stations is influenced by the presence of nearby parallel drifts and crosscuts, as well as likely differences in the creep properties of the salt.

Figure 10-6 also shows the predicted roof-to-floor closure of an infinitely long, single drift with cross section dimensions of 13 x 25 feet. This closure was obtained by modeling and is discussed in Chapter 12. The approximate steady state closure rate at E0/N626 and E140/S1246 is 2.00 inches/year. The steady state closure rate predicted for the infinitely long, single drift is 1.60 inches/year. The nearly 25 percent difference in these rates is probably due to the presence of adjacent drifts and crosscuts. This value compares well with the value of 30 percent obtained from modeling as discussed in subsection 10.3.3.3.

Figure 10-7 presents a comparison of the predicted closure of a 13 x 25-foot drift with the observed behavior of a 12 x 25-foot drift at E0/N626. The closure for the 13 x 25-foot drift was obtained by increasing the closure rate obtained from modeling the infinitely long, single drift by 30 percent. The roof-to-floor closure at E0/N626 does not include the values before the floor was lowered by 4 feet. This comparison indicates that it is reasonable to increase the closure rate of a single, infinitely long, 13 x 25-foot drift by 30 percent to account for the presence of adjacent parallel drifts and crosscuts.

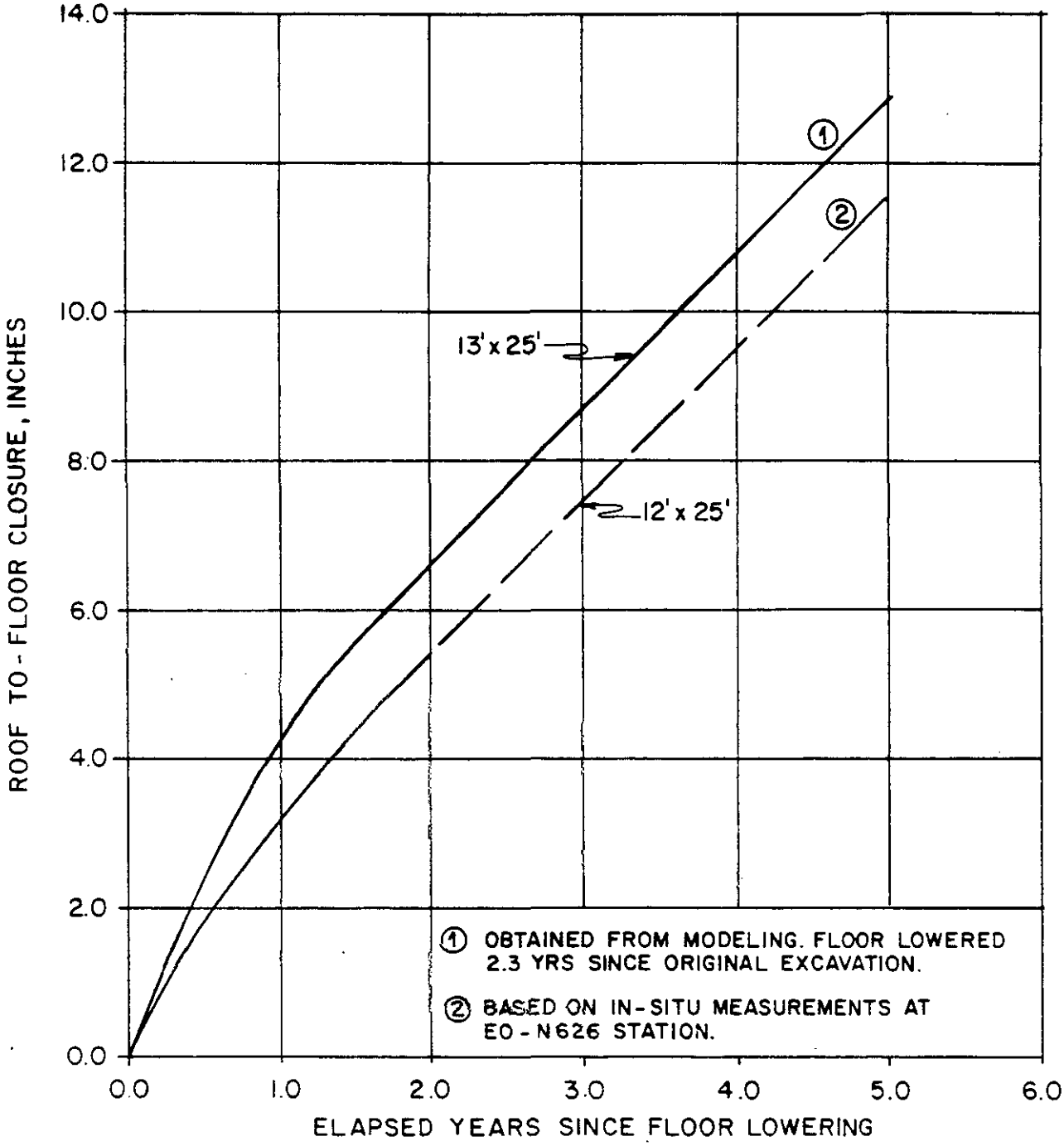


Figure 10-7

DRIFTS
COMPARISON OF PREDICTED AND OBSERVED
ROOF-TO-FLOOR CLOSURE

Wall-to-Wall Closure. The wall-to-wall convergence points at the S1246 station were installed immediately after the original excavation at this location was completed. When the cross section dimensions were 8 x 25 feet, the measurements were close to the true wall-to-wall closure at midheight of the instrument location. On June 30, 1984, the wall-to-wall closure was 5 inches for an elapsed time period of 564 days. After the floor was lowered, a new set of wall-to-wall convergence points was installed. The additional wall-to-wall closure was 3.31 inches through August 26, 1985.

Comparison of Roof-to-Floor to Wall-to-Wall Closures. Table 10-4 summarizes the closure of the E140 drift for locations south of S1620. Until August 1985, these locations were unique in that there were no crosscuts and no nearby parallel drifts at the time of the analysis. The cross section dimension was 8 x 25 feet. The maximum measured roof-to-floor closure of 5.19 inches was at station S1879. Stations S3614, S3639 and S3664 are influenced by the end constraints of the drift which terminates at about S3664.

Effect of Adjacent Drifts. Table 10-5 compares closure in the drifts at S1150. Because the initial readings were not taken immediately after the station location was excavated, the comparison is approximate. Note that, for the E140/S1150 station, the original cross section dimensions were 8 x 25 feet until June 8, 1984, and that no convergence points existed at this location prior to lowering the floor. The closure values at E140/S1150 are the maximum, not only because the opening dimensions are the largest, but also because the opening had already existed for nearly 550 days before the floor was lowered 4 feet. It is also likely that there is mutual influence between the openings.

Effect of Floor Lowering. The E0 drift between N140 and N1420 was increased in height from 8 feet to 12 feet (by lowering the floor) from November 9, 1983, through January 9, 1984. The closure readings increased rapidly as excavation approached the measurement stations but

Table 10-4

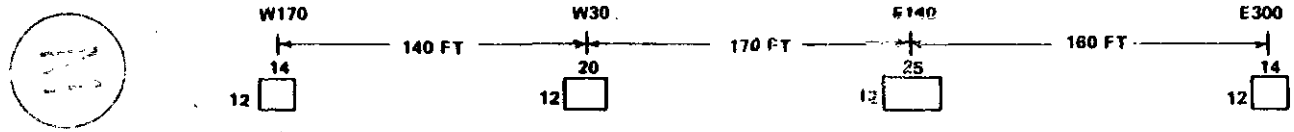
E140 DRIFT SOUTH OF S1620
SUMMARY OF MEASURED CLOSURE
(CROSS SECTION DIMENSIONS = 8 x 25 feet)

Instrument Location	Time-lag between end of excavation and initial reading (days) R-T-F*	W-T-W*	Convergence point reading (inches) Feb. 12, 1985 R-T-F*	W-T-W*
E140/S3664	14	0	1.70	1.48
E140/S3639	0	0	4.07	3.24
E140/S3614	0	0	4.49	3.72
E140/S3250	11	11	4.13	2.97
E140/S2950	10	10	4.19	3.18
E140/S2625	6	6	4.43	3.59
E140/S2350	9	9	4.33	3.44
E140/S2066	8	8	4.32	3.40
E140/S1879	4	2	5.46	4.00

* R-T-F = roof-to-floor
W-T-W = wall-to-wall

Table 10-5

COMPARISONS OF CLOSURE IN DRIFTS AT S1150



	W170/S1150	W30/S1141	E140/S1150	E300/S1150
INSTRUMENT LOCATION				
DATE OF EXCAVATION	AUGUST 21, 1984	AUGUST 21, 1984	JUNE 8, 1984*	JULY 23, 1984
DATE OF INITIAL READING				
CENTRAL ROOF-TO-FLOOR	AUGUST 23, 1984	AUGUST 22, 1984	JUNE 14, 1984	JULY 26, 1984
CENTRAL WALL-TO-WALL	AUGUST 23, 1984	AUGUST 22, 1984	JUNE 14, 1984	JULY 26, 1984
DATE OF LATEST READING FOR BOTH ROOF-TO-FLOOR AND WALL-TO-WALL CONVERGENCE POINTS	SEP. 16,1985	SEP. 16, 1985	AUG. 26, 1985	SEP. 30, 1985
CLOSURE (IN.)				
CENTRAL ROOF-TO-FLOOR	2.46	3.10	3.61	2.18
CENTRAL WALL-TO-WALL	2.62	2.76	3.03	2.35

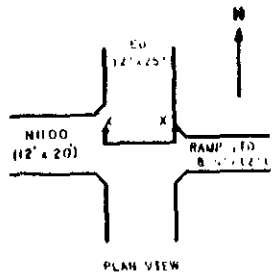
* FLOOR LOWERED BY 4 FT ON JUNE 8, 1984. DIMENSIONS WERE 8 FT X 25 FT BEFORE JUNE 8, 1984. CROSS DRIFTS S1100 AND S1300 EXCAVATED IN AUGUST, 1985.

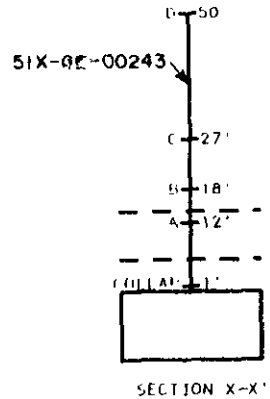
dropped rapidly to, or slightly above, the pre-excavation rate. The floor lowering has affected the salt material above the roof of the openings to distances of at least 30 feet.

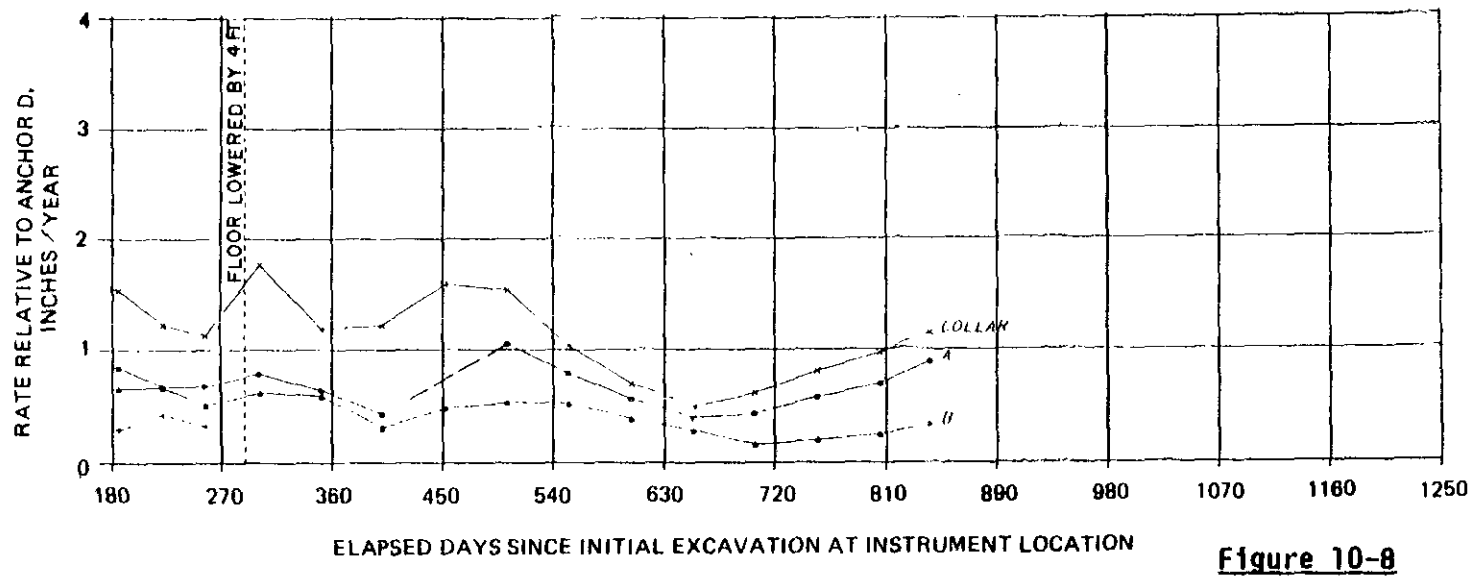
Figure 10-8 shows the relationship of the movement rates for the collar and two intermediate anchors of roof extensometer 51X-GE-00243 at the E0/N1100 intersection. The figure shows that the movement rate of the collar and these anchors increased due to floor lowering but then began decreasing until March 1984 (about 400 days after the initial excavation). The rate then began increasing again from March until August 1984 (about 550 days after the initial excavation). Because excavation activities were performed in the area of this instrument at this time, it is possible that parting at the clay seams above the roof was occurring at an increasing rate.

Figure 10-9 shows the movement rates of the collar and anchors of roof and wall extensometers at E0/N626. The collar movement rate of the east wall extensometer appears to be somewhat less than that of the west wall extensometer. It was also observed that floor lowering has affected the closure behavior of pillars as far as 25 feet from the opening. Similarly, roof behavior has been affected, probably up to at least 30 feet above the roof.

The height of the E140 drift remained at 8 feet during floor lowering in the E0 drift between N140 and N1420. However, excavation performed in the E0 drift appears to have affected the closure behavior of the E140 drift. Figure 10-10 shows the movement rates of the collar and anchor A for roof extensometer 51X-GE-00235 at E140/N624. The collar movement rate was decreasing monotonically until late December 1983. However, it appears to have increased around January 1984. Assuming the instrument was functioning properly and there was no anomalous behavior of clay seams in the roof of the E140 drift, excavation in the E0 drift may have influenced salt behavior as much as 150 feet from the E0 drift.



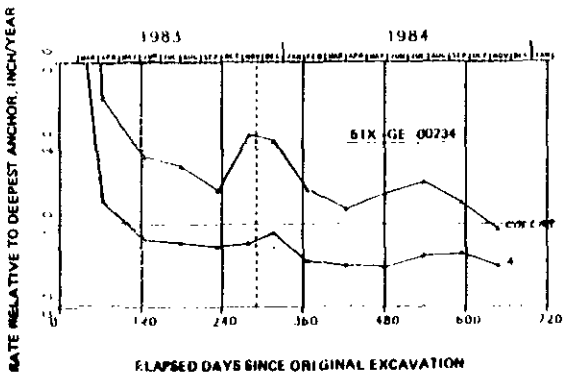


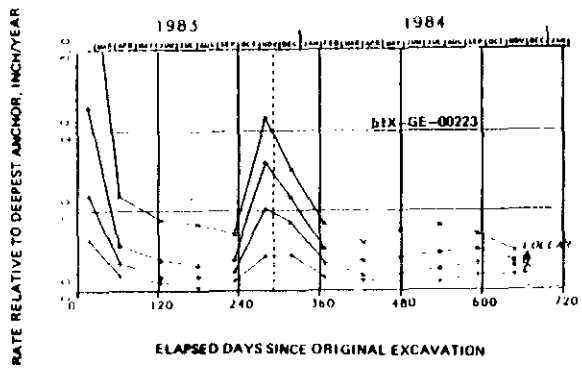


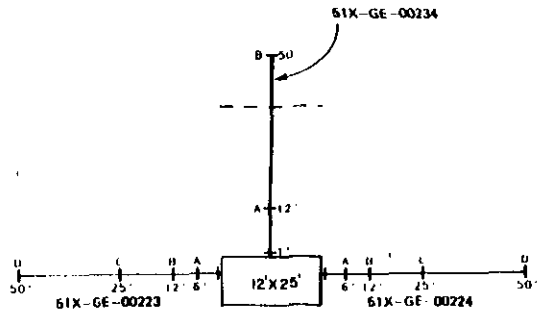
NOTE: RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

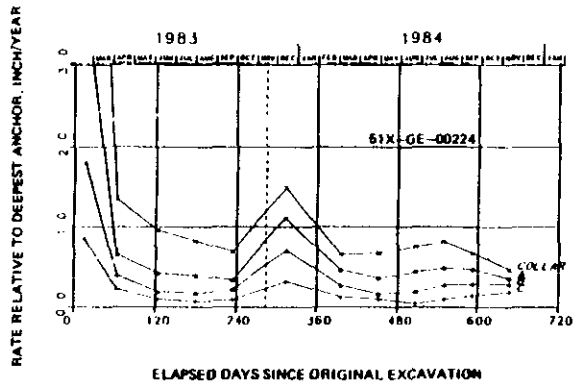
Figure 10-8

DRIFTS
EFFECT OF FLOOR LOWERING ON ROOF BEHAVIOR AT EO/N1100 INTERSECTION









NOTE

VERTICAL DASHED LINE INDICATES TIME WHEN THE FLOOR WAS EXCAVATED FOUR FEET.

Figure 10-9

DRIFTS
EFFECT OF FLOOR LOWERING ON CLOSURE AT EO/N626

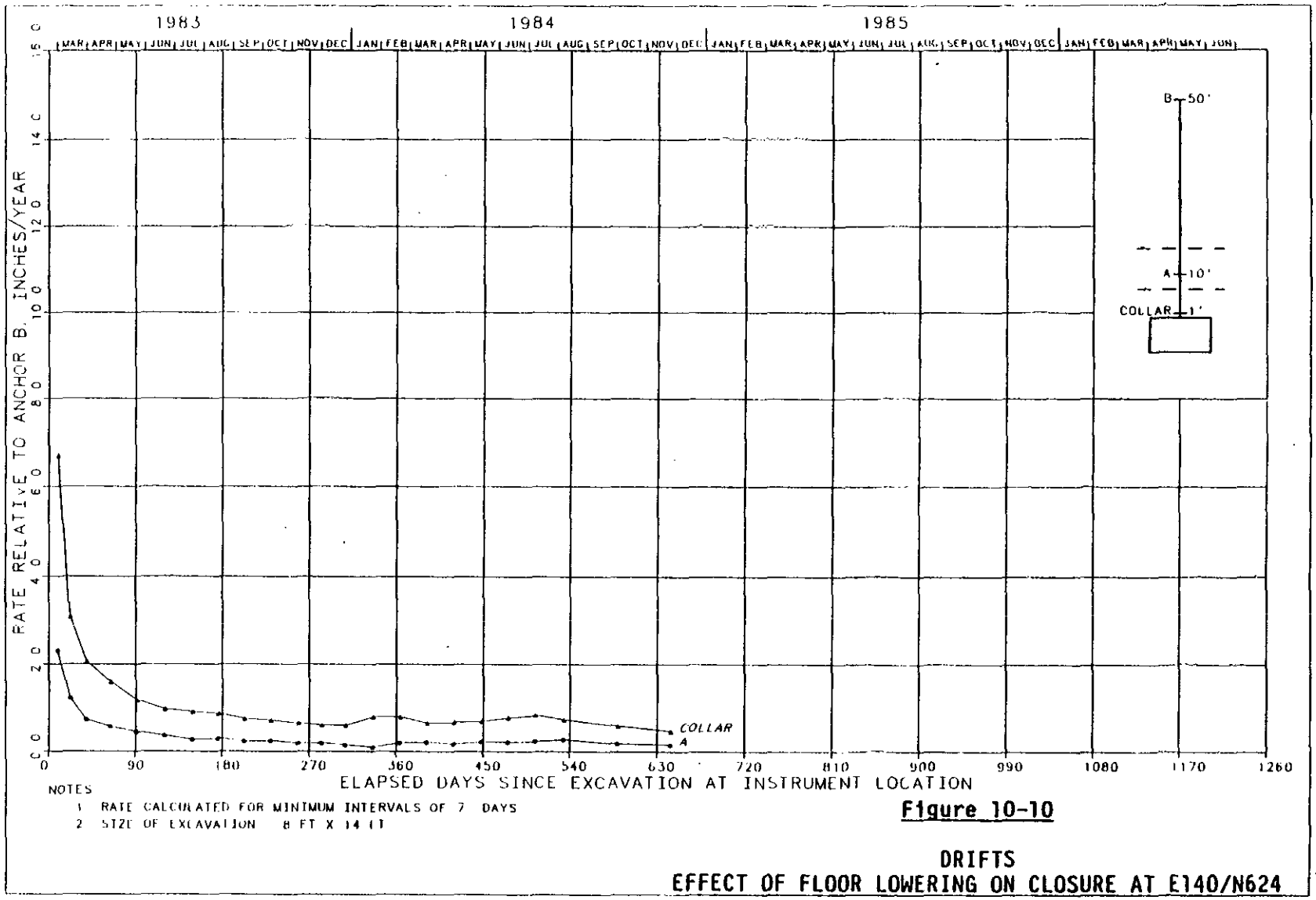


Figure 10-10

DRIFTS
EFFECT OF FLOOR LOWERING ON CLOSURE AT E140/N624

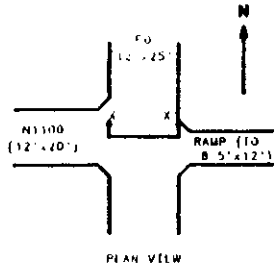
Observations of the effect of floor lowering on closure behavior are summarized below:

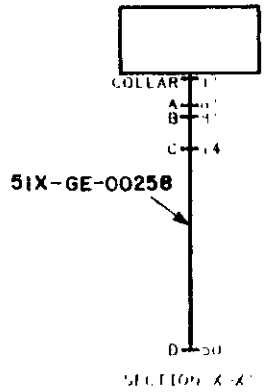
(1) The closure reading at an instrument station increases rapidly as floor excavation approaches the station and decreases rapidly to, or slightly above, the pre-excavation closure rate as excavation passes the instrument station.

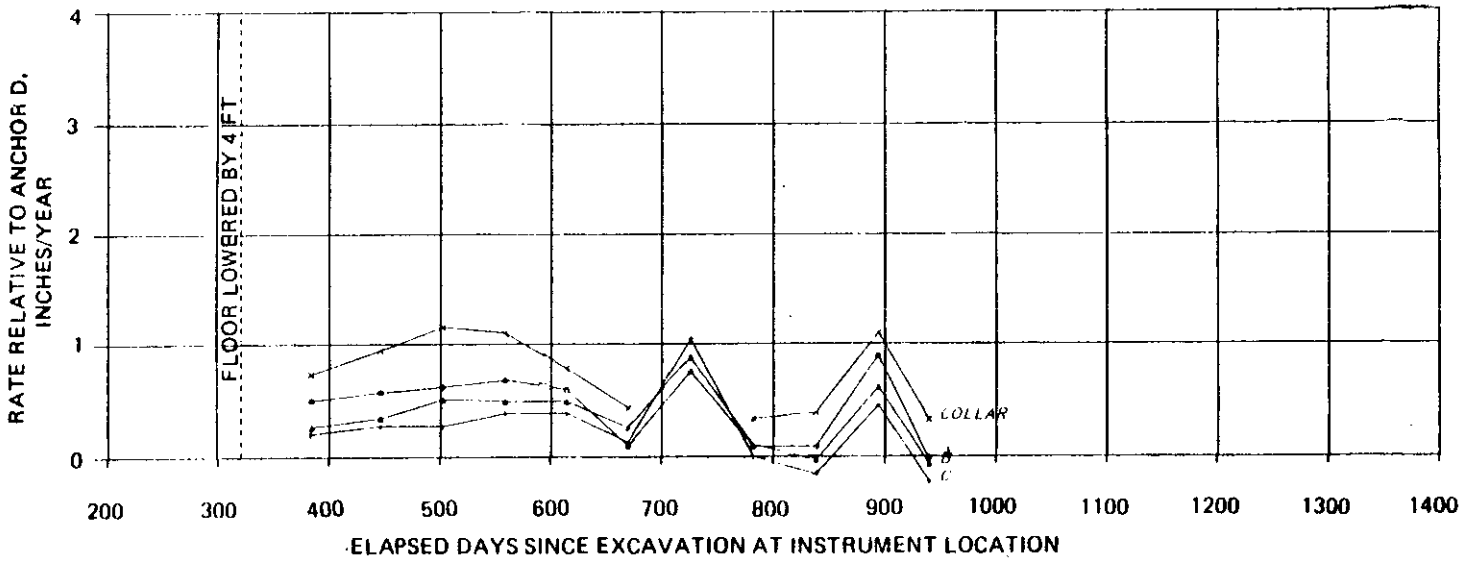
(2) Floor lowering affects creep behavior of the salt above the roof of the openings to depths of at least 30 feet. This effect is short-lived, however, extending over a period of only a few months.

(3) Although the floor of the E140 drift north of the C & SH shaft was not lowered for most of its length, excavation performed in the E0 drift appears to have affected the E140 drift closure.

The movement rates of the anchors of extensometer 51X-GE-00243 at the E0/N1100 intersection increased and then decreased between March and August 1984. Because no excavation activity took place at this time in the vicinity of the instrument station, it was assumed that the clay seams above the roof may have been parting at an increasing rate. Figure 10-8 shows the variation in closure rates for the collar and anchor points with time. The rates of the collar and anchor movements have subsided and are probably returning to their pre-perturbation values. For comparison, the rates of collar and anchor movements of floor extensometer 51X-GE-00258 are shown on Figure 10-11. The rates of movements of the collar and intermediate anchors have a similar trend as the roof extensometer over the same time period. However, this extensometer was damaged due to mining operations on February 8, 1985. Since then, the readings have remained anomalous.







NOTE: RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

Figure 10-11

DRIFTS
RATE OF FLOOR HEAVE AT EO/N1100

10.3.2.3 Model Simulation

A finite element model utilizing an engineering approach was used to simulate the behavior of an 8 x 25-foot drift. The method described in Appendix C was used to mathematically simulate the in situ behavior of the drifts by determining the creep parameters C, A, and z. The following discussion describes the numerical modeling and the utilization of in situ data for the drifts. Also discussed are simulations of the effect of adjacent parallel and perpendicular drifts.

Utilization of Reference Stratigraphy. The reference stratigraphy described in Chapter 6 was used in the analysis. The reference level representing the elevation of clay G is 2,129.40 feet below the ground surface, based on the core hole log at station E140/S1960. Because the finite element method lends itself well to multiple layer analysis in which distinct material properties can be accounted for, the MARC General Purpose Finite Element Program (ref. 6-8) was used.

Structural Characterization. Figure 10-12 shows the finite element model used to predict closures, stresses and deformed shapes as a function of time for an 8 x 25-foot opening. The model consists of 122 plane strain elements with 21 gap/friction link elements modeling the clay seams and an option for lowering the floor 5 feet. The top and bottom boundaries of the model are at depths of 2,045.00 feet and 2,245.00 feet, respectively, below the ground surface. The drift roof, drift floor before lowering, and drift floor after lowering are at depths of 2,128.70, 2,136.70, and 2,141.70 feet, respectively, below the ground surface. The roof beam is 8.10 feet thick and the final floor level is 4.39 feet above MB-139.

Only anhydrite layers with thicknesses greater than 1 foot were included in the model. Calculations showed that most anhydrite layers less than 1 foot thick failed at vertical stresses less than 1 percent of the overburden pressure. Therefore, because their contribution to the stiffness of the model would be insignificant, they were not included.

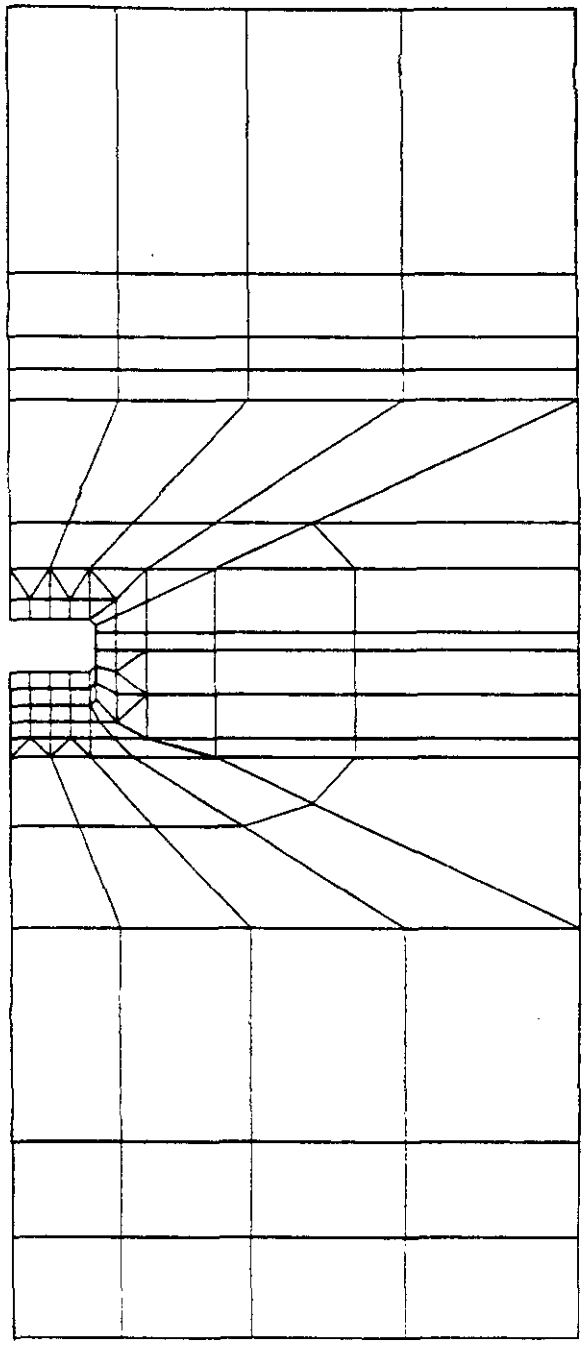


Figure 10-12

DRIFTS
FINITE ELEMENT MODEL - BEFORE FLOOR LOWERING

Clay seams in the model were limited to two above and two below the drift opening. The justification for this is twofold: first, reference 5-4 states that "90 percent of the drift closure measured with ten active slidelines could be captured with four slidelines, two directly above and two directly below the drift"; second, previous analyses have shown that, at locations representative of the more distant clay seams, the shear force is considerably less than the normal force; therefore, any slippage along these clay seams would be negligible compared to that along seams closer to the opening and they need not be included in the model. To simplify the analysis of this model, a coefficient of friction equal to 0.0 was assumed for the gap/friction elements modeling the clay seams.

The lateral boundaries of the model are 82 feet apart. and were established based upon vertical axes of symmetry with regard to adjacent drifts. The upper and lower boundaries of the model were based upon experience from previous analyses and were extended far enough in both directions so that the difference between vertical and horizontal stresses at each point of the boundaries would be within 10 percent of the vertical stresses. Horizontal restraints were assumed for the lateral boundaries while vertical restraints were assumed for the lower boundary of the model. Stress boundary conditions were utilized for the upper boundary.

Element sizes were established to make them proportional in size to the estimated stress gradient across each element. In addition, the orientations of the elements were established in order to have the radiating mesh coincide with the assumed principal stress axes. These aspects of the model were designed to enhance the overall efficiency of the analysis.

Consideration of Drift Opening. The drift openings were originally excavated to 8 x 25 feet. Further development trimmed an additional 4 feet from the floor to provide a 12 x 25-foot opening in the shaft pillar area. To provide continuous response histories from initial

excavation through the floor lowering period, special considerations were provided for modeling the opening.

Determination of Creep Parameters. Data from ten different locations along the E140 drift from S550 to S3250 were reviewed and one representative location was selected to calculate creep parameters for the drifts and for use in predicting closures and stress distributions.

Figure 10-13 shows the correlated roof-to-floor and wall-to-wall in situ data curves from the selected location, as well as the predicted closure based on the calculated creep parameters.

Transformation of Time Domains. Having determined the values of C, A and z to be 1.40×10^{-21} $ksf^{-4.9}$ sec^{-1}, 3.2 and 1.1×10^{-7} sec^{-1}, respectively, the normalized time at which the floor lowering was scheduled to take place was determined by transforming 7.25×10^{7} sec (or 2.3 years) to normalized time using equation C.4-17 in Appendix C.

The normalized time which corresponds to the scheduled real time for drift floor lowering was determined to be 1.4205×10^{-13} $ksf^{-4.9}$ or 418 time increments from the start of the program. Accordingly, the drift height was changed at the end of increment 418, and the analysis continued until a total real time of approximately 5 years was reached.

Effect of Parallel Drifts. The extraction ratio at a particular location is dependent upon the arrangement of the drifts and pillars. Therefore, the effect that the extraction ratio has on structural responses can be determined by considering the effect of adjacent drifts. Two different cases were considered in the analysis. One case assumes the adjacent drifts are parallel to the drift being analyzed while the other case assumes adjacent drifts are perpendicular to the drift being analyzed.

To simplify and minimize the computational effort, a multiple drift model was used for the analysis of the 8 x 25-foot drift. For this

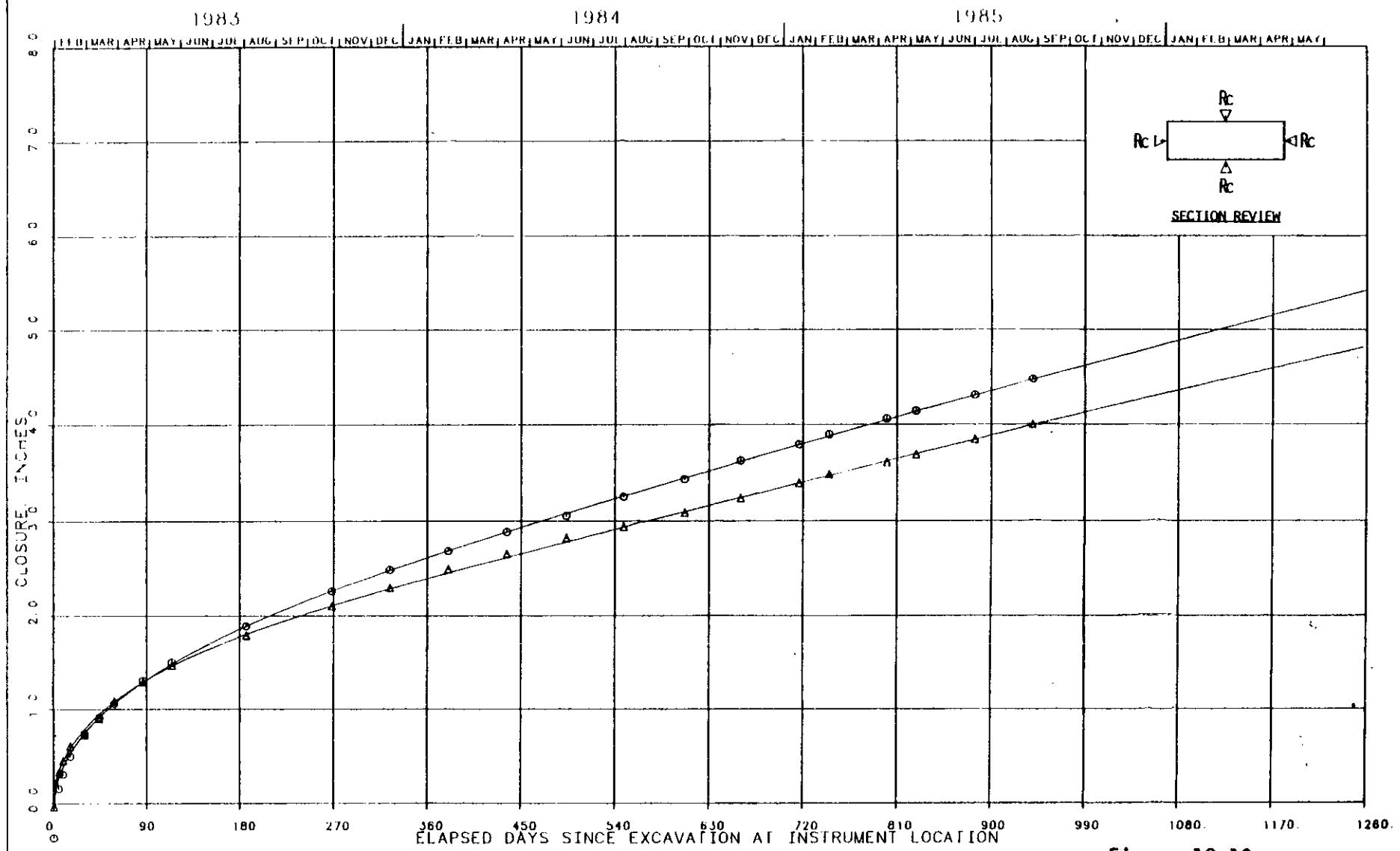


Figure 10-13

DRIFTS
CORRELATED CLOSURE HISTORIES

model, the drift was assumed to be located between an infinite number of parallel drifts, with each having identical cross sections and pillar widths. Two-dimensional analyses using this model were performed assuming a state of plane strain. The boundary displacement conditions at the centerline of the pillar were assumed to be restrained in the horizontal direction but free in the vertical direction. Under these assumptions, this mathematical model can more accurately simulate the geologic conditions in the future when adjacent drifts will exist rather than at the present time when only a single drift exists. Computational results for the parallel drifts are presented in subsection 10.3.3. Parallel drifts with different dimensions and spacings can be incorporated into the present mathematical model and corresponding structural responses can be computed.

Effect of Perpendicular Drifts. Ideally, a three-dimensional analysis is required for the case when the drifts are not parallel to each other. However, the structural responses can be approximated based on the two-dimensional analysis described in this section.

Additional drifts which intersect perpendicular to the drift in question increase the average overburden pressure in the pillar. The two-dimensional analysis of parallel drifts has indicated that the vertical stresses initially increase sharply in the pillar area adjacent to the opening. Over time, salt creep reduces this stress peak as the stresses are redistributed over the width of the pillar. Eventually, the vertical stress level becomes nearly uniform over most of the pillar width.

The total overburden load in the pillar is equal to the average vertical stress multiplied by the pillar support area. Because this total overburden load remains constant before and after the excavation of perpendicular drifts, the average vertical pressure is inversely

proportional to the support area. This increased average vertical stress can, therefore, be expressed as:

$$\bar{\sigma}_r = \bar{\sigma}_i \, W_t/W_2 \qquad (10\text{-}2)$$

where: $\bar{\sigma}_r$ is the average vertical stress of a rectangular pillar, i.e., pillar within a gridwork of intersecting drifts;
$\bar{\sigma}_i$ is the average vertical stress of an infinitely long pillar, i.e., pillar without the perpendicular drifts;
W_t is the distance between the center lines of the perpendicular drifts; and
W_2 is the pillar width in the perpendicular direction, i.e., W_t minus the width of the perpendicular drift.

After the excavation of additional drifts in the perpendicular direction, the restraints at the new wall boundaries are released. Consequently, the distribution of effective stress in the pillar changes. Actual distribution of the effective stresses can be obtained through a three-dimensional computational analysis. However, a two-dimensional analysis can be used to estimate the stress distribution.

A two-dimensional analysis can neither model the restraint conditions nor predict out-of-plane displacements that occur at the boundary of the perpendicular drifts. As a result, the vertical stress distribution from the two-dimensional analysis is assumed to represent a plane some distance from the perpendicular drifts where the actual behavior more closely represents the plane strain condition. The accuracy of this assumption depends upon the distance between the plane being analyzed and the perpendicular drift. In all cases, the results of a two-dimensional analysis represent a lower bound on the effects of perpendicular drifts.

The pillar dimensions are identified as W_1 for the width of the pillar between parallel drifts and W_2 for the width of the pillar

between perpendicular drifts. For an infinitely long pillar, which can be considered as a rectangular pillar with W_1/W_2 equal to zero, the vertical stress distribution of the drift to the center of the pillar can be determined from a two-dimensional analysis. The distribution of the vertical stress $\sigma_i(y)$, shown at the top of Figure 10-14, is symmetrical with respect to the centerline of the pillar and stabilizes within several months after excavation.

For a square pillar, which can be considered as a special case of the rectangular pillar with W_1/W_2 equal to one, the vertical stress distribution should be symmetrical with respect to the two centerlines and two diagonals of the pillar. This is shown graphically in the middle of Figure 10-14, where the x-axis is assumed to be along the drift axis. Assuming the vertical stress distribution $\sigma_s(x,y)$ from the center of the pillar to any of the four walls is the same as the stress distribution $\sigma_i(y)$ across the width of the infinite pillar, the ratio of the average vertical stresses between the square and the infinite pillars can then be estimated from equation 10-3:

$$\frac{\bar{\sigma}_s}{\bar{\sigma}_i} = \frac{\int_0^{W/2} \int_{-x}^{+x} \sigma_s(x,y)\, dydx}{\int_0^{W/2} \int_0^{W/2} \sigma_i(y)\, dydx} \qquad (10\text{-}3)$$

where: $\bar{\sigma}_i$ is the average vertical stress for the infinitely long pillar;

$\bar{\sigma}_s$ is the average vertical stress for the square pillar;

$\sigma_i(y)$ is the vertical stress distribution for the infinitely long pillar; and

$\sigma_s(x,y)$ is the vertical stress distribution for the square pillar.

Based on the computational results from the previous analyses, the average vertical stress of a square pillar is estimated to be 15 percent higher than that for the infinitely long pillar. At the WIPP

facility level, most of the pillars have a rectangular shape. As shown at the bottom of Figure 10-14, a rectangular pillar can be separated into regions which are assumed to act either as an infinite or square pillar. By using a weighted area method, the following equation expresses the effect of varying the pillar's aspect ratio on the average vertical stress:

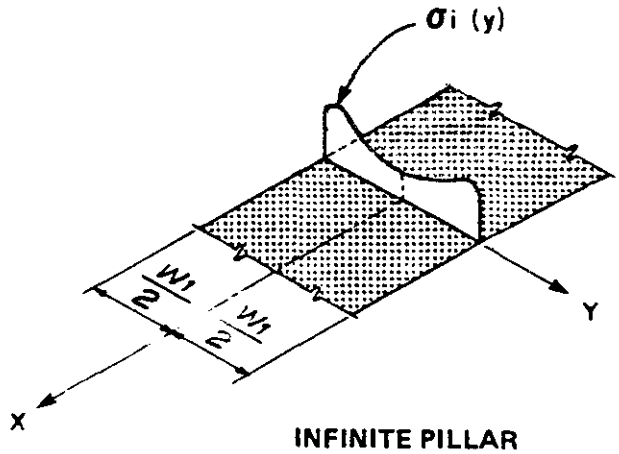
$$\bar{\sigma}_r = (1 + 0.15 \frac{W_1}{W_2}) \bar{\sigma}_i \qquad (10\text{-}4)$$

where: $\bar{\sigma}_r$ is the average vertical stress for the rectangular pillar.

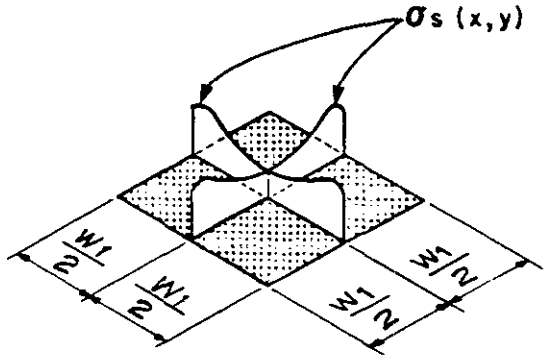
The corresponding change in pillar shortening is proportional to the ratio of $\bar{\sigma}_r$ to $\bar{\sigma}_i$, raised to some power, with an exponent not exceeding n, where n is the exponent in the power law expression for the creep behavior. Subsection 10.3.3.3 presents the results using equation 10-4.

10.3.2.4 Bay Strains

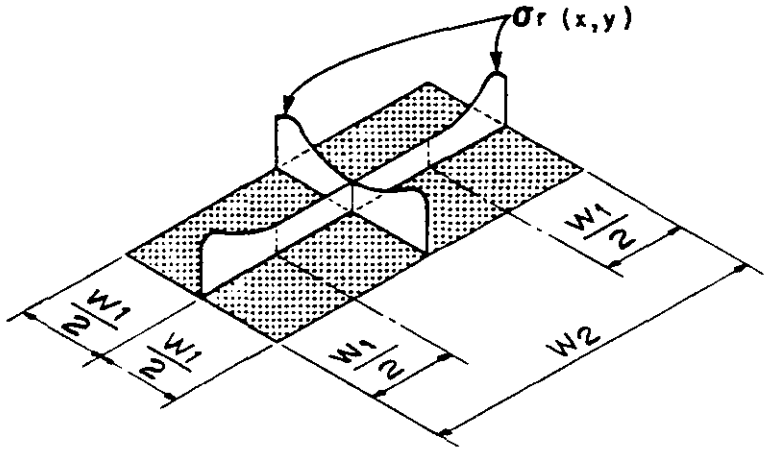
Strains around an opening in salt vary with space and time. Although, it is difficult to measure these strains directly, they can be inferred from the measurements of anchor displacements of multiple-point borehole extensometers. Relative movements between anchors will provide an approximate distribution of strain along the axis of the extensometer. If these relative displacements are normalized over the spacing between the anchors, then these normalized relative displacements are termed "bay strains". The bay strain will be closer to the true strain provided that the spacing between anchors is small and that the deformation varies linearly with spacing between anchors. Bay strains are useful in detecting any anomalous behavior in salt around an opening such as that influenced by discontinuities, clay seams, or the effect of local stress concentrations.



INFINITE PILLAR



SQUARE PILLAR



RECTANGULAR PILLAR

Figure 10-14

DRIFTS
VERTICAL STRESS DISTRIBUTIONS IN VARIOUS PILLARS

Figure 10-15 shows the variation of bay strains with elapsed time since completion of excavation for floor extensometer 51X-GE-00242. This extensometer is located at the intersection of Test Room 2 and the N1100 drift. The sudden increase in the bay strains may not be related to salt behavior and is apparently related to system measurement. Thus, it is likely that the maximum average bay strain in the first 6 feet of salt in the floor is no more than 1 percent. The analysis of bay strains in the floor of the drifts in other locations indicates that the maximum average bay strain generally occurs in the first 6 feet (collar to anchor A) in either the roof or the floor. Figures K-36 to K-45 in Appendix K show the variation of bay strains with elapsed time since excavation.

Figure 10-16 shows the rate of bay strains for extensometer 51X-GE-00242. The overall trend is that the rates decrease with time and are currently less than 0.5 percent/year. Figures K-46 to K-55 in Appendix K summarize the variation of strain rates with time.

The decreasing trend in the rates of bay strain with time is an indication that the salt in the roof and floor of the drifts is currently stable.

10.3.3 Prediction of Future Behavior

The results of the analysis of the 8 x 25-foot drift have been categorized as follows:

(1) Effective stresses and effective creep strains immediately after initial excavation; immediately before and after floor lowering; and 5 years after initial excavation.

(2) Principal stresses immediately after initial excavation; immediately before and after floor lowering; and 5 years after initial excavations.

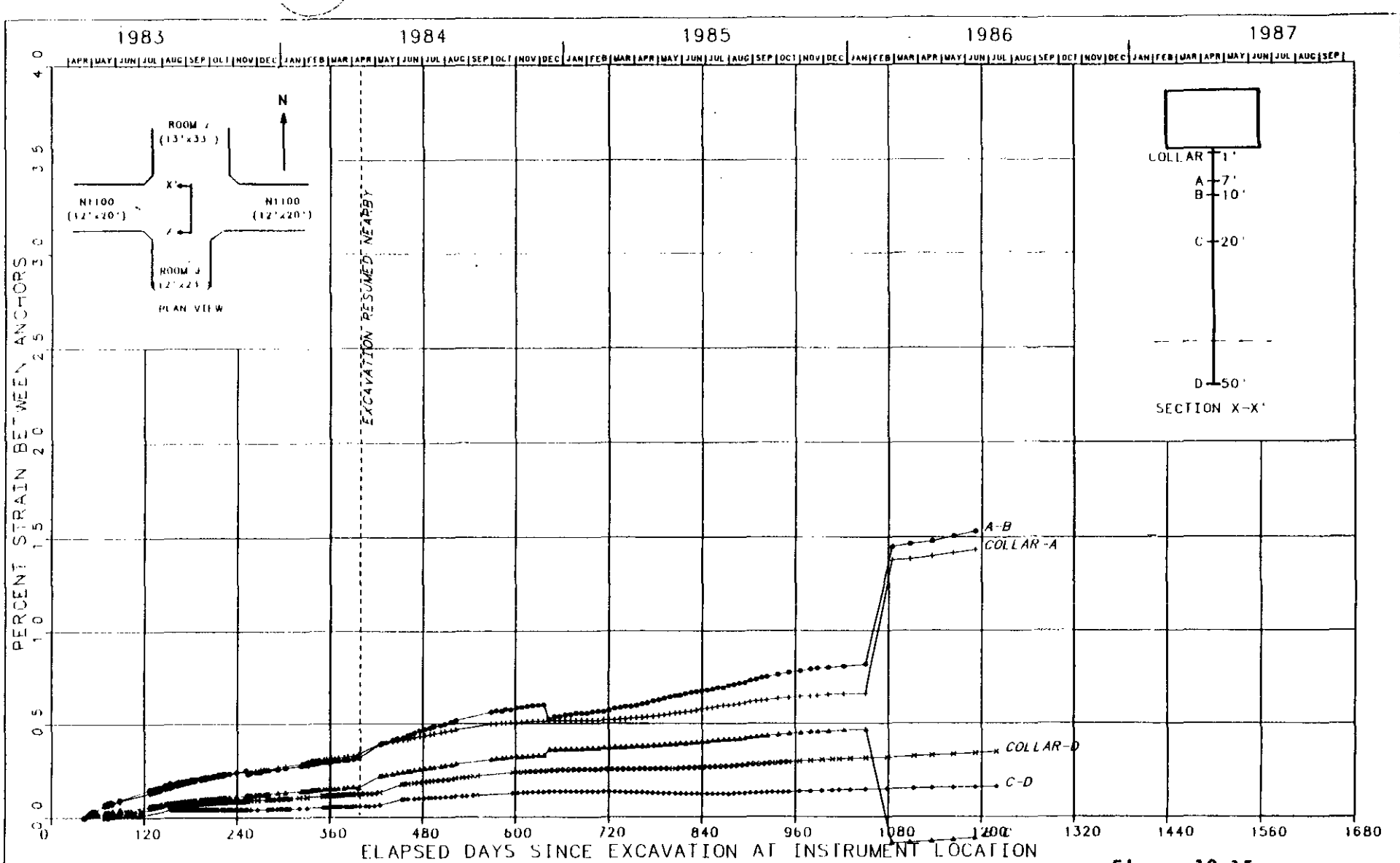
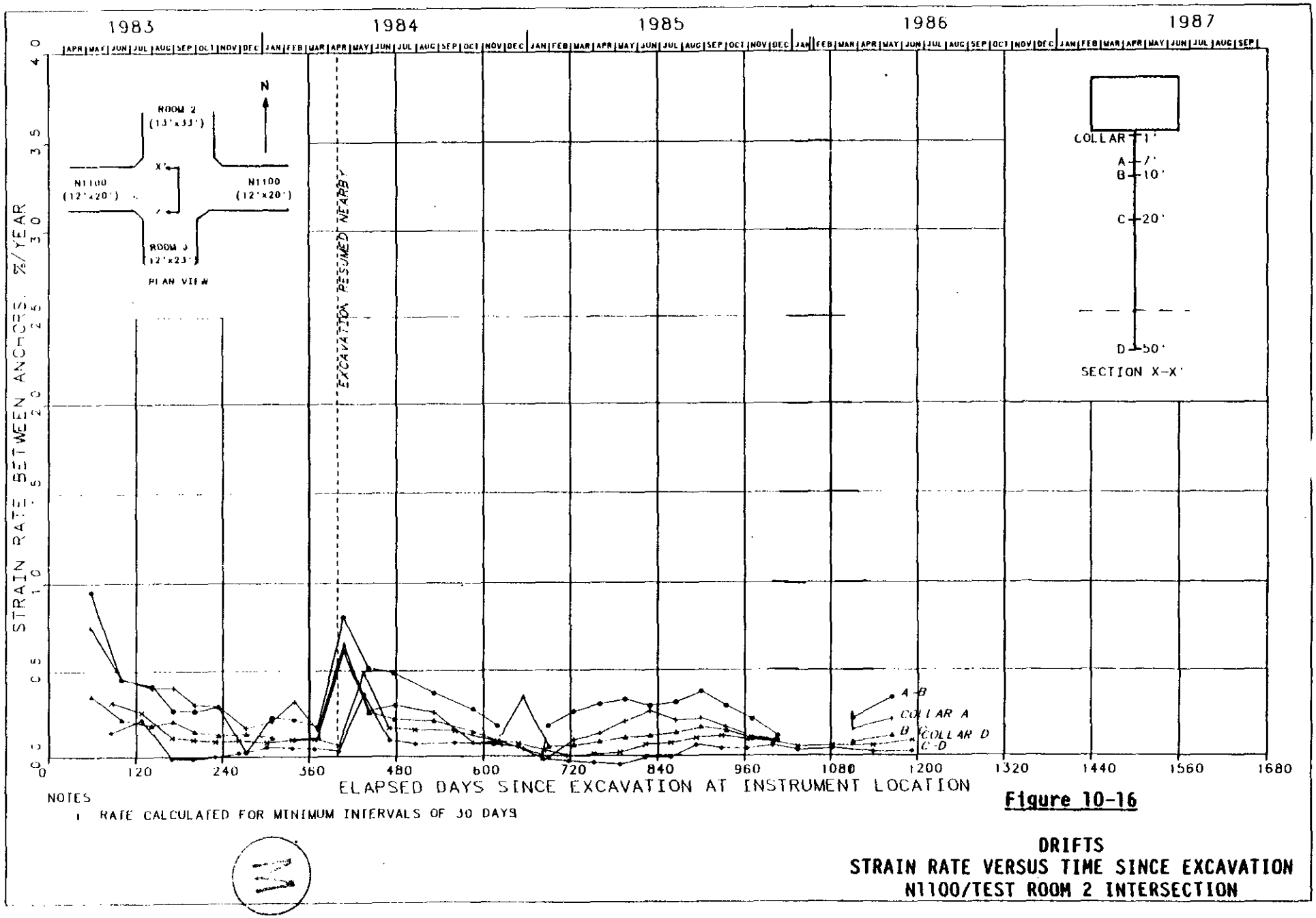


Figure 10-15

DRIFTS
STRAIN VERSUS TIME SINCE EXCAVATION
N1100/TEST ROOM 2 INTERSECTION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

Figure 10-16

DRIFTS
STRAIN RATE VERSUS TIME SINCE EXCAVATION
N1100/TEST ROOM 2 INTERSECTION

(3) Deformed drift shapes immediately before floor lowering and 5 years after initial excavation.

10.3.3.1 Effective Stresses

Figures 10-17 and 10-18 show the distribution of effective stresses in each of the elements of the mesh located near the midheight of the finite element model. The contours are numbered with integers from 1 to 10 with each contour interval representing an effective stress increment of 100 ksf. As time passes, the plots show the effective stresses becoming more concentrated in the anhydrite layer. That is, more energy in the form of strain energy is transferred from the creeping halite and argillaceous halite layers to the anhydrite.

10.3.3.2 Principal Stresses

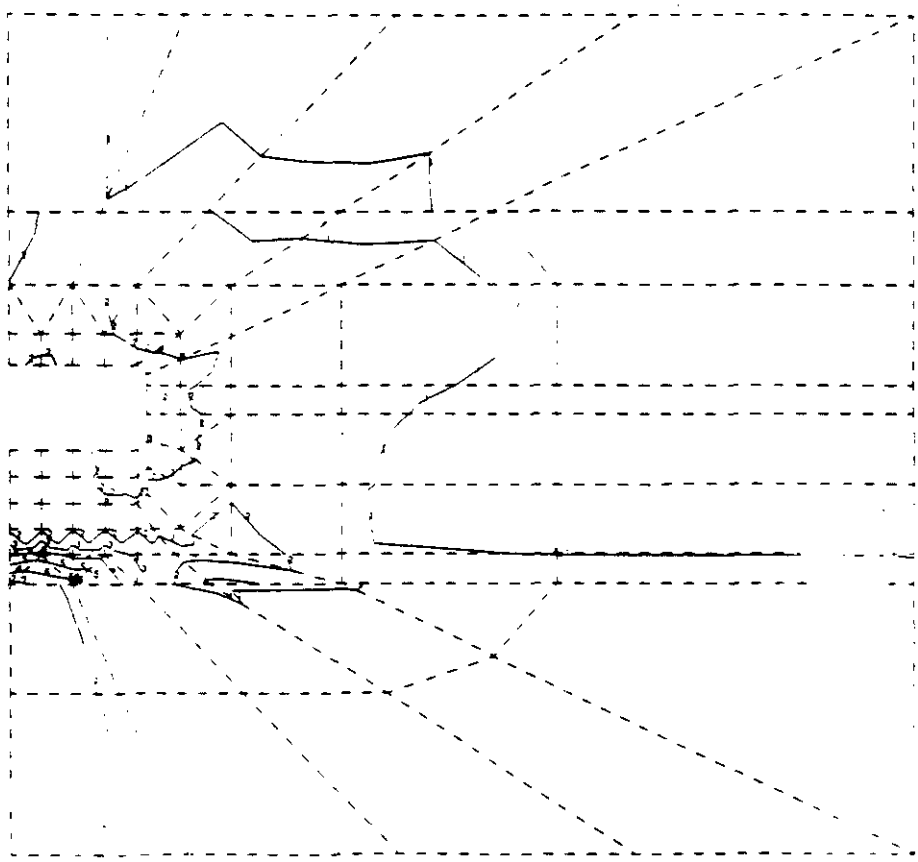
The principal stress plots (Figures 10-19 and 10-20) show that, immediately after excavation, the magnitudes of the predicted principal stresses are relatively large in the corners of the drift and in the anhydrite layer. As the salt creeps, the principal stresses concentrate in the anhydrite layer near the centerline of the drift.

10.3.3.3 Deformation and Closure

A mesh showing the deformed drift shape is presented on Figure 10-21. This mesh shows the outline of the original, undeformed drift in dashed lines while the deformed shape at the corresponding creep time is shown in solid lines.

The deformed shape immediately before floor lowering shows significant vertical deflection (downward) in the roof area of the drift. The drift floor has heaved upward only slightly and the walls have begun to creep inward.

Effects Due to Extraction Ratio. An analysis was performed to simulate the effect on the response of the drift due to a change in the extraction ratio. A change in the extraction ratio is caused by



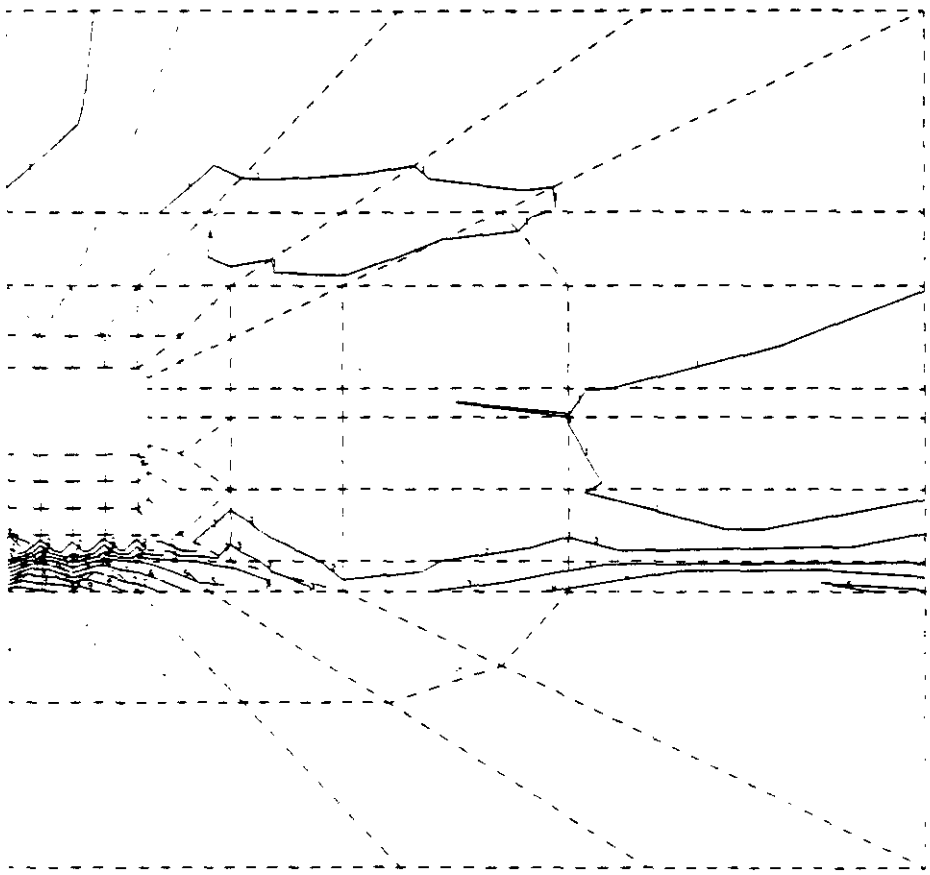
EXPLANATION OF CONTOUR LINES

1 = 100 KSF
2 = 200 KSF
3 = 300 KSF
4 = 400 KSF
5 = 500 KSF
6 = 600 KSF
7 = 700 KSF
8 = 800 KSF
9 = 900 KSF
10 = 1000 KSF

NOTE:
KSF = Kips per square foot.

Figure 10-17

DRIFTS
EFFECTIVE STRESS DISTRIBUTION IMMEDIATELY AFTER EXCAVATION



EXPLANATION OF CONTOUR LINES

1 = 100 KSF
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5 = 500 KSF
6 = 600 KSF
7 = 700 KSF
8 = 800 KSF
9 = 900 KSF
10 = 1000 KSF

NOTE:
KSF = Kips per square foot

Figure 10-18

DRIFTS
EFFECTIVE STRESS DISTRIBUTION IMMEDIATELY BEFORE FLOOR LOWERING

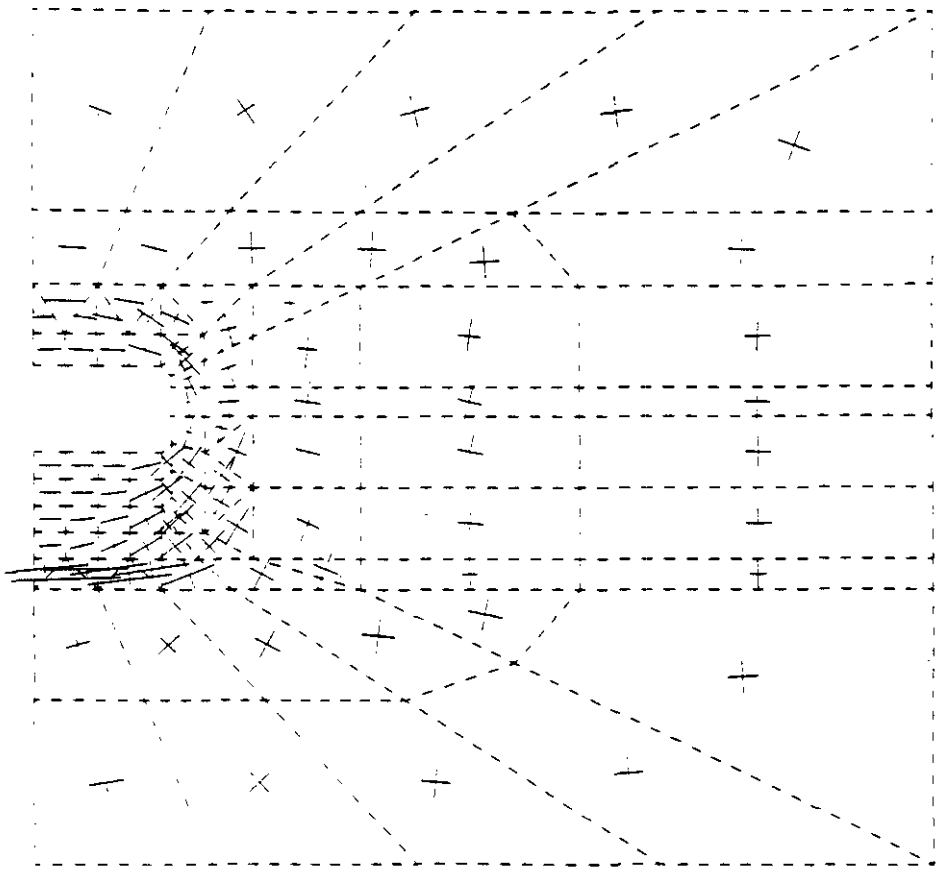


Figure 10-19

DRIFTS
PRINCIPAL STRESSES IMMEDIATELY AFTER EXCAVATION

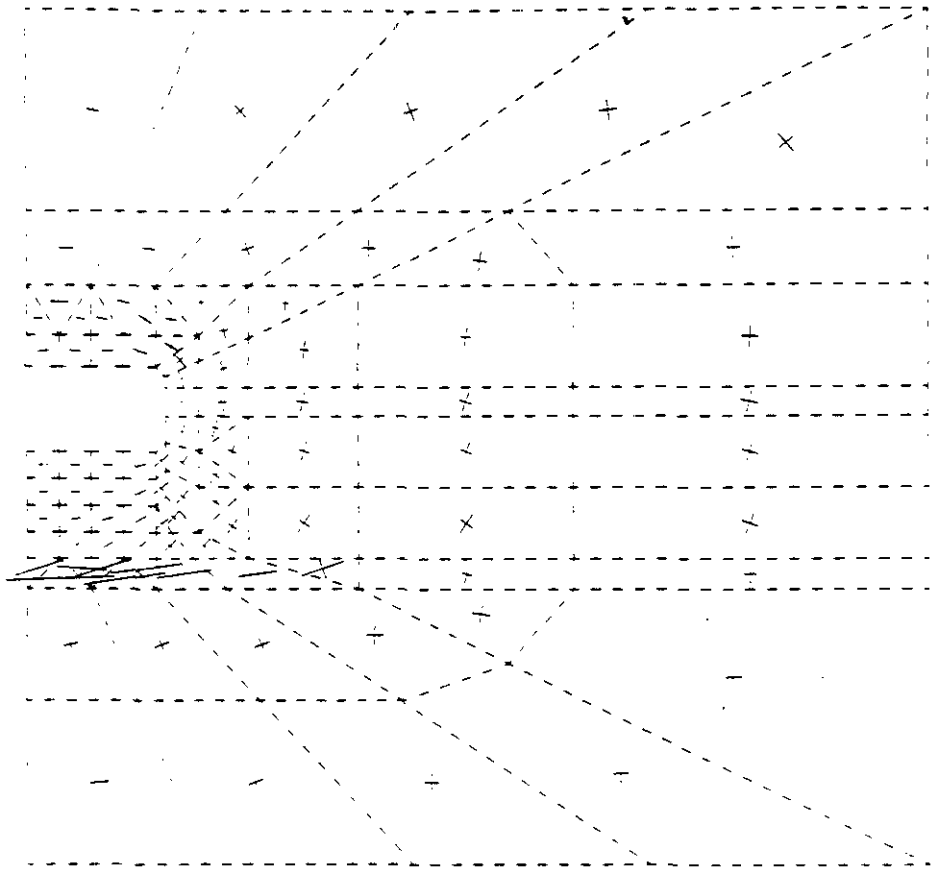


Figure 10-20

DRIFTS
PRINCIPAL STRESSES IMMEDIATELY BEFORE FLOOR LOWERING

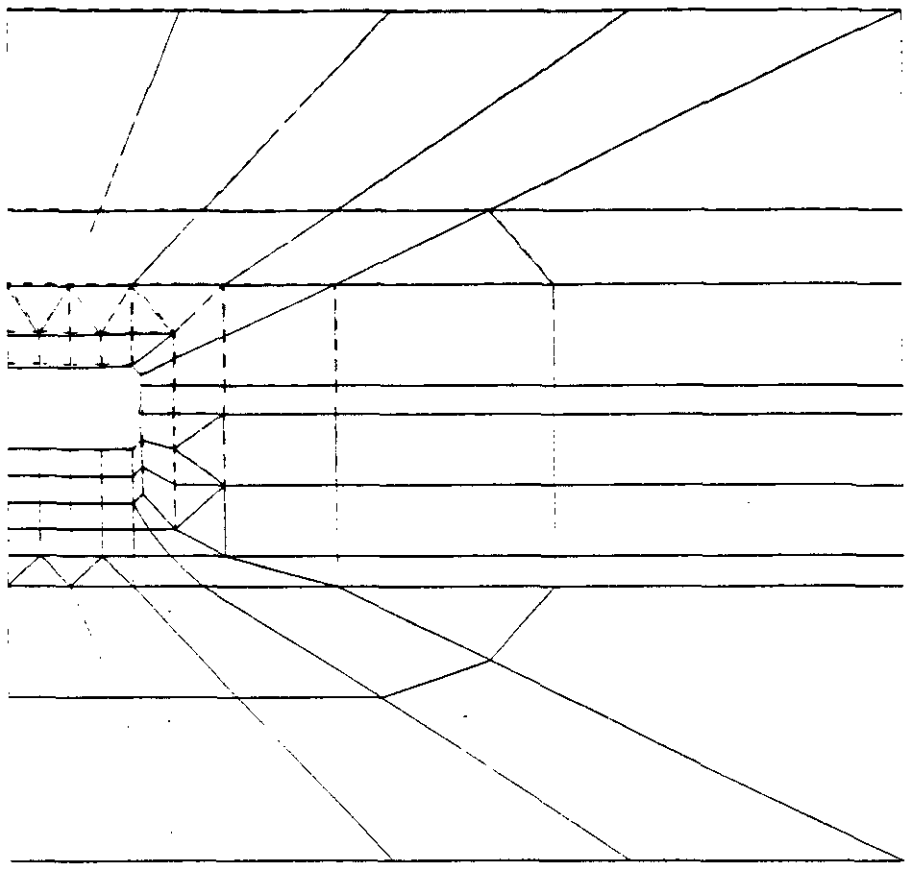


Figure 10-21

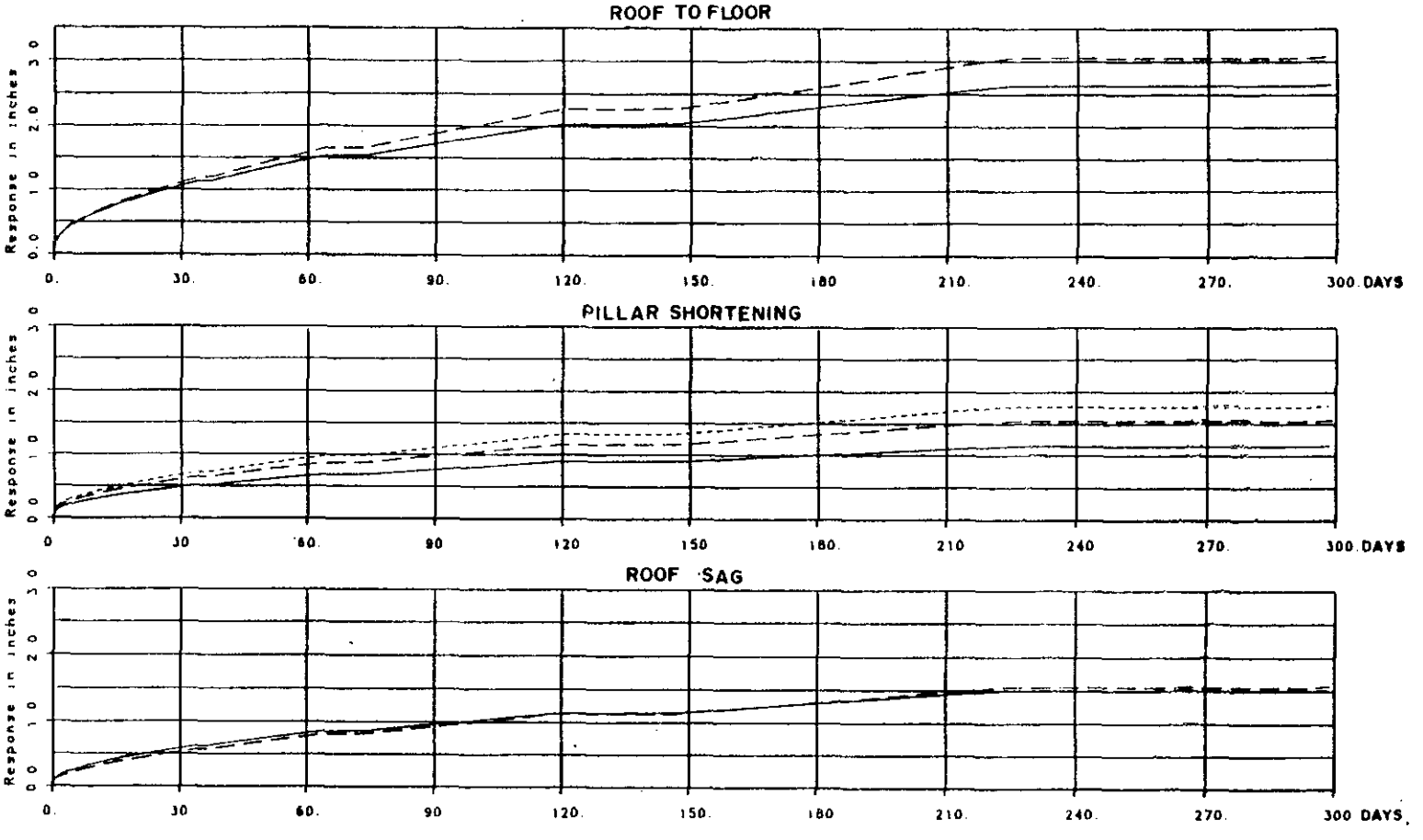
DRIFTS
DEFORMED SHAPE IMMEDIATELY BEFORE FLOOR LOWERING

excavation in adjacent or remote areas. The effect due to excavation in adjacent areas was simulated by modifying the finite element model used in the analysis. The difference is essentially a comparison of a single drift to a set of intersecting multiple drifts. Developing a single drift model which accurately represents the behavior of the infinite pillar requires assuming a width for the model. Therefore, to examine the effect of pillar width on analytical results, a 139-foot wide model similar to the one shown on Figure 10-12 was used as a base case and was later widened to 278 feet. Each model consists of an 8 x 25-foot drift.

Figures 10-22 and 10-23 show comparisons of the closure behavior for the two different pillar widths. Because the width of the model is expected to affect the vertical stresses, both the pillar shortening and roof sag components of closure are included. The top graph in both figures indicates that by halving the pillar width to that of the northern area spacing the roof-to-floor closure increases by about 15 percent.

The effects on pillar shortening due to increased overburden stress from the perpendicular drifts can be seen on the middle graph in Figure 10-22. Comparison of the infinite pillar with and without perpendicular drifts indicates a 15 percent increase in pillar shortening due to the presence of the intersecting drifts. Comparing the curves for the narrow pillar in the top two graphs indicates that pillar shortening contributes approximately half of the total closure response. The 15 percent increase in the pillar shortening then corresponds to a 7 1/2 percent contribution in total closure. This is also true for the total closure rate. The combined effects of single versus multiple drifts and multiple parallel drifts versus an intersecting gridwork account for about a 24 percent difference in the total closure rate.

The effects of releasing the boundary constraints at the perpendicular drift wall can be estimated by the use of equation 10-4. For the



Wide Pillar ——————————

Narrow Pillar — — — — — — — — — —

Narrow Pillar with Perpendicular Drift ----------

Figure 10-22

DRIFTS
COMPARISON OF CLOSURE COMPONENT RESPONSES

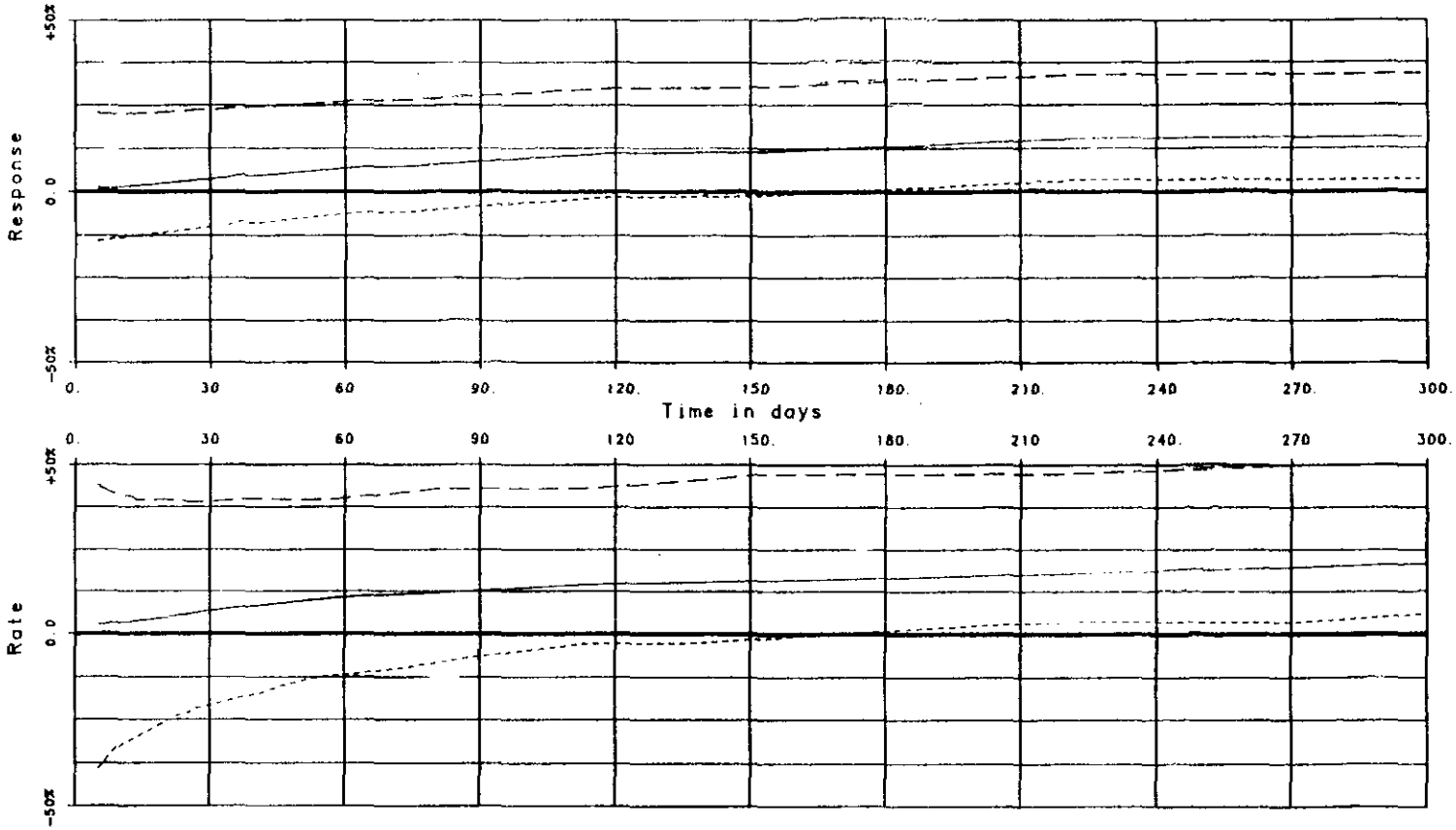


Figure 10-23

DRIFTS
CLOSURE EFFECTS DUE TO PILLAR WIDTH

northern area where the W_1/W_2 ratio is approximately 0.4, the average effective stress is increased by about 6 percent. If the pillar shortening rate is proportional to the square of the increase in average effective stress in the pillar, the boundary release accounts for a 12 percent increase in pillar shortening. As described in the previous paragraph, this 12 percent increase in pillar shortening rate corresponds to about a 6 percent increase in the total closure rate. This factor, combined with the previously described effects, yields about a 30 percent difference in the total closure rate. This compares well with the value presented in subsection 10.3.2.2.

The roof sag component of closure is shown in the bottom graph of Figure 10-23. Figure 10-22 shows the comparison of the closure components of the narrow model relative to the wide model which is equivalent to comparing multiple parallel drifts to a single drift. As this figure indicates, the behavior differences appear to stabilize after about 200 days.

10.3.3.4 Effectiveness of Numerical Modeling

The creep parameters C, A and z were determined using roof-to-floor and wall-to-wall closure data. The effectiveness of the numerical modeling which uses one set of measured data to predict with reasonable accuracy other variables such as stress and strain needs to be verified to infuse confidence in the numerical modeling procedure. Besides, such a comparison will enable testing the adequacy of the basic creep level as well as assumptions regarding the statigraphy assumed for the model.

The 8 x 25-foot drift south of S2180 was isolated until July 1986 and different sets of creep parameters were determined by numerical modeling using roof-to-floor closure data from various convergence point measurements. In situ roof-to-floor closure data for stations south of S2180 indicate that the drift behaves essentially like an infinitely long isolated opening except at the very end of the E140 drift. This affords an opportunity to compare the measured relative displacements in the roof as well as in the floor at one instrument

location with the values obtained from numerical modeling which used roof-to-floor closure data from measurements at some other instrument location to "back calculate" the creep parameters.

Figure 10-24 compares the measured relative displacement between the collar and anchor D of extensometer 51X-GE-00247, in the roof at E140/S1950, with the values obtained from the numerical modeling. The calculated value is the relative vertical displacement of two nodes comparable to the positions of the collar and anchor D of the extensometer. The parameters C, A and z were obtained using roof-to-floor closure data from the instrument location at E140/S1879. The agreement is reasonable because the slopes of both the measured and calculated relative displacements are nearly identical. Figure 10-25 similarly compares the measured relative displacement in floor extensometer 51X-GE-00248 at E140/S1950 with the calculated values from the same numerical modeling. The slope of the in situ curve is 28 percent steeper than the calculated value. This is probably because the numerical model assumes that the anhydrite layer in the floor of the drift as linearly elastic with infinite strength. This may not be true if the anhydrite has pre-existing fractures, and thus may not be able to absorb the heave from the salt below.

Figure 10-26 compares the measured wall-to-wall closure at E140/S1879 with the calculated wall-to-wall closure from the results of the same numerical modeling. The average slope of the curve from numerical modeling is nearly 43 percent steeper than the slope of the curve from measurement data.

10.4 CONCLUSIONS AND RECOMMENDATIONS

The following subsections present conclusions pertaining to validation of the drift reference design and recommendations for design modifications. These are based on a comparison of the design criteria, design bases and reference design configurations with the results of the analysis and evaluation of data collected during the design validation process.

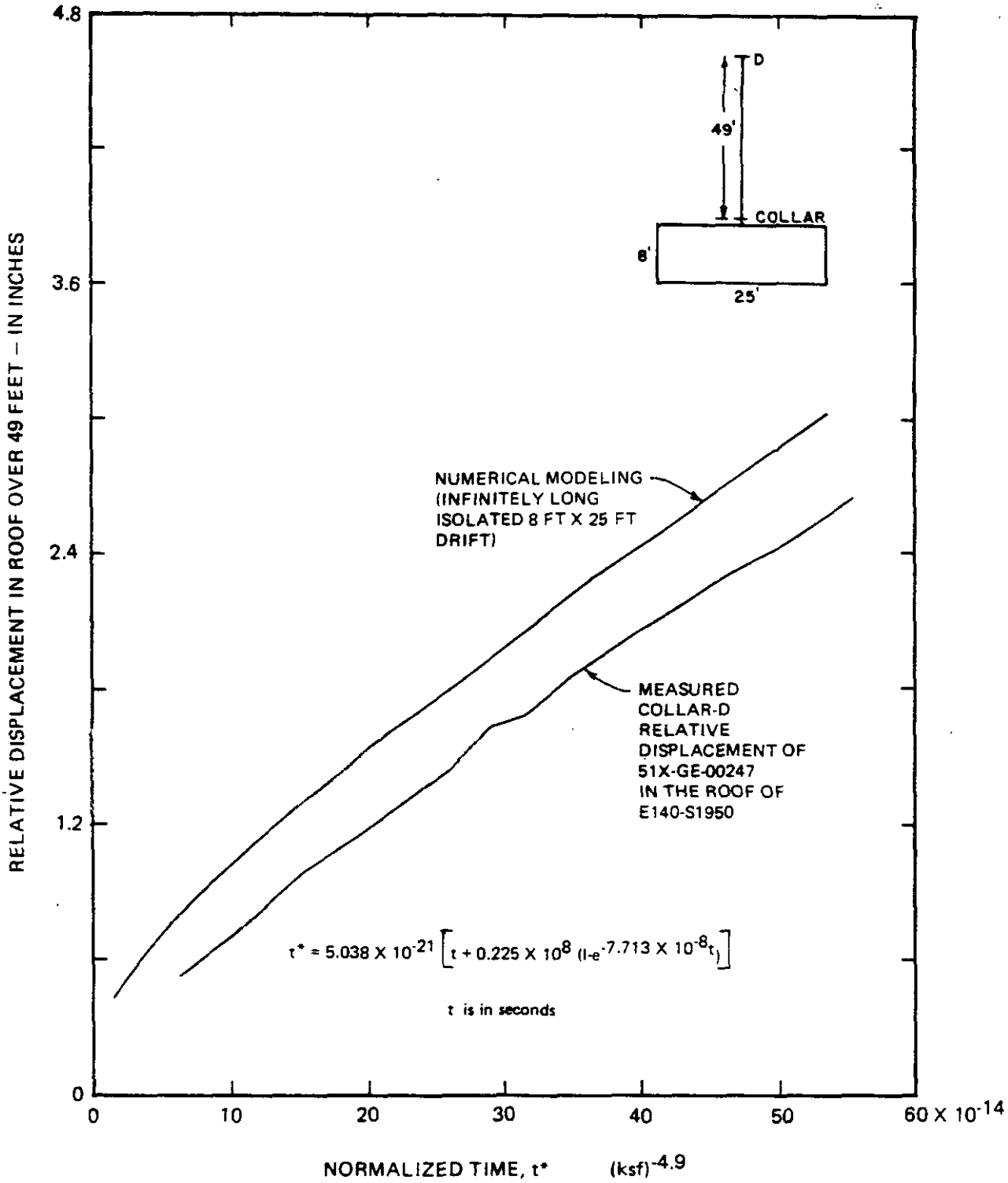


Figure 10-24

DRIFTS
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT
DATA FROM ROOF EXTENSOMETER

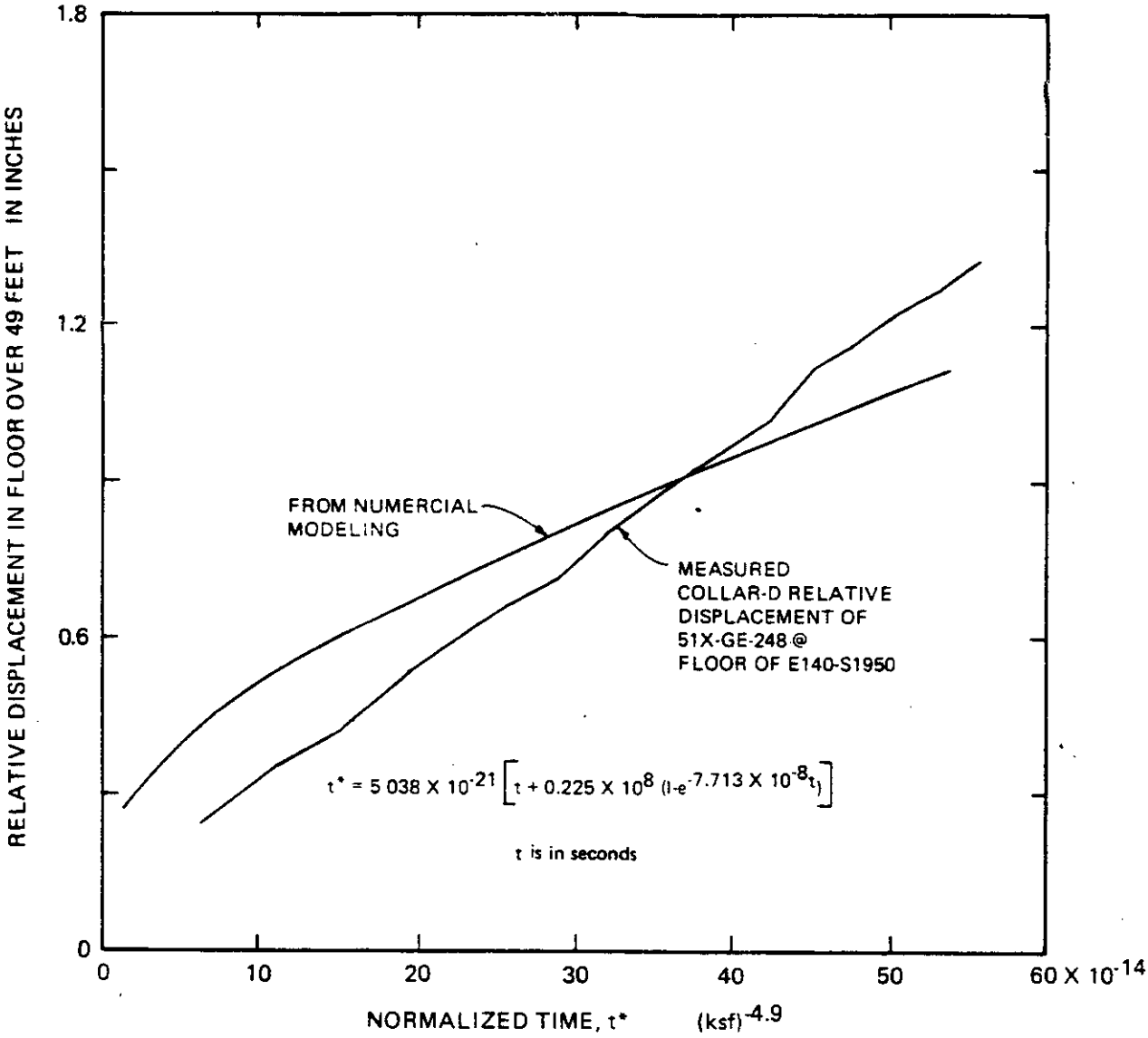


Figure 10-25

DRIFTS
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT
DATA FROM FLOOR EXTENSOMETER

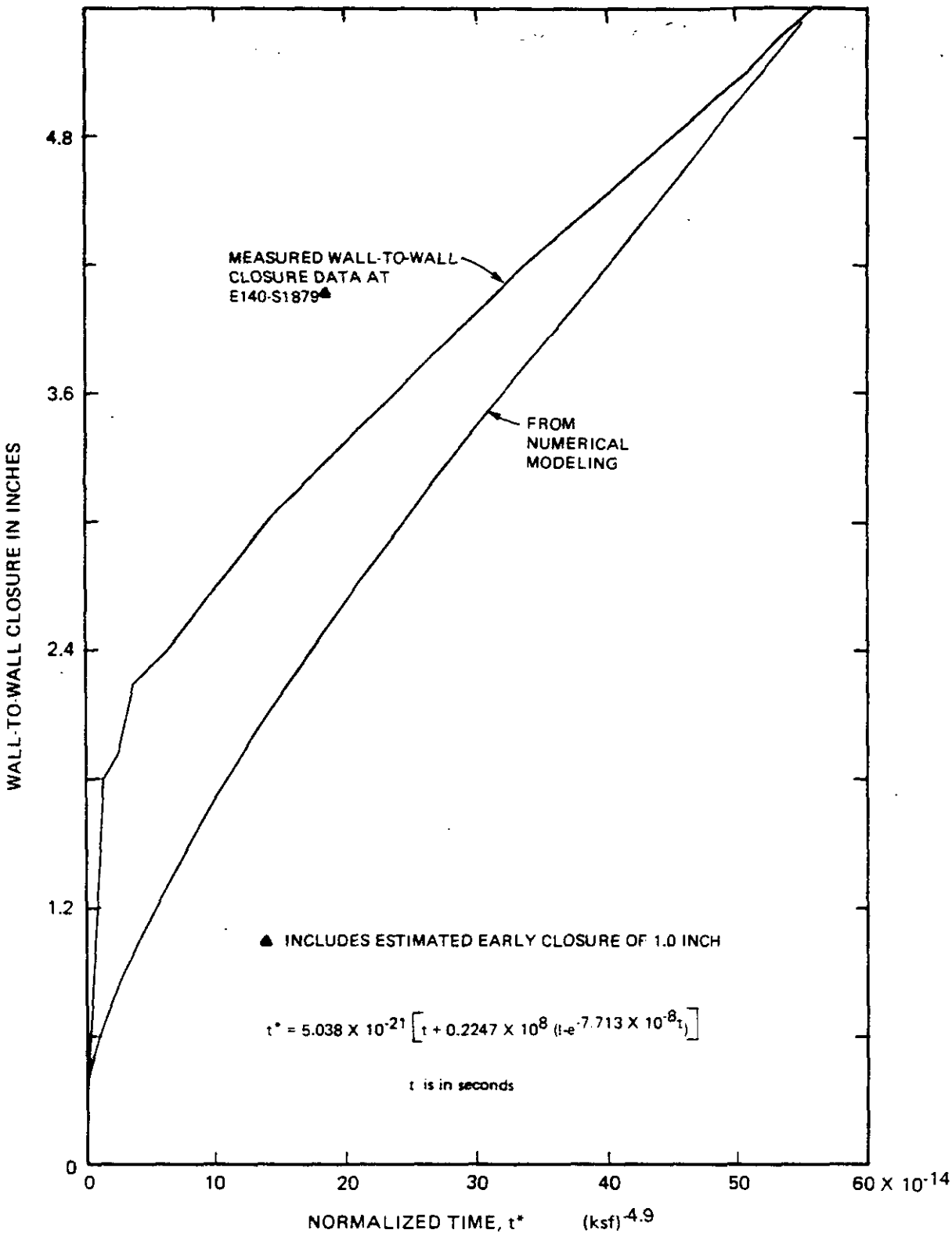


Figure 10-26

DRIFTS
NUMERICAL MODELING VERSUS MEASURED WALL-TO-WALL CLOSURE
AT E140/S1879

10.4.1 Conclusions

The evaluation of field observations and analytical results shows that the design criteria were appropriate for design of the horizontal openings. The three criteria identified as requiring specific evaluation, that the drifts remain within the required structural limits, provide maximum stability, and maintain the minimum required dimensions, were determined to be suitable. The reference design for the horizontal openings is therefore validated.

Spalling from the roof and walls of the drifts and fracturing and spalling at pillar corners will continue. Displacements and separations at clay seams above the roof may slowly increase. This deformational behavior is expected and can be controlled by scaling and rock bolting as necessary.

The average bay strains determined from the relative displacements of extensometer anchors 3 years after drift excavation are within 1 percent. The strain rates as well as the closure rates decrease with time indicating that the drifts are stable. Based on the projections of closure rates, the drifts will continue to be stable.

Fracturing beneath the floor of the drifts is minor and has nowhere developed to near the degree as that beneath the floor of Test Room 3. If additional fracturing develops in the future beneath the drifts, it is also expected to be minor. Based on experience in local potash mines, this type of fracturing is not expected to cause stability or operational problems.

The comparison of measured closure behavior in drifts with different dimensions indicates that the maximum closure and closure rate will occur in 12 x 25-foot drifts. The closure rates are affected by the presence of nearby parallel drifts and crosscuts as well as differences in salt properties. Based on available measurement data and the results of modeling analyses, the closure rate in the 13 x 25-foot

storage area drifts may be 30 percent greater than that of a single, infinitely long drift with the same dimensions (Chapter 12).

Analyses of salt behavior around the 25-foot wide drifts has determined the redistribution of stresses due to the effect of creep. Based on the computed vertical, horizontal and effective stresses, the stress which develops immediately after excavation is followed by relaxation due to creep behavior. According to the analyses, stress should not cause future stability problems in the drifts.

The analyses have also determined the locations of effective creep strain concentrations around the drifts at different times. Based on the predicted values of effective creep strain and the strain limit discussed in Chapter 6, the drifts will remain within the structural stability limits required, with respect to catastrophic failure, during the facility operating life. Minor spalls from the roof and wall surfaces are expected to occur. Analysis of observations in mines and discussion with mine personnel indicates that the surfaces of the drifts may start to deteriorate more rapidly after about 15 years. Increased maintenance will then be required.

10.4.2 Recommendations

Based on the results of design validation of the drifts, it is recommended that all drifts be inspected frequently for operational clearance and safety. If the clearance is insufficient, the drifts must be trimmed to the required dimensions. Trimming the floor to increase drift height is preferred over trimming the roof. Over the 25 year operating life, the roof should not be trimmed more than 12 inches for drifts 25 feet wide or less. Trimming the roof more than 12 inches would make the beam of salt too thin and increase the possiblity of a roof fall. Further trimming must be accomplished from the floor even though this will decrease the thickness of the salt above MB-139. Scaling and rock bolting should be performed where

necessary for safety purposes. Periodic inspection of accessible open boreholes should be performed to monitor the occurrence and behavior of displacements, separations and fracturing in the salt above the roof and beneath the floor of the drifts.

CHAPTER 11
TEST ROOMS

11.1 INTRODUCTION

The four test rooms comprise a panel with a configuration similar to that designed for the waste storage area. The test rooms were instrumented, observed and analyzed in order to evaluate the potential behavior of the storage rooms. This chapter presents the results of data collection activities in the test rooms and the analysis and evaluation of the data with respect to the behavior of the excavated rooms. The information presented here will be used in Chapter 12 to predict the future behavior of the storage rooms and to validate their reference design.

11.2 DESIGN

The test rooms represent a portion of the storage room reference design configuration. The purpose of the test rooms is to provide geotechnical information that can be used to predict the potential behavior of the storage rooms. Because they were excavated to permit validation of the storage room reference design, and will not be used for permanent storage, the test rooms were not specifically addressed in the Design Criteria document. The design criteria apply to the configuration of the storage rooms and, therefore, only indirectly to the configuration of the four-room test panel.

No Design Basis documents were developed specifically for the test rooms. Only two Design Basis documents (refs. 2-9 and 2-18) contain elements pertaining to the test rooms. These elements specify that test rooms shall be provided to verify underground conditions as required by the SPDV Program and that their dimensions shall be 33 feet wide, 13 feet high and 300 feet long. All other design bases that require evaluation are applicable to the storage rooms rather than to the test rooms.

The test room panel is the experimental model for the storage ... Validation of the test panel reference design configuration is not required. The test room data and analyses presented in this chapter are the bases for validation of the storage rooms. Predictions of the future behavior of the storage rooms based on these data analyses are presented in Chapter 12.

11.3.1 Data Collection

Data collection in the test rooms consisted of the accumulation of geotechnical data from geologic mapping, core drilling, observations of deformational behavior and geomechanical instrument measurements. Geologic mapping and core drilling were performed in the four test rooms. The stratigraphy defined by the mapping and core logging is discussed in Chapter 6. Observations of in situ behavior and data from the geomechanical instrumentation program are presented in the following subsections.

11.3.1.1 Field Observations

Some aspects of test room behavior can only be evaluated by visual observation. Visual inspections of the rooms include observations of their general surface conditions in response to stress redistribution and salt creep. These conditions include small spalls from the roof and walls, especially at their intersection, and vertical fracturing at pillar corners and along the walls in response to pillar shortening.

Field observations include other qualitative and quantitative techniques in addition to visual inspections of excavation surfaces. Boreholes are surveyed using video cameras. Horizontal displacements and vertical separations of the geologic strata surrounding boreholes are determined using a probe, as described in Chapter 7, subsection 7.3.1.4. Wall surfaces of large diameter holes are mapped by a geologist.

A qualitative determination of the conditions of the test rooms is made

by site geologists during an inspection of the rooms at least once every 3 months. These inspections have been documented in each GFDR starting with the February 1984 edition (refs. 4-12 through 4-19). Detailed descriptions of observed test room behavior are contained in each of these reports.

As discussed in Chapter 10, an Excavation Effects Program was conducted throughout the underground facility during May through July 1986. This program was conducted to further characterize near-field deformation above and below the facility level. Ten arrays of boreholes were drilled in the roof and floor of the test rooms. The locations of the arrays are shown on Figure 10-1 in Chapter 10.

The results of some of these observations are used in conjunction with the results of numerical analysis and in situ measurement data to quantify the structural behavior of the test rooms. The documented field observations can be separated into four categories: roof and wall spalling; pillar fracturing; roof displacements and separations; and floor displacements, separations and fracturing.

Roof and Wall Spalling. A sounding survey of the roof of each test room was conducted during and immediately after excavation. Only a few areas of drummy rock were discovered and these were either removed or rock bolted.

The rooms have exhibited only minimal spalling over a period of 3 years since their excavation. The drummy areas originally found in the roofs have not grown noticeably, but some additional areas have been discovered by subsequent roof soundings. Additional scaling and rock bolting have been performed in most of these areas. The most noticeable spalling is associated with the argillaceous halite unit (geologic map unit 4, Appendix G, Figures G-1 through G-4) high on the test room walls. This spalling is generally continuous but shallow. Some spalling from the roof close to the walls has also been observed within the past year that has required support by rock bolts in selected areas.

Fracturing. [illegible] formed by the intersection of drifts with [illegible] the fractures have separations that range from essentially closed to about 2 inches wide. They generally extend into the rock perpendicular to the rock surface for an unknown distance. All corners of the test rooms show fracturing and consequent spalling. The fractures first appeared in the pillar corners about 3 to 6 months after excavation. They started as thin, hairline fractures and have steadily grown in length, width and presumably depth. Each of the GFDRs document this gradual development of the fractures. Scaling of these corners has been performed periodically.

Vertical fracturing has developed in the pillars parallel to the room walls. This fracturing is relatively minor and, to date, has been observed only in Test Rooms 3 and 4. The fracturing has been detected in horizontal boreholes drilled into the walls and occurs within approximately 2 feet of the wall surface. The fractures range from closed to about 1/32 inch wide.

Roof Displacements and Separations. Inspections of open boreholes in the test room roofs were conducted using a video camera and/or probe. The video camera produces high-resolution, color videotapes that are useful in identifying horizontal displacements and vertical separations. The probe is used in conjunction with a tape measure to determine the location and amount of movement in the boreholes. As in other areas of the underground facility, expected horizontal and vertical movements of the geologic strata surrounding the boreholes have been observed or measured in the test rooms. These observations are summarized in Table 11-1.

Ten arrays of boreholes were drilled in the test rooms in May 1986 as part of the Excavation Effects Program. These holes were used for additional investigation of test room roof displacements and separations. Each hole was inspected using a probe. Table 11-2 presents a summary of the results of this study.

Table 11-1

TEST ROOMS 1 THROUGH 4
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN ROOFS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
IG-205	4-17-83	3	56	Room 1; 1 ft from west wall	D
IG-206	4-15-83	3	52	Room 1; 1 ft from east wall	D
IG-203	3-26-83	3	52	Room 2; 1 ft from west wall	D
IG-204	3-83	3	52	Room 2; 1 ft from east wall	D
OH-3	8-83	4	20	Room 2 centerline	S, F
P4X-26	10-83	5	52.1	Room 4; N1360/W630	None
P4X-30	12-83	4	50.9	Room 4; N1360/W630	S
-	-	6	8	Room 4; N1360/W639	D, F
-	-	5	$9\pm$	Room 4 center; N1176	S(?)

* D = Displacement; S = Separation; F = Fracturing

Table II-2

EXCAVATION EFFECTS PROGRAM
BOREHOLE INSPECTION SUMMARY

SECTION	OPENING DIMENSIONS (HxW-FT)	EXCAVATION DATE	LOCATION	DATE DRILLED	DATE INSPECTED	OBSERVED CONDITIONS					
						ROOF HOLES			FLOOR HOLES		
						E	A	C	F	B	D
1	13x33	4/83	ROOM 4, N1175	5/15/86	5/15/86	C	S(?) *	C(?)	D, S *	C	S, C
2	13x33	4/83	ROOM 4, N1264	5/16/86	5/16/86	C(?)	NONE	C	NONE	C	S
3	13x33	4/83	ROOM 4, N1361	5/16/86	5/16/86	NONE	D *	NONE	NONE	D, S, F *	S
4	13x33	4/83	ROOM 3, N1198	5/15/86	5/15/86	NONE	NONE	S	NONE	S	S
5	13x33	4/83	ROOM 3, N1243	5/15/86	5/15/86	NONE	NONE	NONE	S, F (USED ROOM 3 LARGE DIAMETER HOLES)		
6	13x33	4/83	ROOM 3, N1312	5/15/86	5/15/86	S	C	NONE	D, S, F (USED PREVIOUSLY DRILLED HOLES MB-FI-01 THROUGH 03)		
7	13x33	3/83	ROOM 2, N1147	5/21/86	5/22/86	NONE	NONE	C	C	F, C	NONE
8	13x33	3/83	ROOM 2, N1231	5/21/86	5/22/86	F	F	NONE	S	S, F, C	F
9	13x33	4/83	ROOM 1, N1159	5/21/86	5/22/86	C	F	NONE	C	S, C	NONE
10	13x33	4/83	ROOM 1, N1275	5/21/86	5/22/86	F	S, F, C	NONE	C	S	S, C

* EXISTING HOLE.

EXPLANATION

D = HORIZONTAL DISPLACEMENT. FOUND ONLY IN PREVIOUSLY DRILLED HOLES. DISPLACEMENT APPEARS TO DEVELOP WITH TIME FOLLOWING HOLE DRILLING.

S = VERTICAL SEPARATION. PROBE NAIL PENETRATES HOLE WALL SURFACE. VERTICAL SEPARATIONS RANGE FROM APPROXIMATELY 1/16 INCH TO 6 INCHES.

F = FRACTURE ZONE. PIECES OF HALITE COMMONLY PICKED OUT OF ZONE BY PROBE NAIL.

C = PROBE NAIL CATCHES ON HOLE WALL SURFACE BUT DOES NOT PENETRATE. INDICATES POSSIBLE SEPARATION OF LESS THAN 1/16 INCH. OCCURENCES AT KNOWN CLAY LAYERS ARE NOT INDICATIVE OF SEPARATION AND ARE NOT INCLUDED IN THIS TABLE.

NOTES:

1. SECTION LOCATIONS AND HOLE CONFIGURATIONS ARE SHOWN IN CHAPTER 10, FIGURE 10-1.
2. HOLES WERE DRILLED VERTICALLY USING A JACK-LEG DRILL.
3. NOMINAL HOLE DEPTH IS 9 FEET BUT SOME HOLES ARE SHORTER DUE TO LOW DRIFT ROOF OR DRILLING DIFFICULTIES.
4. ONE ROOF AND ONE FLOOR HOLE OF EACH ARRAY WERE GENERALLY DRILLED 3 INCHES IN DIAMETER TO ACCOMODATE USE OF BOREHOLE CAMERA IF DESIRED. OTHER HOLES WERE DRILLED 1-7/8 INCHES IN DIAMETER. EXISTING HOLES WERE USED WHERE POSSIBLE.
5. OBSERVATIONS WERE MADE USING A PROBE CONSISTING OF A NAIL ATTACHED PERPENDICULAR TO THE END OF A ROD.

Floor Displacements, Separations and Fracturing. Horizontal displacements, vertical separations and fracturing have been observed beneath the floor of the test rooms in boreholes. They have been observed to occur in MB-139 and in the overlying halite. Geologic maps of Test Room 3 (Room T) boreholes are presented in Appendix G, Figures G-10 through G-31. A summary of the results of the inspection of all small-diameter boreholes drilled in the floor of the test rooms is presented in Table 11-3. The inspections were accomplished using video equipment and/or a probe.

The only prominent exposure of floor fracturing is in the 36-inch diameter boreholes drilled in the floor of the south half of Test Room 3 (Room T). A total of 22 holes were drilled in this area during September and November 1985 for the erection of structural steel columns. A drilling summary is presented in Table 11-4. The holes are approximately 7.2 feet deep. The bottom of many of the holes coincides with the occurence of clay E at the base of MB-139. The remaining holes were terminated above the base of the marker bed.

The holes were logged on a 360 degree foldout at a scale of 1 inch to 1 foot. All features were measured from a level reference line which was later surveyed to determine elevations. Fracture traces, fracture zones and hairline fractures, in addition to lithologic contacts, were logged. A fracture trace is a distinct fracture surface exposed on the wall of the borehole. Fracture traces shown on the logs, unless otherwise noted, are closed within a few inches of the wall surface. A fracture zone is an area on the wall bounded by distinct fractures. Rock within the zone is broken by numerous smaller fractures spaced less than 1 inch apart. The fractured rock is commonly broken out very close to the wall surface of the borehole due to drilling, but becomes closed within 1/2 to 2 inches of the wall surface. Locally, the zone is open or partially filled with drill cuttings. At a distance of 12 inches from the borehole, the cumulative vertical separation measured over the length of the hole varies from less than 1/4 inch to 6 inches. The hairline fractures are closed fractures usually found

...ROUGH 4

RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN FLOOR

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
IG-202	4-18-83	3	52	Room 1; 1 ft from west wall	D
GE-269	1-86	3	55	Room 1 centerline	S, F
IG-201	3-26-83	3	52	Room 2; 1 ft from west wall	D
NG-254	3-84	6	7	Room 2 centerline	None
GE-270	1-86	3	55	Room 2 centerline	S, F
2NPD-01	2-86	5	8.9	Room 2; N1370	S, F
MB-FI-01	12-85	4	12.0	Room 3; N1309	D, S, F
MB-FI-02	12-85	4	12.0	Room 3; N1309	D, S, F
MB-FI-03	12-85	4	12.0	Room 3; N1309	D, S, F
GE-271	1-86	3	55	Room 3 centerline	S, F
P4X-06	1983	5	9.0	Room 4; N1369/W625	D, S, F
P4X-25	10-83	5	50.2	Room 4; N1360/W630	D, S, F
P4X-27	10-83	5	51.1	Room 4; N1360/W630	D, S, F
P4X-29	10-83	5	49.5	Room 4; N1360/W630	D, S, F
P4X-31	11-83	5	50.4	Room 4; N1360/W630	D, S, F
P4X-81	11-83	16	-	Room 4	D, S, F
P4X-83	12-83	16	6.1	Room 4	S, F
P4X-84	1-84	36	9.5	Room 4	D, S, F

* D = Displacement; S = Separation; F = Fracturing

Table 11-4

TEST ROOM 3 (ROOM T)
SUMMARY OF DRILLING

Hole	Date Completed	Drilling Fluid	Communication During Drilling*
TV-01	10-25-85	Brine**	---
TV-02	10-28-85	Air	---
TV-03	11-05-85	Air	TV-07, TV-14 through 75° dipping fracture. TV-15 through fractures in halite close to surface on east side. Surface fracture close to east wall 25 feet south of TV-03. No communication to TV-13. TV-17, TV-12.
TV-04	11-08-85	Air	---
TV-05	11-20-85	Air	---
TV-06	11-13-85	Air	---
TV-07	10-29-85	Air	TV-12
TV-08	11-19-85	Air	---
TV-09	11-21-85	Air	---
TV-10	11-14-85	Air	TV-13, TV-14, TV-17, TV-15, TV-06, TV-11
TV-11	11-11-85	Air	---
TV-12	9-17-85	Air	---
TV-13	10-09-85	Air	TV-12, TV-15
TV-14	10-11-85	Air	TV-15
TV-15	9-23-85	Air	TV-19
TV-16	9-30-85	Air	TV-19, TV-20

TEST ROOM 3 (ROOM T)
SUMMARY OF DRILLING

Hole	Date Completed	Drilling Fluid	Communication During Drilling*
TV-17	10-15-85	Air	---
TV-18	10-02-85	Air	---
TV-19	9-20-85	Air	---
TV-20	9-25-85	Air	TV-19 along main fracture zone on north-northeast side.
TV-21	10-18-85	Air	---
TV-22	10-19-85	Air	TV-19 along main fracture zone on north-northeast side. TV-20 along main fracture zone on west side.

* Communication is indicated by drilling dust emanating from connected holes and detected by driller or geologist.

** Source of brine encountered in TV-01 is clay E at base of MB-139. Driller noted that this clay and about 4 inches of the overlying anhydrite were moist in many holes.

within fracture zones less than 1 inch wide. Some of these appear to be pre-excavation features within MB-139.

Additional small-diameter boreholes were drilled into the test room floors as part of the Excavation Effects Program. The 10 arrays summarized in Table 11-2 include three floor holes at each array. These holes were drilled primarily to determine if the fracturing observed in the 22 large-diameter holes in Test Room 3 extends to other areas beneath the test rooms.

11.3.1.2 Geomechanical Instrumentation

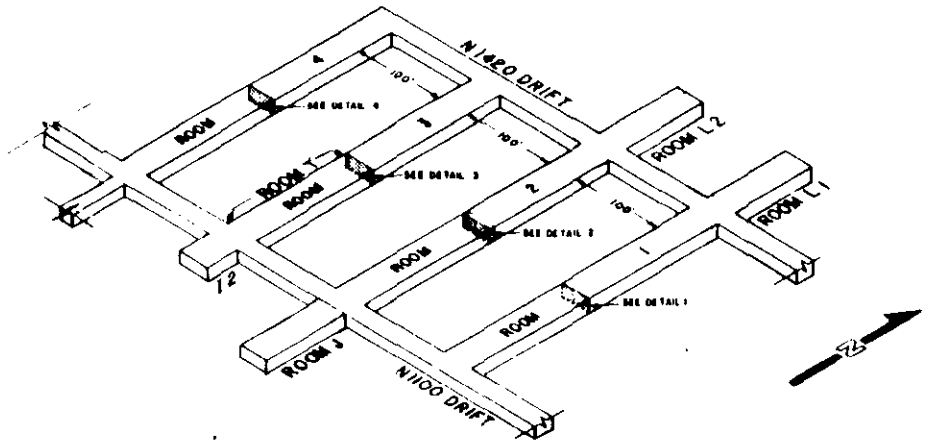
Geomechanical instrumentation in Test Rooms 1 through 4 initially consisted of 19 borehole extensometers, 16 horizontal inclinometers, 6 vertical inclinometers, 4 sets of convergence points, 2 convergence meters, and 2 rigid-inclusion vibrating-wire stressmeters (Figure 11-1). These instruments, with the exception of the inclinometers and convergence points, were connected to the datalogger system on May 13, 1983.

Due to failure for various reasons, some instruments in the test rooms had to be replaced. Those instruments replaced include both stressmeters in Test Room 2 and the extensometers in the floor of Test Rooms 1, 2 and 3. The history of instrument performance and maintenance is discussed in the GFDRs.

Figure 11-2 shows the instruments in each test room and the excavation dates at the instrument locations. Because the excavation of each test room required about 10 days to complete, it was difficult to assign a single date of excavation for some instrument locations. Table 11-5 presents the dates of excavation used for plotting and analysis of the test room data.

11.3.2 Analysis and Evaluation

This section discusses the analysis and evaluation of the results of



ALL COORDINATES BASED ON DISTANCE FROM C@SH SHAFT ℄

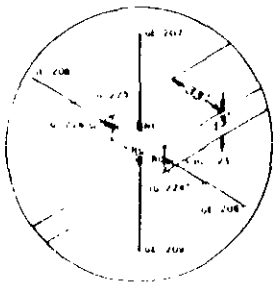
(FOR DETAILS 1, 2, 3, & 4)

EXPLANATION

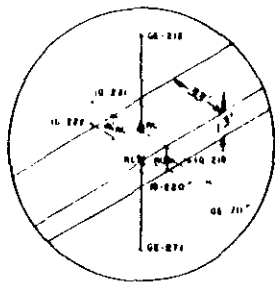
- IG INCLINOMETER
- CE CONVERGENCE METER
- GE EXTENSOMETER
- RC RADIAL CONVERGENCE PI
- SG STRESSMETER (RIGID INCLU

NOTE

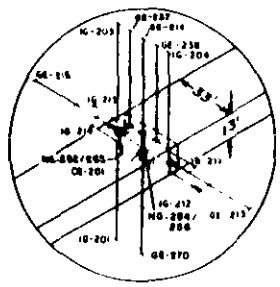
1 EXTENSOMETERS GE 269, GE 270 AND GE 271 REPLACED GE-230, GE-218 AND GE-210, RESPECTIVELY.



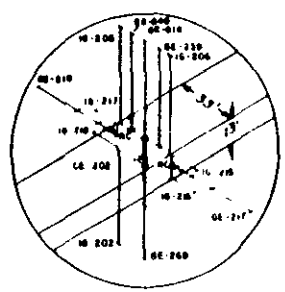
ROOM 4
INSTRUMENTATION LOCATION
DETAIL 4



ROOM 5
INSTRUMENTATION LOCATION
DETAIL 3



ROOM 2
INSTRUMENTATION LOCATION
DETAIL 2



ROOM 1
INSTRUMENTATION LOCATION
DETAIL 1

Figure 11-1

TEST ROOMS INSTRUMENTATI

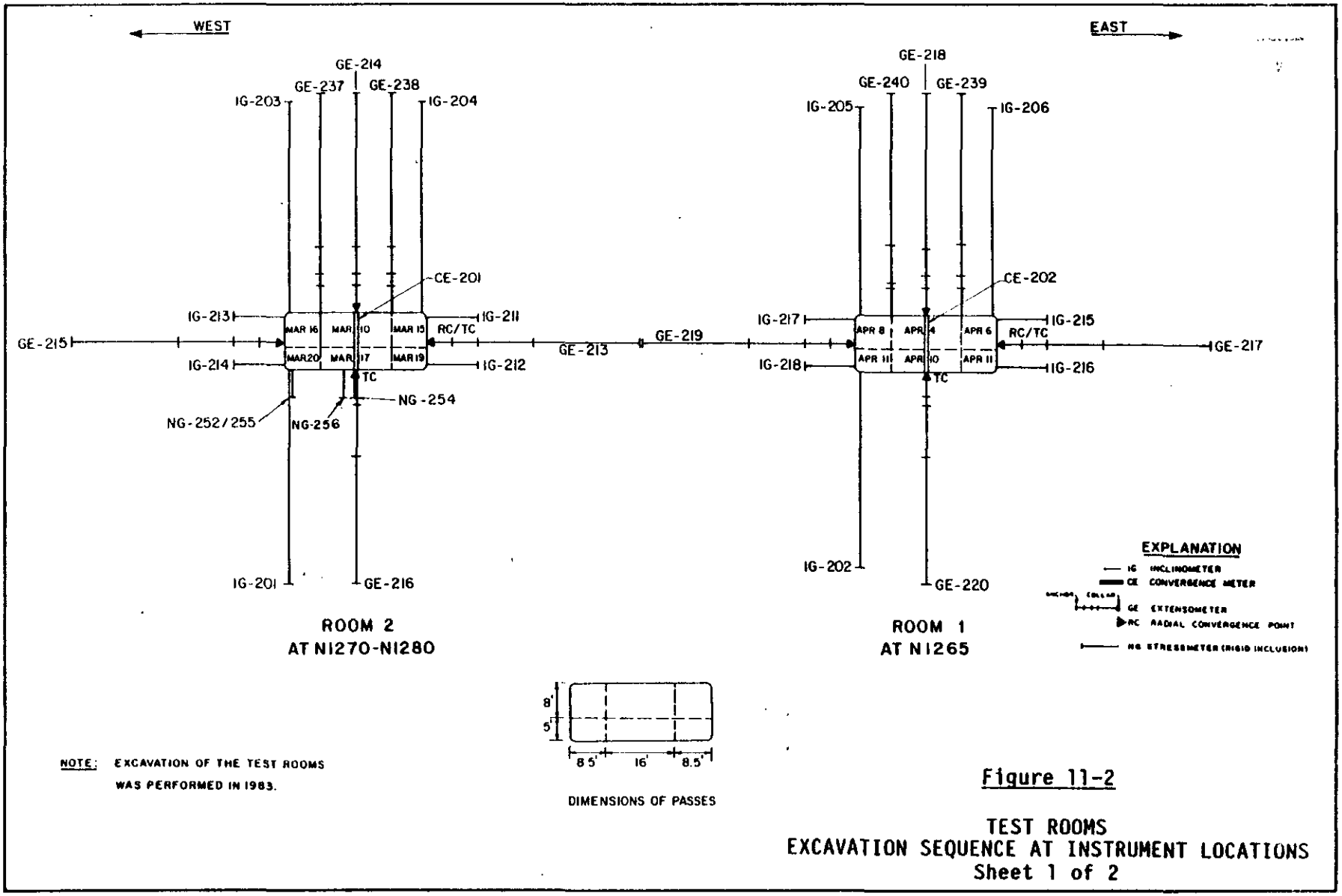
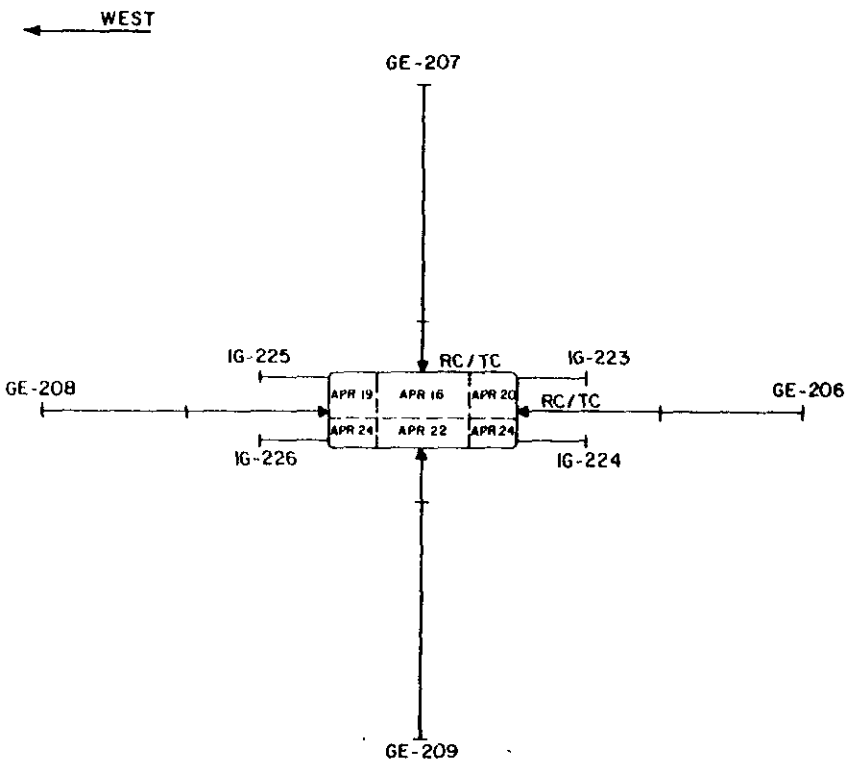
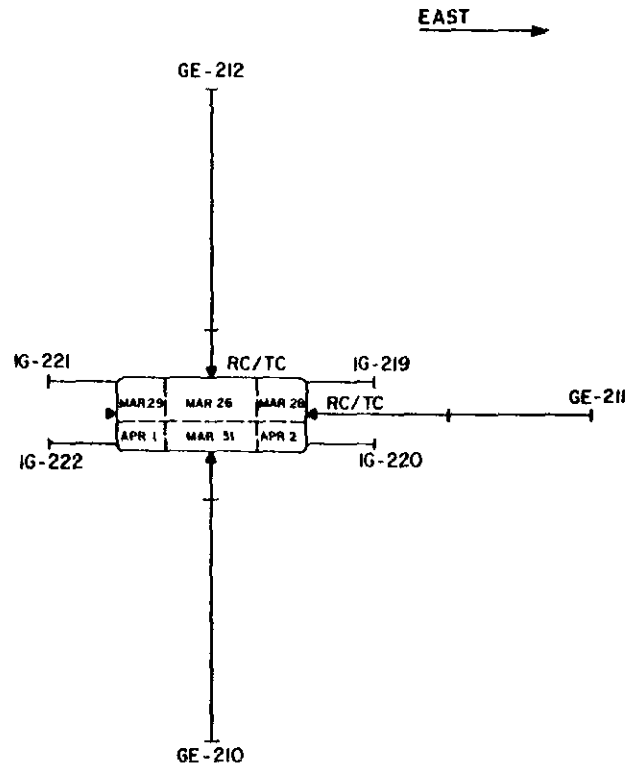


Figure 11-2

TEST ROOMS
EXCAVATION SEQUENCE AT INSTRUMENT LOCATIONS
Sheet 1 of 2



ROOM 4
AT N1275



ROOM 3
AT N1265

DIMENSIONS OF PASSES

NOTE: EXCAVATION OF THE TEST ROOMS WAS PERFORMED IN 1983

Figure 11-2

TEST ROOMS
EXCAVATION SEQUENCE AT INSTRUMENT LOC.
Sheet 2 of 2

Table 11-5

TEST ROOMS
ASSUMED EXCAVATION DATES FOR DATA ANALYSIS

Type of Instrument/Location	Instrument Designation	Assumed Date of Excavation Room 1	Room 2	Room 3	Room 4	Basis for Selection
Convergence meters	51X-CE-00202 51X-CE-00201	Apr. 7, 1983	Mar. 13, 1983			Average of dates for upper and lower center passes.
Roof extensometers - center	51X-GE-00218 51X-GE-00214 51X-GE-00212 51X-GE-00207	Apr. 4, 1983	Mar. 10, 1983	Mar. 26, 1983	Apr. 16, 1983	Date for upper center pass.
Floor extensometers - center	51X GE-00220 51X-GE-00216 51X-GE-00210 51X-GE-00209	Apr. 10, 1983	Mar. 17, 1983	Mar. 31, 1983	Apr. 22, 1983	Date for lower center pass.
Roof extensometers - east side	51X-GE-00239 51X-GE-00238	Apr. 5, 1983	Mar. 13, 1983			Average of dates for upper center and upper east passes.
Roof extensometers - west side	51X-GE-00240 51X-GE-00237	Apr. 6, 1983	Mar. 13, 1983			Average of dates for upper center and upper west passes.
Wall extensometers - east side	51X-GE-00217 51X-GE-00213 51X-GE-00211 51X-GE-00206	Apr. 6, 1983	Mar. 15, 1983	Mar. 28, 1983	Apr. 20, 1983	Date for upper east pass.
Wall extensometers - west side	51X-GE-00219 51X-GE-00215 51X-GE-00208	Apr. 8, 1983	Mar. 16, 1983		Apr. 19, 1983	Date for upper west pass.

Table 11-5 (continued)

TEST ROOMS
ASSUMED EXCAVATION DATES FOR DATA ANALYSIS

Type of Instrument/Location	Instrument Designation	Assumed Date of Excavation Room 1	Room 2	Room 3	Room 4	Basis for Selection
Wall shortening points - east side	IG 215-216 RS IG 211-212 RS IG 219-220 RS IG 223-224 RS	Apr. 8, 1983	Mar. 17, 1983	Mar. 30, 1983	Apr. 22, 1983	Average of dates for upper and lower east passes.
Wall shortening points - west side	IG 217-218 RS IG 213-214 RS IG 221-222 RS IG 225-226 RS	Apr. 9, 1983	Mar. 18, 1983	Mar. 30, 1983	Apr. 21, 1983	Average of dates for upper and lower west passes.
Wall-to-Wall convergence points - near roof	IG 211-213 TC IG 219-221 TC		Mar. 15, 1983	Mar. 28, 1983		Average of dates for upper east and west passes.
Wall-to-Wall convergence points - near floor	IG 212-214 TC IG 220-222 TC		Mar. 19, 1983	Apr. 1, 1983		Average of dates for lower east and west passes.
Wall-to-Wall permanent convergence points - center	Room 1 RC Room 2 RC Room 3 RC Room 4 RC	Apr. 7, 1983	Mar. 15, 1983	Mar. 29, 1983	Apr. 19, 1983	Average of dates for upper east and west passes.
Roof-to-Floor permanent convergence points - center	Room 3 RC Room 4 RC			Mar. 28,1983	Apr. 19, 1983	Average of dates for upper and lower center passes.

Table 11-5 (continued)

TEST ROOMS
ASSUMED EXCAVATION DATES FOR DATA ANALYSIS

Type of Instrument/Location	Instrument Designation	Assumed Date of Excavation Room 1	Room 2	Room 3	Room 4	Basis for Selection
Wall-to-Wall temporary convergence points - center	Room 1 TC	Apr. 7, 1983				Average of dates for upper east and west passes.
	Room 2 TC		Mar. 15 1983			
	Room 3 TC			Mar. 29, 1983		
	Room 4 TC				Apr. 19, 1983	
Roof-to-Floor temporary convergence points - center	Room 1 TC	Apr. 7, 1983				Average of dates for upper and lower center passes.
	Room 2 TC		Mar. 13, 1983			
	Room 3 TC			Mar. 28, 1983		
	Room 4 TC				Apr. 19, 1983	
Floor stressmeters - west corner	51X-NG-00252		Mar. 20, 1983			Date for lower west pass.
	51X-NG-00255		Mar. 20, 1983			Date for lower west pass.
Floor stressmeters - center	51X-NG-00254		Mar. 17, 1983			Date for lower center pass.
	51X-NG-00256		Mar. 17, 1983			Date for lower center pass.

Notes:

(1) The "Elapsed Days Since Excavation" shown on the data plots in Appendix J were calculated using this "Assumed Date of Excavation".

(2) See Figure 11-2 for the excavation sequence at the center of the test rooms.

(3) The dates of excavation for individual inclinometers were not used for plotting.

field observations and numerical modeling of the test rooms using in situ measurement data are also presented. In addition, regression analyses of the closure rate obtained from the closure measurements were also performed. The fitted equations were used to supplement the prediction of closure behavior in the storage rooms and are discussed in Chapter 12.

11.3.2.1 Observed Conditions

Roof and Wall Spalling. Minor spalling from the roof in the test rooms, resulting in shallow drummy areas, has occurred as expected. Drummy areas usually occur within 3 to 6 inches of the roof in areas of clear halite not associated with any noticeable clay. Separations occur along local planes of weakness in the halite, probably created by the orientation of crystal surfaces. This same phenomenon occurs in the drifts. Drummy areas have been identified immediately after excavation and additional areas have developed since that time. These later-occurring drummy areas appear to develop primarily along the roof within several feet of the walls.

Spalling along the walls of the test rooms is a result of local stress concentrations and the low tensile properties of salt. It is also related to the percentage of argillaceous material in the halite and to the proximity of floor and roof intersections. The squeezing of clay F at the upper contact of geologic map unit 4 is associated with the spalling phenomenon. Minor spalling is also associated with map unit 0, near the floor.

Pillar Fracturing. Vertical fracturing in the pillars is the expected result of room deformation and stress concentrations. The fractures that have developed in the walls of the test rooms, parallel to the rooms, are considered to be tension fractures resulting from stress relief. Fractures detected in boreholes drilled in the upper portion of geologic map unit 4 are related to the spalling occurring in this unit.

Horizontal inclinometers in the test room walls show both upward and downward vertical movement toward the center of the wall (Appendix J, Figures J-320 through J-335). Although no displacements have been observed, the inclinometer data indicate that the salt has moved toward the central horizontal axis of the room. This movement, due to vertical compressive stress and salt creep, is discussed further in subsection 11.3.2.2. Tensile stresses resulting from this salt creep and pillar shortening have caused fractures to lengthen and widen and new fractures to develop. Fracturing is more prominent at pillar corners that were not beveled to the 4 x 4-foot design.

Fracturing parallel to the room walls will continue to occur. Spalling and local failure will also continue at pillar corners and will require periodic maintenance.

Roof Displacements and Separations. The displacements observed in various open boreholes in the test room roofs are the result of deformation around the openings. The halite at the storage horizon is interrupted by anhydrite beds and thin clay layers. These layers, particularly anhydrite "b" and the underlying clay G, are directly associated with the displacements observed in the test room roofs.

Lateral displacement in the salt above the test rooms is similar to that detected above the drifts. The halite bounded by the roof and clay G moves toward the room center relative to the upper layers of salt. The movement is, however, not exactly symmetrical about the room centerline. This is confirmed by inclinometer readings in the roof of Test Rooms 1 and 2 which show that the lateral movement of the salt close to the roof is greater to the west than to the east (Appendix J, Figures J-316 through J-319). However, this trend is reversed at about 32 feet above the roof of the test rooms. The halite comprising the lower roof beam is subjected to horizontal compressive stresses resulting in shear along clay G and possible vertical separation as the beam moves downward. Some casing deformations have also been observed within 1 foot of the hole collar of the roof inclinometers. The

re[illegible]ve [illegible] and is probably due to the near surface halite resisting the shear movement along clay G.

Movement within the halite below clay G, opposite to that found elsewhere, has been observed in one borehole in Test Room 4. This may be the result of movement along existing planes of weakness in the halite or of the resistance of the halite to shear movement along clay G.

The current results of the Excavation Effects Program indicate that minimal separation or fracturing has occurred at clay G or in the underlying halite above the test room roofs. In Test Rooms 3 and 4, separations less than 1/16 inch wide have been observed. No separation has been observed at clay G. In the array of holes comprising Section 5 in Table 11-2, above the 36-inch diameter holes in the floor of Test Room 3 (Room T), no separations or fracturing were detected. In hole C of Section 4 in Test Room 3, two 1/4-inch vertical separations were found within 1 foot of the roof. These fractures resulted from roof spalling.

Similar small separations were observed in the roof of Test Rooms 1 and 2. Also, fracture zones (in one case 2.4 inches wide) were detected in the halite below clay G in the center hole of three of the four arrays.

Floor Displacements, Separations and Fracturing. The only prominant display of fracturing observed throughout the entire WIPP underground facility during design validation has been in the area of the 36-inch diameter holes drilled in the floor in the south half of Test Room 3 (Room T). Cross sections of the room floor through these holes are presented in Appendix G, Figures G-33 and G-34. Two distinct fracture zones are evident. The first is a dish-shaped zone that angles 10 to 20 degrees downward from near the room walls, intersects MB-139, and flattens near the room center. This zone is most pronounced along the series of holes shown on Figure G-34. In the

northern cross section (Figure G-33), this fracture zone is evident in the holes west of the room centerline but is not present in the holes east of the centerline. In both sections, this upper fracture zone "daylights" at the floor surface or pinches out before reaching the room pillars.

A second fracture zone, dipping approximately 50 to 60 degrees from horizontal and exposed in the holes closest to the room walls, occurs below the upper fracture zone. This lower zone is more regular and planar than the upper zone. With the exception of one hole, this lower zone occurs entirely within MB-139 and is more developed on the west side of the room.

In addition to the two major fracture zones, some subhorizontal fracturing is present just above clay E at the base of MB-139. This fracturing is most evident in the holes closest to the room centerline. No separations along clay E were observed in any of the holes.

Communication between holes during drilling was observed and is described in Table 11-3. During the drilling of hole TV-03, drilling dust was observed coming up through a surface fracture close to the east wall, 25 feet south of the hole location.

A series of measuring pins were installed in two open holes, TV-03 and TV-19, in late January 1986 to monitor movements within the holes. The pins were installed in MB-139 and in the overlying halite and straddle the fracture zones. Measurements taken until the holes became inaccessible in June 1986 indicated that some small-scale dilation was occurring in both of the holes.

The fractures observed beneath the floor of Test Room 3 are directly related to the excavation geometry and the stratigraphy. Some fractures within MB-139 may have been pre-existing but have opened since room excavation.

[illegible] inch diameter holes were drilled in the north half of Test Room 3 to determine if fracturing is occuring there. These holes were drilled to a nominal depth of 12 feet below the floor. A thin fracture zone was detected within 1 1/2 feet of the floor in two of the holes and minor fracturing was detected in MB-139 in all of the holes. This fracturing is significantly less developed than that observed in the south half of Test Room 3.

The 22 large-diameter holes in Test Room 3 were drilled late in 1985. They are, therefore, too recent to document any lateral displacements along the observed fractures. However, other older floor boreholes do indicate relative displacement. In Test Room 4, boreholes P4X-06, P4X-25, P4X-27, P4X-29 and P4X-31 all show multiple displacements and vertical separations (Table 11-2). These are primarily within MB-139 and exhibit up to 2 inches of lateral displacement and up to 1/2 inch of vertical separation. These five holes are near the room centerline. The relative movement of the multiple displacements observed is complicated and does not follow the simpler interpretation of the roof displacements. The most significant displacements in all of the holes have taken place closest to the floor surface and, in all cases, the salt above the fracture has moved east relative to the underlying salt. Inclinometers IG-202 and IG-201, in Test Rooms 1 and 2, also exhibit similar relative displacement. Both of these inclinometers are on the west side of their respective test rooms. The marker bed and the overlying salt have moved east towards the room centerline relative to the underlying salt. Movement is apparently along clay E and is approximately 3/4 inch.

Although no detailed investigation of the salt beneath the test room pillars has been performed, the Test Room 3 fracture mapping indicates that it is unlikely that fractures extend beneath them to any significant extent. Neither of the two fracture zones identified can be traced into the pillars. The upper fracture zone pinches out prior to reaching the walls or daylights at the floor surface. The lower fracture zone cannot be traced beyond the hole walls, but it is not

suspected of continuing beneath the pillars. One small diameter hole was drilled at an angle into each of the walls of Test Room 3 in May 1986. Except for a localized clay break at a depth of 3.2 feet, there was no evidence of separation.

Fractures and separations have been observed in four large-diameter holes drilled in the floor in the south end of Test Room 4. Fractures were observed in these holes during drilling in November 1983 and January 1984. The fracturing was minor, however, with no separations observed. One hole became inaccessible soon thereafter. Fractures in the other holes have been observed to increase in number and to exhibit separation (Table 11-2). Fractures occur in the marker bed and in the overlying halite. Because two of the holes have restricted access, monitoring of the fractures is difficult. Borehole P4X-84, in the southwest corner of Test Room 4, was mapped in February 1986 and the results are shown in Appendix G, Figure G-32. The separations and displacements in P4X-84 over the 2 year period since excavation are small in comparison to those in the floor holes in the south half of Test Room 3.

A low-angle fracture in the floor of Test Room 2 was observed in August 1985. An inspection in June 1986 showed that it extended from approximately N1242 to N1208. This fracture daylights at the floor surface, 1.5 feet to 6 feet from the west wall, and extends 2 feet below the floor surface toward the east. Approximately 8 to 10 inches of separation is present along this fracture, and approximately 25 square feet of floor in the vicinity of this fracture sounds drummy.

As part of the Excavation Effects Program, a series of holes were drilled in each of the test rooms to determine the extent of floor fracturing and for future monitoring of this phenomenon. Existing boreholes, such as those in Test Rooms 3 and 4, were utilized where possible. The locations of the holes are shown on Figure 10-1 in Chapter 10. These holes were inspected using a probe and the results are summarized in Table 11-2. The holes exhibited some fractures and

The dish-shaped profile observed in the floors in Test Room 3 was also found in some of the hole arrays, although on a much smaller scale. It was most pronounced in several of the holes close to the room walls where separations were estimated to be a maximum of 6 inches. In other locations, the separation ranged from 1/8 inch to 3 inches. Within MB-139, fractures and separations found in the central holes of the Test Room 1 array ranged from approximately 1/8 inch to 3 inches. For other hole arrays, the maximum separations were 1/2 inch and, again, these were found in the central holes.

Horizontal displacements and vertical separations have been observed in various small-diameter boreholes in the test room floors. Horizontal displacements up to 2 1/2 inches and vertical separations estimated to be up to 1/2 inch wide were present in some of these holes. Multiple displacements in single boreholes were also present. The horizontal displacements and vertical separations found in many of the holes are within MB-139 or coincide with the lower contact of this unit. These displacements and separations have developed since room excavation, although some of them may have developed along pre-existing planes of weakness in the marker bed.

In addition to observations made in open boreholes, ground-penetrating radar and gas permeability testing have been conducted in some of the test rooms. A radar survey was conducted in Test Rooms 2 and 3. The radar method has some limitations. It appears to be effective in locating the first reflector such as a fracture or clay seam beneath the floor, but the structure below this is not easily distinguished. MB-139 is readily defined on the records but fractures within it cannot be discerned.

Zones of relatively high permeability have been found to develop immediately beneath the floor of the test rooms and beneath the intersections of Test Rooms 1 and 2 with the N1420 drift. There also appears to be a slight increase in permeability, relative to background values, within MB-139 and immediately beneath the floor of the N1420

drift between Test Rooms 1 and 2. Some increase in permeability also appears to occur in MB-139 near the center of the pillar between Test Rooms 2 and 3. This data is only preliminary, however, because only one hole intersecting MB-139 beneath the pillar has been drilled and tested for permeability.

Gas tracer measurements performed along the centerline in the north half of Test Room 2 and across the N1420 drift to Room L2 indicate the existence of fracturing beneath the floor. A video survey of the boreholes used for the tracer tests shows the presence of fracture zones and separations mainly within MB-139. Holes tested along the N1420 drift, except at intersections, show little increase in background permeability. A video survey of these holes did not show any separations or fracturing.

In summary, subhorizontal fracturing has developed beneath the test room floors. The majority of this fracturing occurs as single fractures or thin fracture zones within MB-139 and the overlying halite. Horizontal displacements ranging up to 2 inches and separations generally ranging up to 1/2 inch have been measured in small diameter boreholes. Separations up to 6 inches have been observed locally. Only the south half of Test Room 3 (Room T) in the WIPP underground facility has exhibited extensive fracturing beneath the floor.

The Excavation Effects Program was designed in part to determine if fracturing similar to that occurring beneath the floor of Test Room 3 has developed in other areas of the facility. The results of this program show that, although small-scale fracturing is occurring beneath all of the test rooms, no other areas of fracturing have developed on the same order of magnitude as that in Test Room 3. The fracturing occurring beneath the floor of Test Room 3 appears to have existed prior to drilling. The stress changes induced by the size and number of holes drilled in this area probably exacerbated the existing fractures.

Roof-to-Floor Closure. Figure 11-3 shows the relationship between measured roof-to-floor closure and the elapsed time since excavation of the four test rooms, as determined from convergence meter and convergence point data. Because of differences in time-lag between the end of excavation and the time of the initial readings, the relative positions of these curves are deceptive. For analysis purposes, the roof-to-floor closure that occurred before installation of the convergence instruments was determined using equation 10-1 in Chapter 10.

In addition, part of the measurement data from the temporary convergence points were added to the permanent convergence instrument data to obtain approximate values of the actual roof-to-floor closure. Table 11-6 shows roof-to-floor convergence point readings and adjusted closure magnitudes for the test rooms. Item 7 in this table shows the approximate roof-to-floor closure obtained by adding suitable portions of the temporary convergence point readings to the readings of the permanent convergence instruments.

It is apparent that the fracturing observed in the floor of the test rooms, and vertical separations in the roof, have contributed to the total roof-to-floor closure. However, based on measured cumulative vertical separations in September 1985, the contribution of floor fracturing to the total roof-to-floor closure is not more than 1 inch.

The total estimated closure (item 9 in Table 11-6) includes the values of early closure estimated by using equation 10-1 in Chapter 10. Based on the indicated additive values, the maximum roof-to-floor closure of approximately 16 1/2 inches through June 1986 occurs in Test Rooms 2 and 3. Test Room 4 has undergone the least roof-to-floor closure. Figure 11-4 shows the adjusted roof-to-floor closure values as a function of time.

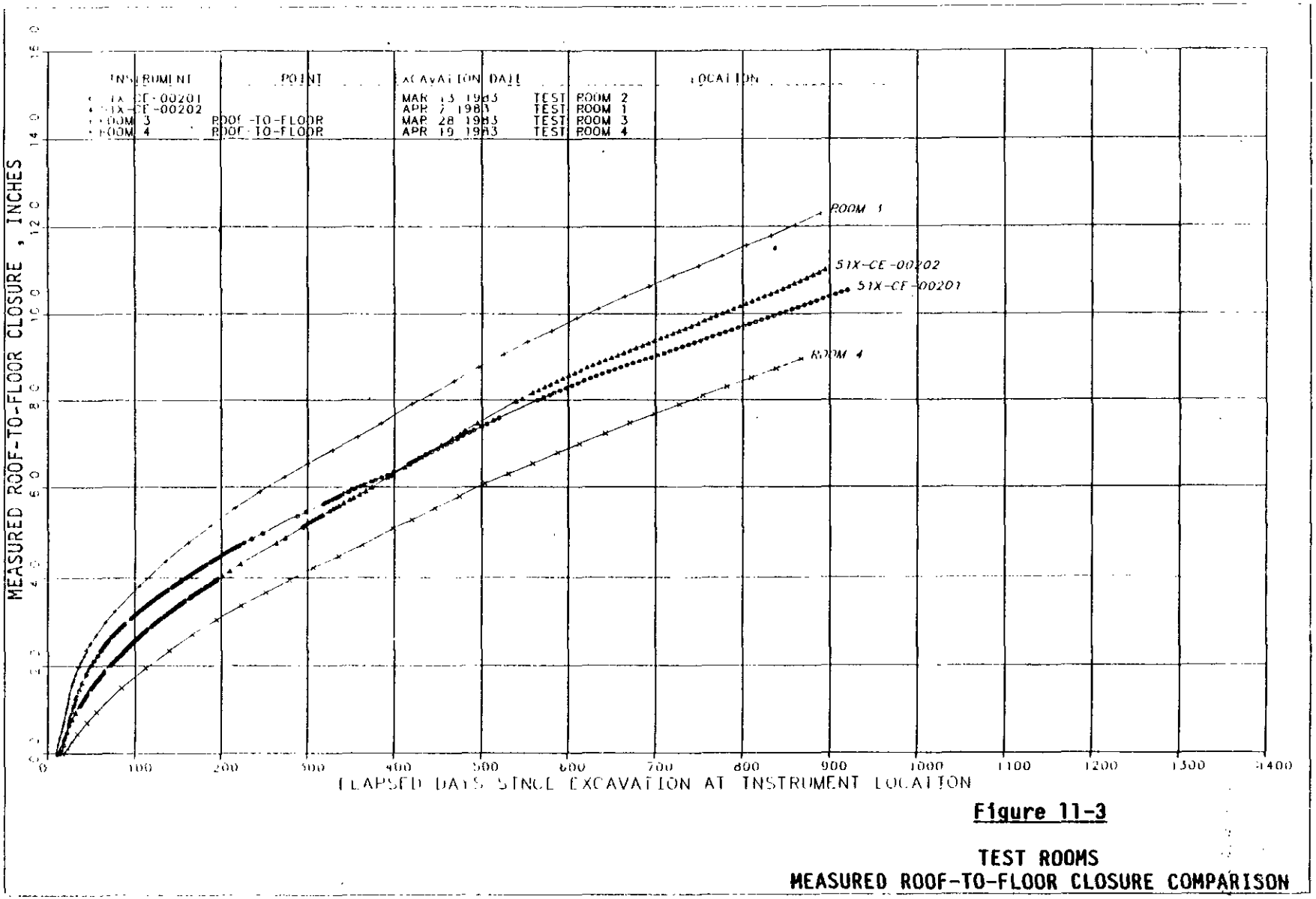


Figure 11-3

TEST ROOMS
MEASURED ROOF-TO-FLOOR CLOSURE COMPARISON

Table 11-6

TEST ROOMS
ROOF-TO-FLOOR CLOSURE COMPARISONS

Description	Test Room 1	2	3	4
(1) Excavation period	April 3-13 1983	March 9-20 1983	March 24-April 3 1983	April 15-25 1983
(2) Date of first reading of temporary convergence (TC) points	April 12, 1983	March 21, 1983	April 4, 1983	April 26, 1983
(3) Date of first reading of permanent convergence (RC and CE) instruments	April 20, 1983	March 29, 1983	April 7, 1983	May 6, 1983
(4) Reading of TC points (inches) on date indicated	0.84 April 20, 1983	0.88 March 28, 1983	0.40 April 7, 1983	0.45 May 5, 198
(5) Reading of RC and CE instruments (inches) on date indicated	13.11 June 13, 1986	12.20 June 13, 1986	13.83 April 28, 1986	10.62 April 28
(6) Total elapsed days of combined TC and RC measurements [Date for (5) - Date for (2)]	1157	1179	1120	1098
(7) Total measured closure (inches) [(4) + (5)]	13.95	13.08	14.23	11.0
(8) Estimated closure (inches) by regression analysis for the period of (2) - (1)	2.39	3.72	2.17	1.3
(9) Total estimated closure (inches) [(7) + (8)]	16.34	16.80	16.40	12.39

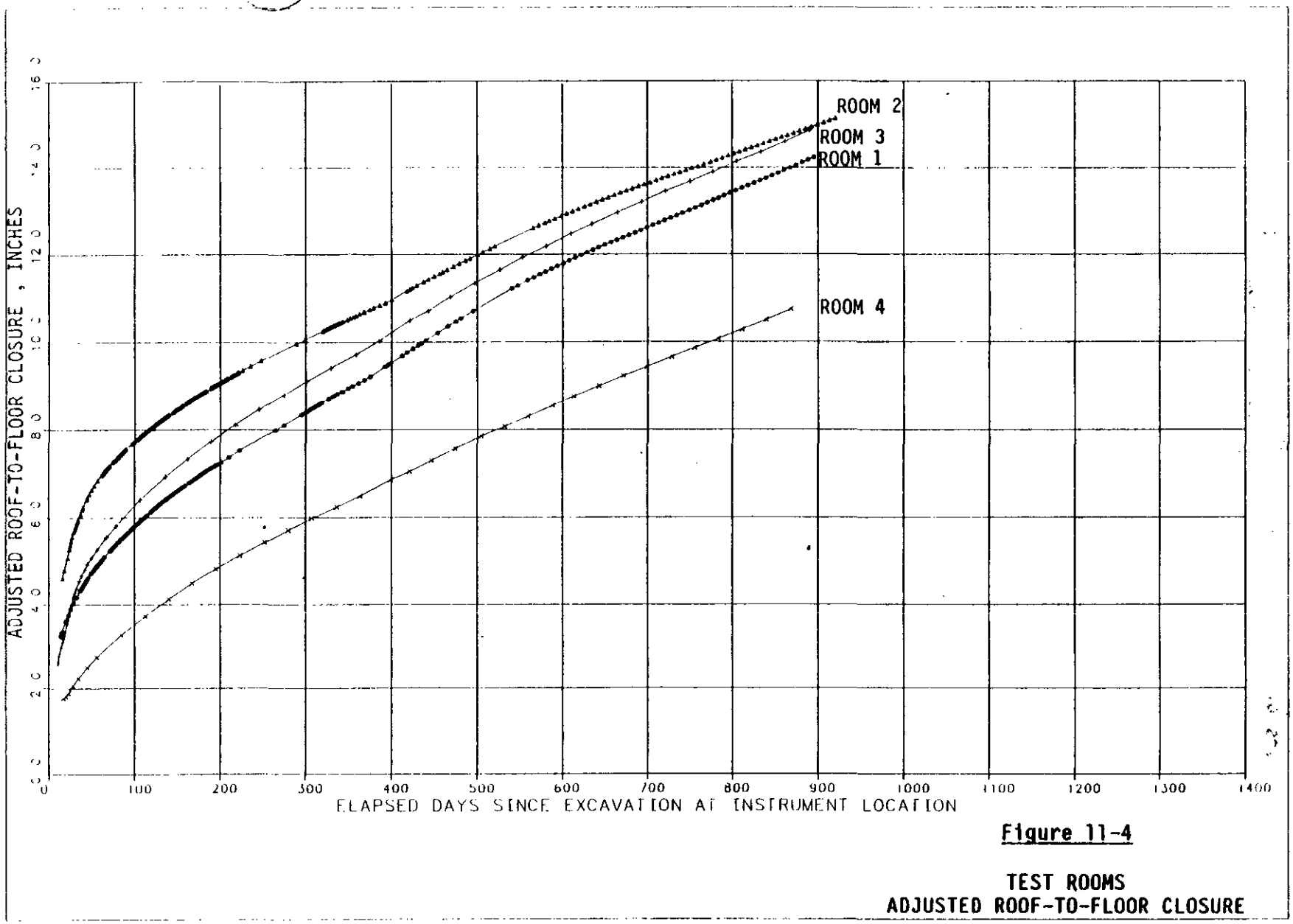


Figure 11-4

TEST ROOMS
ADJUSTED ROOF-TO-FLOOR CLOSURE

Figure 11-4 shows that [illegible] except for occasional [illegible] disturbances from nearby excavations. Provided there are no additional perturbations in and around the test rooms, it is likely that the rate of closure will reach a steady state value. It is possible to get an estimate of the rate of closure using either a phenomenological rheological model or an empirical model that is essentially a curve-fitting procedure. Both methods have been attempted. Numerical methods using the phenomenological approach are discussed in Chapter 5.

Closure rates rather than measured closure are used in the empirical approach because measured closure is not absolute. Early closure measurements are not available because the instruments could not be installed immediately after excavation. However, the calculation of closure rates is not affected by the lack of early measurements. The closure rates are calculated by assuming a linear relationship between closure and elapsed time over a short interval. This time interval has been arbitrarily chosen as a minimum of 7 days.

Because it is expected that the closure rate will initially be relatively high and then decrease to a steady rate, the following equation was used:

$$C(t) = \frac{A}{t^n} + C_c(1 - e^{-at}) \qquad (11\text{-}1)$$

where: $C(t)$ is the closure rate at elapsed time t after excavation;
A, a and n are constants which depend upon the deformation characteristics of the salt, initial stress regime and dimensions of the opening; and
C_c is the steady state closure rate.

The value of C(t) is obtained by arbitrarily choosing a time interval of not less than 7 days. If R_i is the closure reading at calendar time t_i and R_{i+1} is the closure reading at t_{i+1}, then

$$C(t) = \frac{R_{i+1} - R_i}{\Delta t} \qquad (11\text{-}2)$$

where: $\Delta t = (t_{i+1} - t_i) \quad \geq 7 \text{ days}$ (11-3)

The value of t is defined as:

$$t = \frac{t_i + t_{i+1}}{2} \qquad (11\text{-}4)$$

A regression analysis, which is the fitting of an equation like 11-1 to the set of [C(t),t] data points, was performed using NLIN, a commercially available statistical software package (ref. 11-1). The general method used to estimate the constants, herein called the regression parameters, was to minimize the sum of the squares of the differences between the actual measured values and the values predicted by the proposed equation.

Equation 11-1, a nonlinear equation, cannot be converted into linear form. The statistical software NLIN employs iterative methods that attempt to find least-square estimates for nonlinear models. The methods commonly employed are the Gauss-Newton technique and the Marquardt compromise technique (ref. 11-2). However, the requisite partial derivatives of the equation with respect to the parameters must be specified. In many cases, the Marquardt compromise, which is considered to work well in many circumstances, gives a better estimate and provides quicker convergence of the values of the regression parameters. However, nonlinear regression analyses may not always result in good estimates of the regression parameters. In addition, the analysis tacitly assumes that the regressor variables are measured without error. Thus, the observations, which in this case are the values of C(t), were not weighted.

Figure [illegible] roof-to-floor closure rates for Test Room 1 calculated by equation 11-1 to the values calculated using the fitted equation 11-2. The data used was obtained during the first year following the completion of excavation. The regression analysis showed that, for all practical purposes, equation 11-1 could be simplified as

$$C(t) = \frac{A}{t^n} + C_c \qquad (11\text{-}5)$$

because the value of 'a' obtained from the regression analysis was large enough to make the term e^{-at} comparatively negligible. The fitted equation for the roof-to-floor closure data in Test Room 1 has the form

$$C(t) = \frac{206.58}{t^{0.84}} + 2.24(1-e^{-5.27t}) \text{ inches/year} \qquad (11\text{-}6)$$

where: t is the elapsed time in days since excavation.

However, as shown by equation 11-5, equation 11-6 can be approximated as

$$C(t) = \frac{206.58}{t^{0.84}} + 2.24 \text{ inches/year} \qquad (11\text{-}7)$$

The method used was the Marquardt compromise technique. The coefficient of determination is 0.99.

The analysis was repeated later using roof-to-floor closure data at 980 days (2.68 years) after the completion of excavation. The regression equation was

$$C(t) = \frac{211.16}{t^{0.85}} + 2.44 \text{ inches/year} \qquad (11\text{-}8)$$

The steady state closure rate determined using the first year of data only is 9 percent less than the rate determined by using 2.68 years of

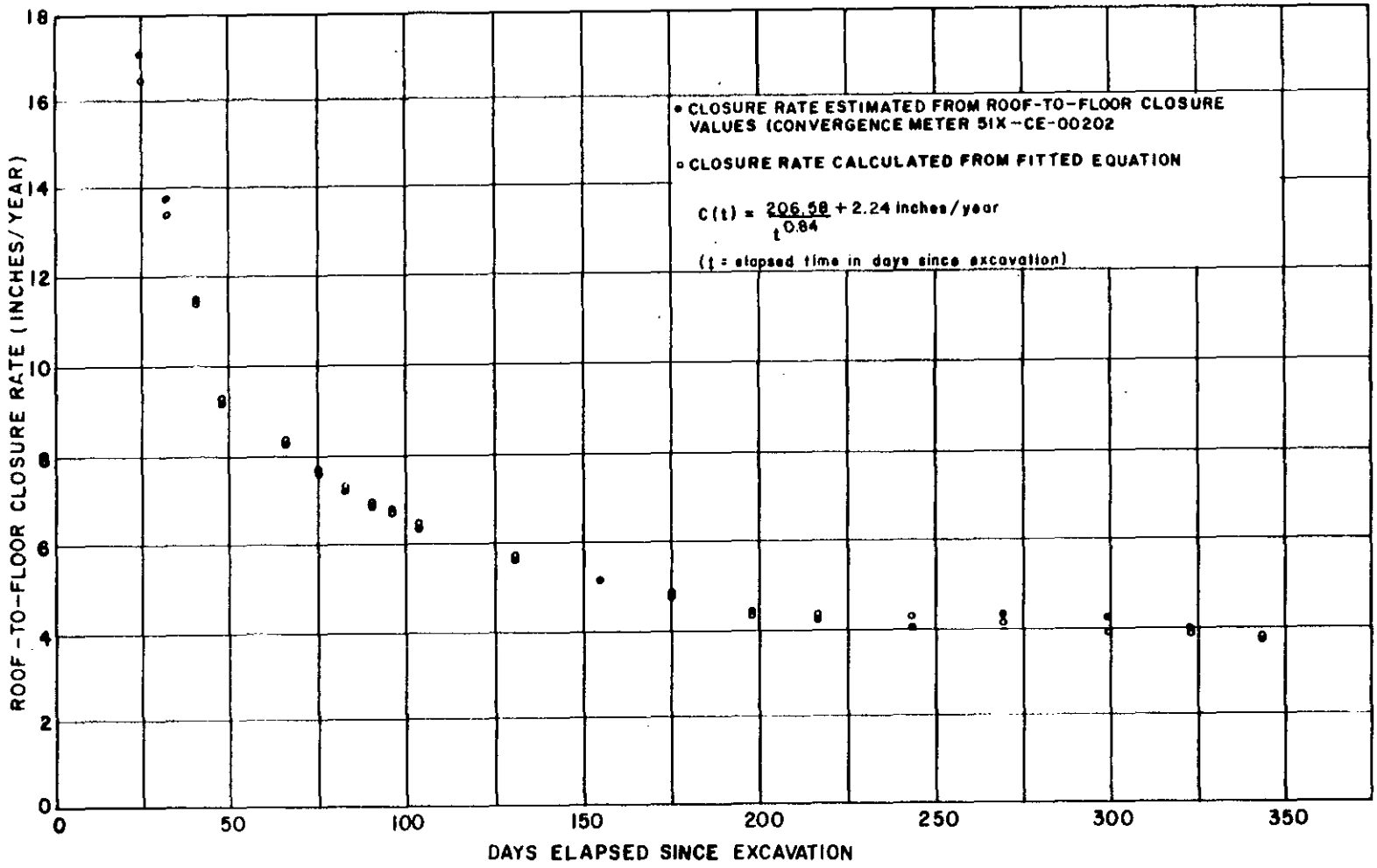


Figure 11-5

TEST ROOM 1
REGRESSION ANALYSIS OF ROOF-TO-FLOOR CLOSURE

measurement data, up to

1986, gave

$$C(t) = \frac{208}{t^{0.85}} + 2.40 \text{ inches/year} \qquad (11\text{-}9)$$

Equations 11-7, 11-8 and 11-9 show the consistency of the regression parameters for different input data sets.

Figure 11-6 shows the predicted roof-to-floor closure rate for Test Room 1 as a function of elapsed time in years using equation 11-9. Based on equation 11-7, the roof-to-floor closure rate at the end of 25 years is expected to be approximately 2.34 inches/year. Using equation 11-8, it will be 2.53 inches/year or 2.49 inches/year using equation 11-9.

Figures 11-7 through 11-10 show the fitted curves based on roof-to-floor closure rates calculated from equation 11-2, using data up to June 1986. To get an approximate idea of the roof-to-floor closure for periods of time greater than 1 year since the completion of excavation, equation 11-7 was integrated with respect to time between the limits of 1 year and time t_2 (in years) to yield

$$R(t) = 0.78(t_2^{0.147} - 1) + 0.20(t_2 - 1) \qquad (11\text{-}10)$$

Figure 11-11 shows the predicted roof-to-floor closure in feet for Test Room 1 (excluding that which has occurred in the first year after excavation) as a function of time in years. According to this prediction, 25 years after excavation this value will be 5.34 feet. A similar analysis using equation 11-9 gave a value of 5.3 feet.

Table 11-7 is a summary of the results of the nonlinear regression analyses for the roof-to-floor closure rates in the test rooms using 3 years of measurement data. The parameters contained in this table are applicable for an elapsed time expressed in years. For Test Room 4, the regression analysis using only the permanent convergence point data did not produce satisfactory results. The analysis was

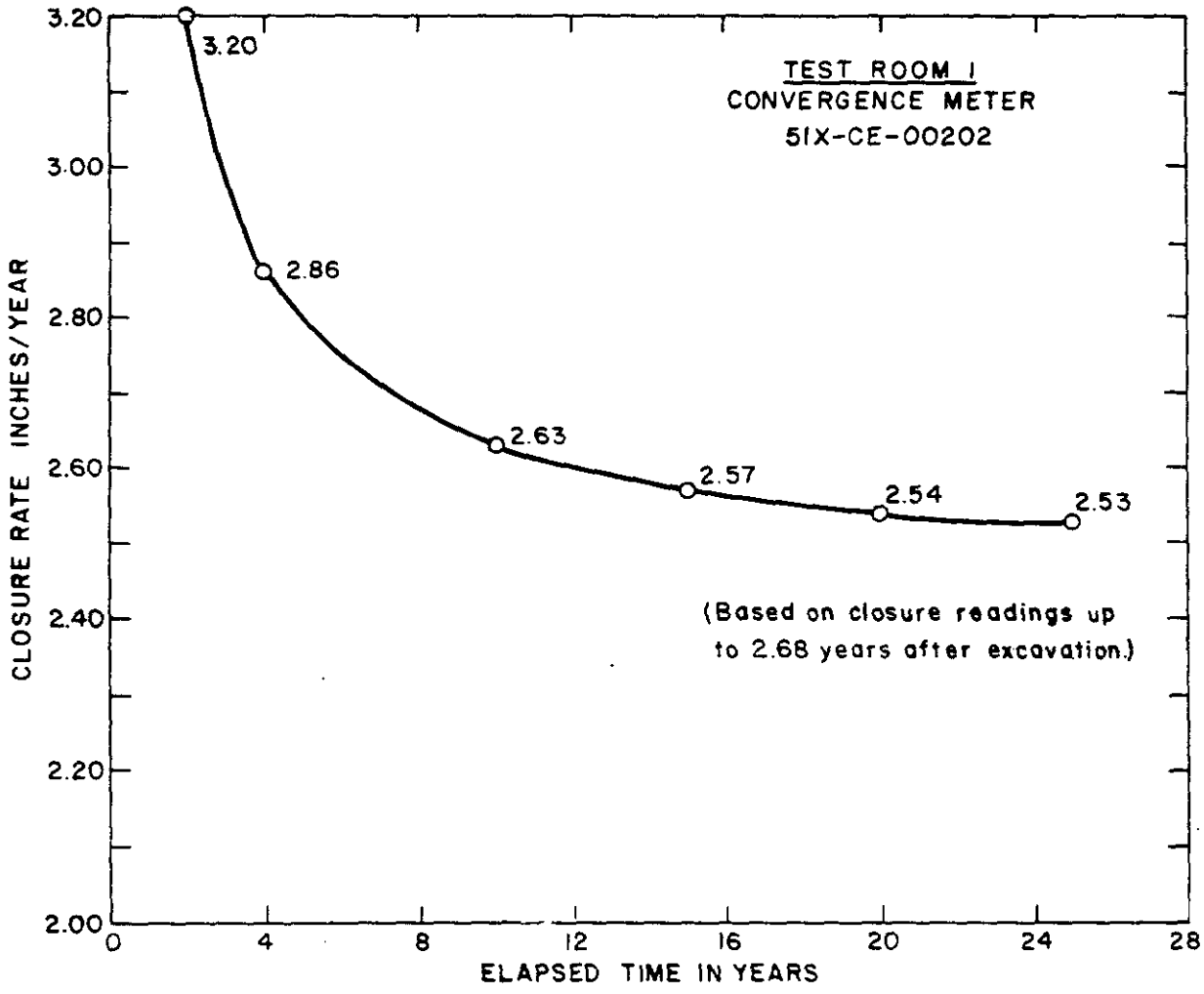
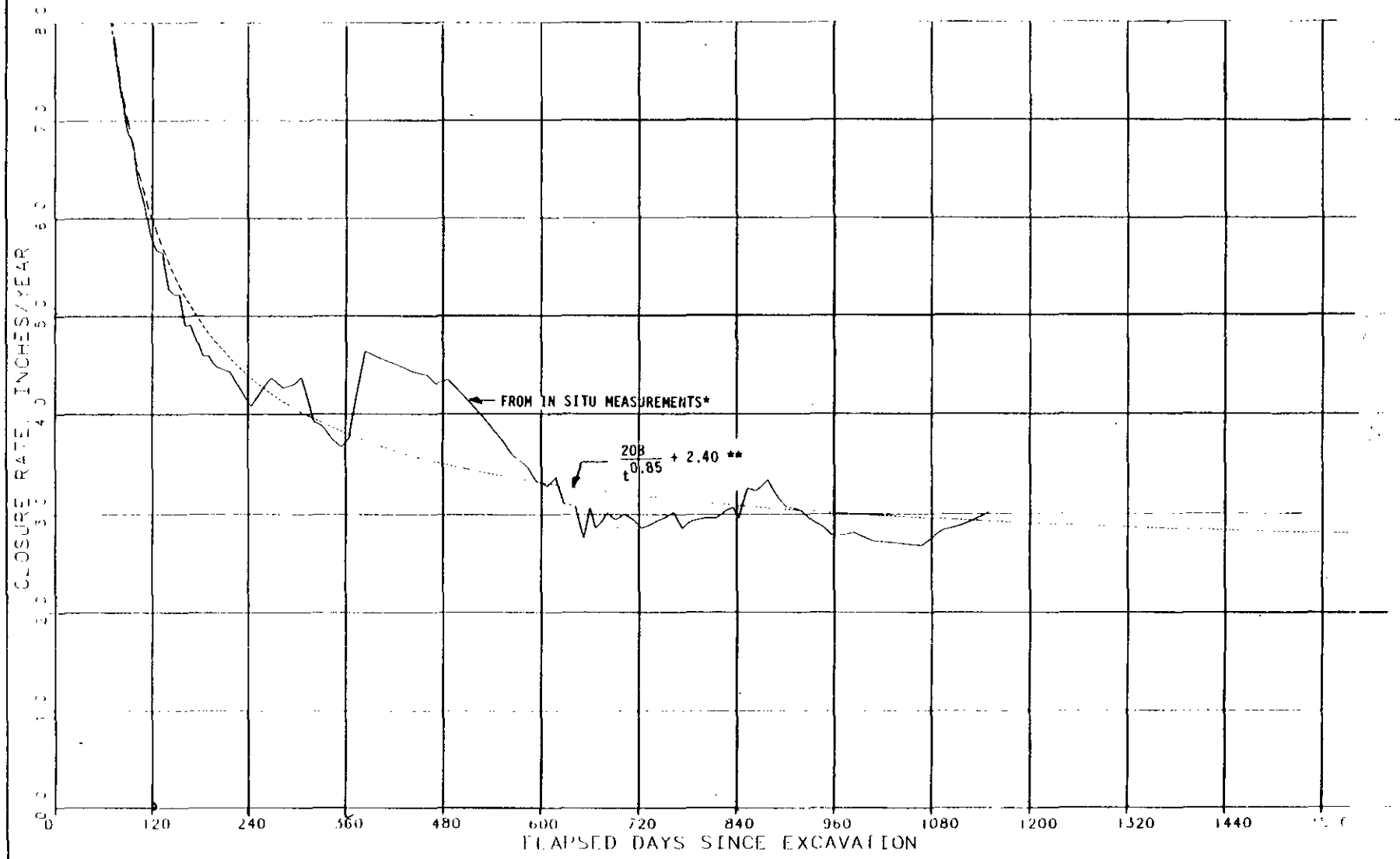


Figure 11-6

TEST ROOM 1
PREDICTED ROOF-TO-FLOOR CLOSURE RATE

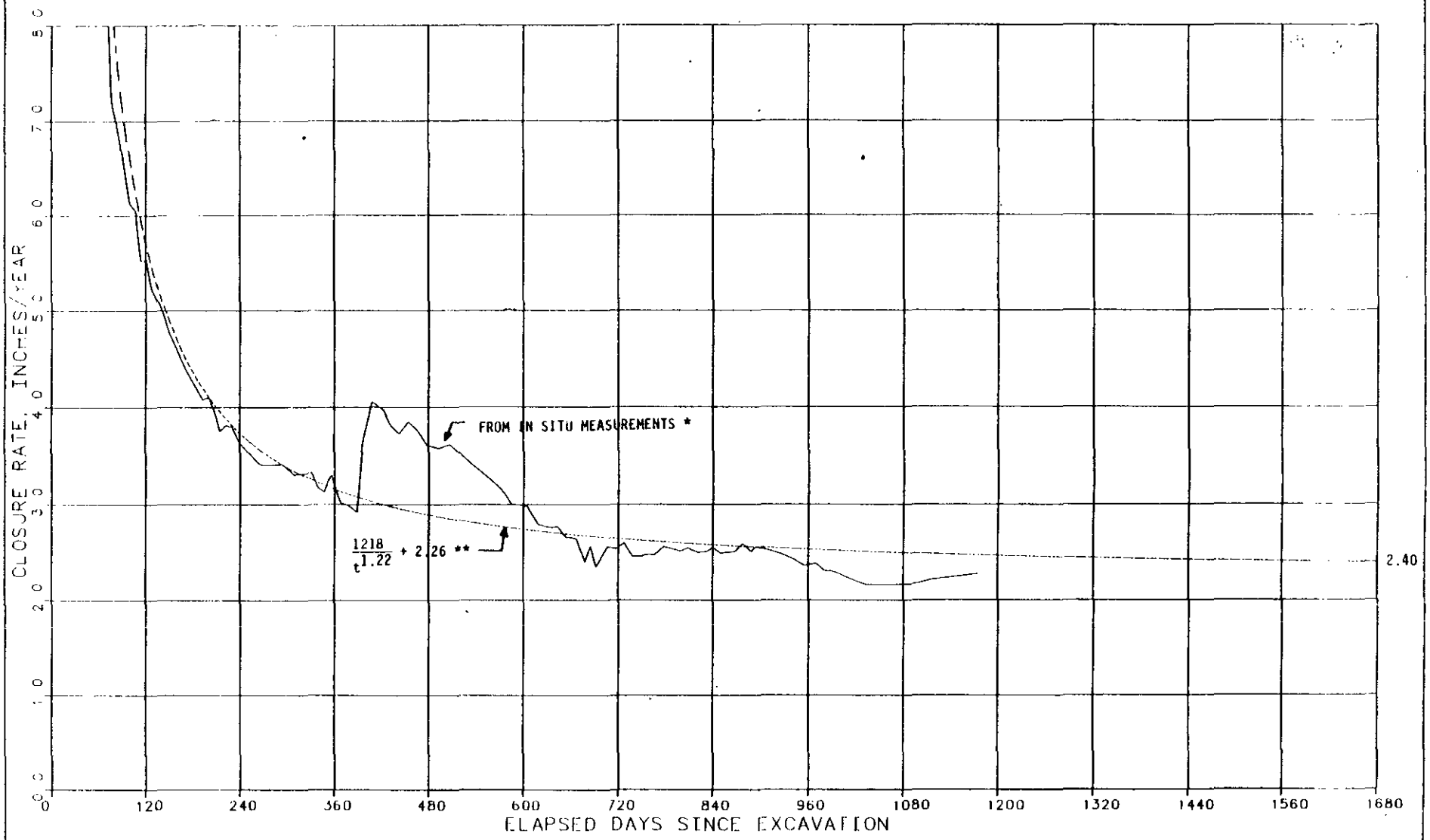


* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-7

**TEST ROOM 1 ROOF-TO-FLOOR CLOSU
RESULTS OF REGRESSION ANALY**

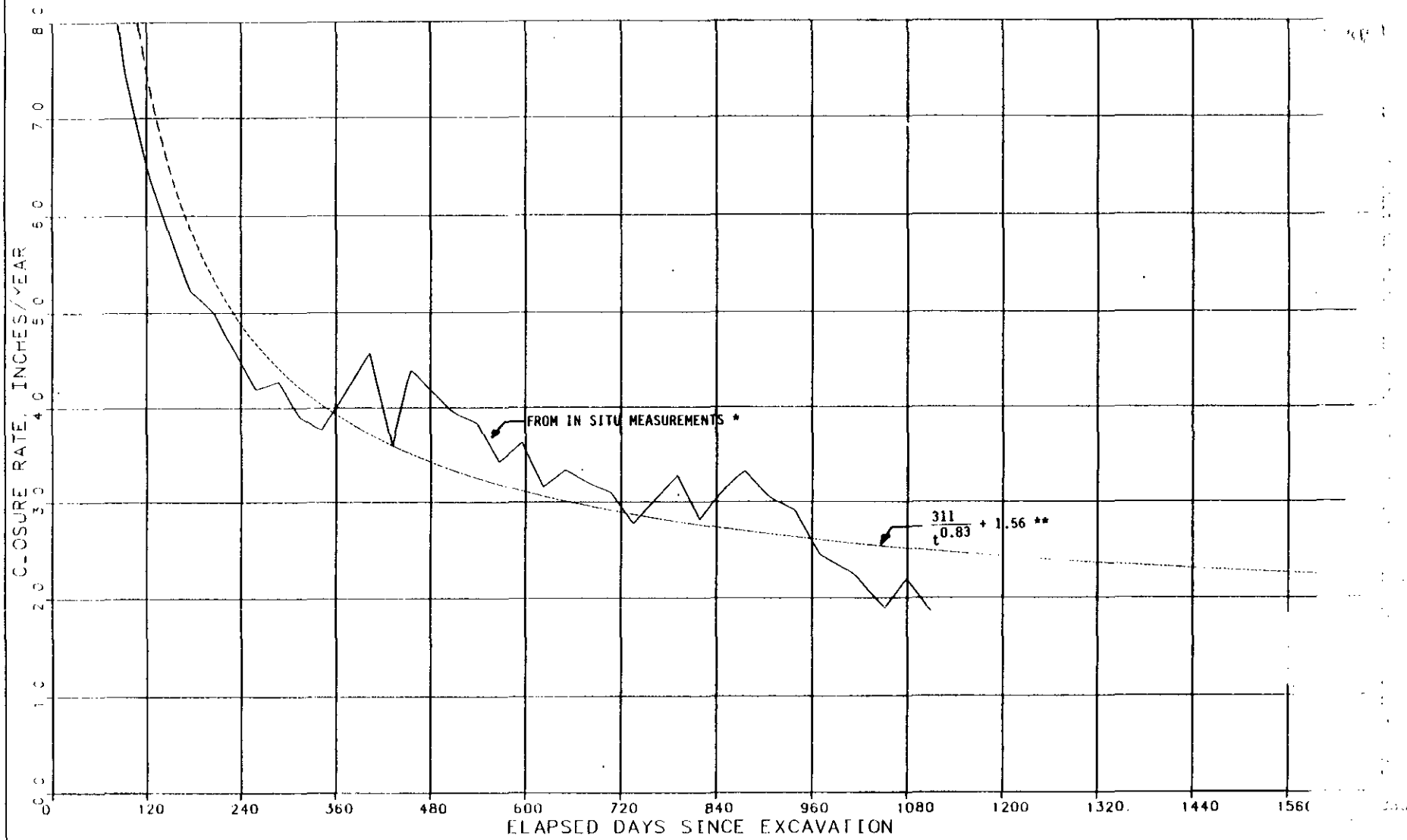


* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-8

TEST ROOM 2 ROOF-TO-FLOOR CLOSURE RATE RESULTS OF REGRESSION ANALYSIS

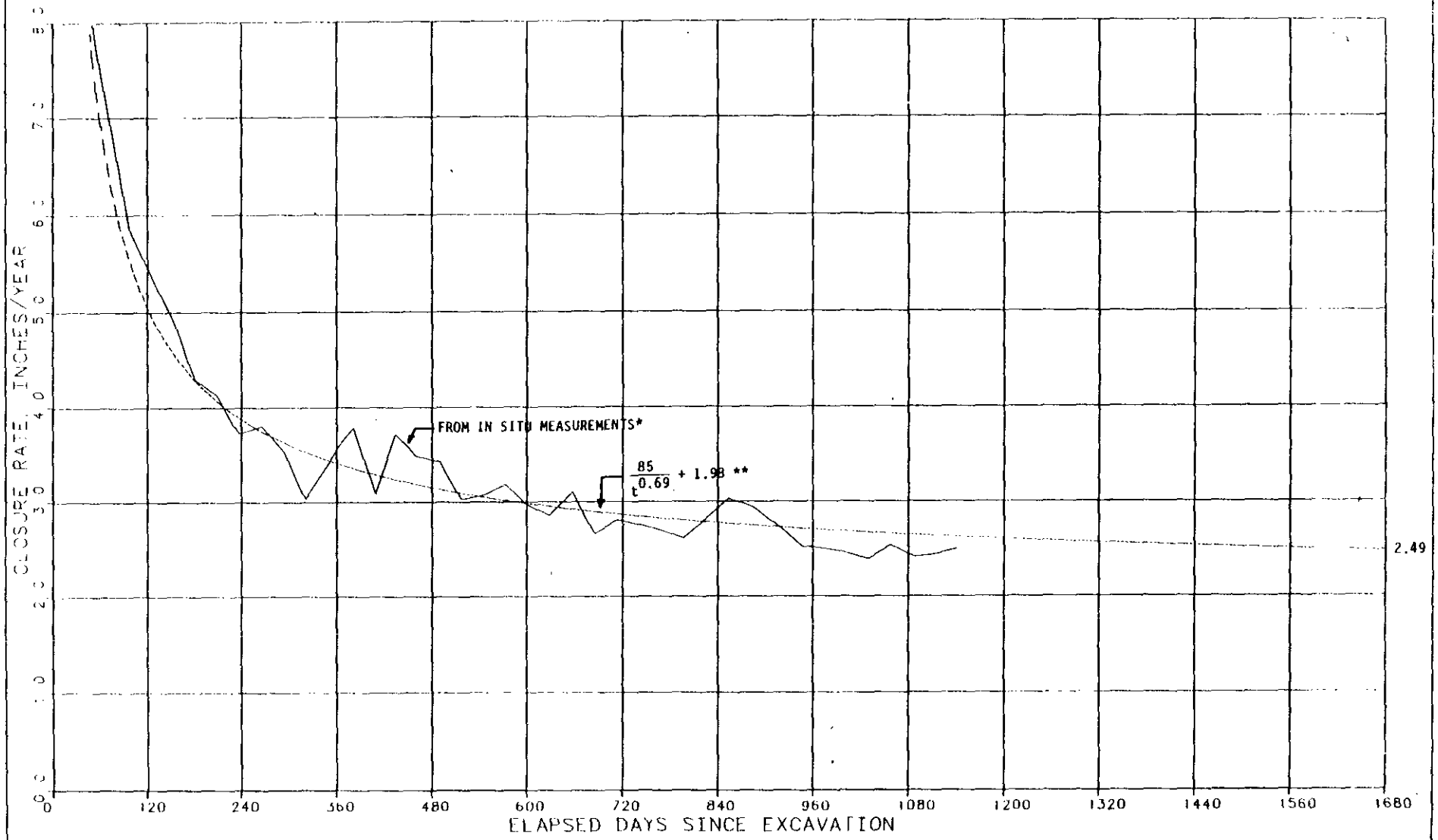


* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-9

TEST ROOM 3 ROOF-TO-FLOOR CLOSURE RESULTS OF REGRESSION ANALYSIS



* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-10

TEST ROOM 4 ROOF-TO-FLOOR CLOSURE RATE RESULTS OF REGRESSION ANALYSIS

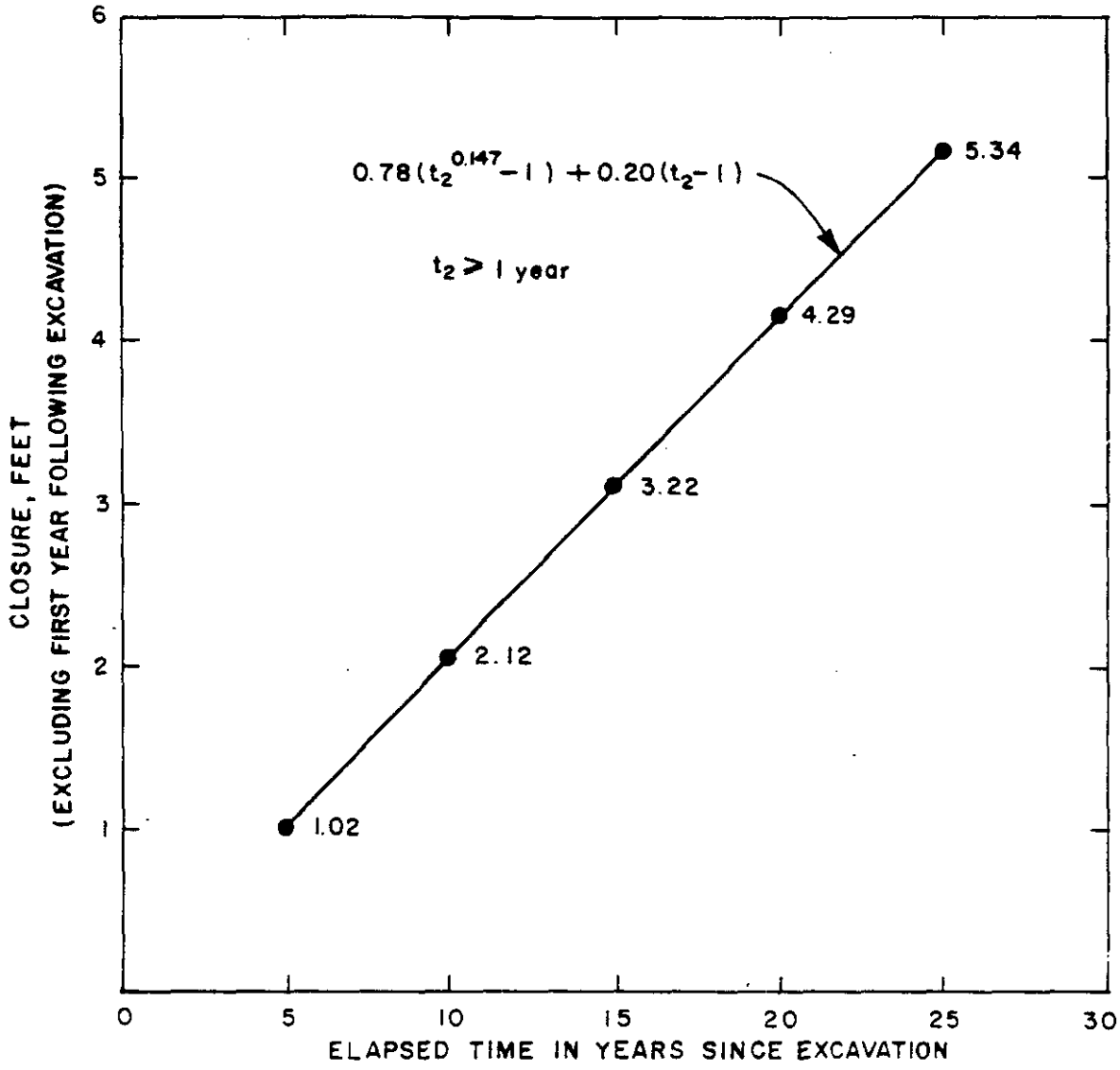


Figure 11-11

TEST ROOM 1
PREDICTED ADDITIONAL ROOF-TO-FLOOR CLOSURE

TEST ROOMS
SUMMARY OF RESULTS OF REGRESSION ANALYSES
FOR ROOF-TO-FLOOR CLOSURE RATES

Description	Test Room 1	2	3	4*
Regression Parameters**				
A	208	1218	311	85
n	0.85	1.22	0.83	0.69
C_c	2.40	2.26	1.56	1.98
r^2	0.99	0.98	0.94	0.97

Note: Analyses based on data obtained through June 1986.

* Data used for regression analysis includes data from temporary convergence points.

** Equation is: $C(t) = \frac{A}{t^n} + C_c$

where: C(t) is closure rate in inches/year;
A and n are constants;
t is elapsed time in days; and
C_c is steady state closure rate.

r^2 is the coefficient of determination.

repeated with [illegible] produced good results. The [illegible] of the regression analysis of roof-to-floor closure rates discussed in this subsection are used in Chapter 12 to define the bounds on the roof-to-floor closure rates for the storage rooms.

Wall-to-Wall Closure. Figure 11-12 summarizes the measured wall-to-wall closure magnitudes for the test rooms. Because of the lack of early measurements, the relative positions of the individual curves are not absolute. Table 11-8 presents an estimate of the actual wall-to-wall closure for the four test rooms. The approach is similar to the one used for estimating the actual roof-to-floor closure values. The maximum wall-to-wall closure occurs in Test Room 3 and is about 13 inches. The minimum wall-to-wall closure is about 9 inches in Test Room 4.

The regression analysis of wall-to-wall closure rates for Test Room 1, using measurement data up to June 1986, shows that the equation has the form

$$C(t) = \frac{202}{t^{0.94}} + 1.75 \text{ inches/year} \qquad (11\text{-}11)$$

where: t = elapsed time in days since excavation.

Comparing equation 11-11 with equation 11-9, the long-term wall-to-wall closure rate will be 73 percent of the roof-to-floor closure rate.

Table 11-9 is a summary of the results of the regression analyses for the wall-to-wall closure rates in Test Rooms 1 through 4. The closure rate values determined from temporary convergence point readings were included in the analysis of Test Room 2. The fitted curves for Test Rooms 2 and 3 are relatively poor. Figures 11-13 through 11-16 show the fitted equations for the wall-to-wall closure rate versus elapsed time curves for Test Rooms 1 through 4.

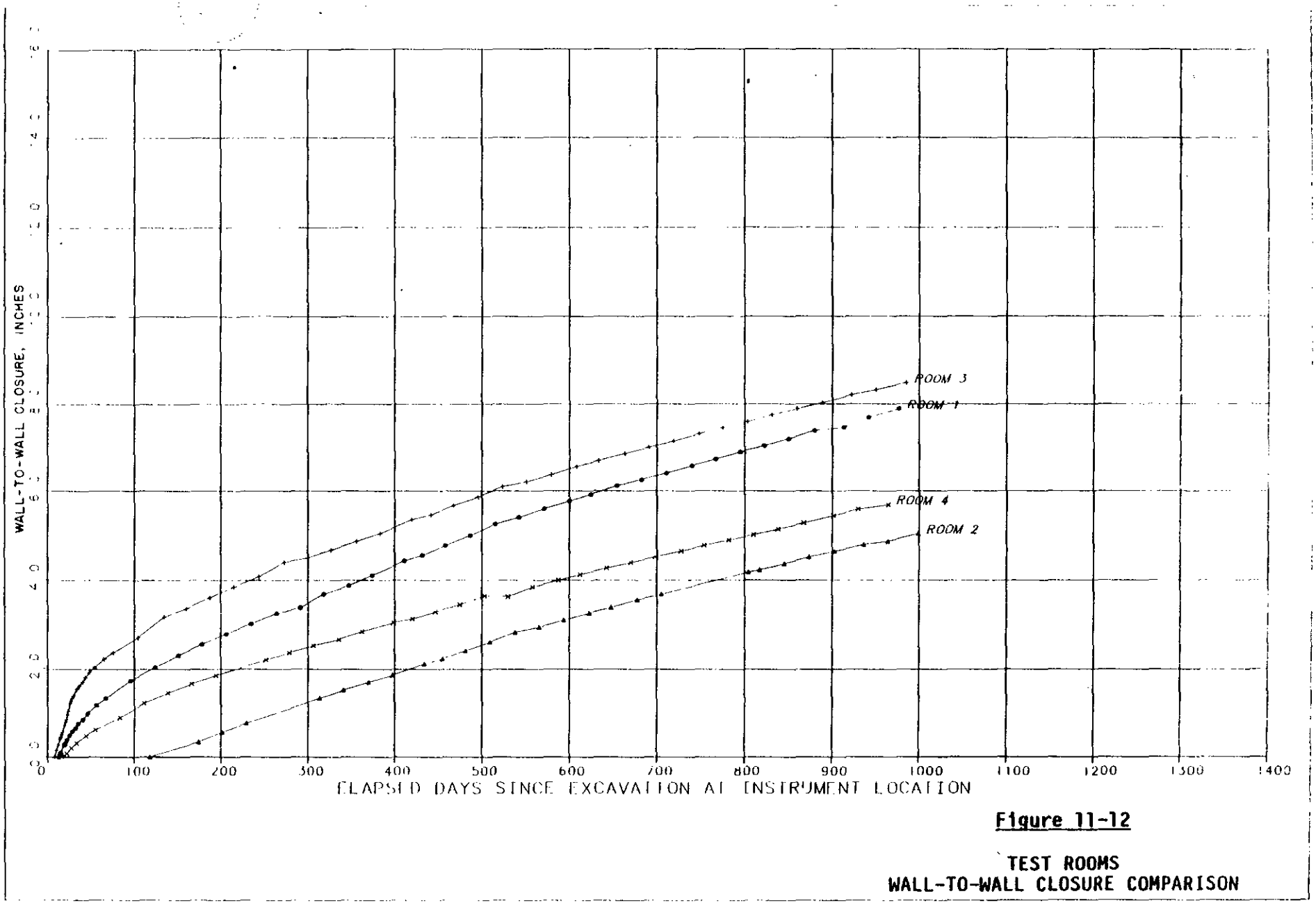


Figure 11-12

TEST ROOMS
WALL-TO-WALL CLOSURE COMPARISON

Table 11-8

TEST ROOMS
WALL-TO-WALL CLOSURE COMPARISONS

Description	Test Room 1	2	3	4
(1) Excavation period	April 3-13 1983	March 9-20 1983	March 24-April 3 1983	April 15-25 1983
(2) Date of first reading of temporary convergence (TC) points	April 9, 1983	March 21, 1983	March 31, 1983	April 21, 19
(3) Date of first reading of permanent convergence (RC) points	April 20, 1983	July 12, 1983	April 7, 1983	May 6, 198
(4) Reading of TC points (inches) on date indicated	1.58 April 20, 1983	3.36 July 12, 1983	1.42 April 7, 1983	1.48 May 5, 1983
(5) Reading of RC points (inches) on date indicated	8.82 June 16, 1986	5.82 June 16, 1986	9.24 June 16, 1986	6.39 June 16, 198
(6) Total elapsed days of combined TC and RC measurements [Date for (5) - Date for (2)]	1166	1151	1176	1151
(7) Total measured closure (inches) [(4) + (5)]	10.40	9.18	10.66	7.87
(8) Estimated closure (inches) by regression analysis for the period of (2) - (1)	1.79	2.51	2.16	1.42
(9) Total estimated closure (inches) [(7) + (8)]	12.19	11.69	12.82	9.29

Table 11-9

TEST ROOMS
SUMMARY OF RESULTS OF REGRESSION ANALYSES
FOR WALL-TO-WALL CLOSURE RATES

Description	Test Room 1	2*	3	4
Regression Constants**				
A	202	222	231	1766
n	0.94	0.79	0.83	1.81
C_c	1.75	0.30	0.74	1.88
r^2	0.96	0.95	0.92	0.99

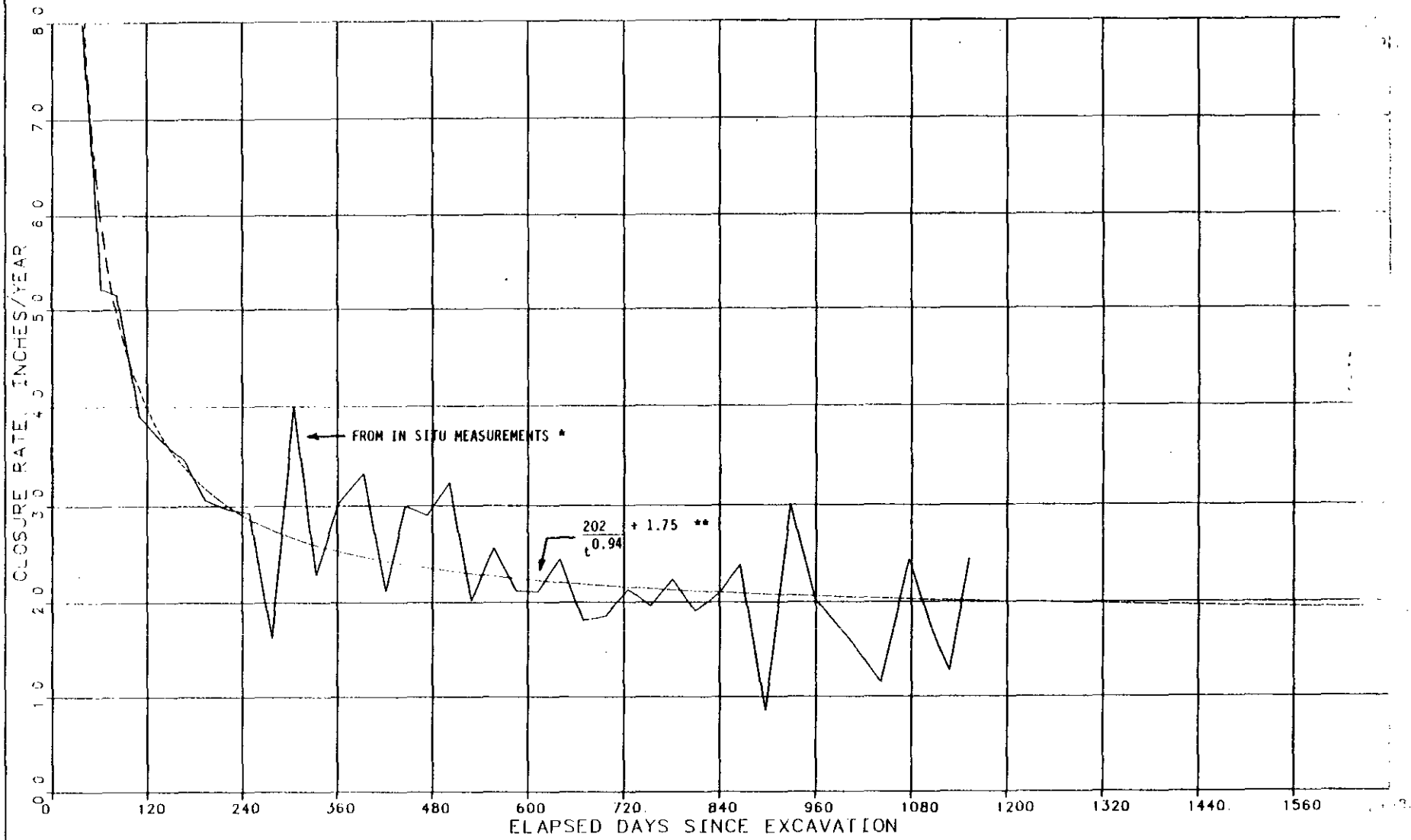
Note: Analyses based on data obtained through June 1986.

* Data used for regression analysis includes data from temporary convergence points.

** Equation is: $C(t) = \frac{A}{t^n} + C_c$

where: C(t) is closure rate in inches/year;
A and n are constants;
t is elapsed time in days; and
C_c is steady state closure rate.

r^2 is the coefficient of determination.

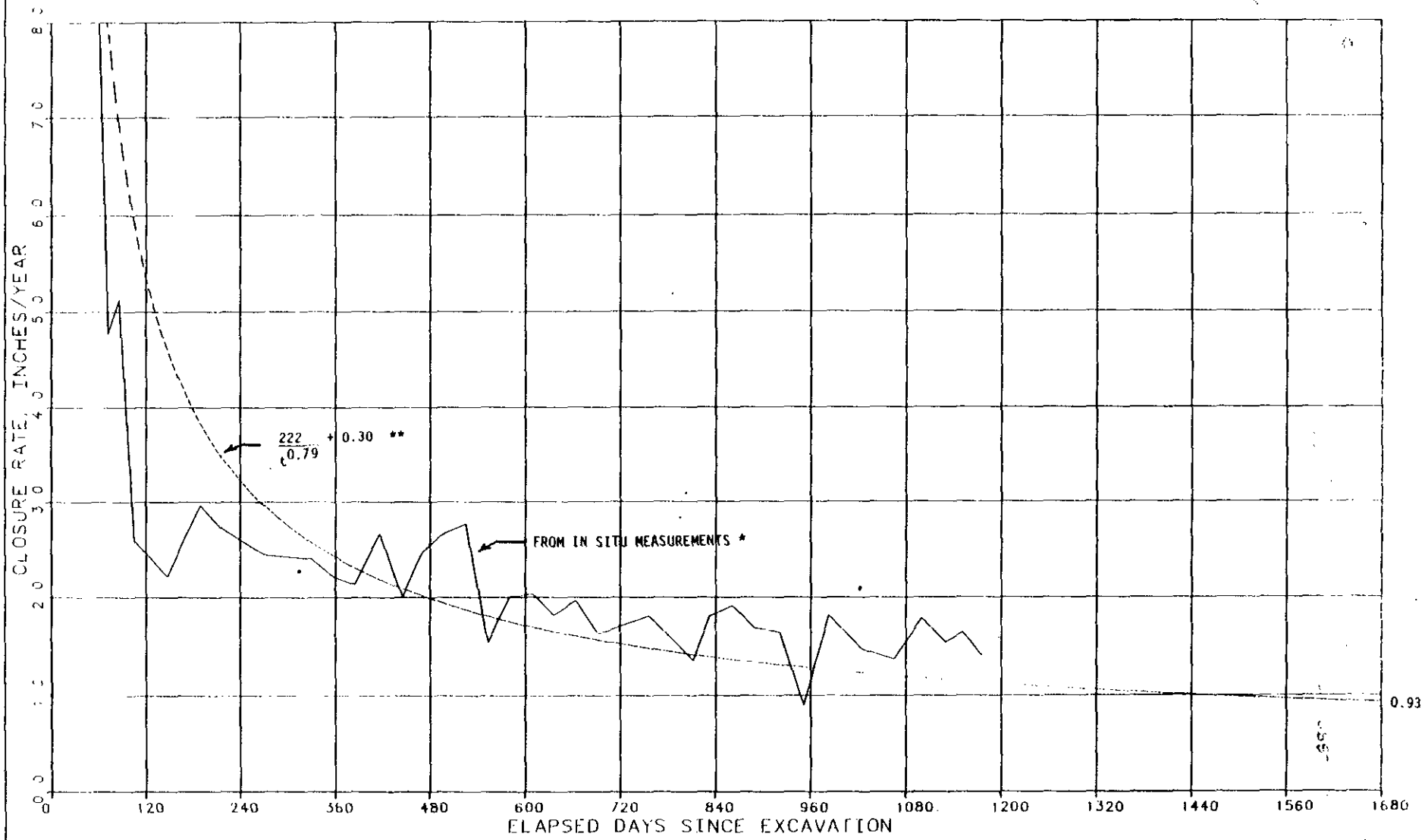


* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-13

TEST ROOM 1 WALL-TO-WALL CLOSURE
RESULTS OF REGRESSION ANALYS

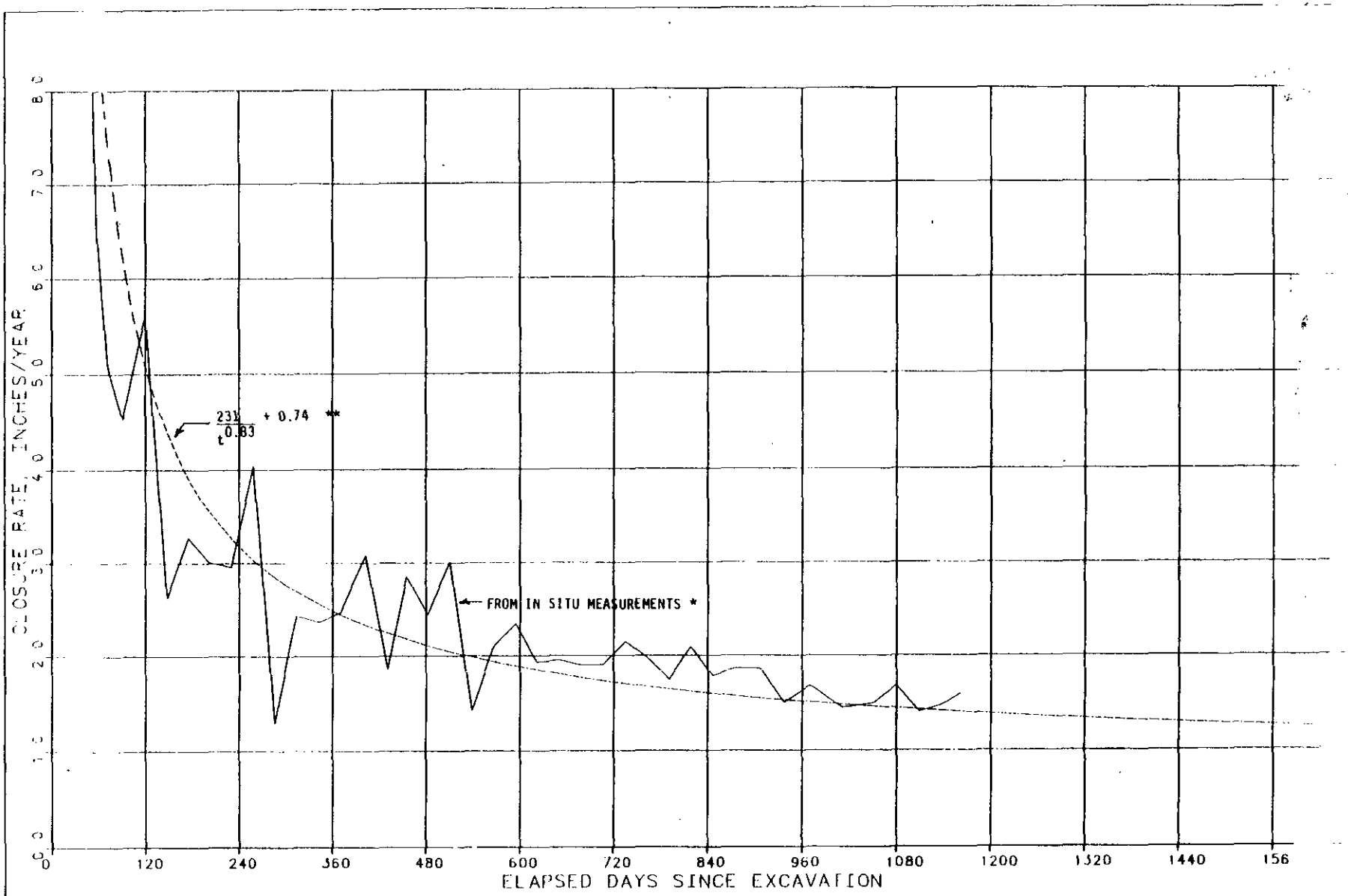


* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-14

TEST ROOM 2 WALL-TO-WALL CLOSURE RATE RESULTS OF REGRESSION ANALYSIS

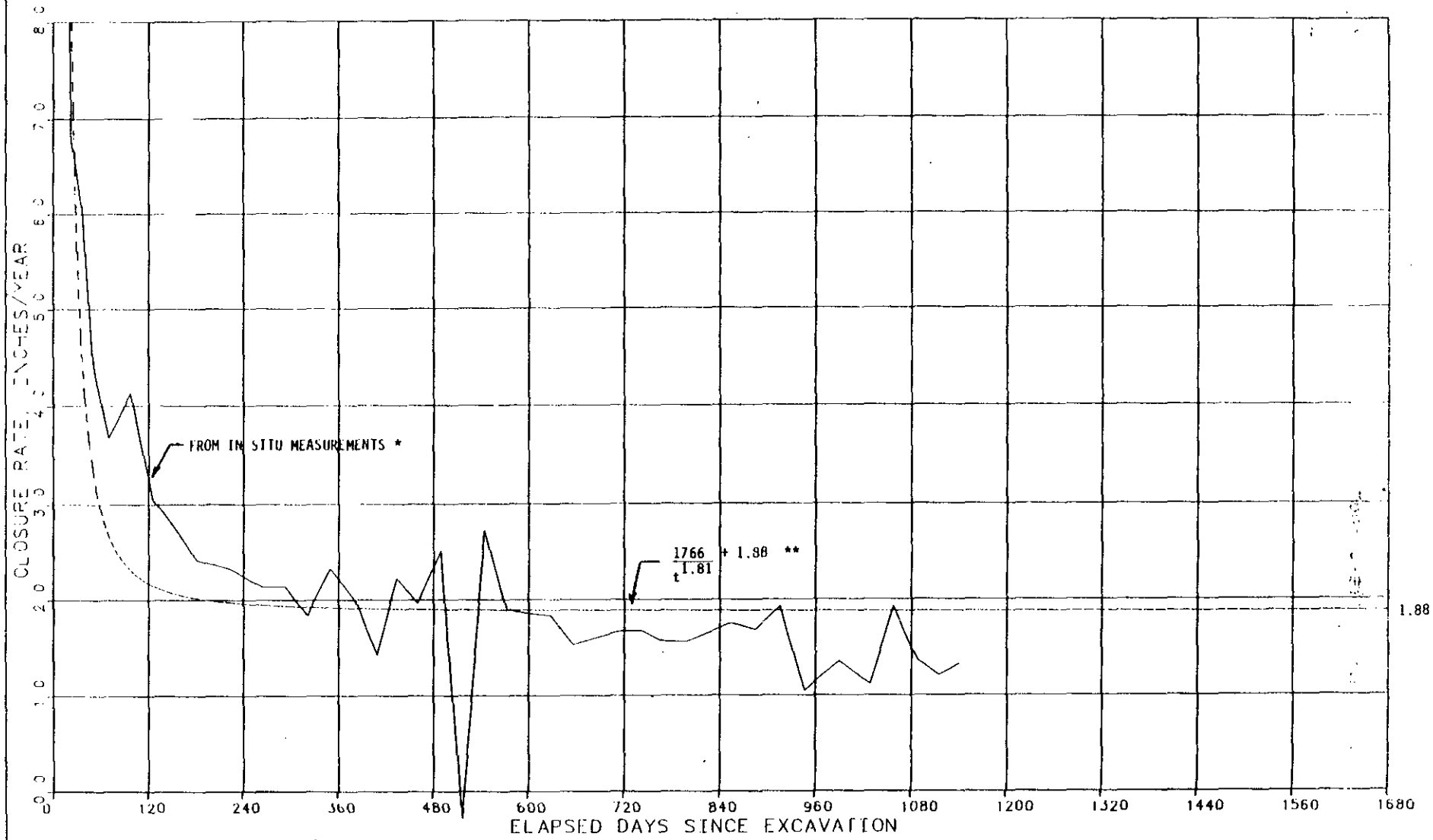


* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-15

TEST ROOM 3 WALL-TO-WALL CLOS
RESULTS OF REGRESSION ANAL



* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-16

TEST ROOM 4 WALL-TO-WALL CLOSURE RATE
RESULTS OF REGRESSION ANALYSIS

Summary of the collar multiple-point borehole extensometers in the test rooms. Because the extensometers could not be installed as soon as the excavation was completed, the collar readings do not reflect absolute closure. The table also shows the sum of the collar movements from both the east and west walls in each of the rooms except Test Room 3, which has no extensometer in the west wall. The last two columns of this table permit a comparison of the sum of the collar movements with wall-to-wall convergence point readings. Ideally, providing the salt is homogeneous, the central vertical lines of the pillars between Test Rooms 1 and 2 and Test Rooms 2 and 3 should be lines of symmetry with zero lateral strain. The deepest anchor at 50 feet for extensometers 51X-GE-00213 and 51X-GE-00215 should be expected to undergo negligible displacement. Therefore, the sum of the collar movements for Test Rooms 2 and 3 should be approximately the same as the wall-to-wall convergence point readings. As shown in Table 11-10, this is the case for Test Room 2. Exact equivalence is difficult to obtain because the collars of the extensometers are recessed into the wall by variable amounts and the time-lag between the end of excavation and the date of initial reading is not the same for the extensometers and the convergence points.

Comparison of Roof-to-Floor to Wall-to-Wall Closure Rates. Table 11-11 presents recent roof-to-floor and wall-to-wall closure rates for the test rooms. The rates were calculated using convergence point readings with a time interval of approximately 1 month. Based on these readings, the average wall-to-wall closure rate is approximately 68 percent of the roof-to-floor closure rate.

11.3.2.3 Deformation

An indication of the deformation of the salt around the test rooms may be obtained by comparing inclinometer measurements around a room. Figure 11-17 shows the cumulative measurements from the four wall inclinometers located around Test Room 3 through March 6, 1985. The inclinations are measured along the plane of the cross section.

Table 11-10

TEST ROOMS
WALL EXTENSOMETER COLLAR MOVEMENTS VERSUS CONVERGENCE POINT READINGS

Test Room	Extensometer	Location	Readings on June 13, 1986 (inches)	Sum of East & West Readings (inches)	Wall-to-Wall Convergence Point Readings on June 16, 1986 (inches)
1	51X-GE-00217	East wall	3.16	7.36	8.82*
	51X-GE-00219	West wall	4.20		
2	51X-GE-00213	East wall	4.95	9.52	9.18**
	51X-GE-00215	West wall	4.57		
3	51X-GE-00211	East wall	4.17	-	9.24*
	-	West wall	-		
4	51X-GE-00206	East wall	3.26	5.95	6.39*
	51X-GE-00208	West wall	2.69		

* From (5) in Table 11-8.
** From (7) in Table 11-8.

Table 11-11

TEST ROOMS
CLOSURE RATE COMPARISONS

Description of Closure Location	Test Room 1	2	3	4
Roof-to-Floor				
Reading/Date	12.88/May 16, 1986	12.03/May 16, 1986	13.65/Mar. 24, 1986	10.39/Mar. 24, 19
Reading/Date	13.11/June 13, 1986	12.20/June 13, 1986	13.83/Apr. 28, 1986	10.62/Apr. 28, 19
Difference in readings	0.23 inch	0.17 inch	0.18 inch	0.23 inch
Time interval	28 days	28 days	27 days	27 days
Rate ($\dot{V}$)	3.00 inch/yr	2.22 inch/yr	2.43 inch/yr	3.10 inch/yr
Wall-to-Wall				
Reading/Date	8.63/May 19, 1986	5.72/May 19, 1986	8.90/Mar. 24, 1986	6.09/Mar. 24, 1
Reading/Date	8.82/June 16, 1986	5.82/June 16, 1986	9.03/Apr. 28, 1986	6.22/Apr. 28, 19
Difference in	0.19 inch	0.10 inch	0.13 inch	0.13 inch

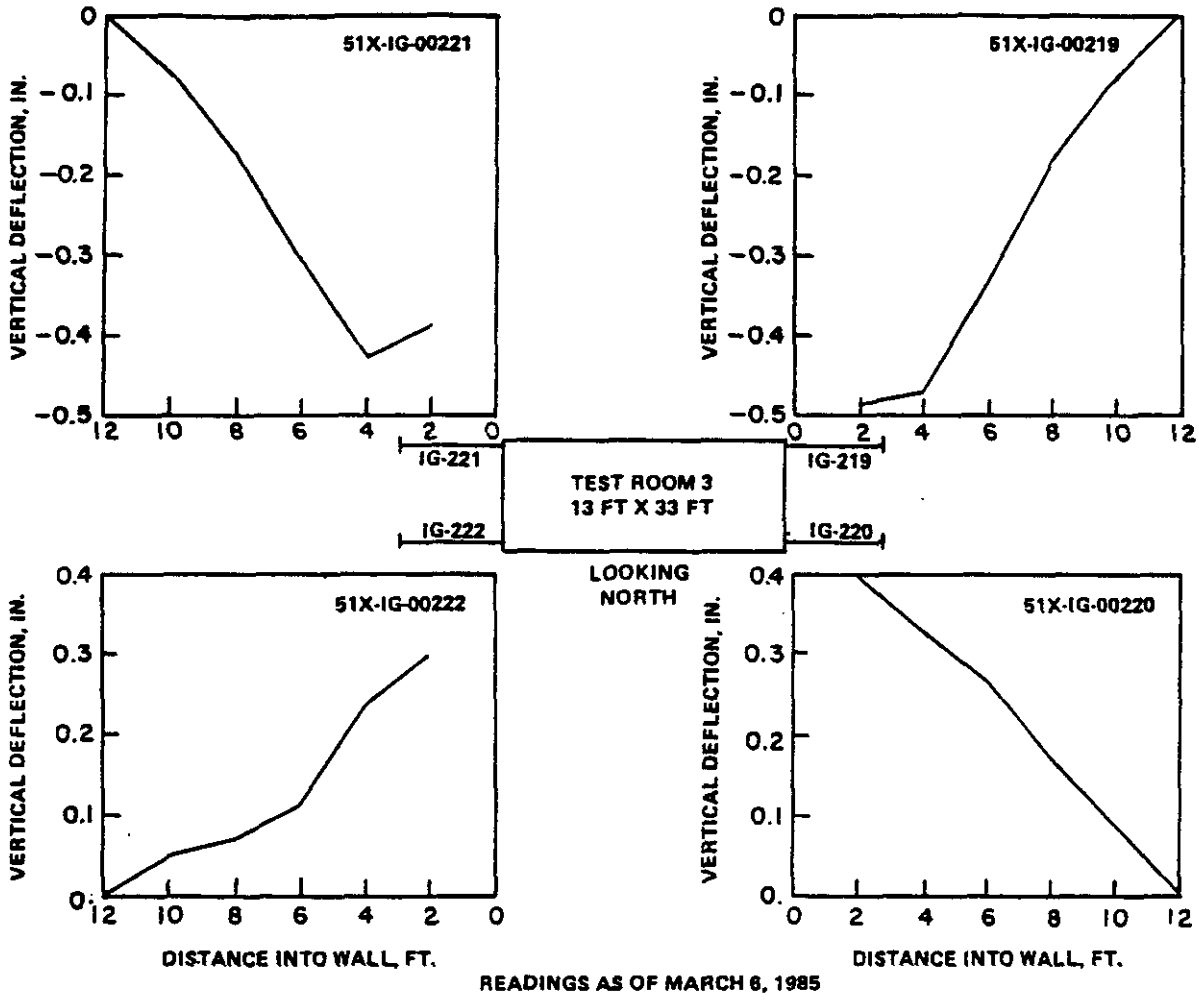


Figure 11-17

TEST ROOM 3
WALL INCLINOMETER BEHAVIOR

Figure 11-[illegible] shows [illegible] March 6, 1985. The initial readings from these inclinometers were taken 9 to 15 days after the completion of excavation in the test room. The current readings indicate that the maximum relative vertical deflection is on the order of 1 inch over a length of 12 feet.

The inclinometers near the roof show vertical downward deflection while those near the floor indicate upward deflection. This indicates that the central multiple-point borehole extensometers located in the walls of the test rooms probably undergo negligible vertical deflection.

11.3.2.4 Bay Strains

Relative movements between anchors of the multiple-point borehole extensometers will provide an approximate distribution of salt deformation around the excavated openings. The relative displacements are normalized over the spacing between anchors and are termed "bay strains". The bay strain is approximately the average axial strain between any two anchor points and will be closer to the true strain provided that the spacing between the anchors is small and that the deformation varies linearly with the spacing between the anchors. Bay strains are useful in detecting any anomalous behavior in the salt around an opening, such as that influenced by discontinuities, clay seams, or the effect of local stress concentrations.

Figure 11-19 shows the strain between the collar and anchor A for the roof extensometers in Test Room 1. The distance between the collar and anchor A is 5 feet. The maximum strain occurs at the east and west sides of the roof of the test room and is equal to approximately 4 percent through June 1986. Although the roof sag, as depicted by collar movement, is higher at the center of the rooms than at the sides, the bay strain is higher at the sides than at the center. As discussed in subsection 11.3.2.5, the numerical modeling also indicates higher strain at the roof and wall intersections. Figure 11-20 shows the vertical strain rates for these same extensometers. The rates are

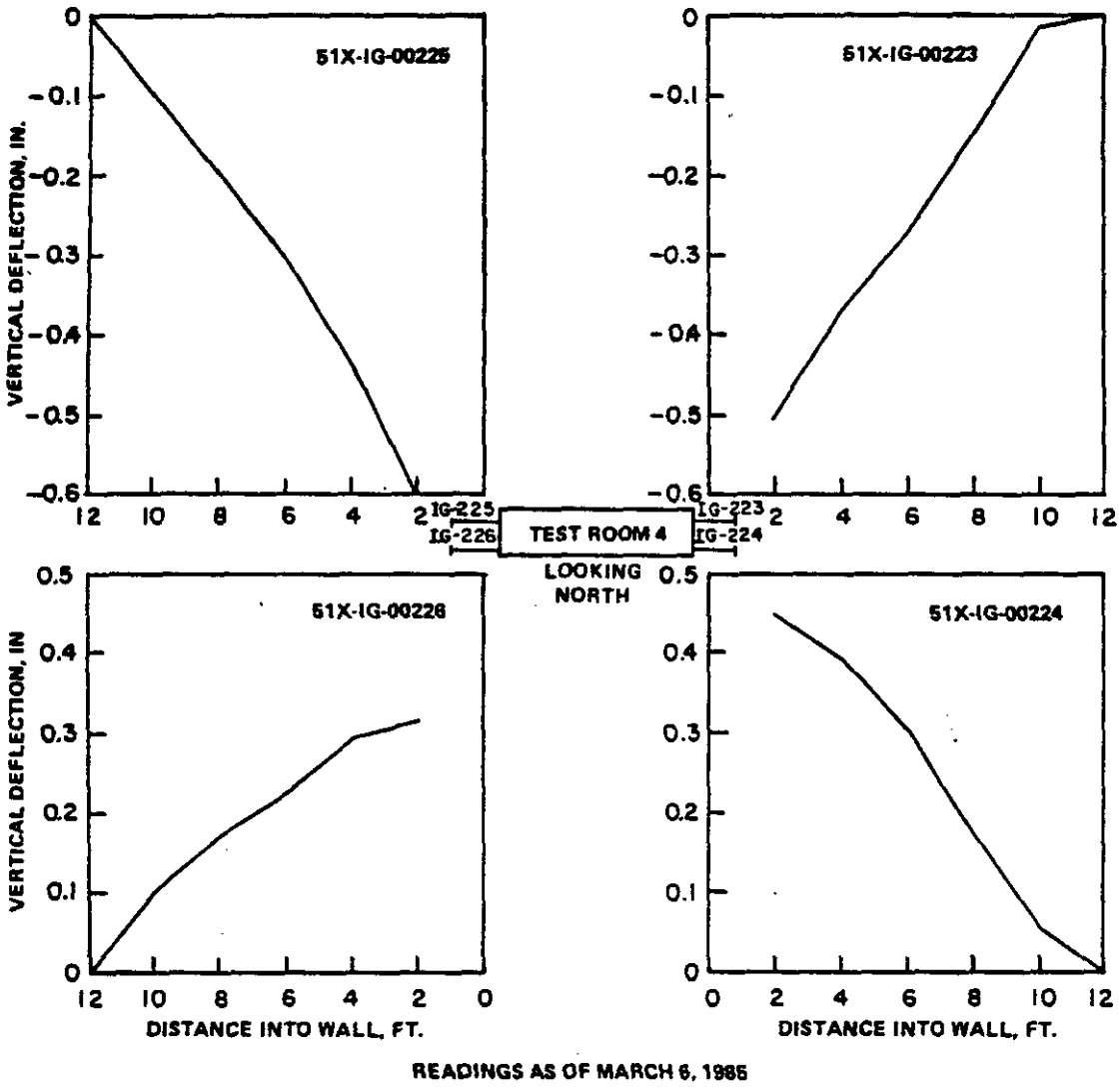


Figure 11-18

TEST ROOM 4
WALL INCLINOMETER BEHAVIOR

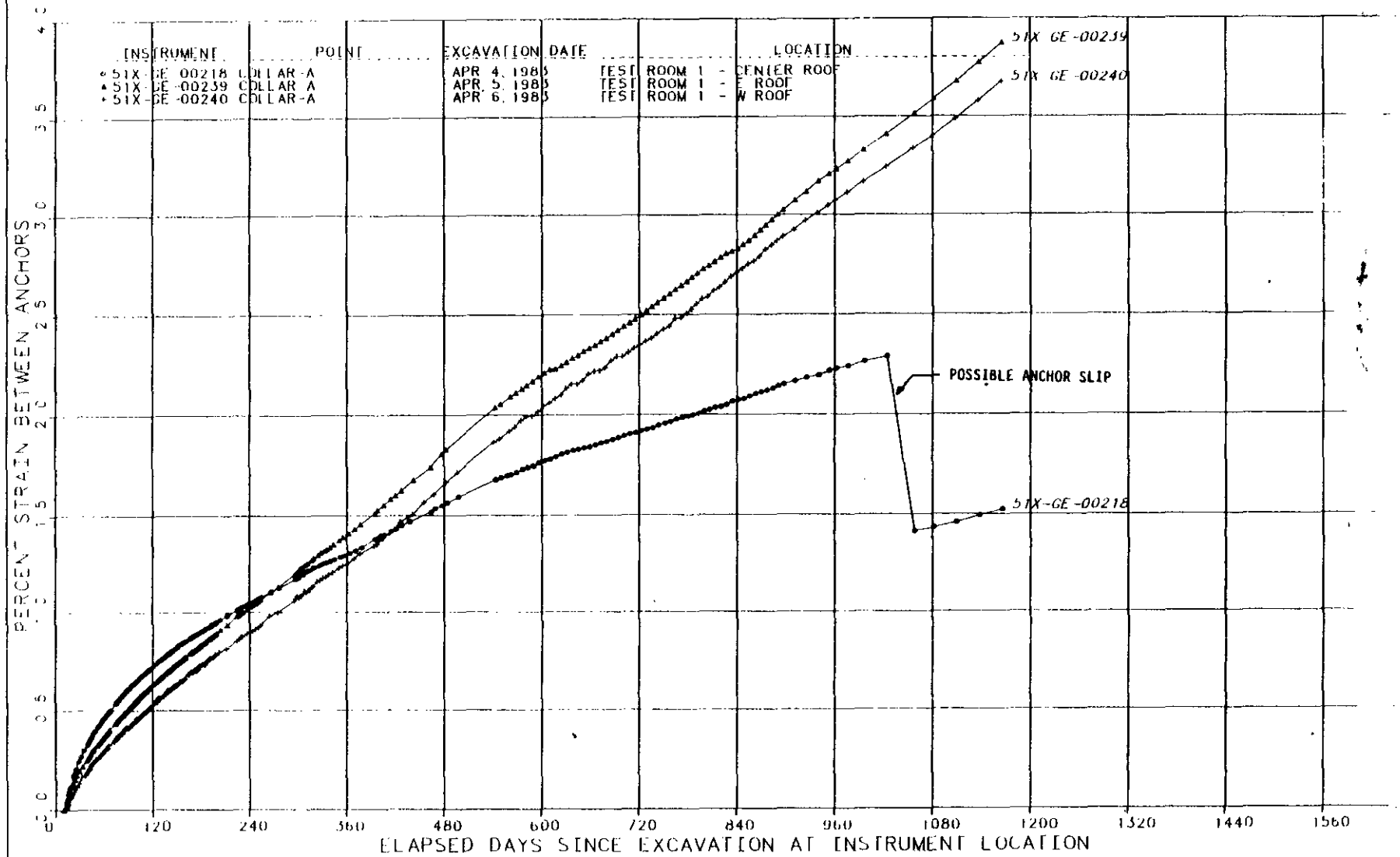
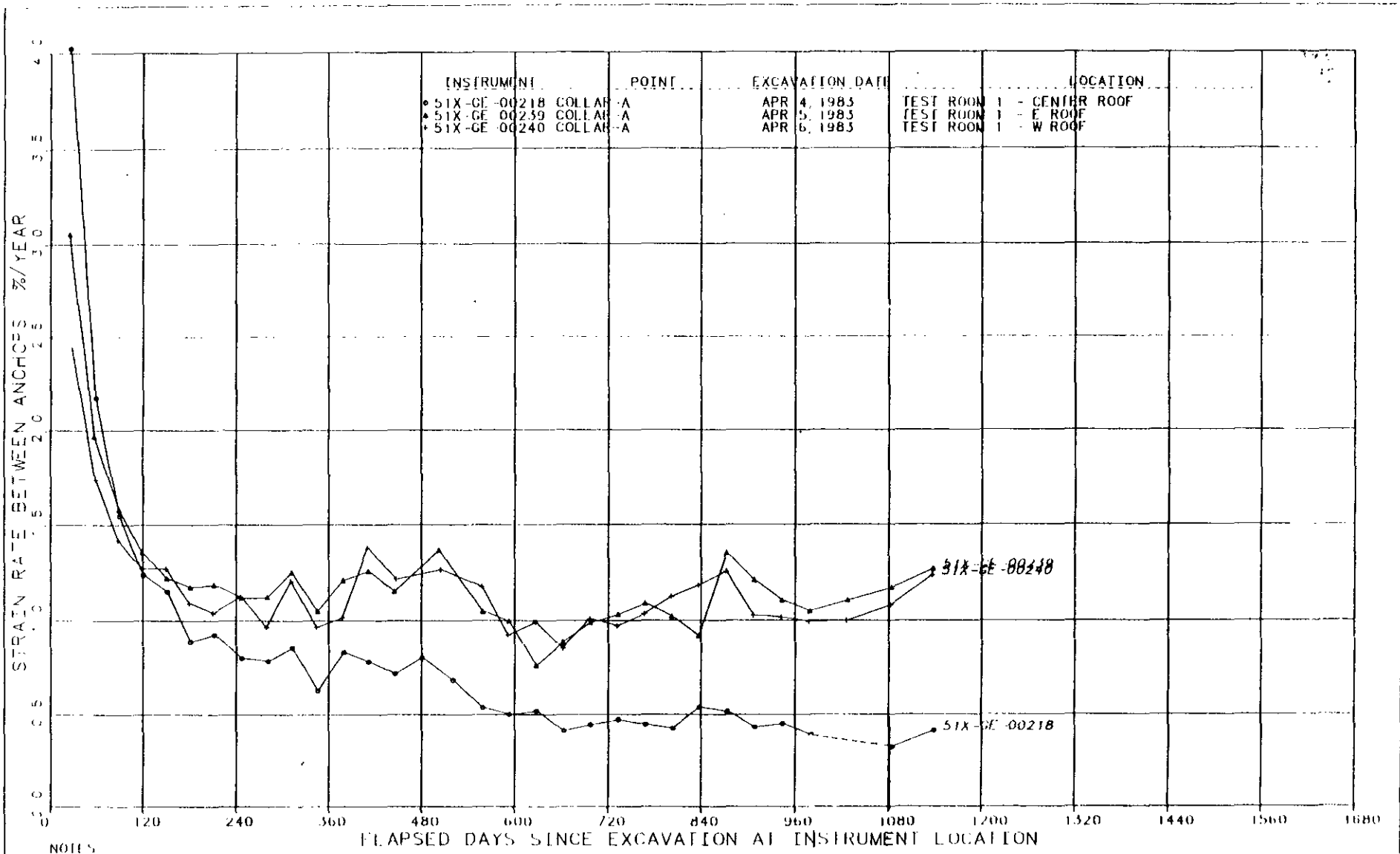


Figure 11-19

TEST ROOM 1 ROOF EXTENSOMETER STRAIN VERSUS TIME SINCE EXCA



NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

Figure 11-20

TEST ROOM 1 ROOF EXTENSOMETERS
STRAIN RATE VERSUS TIME SINCE EXCAVATION

...ne strains, the ...rain ... are higher close to the pillars.

Figures K-37 through K-46 in Appendix K show the bay strains in percent as a function of elapsed time since excavation for all of the test rooms. To monitor more closely the separation across the clay seam at the base of anhydrite "b", the spacing between anchors A and B in Test Rooms 1 and 2 is 1 foot. Currently, the maximum strain occurs between anchors A and B on the west side and central part of the roof in Test Room 1, and is on the order of 5 percent. Because the anchors are not equally spaced, and the deformation varies nonlinearly with the distance along the anchor, a comparison of bay strain between successive anchors may be misleading.

Figures K-47 through K-56 in Appendix K show the strain rate plots for all of the roof and floor extensometers. In general, the strain rate is decreasing with time, except for floor extensometer 51X-GE-00210 in Test Room 3 where, for anchor A, the strain rate increased with time until the extensometer failed (Figure K-42). The decreasing trend in the strain rates is an indication that the salt above the roof and below the floor is currenty stable and will remain stable based on the projected decreasing rate.

11.3.2.5 Model Simulation

As discussed in Chapter 5, Section 5.3, numerical analyses using creep constants obtained from laboratory tests did not provide a good correlation with in situ measured closure. Therefore, an engineering approach using curve fitting methods was employed. The finite element method was used to simulate the behavior of the test rooms and to determine stress distributions. The effects of material properties and the proximity to other rooms were considered for incorporation into the model. The reference stratigraphy used in the model and the material properties of the geologic layers are described in Chapter 6. The constitutive equations used in the analyses, particularly the governing creep equations, are presented in Appendix C. Using the procedures

described in Chapter 5, Section 5.4, in situ roof-to-floor closure data through June 30, 1985, were correlated with the finite element responses to determine the values of creep parameters C, A and z for each test room. In order to eliminate the effect of excavation sequence on computation of the creep parameters, only in situ data taken after the completion of all test room excavation activities were utilized. The average values of these parameters for the four test rooms were then used to predict the responses of the future storage rooms as described in Chapter 12.

Figure 11-21 shows the finite element model for the test room panel based on the reference stratigraphy. The model has 363 nodes and consists of 270 plane strain elements, with gap/friction link elements modeling a clay seam at a depth of 2,104.87 feet. A friction coefficient of 0.4 was used for a member property of the gap/friction link elements. MB-139 was modeled as an elastic layer from a depth of 2,130.36 to 2,133.18 feet. The top and bottom boundaries of the model are at depths of 1,978.5 feet and 2,250.0 feet, respectively. The roof and floor of the room are at depths of 2,112.56 feet and 2,125.56 feet, respectively.

Two openings were incorporated in the finite element model to simulate differences resulting from the proximity of inner and outer rooms. These openings were modeled using height and width dimensions of 13 feet and 33 feet respectively. The boundary on one side of the model was taken as the vertical axis of symmetry for the center pillar and consists of horizontal restraints. The boundary on the other side of the model also utilized horizontal restraints. These boundaries were established based on experience from previous analyses and were extended far enough so that the effects of the boundaries on the structural responses were minimal. Stress boundary conditions were used at the top and bottom of the finite element model. A single vertical restraint at the lower left corner of the model was used to eliminate any rigid body modes in the model.

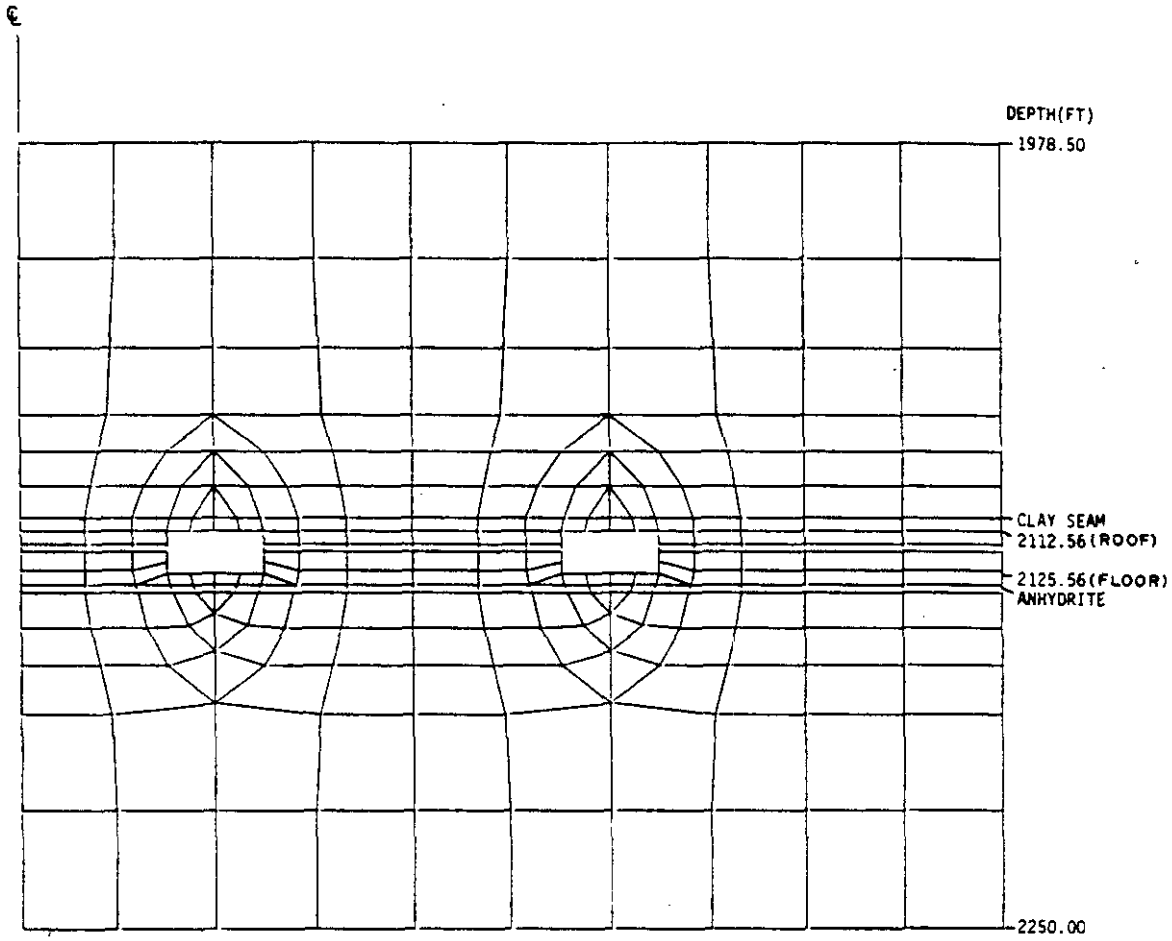


Figure 11-21

TEST ROOMS
FINITE ELEMENT MODEL

Element sizes were proportioned to minimize the stress gradients across each element. In addition, elements were oriented to have the mesh radiating from the opening of the model to be commensurate with estimated orientations of the principal stress axes. These aspects of the model were designed to increase the overall efficiency of the analyses.

Computation of In Situ Responses and Creep Parameters. The test room analyses were performed using the procedures described in Chapter 6 and the MARC General Purpose Finite Element Program (ref. 6-8). Time steps used in the analyses were within the specified tolerances recommended by the MARC Program. The analysis was performed in several stages with each stage containing between 50 and 100 integration steps. After completing each stage, the corresponding real time was computed to determine the required number of integration steps for the subsequent runs.

Figures 11-22 through 11-25 show the correlations of in situ and analytical roof-to-floor closures for Test Rooms 1 through 4. The in situ roof-to-floor closure data for Test Rooms 1 and 2 are from convergence meter readings while the measurements for Test Rooms 3 and 4 are from convergence points. Table 11-12 shows the individual creep parameters C, A and z for all four test rooms determined by numerically correlating the in situ roof-to-floor closure data. The table also shows the mean values of the creep parameters for three test room combinations.

Similarly, Figures 11-26 through 11-29 show the correlations of in situ and finite element wall-to-wall closures for Test Rooms 1 through 4. The in situ wall-to-wall closure data for Test Rooms 1, 3 and 4 are from permanent convergence points while the data from Test Room 2 consists of both temporary and permanent convergence point measurements. Table 11-13 shows the individual creep parameters C, A and z for all four test rooms determined by numerically correlating the in situ wall-to-wall closure data. The table also shows the mean values of the creep parameters for three test room combinations.

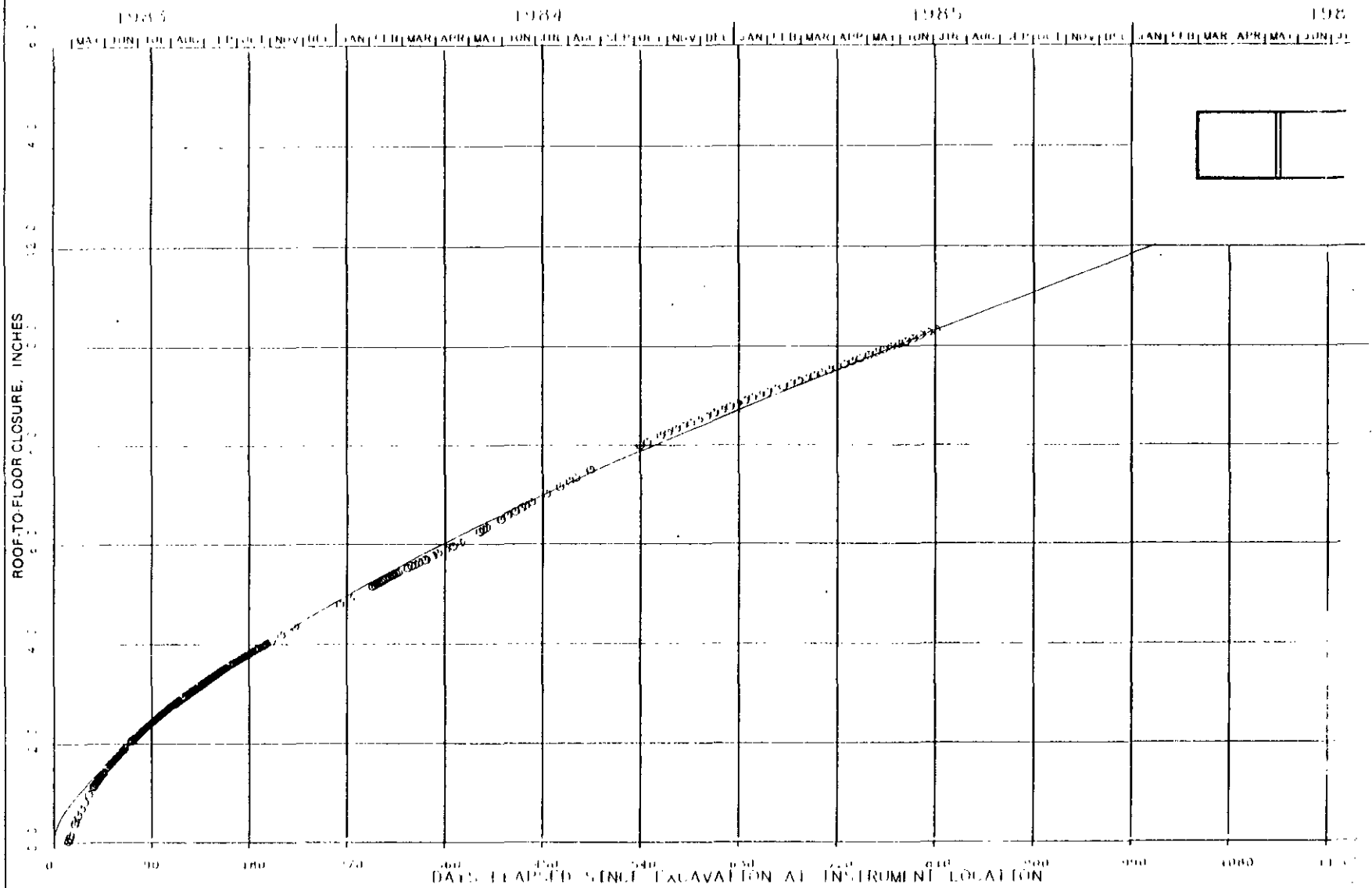


Figure 11-22

TEST ROOM 1
ROOF-TO-FLOOR CLOSURE HISTOR

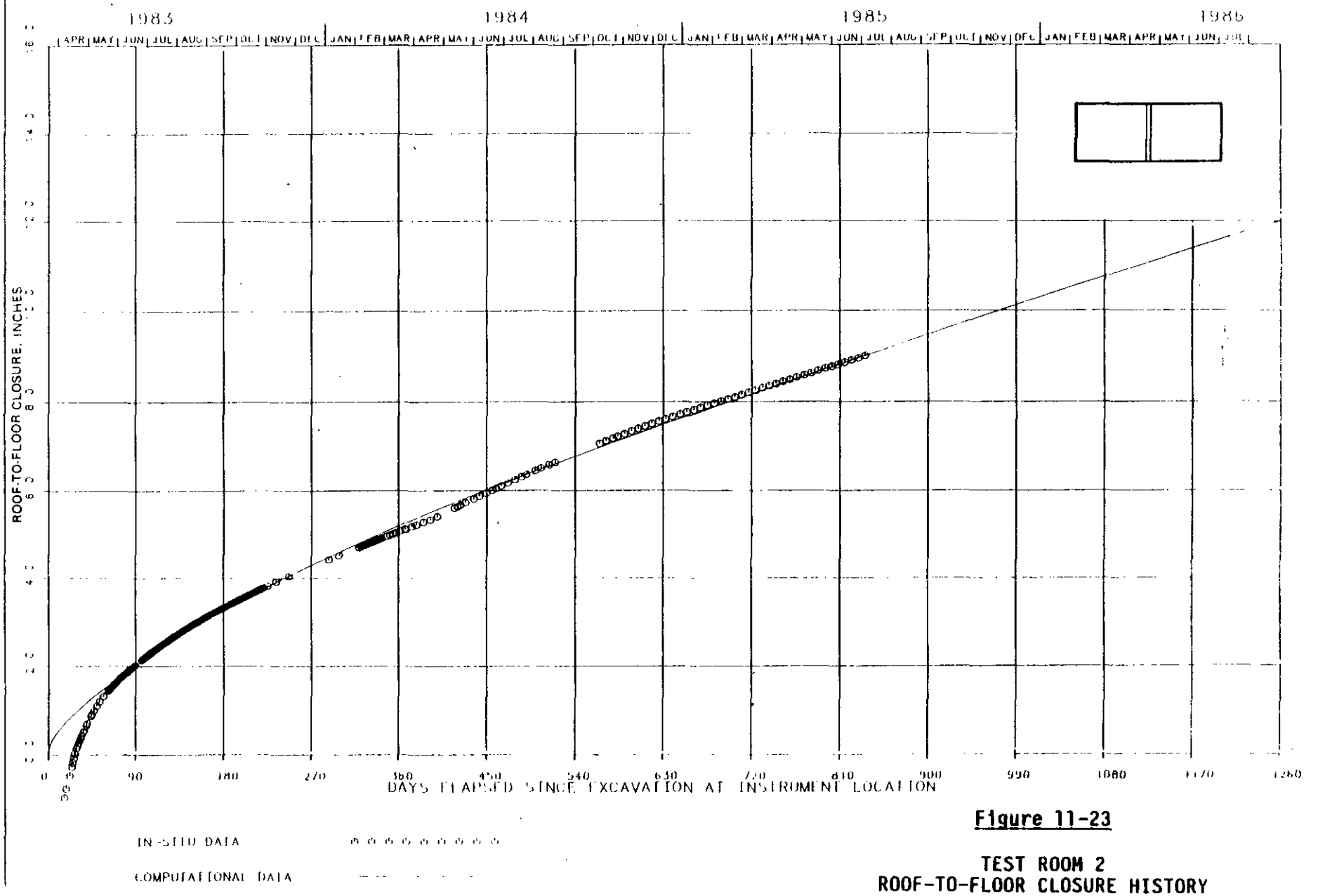


Figure 11-23

TEST ROOM 2
ROOF-TO-FLOOR CLOSURE HISTORY

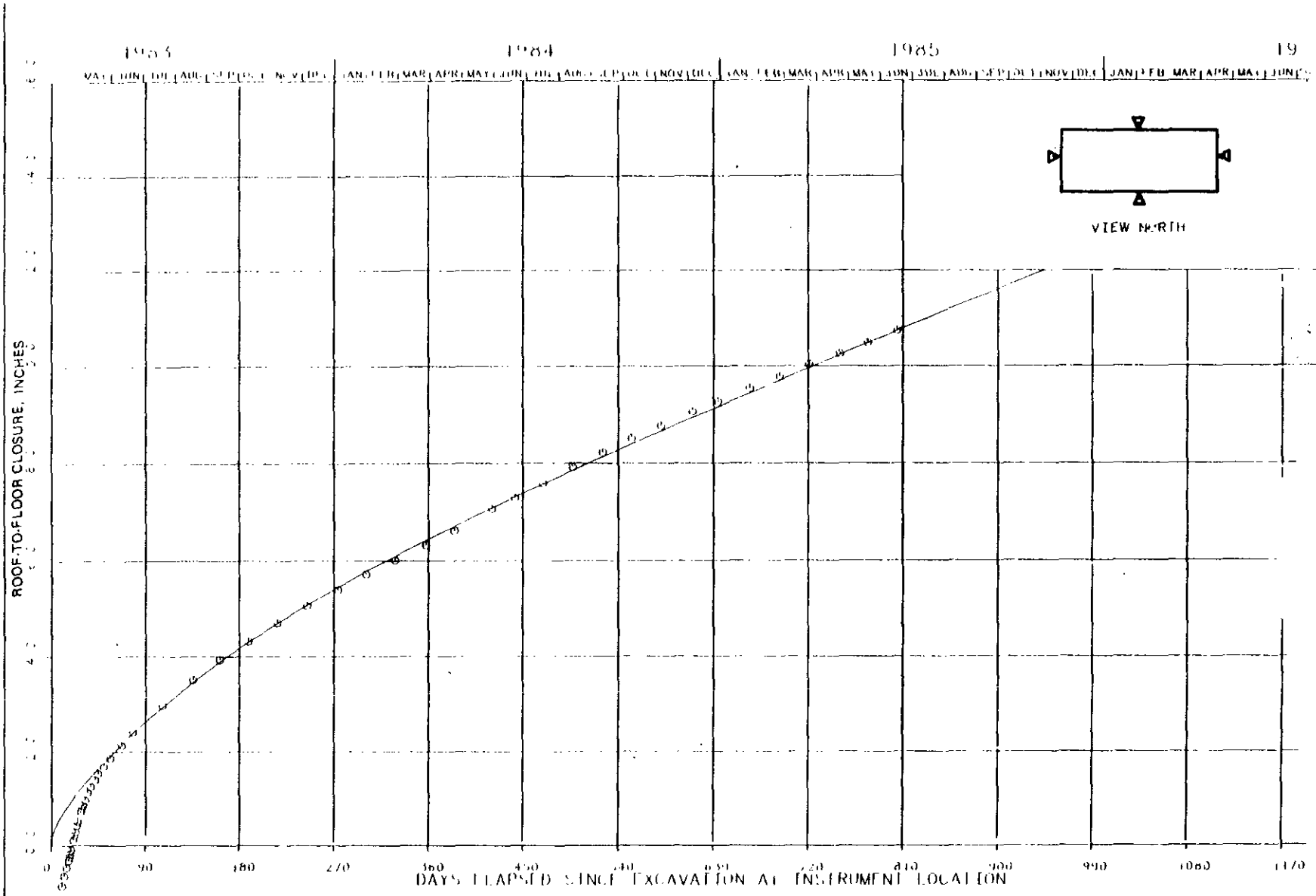


Figure 11-24

TEST ROOM 3
ROOF-TO-FLOOR CLOSURE HISTO

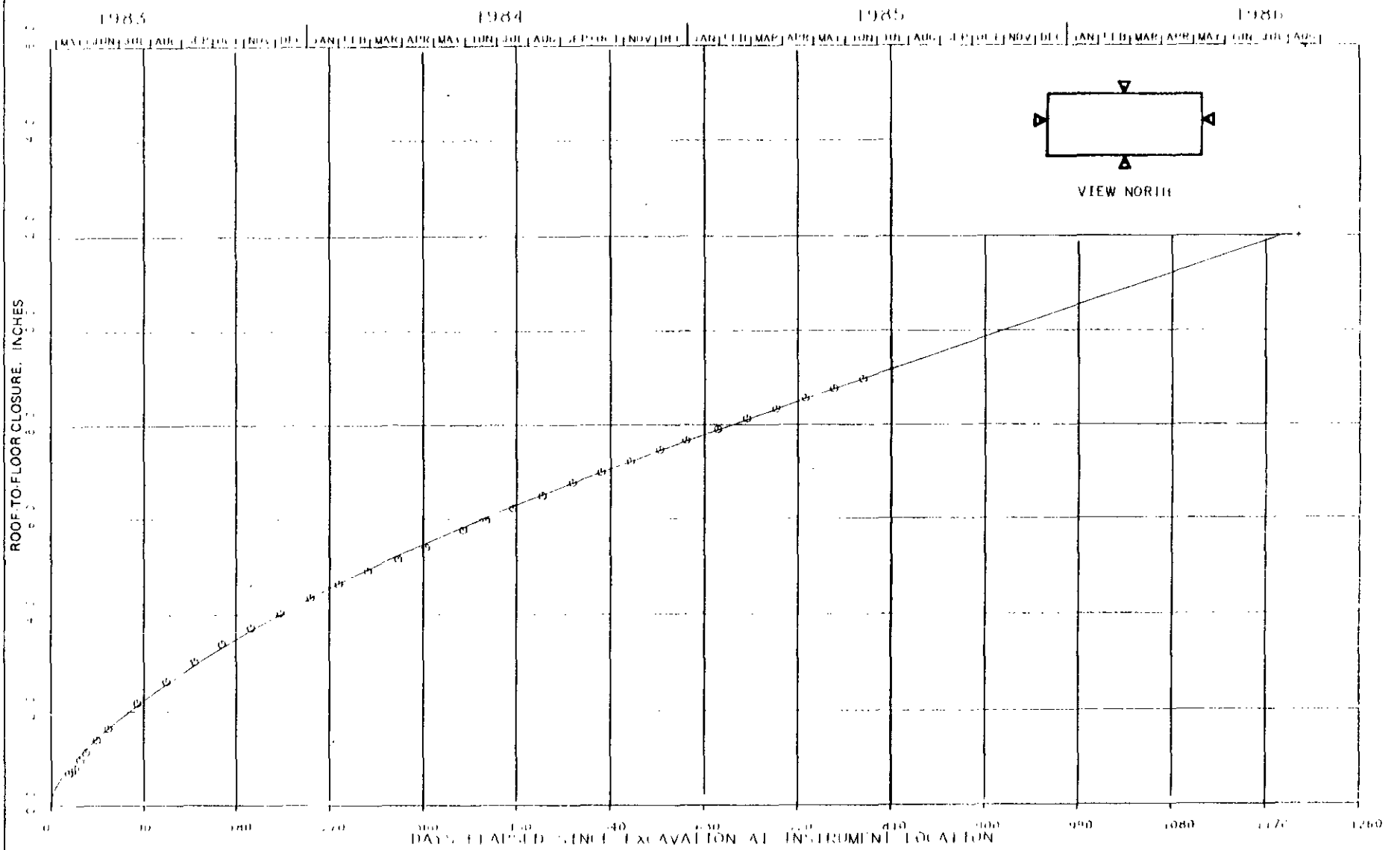


Figure 11-25

TEST ROOM 4
ROOF-TO-FLOOR CLOSURE HISTORY

TEST ROOM CREEP PARAMETERS
DETERMINED FROM ROOF-TO-FLOOR CLOSURES

Test Room	C ($ksf^{-4.9}sec^{-1}$)	A	z (sec^{-1})
1	3.103×10^{-21}	1.593	4.670×10^{-8}
2	1.919×10^{-21}	1.712	4.782×10^{-8}
3	2.516×10^{-21}	2.077	7.268×10^{-8}
4	2.813×10^{-21}	1.712	5.572×10^{-8}
Mean $\bar{X}$ (Rooms 1 thru 4)	2.588×10^{-21}	1.774	5.573×10^{-8}
Mean $\bar{X}$ (Rooms 1 & 4)	2.958×10^{-21}	1.653	5.121×10^{-8}
Mean $\bar{X}$ (Rooms 2 & 3)	2.218×10^{-21}	1.895	6.025×10^{-8}

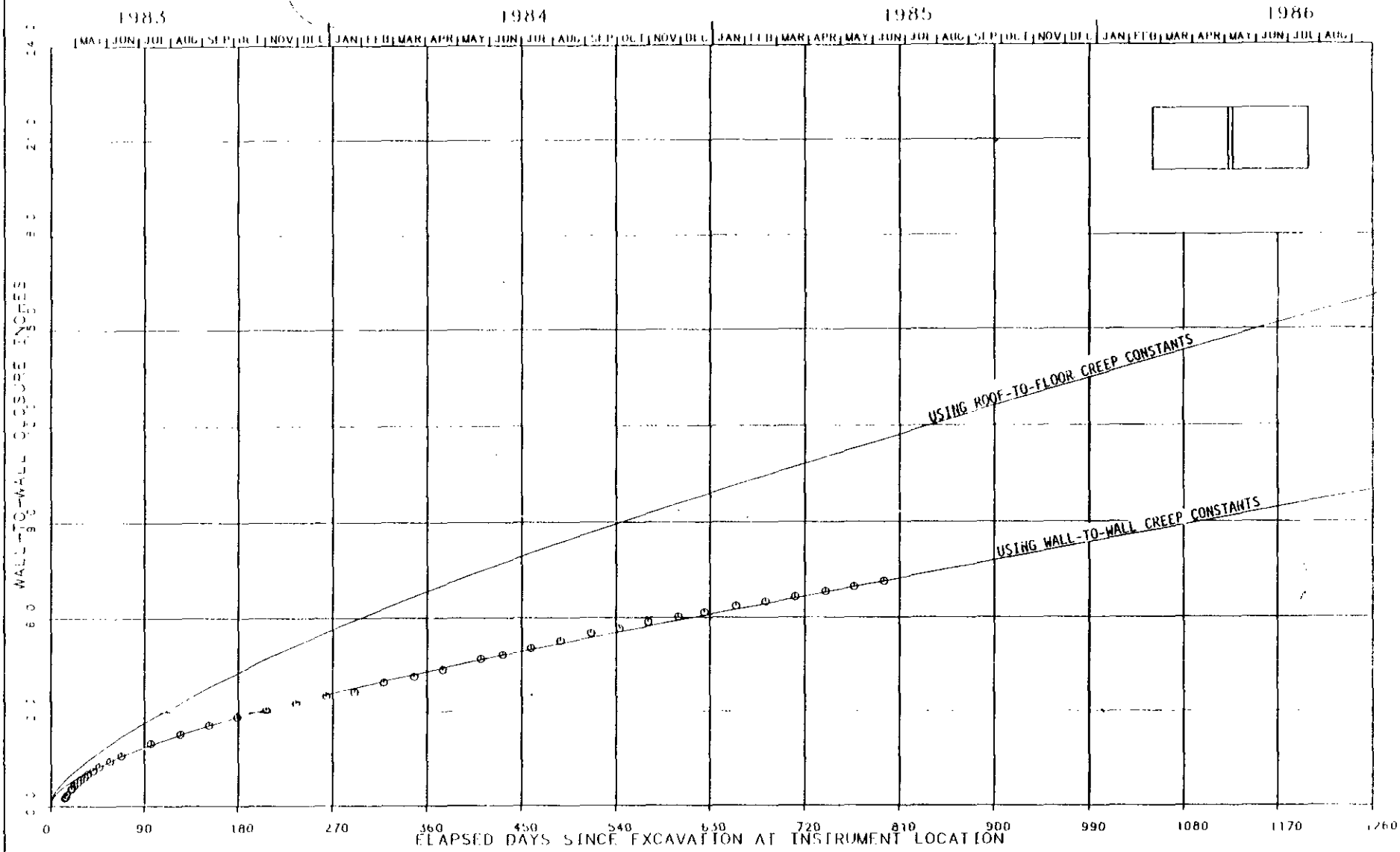


Figure 11-26

TEST ROOM 1
WALL-TO-WALL CLOSURE HISTORY

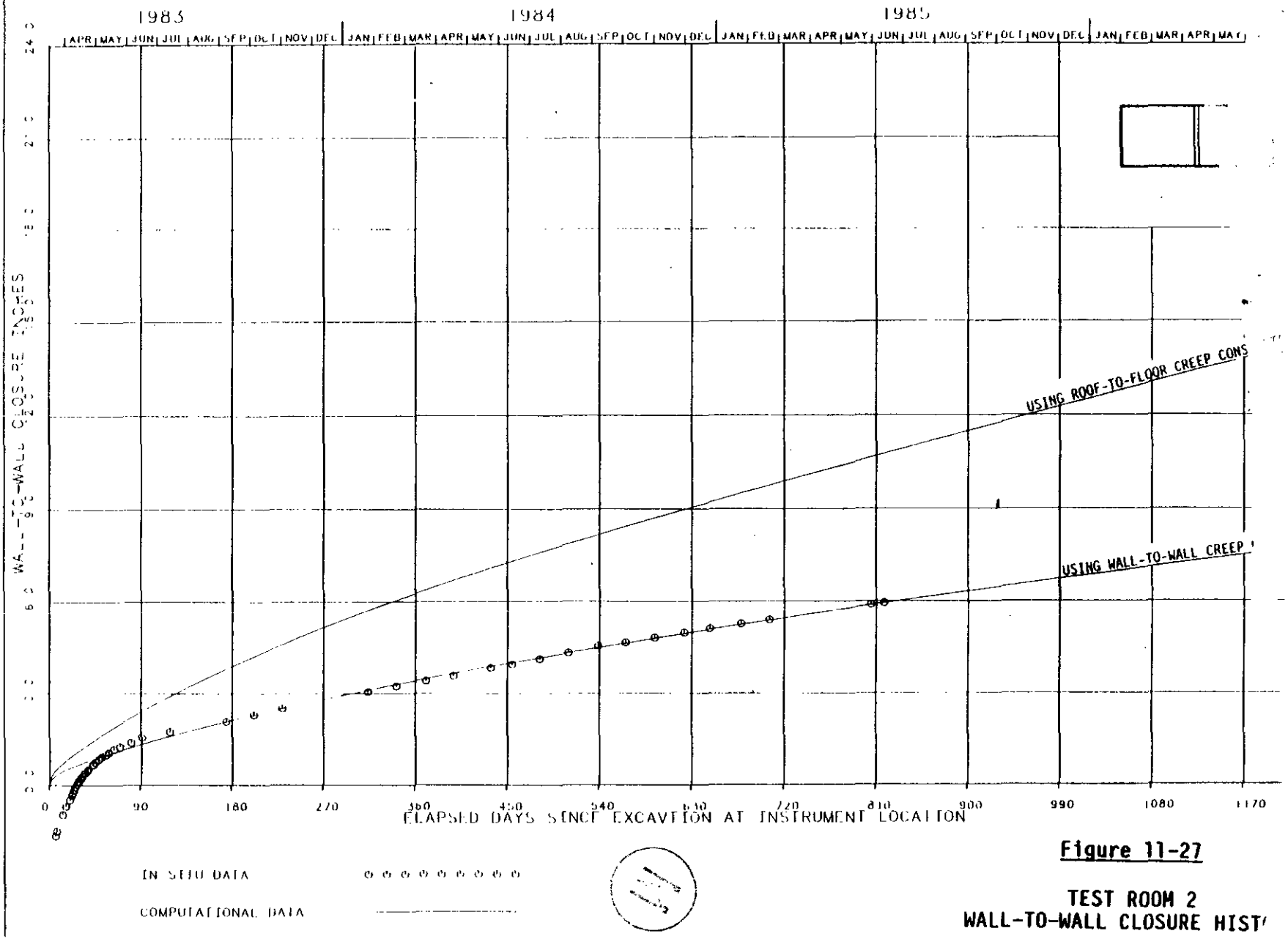


Figure 11-27

TEST ROOM 2
WALL-TO-WALL CLOSURE HIST

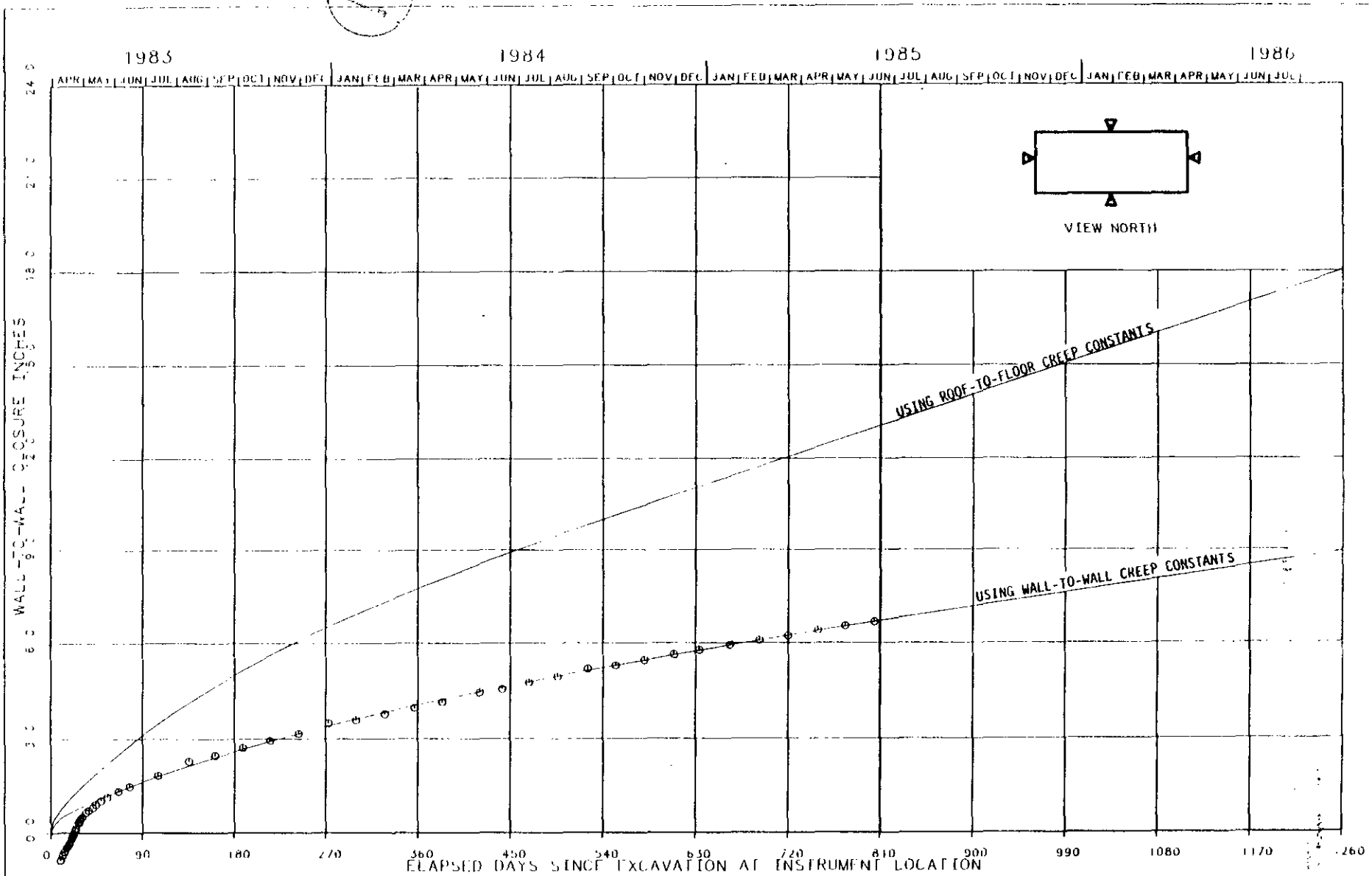


Figure 11-28

TEST ROOM 3
WALL-TO-WALL CLOSURE HISTORY

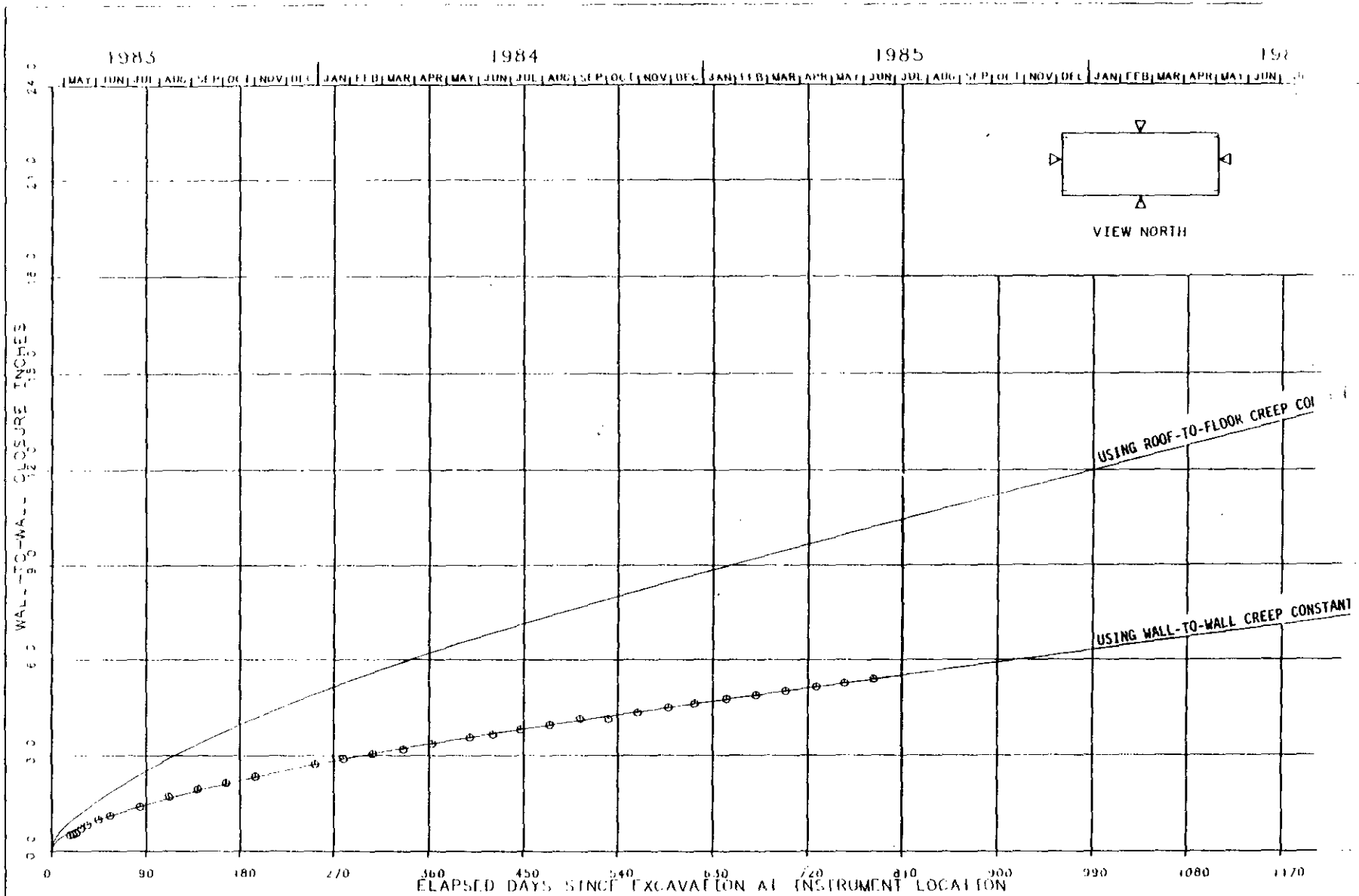


Figure 11-29

TEST ROOM 4
WALL-TO-WALL CLOSURE HIST

Table 11-13

TEST ROOM CREEP PARAMETERS
DETERMINED FROM WALL-TO-WALL CLOSURES

Test Room	C ($ksf^{-4.9}sec^{-1}$)	A	z (sec^{-1})
1	2.054×10^{-21}	1.502	6.810×10^{-8}
2	0.850×10^{-21}	1.630	2.476×10^{-8}
3	1.095×10^{-21}	1.920	4.464×10^{-8}
4	1.444×10^{-21}	1.419	5.276×10^{-8}
Mean $\bar{X}$ (Rooms 1 thru 4)	1.361×10^{-21}	1.618	4.757×10^{-8}
Mean $\bar{X}$ (Rooms 1 & 4)	1.749×10^{-21}	1.461	6.043×10^{-8}
Mean $\bar{X}$ (Rooms 2 & 3)	0.973×10^{-21}	1.775	3.470×10^{-8}

[illegible] and 11-30, the creep [illegible] the test rooms using roof-to-floor closure values vary slightly from the values obtained using wall-to-wall closure values. To illustrate these variations, the upper curves on Figures 11-26 through 11-29 show the wall-to-wall finite element responses using creep parameters determined from roof-to-floor numerical correlations. The discrepancy may be partly due to material anisotropy of the salt which is not taken into account in the constitutive relationship for the salt. However, the most important contributor to the discrepancy may be the behavior of the clay seams and anhydrite beds. The model also does not include the complete effects of anisotropic creep behavior due to the combination of different layers in the actual stratigraphy. This behavior, due to anisotropic geometry, can be shown using a simple one-dimensional model similar to the one used by Branstetter et. al. (ref. 11-3). Consider a block of halite containing N horizontal layers with equal thickness. The creep law for each of the layers is assumed to be

$$\dot{\varepsilon}_c = f_i(t)\sigma^{-n} \qquad i = 1, 2, \ldots\ldots N \qquad (11\text{-}12)$$

The equivalent vertical creep function computed by considering only the creep relation in the vertical direction can be expressed as

$$f_v(t) = \frac{\sum_{i=1}^{N} f_i(t)}{N} \qquad (11\text{-}13)$$

However, the equivalent horizontal creep function computed by considering only the horizontal direction becomes

$$f_h(t) = \left[\sum_{i=1}^{N} f_i(t)^{-\frac{1}{n}} \right]^{-n} N^n \qquad (11\text{-}14)$$

It was found that, for any problem in which $f_i(t)$ varies, the value of the equivalent creep function in the horizontal direction, based on

equation 11-14, is lower than the value in the vertical direction, based on equation 11-13.

Replication of in situ creep behavior by the finite element model would require extensive research into the existing constitutive equations and perhaps modification of the MARC Finite Element Program. It is believed that the present methodology can adequately predict the roof-to-floor and wall-to-wall closures within acceptable engineering accuracy and that further work into anisotropic creep behavior is not justified for design validation.

One method of determining the structural adequacy of the salt is by using the effective strain. Model simulation of Test Room 2 behavior showed that the effective strain reached a maximum value at the intersections of the walls with the roof and floor. As discussed in subsection 11.3.2.4, bay strains in the vertical direction, determined from roof and floor extensometer data, are on the order of 5 percent through June 1986. Field observations of the test room walls have not found any structural failure at these strain values. Occasional minor, shallow spalls are a continuing occurrence, especially along the upper portion of geologic map unit 4.

Based on the results of the model simulation of Test Room 2, the maximum effective strain at the roof and wall intersection will be 6 percent about 15 years after excavation. The corresponding average vertical strain over a 2-foot thickness of salt will be 15 percent. However, effective strain is not directly measurable. At best, only vertical or horizontal strains can be determined from multiple-point borehole extensometer measurements. A comparison of the predicted vertical strain with the vertical strain determined from the relative displacement between the collar and anchor A of the roof extensometers has been made. Because the collar and anchor A are 5 feet apart, the strain calculated from the relative displacements will be an average value. Similarly, the strain from three elements spanning the collar to anchor A interval were summed and averaged for comparison.

shows the [illegible] the roof and wall intersection. Although [illegible] is expressed in terms of t*, the relationship between t* and the real time t is approximately linear. The strain determined from the collar to anchor A readings indicates that the rate is currently decreasing with time.

Figure 11-31 shows the relationship for the center of the roof. This rate is also decreasing with time, even though the numerical analysis shows a constant rate.

11.3.2.6 Effectiveness of Model Simulation

The procedure discussed in the previous subsection and in Chapter 5 used roof-to-floor closure data for the test rooms to calculate the creep parameters C, A and z. Extrapolation of creep behavior was then accomplished using these derived creep parameters.

The numerical analysis gives the displacements of nodal points and stresses within the elements. The effectiveness of the model used can be checked by comparing measurement data other than roof-to-floor closure with the magnitude predicated by the model. For example, relative displacements between anchor points in multiple-point borehole extensometers may be compared with predicted relative displacements between appropriate nodes of the model. Such a comparison will be helpful to assess the effectiveness of model simulation.

Because a symmetrical two-room model representing four rooms was used for model simulation, the relative displacement between the collar and the deepest anchor of the central roof extensometers in Test Rooms 1 and 4 were calculated for an interval of 60 days, and the average value determined. The real time t was converted to the normalized time t* using equation C.4-17 in Appendix C. This is because the numerical analysis was performed in terms of the normalized time. The vertical displacements of appropriate nodes in the finite element model, which approximately duplicate the collar and the deepest anchor of the roof extensometers, were compiled. If the nodes did not exactly match the

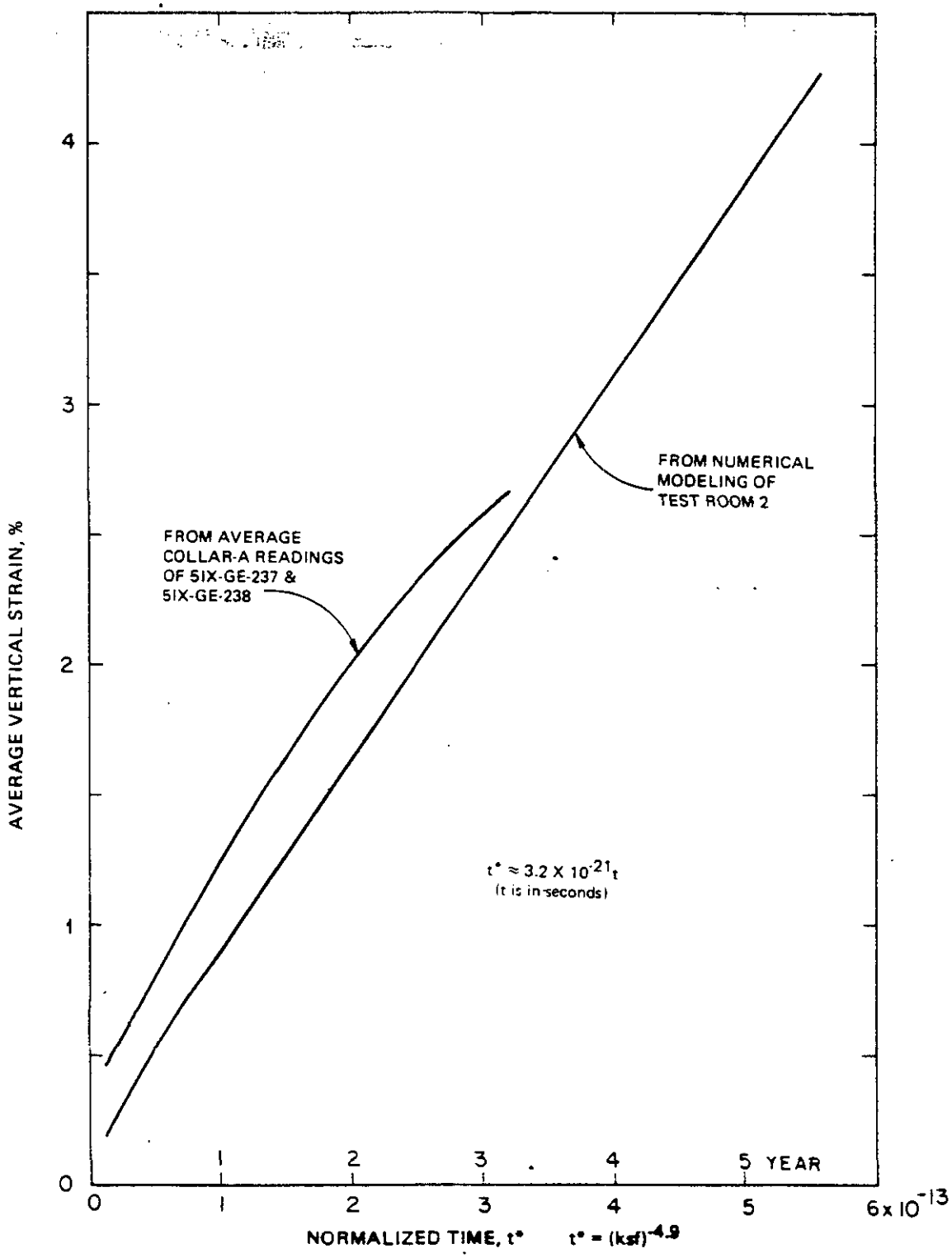


Figure 11-30

TEST ROOM 2
VERTICAL STRAIN AT ROOF AND PILLAR CORNER

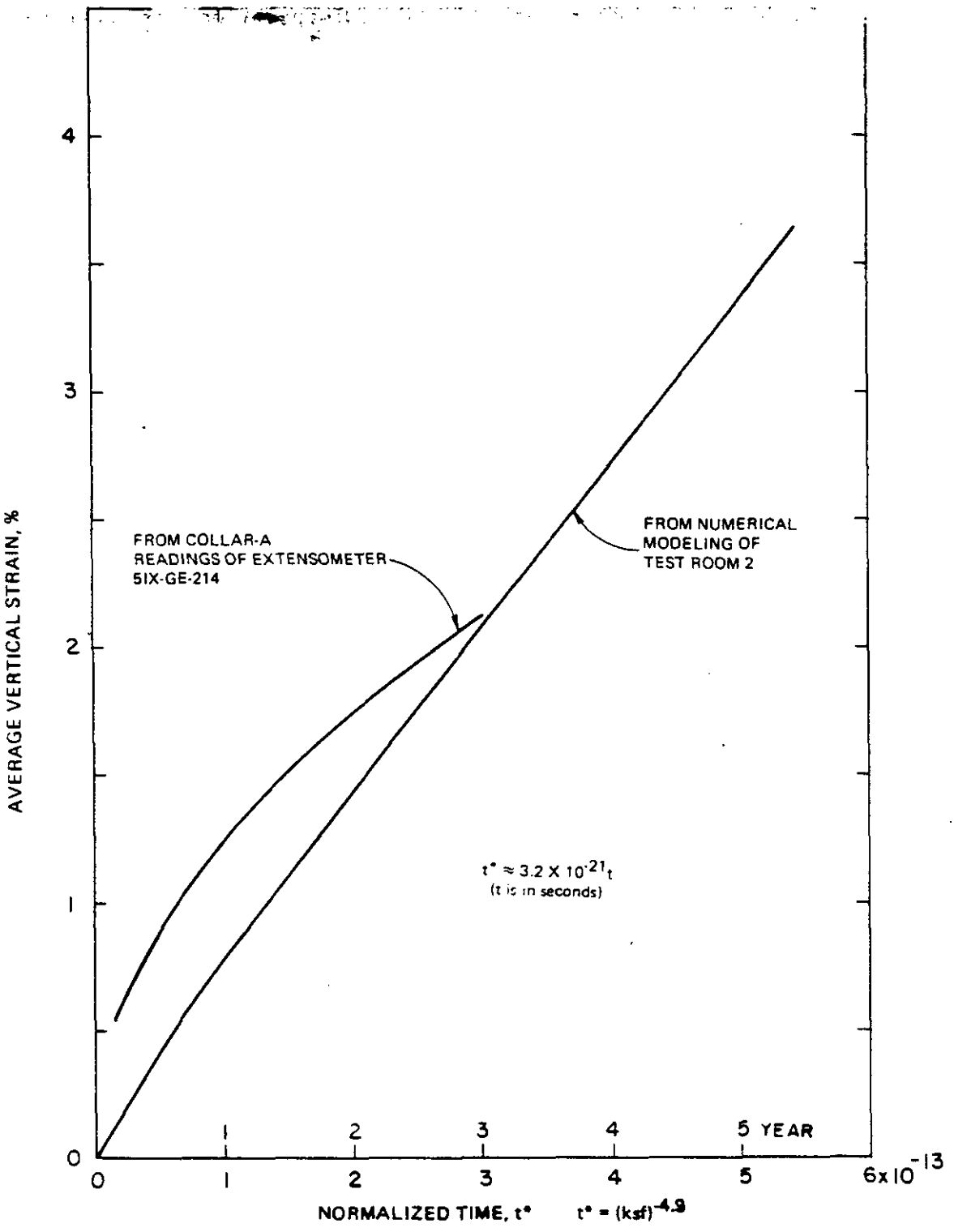


Figure 11-31

TEST ROOM 2
VERTICAL STRAIN AT ROOF CENTER

location of the deepest anchor, then linear interpolation was used to determine the displacement of salt at the required location.

Figure 11-32 compares the average relative displacement between the collar and the deepest anchor for the central roof extensometers 51X-GE-00207 and 51X-GE-00218, with the relative displacement between appropriate nodal points computed from the numerical model. A normalized time t* of 37.07×10^{-14} is equivalent to an elapsed time of nearly 3 years since the completion of excavation at the instrument location. The discrepancy between the measured and calculated relative movements is nearly 2 inches in 3 years.

For large values of t, the normalized time is approximately proportional to the real time, since the exponential term in equation C.4-17 in Appendix C approaches unity. For large values of t* (and t), the calculated relative displacement rate will be approximately 44 percent higher than the measured relative displacement rate if the current rate is maintained. A similar analysis was made for Test Rooms 2 and 3. Figure 11-33 compares the measured values with the values obtained from numerical modeling. The discrepancy in this case is 27 percent with respect to the measured value at nearly 3 years of elapsed time.

A comparison of salt heave measurement data from a floor extensometer in Test Room 4 was made with the values computed from numerical modeling. Figure 11-34 shows the results of this comparison. The numerical model underestimates the salt heave in the floor by approximately 70 percent of the measured value. This discrepancy is probably due to the assumption in the model that MB-139, 4.8 feet below the floor, is elastic and has infinite strength. Measurements from the floor extensometer and observations of fracturing indicate that MB-139 cannot be strictly considered as elastic. As discussed in subsection 11.3.2.1, borehole P4X-84 indicates the presence of lateral displacements and vertical separations in MB-139 beneath the floor of Test Room 4. This indicates that stresses in parts of the anhydrite bed may have reached the failure state.

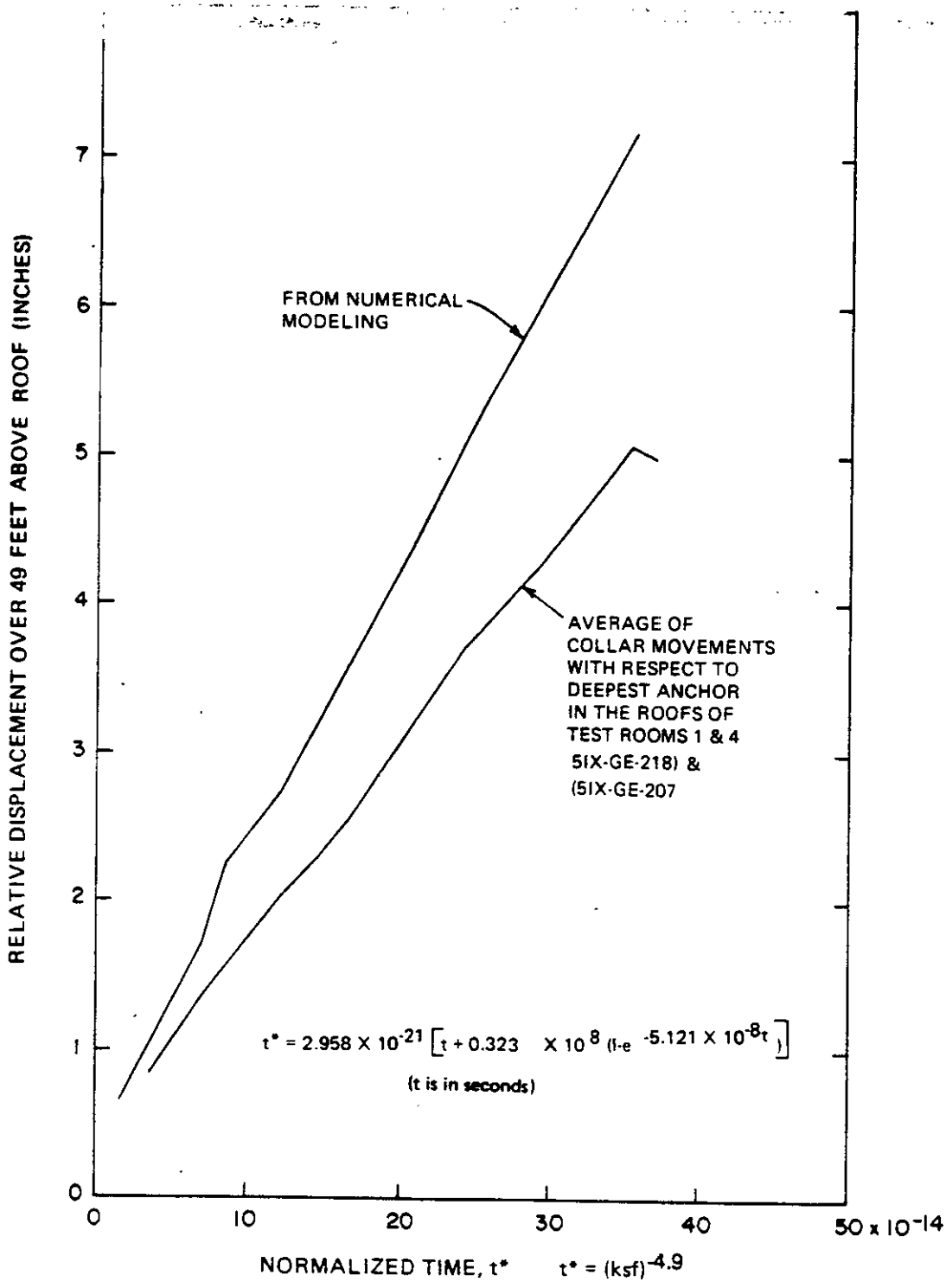


Figure 11-32

TEST ROOMS 1 AND 4 ROOF EXTENSOMETERS
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT DATA

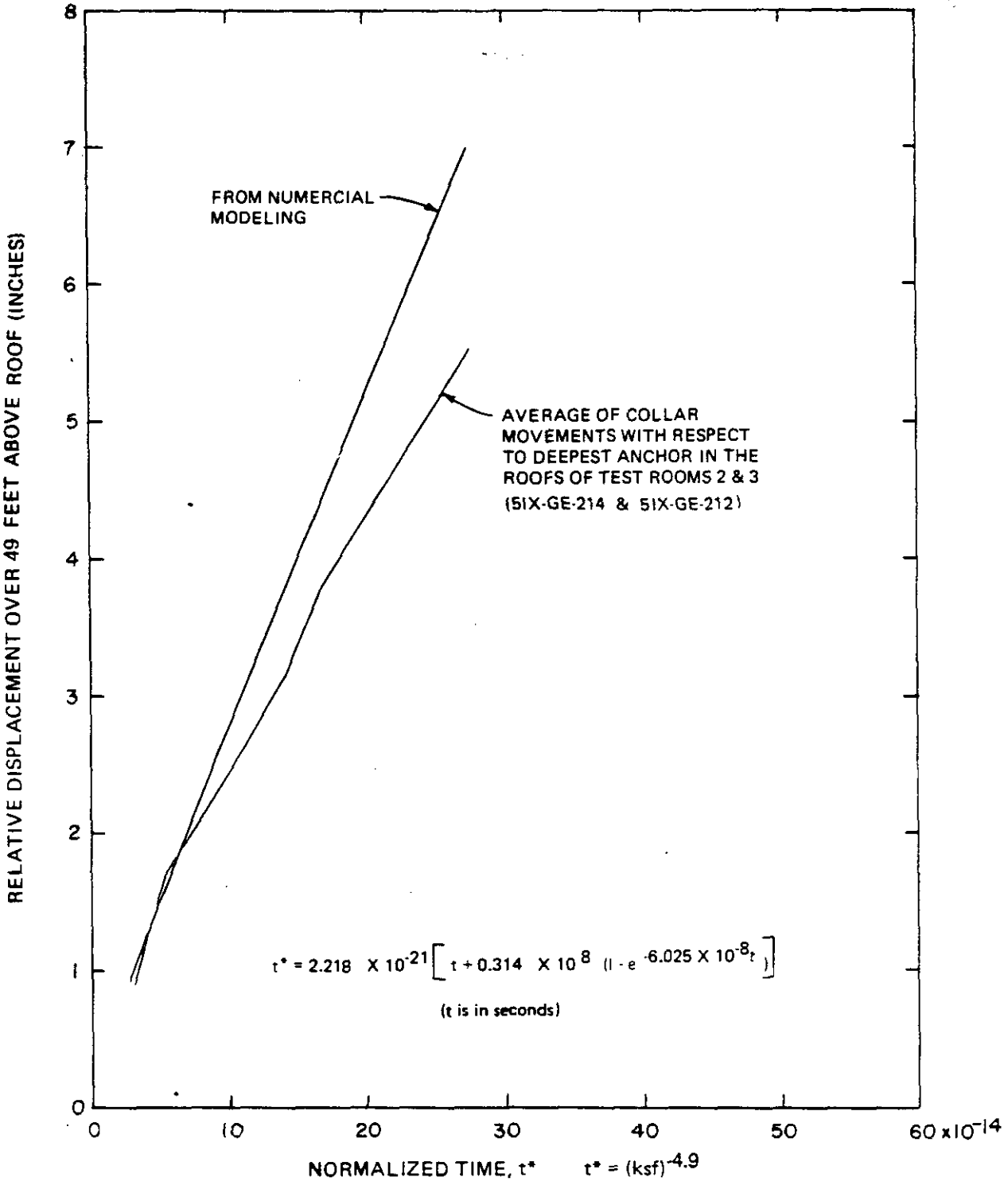


Figure 11-33

TEST ROOMS 2 AND 3 ROOF EXTENSOMETERS
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT DATA

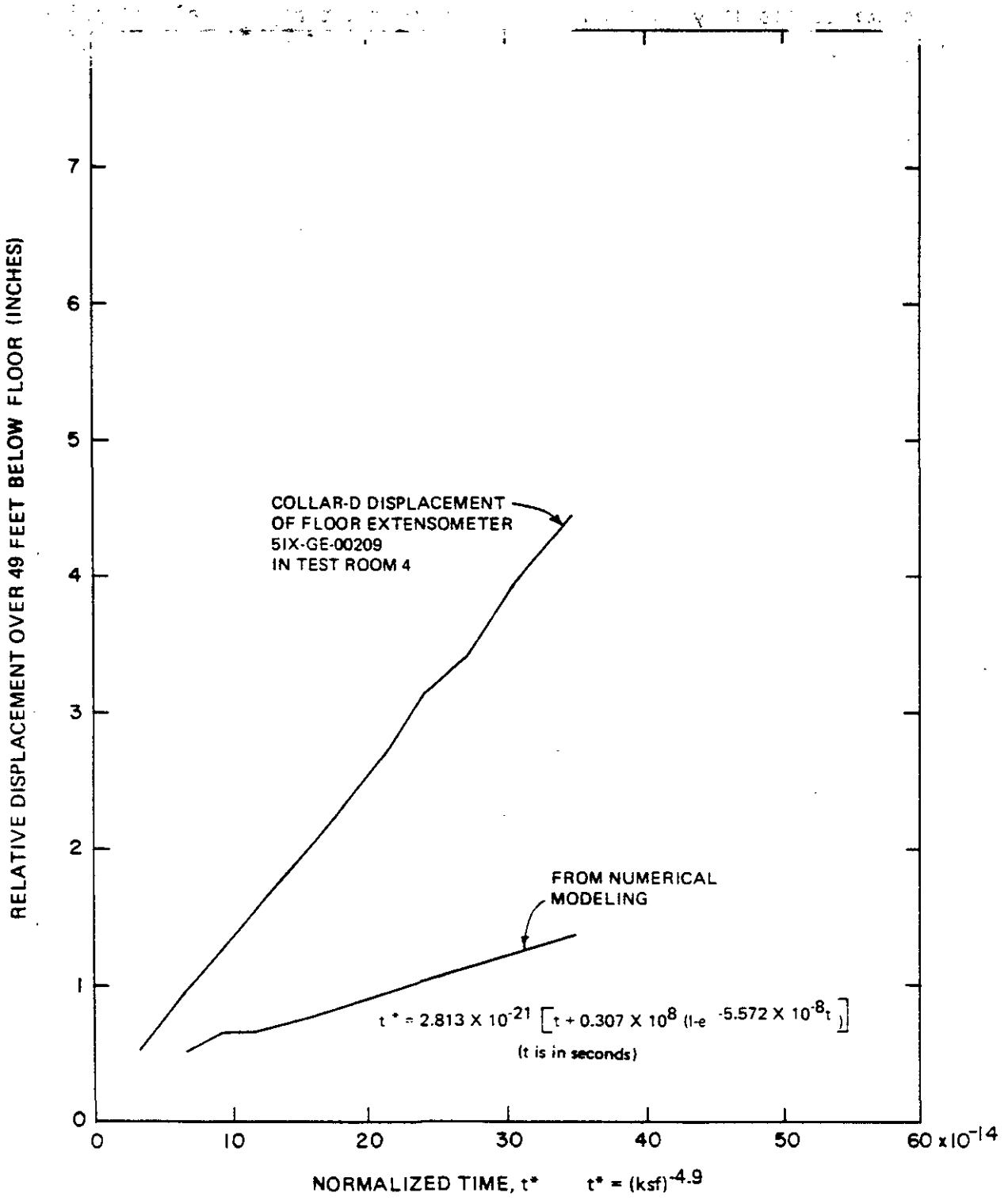


Figure 11-34

TEST ROOM 4 FLOOR EXTENSOMETER
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT DATA

Another possibility is that the fractures might have developed prior to excavation of the test rooms (ref. 6-6). In either case, assumptions of linear elasticity for the anhydrite bed become untenable. Modifications to the material characterization of this anhydrite material will be required to better represent its deformational behavior.

The basic philosophy of the model simulation developed in this report is that in situ measurement data are utilized to back calculate the creep parameters of the salt mass with the attendant discontinuities such as clay seams and anhydrite beds. For the model simulation technique, the in situ roof-to-floor closure data have been used to extract the creep parameters and predict future behavior using these creep parameters. This is because the roof-to-floor closure is deemed critical to evaluate the adequacy of the room dimensions for the effective storage and retrieval of waste. The discussions in the previous paragraphs indicate that there are discrepancies between measured and predicted quantities for variables other than roof-to-floor closure, such as deformations within the salt mass. Such discrepancies are not due exclusively to any inadequacy of the numerical modeling procedure but are also due to differences in the actual and assumed stratigraphy, variations in creep parameters with space and time, and inadequate representation of the stress-strain behavior of the anhydrite bed. However, it has been demonstrated that the model can predict, with sufficient accuracy for engineering purposes, the roof-to-floor closure behavior of the test rooms. A similar model simulation analysis was made for wall-to-wall closure and independent creep parameters were developed. Extrapolation of wall-to-wall closure with time was achieved using these creep parameters. This model simulation technique using in situ data was employed because the more detailed approach using material properties derived from laboratory tests may not produce more accurate results, as discussed in Chapter 5, subsection 5.4.3.

The reference design was based on computations for a single room rather than for multiple rooms. It was assumed that, with a low extraction ratio, the rooms with 100-foot pillars would not have as much early interaction as that which has developed in the four-room test panel. In Figure 11-35 the two lower curves show the computational results of roof-to-floor closure predictions for a 13 x 33-foot room using creep constants obtained from laboratory tests. The bottom curve represents the computational results from reference 11-4, dated August 1982, while the middle curve represents the updated result from reference 11-5, dated March 1985, which used revised creep parameters and an updated reference stratigraphy. In situ closure data for all four test rooms, including adjustments for their early closure, are plotted on the same figure for comparison. Interaction effects may be partly responsible for the discrepancy.

11.4 CONCLUSIONS AND RECOMMENDATIONS

11.4.1 Conclusions

The determination of the closure behavior of the WIPP underground openings using creep constants derived from laboratory experiments underestimated the actual closure. The measured roof-to-floor closure in the test rooms has exceeded 12 inches in the 3 years since the end of their excavation. This does not comply with the design criteria vertical closure allowance of 12 inches in 5 years.

Average vertical strains at roof and wall intersections, as determined from extensometer readings, were close to 3 percent in June 1986 and the strain rate was decreasing. Maximum vertical strain by numerical modeling occurs at roof and wall intersections and compares well with the value determined from in situ measurements.

Spalling from the roofs and walls, and fractures in the pillars and at pillar corners have been observed. Displacements and minor separations have been observed at clay seams and in the underlying halite in

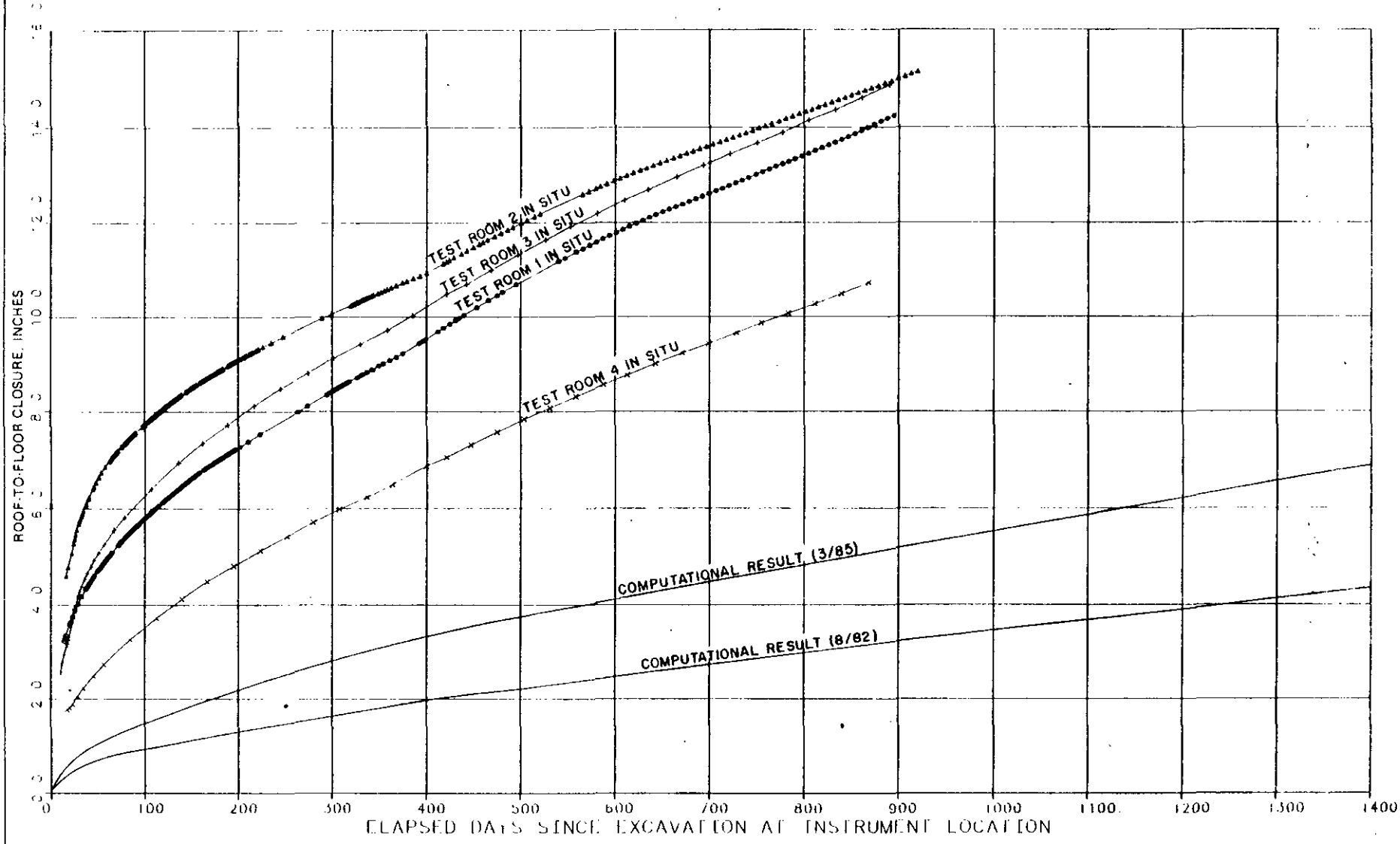


Figure 11-35

TEST ROOMS
COMPARISON OF LABORATORY VERSUS IN SITU DATA

trate the roofs. hese continue. Periodic maintenance of the roof and wall surfaces will be required.

Floor fracturing is well developed in the south half of Test Room 3 (Room T). Floor fracturing also occurs to a minor degree in the other test rooms and in a few areas in the drifts. Because the prominent floor fracturing occurring in Test Room 3 has not been found in any other rooms or drifts, it is considered to be anomalous to the underground facility. It is possible that the number and size of the 22 large-diameter holes in Test Room 3 exacerbated the pre-existing fractures. If floor fracturing occurs in the storage rooms, it is not expected to cause any operational or storage problems. As discussed in Chapter 3, Section 3.2, the WIPP project participants agreed, in a meeting on February 13, 1986, that the underground conditions do not require moving the facility level (ref. 3-2).

11.4.2 Recommendations

Observations and geomechanical instrumentation measurements should continue in the test rooms. Because they are the models for the determination of storage room behavior, trimming, rock bolting and other maintenance in the test rooms should be kept to the minimum required for safety, and the rooms allowed to deform.

It is recommended that Test Room 2, in particular, be preserved. It is the only test room that has not been physically altered. This room will then serve as a model for the storage rooms as they will exist prior to waste emplacement. Test Room 2 should not be trimmed or supported except as anticipated for the storage rooms. Additional instrumentation may be installed and small-diameter holes should be drilled in the roof and floor to observe the development of displacements, separations and fracturing. Large-diameter drilling should be prohibited and the room should be closed to all other activities. Continued observations of Test Room 2 behavior will

provide valuable data on anticipated storage room performance for the period between room excavation and the emplacement of waste.

A program of drilling, testing and geologic mapping should be continued to determine the development and extent of fracturing beneath the test room floors. When this has been determined, several monitoring stations should be established to document the behavior of the fractures. This program should also include monitoring roof displacements and separations. Arrays of small-diameter holes should be drilled in a few locations in each test room as soon as possible to document movement above the roof. However, drilling in Test Room 2 should be kept to a minimum.

Additional efforts are needed to refine constitutive laws for the creep behavior of salt as well as the representation of stratigraphy. The stress-strain-time behavior of anhydrite beds should be more accurately represented.

CHAPTER 12
STORAGE AREA

12.1 INTRODUCTION

The storage area encompasses all rooms, drifts and crosscuts that will be used for the permanent storage of CH and RH TRU wastes. The storage area is located south of the waste shaft station, from S1600 to S3664 (see Chapter 1, Figure 1-2, and this chapter, Figure 12-1, for location and layout). The storage area is arranged to provide a system in which CH and RH TRU wastes can be efficiently and safely handled and stored. A panel of four full-scale test rooms was excavated to determine the adequacy of the opening configuration and dimensions (Chapter 11). Evaluation of in situ data from these test rooms were utilized to predict the closures of, and stresses and strains around, the future storage area rooms and drifts.

This chapter presents information on the reference design of the storage area rooms and drifts, the design validation process, conclusions regarding the suitability of the reference design based on the findings of the validation process, and recommendations for modifications to the storage area design configurations that will, if implemented, result in a validated reference design.

12.2 DESIGN

This section presents the design criteria, design bases and reference design configurations that were used for the WIPP storage area rooms and drifts.

12.2.1 Design Criteria

The Design Criteria, RMC-IIA, for the storage area (ref. 2-8) is summarized in Chapter 2, Table 2-1. This table presents the major criteria that governed the WIPP underground opening reference design, including those criteria that require evaluation as part of the design validation process. The following discussion presents a description of

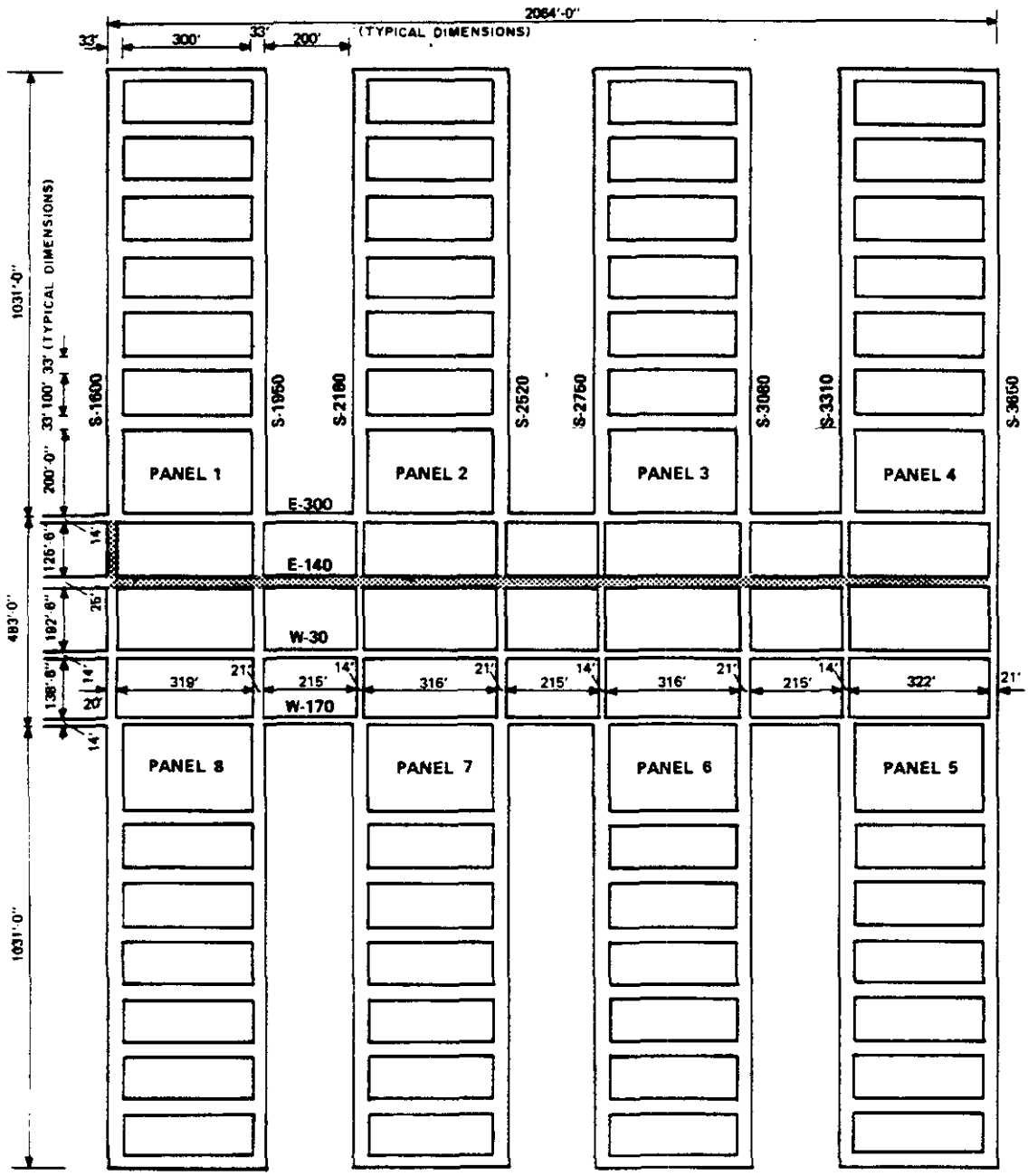


Figure 12-1

STORAGE AREA
REFERENCE DESIGN PLAN

the three design criteria pertaining to the storage area that require evaluation for validation of the reference design.

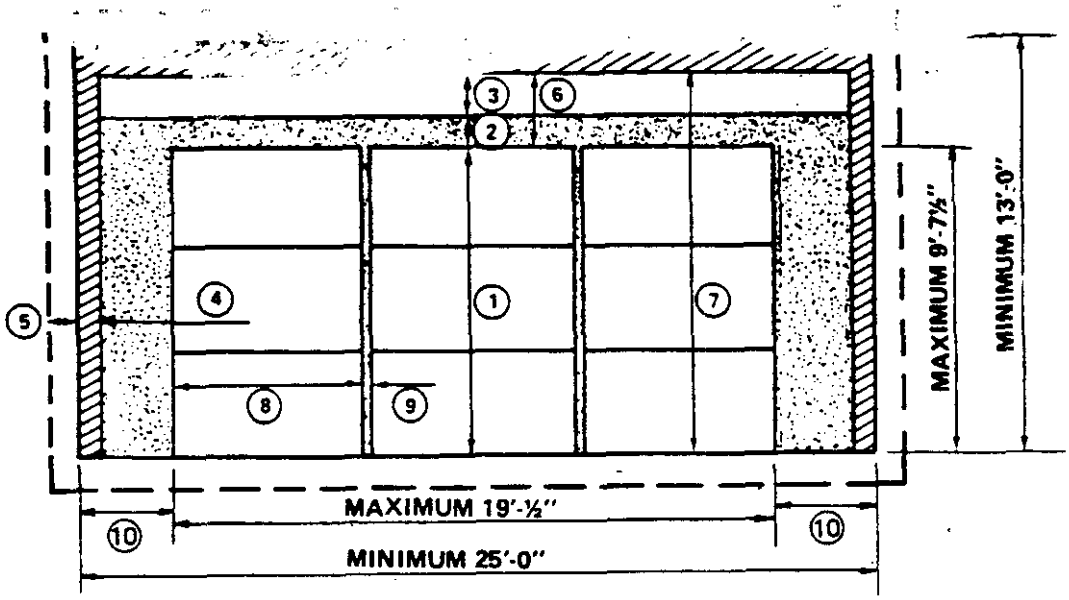
The first criterion requires that the excavation dimensions of the storage area rooms and drifts include an allowance for creep closure sufficient to prevent container breaching by creep-induced stresses during the retrievability period. The second criterion states that each storage room shall allow for salt creep and shall be sized to minimize breaching of the CH waste containers for a period of 10 years. The third criterion states that the underground storage rooms and access drifts shall be designed to be compatible with the waste transport vehicle, with the waste container sizes, shapes, weights, and stacking configurations, and with the waste handling and backfilling equipment requirements.

Other criteria that apply to the storage area reference design also apply to the drifts and were discussed in Chapter 10.

12.2.2 Design Bases

The design bases describe the specific dimensional requirements used to develop the reference design for the storage area drift and room configurations (Figures 12-2 and 12-3). The Design Basis, Underground Excavations (ref. 2-18) contains the bases used for the storage area reference design. The major elements from this Design Basis document are summarized in the following discussion. Although other design bases were also used, they did not have a direct impact on design validation. The specific design bases requiring evaluation during the validation process are presented in Table 12-1.

The design bases specify that the reference design shall provide an underground storage area in which CH and RH TRU wastes can be efficiently handled and stored. The reference design of the waste storage area shall permit simultaneous storage of CH and RH TRU wastes. To the extent possible, the configuration of the storage area shall minimize haulage distances for excavated salt and waste storage.



EXPLANATION

(1) HEIGHT OF WASTE PACKAGES STACKED THREE HIGH: 9'-7 1/2" FOR BOXES; 9'-0" FOR SIX PACKS.

(2) SALT COVER: 1' TO 2'; LEVEL OF SALT IS MAINTAINED AT 10'-8" ABOVE THE FLOOR.

(3) VENTILATION SPACE: 1'-4" MINIMUM UNTIL ROOM OR PANEL IS FILLED AND PLUGGED.

(4) SALT CREEP ALLOWANCE: 1'-0" ROOF; 4 1/2" EACH WALL (ASSUMED TO BE ADEQUATE FOR 5 YEARS).

(5) CONSTRUCTION TOLERANCE: +6". THE CONTRACTOR MUST MAINTAIN THE MINIMUM ROOM DIMENSIONS.

(6) BACKFILLING CONVEYOR CLEARANCE: 2'-4" ABOVE WASTE PACKAGES.

(7) HEADROOM: 12'-0" FOR CH BOXES AND RH TRANSPORTER.

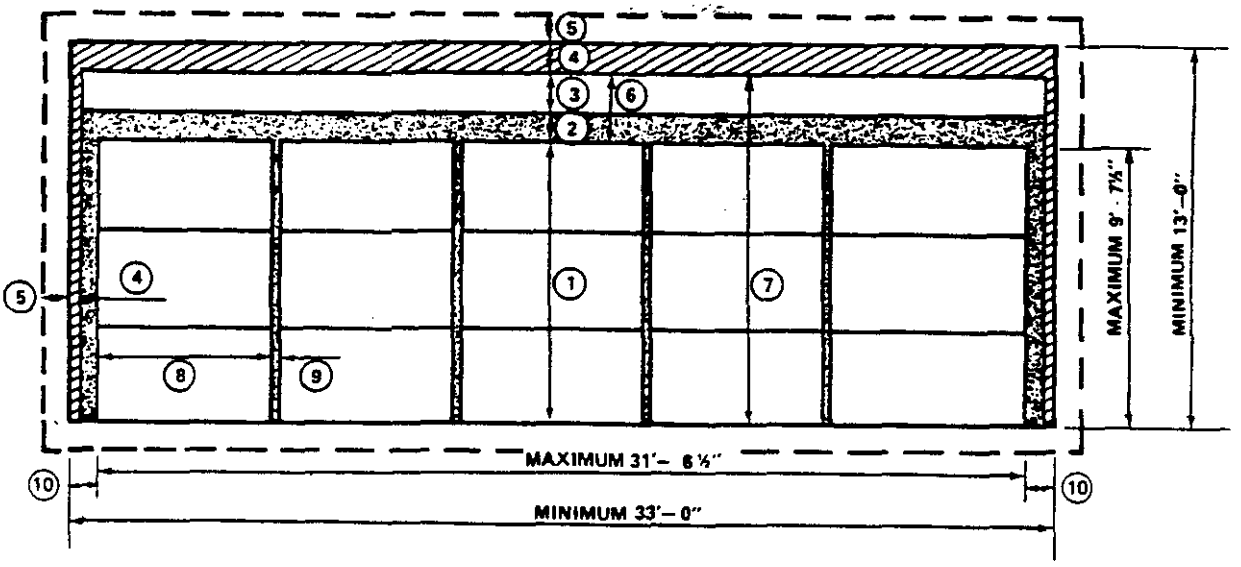
(8) WASTE PACKAGE WIDTH: 6'-2 1/2" FOR BOXES; 6'-1 1/2" FOR SIX PACKS.

(9) STACKING TOLERANCE: 2 1/2" BETWEEN WASTE PACKAGES.

(10) SALT BACKFILL: 3'-0" BETWEEN WASTE PACKAGES AND WALL.

Figure 12-2

STORAGE AREA
DRIFT REFERENCE DESIGN DIMENSIONS



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(7) HEADROOM: 12'-0" FOR CH BOXES AND RH TRANSPORTER.

(8) WASTE PACKAGE WIDTH: 6'-2 1/2" FOR BOXES; 6'-1 1/2" FOR SIX PACKS.

(9) STACKING TOLERANCE: 2 1/2" BETWEEN WASTE PACKAGES.

(10) SALT BACKFILL: 8 3/4" BETWEEN WASTE PACKAGES AND WALL.

Figure 12-3

STORAGE AREA
ROOM REFERENCE DESIGN DIMENSIONS

(1) Operational requirements

a. The storage area rooms, drifts and crosscuts shall be designed to allow for retrieval of all CH and RH waste stored for a period of up to 5 years after the initial emplacement of each waste species.

b. Excavation dimensions in the waste storage area shall be to a uniform height of 13 feet.

(2) Essential features

Provide 1 foot vertical and 9 inches horizontal allowance for creep closure to maintain the minimum design dimensions up to 5 years after initial emplacement.

(3) Safety design requirements

A minimum opening of 16 inches shall be left at the top of the rooms and drifts for air passage above the waste and backfill.

Construction and storage operations shall be physically separated and performed during different shifts.

Each storage room is to be filled with waste containers consisting of six-packs of CH TRU waste storage drums and/or boxes of CH TRU waste. The containers shall be stacked three high and five wide, stored with their longest dimension across the opening. A 2 1/2-inch stacking tolerance shall be allowed between waste packages. All rooms, drifts and crosscuts in the storage area may be used to store CH waste containers stacked three high. For this reason, excavation shall be to a uniform height of 13 feet throughout the waste storage area.

The underground storage area shall provide for the horizontal emplacement of 1,000 RH canisters. The RH canisters, nominally 10 feet long and 26 inches in diameter, shall be stored in the salt pillars. Emplacement holes shall be perpendicular to the walls, approximately midway between the floor and ceiling and evenly spaced laterally. Canister spacing shall be based on the assumption that the average heat output per canister will be 60 watts or less. Thermal loading in the RH waste storage area shall not exceed 10 kilowatts (kw) per acre. Allowing 12 inches for salt creep, RH waste emplacement machinery shall be designed to operate in an effective room height of 12 feet, including all required clearances.

The storage area floor shall be approximately 2,150 feet below the ground surface. The final level of the excavations shall be as determined by the DOE Contracting Officer.

Four parallel entries shall be provided from the shafts to the waste storage area. These entries shall provide separate channels for air intake and exhaust, salt removal, and waste storage.

Excavation dimensions shall include an allowance for salt creep of 1 foot in the vertical direction and 9 inches in the horizontal direction for all rooms for up to 5 years. The tolerance for excavation of roof,

...ater than pl... ... the finished cross section dimensions be less than design dimensions.

Provision shall be made for the expansion of the storage area within the boundaries of Zone II (Chapter 1, Figure 1-1) if required in the future. The area extraction ratio in the storage area shall not exceed 25 percent.

The stored CH TRU waste packages shall be covered with a layer of salt backfill (3/8 inch or less in grain size) for fire protection. The volume of stored CH TRU waste in any one compartment without a vertical fire barrier shall be limited to a maximum of 500,000 cubic feet. For ventilation above the backfilled waste, a minimum opening of 16 inches shall be provided.

No personnel may work in air that has passed over the stored CH TRU waste. However, personnel may work in air that has passed through an opening where RH TRU waste has been emplaced provided that canister holes have been sealed with plugs. Personnel may not work in air that has passed through openings where RH TRU waste is being emplaced.

12.2.3 Design Configuration

The reference design of the storage area was developed in accordance with the design criteria and the design bases. The design configuration is based on the stratigraphy determined from borehole ERDA-9 and on salt creep performance determined from laboratory tests on core extracted from ERDA-9. The ERDA-9 exploratory hole was the only hole within the underground development area which was permitted to penetrate the Salado formation to the underground facility horizon.

The storage area reference design configuration (Figures 12-1, 12-2 and 12-3) consists of eight panels with seven rooms each. The rooms are 13 feet high, 33 feet wide and 300 feet long. The panel entries are also 13 feet high and 33 feet wide. The rooms are separated in each panel

by 100-foot wide pillars and the panels are separated by 200-foot wide pillars. The test rooms discussed in Chapter 11 were designed to be the same size as the storage rooms. The test rooms were constructed to monitor salt performance, permit observations of opening stability, and to permit validation of the storage room reference design.

The reference design provides for the storage of CH waste in one room while RH waste is stored in another room. Emplacement of RH waste canisters into horizontal holes is depicted on Figure 12-4. After the RH waste canisters are emplaced in the walls of the storage room a shield plug is placed in the wall sleeve. When the emplacement of RH waste canisters is completed in the storage room, CH waste can be stored in the same room. During the 5-year demonstration period, the RH waste canisters are stored in steel sleeves in the first room of Panel 1. During permanent storage, they are emplaced in pillars throughout the storage area as dictated by the receival rate of the waste.

The RH waste canisters (with a heat output of 60 watts or less) are placed in horizontal holes spaced so that the local storage area thermal loading does not exceed the design basis limit of 10 kw/acre. For the reference design, and for this report, the thermal effects on storage room behavior were not considered significant. The reference design for RH waste is subject to the results of the ongoing WIPP experimental program.

The reference design configuration also defines stacking configurations and tolerances for ventilation, backfill and salt creep. These tolerances are shown on Figures 12-2 and 12-3 for the storage area drifts and rooms, respectively. In order to meet these requirements, the reference design configuration incorporates a reference operating procedure. This procedure is based on the waste receipt rates, emplacement rates, and retrieval rates stipulated by the design criteria. This operating procedure is part of the storage room reference design and is incorporated in construction package EP-01X.

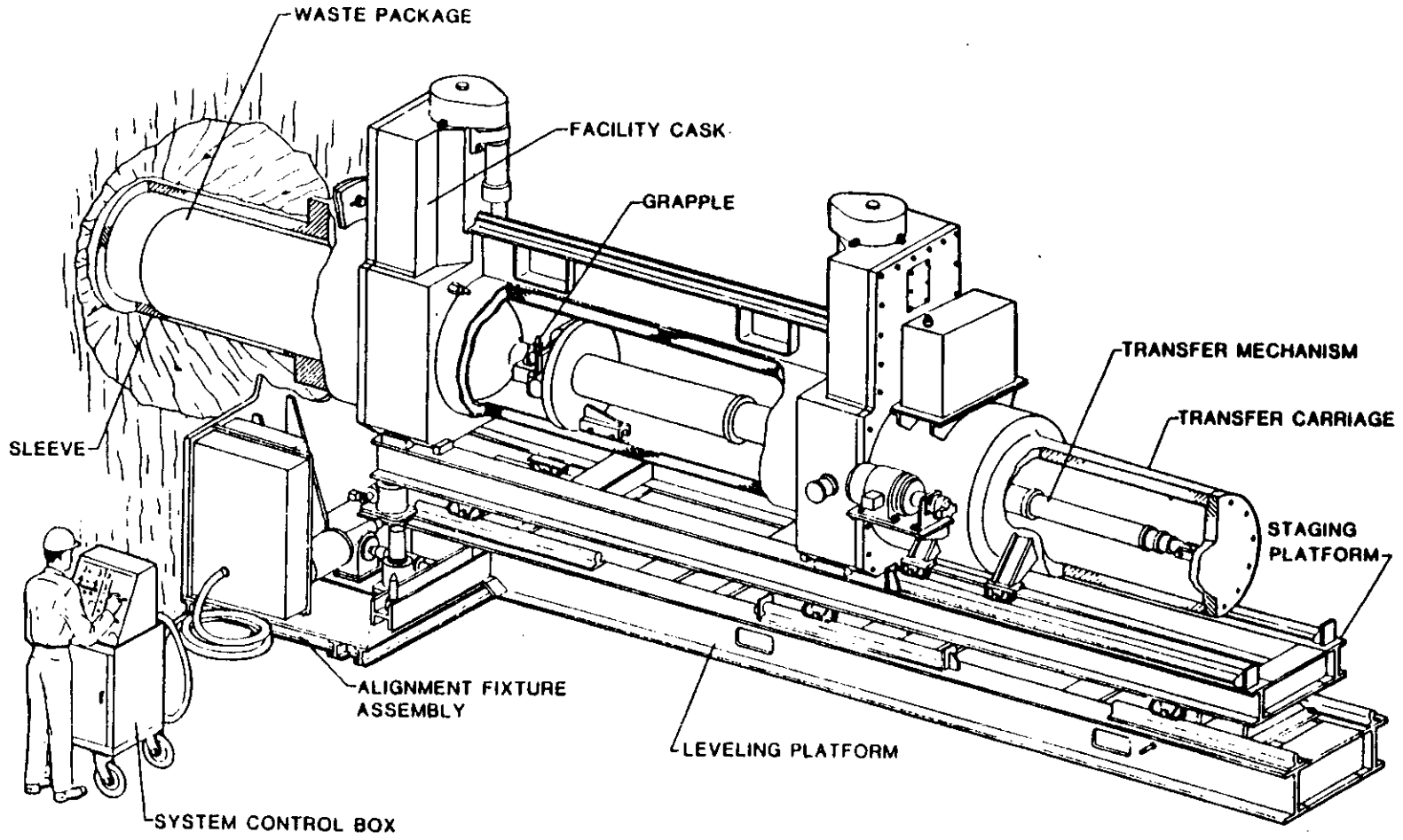


Figure 12-4

STORAGE AREA
HORIZONTAL EMPLACEMENT OF RH WASTE

This package contains the design documents that will be used to operate the WIPP.

12.3 DESIGN VALIDATION PROCESS

The design validation process for the storage area consists of the evaluation of numerical modeling and data analysis from the drifts and test rooms (Chapters 10 and 11) and its application to the reference design of the storage area drifts and rooms. The predicted future performance of the storage area openings was compared to the performance of existing openings having comparable dimensions. This was then used as the upper bound for validating the reference design.

12.3.1 Data Collection

Geomechanical instrumentation data collected from the test rooms were used to compute the creep parameters of the surrounding salt. Geologic mapping and drill cores from the underground facility were used to confirm the stratigraphy of the storage area. Test room instrumentation data and the computation of creep parameters are presented in Chapter 11. Chapter 6 presents information on the geologic mapping, drill cores and development of the reference stratigraphy.

The geomechanical instruments in the test rooms have provided deformation measurements and response data on the excavated openings. Periodic visual inspections of the rooms have provided observational data with which to further evaluate the response of the surrounding salt. Geologic mapping and core drilling in the E140 drift south of the waste shaft have provided information on the stratigraphy in the storage area.

12.3.2 Analysis and Evaluation

12.3.2.1 Storage Rooms

Analysis and evaluation of the storage room reference design have been performed using data collected from the test rooms. The adequacy of

The design was [illegible] behavior, including stress, strain and [illegible], which could be expected to occur over the operating life of each room. The operating life is defined as the period of time from initial excavation of the room until retrieval operations are completed, if the decision to retrieve is made, or until the storage operation for each panel is completed.

Evaluation of the geologic mapping and drill cores from the E140 drift south of the waste shaft has confirmed the continuity of the stratigraphy 50 feet above and below the storage area (refs. 4-1 and 4-2).

Based on an engineering approach (Chapter 5), numerical analyses were performed based on creep parameters determined from test room data and the stratigraphy surrounding the facility level. Because the extrapolation of the in situ closure data for the drifts and test rooms indicates that more than four rooms in a storage panel could influence the total closure and overall creep rate, a mathematical model was developed to estimate the upper bound responses. This requires assuming an infinite array of equally spaced storage rooms such that the centerline of a typical room and the centerline of any one of its pillars form axes of symmetry. In addition, the rooms were assumed to be infinitely long.

Figure 12-5 shows the finite element model that was used to determine the responses for an infinite array of infinitely long storage rooms. The model has 94 nodes and consists of 59 plane strain elements, with gap/friction link elements having a friction coefficient of 0.4 to model a clay seam. Because test room creep parameters are used in predicting the responses of the storage rooms, this model uses the same comparative element sizes and external loads as those used in the test room model described in Chapter 11, Section 11.3. The boundaries on both sides of the model were taken as vertical axes of symmetry to represent the pillar centerlines and consist of horizontal restraints.

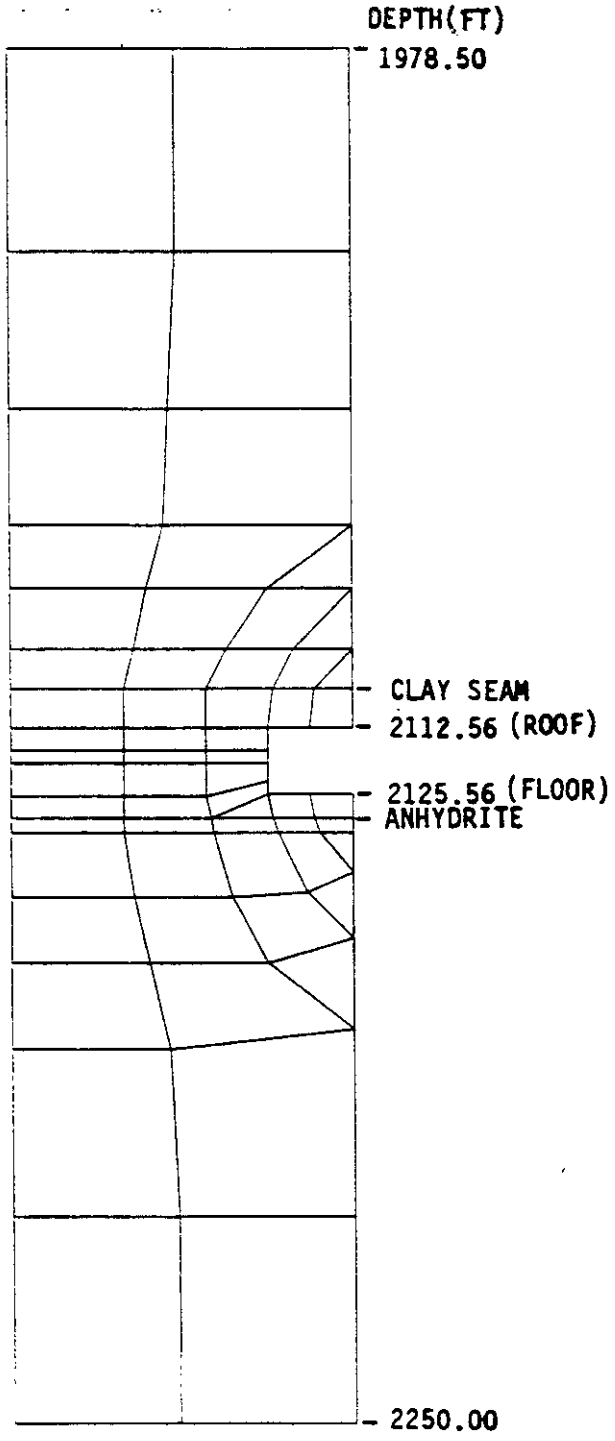


Figure 12-5

STORAGE AREA
ROOM FINITE ELEMENT MODEL

anhydrite bed, and the [illegible] room are based on the reference stratigraphy and are identical to those used in the test room finite element model.

The analyses were performed using the MARC General Purpose Finite Element Program discussed in Chapter 6. The average values of the creep parameters were derived from test room roof-to-floor and wall-to-wall in situ closure data. Using these computed creep parameters, previously presented in Chapter 11, Tables 11-10 and 11-11, the predicted future responses of the storage rooms were computed. The results of the analyses are presented below.

12.3.2.2 Storage Area Drifts

Analysis and evaluation of the 13 x 25-foot drift design for the storage area have been performed using data collected from the existing 8 x 25-foot drifts. The same finite element model used for the 8 x 25-foot drifts (Chapter 10) was used for the larger drifts. A removable floor section extending 5 feet vertically downward from the original floor level was integrated into the model so that this group of elements could be removed at the appropriate stage in the analysis to simulate floor excavation. A coefficient of friction of 0.0 was assumed for the gap/friction elements to model a clay seam. The time between initial excavation and the subsequent floor excavation was assumed to be 2 years. Therefore, all results presented in the following subsection are directly affected by these assumptions. Figure 12-6 shows the model after removal of the floor elements.

12.3.3 Prediction of Future Behavior

12.3.3.1 Storage Rooms

Because the room size and panel configuration of the four test rooms is similar to the design of the proposed storage rooms, the behavior of the storage rooms was computed using the measured data from the test rooms, as presented in Chapter 11. The results of the storage room

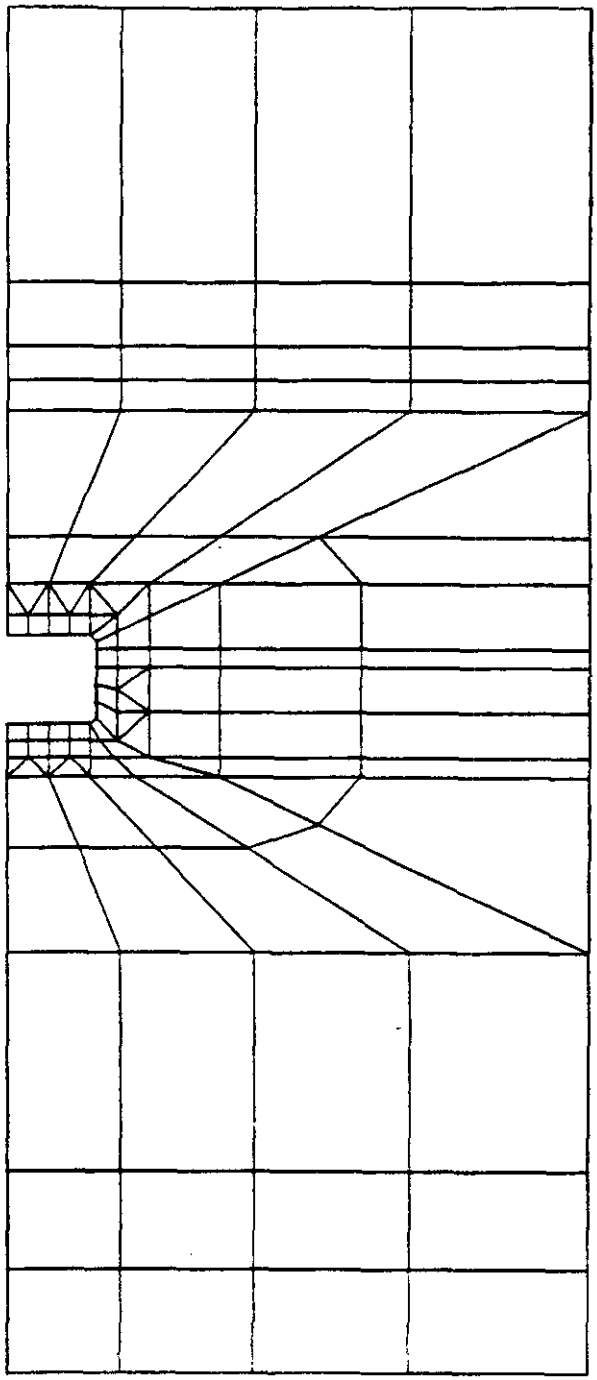


Figure 12-6

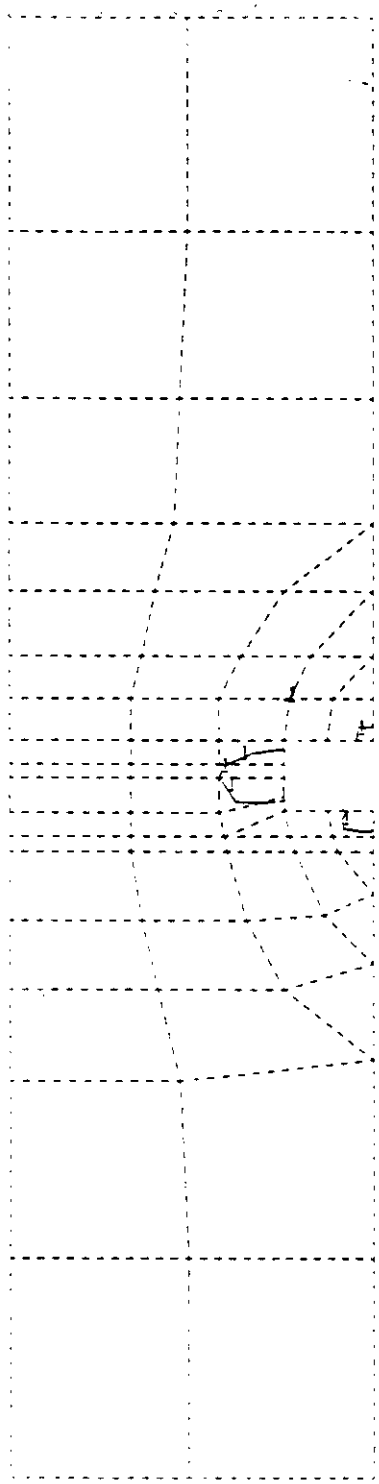
STORAGE AREA
DRIFT FINITE ELEMENT MODEL - AFTER FLOOR LOWERING

alysis [illegible] steps. These integration steps correspond to real times immediately after excavation, 1 year and 10 years after excavation. The horizontal and vertical stresses, effective stresses, effective creep strains, principal stresses and the deformed shapes were plotted at these times based on the mean value of the averaged wall-to-wall and roof-to-floor creep parameters presented in Tables 11-12 and 11-13 in Chapter 11. A closure calculation considering the effects at a room intersection was performed utilizing the values from these tables. Roof-to-floor and wall-to-wall closure predictions for the storage room were then plotted.

Horizontal and Vertical Stresses. The computed horizontal stress distributions in the storage rooms are plotted on selected elements of the finite element mesh immediately after excavation and at times of 1 year and 10 years after excavation (Figures 12-7 through 12-9). A contour interval of 250 ksf was chosen and 10 contour increments were used to span a stress range from 0 to 2,500 ksf compression.

Horizontal stresses immediately after excavation are totally compressive throughout the selected elements of the model. Most of the changes in horizontal stresses in the salt around the opening occur within the first year after excavation and remain practically constant even 10 years after excavation. The walls and the underlying anhydrite bed (MB-139), near the center of the room, have the largest compressive stresses, with values between 250 and 500 ksf compression. As the opening slowly deforms, horizontal stresses tend to become more compressive in the anhydrite bed near the room's vertical centerline. In the anhydrite bed far from the room centerline, the horizontal stresses are relatively low.

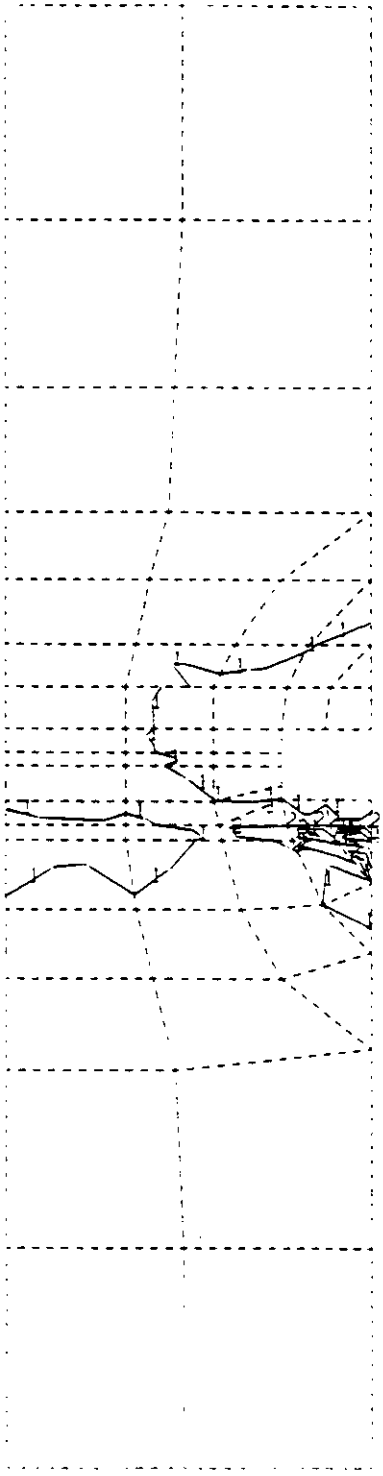
The vertical stress distribution was also plotted for time periods immediately after excavation and at times of 1 year and 10 years after excavation (Figures 12-10 through 12-12). The contour interval and stress range are the same as those used for the horizontal stress plots.



CONTOUR	σ_h(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-7

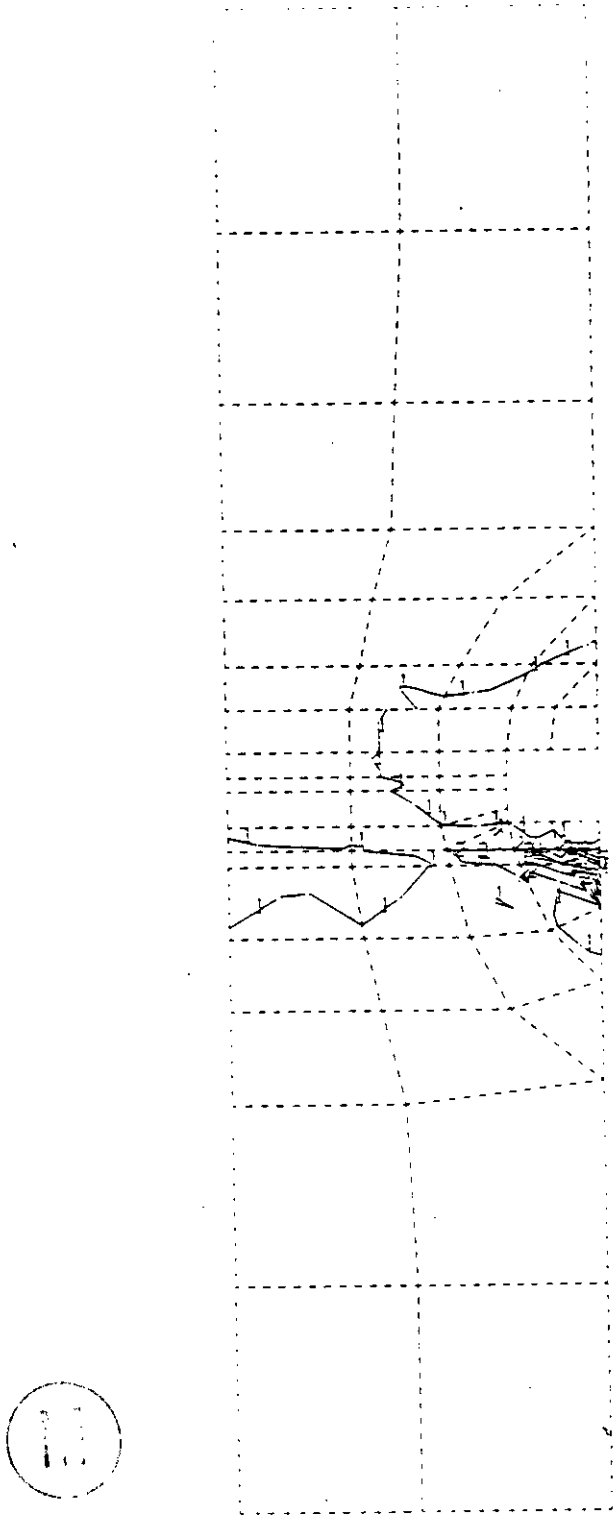
STORAGE ROOMS
HORIZONTAL STRESS DISTRIBUTION IMMEDIATELY AFTER EXCAVATION



CONTOUR	σ_h(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-8

STORAGE ROOMS
HORIZONTAL STRESS DISTRIBUTION 1 YEAR AFTER EXCAVATION



CONTOUR	σ_h(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-9

STORAGE ROOMS
HORIZONTAL STRESS DISTRIBUTION 10 YEARS AFTER EXCAVATION

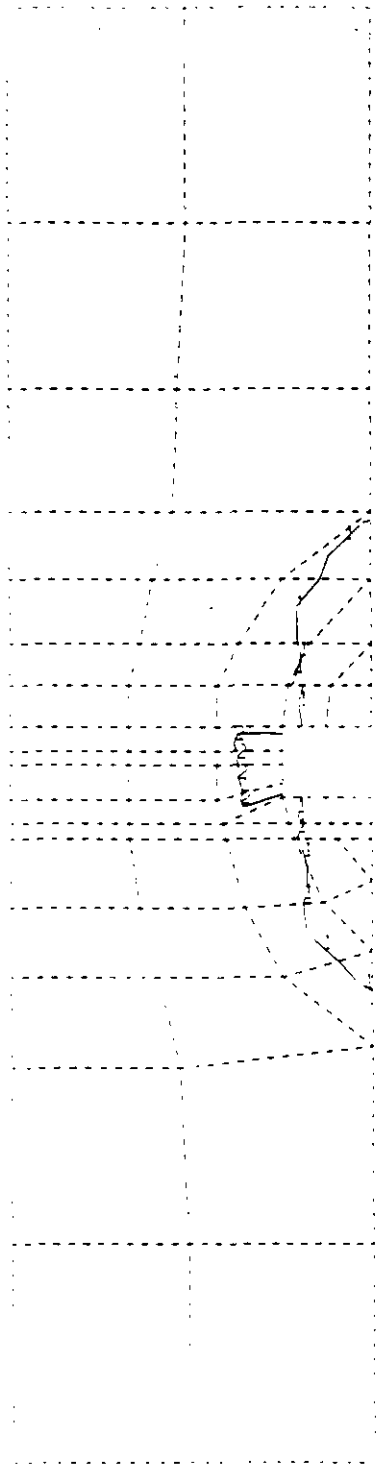
[illegible] in the wall [illegible]
[illegible]ately after excavation of between 500 and 750 ksf com[illegible]
This stress is approximately twice the original lithostatic stress before excavation and clearly shows the expected stress concentrations around the opening immediately after excavation. As the opening deforms, the vertical stress is redistributed around the opening and reduced to between 250 and 500 ksf compression.

Figures 12-11 and 12-12 show very small differences from 1 year through 10 years after excavation. That is, the vertical stress is relatively constant throughout that period with most of the halite roof beam having low stress in the vertical direction. Likewise, the uppermost level of elements in the room's floor has relatively low stress in the vertical direction due to its lack of vertical confinement.

The anhydrite bed (MB-139) below the storage room is, in general, subjected to low vertical stresses; however, some compressive vertical stress is indicated under the pillars.

Effective Stresses and Effective Creep Strains. Figures 12-13 through 12-15 show the computed effective stress distribution in those elements of the finite element model near the room opening. Ten contour increments, each having an interval of 250 ksf, were chosen to span a stress range from 0 to 2,500 ksf. The effective stress plot immediately after excavation shows a relatively low stress concentration in the anhydrite bed below the floor and no stresses greater than 500 ksf in the halite beds.

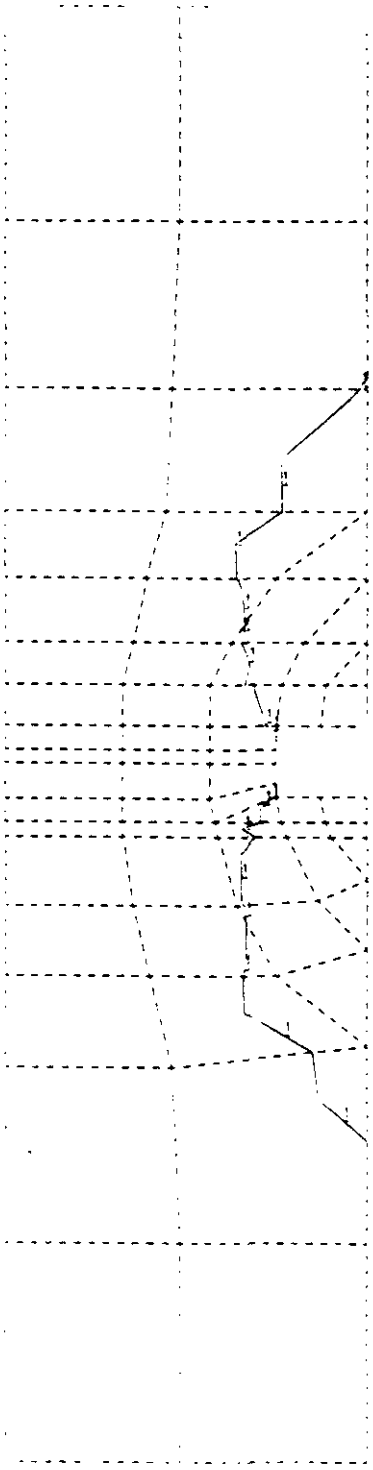
At 1 year and 6.5 years after excavation, the computed effective stresses have increased and concentrated in the anhydrite bed and overlying halite. Because the anhydrite was modeled as being elastic until failure and stiffer than halite, it supports more stress, which results in a large effective stress gradient in the anhydrite. The maximum computed effective stress is 2,600 ksf, concentrated in the anhydrite bed near the room centerline.



CONTOUR	σ_v (ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-10

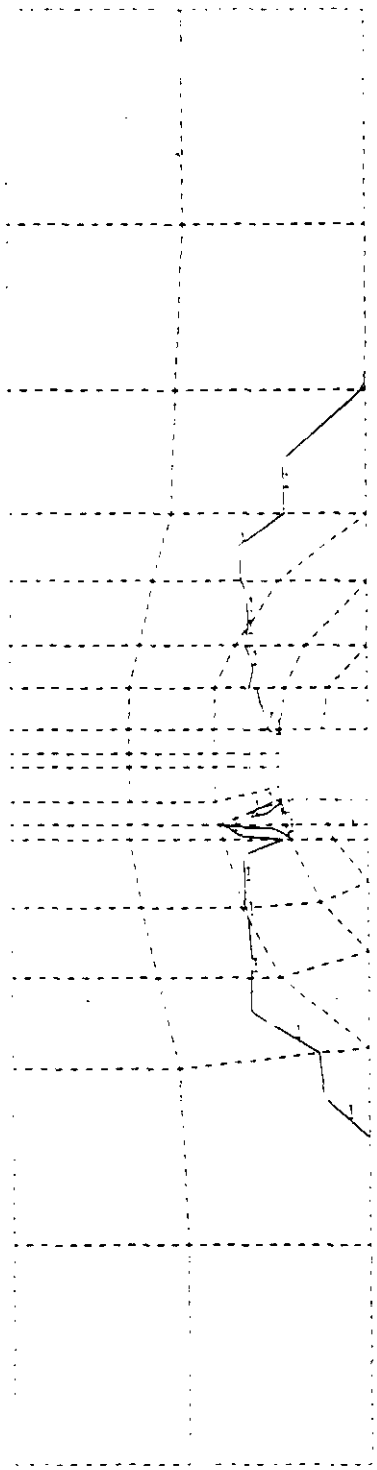
STORAGE ROOMS
VERTICAL STRESS DISTRIBUTION IMMEDIATELY AFTER EXCAVATION



CONTOUR	σ_v(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-11

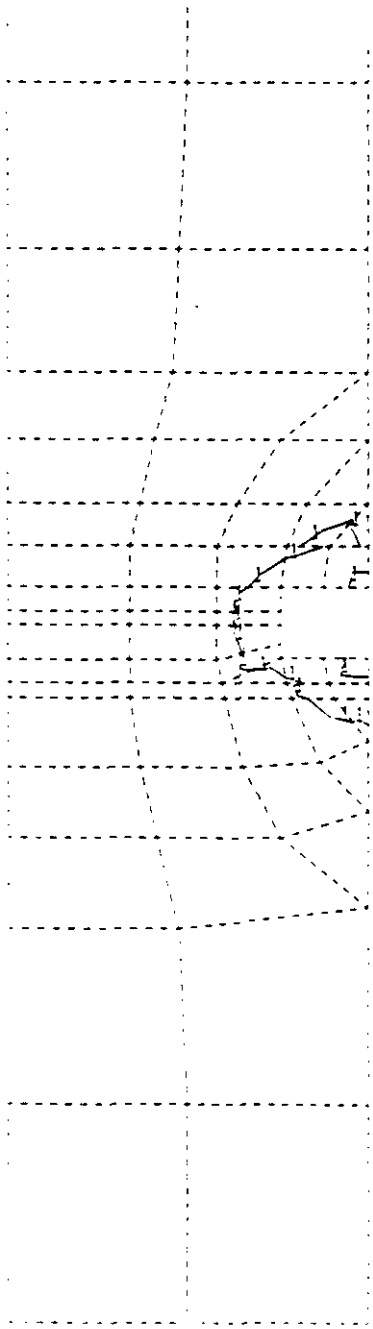
STORAGE ROOMS
VERTICAL STRESS DISTRIBUTION 1 YEAR AFTER EXCAVATION



CONTOUR	σ_v(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-12

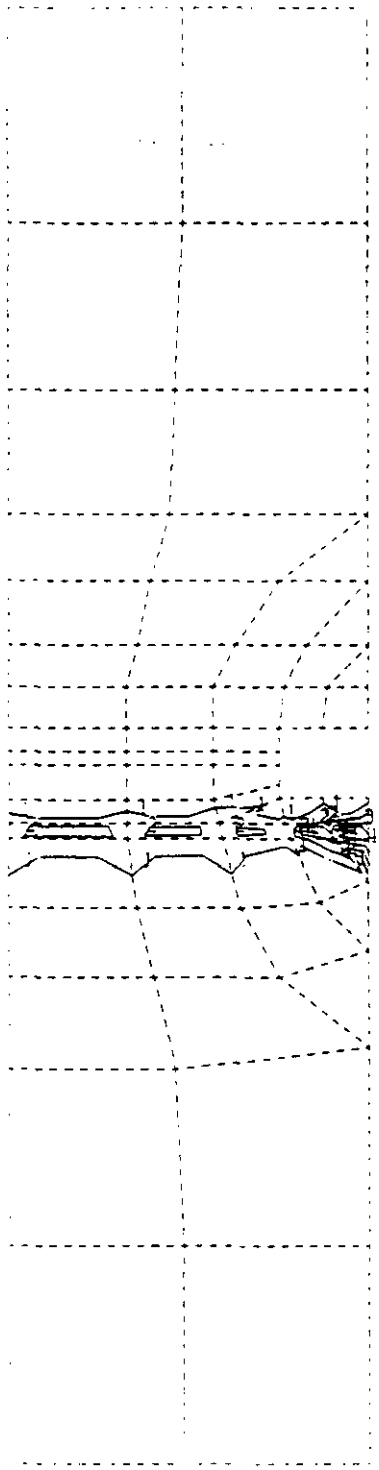
STORAGE ROOMS
VERTICAL STRESS DISTRIBUTION 10 YEARS AFTER EXCAVATION



CONTOUR	$\overline{\sigma}$(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-13

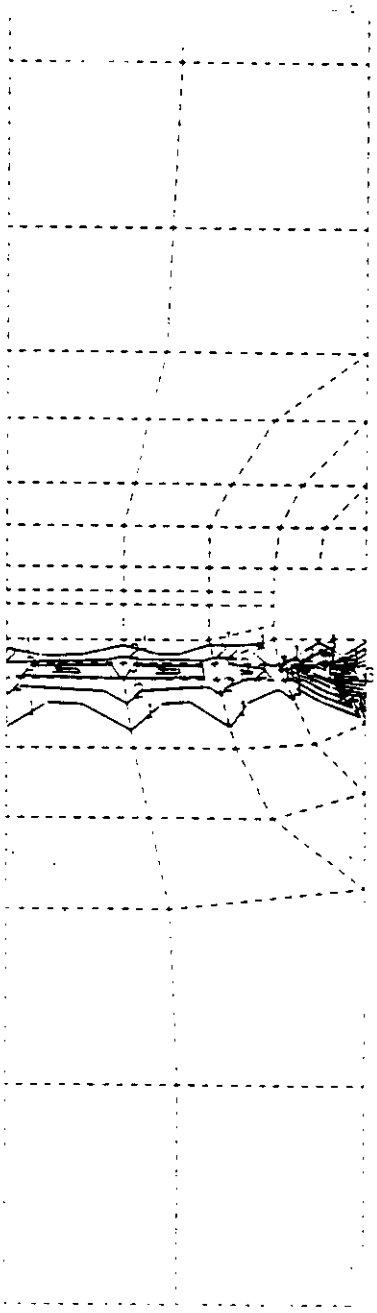
STORAGE ROOMS
EFFECTIVE STRESS DISTRIBUTION IMMEDIATELY AFTER EXCAVATION



CONTOUR	$\bar{\sigma}$(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-14

STORAGE ROOMS
EFFECTIVE STRESS DISTRIBUTION 1 YEAR AFTER EXCAVATION



CONTOUR	$\bar{\sigma}$ (ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-15

STORAGE ROOMS
EFFECTIVE STRESS DISTRIBUTION 10 YEARS AFTER EXCAVATION

Because the model does not include failure criteria for the anhydrite bed, an analysis for potential failure in this bed was performed separately. In Chapter 6, the failure criterion

$$\sqrt{J_2'} = 752 - 0.279J_1 \quad \text{(stress in ksf)} \tag{12-1}$$

was defined for the anhydrite bed based on laboratory tests. Rewriting this equation in terms of the effective stress at failure $\bar{\sigma}_f$ and the first stress invarient at failure $(J_1)_f$:

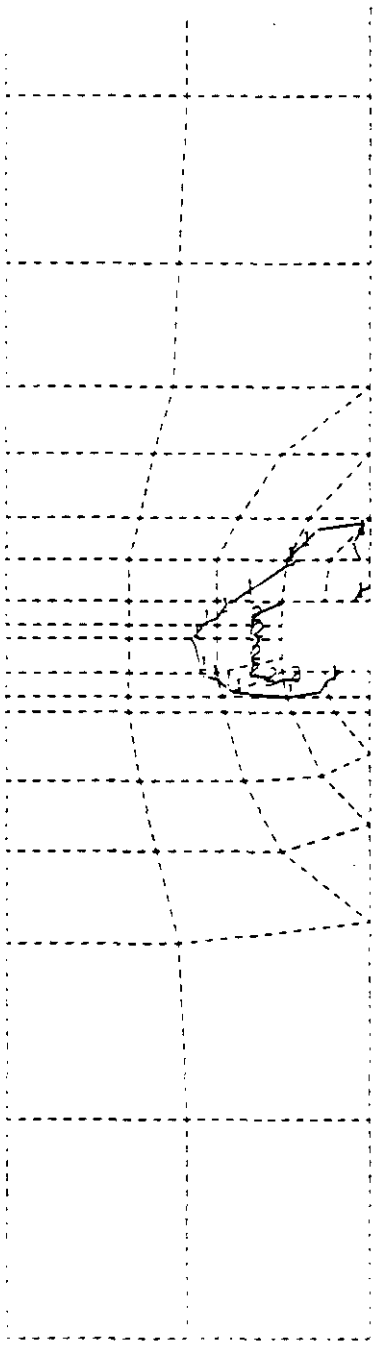
$$\bar{\sigma}_f(\text{ksf}) = 1302.5 - 0.483\,(J_1)_f \tag{12-2}$$

From the results of the numerical modeling, the average effective stress stress at a point close to the center of the room exceeds $\bar{\sigma}_f$ at about 8.5 years since excavation. This does not mean catastrophic failure will occur. Instead, there will be a redistribution of stress in the anhydrite bed which the model cannot consider.

Computed effective creep strain distributions were plotted on selected elements of the deformed mesh at 1 year and 6.5 years after excavation (Figures 12-16 and 12-17). Ten strain increments with an interval of 0.01 were used to span a strain range from 0 to 0.100.

At 1 year after excavation, effective creep strains have concentrated in the region around the room opening. At 6.5 years after excavation, the effective creep strains have further intensified around the room opening and in the region above the anhydrite bed near the room centerline.

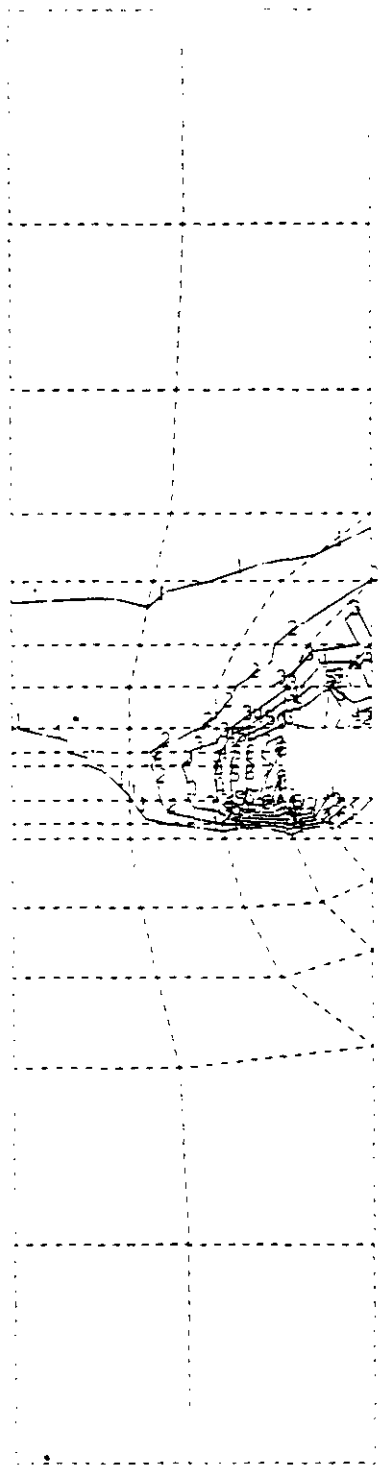
Based on laboratory creep tests on samples of halite, a failure criterion has been proposed (equation 6-5 in Chapter 6). Based on this criterion, the failure effective strain for halite is a function of the mean normal stress intensity and reaches a maximum magnitude of nearly 16 percent at a mean stress intensity of 125 ksf.



CONTOUR	$\bar{\epsilon}$
1	0.01
2	0.02
3	0.03
4	0.04
5	0.05
6	0.06
7	0.07
8	0.08
9	0.09
10	0.10

Figure 12-16

STORAGE ROOMS
EFFECTIVE CREEP STRAIN DISTRIBUTION 1 YEAR AFTER EXCAVATION



CONTOUR	$\bar{\epsilon}$
1	0.01
2	0.02
3	0.03
4	0.04
5	0.05
6	0.06
7	0.07
8	0.08
9	0.09
10	0.10

Figure 12-17

STORAGE ROOMS
EFFECTIVE CREEP STRAIN DISTRIBUTION 10 YEARS AFTER EXCAVATION

creep strain ...

..., and by linear extrapolation beyond 6.5 years, failure will be initiated in the halite about 12 years after the completion of excavation. The failure will be initiated at floor and wall intersections.

However, the numerical modeling also shows that effective strain decreases rapidly with distance away from the opening. Thus, the failure is expected to be confined very close to the opening. This will require periodic scaling and trimming.

Principal Stresses. The computed principal stresses on the plane of a section across the storage rooms are presented in a qualitative manner on Figures 12-18 through 12-20. The magnitudes of the two principal stresses are proportional to the lengths of the corresponding lines which are plotted, perpendicular to each other, at the centroid of each of the elements.

Immediately after excavation, the magnitudes of the principal stresses are relatively large in the corners of the room and in the anhydrite bed. As the room opening deforms, the principal stresses concentrate in the anhydrite bed near the room centerline.

The plots of the principal stresses also show the stress arch which forms around the room due to the transfer of loads around the room opening. The stress arch tends to become enlarged with time and migrates away from the room.

Deformation and Closure. Figures 12-18 through 12-20 also show the predicted deformed shapes of a typical storage room at different times. The dashed lines represent the outline of the deformed shape of the storage room.

Immediately after excavation, deformation starts around the opening. After 1 year of creep, the halite roof beam deforms noticeably at its

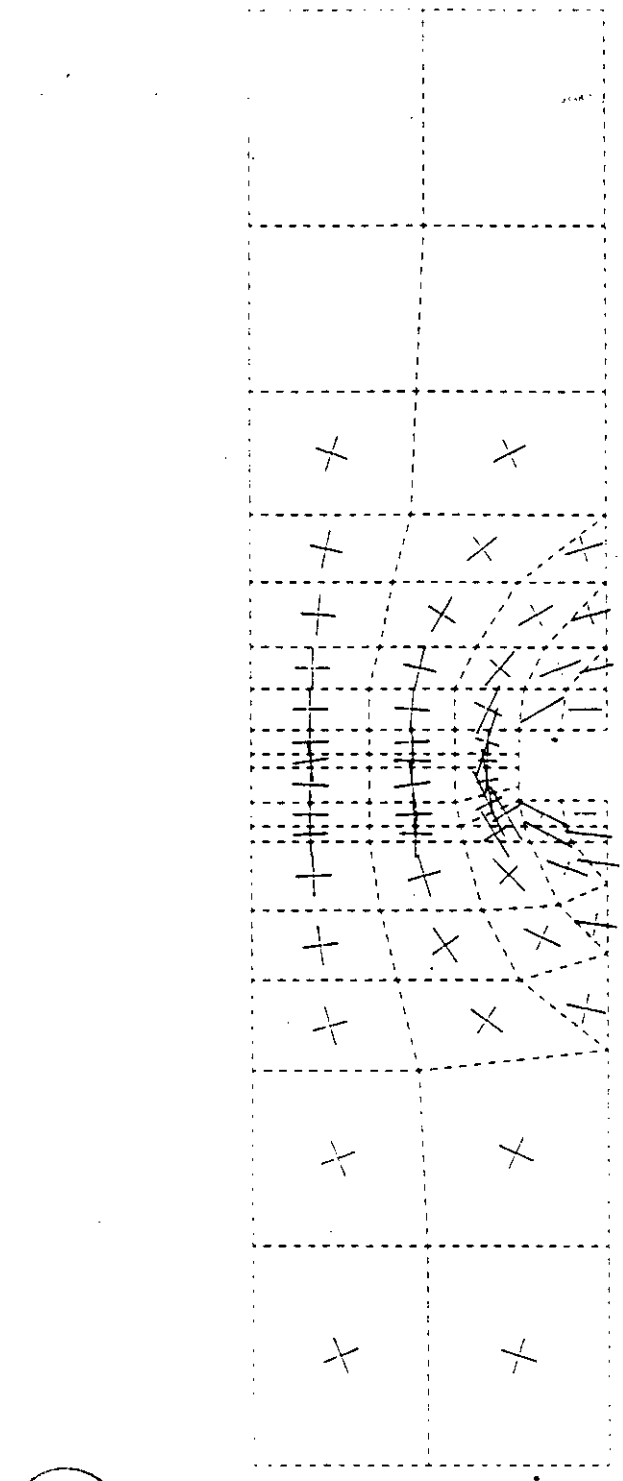


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Figure 12-18

STORAGE ROOMS
PRINCIPAL STRESSES AND DEFORMED SHAPE
IMMEDIATELY AFTER EXCAVATION

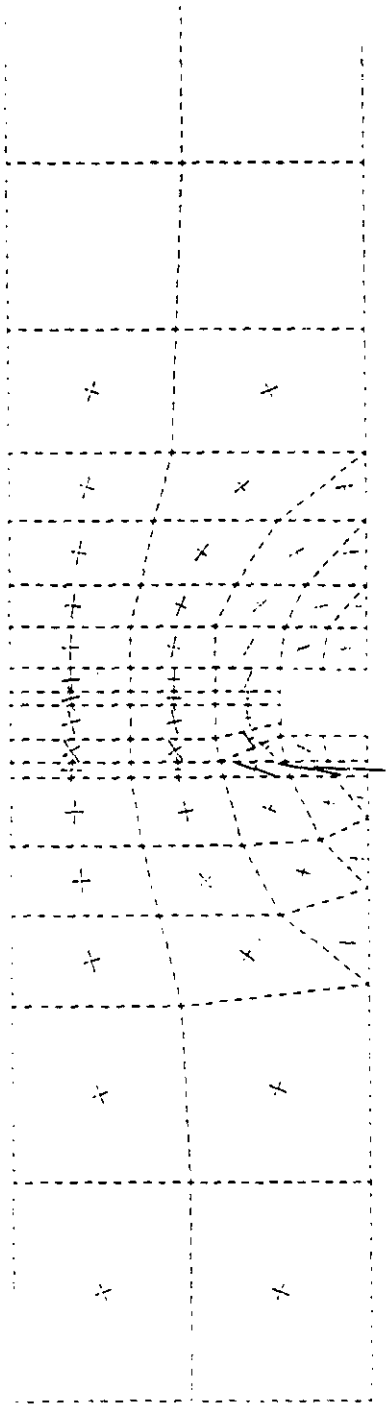


Figure 12-19

STORAGE ROOMS
PRINCIPAL STRESSES AND DEFORMED SHAPE
1 YEAR AFTER EXCAVATION

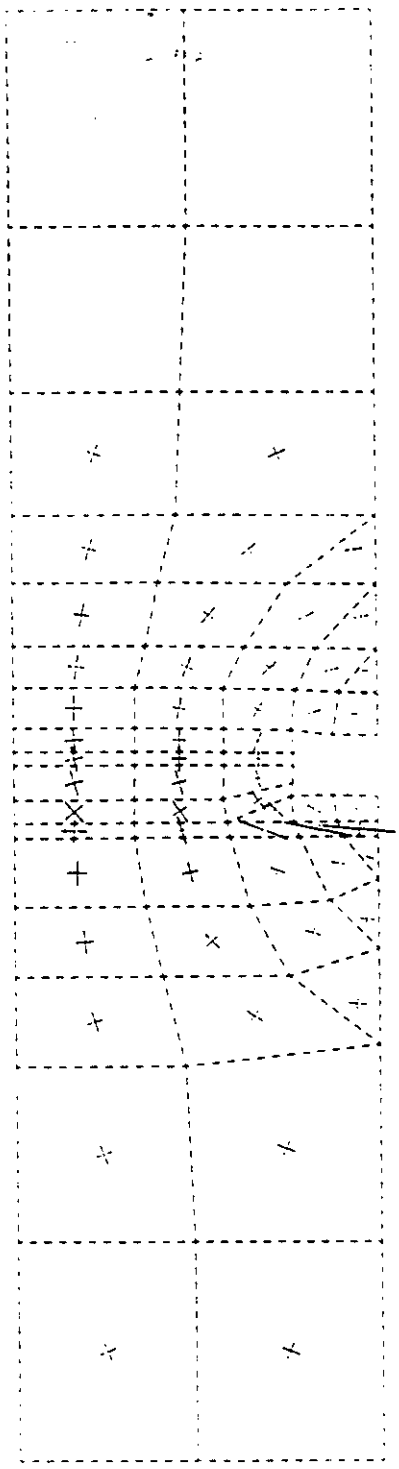


Figure 12-20

STORAGE ROOMS
PRINCIPAL STRESSES AND DEFORMED SHAPE
10 YEARS AFTER EXCAVATION

the predicted all [illegible] However, the floor heave is still very small [illegible], some slippage has occurred along the clay seams. This is graphically depicted as a slight horizontal disjointing of the lines that form the element boundaries along a clay seam.

At 6.5 years after excavation, the predicted deformed shape of the storage room shows much downward deformation in the roof beam at its centerline. The floor has heaved slightly upward, with the upward displacement being somewhat more noticeable in the center of the room. The analysis shows very little deformation in the anhydrite bed even after 10 years. Based on the small amount of floor heave, it appears that the stiff anhydrite bed diminishes the amount of floor creep by supporting a large amount of lateral pressure. However, because there is a potential for the anhydrite bed to fail locally at about 8.5 years after excavation, it may not be able to support this large amount of lateral pressure. This may result in a higher creep rate in the floor than predicted by the model.

As discussed in Chapter 11, laboratory derived creep constants underpredicted actual closure in the test rooms. Thus, back calculation of average creep parameters was made using either measured roof-to-floor or wall-to-wall closure data. The effectiveness of the model simulation techniques used to derive the creep parameters and extrapolate closure behavior were discussed in detail in Chapter 11, subsection 11.3.2.5. Because MB-139 was assumed to be linearly elastic with infinite strength, the numerical modeling underpredicted floor heave but overpredicted roof sag. However, the overall roof-to-floor closure is reasonably well predicted by the model.

In order to show the effect of geometry and extraction on the closure rate, extrapolations of the in situ closure histories for the test rooms and various size drifts, as well as the calculated roof-to-floor and wall-to-wall closures for the storage rooms were plotted for comparison (Figures 12-21 and 12-22). Similar calculations were made using the

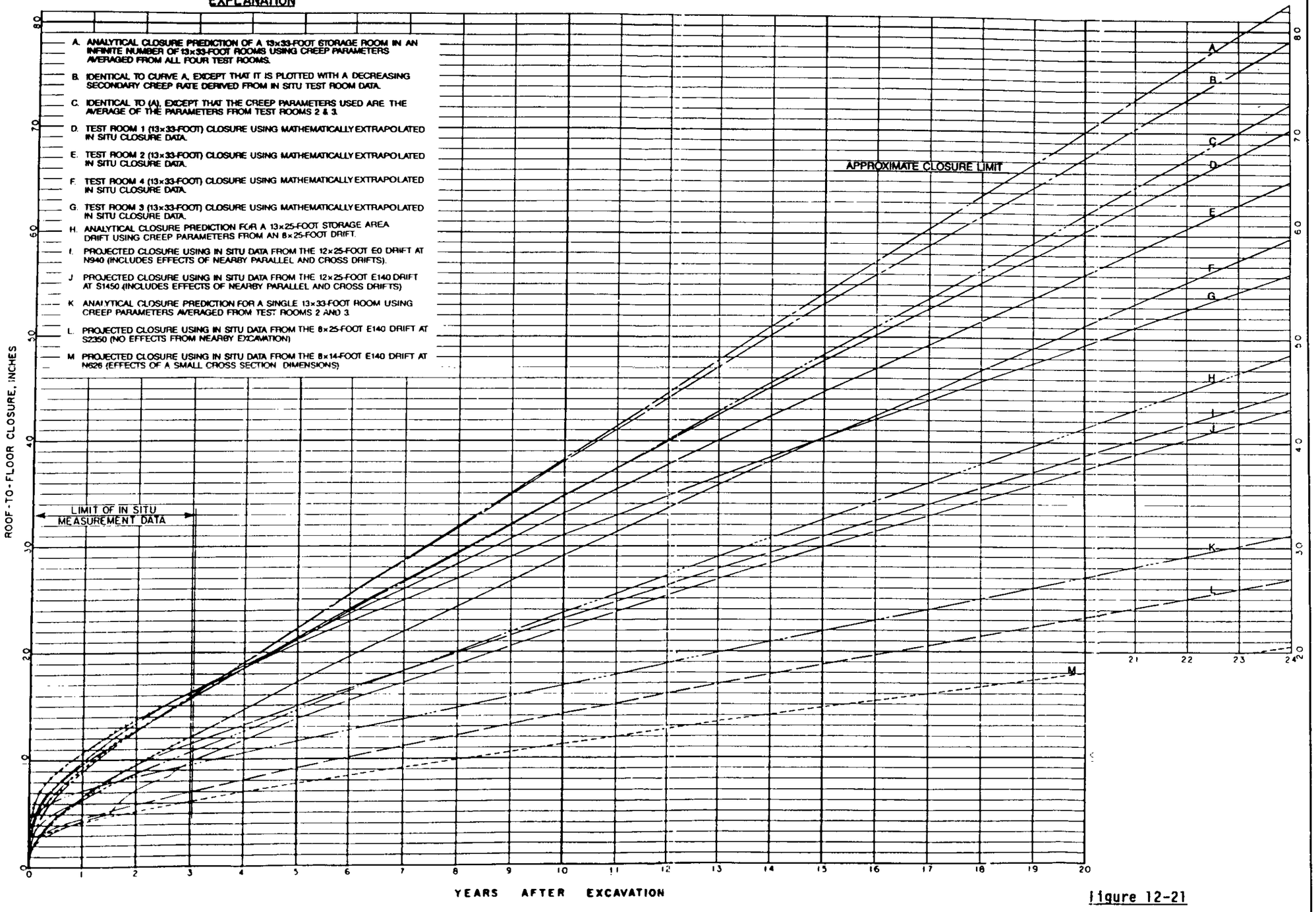


Figure 12-21

ROOF-TO-FLOOR CLOSURE
GEOMETRY AND EXCAVATION EFFECTS

EXPLANATION

A. ANALYTICAL CLOSURE PREDICTION OF A 13×33-FOOT STORAGE ROOM IN AN INFINITE NUMBER OF 13×33-FOOT ROOMS USING CREEP PARAMETERS *AVERAGED FROM ALL FOUR TEST ROOMS.*

B. IDENTICAL TO CURVE A, EXCEPT THAT IT IS PLOTTED WITH A DECREASING SECONDARY CREEP RATE DERIVED FROM IN SITU TEST ROOM DATA.

D. TEST ROOM 1 (13×33-FOOT) CLOSURE USING MATHEMATICALLY EXTRAPOLATED IN SITU CLOSURE DATA.

E. TEST ROOM 2 (13×33-FOOT) CLOSURE USING MATHEMATICALLY EXTRAPOLATED IN SITU CLOSURE DATA.

F. TEST ROOM 4 (13×33-FOOT) CLOSURE USING MATHEMATICALLY EXTRAPOLATED IN SITU CLOSURE DATA.

G. TEST ROOM 3 (13×33-FOOT) CLOSURE USING MATHEMATICALLY EXTRAPOLATED IN SITU CLOSURE DATA.

I. PROJECTED CLOSURE USING IN SITU DATA FROM THE 12×25-FOOT EO DRIFT AT N940 (INCLUDES EFFECTS OF NEARBY PARALLEL AND CROSS DRIFTS).

J. PROJECTED CLOSURE USING IN SITU DATA FROM THE 12×25-FOOT E140 DRIFT AT S1450 (INCLUDES EFFECTS OF NEARBY PARALLEL AND CROSS DRIFTS).

L. PROJECTED CLOSURE USING IN SITU DATA FROM THE 8×25-FOOT E140 DRIFT AT S2350 (NO EFFECTS FROM NEARBY EXCAVATION).

M. PROJECTED CLOSURE USING IN SITU DATA FROM THE 8×14-FOOT E140 DRIFT AT N626 (EFFECTS OF A SMALL CROSS SECTION DIMENSIONS).

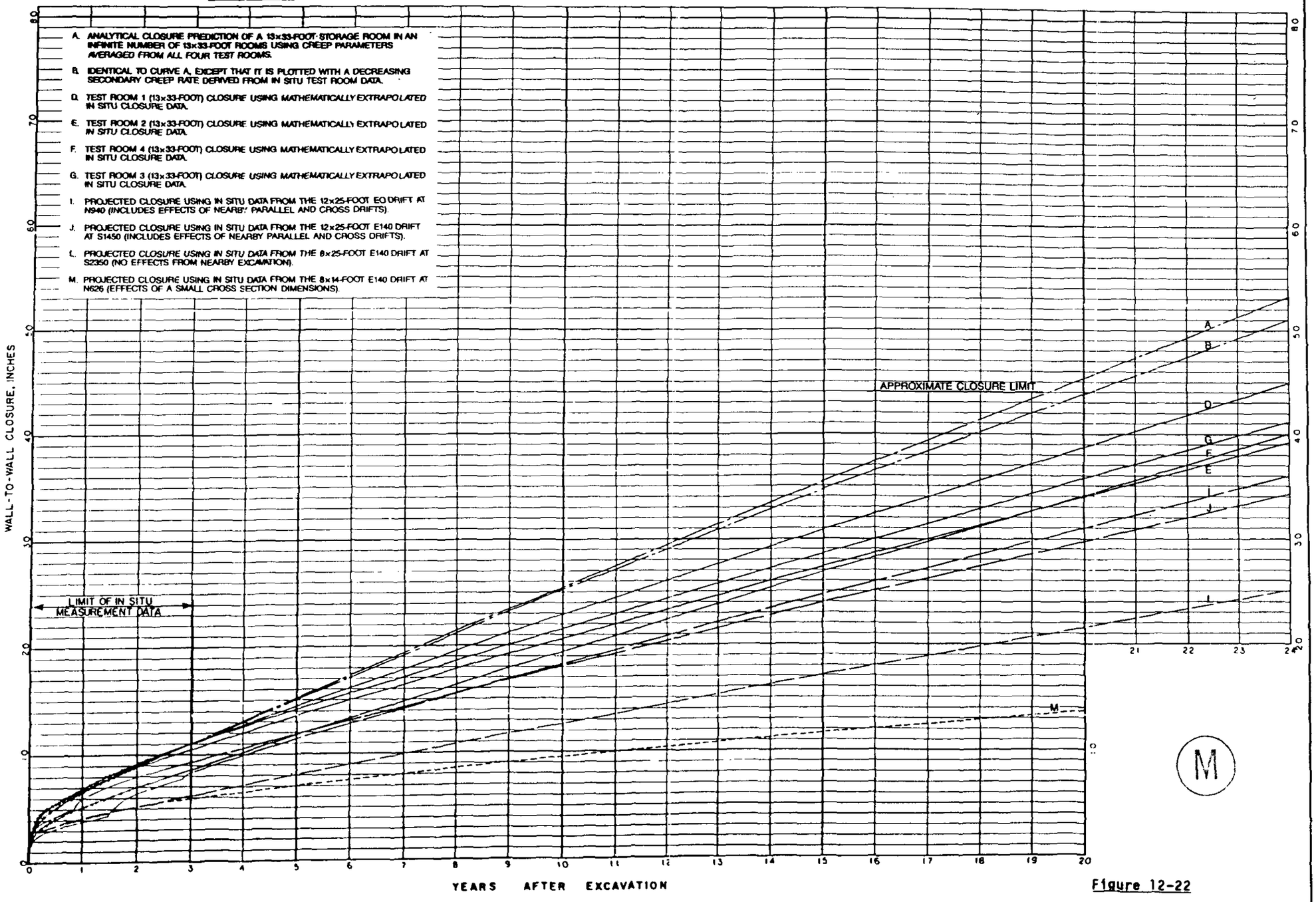


Figure 12-22

WALL-TO-WALL CLOSURE
GEOMETRY AND EXCAVATION EFFECTS

average creep parameters for the two interior 13 x 33-foot test rooms and using an infinite array of rooms to indicate the sensitivity of the value of the parameters. The same parameters were also used in the calculations of a single 13 x 33-foot room model to determine the effects of extraction on the number of rooms in an array. The descriptions of the closure curves plotted on Figures 12-21 and 12-22 are as follows:

(A) Analytical closure prediction of a 13 x 33-foot storage room in an infinite number of 13 x 33-foot rooms using creep parameters averaged from all four test rooms.

(B) Identical to curve A, except that it is plotted with a decreasing secondary creep rate derived from in situ test room data.

(C) Identical to curve A, except that the creep parameters used are the average of the constants from Test Rooms 2 and 3.

(D) Test Room 1 closure using mathematically extrapolated in situ closure data.

(E) Test Room 2 closure using mathematically extrapolated in situ closure data.

(F) Test Room 4 closure using mathematically extrapolated in situ closure data.

(G) Test Room 3 closure using mathematically extrapolated in situ closure data.

(H) Analytical closure predicted for a 13 x 25-foot storage area drift using creep parameters from an 8 x 25-foot drift.

(I) Projected closure using in situ data from the 25 x 25-foot E0 drift at N940 (includes effects of nearby parallel and cross drifts).

(J) Projected closure using in situ data from the 12 x 25-foot E140 drift at S1450 (includes effects of nearby parallel and cross drifts).

(K) Analytical closure prediction for a single 13 x 33-foot room using creep parameters averaged from Test Rooms 2 and 3.

(L) Projected closure using in situ data from the 8 x 25-foot E140 drift at S2350 (no effects from nearby excavation).

(M) Projected closure using in situ data from the 8 x 14-foot E140 drift at N626 (effects of small cross section dimensions).

As expected, the two interior test rooms (Test Rooms 2 and 3) had more closure and higher closure rates during the first year than the outer rooms (Test Rooms 1 and 4). This is due to the fact that Test Rooms 2 and 3 were excavated before Test Rooms 1 and 4. However, Test Rooms 1 and 4 exhibit higher closure rates during the secondary creep stage. This is consistent with the stress arch principle.

An evaluation of these 13 closure curves indicates that geometry and extraction ratio strongly impact the total closure in a seven-room panel within an eight-panel storage area and that the rate of closure will be faster than the extrapolated curves for a test room within the four-room test panel. For conservatism, Curve A (Figures 12-21 and 12-22) is used for storage room analysis, prediction and validation.

Curve A on Figure 12-21 represents the roof-to-floor closure prediction using the average creep parameter values for Test Rooms 1 through 4. These values were previously presented in Chapter 11, Table 11-12. In

the first year following excavation, the roof-to-floor closure curve is non-linear. The primary creep closure rate is very fast, as shown by the steeply sloped region in the first 3 months. Two and one half inches were added to the measured closure values to compensate for the lack of early closure data (Chapter 11). During secondary creep, the curve flattens and becomes approximately linear with a closure rate of approximately 3 inches per year. This closure prediction shows a closure of approximately 22 inches at 5 years after excavation and 54 inches at 15 years after excavation.

Curve A on Figure 12-22 represents the wall-to-wall closure prediction using the average creep parameter values for Test Rooms 1 through 4. These values were previously presented in Chapter 11, Table 11-13. As with the roof-to-floor closure, the wall-to-wall closure is non-linear in the first year following excavation. Again, the closure rate due to primary creep is initially very fast in the first 3 months as shown by the steep slope of the curve. Two inches were added to the measured closure values, as discussed in Chapter 11, to compensate for the lack of early closure data. The curve eventually flattens during the secondary creep phase and becomes approximately linear with a closure rate of about 2 inches per year. The wall-to-wall closure prediction shows a closure of approximately 15 inches at 5 years after excavation and 36 inches at 15 years after excavation.

When the storage rooms are fully occupied by waste and backfill material, the closure of the room will be limited by the ability of the contents to be compacted. Assuming that the volume of the waste container can be compacted by 40 percent and the volume of the backfill material by 15 percent, the roof-to-floor closure is predicted to have a maximum value of 66 inches and the wall-to-wall closure a maximum value of 44 inches. This maximum closure would occur after about 18 years for vertical closure and 19 years for horizontal closure (Figures 12-21 and 12-22). A reduction in the closure rate after the wall and roof surfaces begin compacting the backfill material and exerting pressure on the waste containers has not been considered.

Curve A ... conservative estimates of storage room closure. Therefore, values from these curves were used in evaluating the reference design against the design criteria and design bases requirements. The design bases allow up to 12 inches of closure in the first 5 years after excavation in order to maintain a 16-inch space for ventilation and backfill equipment and to maintain a 12-foot minimum clearance for storage equipment. The estimated vertical closure in 5 years using curve A is about 22 inches. This 10 inch increase over the design basis limit could be accommodated by increasing the reference design room height from 13 feet to 13 feet 10 inches. This would be satisfactory for permanent storage. Another way to accommodate the increased closure and still maintain the 16-inch ventilation space (Figure 12-3) is to eliminate the backfill or reduce its thickness covering the CH containers to 6 inches or less. Deleting the salt backfill would require a change in the design criteria.

The solution to the increased vertical closure is not so simple for permanent storage, however. If at the end of the 5-year demonstration period, a decision is made requiring the stored waste to be retrieved, the design criteria assume that it will take twice as long to retrieve waste as it took to store it. This would result in a room being an additional 10 years old before retrieval is completed. Under these circumstances, a 15-year old room would have a closure of 54 inches, based on Curve A. Assuming that a storage room was excavated to the maximum allowable height of 14 feet, the closure would be 14 inches more than could be accommodated (24 inches for closure allowance, including 12 inches allowed by the design basis and 12 inches for the increase in room height from 13 feet to 14 feet, and 16 inches for ventilation space). This would result in the backfill being compressed and in the possible crushing and breaching of the waste containers. Because this scenario does not comply with the design criteria requirements, other alternatives must be considered.

These alternatives, including modification of the design criteria, are presented in subsection 12.6.2. Two considerations must be addressed here, however, to support the recommendations. First, the 10 year maximum retrieval period assumed by the design criteria is very conservative. Should retrieval be conducted on a three shifts per day basis, rather than the assumed one shift per day, no room would be older than 7 years by the time its waste was retrieved. Based on Curve A, a 7 year old room, from the time of initial excavation, would have a closure of about 28 inches. Assuming a room was excavated to the 14-foot high maximum and allowing 24 inches for closure, the waste containers will not be crushed or breached. However, the ventilation space will be reduced to 12 inches. This could be tolerated because the maximum 28-inch closure will be at the room centerline; additional ventilation space will be gained closer to the room walls. Alternatively, the thickness of the salt backfill over the containers could be reduced or eliminated to maintain the ventilation.

The second consideration supporting the recommendations is that a reduction in room closure can be gained by modifying the excavation technique. A panel of rooms could be excavated to the reference design dimension of 13 to 14 feet high. After a year of closure, these openings will be closing at the rate determined by secondary creep. At this time the rooms could be trimmed to 14 feet high. Trimming will remove the salt that has moved into the room during the year and provide a full dimensioned room that will close at the rate determined by secondary creep. Based on an average secondary creep closure rate of 3 inches per year, the rooms would have the following predicted closures after trimming:

5 years	15 inches
7 years	21 inches
10 years	30 inches
15 years	45 inches

Should the retrieval be effected within 7 years after trimming, a

would meet all of the retrieval requirements without further modification.

In order to gain the reduced closure benefits of secondary creep, the amount of trimming must be kept to a minimum. The rooms should initially be excavated as close to the 14-foot high maximum dimension as possible. The trimming operation a year later should remove no more salt from the floor than necessary to enlarge the room height to 14 feet. This small amount of trimming will minimize the increase in closure that typically follows major re-excavation, as has already been experienced at the WIPP during floor lowering in some drifts (Chapter 10, Figure 10-6, and this chapter, Figure 12-21, Curve J). This is discussed in detail in the next subsection.

The width of the storage rooms presents similar problems. The reference design specifies a minimum room width of 33 feet and a maximum width of 34 feet. Again, Curve A on Figure 12-22 represents the most conservative estimate of horizontal closure. The design basis allows 9 inches of horizontal closure in the first 5 years (4 1/2 inches for each wall). The space between the wall and the waste containers (Item 10, Figure 12-3), for the storage area reference design, will be backfilled with loose salt.

The predicted wall-to-wall closure in 5 years, using Curve A, is about 15 inches. This closure will result in compaction of the salt backfill and possibly in the crushing and breaching of some containers. This condition is suitable for permanent storage. Should retrieval be required, the predicted closure for a 15-year old room would be 36 inches. If it is assumed that the room is excavated to its maximum dimensions, as discussed earlier, the room would be 34 feet wide with the waste containers 15 inches from each wall. This 30 inches of horizontal clearance is not adequate to meet the design criteria requirements for the crushing and breaching of containers, even if backfill were not required. In order to meet the intent of the design criteria, the reference design must be modified. The five alternatives presented in subsection 12.6.2 include modifications to accommodate this horizontal closure.

As is the case with vertical closure in the storage rooms, timing of retrieval operations and two-stage excavation can be used to reduce the wall-to-wall closure. Should three shifts per day be used during retrieval and if the rooms are a maximum of 7 years old, then wall-to-wall closure would be about 20 inches. If the storage operation is conducted on a first emplaced/first retrieved basis and retrieval is effected before a room exceeds an age of 6 years, horizontal closure would be further reduced to 18 inches. Both of these operational changes would decrease the possiblity of crushing or breaching the waste containers.

Two-stage excavation gains additional closure benefits. If a room is initially excavated to the maximum design width of 34 feet and after a year of closure trimmed to 34 feet, closure would be controlled by secondary creep. Based on a wall-to-wall secondary creep closure rate of 2 inches per year, the rooms would have the following predicted closures after trimming:

5 years	10 inches
7 years	14 inches
10 years	20 inches
15 years	30 inches

This will further minimize crushing or breaching of the waste containers.

It is expected that increasing the distance between the waste canisters and the wall by increasing the room to the maximum design width of 34 feet, thereby increasing the amount of loose salt backfill in this space, will increase the time it takes for horizontal closure to consolidate the backfill and transfer sufficient load to crush the waste canisters. This, coupled with the faster retrieval schedules discussed previously and the fact that the backfill will not be completely confined, will minimize crushing and breaching of the canisters as required by the criteria. How much it will be minimized

from in situ ... consoldiation and container stability become available.

12.3.3.2 Storage Area Drifts

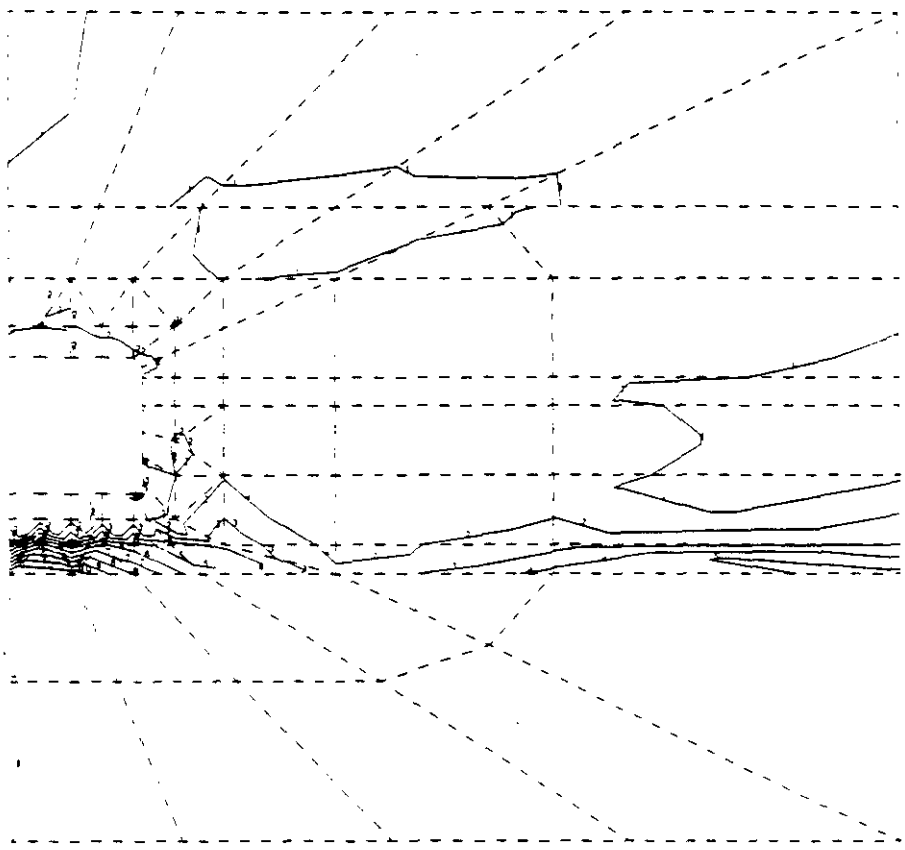
The results of the analysis of the storage area drifts with dimensions of 8 x 25 feet were plotted at various integration time steps. These integration steps correspond to real times immediately after floor lowering and 5 years after initial excavation. The effective stress and effective creep strain, principal stresses, and deformed shape were plotted at these times based on the roof-to-floor creep parameters for a representative station (Chapter 10).

Effective Stresses and Effective Creep Strains. Figures 12-23 and 12-24 show the calculation for effective stress distribution in those elements of the finite element model near the drift opening. As with similar plots for the 8 x 25-foot drifts discussed in Chapter 10, each contour increment represents an effective stress interval of 100 ksf.

The plot of effective stress immediately after floor lowering shows the impact on the stress distribution as a result of the drift height modification. This change in effective stress precipitates a concomitant increase in the creep rate. This appears as a sharp but short increase in slope on the roof-to-floor closure versus time curve (Chapter 10, Figure 10-6, and this chapter, Figure 12-21, Curve J).

At the end of 5 years, the anhydrite bed shows a very large effective stress gradient from top to bottom in the vicinity of the drift floor due to the stiffness of the bed. Maximum effective stresses are in excess of 1,000 ksf.

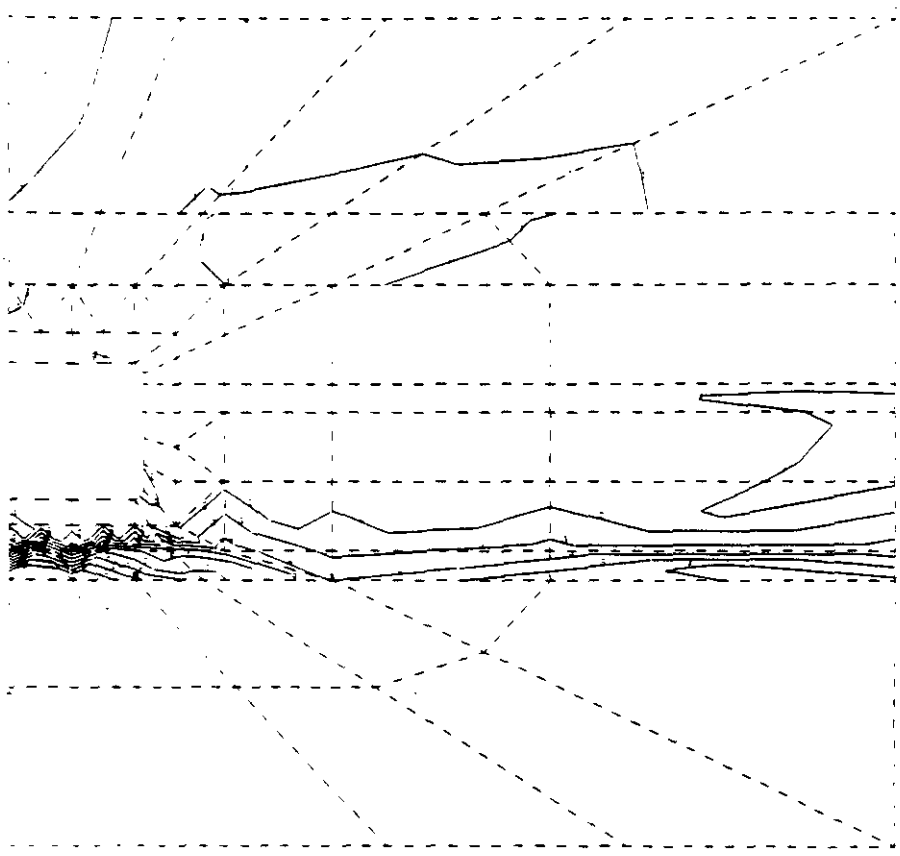
The effective creep strains have concentrated in the region around the drift opening and intensify with time. A rough linear extrapolation of effective creep strain beyond 5 years indicates that the maximum



CONTOUR	$\bar{\sigma}$(ksf)
1	100
2	200
3	300
4	400
5	500
6	600
7	700
8	800
9	900
10	1000

Figure 12-23

STORAGE AREA DRIFTS
EFFECTIVE STRESS DISTRIBUTION IMMEDIATELY AFTER FLOOR LOWERING



CONTOUR	$\bar{\sigma}$(ksf)
1	100
2	200
3	300
4	400
5	500
6	600
7	700
8	800
9	900
10	1000

Figure 12-24

STORAGE AREA DRIFTS
EFFECTIVE STRESS DISTRIBUTION 5 YEARS AFTER EXCAVATION

average effective creep strain may reach 16 percent at about 20 years after excavation. Based on failure criteria for halite obtained from laboratory test data (Chapter 6), failure in halite may start at about 15 percent. However, the numerical modeling indicates that the effective creep strain drops off sharply away from the opening. It is therefore expected that high effective strain would not result in a large scale failure in halite.

Principal Stresses. The plots of principal stresses (Figures 12-25 and 12-26) consistently show the "arch" pattern which develops around the drift in order to transfer loads past the drift opening. The arch is shown to migrate away from the opening with time. As expected, the magnitude of major principal stress is greater in the corners of the drift and in the underlying anhydrite bed. The anhydrite in particular is subjected to large stresses because it is the only material that has been assumed in the model to not creep; it therefore "stores" a large amount of energy in the form of elastic strain.

Deformation and Closure. Figure 12-27 shows the deformed shape 5 years after drift excavation, or approximately 3 years after floor lowering. It should be noted that, while both the roof and walls are creeping inward, the upward floor heave is small by comparison. This phenomenon is due to the stiffening effect of the underlying anhydrite bed.

The stress redistribution that occurs as a result of modifying the drift height is the driving force behind the large roof and wall deflections that are the most prominent features of the plot at 5 years. A close examination of the 5-year deformed plot shows that clay seam slippage has occurred. The most noticeable slippage has occurred in the clay seam located about 8 feet above the existing roof. Here, the maximum horizontal relative displacement across the seam is approximately 3 1/2 inches. Actual relative displacement will be lower because the clay seams have a finite friction coefficient.

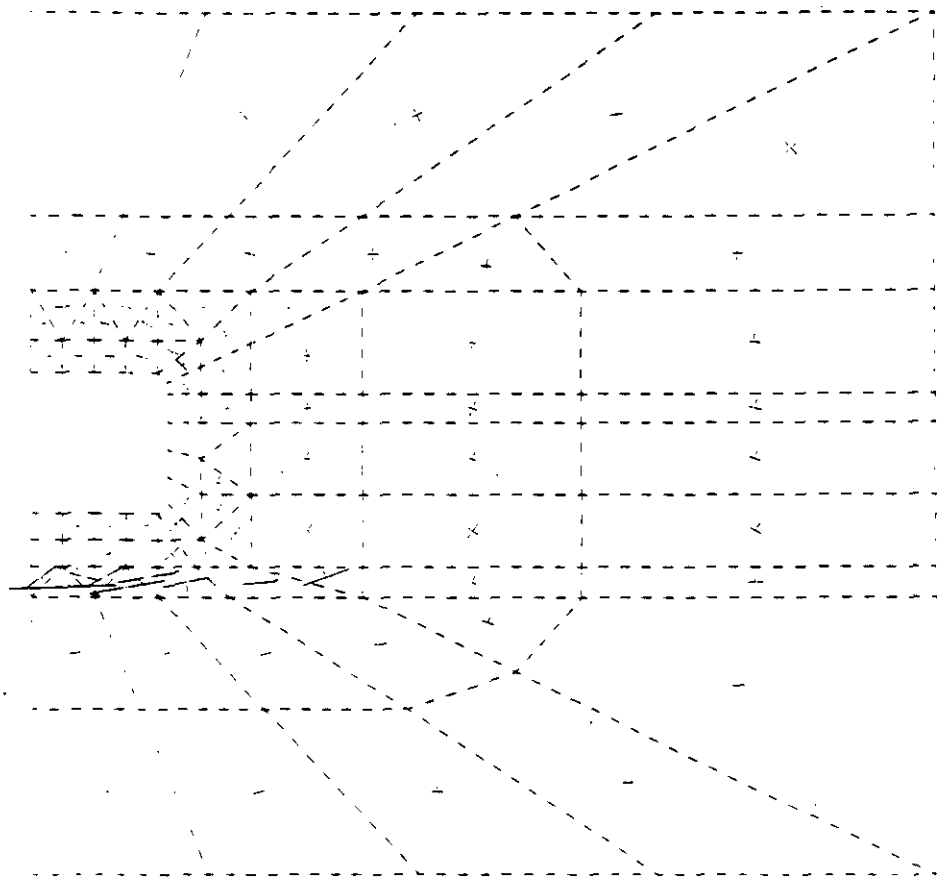


Figure 12-25

STORAGE AREA DRIFTS
PRINCIPAL STRESSES IMMEDIATELY AFTER EXCAVATION

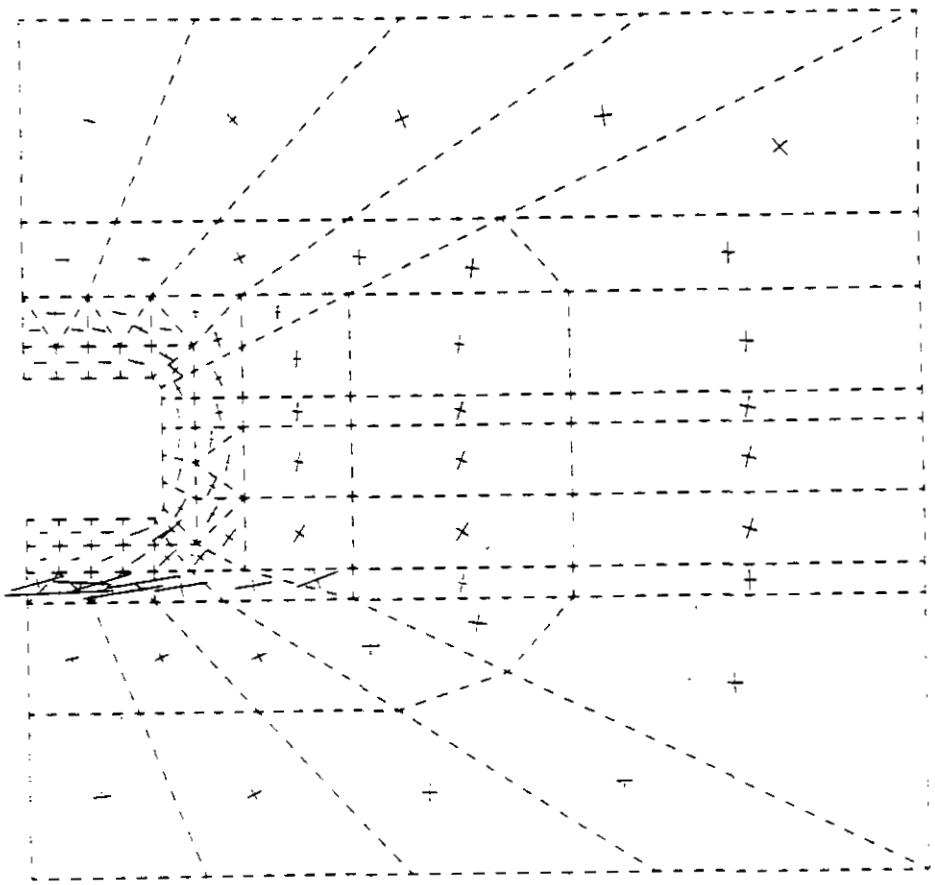


Figure 12-26

STORAGE AREA DRIFTS
PRINCIPAL STRESSES 5 YEARS AFTER EXCAVATION

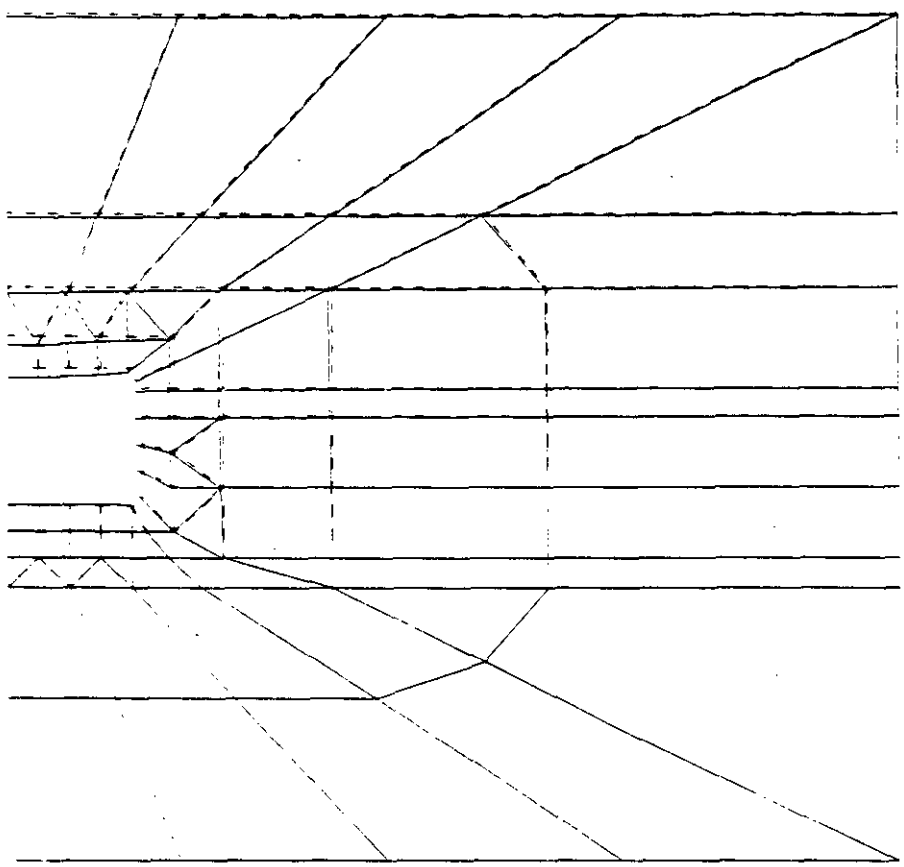


Figure 12-27

STORAGE AREA DRIFTS
DEFORMED SHAPE 5 YEARS AFTER EXCAVATION

Figure 12-28 demonstrates the effect of increasing the vertical dimension of a storage area drift at some point after initial excavation. The finite element model is calibrated with in situ data. It models an 8 x 25-foot drift that has its height increased to 13 feet by excavating an additional 5 feet from the floor. The 8 x 25-foot drift exhibits typical closure; that is, the curve shows high rate of closure during primary creep and a nearly constant closure rate during secondary creep. When the floor is lowered (in this case 2.3 years after excavation), primary creep is temporarily reinitiated. The secondary creep phase is eventually re-established, but with some difference. The slope of the curve during secondary creep after floor lowering is slightly steeper than the secondary creep prior to floor lowering. The rate of closure does not return to the initial rate, but rather reflects the new, larger dimension of the drift. In this model, the modified drift has 11 inches of vertical closure 5 years after initial excavation.

The same computation included wall-to-wall closure. The effects of floor lowering were the same as for roof-to-floor closure. After floor lowering, primary creep was reinitiated and followed by a new secondary creep phase with a slightly higher closure rate. Five years after initial excavation, the predicted horizontal closure is about 8 inches.

A rough extrapolation of the predicted roof-to-floor and wall-to-wall closures based on model simulation and resulting secondary creep closure indicates the following:

Time (Years)	Roof-to-Floor Closure at 2.0 inches/year (inches)	Wall-to-Wall Closure at 1.6 inches/year (inches)
10	20	16
15	30	24
20	40	32
25	50	40

The maximum effective strain around the drift opening reaches 6 percent about 8 years after excavation. Based on in situ observations and the

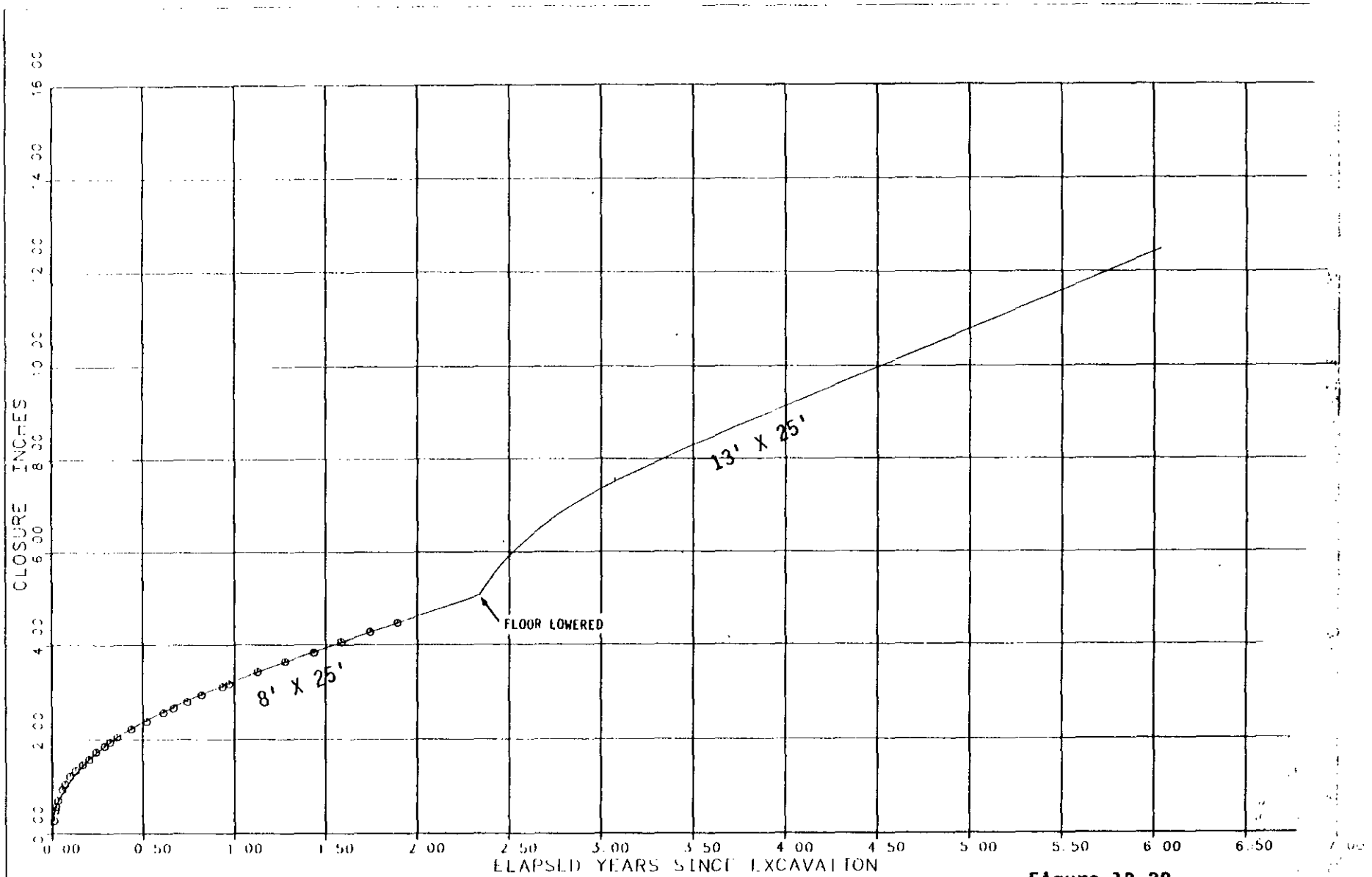


Figure 12-28

STORAGE AREA DRIFTS
ROOF-TO-FLOOR CLOSURE PREDICTION

results of modeling the test rooms, this effective strain of 6 percent may not result in instability of the drifts. However, in 15 years the effective strain at the excavation surface will exceed 10 percent locally and the roof-to-floor closure will be nearly 30 inches. According to the failure criterion, based on laboratory tests on samples of halite (Chapter 6), the halite is supposed to fail at about 16 percent effective strain. Therefore, minor surface deterioration can be expected and some trimming will be required to permit operation of the waste storage equipment. Because the effective strain decreases rapidly within the salt, trimming on the order of only a few feet may be needed after 20 years.

The storage drifts, as with the storage rooms, must accommodate greater than predicted closure. The reference design provides for waste storage in the storage area drifts only after all of the main storage rooms are filled. Since this would occur toward the end of the operating phase, waste in these drifts would not be subject to retrieval under the provisions governing the 5-year demonstration period. Waste stored in the drifts would be on a permanent basis.

Increased closure does impact waste emplacement and emplacement machinery. In the reference design, the greatest age a drift would reach before waste was emplaced would be about 15 years. At this age, based on the calculated closure for a 13 x 25-foot drift, the predicted roof-to-floor closure would be about 25 inches and the predicted wall-to-wall closure would be about 20 inches. The storage drifts would have to be trimmed to permit proper storage and equipment clearance. Similarly, the storage drifts and crosscuts less than 25 feet wide would also require trimming.

12.3.3.3 Intersections

The modeling of intersections is an expensive, three-dimensional analysis. However, to estimate closures at a storage room intersection, a simplified method can be utilized in place of a

Two-dimensional analysis [illegible] and develops the mathematical relationship [illegible] floor closure at the intersections.

When normalized time is sufficiently large, analytical results have consistently shown that room closure in the normalized time domain can be estimated by the following equation:

$$u = u^*_o + \dot{u}^*_f \, t^* \qquad \text{when: } t^* > 1x10^{-11} \text{ ksf}^{-4.9} \qquad (12\text{-}3)$$

where: $t^* = C[t + \frac{A}{z}(1 - e^{-zt})]$ is the normalized time;

u^*_o is a constant; and

$$\dot{u}^*_f = \lim_{\Delta t \to 0} \frac{\Delta u}{\Delta t^*}$$

Closure for the storage room intersections, in normalized time, was calculated using the creep parameters discussed in Chapter 11 and in situ data collected near the intersections of the N1420 drifts with Rooms L1 and L2. As expected, the closure history follows equation 12-3 when the normalized time is greater than $8.0x10^{-12}$ ksf$^{-4.9}$. The average values of u^*_o and $\dot{u}^*_f$ for Rooms L1 and L2 were calculated to be 0.0450 feet and $1.967x10^{12}$ ksf$^{-4.9}$, respectively.

After determining the values of u^*_o and $\dot{u}^*_f$, equation 12-3 can be utilized for computing the closure at a storage room intersection. Figure 12-29 shows the roof-to-floor closure prediction at a storage room intersection.

12.4 STORAGE AREA PLUGS

The design criteria require that the storage area reference design contain provisions for the isolation of the waste storage panels from each other. The reference design contains recommended locations for plugs which would provide this isolation. It does not, however,

provide a specific design for the plugs. The design of the plugs is currently under investigation by SNL (ref. 12-8).

The recommended locations for the plugs are shown on Figure 12-30. The plugs will be constructed in the entry drifts to each panel. The four main access drifts to the storage area will also contain plugs. The section of the entry drifts leading from the access drifts to the first storage room is 200 feet long. The reference design contains provisions for the construction of approximately 100-foot long plugs centered in this 200-foot section of each entry drift.

Originally, the reference design contained entry drift cross section dimensions of 13 feet high and 33 feet wide. These dimensions are the same as those for the storage room reference design and were chosen based on waste container stacking considerations. This design was modified as the result of a meeting between the DOE and all project participants (ref. 3-2). The reference design modification was based on the necessity to minimize the cross section area of the plugs while maintaining sufficient room for the excavation and waste storage equipment.

The reference design modification for the entry drifts is shown on Figure 12-31. The 100-foot long section containing the plug has been reduced in cross section to 13 feet high and 14 feet wide for the exhaust drift and 20 feet wide for the intake drift. However, the operating contractor may further modify these dimensions to accommodate equipment. The four main access drifts will retain their original cross section dimensions in the areas of the planned plugs.

The plug shown on Figure 12-31 would consist of multiple components as described in reference 12-8. These components include a central core of bentonite or bentonite-based mix, salt-brick bulkheads, and cement-based bulkheads. Prior to constructing the multiple-component plug in an entry drift, the operating contractor must investigate the disturbed zone surrounding the drift. In particular, the occurrence of any fractures within and above MB-139, beneath the floor, and any

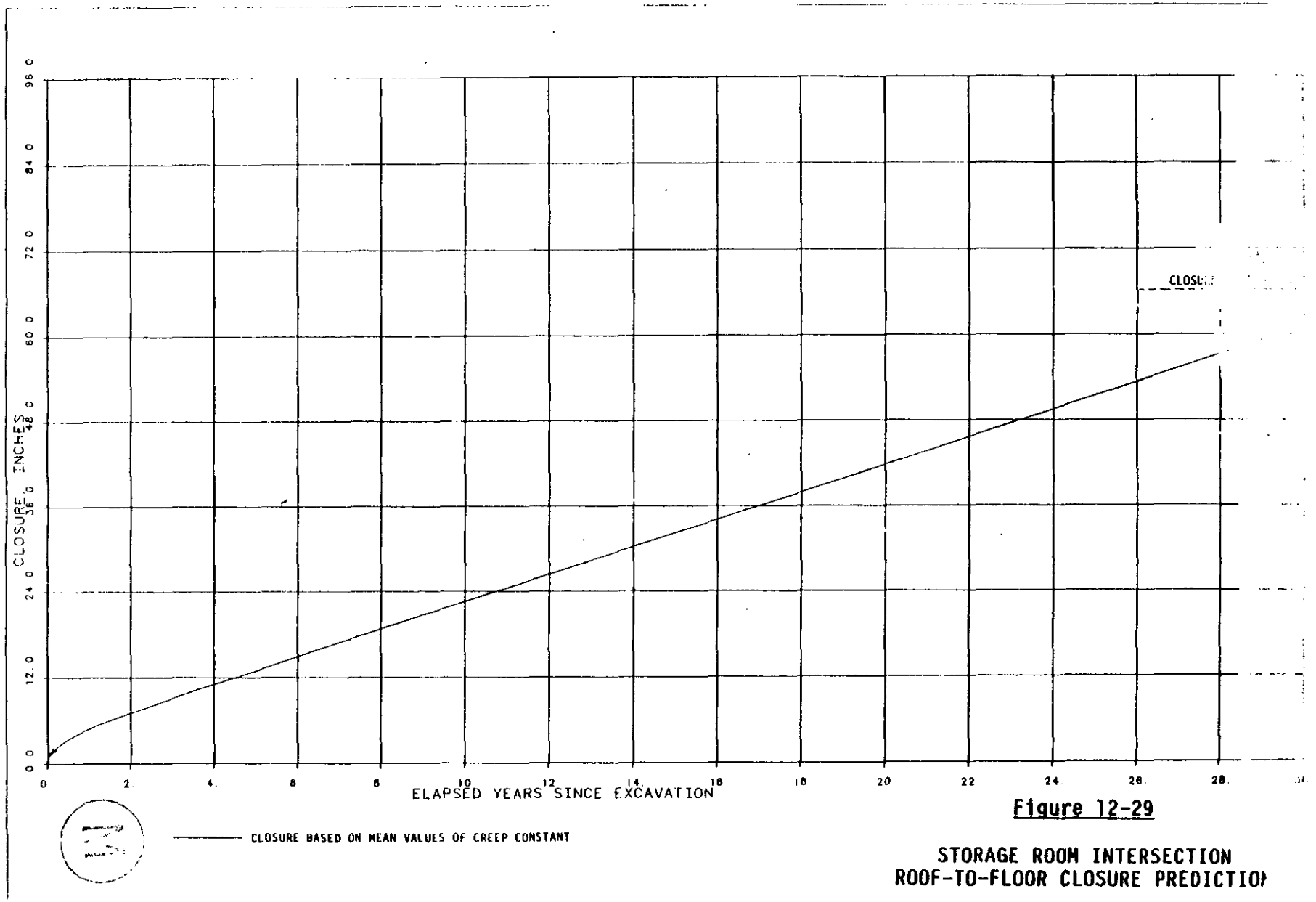


Figure 12-29

STORAGE ROOM INTERSECTION
ROOF-TO-FLOOR CLOSURE PREDICTION

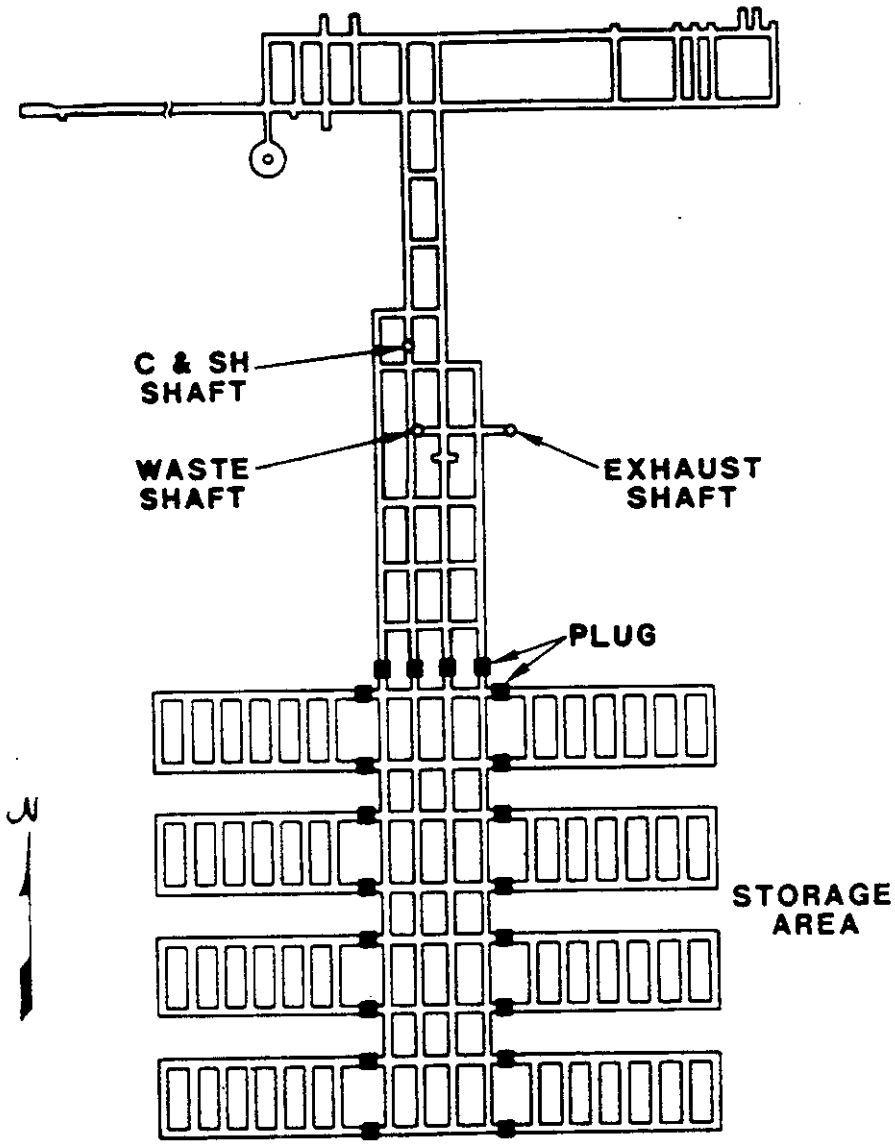


Figure 12-30

STORAGE AREA
PLUG LOCATIONS

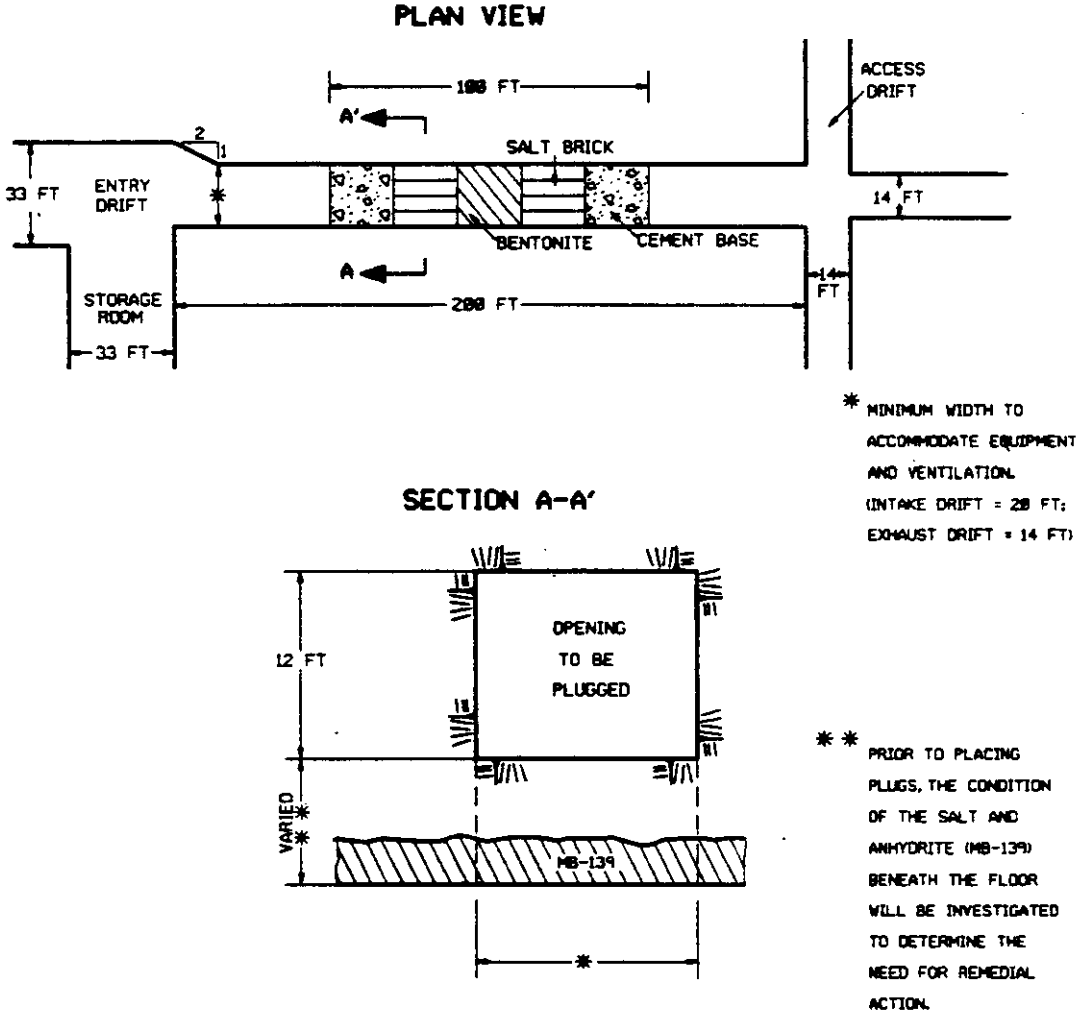


Figure 12-31

STORAGE AREA
PROPOSED PANEL PLUG REFERENCE DESIGN

separations at clay seams above the roof will need to be evaluated. If zones of unacceptable permeability are detected in the floor, the plug area should be lowered to remove the fractured zone and MB-139. Similarly, should any separations be found at clay seams above the entry drift, the roof should be excavated up through the highest seam exhibiting separation.

If the disturbed zone effects are not substantial, low-pressure grouting may be considered as an alternative remedial action. This would permit retention of the minimum cross section for the plug area. In addition, pressure grouting could be used in conjunction with excavation to treat deeper fractures, if present.

12.5 STORAGE ROOM BACKFILL

In accordance with the design criteria, the storage room reference design includes backfilling the rooms with crushed salt after waste emplacement. The storage area drift and room dimensional requirements are shown on Figures 12-2 and 12-3. The thickness of the salt backfill covering the waste packages shown on these figures is 1 to 2 feet. This is to be the thickness of the salt after placement and does not take into account backfill consolidation during room closure.

The only purpose for backfilling presented in the criteria is to provide fire protection in the storage rooms based on an accident scenario in which spontaneous ignition of the contents of a CH TRU waste container results in fire propagation to adjacent containers. Recent studies concerning the potential for spontaneous ignition in CH TRU waste containers have indicated that this is not a credible scenario. Although backfill is a design criteria requirement and therefore must be incorporated into the reference design, the results of these studies indicate that backfill will not be necessary for fire protection.

The following subsections present conclusions pertaining to validation of the WIPP storage area reference design and recommendations for design modifications to achieve validation of the reference design. These are based on a comparison of the design criteria, design bases and reference design configurations with the results of the analysis and evaluation of data collected during the design validation process.

12.6.1 Conclusions

The most significant finding of the design validation program is the difference between closure predicted from laboratory test data and the closure actually occurring in the underground facility. The storage area reference design configurations were designed before long-term in situ data were available. Closure rates were estimated using creep constants derived from the laboratory analyses of salt cores from borehole ERDA-9. These estimates resulted in the establishment of a closure limit of 12 inches in the first 5 years following excavation. Evaluation of the in situ data demonstrates that this closure limit is insufficient. The predicted closure based on laboratory analyses underestimates the actual closure at 3 years by about a factor of three (Figure 11-35). Establishing the causes for this underprediction of closure requires additional study and research and is beyond the scope of this report.

Vertical and horizontal closure demonstrated by the in situ data will not allow the reference design to meet the design criteria requirements. The waste containers will most likely be crushed and breached. Furthermore, because of the in situ closure the waste container stacking configurations and transport vehicle would not be compatible with the reference design room and drift configurations. In order for the reference design to comply with the design criteria, the storage area design configurations or the design criteria will have to be modified. Five alternative modifications are presented in the next subsection.

The analytical results for the storage area show the redistribution of stresses around the openings due to the effects of creep. Based on the computed vertical, horizontal and effective stresses, the magnitude of stresses immediately adjacent to the openings decreases and the stress arch around the openings migrates away with time. The maximum stress occurs immediately after excavation and is followed by relaxation due to creep behavior. Therefore, the stresses will not cause a future stability problem in the storage area except in MB-139, where a gradual buildup of stress may cause local failure of the anhydrite. This failure is expected to be in the form of floor slabbing and should not affect the structural performance of the openings nor hinder the waste storage operations. Investigations of the test room floors indicate that major fracturing has occurred only in the south half of Test Room 3 (Room T). All other floor fracturing has been minor.

The analysis shows the locations of effective creep strain concentrations at different times around the openings. Based on the predicted values of effective creep strain and the strain limit discussed in Chapter 6, effective creep strain may locally exceed the critical strain which is based on laboratory test data. However, this is not expected to disturb the overall structural stability within the limits required for safety during the 5-year demonstration period and permanent storage. Minor spalls and failures on the wall surfaces, similar to the ones discussed in Chapter 11, are expected to occur and can be easily identified and monitored. Scaling of these minor failures, when necessary, is considered a normal maintenance operation.

The facility stratigraphy is continuous and uniform. No anomalous conditions have been encountered that would jeopardize facility operations or waste storage integrity. The fracturing that is occurring beneath the test room floors may develop to some degree beneath the storage rooms. These fractures are not considered to be deleterious to storage room performance. There have been no occurrences of gas or brine in quantities that would adversely affect waste storage operations.

[illegible] plugs as [illegible]. The reference design [illegible] drifts contains a reduced cross section in the plug area. The minimum dimensions for the plug area will be dictated by operating requirements. The dimensions may also require alteration if disturbed zone effects are present that necessitate additional excavation.

An independent study has concluded that spontaneous combustion in the waste containers is not a credible event. In this case, crushed salt backfill will not be required for fire protection. Because it has been determined that the storage rooms will close at a rate faster than originally anticipated, deletion of the backfill requirement will provide additional allowance for vertical closure. This has favorable implications in terms of recommended modifications discussed in the next subsection.

12.6.2 Recommendations

The reference design will be validated when any of the following alternative modifications or combinations thereof are incorporated:

(1) Maintain the reference design room dimensions (13 to 14 feet high and 33 to 34 feet wide), retain the salt backfill but reduce the volume of waste to be stored and modify the waste stacking configuration in each room and entry drift (Figure 12-32). These changes would be required only during the 5-year demonstration period. Revise the criteria to require that retrieval operations be accomplished within 7 years of excavating each room. This will assure that the waste containers will not be crushed or breached. However, it will require a significant number of additional rooms during and after the demonstration period.

(2) Maintain the reference design room dimensions and the waste storage volume. Revise the criteria to delete the requirement for salt backfill and to require that if the

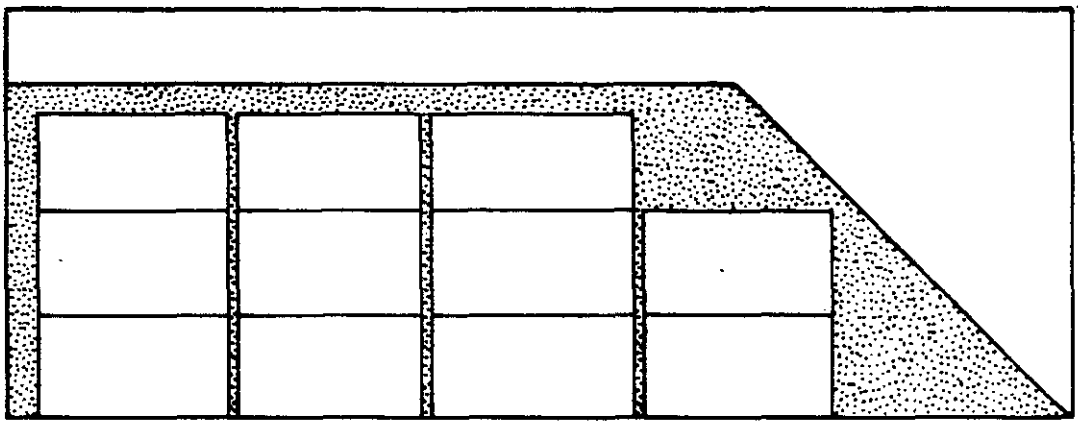


Figure 12-32

STORAGE AREA
MODIFIED WASTE STACKING CONFIGURATION

any room in which waste [illegible] years. This will preclude the possibility of crushing and/or breaching any waste containers and will make retrieval easier and more rapid. No additional rooms will be required.

(3) Maintain the reference design room dimensions, the waste storage volume, and the salt backfill. Revise the storage operations during the 5-year demonstration period so that the waste stored first can be retrieved first. Excavate the rooms to 14 x 34 feet initially and then trim them to 14 x 34 feet a year later. Rooms having waste retrieved will not be older than 6 years and the wall-to-wall closure will be approximately 12 inches. This would minimize the crushing and breaching of the waste containers. The criteria are to be revised as stated under (5) of these recommendations. However, due to the first-in/first-out recommendation, more rooms will be required during the 5-year demonstration period to accommodate the expected volume of waste. Trimming to the final dimensions will also increase operating costs. The total number of rooms required will be the same as provided by the reference design.

(4) For the 5-year demonstration period, reduce the storage room width from 33 feet to 28 feet, maintain the 13 to 14-foot height, and reduce the pillar width to 84 feet. Maintain the first room for RH emplacement at 33 feet to 34 feet wide and 13 feet to 14 feet high as provided in the reference design. Reduce the volume of waste to be stored in each room and maintain the salt backfill. Excavate the rooms to 14 x 28 feet then, after approximately 1 year, trim them to 14 x 28 feet again. Provide for first-in/first-out emplacement and retrieval during the 5-year demonstration period. This will reduce the rate of creep to approximately

the rate for the 13 x 25-foot drifts. The potential for crushing and breaching of the waste containers will be minimized and the stability should be better than that for a 33-foot wide room. The total volume of excavation will be approximately the same. If this alternative is selected, additional engineering evaluation will be required.

(5) Maintain all of the features of the reference design. That is, maintain the storage room configuration of 13 feet high and 33 feet wide, maintain the salt backfill, maintain the planned volume of waste to be stored in each room and drift, and maintain the same optimized excavation plan for the 5-year demonstration period and permanent storage. Revise the design criteria to allow crushing and breaching of the CH waste containers during the 5-year demonstration period as well as during permanent storage. Also, revise the criteria requiring a demonstration of waste package handling to include a demonstration of the retrieval of crushed and breached containers prior to receiving waste. This alternative will not only demonstrate the safe retrieval of waste if required during the 5-year demonstration period but also at any time during permanent storage.

In addition to these recommended alternative modifications, the following modifications are recommended:

(6) The drifts used for storage will have to be maintained and trimmed to provide the required equipment and storage clearances. The closure rates are not critical for storage because these drifts will be used only for permanent storage near the end of the permanent storage period.

the plugs in the

(8) Install instrumentation in the storage rooms to obtain in situ data to monitor storage room behavior.

GLOSSARY

G.1 TERMINOLOGY

Back - The roof of underground horizontal openings.

Bunton - Horizontal, tubular steel section installed in the C & SH shaft to support the wood guide rails which center the shaft conveyance as they travel in the shaft.

CH TRU waste - Contact-handled transuranic waste that is packaged so that the dose rate at the surface of the waste package is not greater than 200 millirem/h.

Closure - The gradual decrease in distance between two opposing points in an underground opening as a result of rock or salt movement.

Convergence - See "closure".

Datalogger - Computer system that collects and records the output of geomechanical instrumentation.

Design bases - Detailed requirements established from the design criteria to provide additional direction in development of the engineering design of the WIPP underground facilities.

Design configuration - Engineered design dimensions of underground facility openings based on requirements of design criteria and design bases.

Design criteria - General requirements established to govern the engineering design of the WIPP underground facilities.

Design validation - The process of confirming the WIPP underground opening reference design by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. Validation is achieved through an assessment of the condition and behavior of the underground openings, and on predictions of their future behavior, based on in situ observations and measurements.

Drummy - Term used to describe rock that sounds hollow or loose when tapped with a solid object; used especially in relation to a mine roof.

Facility level - The underground horizontal portion of the WIPP facility developed for waste storage purposes.

Floor/roof beam - The rock thickness between the floor or roof of an excavated opening and the first underlying or overlying clay seam.

Galloway - A multi-decked steel platform suspended in a shaft and raised or lowered by means of a cable hoist. It is used to transport material and personnel in the shaft, particularly during shaft outfitting.

Guide - Vertical shaft member of steel or wood which is used to center the conveyance equipment as it travels in the shaft.

Long-term monitoring - The extended acquisition and evaluation of data to determine the geomechanical response of the rock/salt to excavation. These data will supplement the R & D program.

Muck - The broken rock and other material that is removed during shaft or horizontal opening excavation.

Penecontemporaneous - Term used to indicate a geologic process that occurs concurrent with or after sediment deposition but before lithification.

Potash - Any potassium-rich rock mined and refined to produce products used in agriculture or industry.

Preliminary design validation - The process of achieving a preliminary evaluation of the underground design criteria, design bases and design configurations early in construction, primarily by visual observations of the underground openings and geomechanical instrumentation measurements.

R & D Program - The WIPP mission designed to provide a technical understanding of systems design, safety and environmental assessments for the disposal of radioactive waste from U.S. defense programs. The program includes technology development through laboratory testing of theoretical analysis and in situ testing to evaluate the techniques used to monitor the responses of materials and facility systems.

RH TRU waste - Remote-handled transuranic waste that is packaged so that the dose rate at the surface of the package is greater than 200 millirem/h but less than 100 rem/h.

Rib - The vertical wall of underground horizontal openings.

Scaling - The removal of loose rock from underground opening surfaces.

Shaft outfitting - The process of installing shaft furnishings (utilities, buntons, guides, conveyance equipment, etc.), as well as stabilizing the wall by means of rock bolts, wire mesh or lining.

Short-term monitoring - The acquisition and evaluation of data to determine the initial geomechanical response of the rock/salt to excavation.

Site and Preliminary Design Validation (SPDV) - A WIPP program consisting of two integrated subprograms, Site Validation and Preliminary Design Validation, that are defined in their individual listings.

Site characterization - The process of obtaining geotechnical data and conducting experiments to determine the suitability of the WIPP site for a research and development facility to demonstrate the safe disposal of defense-related nuclear waste.

Site validation - The process of achieving the highest practicable level of confidence in the site's suitability and overall qualification through subsurface investigations.

Slabbing - The weakening of rock fragments or segments along fractures parallel to the excavation surface.

Spud - To begin drilling a well, hole or shaft.

Spalling - The breaking loose of chips, thin slabs, or fragments from the outer surface of a rock mass.

Telltale pipe - A pipe used to monitor the effectiveness of the chemical water seals in the shaft keys. The pipe provides a pathway for water to flow through the concrete beneath the seals from the salt/concrete interface to the inside face of the concrete key.

Transuranic (TRU) waste - Radioactive waste containing transuranic elements created by the absorption of neutrons into uranium atoms.

Underground development level - See "facility level".

Underground facility horizon - The stratigraphic interval within the Salado formation, from a depth of approximately 2,100 to 2,170 feet (elev. 1240 to 1310 feet), which was selected for testing and storage of low-level nuclear waste.

G.2 ACRONYMS

ACI	American Concrete Institute
AEC	Atomic Energy Commission
BNI	Bechtel National, Incorporated
BTP	Brine Testing Program
C & SH	Construction and salt handling
CH TRU	Contact-handled transuranic
DOE	U.S. Department of Energy
FEIS	Final Environmental Impact Statement
GFDR	Geotechnical Field Data Report
GSA	Geological Society of America
GTP	Gas Testing Program
LTC	Local termination cabinet
MIIT	Material Interface-Interactions Test
MOC	Management and Operating Contractor
MSHA	Mine Safety and Health Administration
NAS	National Academy of Sciences
R & D	Research and development
RH TRU	Remotely-handled transuranic
RMC-IIA	Revised Mission Concept IIA
SAR	Safety Analysis Report
SME	Society of Mining Engineering
SNL	Sandia National Laboratories
SPDV	Site and Preliminary Design Validation
TRU	Transuranic
TSC	Technical Support Contractor
USGS	United States Geological Survey
WIPP	Waste Isolation Pilot Plant

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DETAILED DESIGN REPORT FOR AN OPERATIONAL PHASE PANEL-CLOSURE SYSTEM

DOE/WIPP-96-2150

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MASTER

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I certify under penalty of law that this document was prepared under my supervision for Westinghouse Electric Corporation, Waste Isolation Division, Waste Isolation Pilot Plant, by IT Corporation according to the IT Environmental Engineering and Services Quality Assurance Program. This program is designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete.

John B. Case, P.E.
New Mexico
Certification No. 8049
Expires December 31, 1997

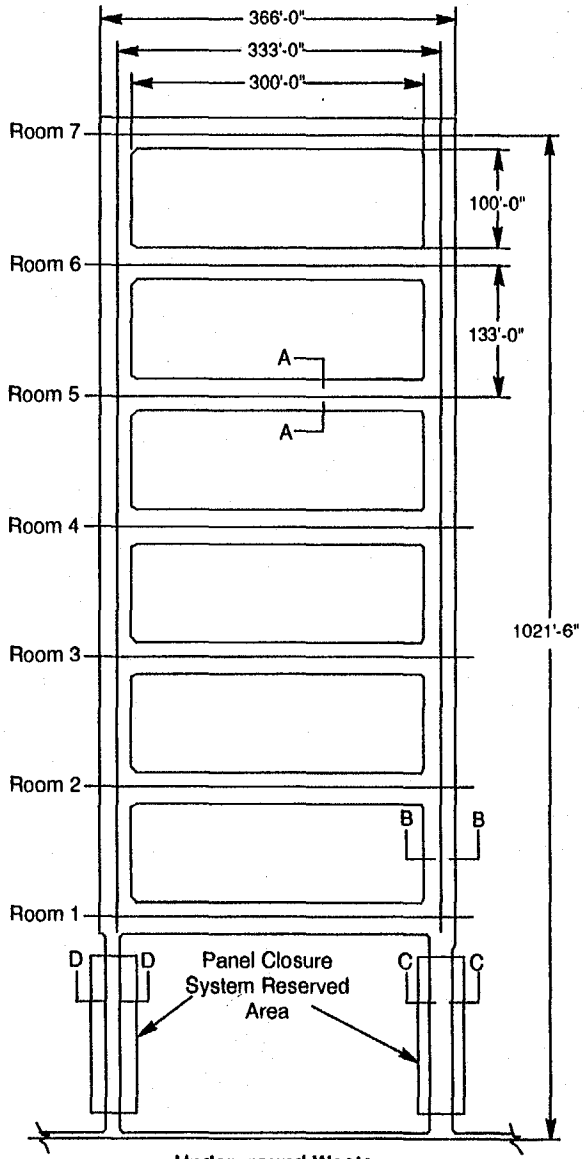
Executive Summary

Scope. Under contract to Westinghouse Electric Corporation (Westinghouse), Waste Isolation Division (WID), IT Corporation has prepared a detailed design of a panel-closure system for the Waste Isolation Pilot Plant (WIPP). Preparation of this detailed design of an operational-phase closure system is required to support a Resource Conservation and Recovery Act (RCRA) Part B permit application and a no-migration variance petition. This report describes the detailed design for a panel-closure system specific to the WIPP site. The recommended panel-closure system will adequately isolate the waste-emplacement panels for at least 35 years.

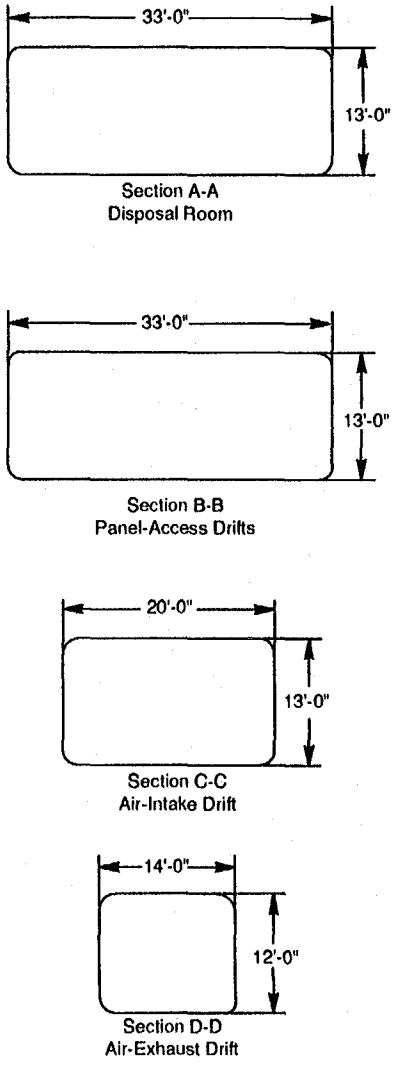
Purpose. This report provides detailed design and material engineering specifications for the construction, emplacement, and interface-grouting associated with a panel-closure system at the WIPP repository, which would ensure that an effective panel-closure system is in place for at least 35 years. The panel-closure system provides assurance that the limit for the migration of volatile organic compounds (VOC) will be met at the point of compliance, the WIPP site boundary. This assurance is obtained through the inherent flexibility of the panel-closure system. The panel-closure system will be located in the air-intake and air-exhaust drifts (Figure ES-1). The system components have been designed to maintain their intended functional requirements under loads generated from salt creep, internal pressure, and a postulated methane explosion. The design complies with regulatory requirements for a panel-closure system promulgated by RCRA and the Mine Health and Safety Administration (MSHA). The design uses common construction practices according to existing standards.

Background. The engineering design considers a range of expected subsurface conditions at the location of a panel-closure system. The geology is predominantly halite with interbedded anhydrite at the repository horizon. During the operational period, the panel-closure system would be subject to creep from the surrounding host rock that contains trace amounts of brine.

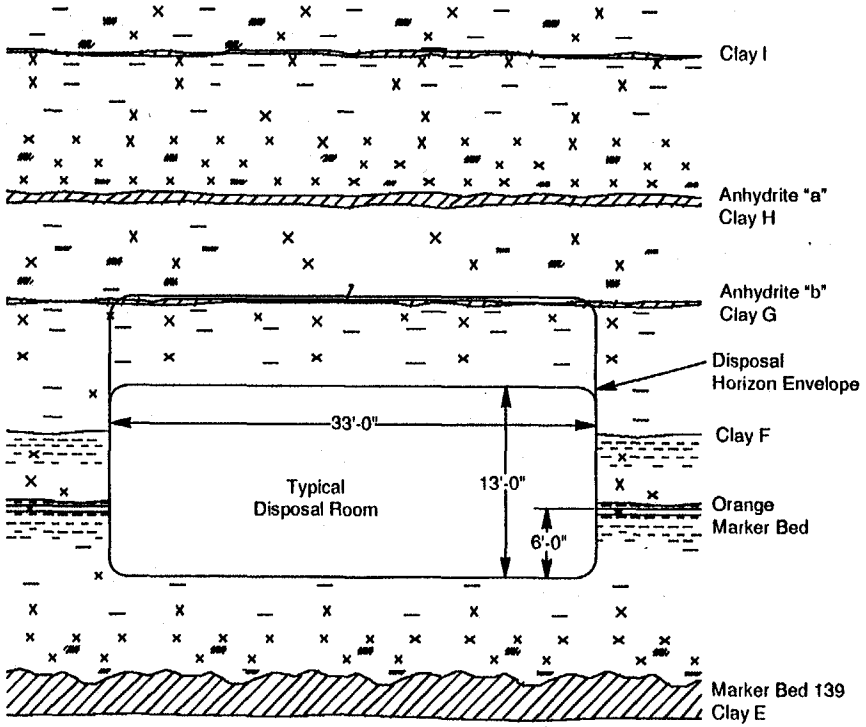
During the conceptual design stage, two air-flow models were evaluated: (1) unrestricted flow and (2) restricted flow through the panel-closure system. The "unrestricted" air flow model is defined as a model in which the gas pressure that develops is at or very near atmospheric pressure such that there exists no back pressure in the disposal areas. Flow is unrestricted in this model. The "restricted" air flow model is defined as a model in which the



Underground Waste Disposal Panel



Typical Excavation Sections



Disposal Horizon Stratigraphy

Note: Figure is Not to Scale
All Dimensions Shown are Nominal

Figure ES-1
Typical Facilities-Typical Disposal Panel
(After Westinghouse, 1995c)

back pressure in the waste emplacement panels develops due to the restriction of flow through the barrier, and the surrounding disturbed rock zone. The analysis was based on an assumed gas generation rate of 8,200 moles per panel per year (0.1 moles per drum per year) due to microbial degradation, an expected volumetric closure rate of 28,000 cubic feet (800 cubic meters) per year due to salt creep, the expected headspace concentration for a series of nine VOCs, and the expected air dispersion from the exhaust shaft to the WIPP site boundary. The analysis indicated that the panel-closure system would limit the concentration of each VOC at the WIPP site boundary to a small fraction of the health-based exposure limits during the operational period.

Alternate Designs. Various options were evaluated considering active systems, passive systems, and composite systems. Consideration of the aforementioned factors led to the selection of a passive panel-closure system consisting of: (1) a standard concrete barrier, rectangular in shape, or (2) an enlarged tapered concrete barrier. Options (1) and (2) will be grouted at the interface and may contain an explosion-isolation wall or a construction-isolation wall. This system provides flexibility for a range of ground conditions likely to be encountered in the underground repository. No other special requirements for engineered components beyond the normal requirements for fire suppression and methane explosion or deflagration containment exist for the panel-closure system during the operational period.

The panel-closure system design incorporates mitigative measures to address the treatment of fractures and therefore minimizes the potential migration of contaminants. The design option for mitigating fractures includes excavating the disturbed rock zone (DRZ) and emplacing an enlarged concrete barrier.

To be effective, the excavation and installation of the panel-closure system must be completed within a short time frame to minimize disturbance to the surrounding salt. A rigid concrete barrier will promote interface stress buildup, as fractures are expected to heal with time. For this purpose, the main concrete barrier would be tapered to reduce shear stress and to increase compressive stress along the interface zone. If ground conditions are more favorable, the design can be simplified to a standard concrete barrier with an explosion-isolation or construction-isolation wall without DRZ removal.[1]

[1]DRZ removal is used in the context of the removal of fractured rock.

Design Classification. Procedure WP 09-CN3023 (Westinghouse, 1995a) was used to establish a design classification for the panel-closure system. It uses a decision-flow-logic process to designate the panel-closure system as a Class IIIB structure. This is because during the methane explosion the concrete barrier would not fail.

Design Evaluations. To investigate several key design issues, design evaluations were performed. These design evaluations can be divided into those that satisfy (1) the operational requirements of the system and (2) the structural and material requirements of the system.

The conclusions reached from the evaluations addressing the operational requirements are as follows:

- Based on an air-flow model used to predict the mass flow rate of carbon tetrachloride through the panel-closure system for the alternatives, the air-flow analysis suggests that the fully enlarged barrier provides the highest protection for restricting VOCs during the operational period of 35 years.

- Results of the Fast Lagrangian Analysis of Continua (FLAC) analyses show that the recommended enlarged configuration is a circular rib-segment excavated to Clay G and under MB 139. Interface grouting would be performed at the upper boundary of the concrete barrier.

- The results of the transverse plane-strain models show that higher stresses would form in MB 139 following excavation, but that after installation of the panel-closure system, the barrier confinement will result in an increase in barrier-confining stress and a reduction in shear stress. The main concrete barrier would provide substantial uniform confining stresses as the barrier is subjected to secondary salt creep.

- The removal of the fractured salt prior to installation of the main concrete barrier would reduce the potential for flexure. The fracturing of MB 139 and the attendant fracturing of the floor could reduce structural load resistance (structural stiffness), which could initially result in barrier flexure and shear. With the removal of MB 139, the fractured salt stiffens the surrounding rock and results in the development of more uniform compression.

- The trade-off study also showed that a panel-closure system with an enlarged concrete barrier with the removal of the fractured salt roof and anhydrite in the floor was found to be the most protective.

The conclusions reached from the design evaluations addressing the structural and material requirements of the panel-closure system are as follows:

- Existing information on the heat of hydration of the concrete supports placing concrete with a low cement content to reduce the temperature rise associated with hydration. Plasticizers might be used to achieve the required slump at the required strength. A thermal analysis, coupled with a salt creep analysis, suggests installation of the enlarged barrier at or below ambient temperatures to adequately control hydration temperatures.

- In addition to installation at or below ambient temperatures, the concrete used in the main barrier would exhibit the following:

  - An 8 inch (0.2 meter) slump after 3 hours of intermittent mixing

  - A less-than-25-degree Fahrenheit heat rise prior to installation

  - An unconfined compressive strength of 4,000 pounds per square inch (psi) (28 megapascals [MPa]) after 28 days

  - Volume stability

  - Minimal entrained air.

- The trace amounts of brine from the salt at the repository horizon will not degrade the main concrete barrier for at least 35 years.

- In 20 years, the open passage above the waste stack would be reduced in size. Further, rooms with bulkheads at each end would be isolated in the panel. It is unlikely that a long passage with an open geometry would exist; therefore, the dynamic analysis considered a deflagration with a peak explosive pressure of 240 psi (1.7 MPa).

- The heat-transfer analysis shows that elevated temperatures would occur within the salt and the explosion-isolation wall; however, the elevated temperatures will be isolated by the panel-closure system. Temperature gradients will not significantly affect the stability of the wall.

- The fractures in the roof and floor could be affected by expanding gas products reaching pressures on the order of 240 psi (1.7 MPa). Because the peak internal pressure from the deflagration is only one fifth of the pressure, fractures could not propagate beyond the barrier.

A composite system is selected for the design with various components to provide flexibility. These design options are described below.

Design Options. Figure ES-2 illustrates the options developed to satisfy the requirements for the panel-closure system. The basis for selecting an option depends on conditions at the panel-closure system locations as would be documented by future subsurface investigations.

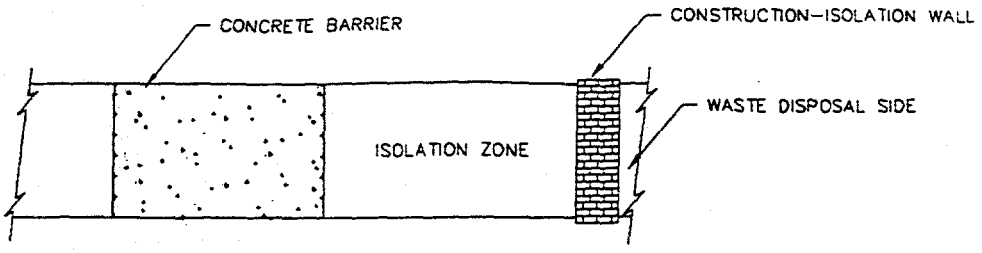
These design options provide flexibility in satisfying the design migration limit for the flow of VOCs out of the waste-emplacement panel. An enlarged concrete barrier would be selected for the air-intake and air-exhaust drifts that have fractured rock to eliminate significant flow of VOCs. Several methods are available for detecting the location and extent of fractures in the DRZ for optimum placement of an enlarged concrete barrier. These detection methods include ground-penetrating radar (GPR) and inspection of observation boreholes.

For future waste panels, GPR would be used to monitor fracture development. Radar surveys would be conducted shortly after excavation to provide a baseline for comparison to future radar surveys. GPR would be used periodically to monitor the development of brittle deformation in the new air-intake and air-exhaust drifts of a panel.

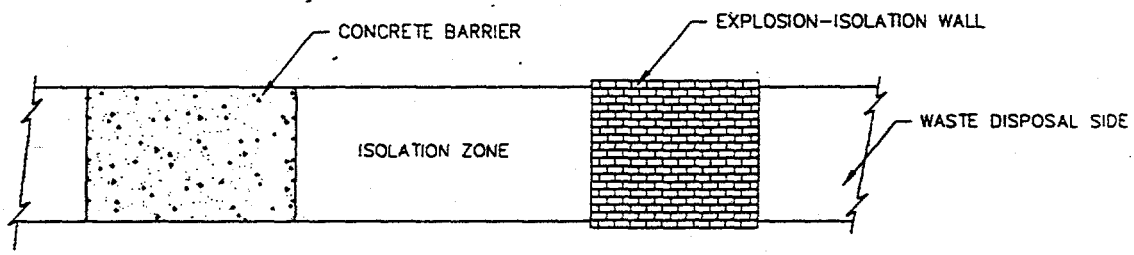
Observation boreholes would be drilled into the roof or floor of an excavation and would be inspected for fractures and bed separation. Observations in the boreholes can be made with a small video camera, or a simple scratch rod.

While no specific requirements exist for barricading inactive waste areas under the MSHA, their intent is to safely isolate these abandoned areas from active workings using barricades of "substantial construction." A previous analysis (DOE, 1995) examined the issue of methane gas generation from transuranic waste and the potential consequence in closed areas. The principal concern is whether an explosive mixture of methane with an ignition source would result in deflagration. If a methane explosion is considered possible, a concrete block wall of sufficient thickness will be used to resist dynamic and salt creep loads. A construction isolation wall will be used in the absence of explosive conditions.

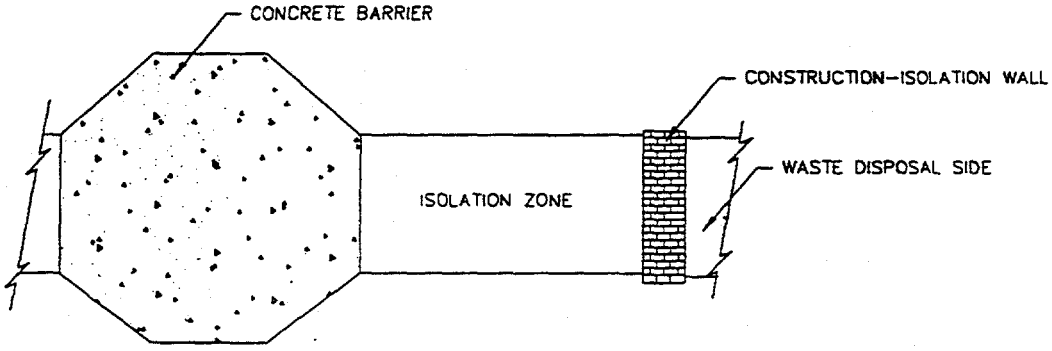
It was shown (DOE, 1995) that an explosive atmosphere may exist after approximately 20 years. A panel-closure system with a closure life less than 20 years would not require an explosion-isolation wall, because an explosive mixture could not accumulate. A construction-isolation wall will suffice to provide isolation during construction of the main concrete barrier.



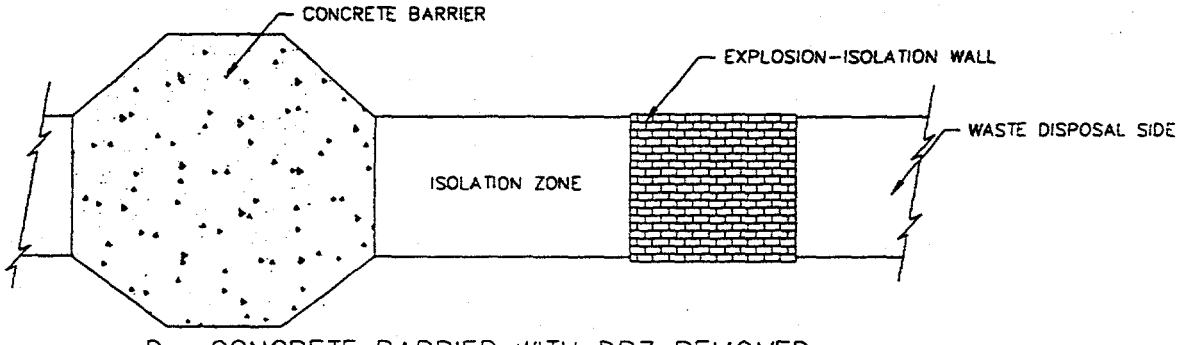
A. CONCRETE BARRIER WITHOUT DRZ REMOVED AND CONSTRUCTION ISOLATION WALL



B. CONCRETE BARRIER WITHOUT DRZ REMOVED AND EXPLOSION ISOLATION WALL



C. CONCRETE BARRIER WITH DRZ REMOVED AND CONSTRUCTION ISOLATION WALL



D. CONCRETE BARRIER WITH DRZ REMOVED AND EXPLOSION ISOLATION WALL

Figure ES-2
Main Barrier with Wall Combinations

Design Components. The enlarged concrete barrier will be located at the optimum location in the air-intake and air-exhaust drifts following observation of subsurface conditions. The enlarged concrete barrier will be composed of plain concrete with sufficient unconfined compressive strength. The barrier will consist of a circular rib segment excavated into the surrounding salt where the central portion of the barrier will extend just beyond Clay G and MB 139. FLAC analyses showed that plain concrete will develop adequate confined compressive strength.

The enlarged concrete barrier will be placed in four cells, with construction joints formed perpendicular to the direction of potential air flow. The concrete will be placed through 6-inch (15.2 centimeter) diameter steel pipes and will be vibrated from outside the formwork. The formwork is designed to withstand the hydrostatic loads that would occur during installation with minimal bracing onto exposed salt surfaces. This will be accomplished by a series of steel plates that are stiffened by angle iron, with load reactions carried by spacer rods. Some exterior bracing will be required when the concrete is poured into the first cell at the location for the enlarged concrete barrier. All structural steel will be American Society of Testing and Materials [grade] A36 in conformance with the latest standards specified by the American Institute for Steel Construction. After concrete placement, the formwork will be left in place and will stiffen the enlarged concrete barrier if nonuniform reactive loadings should occur after panel closure.

After completion of the enlarged concrete barrier installation, it will be grouted through a series of grout supply and air return lines that terminate in grout boxes. The boxes will be mounted near the top of the barrier. The grout will be injected through one set of lines and returned through a second set of air lines.

An explosion-isolation wall, constructed with concrete-blocks, will mitigate the effects of a methane explosion. The explosion-isolation wall would consist of 3,500 psi (24 MPa) concrete blocks mortared together with a bonding agent. The concrete-block wall design complies with MSHA requirements, because it consists of noncombustible materials of "substantial construction." The concrete-block walls will be keyed into the salt. For the WIPP, an explosion-isolation wall is designed to resist loading from salt creep.

The compliance of the detailed design was evaluated against the design requirements established for the panel-closure system. The design complies with all aspects of the design basis established for the panel-closure system.

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List of Abbreviations/Acronyms

ACI	American Concrete Institute
AISC	American Institute for Steel Construction
*CFR	Code of Federal Regulations
cm	centimeter
°C	degrees celsius
°F	degrees Fahrenheit
DOE	U.S. Department of Energy
DRZ	disturbed rock zone
EEP	Excavation Effects Program
ESC	expansive salt-saturated concrete
FLAC	Fast Lagrangian Analysis of Continua
ft	foot (feet)
GPR	ground-penetrating radar
Kips	1,000 pounds
m	meter(s)
MB 139	Marker Bed 139
MPa	megapascal(s)
MSHA	Mine Safety and Health Administration
NaCl	sodium chloride
NMVP	no-migration variance petition
psi	pound(s) per square inch
RCRA	Resource Conservation and Recovery Act
SMC	Salado Mass Concrete
TRU	transuranic
VOC	volatile organic compound(s)
Westinghouse	Westinghouse Electric Corporation
WID	Waste Isolation Division
WIPP	Waste Isolation Pilot Plant

1.0 Introduction

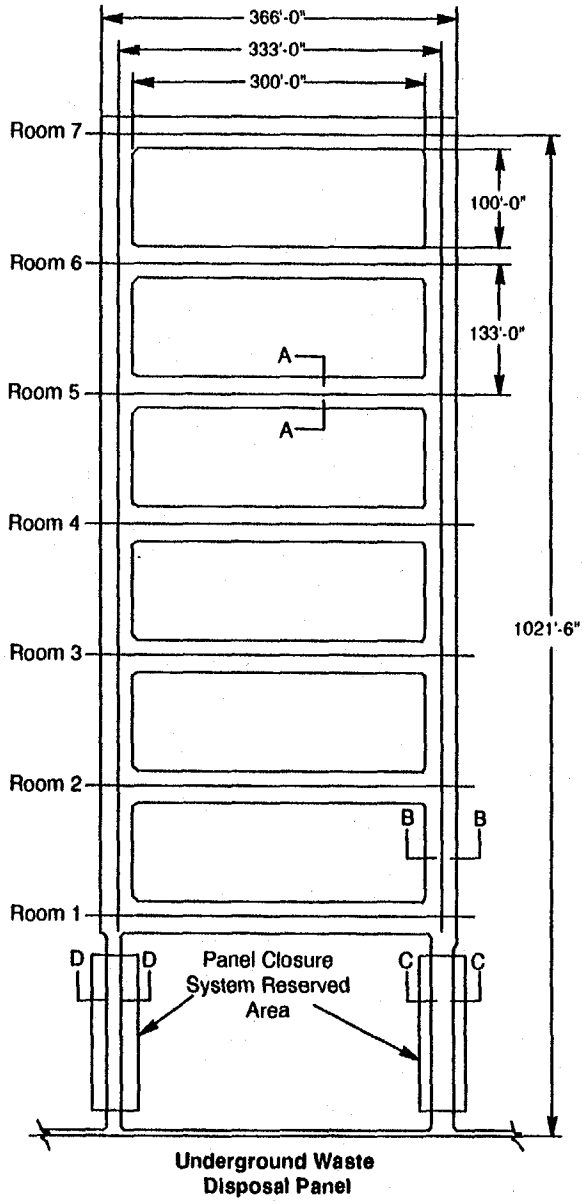
The Waste Isolation Pilot Plant (WIPP), a U.S. Department of Energy (DOE) research facility located near Carlsbad, New Mexico, was established to demonstrate the safe disposal of defense-generated transuranic (TRU) waste. The WIPP repository is approximately 2,150 feet (ft) (655 meters [m]) below the surface, in the Salado Formation. The WIPP facility consists of a northern experimental area, a shaft-pillar area, and a waste-emplacement area.

One important aspect of future repository operations at the WIPP is the activities associated with closure of waste-emplacement panels. Each panel consists of air-intake and air-exhaust drifts, panel-access drifts, and seven rooms (Figure 1-1). After completion of waste-emplacement activities, each panel will be closed, while waste emplacement may be occurring in the other panel(s). The closure of individual panels during the operational period will be conducted in compliance with project-specific health, safety, and environmental performance criteria.

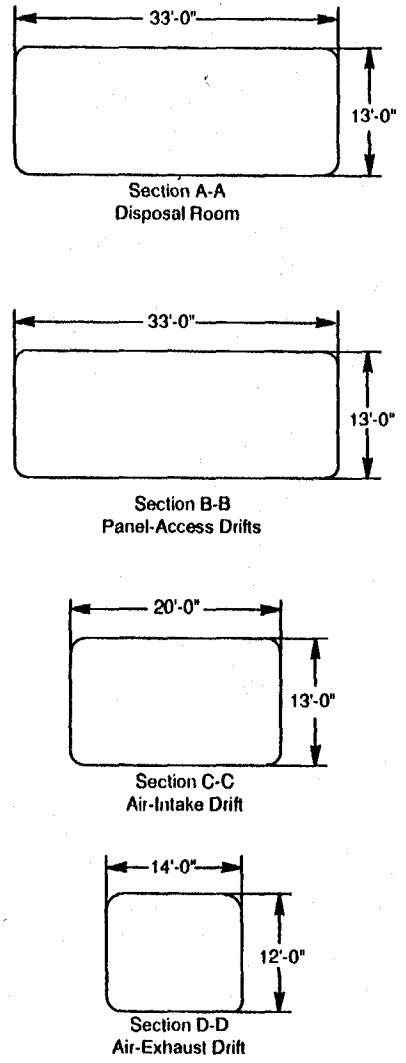
1.1 Scope

This report provides information on the detailed design and material engineering specifications for the construction, installation, and interface grouting associated with a panel-closure system for a minimum operational period of 35 years. The panel-closure system design provides assurance that the limit for the migration of volatile organic compounds (VOC) will be met at the point of compliance, the WIPP site boundary. This assurance is obtained through the inherent flexibility of the panel closure system. The panel-closure system will be located in the air-intake and air-exhaust drifts to each panel (Figure 1-1). The panel-closure system design maintains its intended functional requirements under loads generated from salt creep, internal panel pressure, and a postulated methane explosion. The design complies with regulatory requirements for a panel-closure system promulgated by the Resource Conservation and Recovery Act (RCRA) and Mine Safety and Health Administration (MSHA).

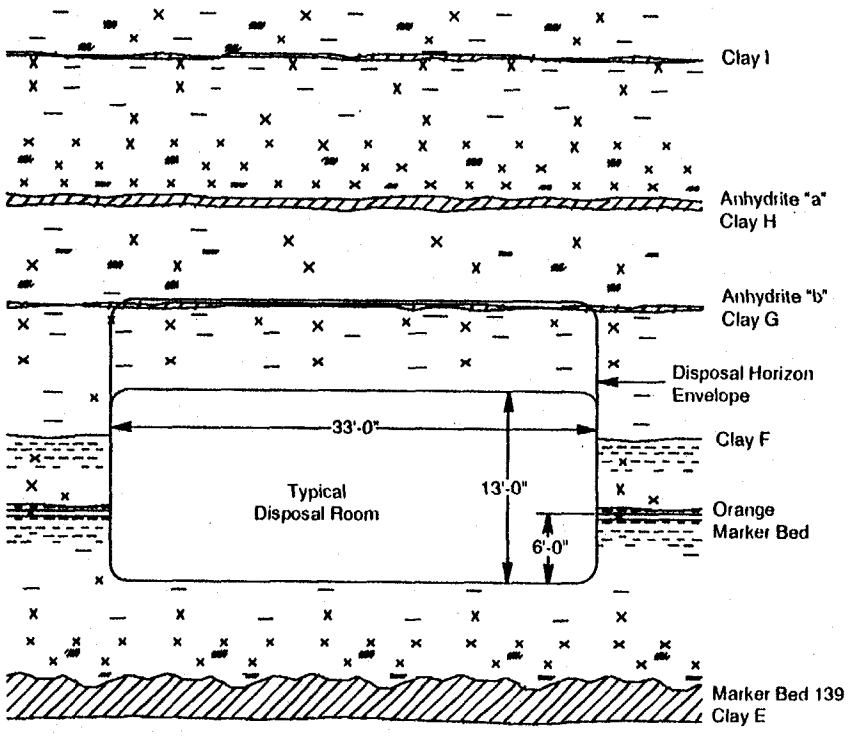
Figure 1-2 illustrates the design process used for preparing the detailed design. The design process commenced with the evaluation of the performance requirements of the panel-closure system through review of the work performed in developing the conceptual design and the "Underground Hazardous Waste Management Unit Closure Criteria for the Waste Isolation Pilot Plant Operation Phase" (Westinghouse, 1995b). The various design evaluations were



Underground Waste Disposal Panel



Typical Excavation Sections



Disposal Horizon Stratigraphy

Note: Figure is Not to Scale
All Dimensions Shown are Nominal

Figure 1-1
Typical Facilities-Typical Disposal Panel
(After Westinghouse, 1995c)

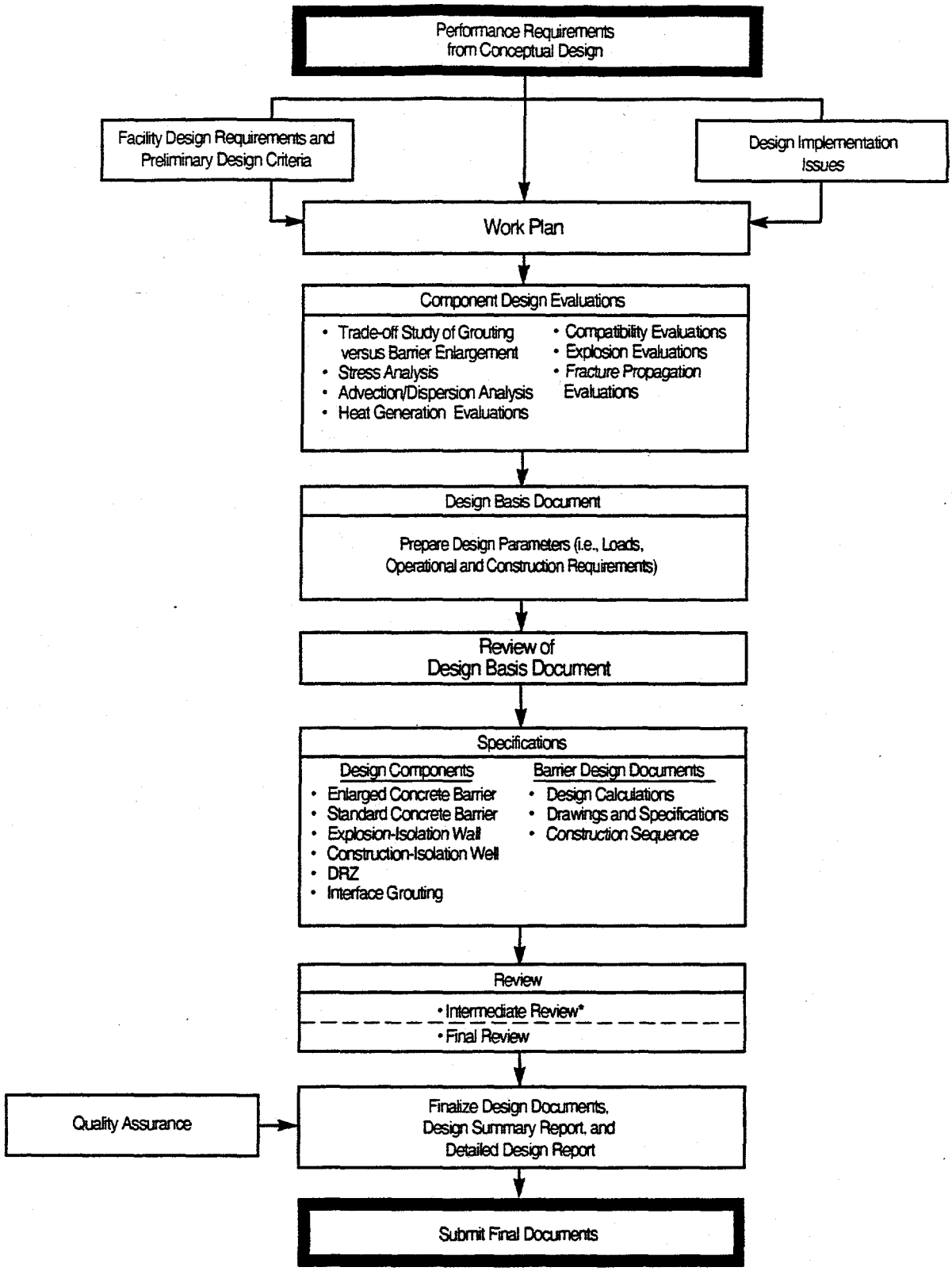


Figure 1-2
Design Process for the Panel-Closure System

performed to address specific design-implementation issues identified by the project. The results of these design evaluations are presented in this report.

1.2 Design Classification

Procedure WP 09-CN3023 (Westinghouse, 1995a) was used to establish a design classification for the panel-closure system. The design classification for the panel-closure system evolved from addressing the short-term operational issues regarding the reduction of VOC migration. Figure 1-3 shows the decision flow logic process used to designate the panel-closure system as a Class IIIB structure.

1.3 Regulatory Requirements

The following subsections discuss the regulatory requirements specified in RCRA and MSHA for the panel-closure system.

1.3.1 Resource Conservation and Recovery Act (40 CFR 264, 268, and 270)

In accordance with Title 40, Code of Federal Regulations (CFR), Part 264, Subpart X (40 CFR 264, Subpart X), "Miscellaneous Units," and 40 CFR 270.23, "Specific Part B Information Requirements for Miscellaneous Units," a RCRA Part B permit application has been submitted for the WIPP facility. According to 40 CFR 268.6, the DOE has opted to pursue a no-migration variance petition (NMVP) instead of treating waste to meet the land disposal restrictions (40 CFR 268) (EPA, 1995).

1.3.2 Protection of the Environment and Human Health

Both the draft NMVP and the WIPP RCRA Part B permit application indicate that VOCs must not exceed health-based standards beyond the WIPP site boundary. Worker exposure to VOCs, and VOC emissions will not pose greater than a 10^{-6} excess cancer risk to the nearest resident in order to meet health-based standards. The panel-closure system design incorporates measures to mitigate VOC migration for compliance with these standards.

1.3.3 Closure Requirements (20 New Mexico Administrative Code 4.1, Subpart V)

The DOE will notify the Secretary of the New Mexico Environment Department in writing at least 60 days prior to the date on which partial and final closure activities are scheduled to begin.

A. Select a system structure or component for classification. (Start with a mitigating item)

B. Is the system, structure, or component required to mitigate the consequences of an accident?

C. Would the system, structure, or component failure result in loss of safety functions of a Design Class I components?

D. Does the system, structure, or component provide any function related to nuclear materials?

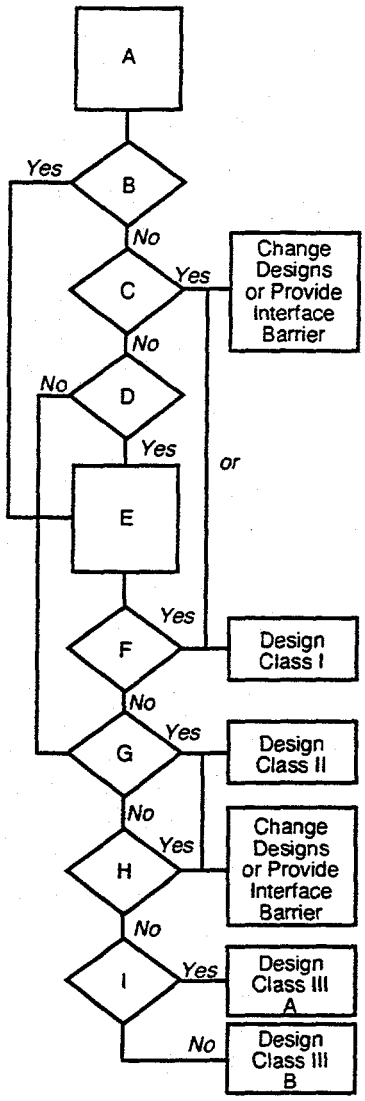
E. Select a conservative accident scenario and perform safety analysis.

F. Does the cumulative radiological consequences following the accident exceed 25 Rem whole body or 75 Rem organ dose commitment to an individual at the Zone I boundary

G. Does the structure, system, operation or component conform to the Class II criteria as defined in Attachment 2?

H. Would the structure, system, operation or component failure result in loss of the required function of a Class II component?

I. Are special design requirements necessary to ensure that failure of the system, structure, or component will NOT result in a significant shutdown of the facility or inhibit accessibility or maintainability of required equipment or have special significance to health and safety of operations personnel?



B. _____YES __X__ NO
Descibe requirement

C. _____YES __X__ NO
Failure mode and affected class I component

D. _____YES __X__ NO
Describe function

E. _____YES __N/A__ NO
Attach safety analysis

F. _____YES _____ NO
Calculate dose rates
N/A
(Attach calculations to this form)

G. _____YES __X__ NO
Criteria
N/A

H. _____YES __X__ NO
Failure mode and affected Class II component

I. _____YES __X__ NO
Requirements

Figure 1-3
Design Classification of the Panel-Closure System
(Modified from Westinghouse, 1995a)

1.3.4 Mining Safety and Health Administration

The significance of small natural-gas occurrences within the WIPP repository is within the classification of Category IV for natural gas under the MSHA (30 CFR 57, Subpart T) (MSHA, 1987). These regulations include the hazards of methane gas and volatile dust. Category IV "applies to mines in which non-combustible ore is extracted and which liberate a concentration of methane that is not explosive nor capable of forming explosive mixtures with air based on the history of the mine or the geological area in which the mine is located." For "barriers and stoppings," the regulations provide for noncombustible materials (where appropriate) for the specific mine category and require that "barriers and stoppings" be of "substantial construction." Substantial construction implies construction of such strength, material, and workmanship that the barrier could withstand air blasts, methane detonation or deflagration, blasting shock, and ground movement expected in the mining environment.

1.4 Report Organization

This report presents the engineering package for the detailed design of the panel-closure system. Chapter 2.0 presents the design evaluations. Chapter 3.0 describes the design and Chapter 4.0 presents the Constructability Design Calculations Index. Chapter 5.0 shows the technical specifications. Chapter 6.0 presents the design drawings. The conclusions are presented in Chapter 7.0 and the references presented in Chapter 8.0. Appendices to this report provide detailed information to support the information contained in Chapters 2.0 through 7.0 of this report.

2.0 Design Evaluations

This chapter presents the results of the various design evaluations that support the panel-closure system: (1) analyses addressing the operational requirements, and (2) analyses addressing the structural and material requirements. The first group includes air-flow analyses, an advection/dispersion analysis, and stress analyses using the Fast Lagrangian Analysis of Continua (FLAC) (Itasca, 1995), which support a trade-off study comparing grouting to removal of fracture zones in both the roof and floor. The second group addresses the issue of material compatibility with the host rock and heat-generation that may cause thermal cracking in the main concrete barriers during cement hydration. The second group also includes methane-explosion and fracture-propagation evaluations to address the dynamic pressure and subsequent temperatures generated by a postulated methane explosion.

2.1 Analyses Addressing Operational Requirements

The panel-closure system incorporates design features to address a range of ground conditions, including the most severe ground conditions expected in the air-intake and air-exhaust drifts. The alternatives for dealing with the most severe ground conditions include excavating the fractured disturbed rock zone (DRZ)[2] and installing an enlarged concrete barrier or partially enlarged concrete barrier with interface grouting or emplacing a standard concrete barrier with formation grouting. To evaluate the effectiveness of these alternatives for a panel-closure system, air-flow analyses and structural analyses were performed. The air-flow analyses examined the flow of VOCs through the panel-closure system for these alternatives.

The flow of VOCs is influenced by interface stress development. At the interface, the flow was assumed to be equivalent to a fracture zone. To investigate interface-stress development and the influence of barrier shape, structural analyses were performed for the main concrete barrier. These structural analyses were then used to determine the loads on the main concrete barrier.

The following sections address the air-flow analyses, the advection/dispersion analysis, and the stress analyses that support the trade-off study for designs with or without DRZ removal for overall protection of human health and the environment and compliance at the WIPP site boundary.

[2]DRZ removal is used in the context of the removal of fractured rock in the DRZ.

2.1.1 Air-Flow Analyses

The purpose of the air-flow analysis was to evaluate the trade-offs among a standard concrete barrier with formation grouting, a partially enlarged concrete barrier with partial DRZ removal (roof), and a fully enlarged concrete barrier with complete DRZ removal. Subsequent analyses were performed to evaluate air flow for these alternatives. The air-flow model (DOE, 1995) was used to evaluate the effective intrinsic barrier permeability of the main concrete barrier for these alternatives and to assess VOC flow performance.

In previous studies (DOE, 1995), two air-flow models were evaluated: 1) unrestricted flow, and 2) restricted flow through a panel-closure system. Unrestricted air flow is defined as flow in which the gas pressure develops at or very near atmospheric pressure. No back pressure exists in the waste emplacement areas. Restricted flow is defined as flow in which a back pressure develops due to the restriction of flow through the barrier and the surrounding disturbed rock zone. The analyses were based on an assumed gas generation rate of 8,200 moles per panel per year (0.1 moles per drum per year) due to microbial degradation, an expected volumetric closure rate of 28,000 ft^3 (800 m^3) per year due to salt creep, the expected headspace concentration for nine VOCs, and the expected air dispersion from the exhaust shaft to point of compliance, the WIPP site boundary. The previous analyses indicated that the panel-closure system would limit the concentration (Figures 2-1 and 2-2) of each VOC to a small fraction of the health-based exposure levels during the operational period at the WIPP site boundary.

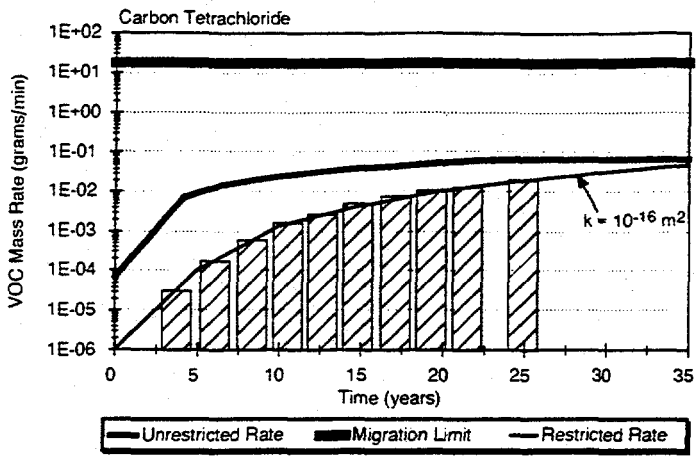
2.1.1.1 Evaluation Procedure

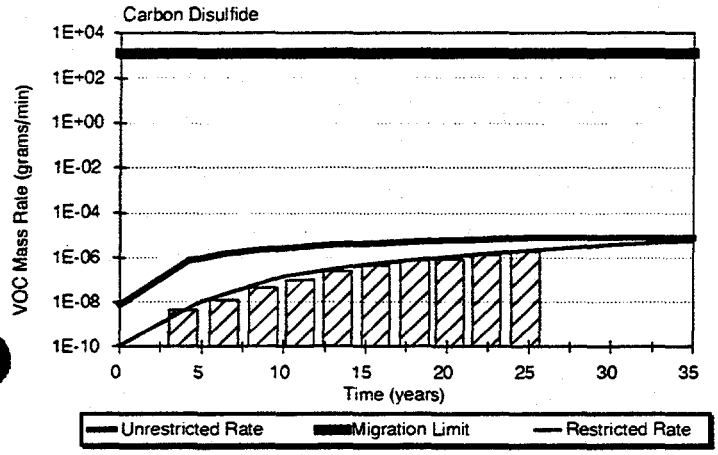
In the following analysis, the gases generated in the waste-emplacement area are in part compressed in the void space within a panel and in part flow into the main return air. The following assumptions were made in this model:

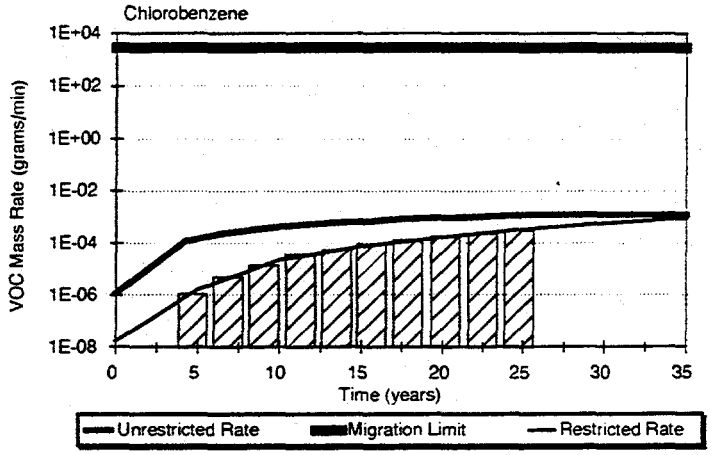
- That the gases (including VOCs) within the void space will obey the ideal gas law. The gases will be generated at a rate of 0.1 moles per drum per year and will be stored by an increase in gas pressure. The rate of pressure buildup will be so gradual that it occurs at constant temperature.

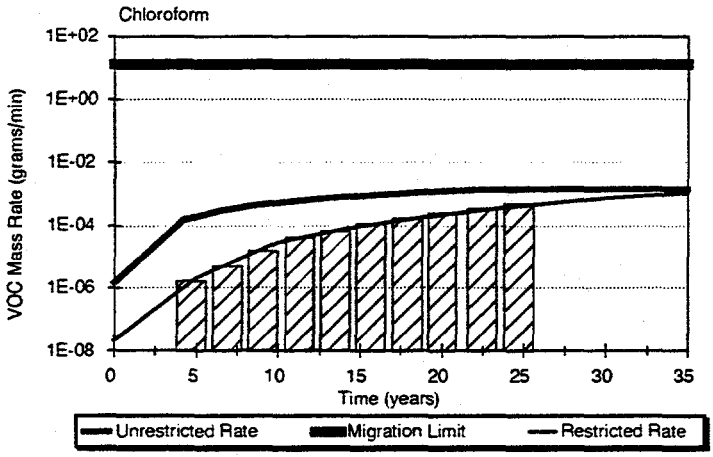
- That volumetric reduction due to creep will reduce the void space at a rate of 28,000 ft^3 (800 m^3) per year and will result in pressurization.

- That the flow of gas out of the panel will obey Darcy's law under quasisteady-state conditions. Under quasisteady-state conditions, the air pressure within the panel-closure system will change so gradually that the compressive storage of the air within the void space of the panel-closure system could be neglected.









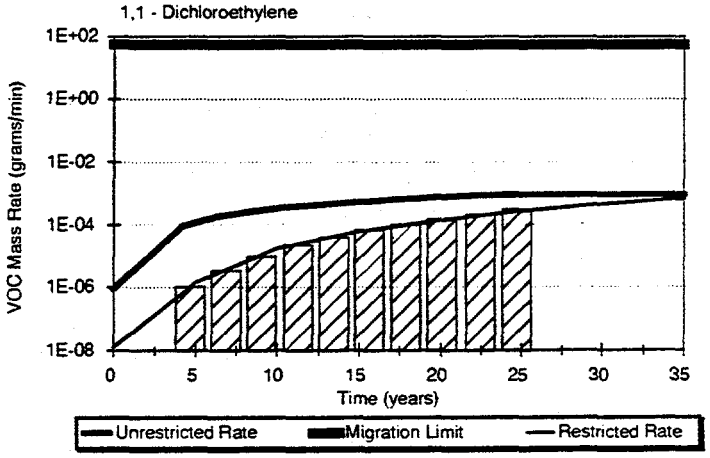


Figure 2-1

Closed-Panel Release Rate Versus Limit Comparison for Carbon Tetrachloride and Other VOCs
(After DOE, 1995)

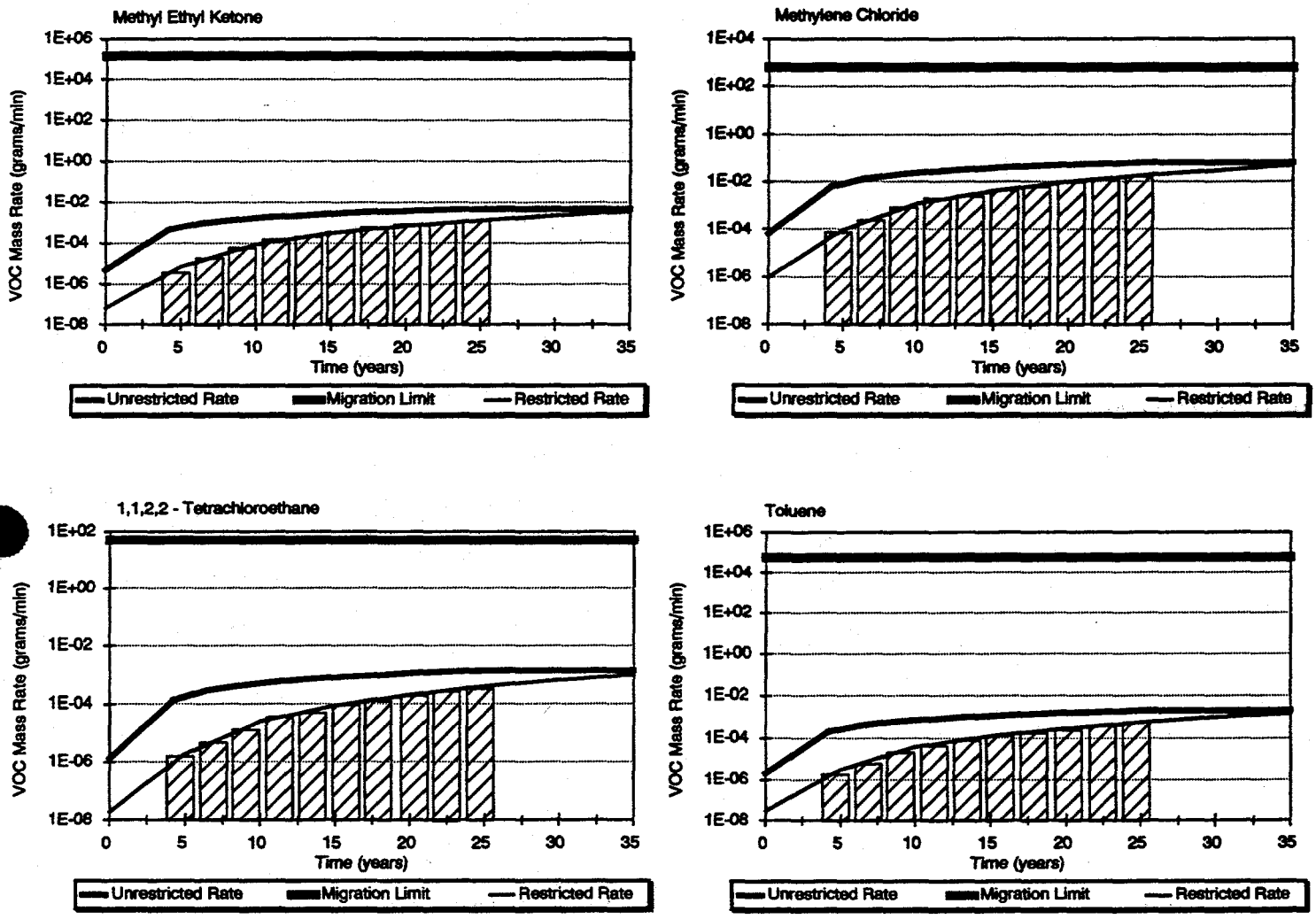


Figure 2-2
Closed-Panel Release Rate Versus Limit Comparison for Other VOCs
(After DOE, 1995)

- That the rates of gas generation, air outflow, and change in compressive storage will balance.
- That hydrodynamic dispersion will be neglected in the analysis.
- That the analysis will consider the superposition of flow rates from individual panels according to the operating schedule for an operational life of at least 35 years.

The air flow under these assumptions follows a nonlinear first-order ordinary differential equation. The model is characterized by molar gas generation and a reduction in void volume that results in an increase in air pressure.

The problem can be stated by solving the system of nonlinear ordinary differential equations as derived in Appendix A:

$$\frac{dP}{dt} = R * T * \frac{(g_r - \frac{P}{RT} * C * \frac{P - P_{atm}}{\gamma}) * V - n\frac{dV}{dt}}{V^2}$$

$$\frac{dn}{dt} = g_r - \frac{P}{R*T} * C * \frac{P - Patm}{\gamma}$$

where

dt	=	Change in time (years)
R	=	Universal gas constant
T	=	Absolute temperature
n	=	Moles of gas in the panel that is a function of time
P	=	Pressure
P_{atm}	=	Atmospheric pressure
C	=	Conductance of the panel-closure system = $K_s * \frac{A}{L}$
K_s	=	Air conductivity of the panel-closure system
A	=	Cross sectional area of the panel-closure system
L	=	Flow path length of the panel-closure system
γ	=	Air density
g_r	=	Gas generation rate
V	=	Panel volume

$\frac{dV}{dt}$ = Panel volumetric-closure rate

$\frac{dP}{dt}$ = Panel-pressure rate

$\frac{dn}{dt}$ = Panel-molar storage rate.

The above relationships are subject to the following initial conditions: (1) that the pressure in the panel will be atmospheric, and (2) the moles equals the moles of gas occupying the initial panel void volume at the temperature of the repository.

The analysis assumed that the volume of the waste is equal to the total waste capacity of a panel (600,000 ft^3 [16,990 m^3]) (DOE, 1994a) times the assumed average solid volume of the waste drums (23 percent) (IT, 1994). The analysis uses a solid waste volume equal to 138,000 ft^3 (3,910 m^3) for the panel and this volume remains constant during the operational life of the panel. The analysis then evaluates the void volume at panel closure, approximately four years after panel excavation.

The waste-emplacement capacity of a panel includes the seven rooms and the panel-access drifts from Room 1 to Room 7. The analysis uses closure rate and total closure data from the Geotechnical Analysis Report (DOE, 1994b). A combination of field data and empirical analysis is used to determine long-term closure rates for 35 years as presented in Appendix B.

The effective conductivity (K_s) can be further expressed in terms of an effective intrinsic panel-closure system permeability as (Freeze and Cherry, 1979):

$$K_s = \frac{k_s * \rho * g}{\mu}$$

where

K_s = Air conductivity
k_s = Effective concrete barrier permeability (m^2)

ρ = Mass density
g = Acceleration due to gravity
μ = Absolute viscosity.

The calculations assumed that the cross-sectional area for flow through the DRZ and the panel-closure system will equal 9 times the air-intake and air-exhaust area or that the DRZ extends out 3 radii from the center. Case and Kelsall (1986) evaluated permeability measurements performed by Peterson et al. (1985). These data showed a zone of increased permeability (10^{-18} to 10^{-20} ft^2 [10^{-19} m^2 to 10^{-21} m^2]) from (3 to 42 ft [1 to 14 m]). The boundary of the DRZ used in the analysis falls within their range.

The effective intrinsic permeability was calculated by considering the permeabilities over their respective areas of the various media, as presented in Table 2-1. The assumed flow path length equaled 26 ft (7.92 m). The effective permeability was equal to 1×10^{-15} ft^2 (10^{-16} m^2) for the standard concrete barrier with formation grouting. For an enlarged concrete barrier with complete DRZ removal, the effective permeability would equal 1×10^{-16} ft^2 (10^{-17} m^2).

Table 2-1
Intrinsic Permeability of Flow Components

Component	Intrinsic Permeability		Reference
	ft^2	m^2	
Dilated salt	10^{-18}	10^{-19}	Cook and Case, 1991
Fractured salt (grouted)	10^{-15}	10^{-16}	DOE, 1995
Clay seams	10^{-16}	10^{-17}	Freeze and Cherry, 1979
Concrete barrier	10^{-18}	10^{-19}	Gulick and Wakeley, 1989
Marker Bed 139	10^{-15}	10^{-16}	DOE, 1995
Interface zone	10^{-10}	10^{-11}	Fernandez et al., 1994

2.1.1.2 Modeling Results

Figure 2-3 shows that, after closure, the pressure within the panel will build up gradually, due to the large compressibility of the panel void space relative to the air flow rate out of the

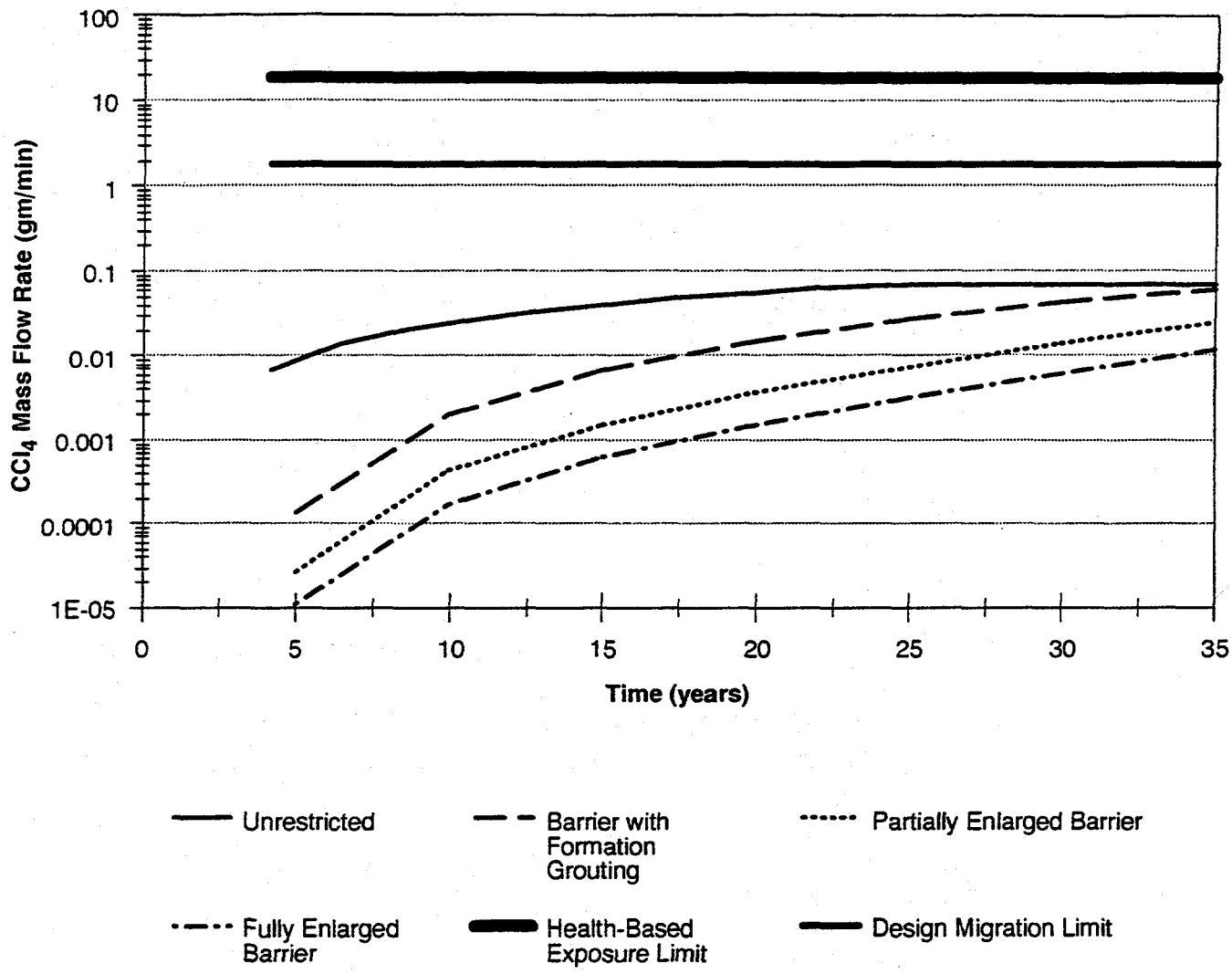


Figure 2-3
Air-Flow Analyses Using Several Alternatives

panel. The panel-closure system will be effective in restricting flow to a value less than the unrestricted flow rate during this period.

2.1.1.3 Conclusions

The air-flow model (DOE, 1995) was used to predict the performance of a grouted standard concrete barrier, a partially enlarged concrete barrier, and a fully enlarged concrete barrier for the mass flow rate of carbon tetrachloride. The analysis suggests that the alternate barrier systems would be effective in restricting air flow over the operational period and that the panel-closure system will restrict flow to at least 1 order of magnitude below the health-based migration limit in preventing the release of VOCs (Figure 2-3).

2.1.2 Advection/Dispersion Evaluation

The purpose of the advection/dispersion evaluation was to assess contaminant transport time through various media. The panel-closure system will be constructed to reduce the air flow-rate by using compressive storage in the panel void space. The model (DOE, 1995) showed that the panel-closure system will restrict transient flow for at least the operational period to an effective gas-generation rate that is substantially less than the steady state flow rate of about 35,000 ft^3 (1,000 m^3) per year.

2.1.2.1 Evaluation Procedure

As panel pressure develops with time, the gases generated from the waste will travel through the panel-closure system to the active underground workings. The model (DOE, 1995) considered that the VOC concentration front will instantaneously develop in the active underground workings and the gases would advect due to velocity variations as panel pressures increased. The more detailed analysis presented below considers the flow distribution and how the concentration of VOCs would be affected by the mechanisms of advection and dispersion. If movement were slow through the panel-closure system, the breakthrough would be delayed.

The relative significance of each of the air-flow zones can be evaluated by studying flow conductance. The flow conductance through the panel-closure system is given by the equation:

$$C = \sum \frac{K_i * A_i}{L_i}$$

where:

C	= Flow conductance
K_i	= Air conductivity of the ith component
A_i	= Cross sectional area of the ith component
L_i	= Length.

The conductance through the panel-closure system will depend on the cross-sectional area and the length. Table 2-2 summarizes the values for each component. The calculations show that flow through fractured salt and MB 139 will dominate the conductance.

Table 2-2
Air Conductance Through System Components

Component	Effective Porosity	Air Conductivity (meters per second)	Approximate Cross-Sectional Area ($meter^2$)	Conductance per Unit Length ($meter^3$ per second)
Dilated salt	0.001	6.2×10^{-14}	170	1.0×10^{-11}
Fractured salt	0.040	6.2×10^{-10}	16	9.9×10^{-9}
Clay seams	0.400	6.2×10^{-12}	0.09	5.6×10^{-13}
Marker Bed 139	0.040	6.2×10^{-11}	11	6.8×10^{-10}
Concrete barrier	0.200	6.2×10^{-14}	27	1.7×10^{-12}

The contaminant breakthrough of VOCs through the panel-closure system under the assumption of advection will occur when the contaminant front traversed the length. The average linear velocity equals the Darcy flux divided by the effective porosity for the various flow components. The average linear velocity that varies with time is given by:

$$V(p(t))_{avg_i} = \frac{K_i * (p(t) - p_{atm})}{n_e * L * \gamma}$$

where:

$V(p(t))_{avg_i}$	=	Average linear velocity for the ith component
K_i	=	Air conductivity
$p(t)$	=	Panel pressure as a function of time
p_{atm}	=	Atmospheric pressure
L	=	Length of the barrier
γ	=	Air density
n_e	=	Effective porosity.

The second evaluation of the air-flow modeling evaluated the effects of hydrodynamic dispersion on contaminant transport, using a one-dimensional dispersion model. This model was chosen to evaluate the effects of dispersion on VOC migration rates through the panel-closure system. To isolate the effects of mechanical dispersion, molecular diffusion was considered insignificant. The advection-dispersion equation is given by Freeze and Cherry (1979):

$$C = \frac{C_0}{2}\left[erfc\left(\frac{L - V_x * t}{2\sqrt{D_L * t}}\right) + exp\left(\frac{V_x}{D_l}\right) erfc\left(\frac{L + V_x * t}{2\sqrt{D_L * t}}\right)\right]$$

where:

$$D_L = a_L V_x + D^*$$

and

erfc	=	Complimentary error function
D_L	=	Longitudinal coefficient of dispersion
a_L	=	Dispersivity
V_x	=	Average linear velocity
C	=	Concentration of contaminant at time t
D^*	=	Molecular diffusion
C_0	=	Initial concentration
t	=	Time
L	=	Length.

- That the air-flow velocity will be constant.
- That the gases (including VOCs) within the void space will obey the ideal gas law.
- That the flow of air out of the panel will obey Darcy's law under quasisteady-state conditions. Under quasisteady-state conditions, the air pressure within the panel-closure system will change so gradually that the compressive storage of air within the void space of the air-intake and air-exhaust drifts will be neglected.
- That two-phase flow and interactions between air and brine will be neglected, although the resaturation of salt would tend to reduce the flow of VOCs through the barrier system.

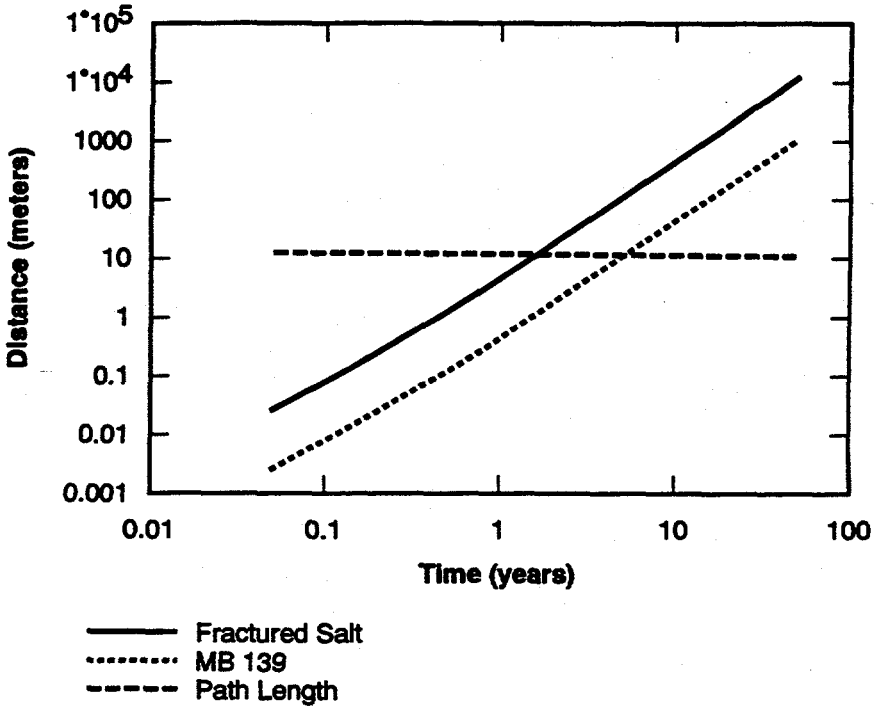
The air-flow velocity was calculated for each component of the panel-closure system using the maximum pressure determined from the air-flow model (DOE, 1995). Once a constant velocity was calculated for each component, the concentration as a function of time was determined for each of the panel-closure system components: fractured salt, fractured anhydrite, clay seams, and the standard concrete barrier.[3] To study the effects of dispersion, a range of different dispersivities was used. Mass flow as a function of time was then determined for carbon tetrachloride and was summed over all components of the panel-closure system.

2.1.2.2 Modeling Results

In the model presented for air flow, the pressure varies as a function of time for flow through the panel-closure system. This will result in a change in the average linear velocity as a function of time that was calculated for each of the various components: fractured salt, MB 139, clay seams, and the panel-closure system. The average linear velocity was then integrated over time.

Breakthrough times for a panel-closure system length of 40 ft (12 m) were computed (Figure 2-4). The analysis suggests that contaminant breakthrough through fracture zones may occur within one to several years, while contaminant breakthrough in the barrier and the dilated salt would not be expected during the WIPP operational period. The analysis shows that for fractured components with high air conductivity and low fracture porosity, large linear velocities result, with breakthrough occurring within months of panel closure. For the

[3]No credit is taken for the explosion isolation or construction isolation wall which is a conservative assumption.



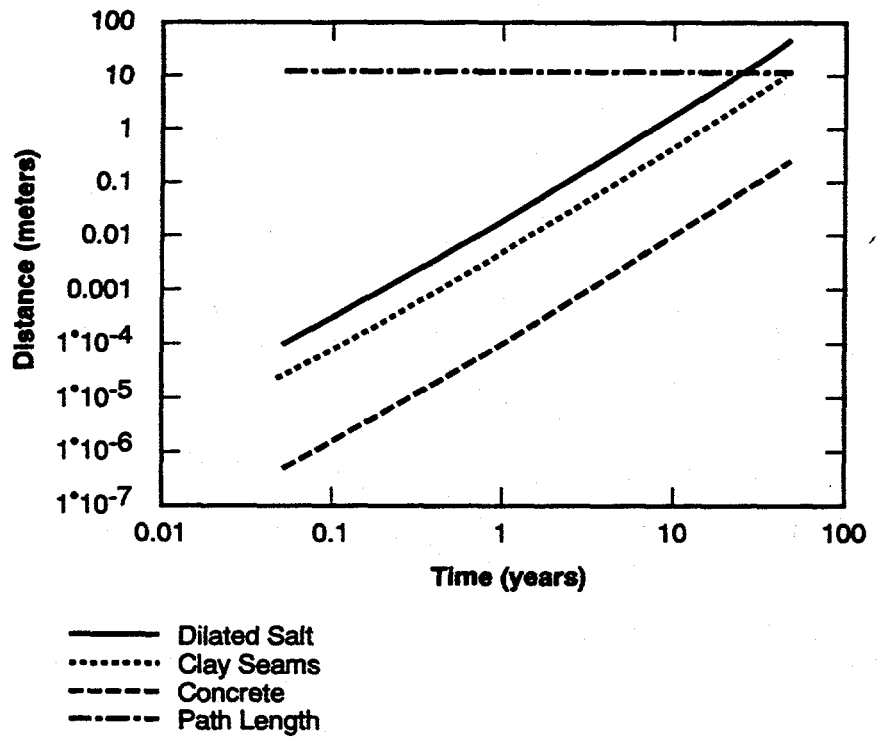


Figure 2-4
Breakthrough Time for VOCs through Several Media

other components, with much lower air conductivity and higher effective porosity the breakthrough would occur many years after panel closure.

In summary, the results of more detailed air-flow modeling suggest the appropriateness of the model for the instantaneous breakthrough of contaminants and the insignificance of dispersion. The results of the air-flow model emphasize the importance of treating fracture zones, either by removal or by grouting for restricting the flow of VOCs.

The results from the second evaluation support the conclusion that breakthrough of VOCs will occur rapidly through the dominant paths of the fractured salt and fractured anhydrite. Because of this, the effects of dispersion will be insignificant on the VOC mass flux.

2.1.2.3 Conclusion

In conclusion, because air-flow modeling results show that breakthrough will occur rapidly and that the effects of hydrodynamic dispersion will be insignificant, the air-flow model (DOE, 1995) is conservative and appropriate.

2.1.3 Stress Analysis

The purpose of the stress analysis was to evaluate the interaction of the main concrete barrier of the panel-closure system with the surrounding salt for different combinations and geometries. The panel-closure system will consist of: (1) a standard concrete barrier or (2) an enlarged concrete barrier. Options (1) and (2) will contain interface grouting and be combined with an explosion-isolation or construction-isolation wall. The walls will isolate the concrete barrier from the waste-emplacement panel and the effects of a postulated methane explosion. Stresses are expected to develop in the concrete-barrier component due to continued primary and secondary creep closure of the air-intake and air-exhaust drifts after installation of the concrete barrier. An estimate of the stress levels expected in the concrete barrier determined the deformability and strength required for the concrete. The development of stresses in the salt around the concrete barrier was also evaluated to estimate the time required for DRZ healing for these options.

2.1.3.1 Evaluation Procedure

The evaluation was performed using the FLAC computer code (Itasca, 1995). Six detailed structural-analysis models were prepared to evaluate the salt/structural interaction of the proposed system. These models included two transverse-plane strain models across the air-intake and air-exhaust drifts associated with a waste-emplacement panel, two long

axisymmetric models, and two short axisymmetric models. The properties used in these models were taken from the Backfill Engineering Analysis Report (IT, 1994) as presented in Appendix C.

2.1.3.2 FLAC Models

Since 1991, FLAC has been used to model underground excavations at the WIPP. FLAC is a two-dimensional, explicit finite difference code that simulates the behavior of rock and soil-like structures. The WIPP Reference Creep Law is built into FLAC and has been verified to U.S. Nuclear Regulatory Commission standards (Itasca, 1995). In addition, FLAC has been verified against the WIPP Second Benchmark Problem (Krieg, 1984). The following subsections describe the geometry and boundary conditions of the model used in the FLAC analysis.

Plane-Strain Model Geometry. Two cross-sectional transverse plane-strain models were run using the air-intake and air exhaust drift geometries. These models used a simplified stratigraphy for approximately 250 ft (75 m) above and below the excavation horizon (Figure 2-5). The models included the interaction of the excavation and the main concrete barrier with MB 139 over time. The cross-sectional dimension of the air-intake drift is 13 by 20 ft (4 by 6 m), while the air-exhaust drift is 12 by 14 ft (3.6 m by 4.3 m). Each model was run with the initial excavation and allowed to creep for a period of 5 years,[4] the time expected for panel excavation and waste emplacement. After 5 years, the drift at the concrete barrier location was excavated just beyond Clay G and Clay E, removing MB 139, and the ribs were excavated to curved segments between these clays. Each model was then run for an additional month simulating the time required to excavate the enlarged area and install the concrete barrier. After the enlarged excavation was open for one month, the model was continued with the installed concrete barrier. The actual construction schedule may be longer for the enlarged barrier; however, the effects on long-term interface stress buildup will be insignificant. As the stresses increased in the concrete barrier and the surrounding salt the model was run for an additional 35 years, representing the required period of performance for a concrete barrier.

[4]For Panel One, the period between excavation and barrier emplacement would be greater than 5 years. A longer period of time might result in more bed separation. However, since fractured salt is removed to Clay G and the barrier is placed over a short period, the design is considered robust, and the effects of a longer period for Panel One are insignificant.

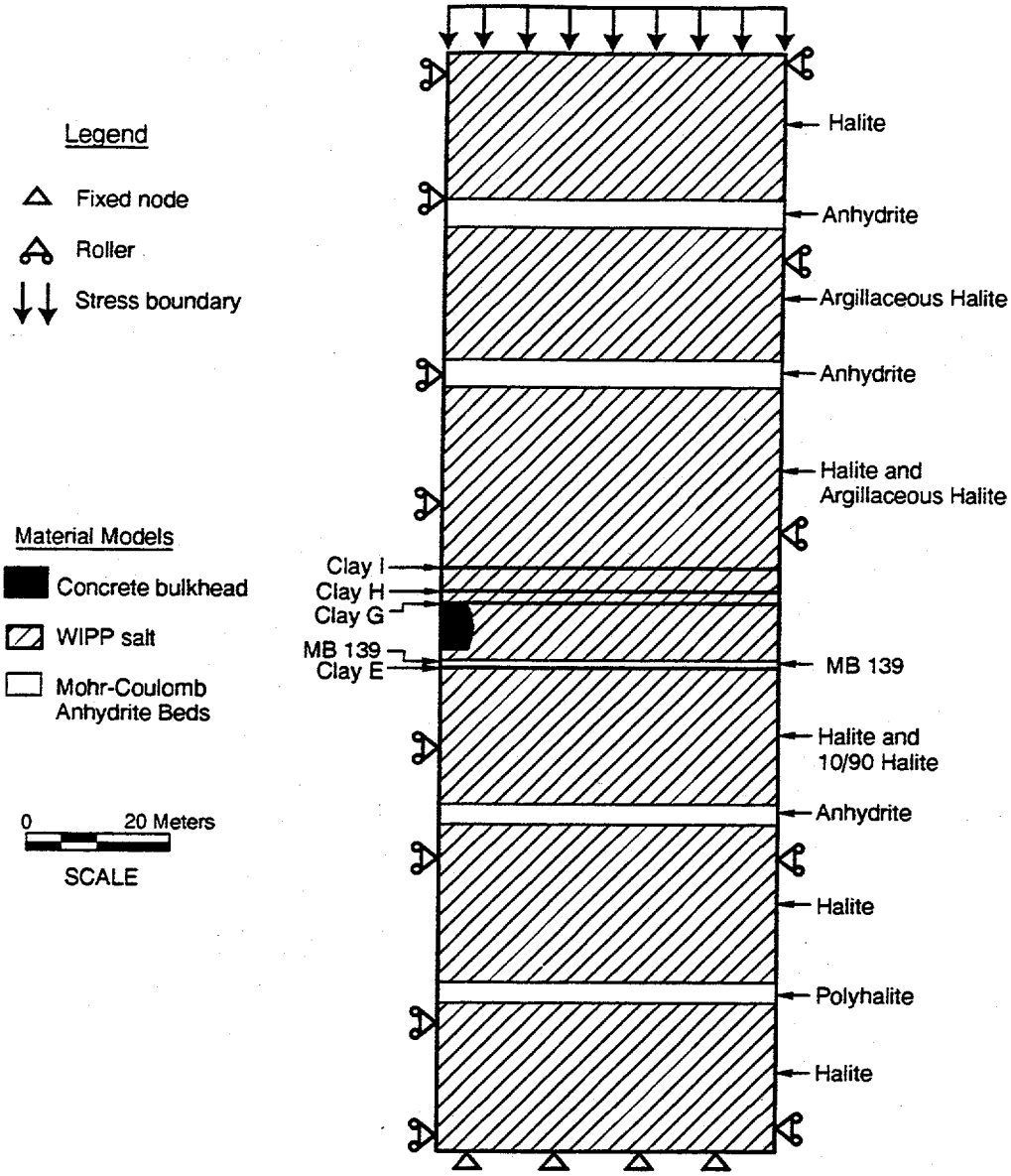


Figure 2-5
Transverse Model for FLAC Analysis

Axisymmetric Models. Four axisymmetric models were run to evaluate the long-term loadings expected on the ends of the concrete barrier. The models (Figure 2-6) were simplified using a homogeneous salt and radial loading. The model for the concrete barrier was symmetrical around the central axis. The cases illustrate that the presence of the barrier ends will result in a longer cylindrical barrier, and that the shorter barrier with the two plug ends will result in a more tapered shape.

Material Properties Used in Modeling. The material properties used for the reference stratigraphy presented in the Backfill Engineering Analysis Report (IT, 1994) were used in the FLAC analysis. These properties (Appendix C) included the elastic, primary creep, and secondary creep constitutive properties of the halite, polyhalitic halite, and argillaceous halite. They also included the elastic properties of the anhydrite and the concrete.

Modeling Results—Transverse Plane-Strain Models. The results of the transverse plane-strain models suggest that higher stresses will form in MB 139 following excavation, but that after barrier emplacement, an increase in barrier-confining stress and a reduction of shear stress will occur in and around the barrier. The results further suggest that substantial uniform confining stresses will develop as the barrier is subjected to the secondary salt creep.

Modeling Results—Axisymmetric Models. The results of the axisymmetric models agree with the results of the transverse models for the prediction of interface stress and suggest the appropriateness of an axisymmetric model to evaluate the long-term stress abutment zone effects. The modeling results for the longer cylindrical barrier suggest that the radial stresses increase by a factor of 2 at the ends of the barrier. The high-stress concentration at the ends of the barrier extends a distance of several meters. Tensile stress develops at the ends of the longer cylindrical barrier. The short axisymmetric barrier, with the design achieving a more tapered configuration, shows that a more uniform state of compression develops all around the barrier. The principal stress results after a period of 30 years for this barrier with DRZ removal are presented in Figure 2-7. These results show that the barrier is in a state of overall compression.

2.1.3.3 Stress Analysis of the Concrete Barrier on an Elastic Foundation

An analysis was performed treating the concrete barrier as a beam on an elastic foundation. After several years it is expected that loads would develop uniformly in the concrete barrier; however, the concrete barrier may be subjected initially to nonuniform loading (Figure 2-8).

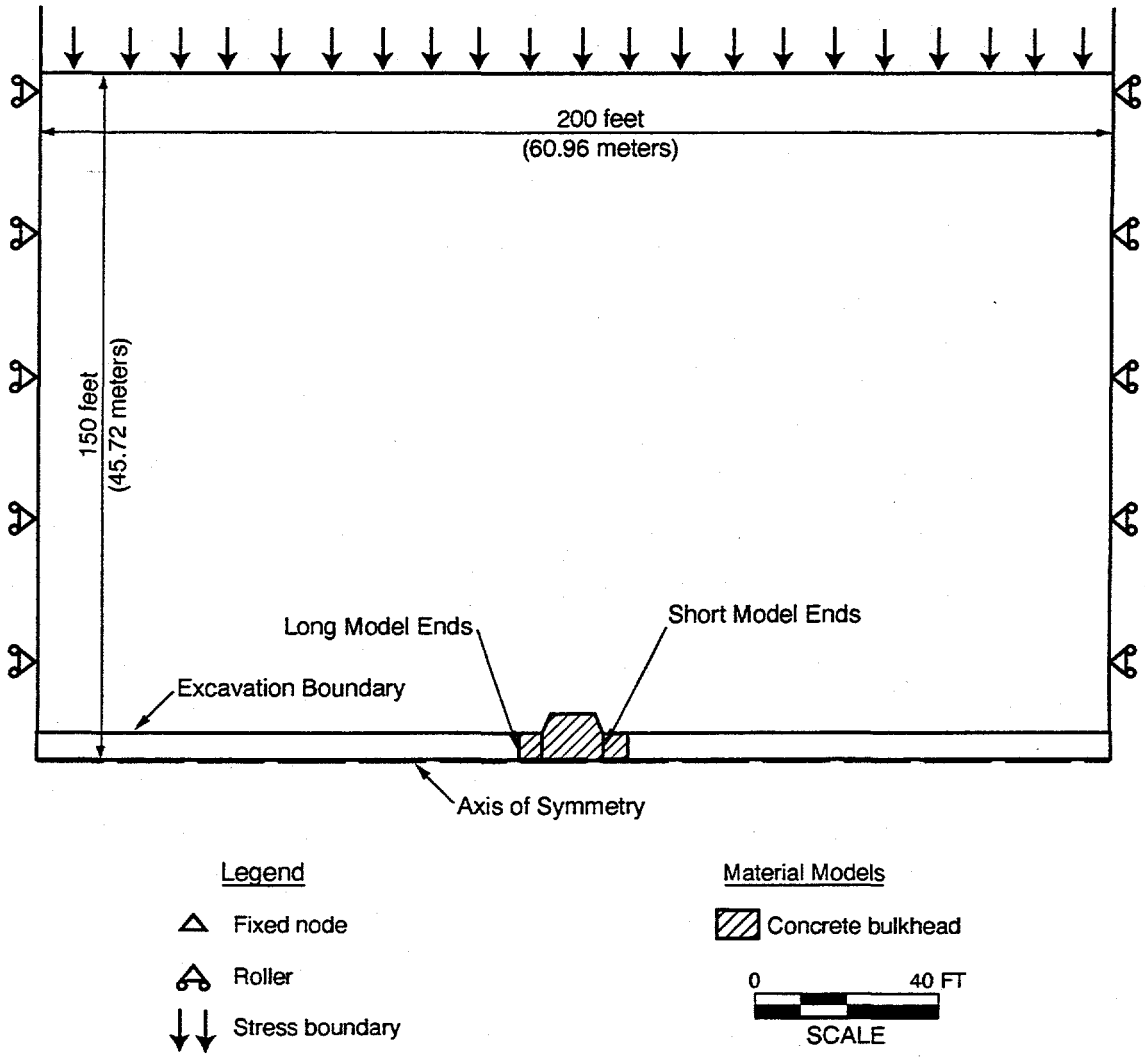


Figure 2-6
Axisymmetric Models for FLAC Analysis

JOB TITLE : Short Axisymmetric Model for Intake Drift - 30 Years After Plug Emplacement

FLAC (Version 3.22)

LEGEND

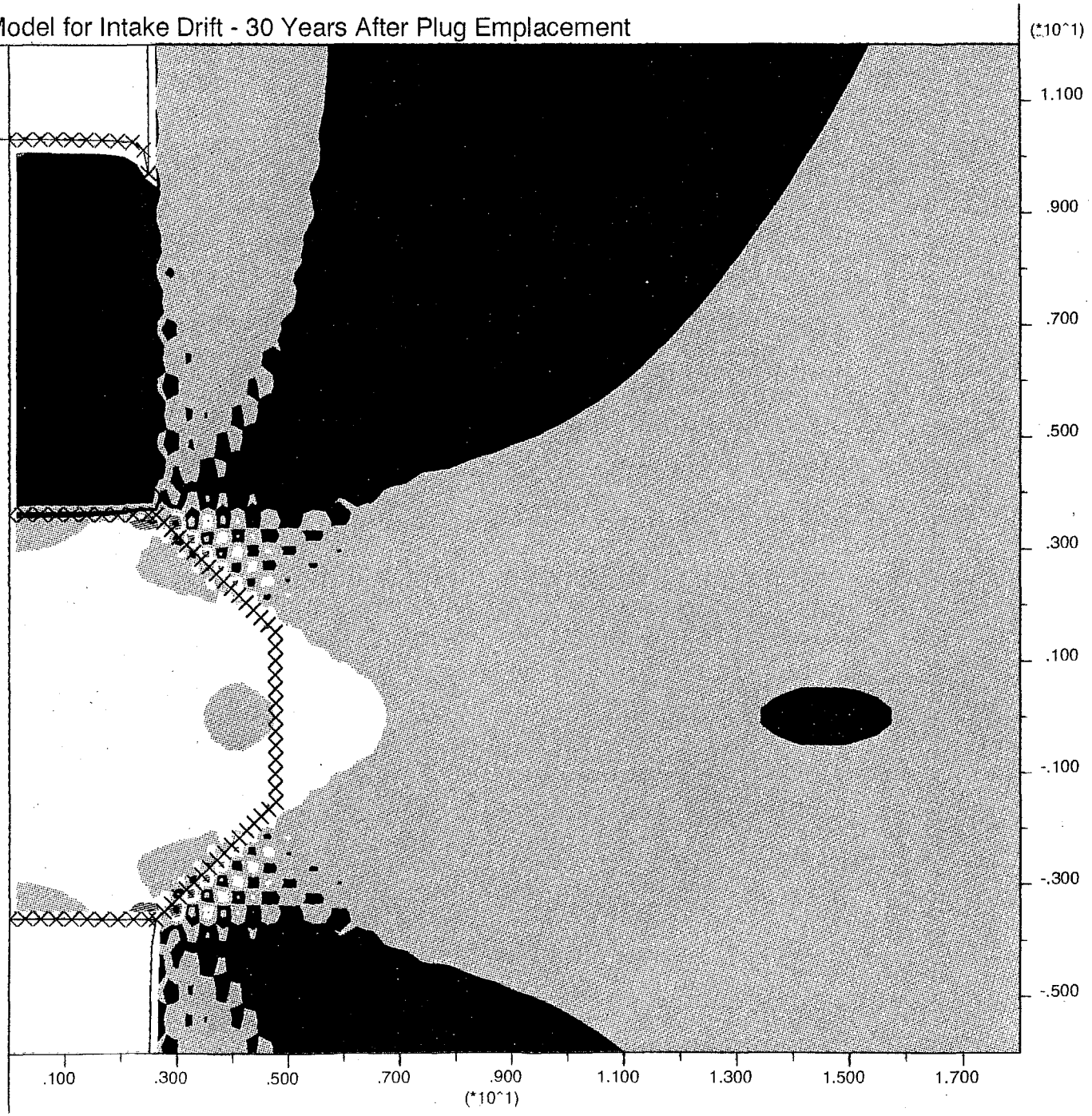
8/21/1995 11:02
step 61637
Creep Time 1.1070E+09
0.000E+00 <x< 1.800E+01
-6.000E+00 <y< 1.200E+01

Maximum principal stress
-3.50E+07
-3.00E+07
-2.50E+07
-2.00E+07
-1.50E+07
-1.00E+07
-5.00E+06
0.00E+00

Contour interval= 5.00E+06
Marked Gridpoints
Boundary plot

0 5E 0

IT Corporation



JOB TITLE : Short Axisymmetric Model for Intake Drift - 30 Years After Plug Emplacement

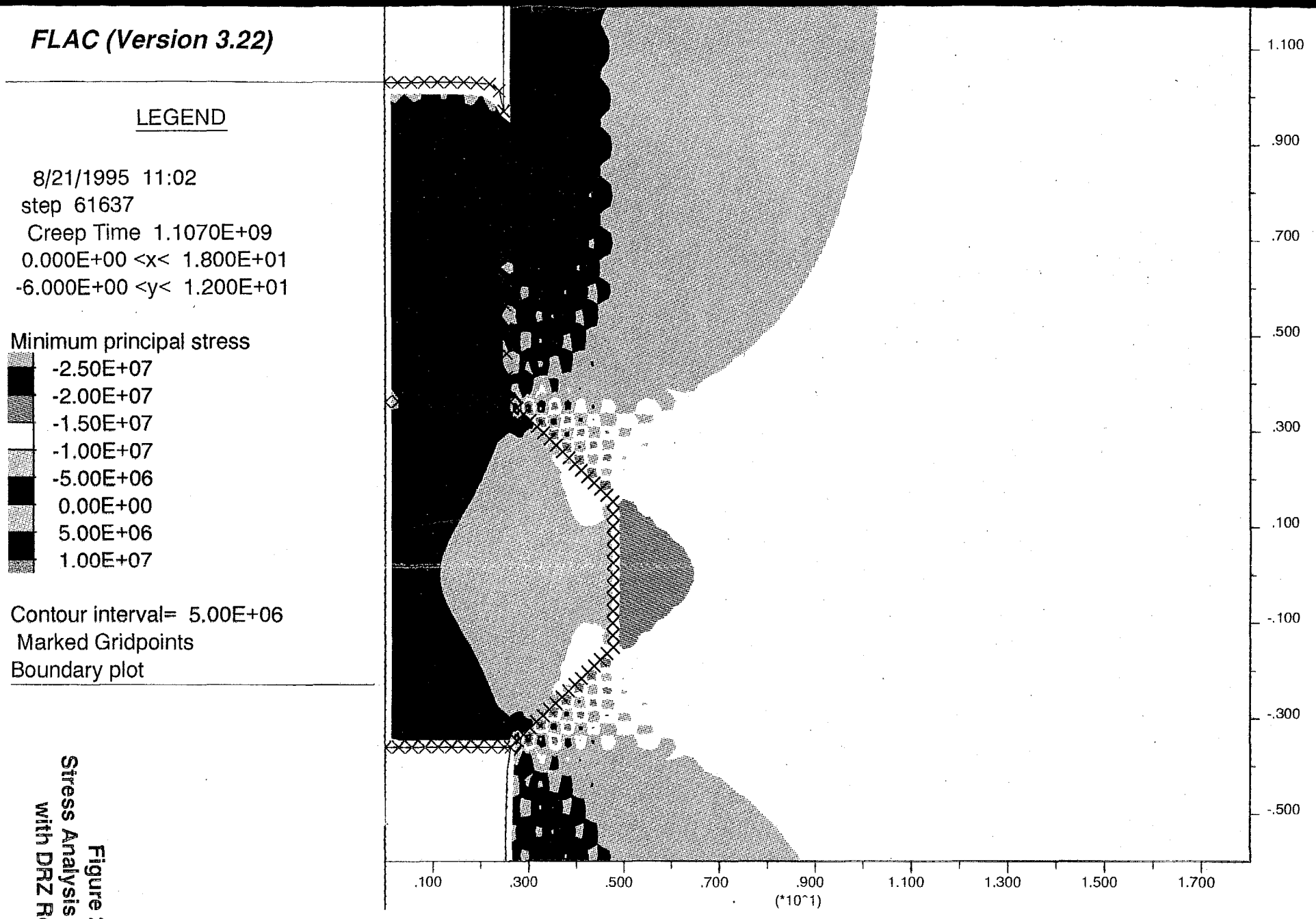


Figure 2-7
Stress Analysis of a Barrier
with DRZ Removal

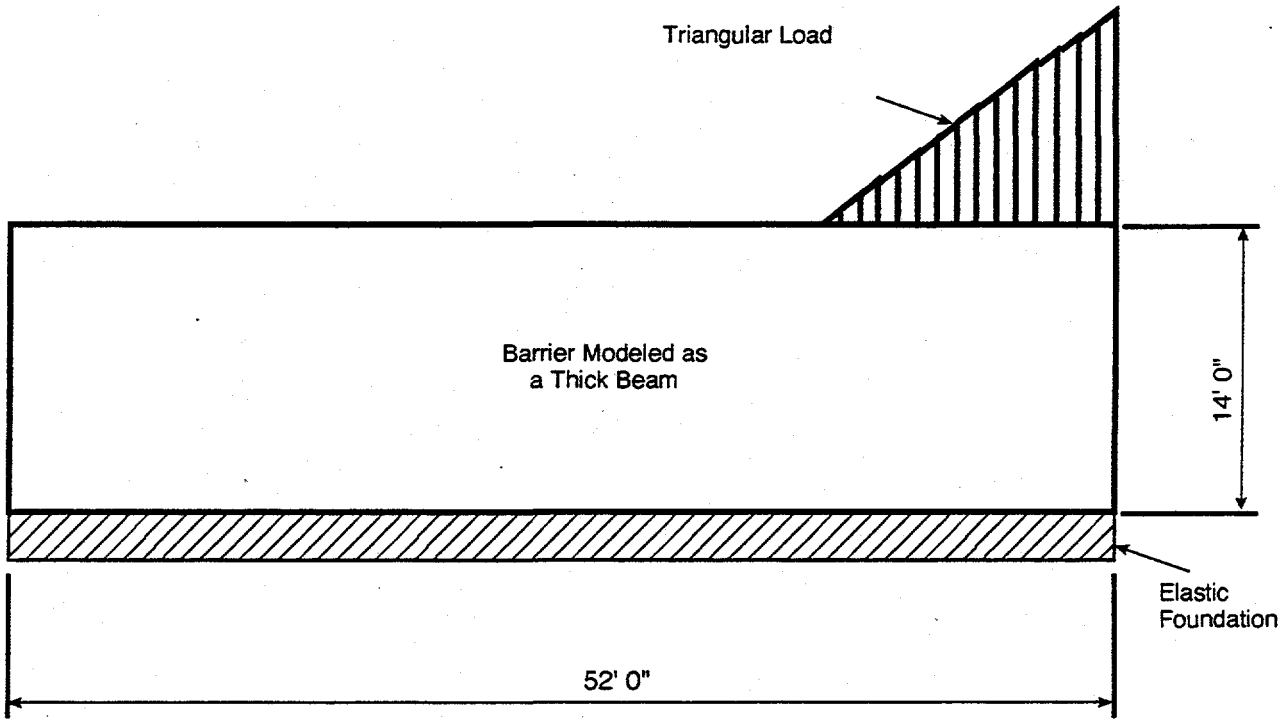


Figure 2-8
Stress Analysis of a Barrier on Elastic Foundation

The analysis of the concrete barrier on an elastic foundation shows that, for various assumed loadings that will develop, the amount of flexure and transverse shear was minimal and would result in insignificant nonuniform load reactions and failure of plain concrete in flexural tension or shear (Figure 2-9). The only manner in which flexure will develop would be through nonuniform loading. The assumed approximate stress gradient for the first room for the Chabannes solution (DOE, 1995) at a distance of 80 ft (24 m) equals 300 pounds per square inch (psi) (2.1 megapascals [MPa]) over 50 ft (15 m). The analysis evaluated the effects of varying the modulus of subgrade reaction for the barrier (equal to 500,000 psi [3,500 MPa]). The results suggest that the potential for flexural tension and shear will be greater when loads were resisted by fractured salt. The removal of fractured salt from the central portion of the excavation should result in a more uniform loading on the barrier and stiffer resistance in reaction that reduces short-term flexural tension and shear.

2.1.3.4 Interface Stress Buildup

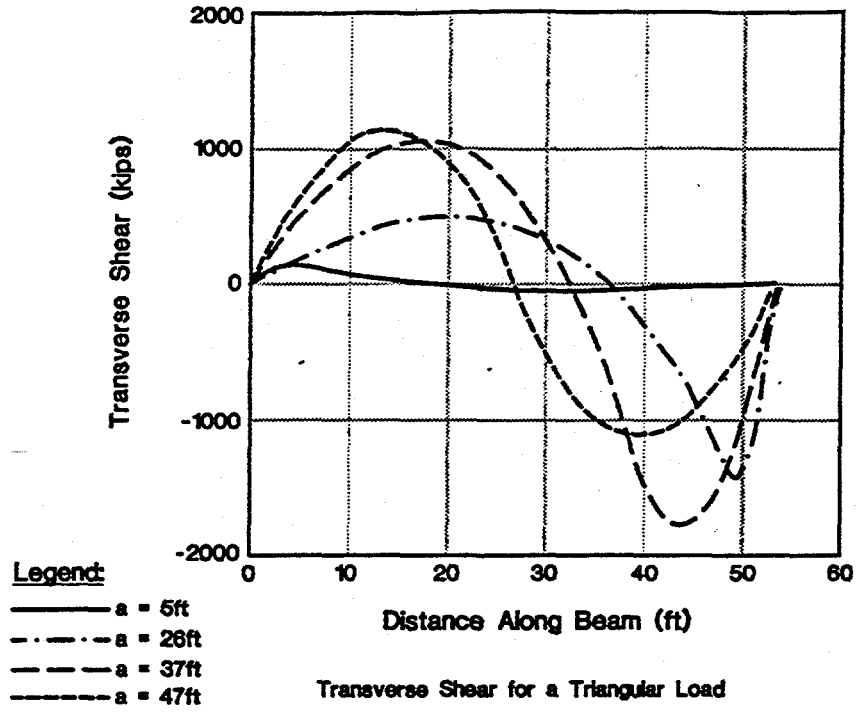
Previous small-scale sealing studies (Case and Kelsall, 1986) showed that stress in seals in contact with salt develop rapidly (Figure 2-10). As an example, in the 3 ft- (91- centimeter [cm])-diameter plug for the Small Scale Seal Performance Test, interface stress developed to about 1,000 psi (7 MPa) within 1,000 hours. An analysis was conducted to evaluate the effects of concrete barrier stiffness on the recovery of the DRZ for the alternatives. The technical approach to the standard analysis considered an infinitely long cylindrical concrete barrier[5] in an infinite medium (DOE, 1995). Figure 2-11 illustrates that interface stresses for the standard concrete barrier with formation grouting would develop more slowly than the enlarged concrete barrier, resulting in less healing of the surrounding DRZ for at least the 35-year operational period.

2.1.4 Tradeoff Study of Formation Grouting versus DRZ Removal

The purpose of this study was to evaluate the tradeoffs of formation grouting versus DRZ removal for the alternatives for overall protection of human health and the environment. The tradeoff study considered compliance with the design migration limit, barrier effectiveness, and implementability of the design at the WIPP. This evaluation was performed qualitatively through examination of the results of air-flow and stress analyses as presented in previous sections. The alternatives included a standard concrete barrier with formation grouting, a

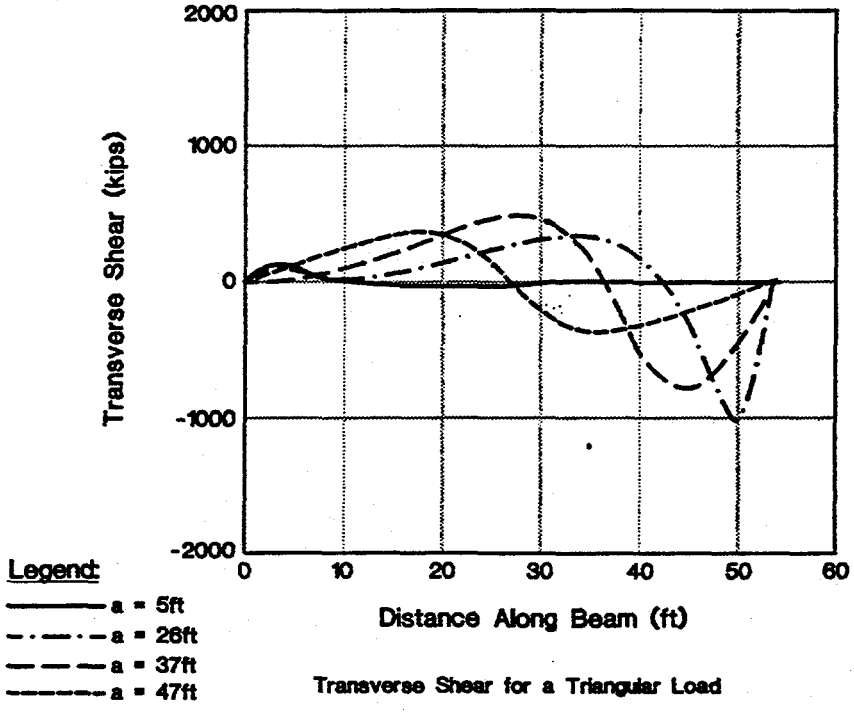
[5]A cylindrical concrete barrier develops interface stress less rapidly than a spherical concrete barrier. However, the analysis of a cylindrical barrier provides a relative comparison of the effects of fractured salt on the development of interface stress for a long cylindrical barrier.

Fractured Salt



Transverse Shear for a Triangular Load

Unfractured Salt



Transverse Shear for a Triangular Load

Figure 2-9
Reactive Barrier Loads

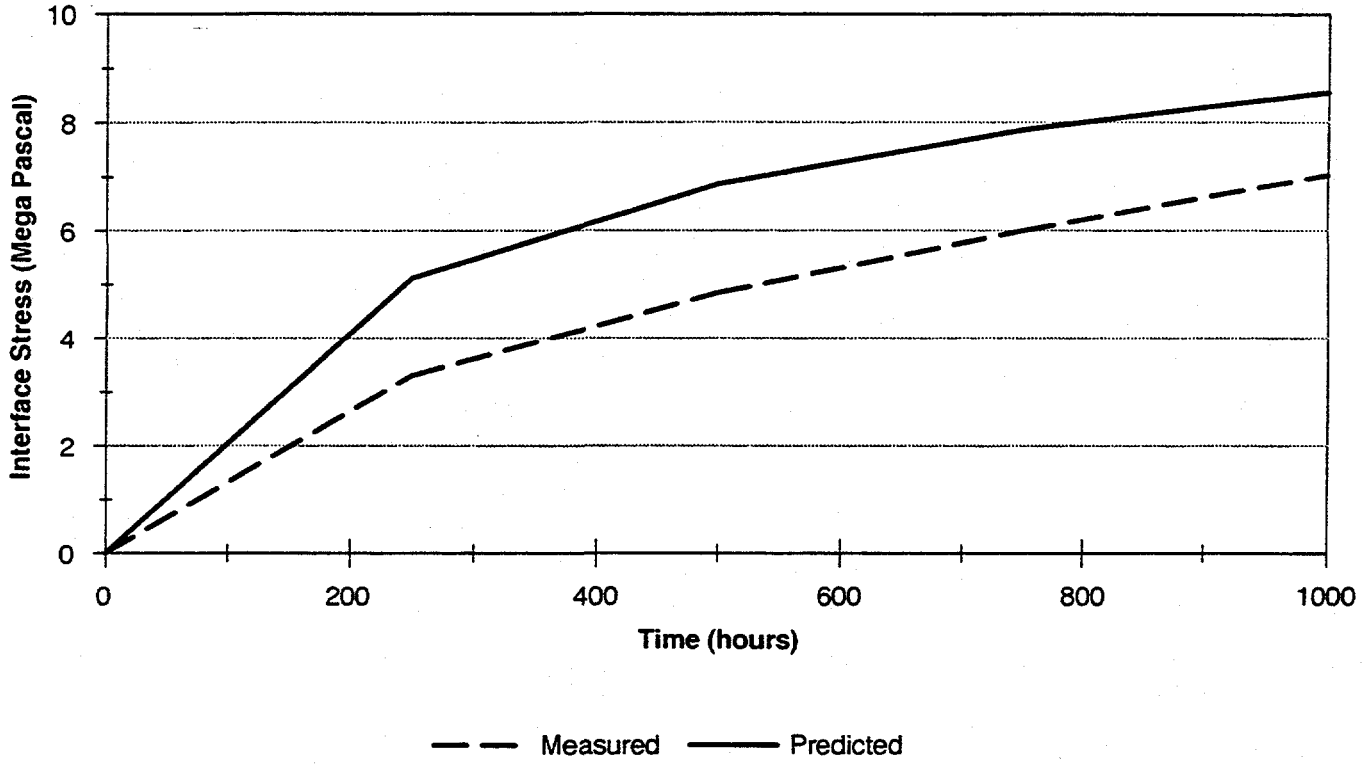


Figure 2-10
Development of Interface Stress in the Large 91-cm-Diameter Plug
(After Case and Kelsall, 1986)

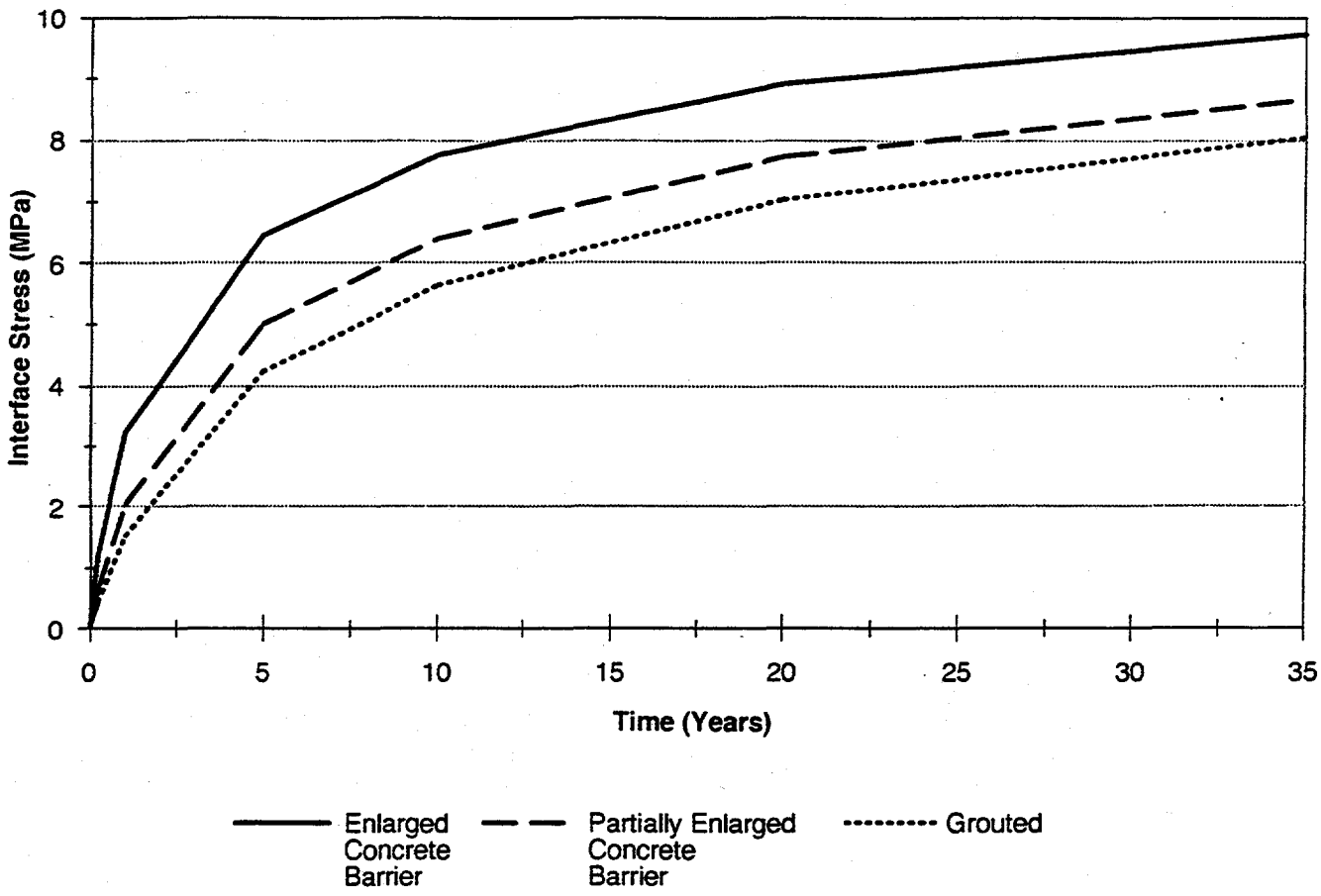


Figure 2-11
Effect of Enlarging Barrier on Interface Stress

partially enlarged concrete barrier with DRZ removal in the roof, and a fully enlarged barrier with complete DRZ removal. In all cases, the most severe ground conditions were considered. Existing information and the previous modeling efforts were combined to provide insight to the performance of the alternatives.

Bench-scale tests done by Terra-Tek showed the importance of interface zone permeability (Fernandez, et al., 1994). For sealed boreholes, flow occurs either through the seal matrix or through the interface zone. These tests showed that the "effective barrier permeability" for flow through the interface zone to be 1 to 2 orders of magnitude greater than the permeability of the plug material. This result supports the theory that the interface zone behaves like a fracture, in that at low effective stress levels, the interface opens and exhibits high conductivity. At higher stress levels, the interface closes and exhibits a much lower conductivity that is independent of effective stress. These studies suggest that the excavation of a more circular shape that reduces stress concentrations and the emplacement of a sufficiently strong barrier that would reduce shear stresses, and increase confining stresses at the interface zone is preferable.

The discussion presented above allows an evaluation of the compliance of the alternatives with the design migration limit and a qualitative evaluation of the effectiveness of the alternatives in light of the previous stress analyses performed. The stress analyses performed suggested that for the barrier with formation grouting, there is a greater potential for barrier flexure when fractures in the surrounding rock are present, and that the interface stress would develop more slowly because of the compliance of these fractures. This will then result in potentially higher VOCs flow through the interface zone, and reduced effectiveness. The development of lower interface stresses would result in lower confining stresses in the surrounding DRZ, and a slower rate of DRZ healing.

In evaluating the tradeoffs among the alternatives, it was noted that all three alternatives could be implemented. Technologies exist for the placement of a barrier with formation grouting (DOE, 1995). Further, methods are available for the excavation of an enlarged barrier with DRZ removal. Fernandez et al., 1989 evaluated various techniques for enlargement of barriers. These included the use of expansive agents, and hydraulic splitters in addition to the methods for continuous mining. The use of expansive agents could be used in the floor to excavate to below MB 139. While the use of these more labor intensive methods would take longer and make barrier emplacement more difficult, the techniques are

nevertheless available. The alternatives involving rock removal can be implemented in the underground WIPP repository.

In conclusion, the evaluations addressing the operational requirements of the panel-closure system show that, for the most severe ground conditions to be encountered, the maximum protection is provided when an enlarged concrete barrier is used. The severity of the ground conditions relate to the size and age of the air-intake and air-exhaust drifts, and the distance to the room intersections. The longer the time period between excavation, and panel closure, the greater the degree of fracturing that could occur. For example, the period of time for Panel 1 has been much longer than the four year period currently planned for other panels. Where the time between excavation and panel is short, fracturing may be absent or inconsequential, and the design can be simplified to a standard barrier with no DRZ removal.

2.2 Structural and Material Requirements

This section presents evaluations relating to the structural and material requirements for the panel-closure system.

2.2.1 Material-Compatibility Evaluations

The purpose of the material-compatibility evaluations is to select the most suitable concrete and grout materials for a panel-closure system. This section evaluates the concrete and grout compositions and their geochemical compatibility with the host rock and brine. This section also evaluates the geotechnical properties and permeabilities of a concrete/grout to liquid phase and gaseous phase contaminants (brine and VOCs, respectively).

2.2.1.1 Evaluation Procedure

Project information was reviewed for appropriate concrete-barrier materials that would minimize VOC migration and cement hydration for candidate materials.

2.2.1.2 Concrete-Barrier Material Candidates

The selection of candidate materials for use as concrete and grout in a panel-closure system requires that numerous criteria be satisfied in terms of the 35-year period of performance. The materials must be chemically compatible with the host rock and brine (Salado Formation) without chemical degradation. Concrete used in the main concrete barrier must be sufficiently strong enough to support lithostatic loads and resist the compressive stress of the creeping salt. The concrete must cure at a low heat of hydration. If the concrete evolves heat too rapidly (i.e., greater than 14 degrees celsius (°C) (25 degrees Fahrenheit [°F]), it may

experience rapid slump loss before hardening and excessive thermal stress after hardening. Slump loss directly affects the workability and pumpability of the concrete. The workability of the concrete must allow ample time and the pumpability must be adequate for installation. The most desirable characteristics for achieving adequate pumpability were a 4-hour working time (Wakeley et al., 1994). The concrete must perform under large-scale installation conditions. Grout must form a tight seal between the concrete barrier and the host rock.

Wakeley et al. (1993) studied and developed (Gulick and Wakeley, 1989) salt-saturated concrete and grout in the floor of the WIPP repository for six years (Appendix D). Then the concrete and grout plugs along with some host rock were overcored. The study concluded that little or no deterioration occurred to the concrete or grout. Overall the compressive strengths increased with time with the lowest values from samples taken in the DRZ. Reaction rims with increased permeability were noted on anhydrite surrounding the plugs, suggesting interaction between the grout or concrete and host rock. There was also evidence of halite dissolution in the anhydrite zone near the plugs; however, the presence of halite facilitated better bonding between the grout or concrete and the host rock. Crystallization of new phases was also noted on free surfaces, indicating that strongly ionic, magnesium-bearing fluids were present and moving. The movement of the fluid improved the bonding with the host rock.

Gulick and Wakeley (1989) proposed expansive salt-saturated concrete (ESC) (Appendix E) and grout mixtures that yielded favorable results for suitability in a panel-closure system. The formulation for their grout mixture is indicated in Table 2-3.

Table 2-3
Salt-Saturated Grout (BCT-1F)

Component	Percent of Total Mass
Class H cement	48.3
Class C fly ash	16.2
Cal seal® (plaster)	5.7
Sodium chloride	7.9
Dispersant	0.78
Defoamer	0.02
Water	21.1

Class H cement is a standard oil-well cement that has been used extensively in grouts and concretes in underground applications. Class C fly ash contributes expansive properties to concrete. Cal Seal® (a plaster of paris, manufactured by Halliburton) also develops expansive properties in mixtures containing Class H cement. Expansive components that are added to the concrete or grout mixtures enhance bonding with the host rock.

Wakeley et al. (1993) later researched concrete mixtures that would behave optimally under the type of large-scale installation conditions associated with the panel-closure system. The concrete mixture was also designed to keep the temperature due to heat of hydration less than 14°C (25°F). The concrete mixture that resulted from this study was termed the Salado Mass Concrete (SMC), and it superseded ESC as the performance mixture (Wakeley et al., 1993). Table 2-4 summarizes the SMC composition.

Table 2-4
Salado Mass Concrete

Component	Percent of Total Mass
Class H cement	4.93
Chem Comp III	2.85
Class F fly ash	6.82
Fine aggregate	33.58
Coarse aggregate	43.02
Sodium chloride	2.18
Defoaming agent	0.15
Sodium citrate	0.09
Water	6.38

Class F fly ash increases the aluminum content of the concrete mixture, which decreases the heat of hydration and increases the setting speed. A mixture of fine and coarse aggregate decreases the porosity of the concrete, and the fine aggregate contributes more silica over time.

For Class M cement and Class F fly ash addition of sodium chloride to the mixture ensures that the water content of the concrete is in equilibrium with the host rock to minimize dissolution, and inhibit deterioration of the concrete. The use of defoaming agents inhibit air entrainment in the concrete mixture.

Wakeley et al. (1994) studied under laboratory conditions the effects of various compositions of brines and concretes, including the SMC formulation. The study evaluated the susceptibility of concretes to chemical degradation by brines. Both pastes containing no aggregate, and mortars containing fine aggregate were formulated and tested in simulated brines containing magnesium and sulfate concentrations representing the brines at the repository horizon. The study concluded that high-magnesium brines exacerbated the deterioration of pastes and mortars; mortars deteriorated more rapidly than pastes. This study concluded that loss of calcium was the primary cause of weakened concrete materials. The use of salt in mortars with an expansive component slowed the rate of deterioration. These experiments were carried out under extreme experimental conditions unrepresentative of the trace amount of brine that will be encountered during large-scale installation of the concrete barriers.

2.2.1.3 VOC Interaction

Theoretically, if the pH of the VOCs is too low, it could negatively impact the structural integrity of the concrete barrier. The higher the VOC pH, the less likelihood for physical degradation of the concrete barrier. Using a portland cement with a pH greater than 12 should ensure the integrity of the concrete barrier.

2.2.1.4 Cement Hydration

Mathewson (1981) reported that the aggregate mineralogy significantly affects the curing/hydrating process by generating heat and alkali fluids, which can have deleterious effects on the strength of the concrete. Minerals susceptible to an alkali-aggregate reaction are hydrated silicates, opaline shale, chert, siliceous limestones, rhyolite, and dacite. Nonreactive minerals include quartz, feldspar, calcite, and the ferromagnesium minerals.

2.2.1.5 Conclusions

Previous studies suggest the application of the SMC to the design of the panel-closure system. This concrete possesses characteristics of low heat of hydration and workability. Because of the trace amounts of brine and the impermeable nature of the concrete, a standard concrete with a low heat of hydration and similar workability was considered acceptable. Therefore,

the design specifies a plain cement concrete mix that must be verified with testing. The cement will be Portland cement, type II modified, with pozzalan or type IV, to limit the heat of hydration of the resultant mix.

2.2.2 Heat-Generation Evaluations

Heat-generation studies evaluated the effects of the heat of hydration for the installation of the concrete barrier. The curing of concrete is facilitated by hydration in that the water present in the mixture reacts with calcium and silica to incorporate water into the resulting mineral phase. This process is an exothermic reaction, resulting in a temperature increase in the concrete barrier and host rock. This temperature increase causes a thermal expansion of the concrete barrier and increases the interface stress. As the concrete cools, the interface stress decreases, and tensile strain may occur at the interface.

2.2.2.1 Evaluation Procedure

The one-dimensional radial numerical and analytical model SHAFT.SEAL (Case et al., 1992) solves for temperature and stress as a function of radial position, in either the barrier or the surrounding host rock. The model uses the implicit finite-difference method (Carnahan et al., 1990) to analyze the temperature rise and fall following completion of the hydration. The model assumes radial conductive heat transfer to the surrounding host rock.

The analysis used thermal and thermomechanical properties from previous modeling efforts (Case and Kelsall, 1986; Van Sambeek and Stormont, 1987). The proposed concrete mixture exhibits a double-humped hydration curve (Figure 2-12) (Van Sambeek and Stormont, 1987). The first "hump" results from a reaction that occurs shortly after the mixing of the concrete. The double-hump manifestation in the temperature-versus-time data of the expansive salt-based concrete reduces the maximum temperature by increasing the time over which the hydration takes place. This is beneficial in large volumes of concrete where the dissipation of heat in the interior of the concrete barrier is slow. The analyses used input properties for the candidate material as determined from laboratory studies (Van Sambeek and Stormont, 1987), with modifications made to account for a reduced heat of hydration for the SMC. Table 2-5 summarizes the properties used in the analysis. The placement temperature was selected at ambient temperature.

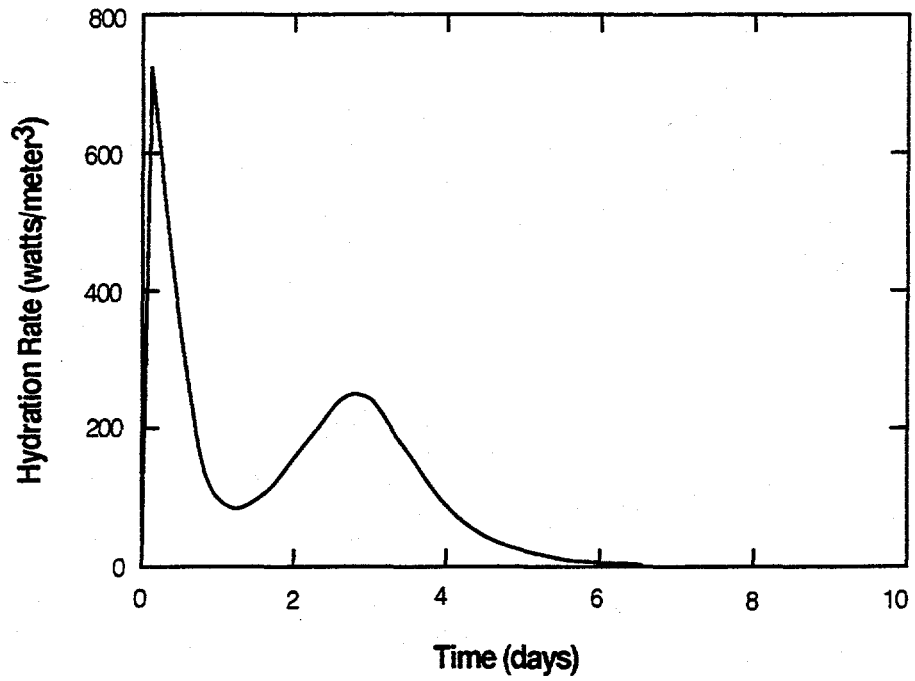


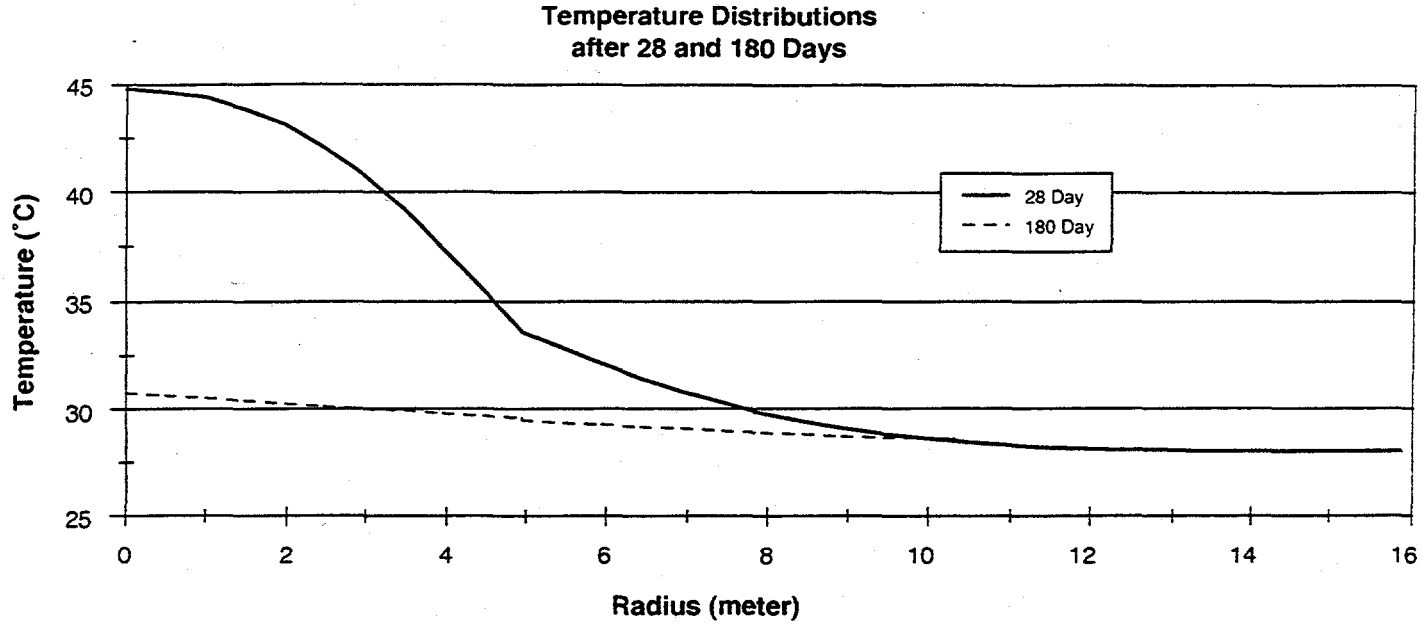
Figure 2-12
Heat of Hydration for Expansive Salt Concrete
(After Van Sambeek and Stormont, 1987)

Table 2-5
Thermal and Thermomechanical Properties for SHAFT.SEAL Analysis

Property	Value
Barrier properties: Plug diameter	 10 meters
Concrete placement temperature	28°C
Concrete Properties: Specific heat Thermal conductivity Density Young's Modulus Poisson's ratio Thermal expansion coefficient	 980 joules/(kilogram-Celsius) 2.1 watts/(meters-Celsius) 2,280 kilograms/cubic meter 28,000 MPa 0.20 12.6×10^{-6} 1/°C
Rock properties: Specific heat Thermal conductivity Density Rock temperature Young's Modulus Poisson's ratio Thermal expansion coefficient	 860 joules/(kilogram-Celsius) 4.94 watts/(meters-Celsius) 2,300 kilograms/cubic meter 28°C 31,000 MPa 0.25 45.0×10^{-6} 1/°C

2.2.2.2 Modeling Results

The modeling results include the temperature and stress distributions in the concrete barrier and the surrounding host rock at various times (Figure 2-13). The thermal analysis shows that temperatures initially rise uniformly due to cement hydration, maintaining a high radial thermal gradient within the interface zone. Thermal gradients decreased with time as hydration nears completion, and the heat thermally diffuses to the surrounding rock. After 28 days, temperatures rose to about 45°C (102°F), inducing a thermal gradient and thermal stress at the interface zone. After this time, the temperatures fell and approached the in situ rock temperature after an additional 28 days. The temperatures suggest that the heat pulse will be short and that the placement of the concrete, combined with the high thermal diffusivity of the salt, will control hydration temperatures to an acceptable level. The stress analysis suggests that tensile stress in the concrete will be offset by the rapid buildup of compressive stress, due to salt creep of the host rock.



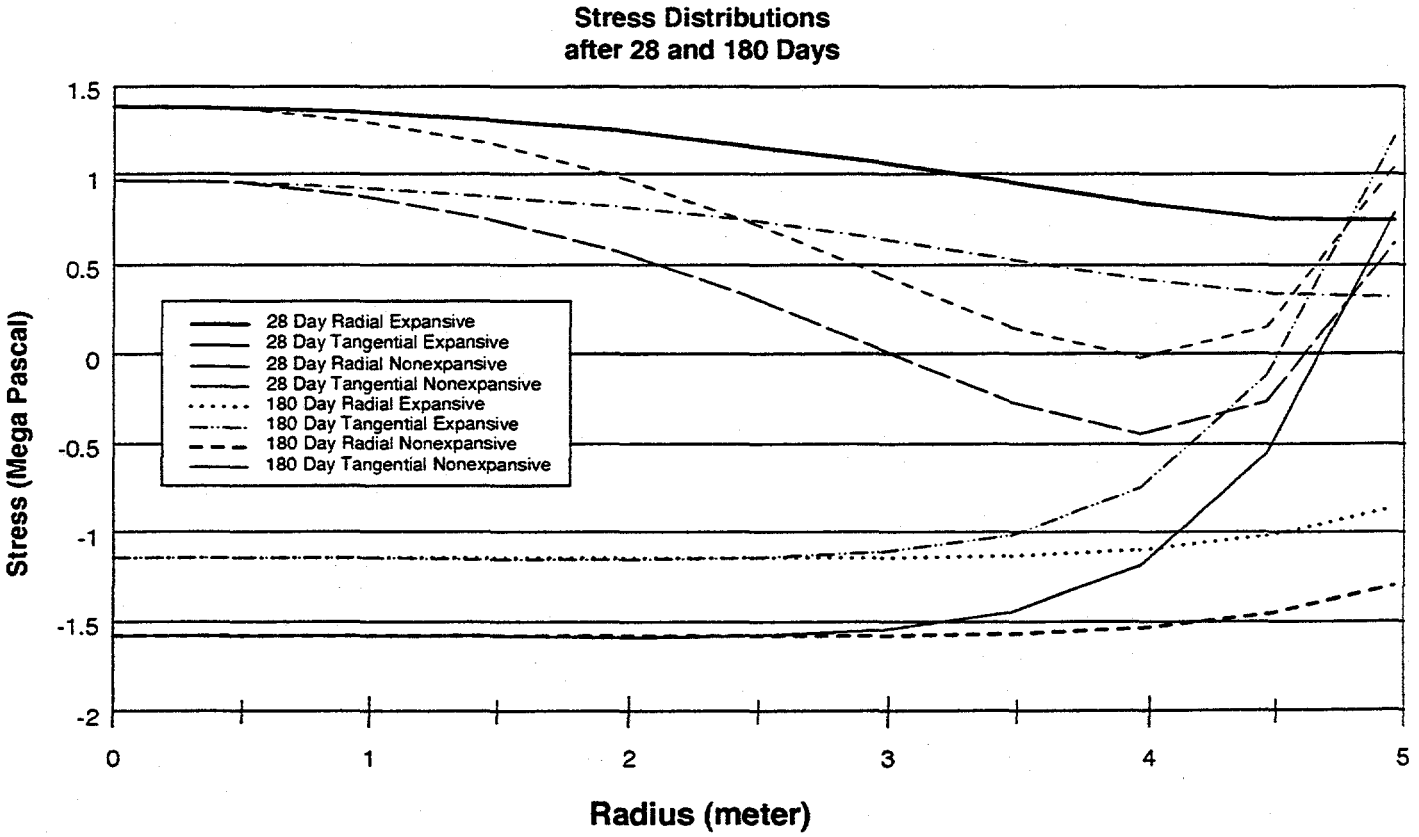


Figure 2-13
Temperature and Stress Distributions for Concrete Barrier

2.2.2.3 Conclusions

Hydration temperatures will be controlled through the selection of an appropriate concrete to reduce the potential for tensile cracking and separation at the interface zone. A thermal analysis using information on the heat of hydration of the concrete coupled with a salt-creep analysis suggests that, for the size of pour, placing the concrete at ambient temperature will control hydration temperatures. Finally, because steel formwork will be used during installation, such formwork will conduct heat away from the face of the concrete and thereby cool the concrete.

2.2.3 Explosion Evaluations

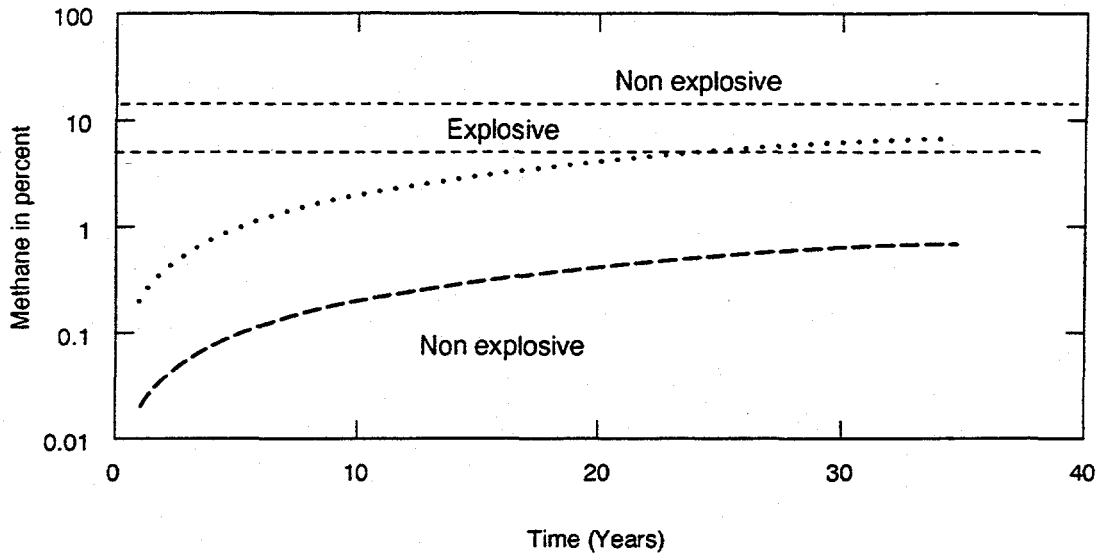
The methane-explosion evaluation focused on the pressure and thermal effects of such an explosion on the explosion-isolation wall. The DOE (1995) suggests that gas-generation rates, due to microbial degradation, might range from 0.01 to 0.1 moles per drum per year, with methane comprising 70 percent of the gas. It is estimated that the potential for a methane explosion would not occur prior to closure of the first waste-emplacement panel for a gas generation rate of 0.1 moles per drum per year. Such an explosion could occur approximately 20 years after closure of the first panel. This time is determined by comparing the percent volume concentration to the explosive limits for methane as shown in Figure 2-14.

If the composition of the air in the closed panel were 18 percent oxygen, the explosive range will be from about 5 to 15 percent methane by volume. Above 15 percent methane, the atmosphere in an abandoned waste-emplacement panel would be "fuel rich" and would not be capable of sustaining an explosion. With a reduction in the amount of oxygen available, the explosive range narrows, and the potential will be nonexistent below a 12 percent oxygen composition.

A methane explosion would generate an initial pressure transient that would impinge on the explosion-isolation wall. Subsequently, temperatures would rise in the panel, as well as raise the temperature in the explosion-isolation wall.

2.2.3.1 Evaluation Procedure

Two analyses were conducted to evaluate methane-explosion effects: 1) a dynamic analysis, and 2) a thermal heat-transfer analysis of the explosion-isolation wall. After an explosion, the explosion-isolation wall would be subjected to short-term dynamic loading. The design pressure can be calculated as the maximum pressure times the dynamic load factor (Biggs, 1964). The dynamic load factor will depend on the shape of the pressure-time transient. An



Gas generation rate = 0.1 moles/drum/year .....

Gas generation rate = 0.01 moles/drum/year — — — —

Figure 2-14
Methane Concentrations in the Waste Panel Over Time
(After DOE, 1995)

explosion will result in a wave front that will rise instantaneously and then drop gradually. In this study, the transient pressure pulse is idealized as having an instantaneous rise and an exponential decay (Figure 2-15).

In the event of a hydrocarbon explosion: either (1) deflagration will result in a rapid rise of pressure, with no transition to a detonation, or (2) a detonation wave front will propagate as a supersonic shockwave. The transition to a detonation is a function of two parameters: (1) the methane concentration at the time of the explosion, and (2) the ability for a wave front to form. In underground excavations, the latter condition typically requires a reasonably long passage through which the combustion wave travels and transforms to a detonation. After 20 years, the open passage above the waste stack will be reduced in size, and it is unlikely that a long passage with an open geometry will exist. Further, individual rooms will be isolated by bulkheads at each end. Therefore, the dynamic analysis considers a deflagration.

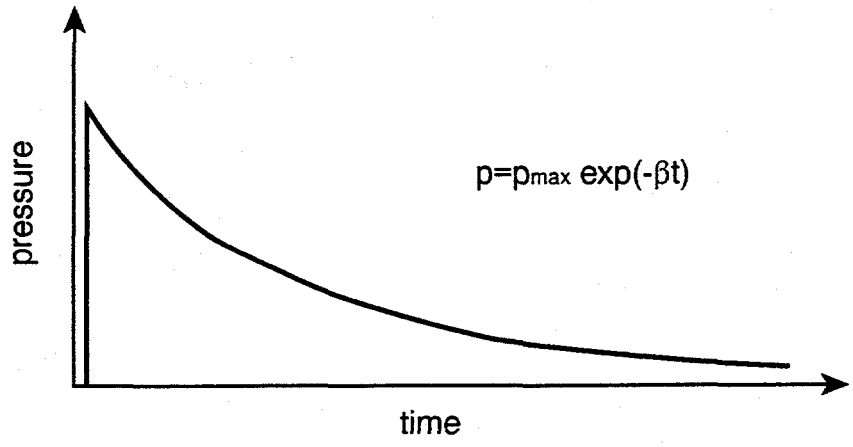
The second analysis involves a thermal analysis with a heat-transfer model (Appendix F). The heat-transfer model under the postulated explosion within the panel considers the heat balance between the gas and the walls of the panel for a stoichiometric mixture of methane. The rate at which the gas temperature will rise within the panel depends on (1) the number of moles of methane, (2) the specific heat capacity of the gas and the heat transfer to the salt and the walls through radiation, (3) convection along the vertical and horizontal surfaces, and (4) conduction within the salt and walls. Because the properties involved in the heat transfer analysis are temperature-dependent, a numerical model was run using the explicit finite difference method. The model provided the necessary information for evaluating thermal effects in selecting the size of the explosion-isolation wall.

2.2.3.2 Analysis Results

The peak explosive pressure was taken from the pressure rising from a deflagration that is about 8 times the ambient pressure (2 atmospheres) at the time of the explosion. This results in a peak pressure of 240 psi (1.7 MPa).[6]

The dynamic load factor will depend on the natural frequency of the explosion-isolation wall. The value for the dynamic load factor approaches a value of 2, with increased natural

[6]The analysis is conservative in that the presence of the waste drums would result in dampening of the explosion.



LEGEND

p = Pressure

p_{max} = Maximum pressure

t = Time

β = Shape factor for experimental curve

Figure 2-15
Pressure Pulse Versus Time

frequency for a variety of exponential curves (Figure 2-16). Based upon this loading, an explosion-isolation wall was designed to adsorb the energy from such an explosion.

The thermal-analysis results are presented in Figures 2-17 through 2-19. Figure 2-17 shows the gas temperature, the salt-wall temperature, and concrete wall temperature following the explosion. In the analysis, the gas reached a temperature of 2,500 Kelvin after about 20 seconds and then declined with time. The gas approached ambient temperatures after about 1.5 hours. Figures 2-18 and 2-19 show the temperature distribution as a function of distance into the walls. The results show that, at the initial time, the heat transfer from combustion gas to the salt and walls will result in a large temperature gradient at the wall. At later times, heat will be conducted through the wall, and the salt and the thermal gradient will be reduced. After 2 hours, the elevated temperature in the wall will propagate a maximum of 6 inches (15 cm) into the wall. Because the explosion-isolation wall is designed to resist creep deformation, temperature gradients will not significantly affect the stability of the wall.

2.2.3.3 Conclusions

The explosion-isolation wall was designed for a peak deflagration pressure of 240 psi (1.7 MPa) under pseudostatic conditions, with a dynamic load factor of 2.0. Because the explosion-isolation wall is designed to resist creep deformation, temperature gradients will not significantly affect the stability at the wall.

2.2.4 Fracture-Propagation Studies

The fracture-propagation studies evaluated the potential for fracture propagation, using the results of previous analyses. These analyses included a stress analysis and explosion evaluations.

2.2.4.1 Evaluation Procedure

The results of the thermal analysis suggest that elevated temperatures within an explosion-isolation wall and salt will be a localized phenomenon. During an explosion, which may potentially occur 20 years after closure of the first panel, two phenomena could affect the potential fracturing of the salt: (1) the expansion of the explosion products into existing fractures and (2) the potential reflection of sonic waves off free surfaces around the barrier. These effects were evaluated.

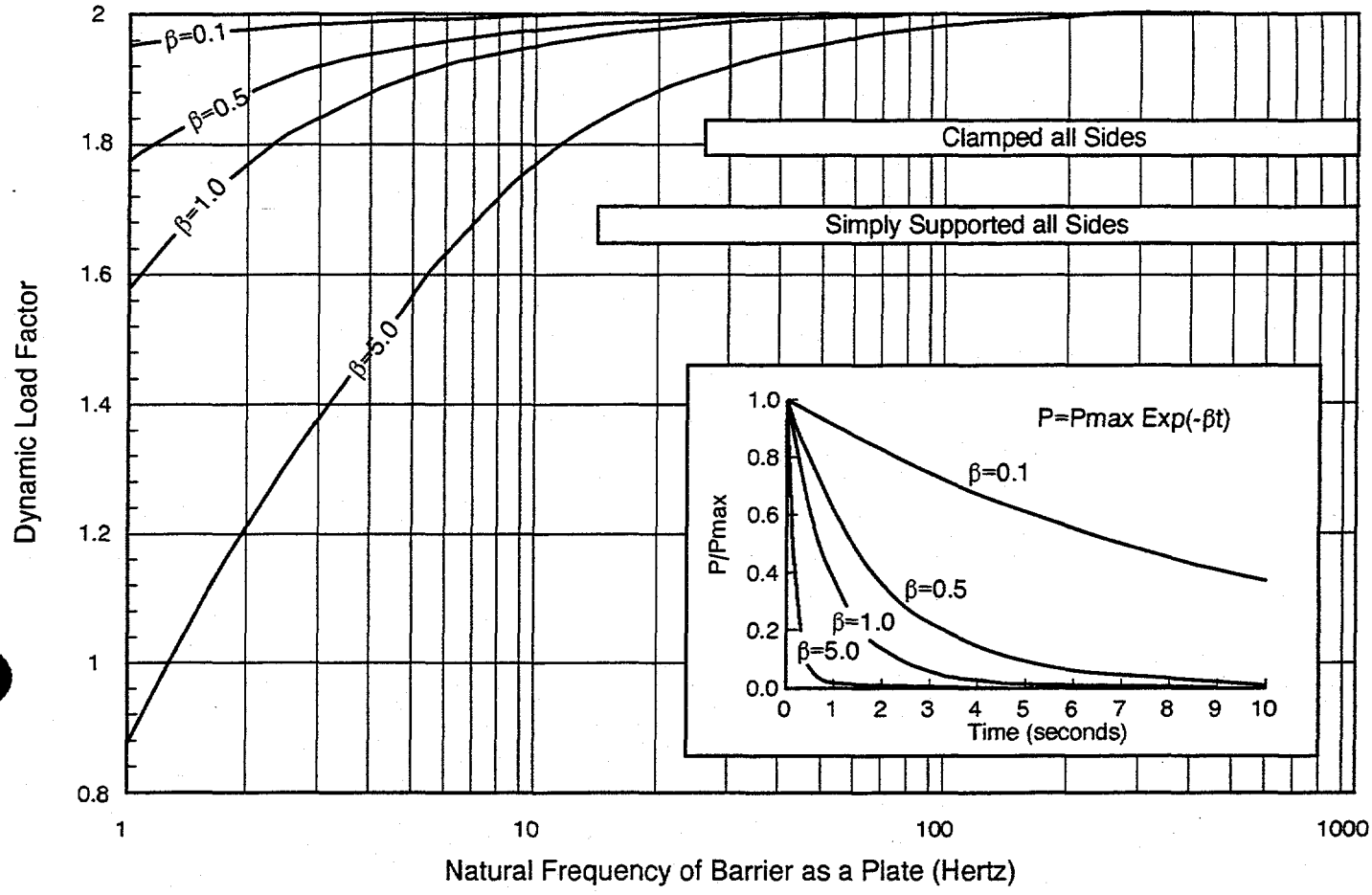


Figure 2-16
Dynamic Load Factor Versus Frequency of the Concrete Wall as a Plate

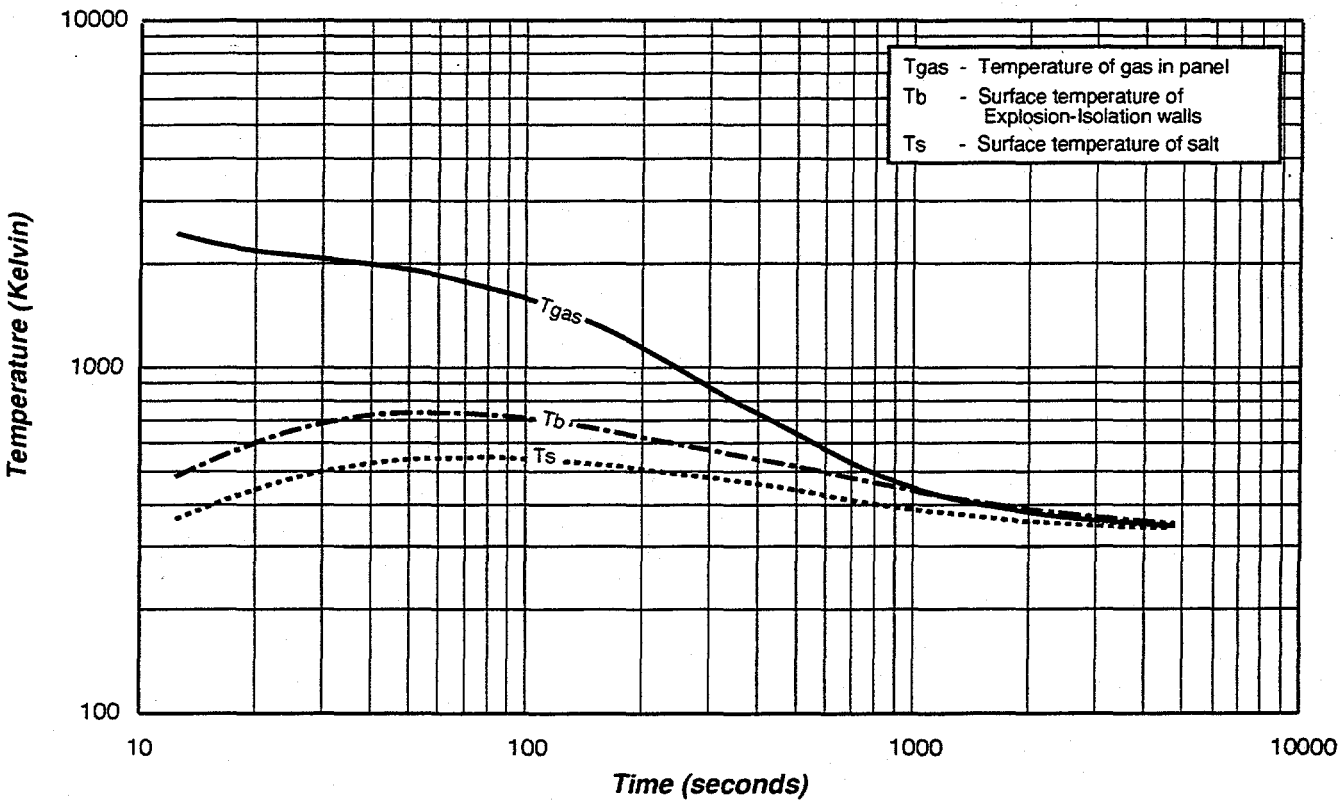


Figure 2-17
Temperature Variation with Time for Gas, Salt, and Explosion-Isolation Walls

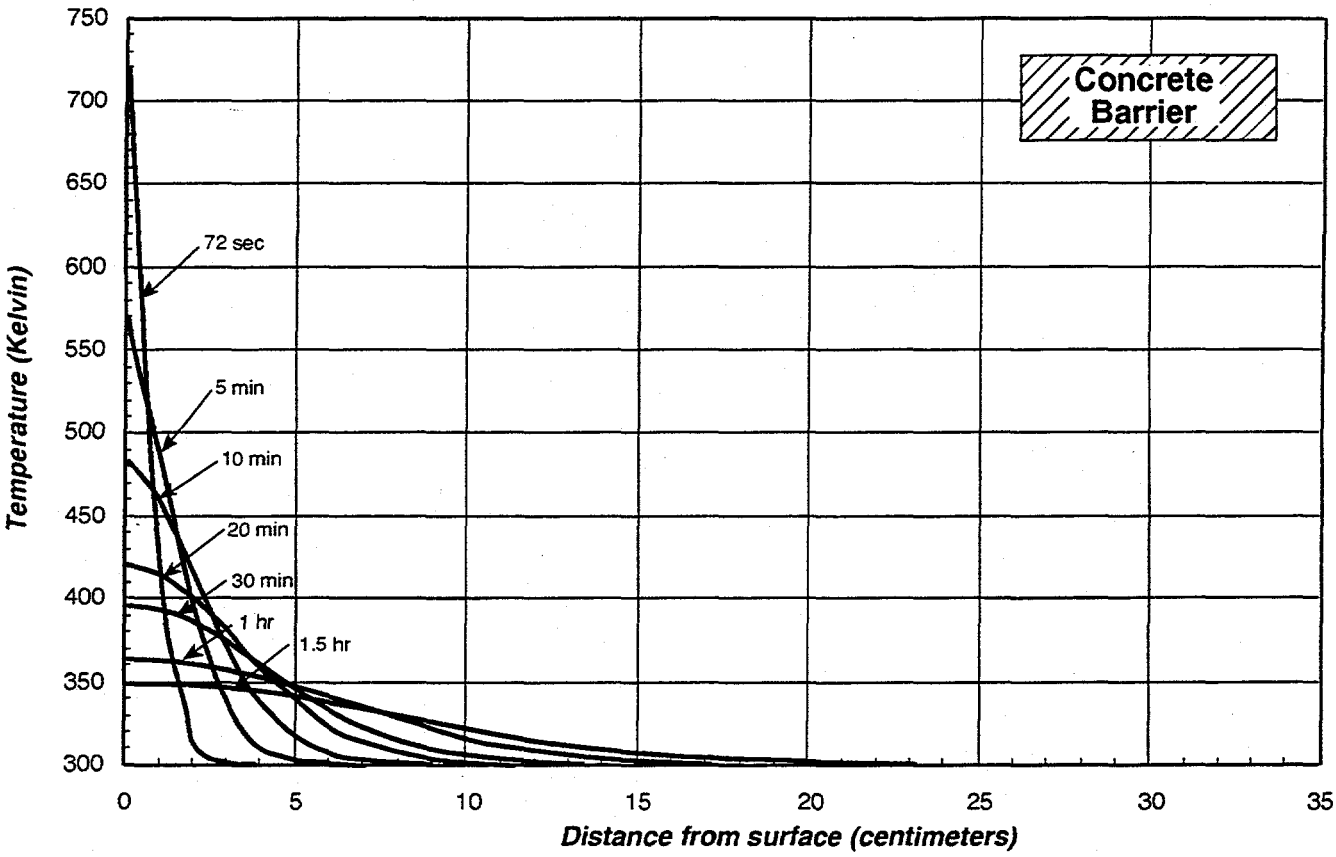


Figure 2-18
Temperature Distribution with Time for Concrete Barrier

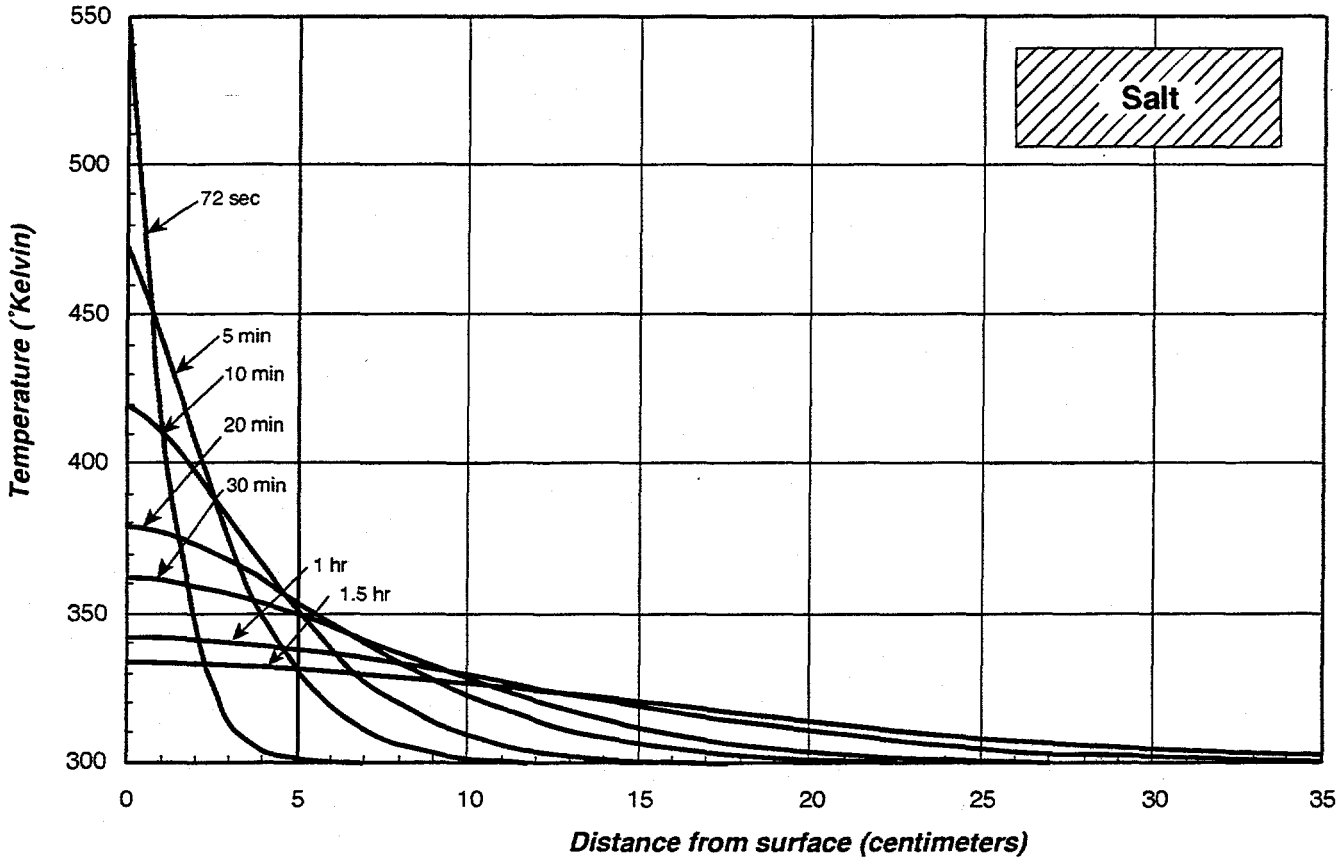


Figure 2-19
Temperature Distribution with Time for Salt

2.2.4.2 Evaluation Results

The fractures in the roof and floor could be affected by the expansion of the gas products on the order of 240 psi (1.7 MPa), which decay rapidly with time and attenuate with distance. Around the wall, the confining stress on the order of 1,450 psi (10 MPa) could develop after 20 years, as presented in Section 2.1.3. Horizontal fracture propagation could occur around the concrete barrier only if the internal gas pressure exceeded the confining pressure. Because the peak internal pressure from the deflagration is only about one-fifth of the confining pressure, fractures would not propagate through or around the main wall.

Following an explosion, the wall would be subject to sonic waves that would impinge on the wall. As the sonic wave encountered a contrast in wall stiffness, a portion of the sonic wave would be refracted, and a portion would be reflected (Jaeger and Cook, 1972). This would result in minor tensile spalling of the isolation wall.

2.2.4.3 Conclusions

At the time of a potential explosion, the development of confining stress relative to the explosion pressure would prevent fracturing around the main concrete barrier. With the selection of a thick enough wall, the effects of a postulated methane explosion can be isolated from the main concrete barrier.

3.0 Design Description

This chapter presents the final design selected from the evaluations performed in the previous chapter. It presents design modifications to cover a range of conditions that may be encountered in the underground and describes the design components for the panel-closure system. Finally, information is presented on the proposed construction for the panel-closure system.

3.1 Design Concept

The composite panel-closure system selected is (1) a standard concrete barrier, rectangular in shape, or (2) an enlarged tapered concrete barrier. Options (1) and (2) will be grouted along the interface and may contain explosion- or construction-isolation walls. Figure 3-1 illustrates these design components. The construction methods and materials to be used to implement the design have been proven in previous mining and construction projects. The standard concrete barrier without DRZ removal will most likely apply to future panel air-intake and air-exhaust drifts where the time duration between excavation and barrier emplacement is short. The enlarged concrete barrier with DRZ removal would apply to Panel 1 where a significant time lapse will occur between excavation and barrier emplacement. The design concept for the enlarged concrete barrier incorporates:

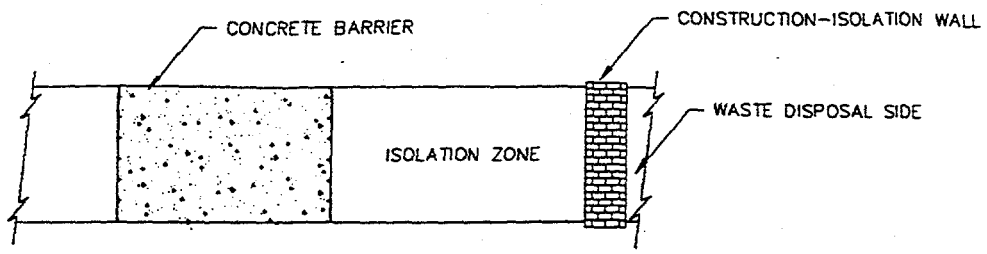
- A concrete barrier that is tapered to promote the rapid stress buildup on the host rock. The stiffness was selected to provide rapid buildup of compressive stress and reduction in shear stress in the host rock.

- The enlarged barrier requires DRZ removal just beyond Clay G and MB 139, and to a corresponding distance in the ribs to keep the tapered shape approximately spherical. The design includes DRZ removal and thereby limits VOC flow through the panel-closure system.

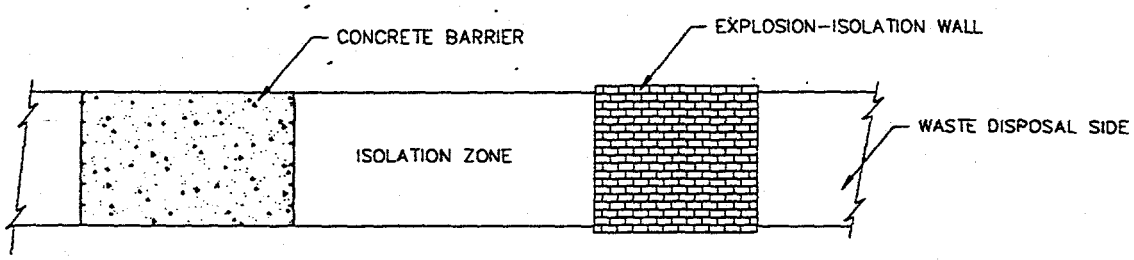
- The design of the panel-closure system includes either a construction- or an explosion-isolation wall designed to provide strength and deformational serviceability during the operational period. The length was selected to assure that uniform compression develops over a substantial portion of the structure and that end-shear loading that might result in fracturing of salt into the back is reduced.

3.2 Design Options

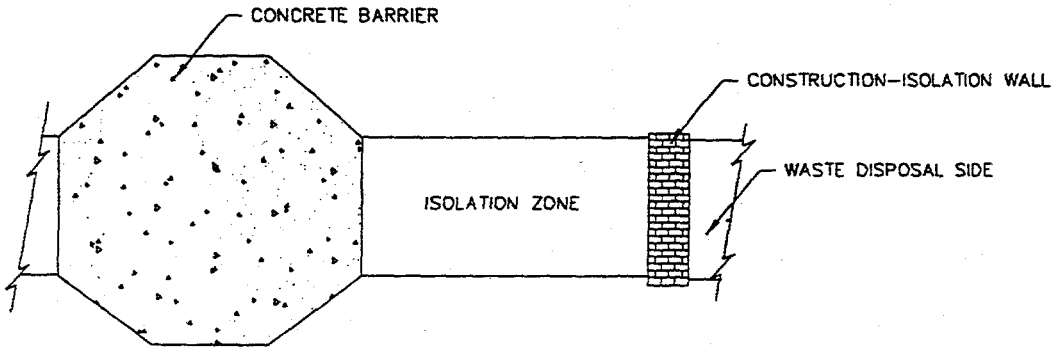
The design options consist of the following:



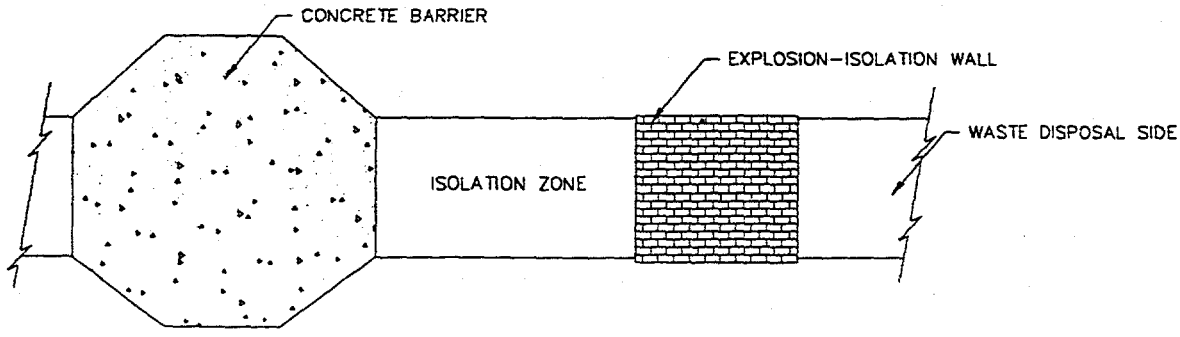
A. CONCRETE BARRIER WITHOUT DRZ REMOVED AND CONSTRUCTION ISOLATION WALL



B. CONCRETE BARRIER WITHOUT DRZ REMOVED AND EXPLOSION ISOLATION WALL



C. CONCRETE BARRIER WITH DRZ REMOVED AND CONSTRUCTION ISOLATION WALL



D. CONCRETE BARRIER WITH DRZ REMOVED AND EXPLOSION ISOLATION WALL

Figure 3-1
Main Concrete Barrier with Wall Combinations

- An enlarged concrete barrier with the DRZ removed and a construction-isolation wall
- An enlarged concrete barrier with the DRZ removed and an explosion-isolation wall
- A rectangular concrete barrier without the DRZ removed and a construction-isolation wall
- A rectangular concrete barrier without the DRZ removed and an explosion-isolation wall.

In each case, interface grouting will be used for the upper barrier/salt interface. The process for selecting these options would depend on the subsurface conditions at the panel-closure system locations described in the following subsections.

3.2.1 Selection of the Concrete Barrier

The design provides flexibility to satisfy the design migration limit for the flow of VOCs out of the panel. An enlarged concrete barrier will be selected where air-intake and air-exhaust drifts have fractured with age resulting in significant flow of VOCs. These conditions apply to the most severe ground conditions in the air-intake and air-exhaust drifts of Panel 1. If ground conditions are more favorable such as might be the case for future panel entries, then the panel-closure system can be simplified to a standard concrete barrier, rectangular in shape, with a construction-isolation wall.

Several methods are available for detecting the location and extent of fractures in the DRZ (DOE, 1995). These methods include ground-penetrating radar and observation boreholes, which have already been used for underground fracture detection at the WIPP (DOE, 1995). These methods will be used to determine when conditions are favorable, and the standard concrete barrier can be used to limit/restrict VOC flow.

The GPR methods and other exploratory methods show where fractures are minimal in order to select an optimum location for the panel-closure system. In such areas, the design can be simplified to a standard concrete barrier without DRZ removal. The area with the least number of fractures as determined by these exploratory methods would mean that compressive stresses increase on the standard concrete barrier. The effective concrete barrier permeability will be reduced with time as stresses increase on the standard concrete barrier.

GPR is a nondestructive electromagnetic reflection technique that is sensitive to variations in the dielectrical constant of rock salt. The use of GPR is a proven technology for detecting shallow fracture zones in the underground and will have practical value in determining the location of a panel-closure system (IT, 1993). GPR surveys perpendicular to the long axis and axial surveys of the drift would provide data to determine the optimum location for the main concrete barrier. Fractured rock will be removed as necessary for installation of the concrete barrier.

For future waste-emplacement panels, GPR will be used to monitor fracture development. Radar surveys could be conducted shortly after excavation to provide a baseline with which to compare future radar surveys. GPR will be used periodically to monitor the development of brittle deformation occurring in the new air-intake and air-exhaust drifts.

Observation boreholes will be drilled into the roof or floor of the new air-intake and air-exhaust drifts and will be used for observation of fractures and bed separation. Observations can be made in the boreholes using a small video camera, or a scratch rod. A scratch rod survey will be performed in accordance with the current Excavation Effects Program (EEP) procedure.

The EEP was initiated in 1986 with the occurrence of fractures in Site and Preliminary Design Validation Room 3. The purpose of the EEP is to study fractures that develop as a result of underground excavation at the WIPP and to monitor those fractures. Borehole inspections have been successful for determining the fracturing and bed separation in the host rock. These inspections have been performed since 1983 (Francke and Terrill, 1993). This technique in addition to the above will be used to determine the optimum location for the panel-closure system.

3.2.2 Selection of an Explosion- or Construction-Isolation Wall

While no requirements for barricading waste areas exist under the MSHA, the intent of the regulations is to safely isolate abandoned areas from active workings using barricades of "substantial construction." The previous analysis (DOE, 1995) examined the issue of methane gas generation from TRU waste and its potential consequence in closed areas. The principal concern is the occurrence of an explosive mixture of methane and an ignition source, which would result in deflagration. If a methane explosion is considered possible, an explosion-isolation wall of sufficient thickness will be used to resist dynamic and creep loads. In the absence of explosive conditions, a construction-isolation wall will be used.

3.3 Design Components

The following subsections present system and components design features.

3.3.1 Concrete Barrier

The enlarged concrete barrier consists of plain concrete, with sufficient unconfined compressive strength and with an approximately circular cross-section excavated into the salt over the central portion of the barrier (Figure 3-2). The enlarged concrete barrier will be located at the optimum locations in the air-intake and air-exhaust drifts with the central portion extending just beyond Clay G and MB 139.

The enlarged concrete barrier will be placed in four cells, with construction joints perpendicular to the direction of potential air flow. The concrete strength will be selected according to the standards specified by the latest edition of the ACI code for plain concrete. The concrete will be placed through 6-inch- (15-cm)-diameter steel pipes and vibrated from outside the formwork. The formwork is designed to withstand the hydrostatic loads during construction, with minimal bracing onto exposed salt surfaces. This will be accomplished by placing a series of steel plates that are stiffened by angle iron, with load reactions carried by spacer rods. The spacer rods will be staggered to reduce potential flow along the rod surfaces through the barrier. Some exterior bracing will be required when the first cell is poured. All structural steel will be ASTM A36, with detailing, fabrication, and erection of structural steel in conformance with the latest edition of the AISC steel manual (AISC, 1989). After concrete placement, the formwork will be left in place.

The above design is for the most severe conditions expected to be encountered at the WIPP. If actual conditions are found to be more favorable (i.e., if the age of the entries at the time of emplacement is less, and if the fractured DRZ does not develop, or there is adequate design margin for the flow of VOCs), the design can be simplified to a rectangular barrier without DRZ removal (Figure 3-3).

3.3.2 Explosion- and Construction-Isolation Walls

An explosion-isolation wall, consisting of concrete-blocks, will mitigate the effects of a postulated methane explosion. The explosion-isolation wall consists of 3,500-psi (24-MPa) concrete blocks mortared together with cement (Figure 3-4).

The concrete block wall design complies with MSHA requirements (MSHA, 1987) because it uses incombustible materials of substantial construction. The explosion-isolation wall will be

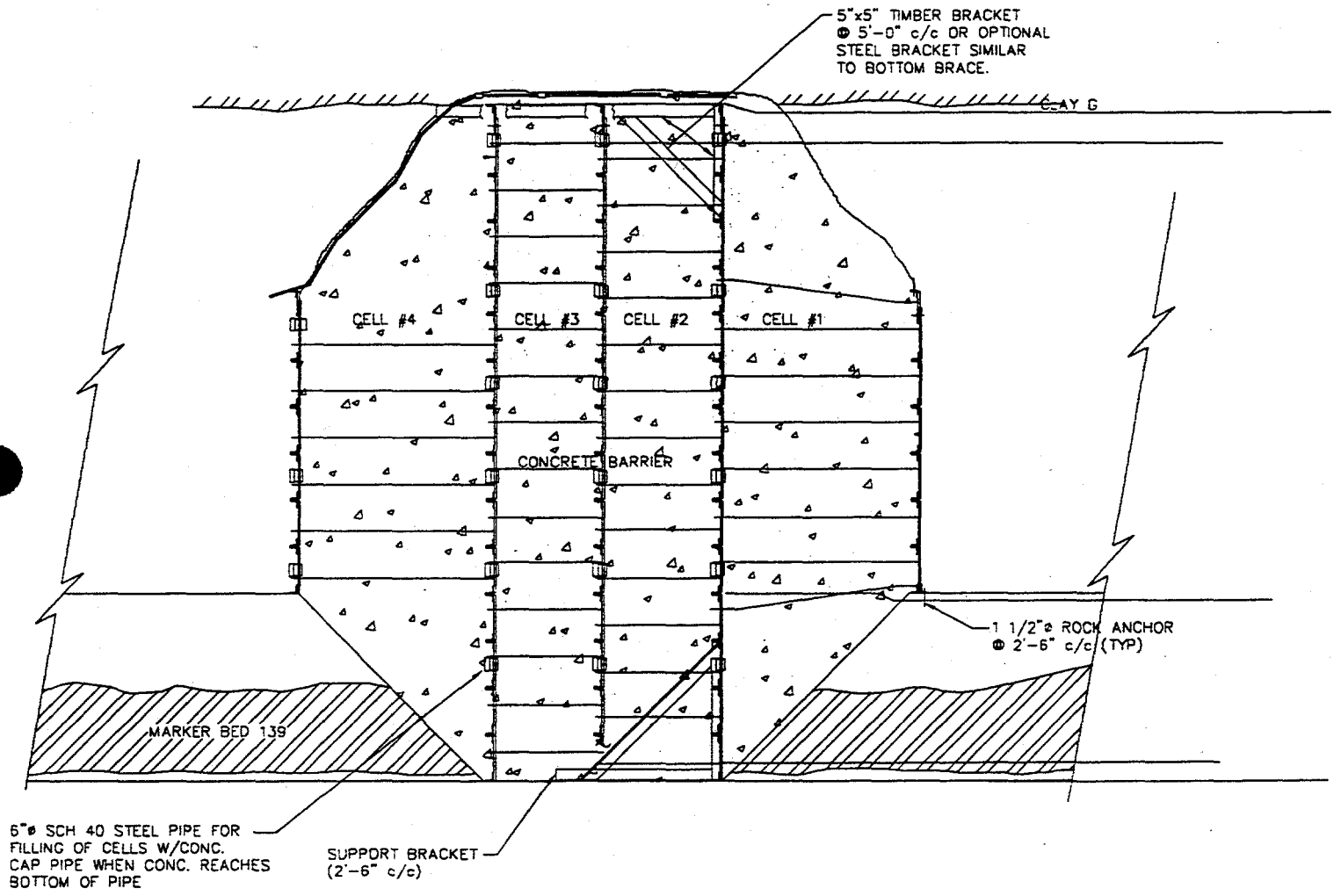


Figure 3-2
Concrete Barrier with DRZ Removal

placed into the salt for support. The explosion-isolation walls are designed to resist creep loading from salt deformation. In the absence of the postulated methane explosion, the design will be simplified to a construction-isolation wall. The construction-isolation wall design provides temporary isolation during the time the main concrete barrier is being constructed.

3.3.3 Interface Grouting

After construction of the main concrete barrier, the interface between the main concrete barrier and the salt will be grouted through a series of grout-supply and air-return lines that will terminate in grout distribution collection boxes. The openings in these boxes will be protected during concrete placement (Figure 3-5). The grout boxes will be mounted near the top of the barrier. The grout will be injected through one distribution system, with air and return grout flowing through a second distribution system.

3.4 Panel-Closure System Construction

The construction methods and materials to be used to implement the design have been proven in previous mining and construction projects. The design uses common construction practices according to existing standards. The proposed construction sequence follows completion of the waste-emplacement activities in each panel: (1) Perform subsurface exploration to determine the optimum location for the panel closure system, (2) select the appropriate design option for the location, (3) prepare surfaces for the construction- or explosion-isolation walls (if required), (4) install these walls, (5) excavate for the enlarged concrete barrier (if required), (6) install concrete formwork, (7) emplace concrete for the first cell, (8) grout the completed cell, and (9) install subsequent formwork, concrete and grout until completion of the enlarged concrete barrier.

The explosion-isolation or construction-isolation walls will be located at some distance from the main concrete barrier. The host rock will be excavated 6 inches (15 cms) around the entire perimeter prior to installing the explosion-isolation wall. The surface preparation will produce a level surface for placing the first layer of concrete blocks. Excavation may be performed by either mechanical or manual means.

Excavation for the enlarged concrete barrier will be performed using mechanical means, such as a cutting head on a suitable boom. The existing roadheader at the main barrier location in each drift is capable of excavating the back and the portions of the ribs above the floor level. Some manual excavation may be required in this situation as well. If mechanical means are not available, drilling boreholes and an expansive agent can be used to fragment the rock

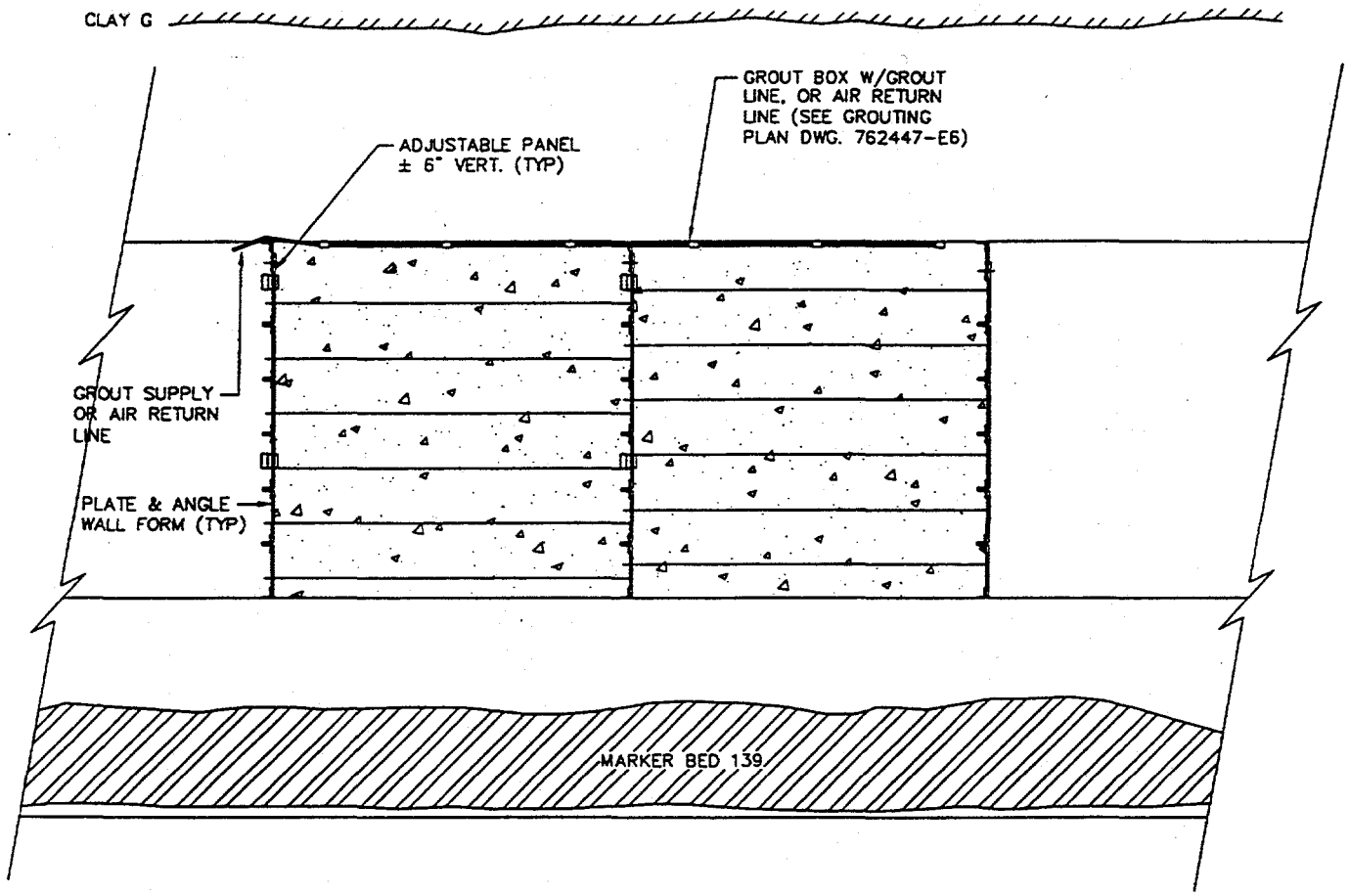


Figure 3-3
Concrete Barrier Without DRZ Removal

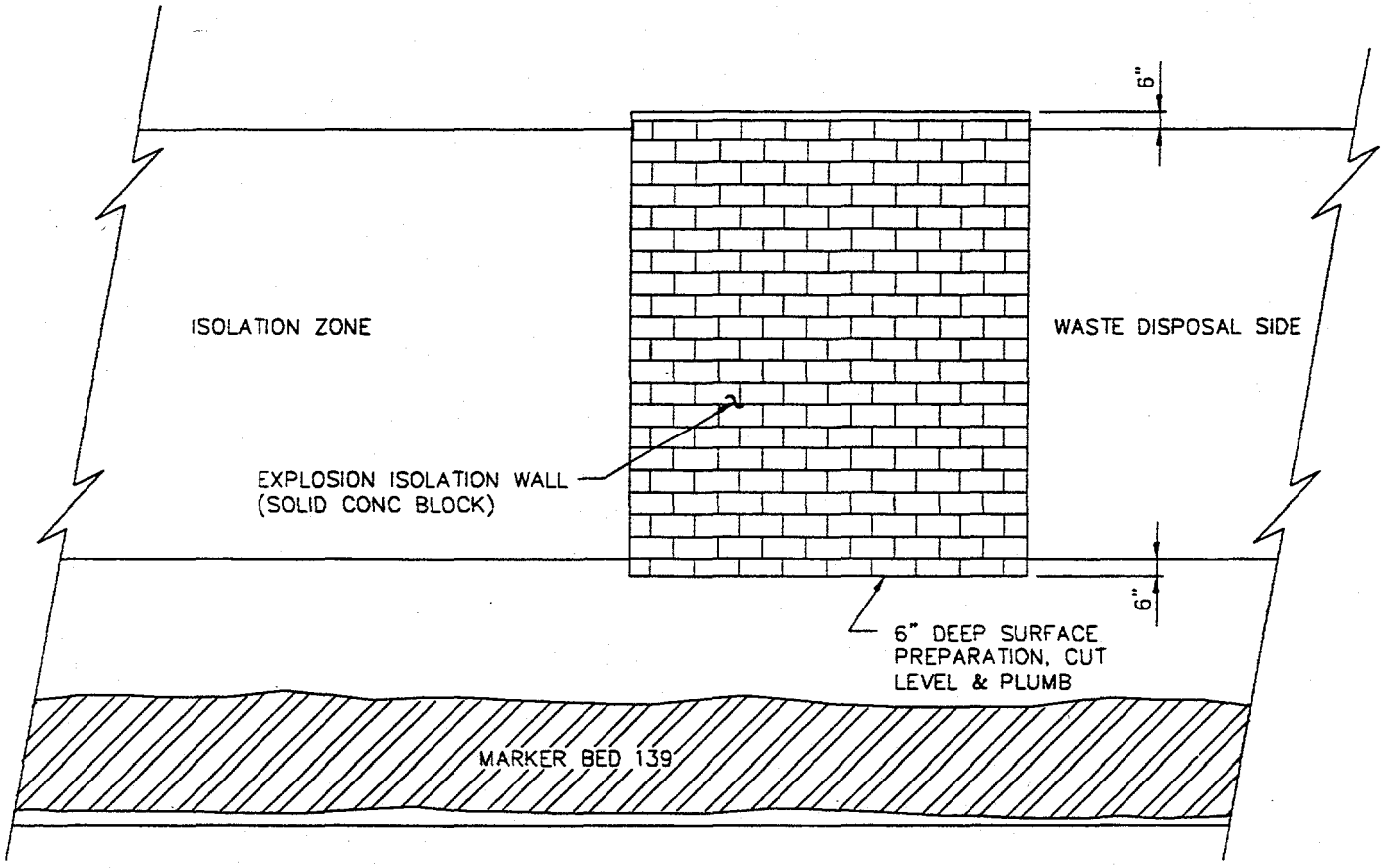
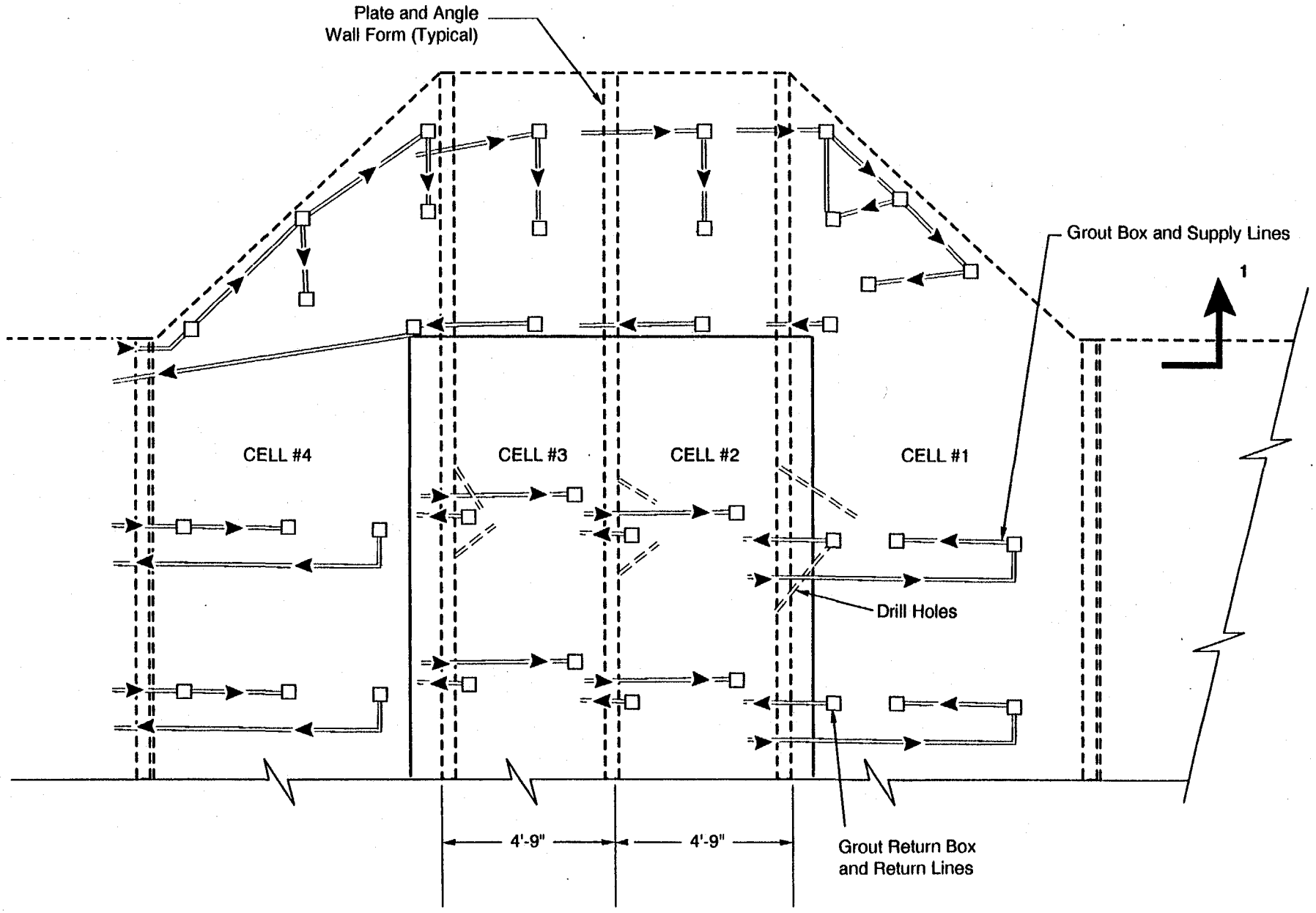


Figure 3-4
Explosion-Isolation Wall



Plan View of an Enlarged Bulkhead

Figure 3-5
Grouting Details

(Fernandez et al., 1989). Excavation will follow the lines and grades established for the design. The roof will be excavated to just above Clay G and then the floor to just below MB 139 to remove the DRZ. The tolerances for the enlarged concrete-barrier excavation are +6 to 0 inches (+15 to 0 cm). In addition, loose or spalling rock from the excavation surface will be removed to provide an appropriate surface abutting the enlarged concrete barrier. The excavations will be performed according to approved ground control plans.

Following completion of the roof excavation for the enlarged barrier, the floor will be excavated. If mechanical means are not available, drilling boreholes and using an expansive agent to fragment the rock (Fernandez et al., 1989) is a method that can be used. Expansive agents would load the rock salt and anhydrite, producing localized tensile fracturing in a controlled manner, to produce a sound surface.

A batch plant at the surface or underground will be prepared for batching, mixing, and delivering the concrete to the underground in sufficient quantity to complete placement of the concrete within one form cell. The placement of concrete will be continuous until completion, with a target time for completing one section of 8 to 10 hours, allowing an additional 2 hours for cleanup of equipment.

Pumping equipment suitable for placing the concrete into the forms will be provided at the main concrete barrier location. After transporting, and prior to pumping, the concrete will be remixed to compensate for segregation of aggregate during transport. Batch concrete will be checked at the surface at the time of mixing and again at the point of transfer to the pump for slump and temperature. Admixtures may be added at the remix stage in accordance with the batch design.

4.0 Design Calculations

Table 4-1 summarizes calculations to support the construction details for an explosion-isolation wall, construction-isolation wall, and structural steel formwork for concrete barriers up to a 29-ft high. The codes for the explosion-isolation and construction-isolation wall are specified by the Uniform Building Code (International Conference of Building Officials, 1994), with related seismic design requirements. The external loads for the solid block wall are as developed in the methane-explosion and fracture propagation design evaluations.

Table 4-1
Constructability Design Calculations Index

Section	Design Area	Category
1.0	Explosion-isolation wall	W
2.0	Explosion-isolation wall seismic check	S
3.0	Formwork design	F

The structural formwork for all cells is designed in accordance with the AISC guidelines on allowable stress (AISC, 1989). Lateral pressures are developed using ACI 347R-88, using a standard concrete weighing 150 pounds per cubic foot (2,410 kg/m^3) with a slump of 8 inches (20 cm) or less. Design loadings reflect full hydrostatic head of concrete, with lifts spaced at 4 ft (1.2 m) intervals from bottom to top through portals, with no external vibration. All forms will remain in place.

5.0 Technical Specifications

The specifications are in the engineering file room at the WIPP and are the property of Westinghouse WID. These specifications are included as an attachment in Appendix G and summarized in Table 5-1.

Table 5-1
Technical Specifications for the WIPP Panel-Closure System

Division 1 - General Requirements	
Section 01010	Summary of Work
Section 01090	Reference Standards
Section 01400	Contractor Quality Control
Section 01600	Material and Equipment
Division 2 - Site Work	
Section 02010	Mobilization and Demobilization
Section 02222	Excavation
Section 02722	Grouting
Division 3 - Concrete	
Section 03100	Concrete Formwork
Section 03300	Cast-in-Place Concrete
Division 4 - Masonry	
Section 04100	Mortar
Section 04300	Unit Masonry System

6.0 Drawings

The drawings (Appendix H) are in the engineering file room at the WIPP and are the property of the Westinghouse WID and summarized in Table 6-1.

Table 6-1
Panel-Closure System Drawings

Drawing Number	Title
762447-E1	Title Sheet
762447-E2	Underground Waste Disposal Plan
762447-E3	Air Intake Drift Construction Details
762447-E4	Air Exhaust Drift Construction Details
762447-E5	Construction and Explosion Barrier Construction Details
762447-E6	Grouting and Miscellaneous Details

7.0 Conclusions

This chapter presents the conclusions for the detailed design activities of the panel-closure system. A design basis, including the operational requirements, the structural and material requirements, and the construction requirements, was developed that addresses the governing regulations for the panel-closure system. Table 7-1 summarizes the design basis for the panel-closure system and the compliance with the design basis. The panel-closure system design incorporates mitigative measures to address the treatment of fractures and therefore counter the potential migration of VOCs. Several alternatives were evaluated for the treatment of fractures. These included excavation and emplacement of a fully enlarged barrier with removal of the DRZ, excavation of the roof and emplacement of a partially enlarged barrier, and emplacement of a standard barrier with formation grouting.

To investigate several key design issues and to implement the design, design evaluations were performed. These design evaluations can be divided into evaluations satisfying the operational requirements of the system and evaluations satisfying the structural and materials requirements of the system. The conclusions reached from the evaluations addressing the operational requirements are as follows:

- Based on an air-flow model used to predict the mass flow rate of carbon tetrachloride through the panel-closure system for the alternatives, the air-flow analysis suggests that the fully enlarged barrier is the most protective for restricting VOCs during the operational period of 35 years.

- Results of the FLAC analyses show that the recommended enlarged configuration is a circular rib-segment excavated to Clay G and under MB 139. Interface grouting would be performed at the upper boundary of the concrete barrier.

- The results of the transverse plane-strain models show that high stresses would form in MB 139 following excavation, but that after installation of the panel-closure system, an increase in barrier-confining stress and a reduction in shear stress would result. The concrete barrier would provide substantial uniform confining stresses as the barrier is subjected to secondary salt creep.

- The removal of the fractured salt prior to installation of the main concrete barrier would reduce the potential for flexure. With the removal of MB 139, the fractured salt stiffens the surrounding rock and results in the development of more uniform compression.

Table 7-1
Compliance of the Design with the Design Requirements

Type of Requirement	Requirement	Section	Compliance with Requirement	Notes on Compliance
Operational	Individual panels shall be closed in accordance with the schedule of actual waste emplacement.	2.1.1	Complies	Gas-flow models used for design are based on the waste-emplacement operational schedule.
	The panel-closure system shall provide assurance that the limit for the migration of volatile organic compounds (VOC) of concern will be met at the point of compliance. To achieve this assurance, the design shall consider the potential flow of VOCs through the several components of the disturbed rock zone and the panel-closure system.	2.1.1, 2.1.2	Complies	Gas-flow modeling shows that the VOC flow is less than the design migration limit.
	The panel-closure system shall comply with its intended functional requirements under loads generated from creep closure and any internal pressure that might develop in the disposal panel under reasonably anticipated conditions.	2.1.2, 4.0	Complies	Stress analyses and design calculations show that the panel-closure system performs as intended.
	The panel-closure system shall comply with its intended functional requirements under a postulated methane explosion.	2.2.3, 2.2.4, 4.0	Complies	The methane explosion studies, fracture propagation studies, and supporting design calculations show that the panel-closure system performs as intended.
	The operational life of the panel-closure system shall be at least 35 years.	2.1.1	Complies	Gas-flow modeling and analyses shows satisfactory performance for at least 35 years.
	The panel-closure system for each individual panel shall not require routine maintenance during its operational life.	3.2	Complies	Passive design components require no routine maintenance.
	The panel-closure system shall address the most severe ground conditions expected in the panel entries. If actual conditions are found to be more favorable, this design can be simplified and still satisfy the operational requirements of the system.	2.1.1 2.1.3 3.2	Complies	Design is based upon flow and structural analyses for the most severe expected ground conditions. If conditions are less severe, simpler design options are used. The various design options accommodate all expected conditions.

Table 7-1 *(Continued)*
Compliance of Design with the Design Requirements

Type of Requirement	Requirement	Section	Compliance with Requirement	Notes on Compliance
Design configuration and essential features	The panel-closure system shall be emplaced in the air-intake and air-exhaust drifts identified by Westinghouse (1995c)	3.2	Complies	The design shows placement in the designated areas for panel closure.
	The panel-closure system shall consist of a concrete barrier and construction-isolation and explosion-isolation walls with dimensions to satisfy the operational requirements of the system.	3.2, 3.3	Complies	The panel-closure system design uses the identified components with dimensions to satisfy the operational requirements of the system.
Safety	The design class for the panel-closure system shall be IIIb. Design and construction shall follow conventional mining and construction practices.	3.4	Complies	Components are designed according to Class IIIb. The construction sequence for the design followed conventional mining practices.
	The structural analysis for the underground shall use the empirical data acquired from the WIPP Excavation Effects *Program.*	2.1.2	Complies	The structural analysis uses properties that model creep closure for stress analyses from data acquired in the WIPP Excavation Effects Program.
Structural and material	The panel-closure system materials shall be compatible with their emplacement environment and function. Surface treatment between the host rock and the panel-closure system shall be considered in the design.	2.2.1	Complies	The material compatibility studies showed no degradation of materials and no need for surface treatment.
	The selection and placement of concrete in the concrete barrier shall address potential thermal cracking due to the heat of hydration.	2.2.2	Complies	The heat generation studies show that hydration temperatures are controlled by appropriate selection of cement type and placement temperature.
	The panel-closure system shall sustain the dynamic pressure and subsequent temperature generated by a postulated methane explosion.	2.2.3, 2.2.4, 4.0	Complies	The methane explosion study shows that the explosion-isolation wall protects the concrete barrier from pressure loading and thermal loading. The fracture propagation study shows that the system performs as intended.

Table 7-1 *(Continued)*
Compliance of Design with the Design Requirements

Type of Requirement	Requirement	Section	Compliance with Requirement	Notes on Compliance
Construction	The panel-closure system shall use to the extent possible normal construction practices according to existing standards.	3.4	Complies	The specifications include normal construction practices used in the underground at WIPP and according to the most current steel and concrete specifications.
	During construction of the panel-closure system, a quality assurance/quality control program shall be established to verify material properties and construction practices.	3.4	Complies	The specifications include materials testing to verify material properties and construction practices.
	The construction specification shall take into account the shaft and underground access capacities and services for materials handling.	3.4	Complies	The specifications allow construction within the capacities of underground access.

- The trade-off study also showed that a panel-closure system with an enlarged concrete barrier with the removal of the fractured salt roof and anhydrite in the floor was found to be the most protective.

The conclusions reached from the design evaluations addressing the structural and material requirements of the panel-closure system are as follows:

- Existing information on the heat of hydration of the concrete supports placing concrete with a low cement content to reduce the temperature rise associated with hydration. The slump at the required strength would be achieved through the use of plasticizers. A thermal analysis coupled with a salt creep analysis suggest installation of the enlarged barrier at or below ambient temperatures to adequately control hydration temperatures.

- In addition to installation at or below ambient temperatures, the concrete used in the main concrete barrier would exhibit the following:

  - An 8 inch (0.2 meter) slump after 3 hours of intermittent mixing
  - A less-than-25-degree Fahrenheit heat rise prior to installation
  - An unconfined compressive strength of 4,000 psi (28 MPa) after 28 days
  - Volume stability
  - Minimal entrained air.

- The trace amounts of brine from the salt at the repository horizon should not degrade the main concrete barrier for at least 35 years.

- In 20 years, the open passage above the waste stack would be reduced in size. Further, rooms with bulkheads at each end would be isolated in the panel. It is unlikely that a long passage with an open geometry would exist; therefore, the dynamic analysis considered a deflagration with a peak explosive pressure of 240 psi (1.7 MPa).

- The heat-transfer analysis shows that elevated temperatures would occur within the salt and the explosion-isolation wall; however, the elevated temperatures will be isolated by the panel-closure system. Temperature gradients will not significantly affect the stability of the wall.

- The fractures in the roof and floor could be affected by expanding gas products reaching pressures of the order of 240 psi (1.7 MPa). Because the peak internal pressure from the deflagration is only one fifth of the pressure, fractures could not propagate beyond the wall.

The design options to satisfy the design requirements for the panel-closure system include (1) a standard barrier, rectangular in shape, or (2) an enlarged concrete barrier, approximately

spherical in shape. Options (1) and (2) will be grouted at the interface and may contain explosion- or construction-isolation walls.

The design provides flexibility to satisfy the design migration limit for the flow of VOCs out of the panels. An enlarged concrete barrier would be selected where the air-intake and air-exhaust drifts have aged and where there is fracturing resulting in significant flow of VOCs. These conditions apply to the most severe ground conditions in the air-intake and air-exhaust drifts of Panel 1. If ground conditions are more favorable, such as might be the case for future panel entries, the design can be simplified to a standard concrete barrier rectangular in shape, with a construction isolation wall. GPR and observation boreholes are available for detecting the location and extent of fractures in the DRZ. These methods will be used to select the optimum location and appropriate panel-closure system.

The design is presented in this report as a series of calculations, engineering drawings, and technical performance specifications. The drawings illustrate the construction details for the system. The technical performance specifications cover the general requirements of the system, site work, concrete, and masonry. Information on the proposed construction method is also presented.

The design complies with all aspects of the design basis established for the WIPP panel-closure system. The design can be constructed in the underground environment with no special requirements at the WIPP.

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APPENDIX A
DERIVATION OF RELATIONSHIPS FOR THE AIR-FLOW MODELS

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A1.0 Introduction

This appendix shows the unrestricted and restricted air-flow models used to determine the performance of the panel closure system alternatives. These analyses are order-of-magnitude estimates of the volume of gas that might flow through the panel seal systems at the Waste Isolation Pilot Plant (WIPP).

A2.0 Model for Unrestricted Flow of VOCs

A model for the unrestricted flow of volatile organic compounds (VOC) was developed to predict the mass flow rates of VOCs and to compare this mass flow rate to the design migration limit for VOCs. As gas generation and panel volumetric creep closure proceed, a mixture of gases containing the VOC concentrations flows from each waste container. It is assumed for the unrestricted flow model that the headspace concentrations serve as a constant source of VOCs. This assumption is highly conservative, because most containers only have trace quantities of VOCs either trapped in the headspace or adsorbed on the surfaces of the various waste forms. It is believed that only a small number of waste containers have significantly greater sources of VOCs, such as a solvent-soaked rag or a can containing residual partially dried paint. Only these waste containers have a likelihood of maintaining a constant headspace VOC concentration as gas generation proceeds. However, the exact proportion of waste containers with higher VOC concentrations versus those with trace quantities is currently unknown. These data are based on results of the characterization of approximately 500 transuranic (TRU) mixed waste drums at the Idaho National Engineering Laboratory (INEL) and Rocky Flats.

The VOCs migrate due to advection from volumetric closure of the panel void space at a rate of about 28,250 ft^3 (800 m^3) per year. Gas generation for the waste inventory at a rate of 0.1 mole per drum per year (8,200 moles per panel per year) results in a volumetric flow rate of 7,060 ft^3 (200 m^3) per year. Because flow is unrestricted, the VOCs migrate under a pressure of one atmosphere. Other assumptions in the unrestricted model are as follows:

- Any gases released into the mine atmosphere would be reduced in concentration by 460,000[1] cfm of uncontaminated air. The mass flow rate of individual VOCs from individual panels following their closure is summed to determine the mass flow rate of VOCs through the exhaust shaft.

- This calculation considers the schedule for closure of individual panels as illustrated in Figure A-1 during the operational life of the WIPP. The VOC mass flow rate changes with time, with the maximum mass flow release occurring after 10 panel equivalents have been closed, about 25 years.

- Each VOC is analyzed in the calculations. Carbon tetrachloride is the most restrictive VOC in terms of satisfying the health-based levels for individual VOCs.

- Open panels of waste will not be considered as a source contributing to the emissions for a no-migration demonstration.

Considering only advection to result in the migration of VOCs, the mass-balance relationship is:

$$C_p * Q_p = C_{es} * Q_{es}$$

where

C_p = Head space concentration for an individual VOC
Q_p = Flow rate of VOCs from the panel that may vary with time
C_{es} = Concentration of VOCs at the exhaust shaft.
Q_{es} = Underground ventilation flow rate for the exhaust shaft

Air dispersion modeling is used for evaluating the receptor concentrations at the WIPP site boundary based upon the exhaust shaft source term. The air dispersion modeling considers such factors as meteorological data, release velocity, release temperature, and proximity of the WIPP site boundary to the exhaust shaft. The results of the modeling are expressed as a ratio R of the concentration at the exhaust shaft to the concentration at at the WIPP site boundary:

$$C_{es} \leq RC_{hbl}$$

This inequality can be expressed in terms of mass flow rate:

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[1]The design ventilation rate for the WIPP underground is 425,000 standard cfm (12,000 standard m^3 per minute) under standard temperature and pressure conditions of 25 degrees Celsius and 1 atmosphere. The ventilation flow rate of 460,000 cfm (13,025 m^3 per minute) is the observed ventilation rate at the repository horizon under actual temperature and pressure conditions.

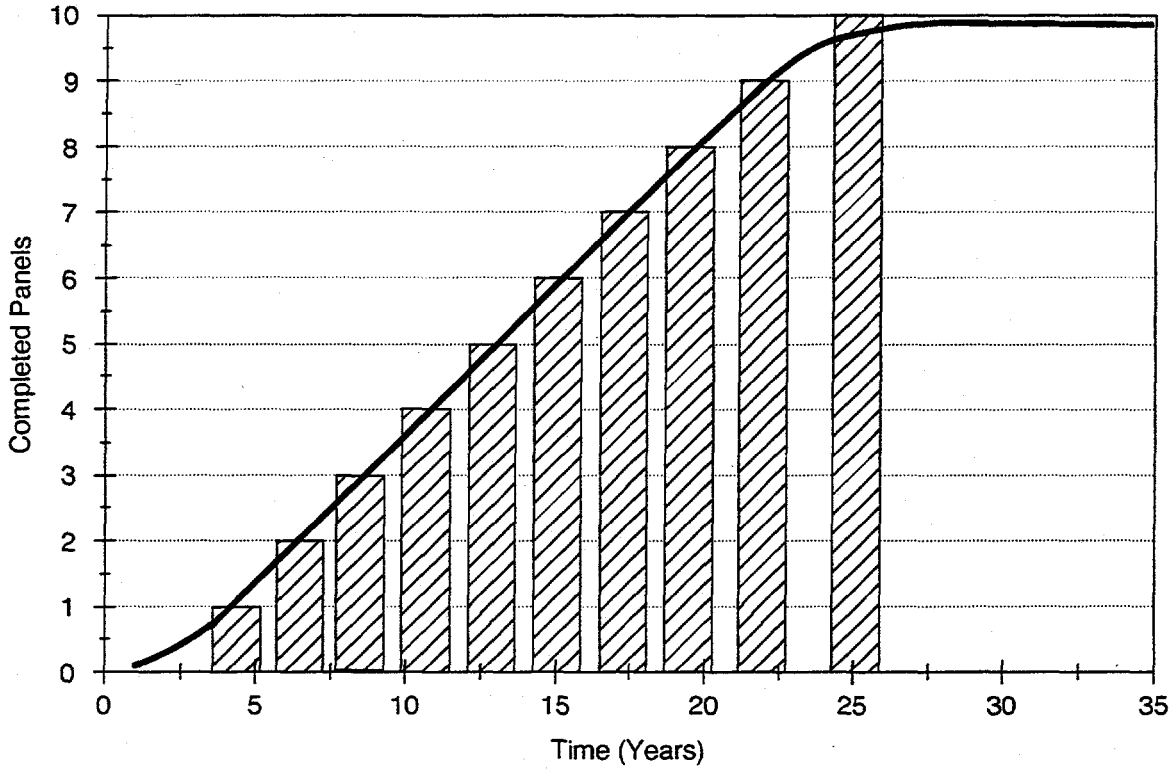

Figure A-1
Schedule for Panel Completion

$$\frac{C_p * Q_p}{Q_{es}} * \frac{1}{R} \leq C_{hbl}$$

where

R = Ratio of the concentrations at the exhaust shaft to the concentrations at the WIPP site boundary

C_{hbl} = Concentration to satisfy the health-based level for the individual VOC.

The ratio of the concentrations at the WIPP site boundary, R equals 10,753, reflecting the substantial atmospheric dispersion in reducing the concentration of VOCs.

The flow rates of VOCs from the panels are calculated for two mechanisms, gas generation and volumetric closure, using the following:

$$Q_p = Q_{gr} + Q_c$$

where

Q_{gr} = Volumetric flow rate due to gas generation[2] (200 m^3 per year per panel)

Q_c = Volumetric flow rate due to panel volumetric closure (800 m^3 per year per panel).

Table A-1 presents the closed panel release limits (migration limits) for VOCs based upon the health-based concentrations of individual VOCs. This inequality can be rewritten as:

$$C_p \cdot Q_p \leq C_{hbl} \cdot Q_{es} \cdot R$$

Table A-2 presents for a single closed panel and ten equivalent closed panels, the release rate for individual VOCs at the end of the 35-year operating period.

For the WIPP site boundary, the VOC concentrations are reduced substantially in the atmosphere. The above analysis shows that the concentration at the WIPP site boundary would be approximately 4 orders of magnitude lower than the concentration at the exhaust shaft. The predicted VOC mass flow rates due to unrestricted flow suffice to comply with the

[2]The volumetric flow due to gas generation is calculated as the gas generation rate (0.1 moles per drum per year) times the number of drums within a panel times the specific volume under atmospheric pressure.

Table A-1
Closed Panel Release Limits for VOCs

Compound	WIPP Site Boundary Health-Based Exposure Level[a] (micrograms per cubic meter)	Exhaust Shaft Concentration Migration Limit (micrograms per cubic meter)	Closed Ten Panel Migration Limit (grams per minute)
Carbon disulfide	10.00	107,530	1,400
Carbon tetrachloride	0.13	1,398	18
Chlorobenzene	20.00	215,060	2,801
Chloroform	0.09	968	13
1,1-dichloroethylene	0.40	4,301	56
Methyl ethyl ketone	1000.00	10,753,000	140,045
Methylene chloride	4.26	45,808	597
1,1,2,2-tetrachoroethane	0.35	3,764	49
Toluene	400.00	4,301,200	56,018

Table A-2
Closed Panel Release Rates for VOCs

Compound	Average Headspace Concentration (milligrams per cubic meter)[a]	Single-Panel Volumetric-Release Rate (cubic meters per minute)	Ten-Panel Volumetric-Release Rate (cubic meters per minute)	Single-Panel Mass-Release Rate (grams per minute)	Ten-Panel Mass-Release Rate (grams per minute)
Carbon disulfide	0.41	0.0019	0.019	7.80×10^{-7}	7.80×10^{-6}
Carbon tetrachloride	3625.77	0.0019	0.019	6.90×10^{-3}	6.90×10^{-2}
Chlorobenzene	63.99	0.0019	0.019	1.22×10^{-4}	1.22×10^{-3}
Chloroform	76.79	0.0019	0.019	1.46×10^{-4}	1.46×10^{-3}
1,1-dichloroethylene	48.68	0.0019	0.019	9.26×10^{-5}	9.26×10^{-4}
Methyl ethyl ketone	241.73	0.0019	0.019	4.60×10^{-4}	4.60×10^{-3}
Methylene chloride	3387.03	0.0019	0.019	6.45×10^{-3}	6.45×10^{-2}
1,1,2,2-tetrachloroethane	69.65	0.0019	0.019	1.33×10^{-4}	1.33×10^{-3}
Toluene	105.51	0.0019	0.019	2.01×10^{-4}	2.01×10^{-3}

[a]Westinghouse Electric Corporation, 1995, "Underground Hazardous Waste Management Unit Closure Criteria for the Waste Isolation Pilot Plant Operational Phase," *WID/WIPP-2038*, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, New Mexico.

closed ten-panel migration limit based upon the health-based levels at the WIPP site boundary over the operational life of the repository.

A3.0 Air Model

The modeling assumptions for the restricted air-flow model are as follows:

- The gases are generated at a specified rate (0.10 moles per drum per year).
- The gases flow out of the panel entries according to Darcy's law under quasi-steady state conditions.
- The gases within the pore space obey the ideal gas law
- The rates of gas generation, gas outflow, and change in compressive storage must balance.
- Hydrodynamic dispersion is neglected in the analysis.

After panel closure, the volume, moles of gas, and pressure are changing as functions of time. The ideal gas law (Hiller and Herber, 1960) is written as:

$$p = \frac{n*R*T}{V}$$

where

p = Pressure
n = Moles of gas in the panel
R = Universal gas constant
T = Absolute temperature
V = Volume

Differentiating with respect to t and using the chain rule, we obtain the following relationship:

$$\frac{dp}{dt} = R*T* \frac{\frac{dn}{dt}*V - n*\frac{dV}{dt}}{V^2}$$

The volumetric closure rate is negative and constant as discussed below. The rate at which gas enters the panel minus the rate that gas leaves the panel must equal the change in moles stored. We obtain the mass-balance relationship:

$$\frac{dn}{dt} = g_r - \frac{p}{R*T} * K_s * \frac{A}{L} * \frac{p - p_{atm}}{\gamma}$$

where

g_r	=	Panel gas generation rate
p_{atm}	=	Atmospheric pressure
γ	=	Air density
K_s	=	Effective panel closure system conductivity
A	=	Cross-sectional area
L	=	Length of flow path

We define the conductance (C) as:

$$C = K_s * \frac{A}{L}$$

and substituting into the ordinary differential equations (ODE), we obtain

$$\frac{dp}{dt} = R*T* \frac{g_r - \frac{p}{R*T} * C * \frac{p - p_{atm}}{\gamma} * V - n * \frac{dV}{dt}}{V^2}$$

$$\frac{dn}{dt} = g_r - \frac{p}{R*T} * C * \frac{p - p_{atm}}{\gamma}$$

These two first-order coupled ODEs can be solved by a simple explicit finite difference technique:

$$p_j = p_{j-1} + R * T * \frac{g_r - \frac{p_{j-1}}{R*T} * C * \frac{p_{j-1} - p_{atm}}{\gamma} * V - n_{j-1} * \frac{dV}{dt}}{V^2} * \Delta t$$

$$n_j = n_{j-1} + g_r - \frac{p_{j-1}}{R*T} * C*\frac{p_{j-1} - p_{atm}}{\gamma}\Delta t$$

where

p_j, n_j = the pressure and moles of gas at the current time step
P_{j-1}, n_{j-1} = the pressure and moles of gas at the previous time step

subject to the boundary condition that the initial pressure equals atmospheric pressure, and the initial moles of gas can be determined by the ideal gas law at initial volume and pressure. Further note that the volume can be expressed as the linear function:

$$V(t) = \alpha * t + \beta$$

where

α = slope of the volume-time relationship
β = intercept of volume-time relationship
t = time

These expressions can be substituted into the above explicit finite difference relationships, and the pressure and molar air flow rates determined as functions of time.

$$\frac{dV}{dt} = \alpha$$

APPENDIX B

CALCULATIONS IN SUPPORT OF PANEL GAS PRESSURIZATION DUE TO CREEP CLOSURE

APPENDIX B
CALCULATIONS IN SUPPORT OF PANEL GAS PRESSURIZATION DUE TO CREEP CLOSURE

B.1.0 Introduction

This appendix presents the closure mechanisms and supporting calculations for panel volumetric closure for the analysis of gas pressurization within a closed panel at the Waste Isolation Pilot Plant (WIPP). The volume reduction is due to the panel volume change from viscoplastic creep closure of the walls, roof, and floor. As the walls, roof, and floor of the excavations converge, the total volume of the panel decreases. The volumetric closure of a panel is the result of several different mechanisms working in tandem. These mechanisms include:

- Viscoplastic creep of the salt toward the excavation
- Fracturing in the roof and floor caused by the deviatoric stresses around the excavation
- Bed separation at the clay seams in the roof and the floor.

The combination of these three mechanisms causes the observed convergence rates in Panel 1. Of these mechanisms, only creep of the salt reduces the total volume of the panel and pore space in the surrounding disturbed rock zone (DRZ). Fracturing in the roof and floor and bed separation transfer the void volume within the excavation to the DRZ. This void volume within the DRZ is assumed to be interconnected with the open excavation. Therefore the total reduction in volume within the panel, based simply on room closure, overestimates the effective reduction in void volume. However, quantifying the amount of interconnected void space within the DRZ would require a much more detailed analysis. The total volume change calculated from the room closure measurements is therefore considered conservative.

Other assumptions made in this calculation are:

- The volumetric closure rates are constant after panel closure.
- The waste in the panel provides no significant resistance to creep closure during the initial 35 years.

- The air volume is the total volume of the excavations minus the solid volume of the waste in drums or other waste packages. This is estimated to equal 138,000 ft^3 (3,908 m^3).

- The closure rate of each room in the panel equals the closure rate at the midpoint of the room.

- The length of each room or drift is constant; to simplify the calculations, only the width and height change with creep closure.

- The panel is comprised of seven rooms and two panel access drifts.

B.2.0 Panel Volume Change Calculation

The panel volume change calculation is performed by first calculating the initial panel volume, then calculating the room and drift closure rates, and finally calculating the panel volumetric closure rate. Following is a detailed description of each part of the calculation.

B.2.1 Initial Panel Volume

The initial panel volume is determined immediately after completion of excavation. The total volume is calculated by summing the individual room and drift volumes within the panel. These volumes are based on the as-built dimensions of the excavated rooms and drifts in Panel 1 (DOE, 1993). Table B-1 presents the room and drift dimensions and the calculated volume of each room and drift. The volume of the air-intake and air-exhaust drifts is not included. The total initial volume of Panel 1 is 1,669,434 ft^3 (47,273 m^3).

The total solid volume of the waste in a filled panel is 138,000 ft^3 (3,908 m^3) (DOE, 1994; Butcher, et al., 1991). Subtracting the waste volume from the total panel volume gives the total initial air volume (1,531,434 ft^3 [43,365 m^3]) in the panel.

B.2.2 Closure Rates

Using convergence data from Panel 1 the average closure rates of the rooms and drifts are determined (DOE, 1993). Closure rates within the rooms and drifts are higher in the first five years after excavation. The roof-to-floor and wall-to-wall closure rates for each of the rooms and drifts are presented in Table B-2.

Because all of the excavations in Panel 1 are approximately 13 x 33 ft (4 x 10 m), the closure rates for each room or drift are the same.

Table B-1
Initial Room and Drift Dimensions and Volume of Panel 1

Room or Drift	Initial Width (ft)	Initial Height (ft)	Initial Length (ft)	Initial Volume (ft^3)
Room 1	33	13	300	128,700
Room 2	33	13	300	128,700
Room 3	33	13	300	128,700
Room 4	33	13	300	128,700
Room 5	33	13	300	128,700
Room 6	33	13	300	128,700
Room 7	33	14	300	138,600
South 1950 panel access drift	33	14	848	391,776
South 1600 from Room 1 to Room 5	33	13	573	245,817
South 1600 from Room 5 to Room 7	33	14	262	121,044
Total Initial Panel Volume				1,669,437

B.2.3 Volumetric Panel Closure Rate

Using the closure rates from Table B-2, the dimensions of the rooms and drifts in Panel 1 can be calculated at the end of each progressive year or for subsequent years using the following equations.

For 0 to 5 years after excavation:

$$V_t = (w_i - R_H t) \times (h_i - R_{Vo} t) \times l_i$$

Table B-2
Room and Drift Closure Rates
(DOE, 1993)

Room or Drift	Vertical Closure Rate		Horizontal Closure Rate	
	0 to 5 Years (ft/yr)	> 5 Years (ft/yr)	0 to 5 Years (ft/yr)	> 5 Years (ft/yr)
Room 1	0.3194	0.2109	0.2234	0.1160
Room 2	0.3194	0.2109	0.2234	0.1160
Room 3	0.3194	0.2109	0.2234	0.1160
Room 4	0.3194	0.2109	0.2234	0.1160
Room 5	0.3194	0.2109	0.2234	0.1160
Room 6	0.3194	0.2109	0.2234	0.1160
Room 7	0.3194	0.2109	0.2234	0.1160
South 1950 panel access drift	0.3194	0.2109	0.2234	0.1160
South 1600 from Room 1 to Room 5	0.3194	0.2109	0.2234	0.1160
South 1600 from Room 5 to Room 7	0.3194	0.2109	0.2234	0.1160

For greater than 5 years after excavation:

$$V_t = (w_i - R_H t) \times (h_i - R_{V5}(t-5) - R_{V0}5) \times l_i$$

where

V_t = Volume of the room at time t
t = Time (in years)
w_i = Initial room width
h_i = Initial room height
l_i = Initial room length
R_H = Horizontal closure rate (ft/year)
R_{V0} = Vertical closure rate for first 5 years (ft/year)
R_{V5} = Vertical closure rate after 5 years (ft/year).

We obtain the incremental change in volume:

$$\Delta V = V_1 - V_2$$

where

V_1 = Volume of room at time t_1 (ft^3)
V_2 = Volume of room at time t_2 (ft^3)
ΔV = Change in volume of room between time t_1 and t_2 (ft^3)
t_1, t_2 = Years after excavation

The volume of all the rooms within the panel is calculated at the time of four years after excavation, when the waste is assumed to have been emplaced the amount of time required for waste emplacement (Table B-3). The total volume of the panel after four years is 1,469,112 ft^3 (41,601 m^3). The volume of the panel is then calculated at five years after excavation or one year after panel closure (Table B-3). This volume is 1,420,312 ft^3 (40,219 m^3), and the volume reduction in that year is 48,800 ft^3 (1,382 m^3).

The initial volume in a closed panel after approximately four years is obtained from the total volume at four years (1,469,112 ft^3 [41,601 m^3]) minus the solids volume (138,000 ft^3 [3,908 m^3]), or 1,331,112 ft^3 (37,693 m^3). This volume is used as the initial volume for the restricted air-flow model calculations.

The rate of change for panel volume is assumed to be constant for the first five years after excavation, because the vertical and horizontal closure rates are constant during this period. (Actually, rate of volume change over time decreases slightly with each year due to "corner effects," but this error is less than 2 percent and is considered insignificant.) Table B-3 also shows the panel volumes at 15 and 16 years after excavation and the change in volume between those years. The volumetric panel closure rate is 28,673 ft^3 per year (812 m^3 per year). This is the rate in volume change per year in the panel from five to approximately 35 years after excavation.

At approximately 16 years after excavation, the roof comes in contact with the waste stack. Only 35 years after excavation does the waste stack begin to provide significant resistance to creep (approximately 2 MPa). This resistance is expected to slow the vertical convergence rate by some amount.

Table B-3
Panel Volume at Various Times

Room or Drift	Volume of Room (ft^3)			
	At 4 Years	At 5 Years	At 15 Years	At 16 Years
Room 1	112,914	109,069	85,662	83,401
Room 2	112,914	109,069	85,662	83,401
Room 3	112,914	109,069	85,662	83,401
Room 4	112,914	109,069	85,662	83,401
Room 5	112,914	109,069	85,662	83,401
Room 6	112,914	109,069	85,662	83,401
Room 7	122,545	118,633	94,879	92,583
South 1950 panel access drift	346,395	335,337	268,191	261,702
South 1600 from Room 1 to Room 5	215,665	208,321	163,614	159,296
South 1600 from Room 5 to Room 7	107,023	103,607	82,861	80,856
Total Volume of Panel 1	1,469,112	1,420,312	1,123,529	1,094,856
Change in Volume		48,800		28,673

B.3.0 References

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APPENDIX C
FLAC MODELING OF THE PANEL CLOSURE SYSTEM

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FLAC MODELING OF THE PANEL CLOSURE SYSTEM

Numerical modeling is considered one of the better methods available for quantifying the interaction of concrete barriers with the surrounding media. Therefore, a series of models have been developed for this report to evaluate the interaction of the main concrete barrier of the panel closure system with the surrounding salt for different alternatives and concrete barrier geometries. This appendix discusses the code used and describes the material constitutive models used in the stress analysis.

C.1.0 The FLAC Code

FLAC software has been used for numerical modeling of the underground excavations at the WIPP since 1991. FLAC is a two-dimensional explicit finite difference code that simulates the behavior of rock and soil-like structures. The WIPP Reference Creep Law is built into FLAC and has been verified to Nuclear Regulatory Commission standards (Itasca, 1995). In addition, all versions of FLAC used by the Westinghouse Waste Isolation Division have been verified against the WIPP Second Benchmark Problem (Krieg, 1984).

C.2.0 Material Constitutive Models

The material properties associated with the material constitutive models are given in Tables C-1 through C-3. These properties are the standard properties which have been used in previous WIPP geotechnical FLAC modeling such as the Backfill Engineering Analysis Report (BEAR) (IT, 1994). Note that the stress analysis of the concrete barrier also uses the same stress-strain relationship for the uncompacted crushed salt as was used in the BEAR. The stress analysis in Figure 4-4 used uncompacted crushed salt on one side of the enlarged concrete barrier and open void space on the other side. The crushed salt has subsequently been eliminated from the panel closure system final design. The symmetry in the principal stress plots for the enlarged concrete barrier analysis indicated that the presence or absence of the crushed salt does not significantly affect the stresses within the enlarged concrete barrier. Therefore, the FLAC analysis results presented in Figure 4-4 apply to the panel closure system final design.

Table C-1[a]

FLAC[b] Model Time-Dependent Material Properties

Property	Halite	Argillaceous Halite	Halite, 10% Polyhalite
Bulk modulus (GPa)	20.7	20.7	22.1
Shear modulus (GPa)	12.4	12.4	13.2
Density (kg/m^3)	2,300	2,300	2,300
Activation energy (cal/mol)	12,000	12,000	12,000
A	4.56	4.56	4.56
B	127	127	127
D ($Pa^{-4.9}/s$)	5.79×10^{-36}	1.74×10^{-35}	5.21×10^{-36}
n	4.9	4.9	4.9
Gas constant (cal/mol K)	1.987	1.987	1.987
Critical strain rate	5.39×10^{-8}	5.39×10^{-8}	5.39×10^{-8}

Table C-2[a]

FLAC[b] Elastic Material Properties

Property	Anhydrite	Polyhalite	Concrete
Bulk modulus (GPa)	83.4	65.8	11.6
Shear modulus (GPa)	27.8	20.3	9.0
Density (kg/m^3)	2,300	2,300	2320
Cohesion (MPa)	27	17.2	–
Friction (degrees)	29	46.5	–

Table C-3[a]

FLAC[b] Clay Seam Material Properties

Property	Value
Normal stiffness (Pa/m)	1.0×10^{12}
Shear stiffness (Pa/m)	5.0×10^{10}
Cohesion (Pa)	0.0
Friction (degrees)	5

[a]IT, 1994

[b]FLAC = Fast Lagrangian Analysis of Continua
GPa = Gigapascal(s)
kg/m^3 = Kilogram(s) per cubic meter
cal/mol = Calorie(s) per mole
$Pa^{-4.9}/s$ = Pascal(s) to the negative 4.9 per second
cal/mol K = Calorie(s) per mole Kelvin
A,B,n = unitless model factors
D = model factor
Pa/m = Pascal(s) per meter
MPa = Megapascal(s)

C.3.0 References

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APPENDIX D
BRINE/CEMENT INTERACTIONS

APPENDIX D
BRINE/CEMENT INTERACTIONS

Concern about potentially deleterious constituents in the Waste Isolation Pilot Plant (WIPP) brines were initially raised when evidence of some minor concrete deterioration in the waste shaft key was noted. The cause is geochemical alteration of the concrete shaft liner and shaft grout by the brine present at the Rustler-Salado contact. Chemical constituents detected in brine samples included both organic and inorganic compounds that probably originated from dissolution of the concrete liner and grout materials used in the shaft construction. The presence of large amounts of organics that likely originated from the chemical grout appeared to have complexed the calcium present in the brine, interfering with the inorganic chemistry of the naturally occurring brine. The brines in contact with the waste shaft key were also found to be significantly higher in both chlorides and magnesium than the Salado Formation brine. These factors probably resulted in a Rustler/Salado brine chemistry more aggressive than that of the naturally occurring Salado brines that may contact the panel barrier.

Lankard Materials Laboratory (LML) (1992) concluded that there has been both a "physical attack" component and a "chemical attack" component acting upon the waste shaft key by brines. A "worst-case" scenario proposed by LML indicated that deterioration from both chemical and physical factors could result in a loss of material on the shaft side of the concrete liner at a rate of approximately 12 centimeters (5 inches) over a 50-year period.

The very local deterioration of the waste shaft key concrete resulted in some reduction in its load-bearing capacity and some increase in its permeability to brine infiltration. In addition, exposure of chemical residue deposits to the air within the shaft may have created a spalling effect that also facilitated local concrete deterioration on the interior (shaft opening) side of the liner.

Sandia National Laboratories/New Mexico (SNL/NM) studied the effect of high-magnesium brine interactions on various candidate barrier materials (SNL/NM, 1994). High-magnesium brines are characteristic of the Rustler-Salado contact, which is the location of the waste shaft key. The study was intended to evaluate chemical impacts to mass-concrete barriers in the WIPP panels and to the Salado Formation. However, the results of the study were also used to evaluate the cause of the deterioration of the waste shaft key. IT Corporation (IT) (1994),

in a separate study, also evaluated the geochemistry of brines associated with the waste shaft key near the Rustler-Salado Formation contact.

Both studies concluded that the brines have chemically reacted with the constituents in the concrete and grouts used in the waste shaft key liner. The SNL/NM (SNL/NM, 1994) study theorized that the loss of the liner's strength was facilitated by the loss of calcium from the concrete liner. SNL/NM noted that the magnesium present in the brine replaced calcium in the concrete, but the replacement process occurred as a delayed reaction. Magnesium replacement did not occur until after the structural integrity of the waste shaft key liner was already impacted negatively by the loss of calcium, which increased the porosity of the liner. This resulted in a more open and permeable microstructure not attributable solely to a weakening effect from magnesium replacement. Both the IT and SNL/NM studies supported the conclusion that the waste shaft key liner deterioration occurred only locally and in the outermost reaction zone of the liner, so that the structural integrity of the liner as a whole was not significantly impacted. SNL/NM proposed that further deterioration of the liner may be limited only to areas of the concrete liner that develop stress fractures.

Wakeley et al. (1993) studied salt-saturated concrete and grout emplaced in the floor of the WIPP repository six years before its retrieval. The concrete and grout used in the study were cementitious, rather than organic. In retrieving the concrete and grout plugs, the plugs were overcored to also retrieve some host rock.

The study concluded that little to no deterioration occurred to the concrete or grout and that general compressive strengths of the concrete and grout increased over time. The lowest compressive strength values were observed in samples taken from the disturbed rock zone. Reaction rims with increased permeability were noted on anhydrite surrounding the plugs, suggesting interaction between the grout or concrete and host rock. However, comparable evidence of a reaction with the concrete or grout was not seen. There was also evidence of dissolution of halite in the anhydrite zone near the plugs; however, the evidence also indicates that the presence of the halite facilitated better bonding between the grout or concrete and the host rock. Crystallization of new phases was also noted on free surfaces, indicating that strongly ionic magnesium-bearing fluids were present and moving. The fluid movement appeared to have no effect on the host rock other than to improve bonding.

The differences in the appearances, strengths, and phase assemblages between the grout/concrete plugs in the study discussed above and the waste shaft key liner concrete are

different enough that two extremely different service environments can be inferred. The magnesium level and fluid transport are apparently much greater in the waste shaft key location, facilitating a greater degree of deterioration of the waste shaft key concrete than was noted in the plugs studied by Wakeley et al. (1993). The waste shaft key concrete liner was also composed of organic constituents, which appeared to be more reactive with the brine chemistry. The main concrete barrier will be located in a service environment similar to that studied by Wakeley et al. (1993), where very minor amounts of brine would contact the main concrete barrier.

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APPENDIX E

PREVIOUS STUDIES OF PANEL-CLOSURE SYSTEM MATERIALS

APPENDIX E
PREVIOUS STUDIES OF PANEL-CLOSURE SYSTEM MATERIALS

In researching the available literature relating to panel-closure system designs and materials, studies on both long-term and short-term barrier performance were evaluated. The intended function of the main concrete barrier described in this report is to provide short-term (35 years) barrier capability until the repository host rock reconsolidates around the barrier. However, studies on long-term barrier performance were found useful for the panel-closure system material compatibility evaluation performed for this document. The results of these studies provided insight into the complex issues to be considered for selecting an appropriate concrete and grout for the panel-closure system.

Stormont (1987) studied small-scale seal performance tests (SSSPT). The SSSPTs were designed as in situ experiments to evaluate the performance of candidate seal materials. Barrier systems consisted of the barrier itself, the barrier-rock interface, and the surrounding rock. The system performance was evaluated using thermal/mechanical and fluid flow (both gas and brine) data generated by testing under expected repository conditions. Thermal, mechanical, and hydrologic performance of the barriers was evaluated. Test Series A consisted of a bulkhead constructed of salt-based concrete. Regarding hydration of the concrete, stresses and strains induced in the rock and the barrier were a result of hydration. Stresses and strains also resulted from the salt creep and from the panel-closure system material. Evaluation of these stresses and strains yielded information about the stability of the barrier system and the structural/fluid flow relationship. The permeabilities of the barrier material with respect to gas and brine were important for evaluating the potential for a repository breach scenario. Test Series A was conducted in geologic horizons that included bedded halite and interbeds of clay and anhydrite.

Three types of concrete were evaluated for the Test Series A study: salt-free concrete, salt concrete, and expansive salt-based concrete. The latter proved to yield the most favorable results due to its significant expansive properties, which create a tight interface; its workability (about 4 hours); and for its ability to inhibit dissolution of surrounding salt during cement hydration.

Stormont (1988) also studied the performance of grout and concretes as constituents of main concrete barriers for the panel-closure system. The use of cementitious grouts within the disturbed rock zone adjacent to the main barrier was determined to be detrimental at times, as it could facilitate fracture propagation. To prevent the load reaction causing the fracture propagation, Stormont proposed the emplacement of rigid concrete at the main barrier location. Stormont's investigations of concrete to form the actual main barrier indicated that concrete is impermeable, and any associated leakage across the barrier would occur at the concrete/rock interface zone. Leakage could be attributed to concrete shrinkage and the integrity of the rock itself. However, Stormont noted that the presence of halite in the host rock would result in compressional forces exerted on the concrete barrier over time, with little or no leakage occurring.

SSSPT performed by Stormont (1988) and Finley and Tillerson (1992) evaluated salt-based concrete, bentonite, and salt blocks for barrier performance. In the salt-based concrete barriers, both brine and gas migration across the barrier-rock interface were retarded by salt creep adjacent to the barrier and the expansive properties of the salt-based concrete. The salt-based concrete barriers also withstood significant back-pressure forces. Bentonite and salt blocks did not perform as satisfactorily with respect to their load-bearing capacities or fluid permeabilities.

Hansen et al. (1994) discussed barrier materials for vertical shaft environments in terms of the barriers' long- and short-term components. The single long-term component envisaged in their studies was reconsolidated salt, especially engineered to achieve a barrier function in approximately 100 years. However, short-term materials included concrete, bentonite, grout, chemical seal rings, and potential alternatives, although the alternatives were not included in a reference barrier design. Each barrier component had a functional requirement to prevent the passageways from becoming the preferred passageways for transport of brines or gases to or from the repository. Short-term components provided barriers to brine and groundwater inflow to the consolidating and long-term members and to the repository. The composition of each selected barrier was based on experience in the mining industry, assurance of function through test results, and compatibility with the stratigraphy in which the barrier was placed. The authors looked at specific geologic horizons with respect to their ability to prevent brine and gas flow.

Test Series B (Peterson et al., 1987) more likely approximated the configuration of the proposed panel barrier, which will be emplaced in a horizontal drift leading to the waste-

emplacement panels. The type of material used in the testing was a salt-saturated expansive concrete, as was used in Test Series A.

In both the A and B test series, the parameter of primary interest was the barrier permeability. For calculational purposes, it was assumed that all flow goes through the barrier. However, some flow may enter the surrounding formation as well, although it is difficult to determine and quantify. Factors affecting measured flow rates through the barrier would include the pressure under which the brine was flowing. If a brine was saturated with respect to its liquid phase at ambient conditions, added pressures may decrease its saturation and encourage dissolution of the surrounding halite.

In one test, barrier brine flow rate decreased slowly with time; this is an important consideration when modeling long-term response. Possible mechanisms causing this decrease include precipitation, healing, or creep closure of open pore spaces. Estimates of brine and gas permeabilities depend strongly on the degree of pore saturation.

Only gas-flow tests were performed in the B Series. All of the barriers leaked (though at slow rates) in the B Series tests. No leakage occurred at the barrier/formation interface. Leaks were associated with a small formation fracture and with an instrumentation bundle. Gas-flow tests performed approximately one year later indicated no leakage associated with the barriers.

Test Series C (Stormont et al., 1987) consisted of salt and salt-bentonite block barrier material emplaced in a horizontal drift within almost pure halite. Four barriers were composed of salt blocks, and four barriers consisted of salt-bentonite blocks. Four of the barriers, two representing each type of material described above, were evaluated without instrumentation, for fluid flow and permeability testing. Instrumentation and cabling are often leak paths for such testing. The instrumentation used in the other barriers measured deformations and pressures and provided other important data. The data suggest that crushed salt provides very little resistance to closure until the crushed salt is very dense. Deformation experiments were designed to verify or refute this evidence.

Principal advantages to salt-block emplacements as opposed to mechanical or pneumatic backfilling were that initial porosity of the crushed or granular salt was minimized, reducing the time required for effective or complete salt consolidation. This in turn reduced the likelihood of brine influx from the surrounding strata that could impede the consolidation

process. Block emplacements also allowed considerable control over production and emplacement. Blocks could be tailored to achieve certain properties, such as addition of bentonite or moisture.

Experiments with different types of blocks indicated that the relative density of the blocks increased with the maximum particle size used. Further, blocks cured in humid environments became extremely friable and unviable. Within the Waste Isolation Pilot Plant (WIPP) facility, the humidity of the ventilation air is below the critical humidity of 75 percent (the air will take moisture from the salt).

Blocks cured at ambient conditions were the most resilient in that they resisted chipping and shattering. Their "toughness" was a result of the development of an indurated "skin" from particle caking. Caking occurs when moisture at particle contacts is evaporated, resulting in bridging and microcrystalline growth that essentially cements the particles together. However, an indurated skin may also hinder consolidation at the interfaces between blocks from a lack of available water believed necessary for rapid consolidation.

The purpose of adding bentonite to salt blocks was to reduce the permeability without requiring extensive consolidation. Data collected indicated that permeabilities to brines and water fell off to microdarcy values somewhere between 25 and 50 percent bentonite by weight. For this experiment, a 1:1 ratio of salt to bentonite was used. Over 90 percent of the bentonite was composed of the clay mineral montmorillonite. Water was also introduced into the mixture.

Salt/bentonite blocks cured in the humid environment took sufficient moisture from the air to become extremely friable, and therefore, unviable. Under covered conditions, less moisture was lost. Salt/bentonite blocks were also tougher than salt-only blocks. Also, greater amounts of moisture contributed to a tougher block than the addition of less moisture.

The use of mortars was necessary to fill the voids between the blocks and the borehole wall. Mortar was generally only emplaced into the interface and not between blocks. The mortars were composed of the same materials as the blocks.

In summary, both types of blocks were found to lose excessive moisture to the dry mine atmosphere unless they were covered between the time of production and the time of emplacement. Initial fluid flow testing of the salt/bentonite barriers revealed that erosion

along the block/rock interface occurred when the brine was introduced too rapidly to allow the bentonite to take up the water and swell to shut down flow paths. Subsequent testing with slower introduction of brine confirmed this result, that is, salt/bentonite blocks could be effective barriers to brine flow. Structural measurements provided data to test laboratory models of salt consolidation. To date, the measurements do not contradict model predictions of the barriers providing little resistance to hole closure until they become very dense.

The concrete and grout used in the above-referenced study were developed by Gulick and Wakeley (1989). They proposed expansive salt-saturated concrete (ESC) and grout mixtures that yielded favorable results for suitability as panel barrier and grout materials during the in-place testing at the WIPP repository. The grout composition was summarized in the text of this report in Section 2.2.1. The formulation for the ESC is shown in Table E-1.

Table E-1
Expansive Salt-Saturated Concrete

Component	Percent of Total Mass
Class H cement	9.03
Chem comp III	6.03
Cal seal (plaster)	1.80
Class C fly ash	5.10
Fine aggregate	34.11
Coarse aggregate	34.58
Sodium chloride	2.50
Defoaming agent	0.21
Sodium citrate	0.11
Water (iced)	6.60

Class H cement is a standard oil-well cement. It has been used extensively in grouts and concretes in underground applications. Class C fly ash contributes expansive properties to the concrete. Cal Seal (a plaster of paris manufactured by Haliburton) also develops expansive properties in mixtures containing Class H cement. Expansive components that are added to the concrete or grout mixtures enhance bonding between the concrete or grout and the host rock. The addition of sodium chloride to the mixture is necessary to assure that the water

content of the concrete or grout is in equilibrium with the host rock. This prevents dissolutioning, and also inhibits or reduces deterioration of the concrete or grout. Defoaming agents inhibit air entrainment in the concrete or grout mixture.

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APPENDIX F

HEAT TRANSFER MODEL DERIVATION METHANE EXPLOSION

APPENDIX F
HEAT TRANSFER MODEL DERIVATION
METHANE EXPLOSION

Under the conditions of a postulated methane explosion within the panel, the temperature of the gas is raised by the combustion process to an initial value $T_{g\ init}$ with time t = 0 corresponding to initial conditions in the panel. Subsequently, the gas temperature in the panel decreases as heat is transferred to the surrounding salt and to the two explosion-isolation walls in the air-intake and air-exhaust drifts of each panel.

At time t = 0 the pressure in the panel is P_{init} based on panel closure due to creep and the elevation in pressure resulting from the explosion. Thus, the rise time of the temperature is not considered in the model.

At time t = 0, the volume of the panel is V_{init} and is assumed to remain constant throughout the cooling of the gas in the panel because of the short duration of the explosion. This means that the effect of creep on the panel volume is assumed negligible during the postulated explosion. The initial volume is given by:

$$V_{init} = V_{panel} - V_{waste} - V_{creep}$$

where

V_{init} = Initial volume
V_{panel} = Volume of the panel
V_{waste} = Volume of the waste
V_{creep} = Volume reduction due to creep

and is taken as given at the start of the heat transfer analysis and assumed to remain constant during the transfer of heat to the panel walls, roof, and floor.

F.1.0 Heat Balance

Assuming a constant volume is equivalent to stating that any creep closure of the panel volume during the explosion and subsequent cooling can be neglected.

$$\frac{dQ_{volume\ of\ gas}}{dt} = qA_{walls,\ floor,\ roof}$$

where $Q_{volume\ of\ gas}$ represents the heat contained in the hot gases subsequent to an explosion, q is the heat flux rate at the boundaries of the panel volume, and $A_{walls,\ floor,\ roof}$ is the surface area of the panel volume.

Following D'Appolonia (1978) it is conservatively assumed that the heat transfer to the surrounding walls, floor, roof, is related to the rate of change of enthalpy of the reaction products gas. Thus, the heat content of the room is given by:

$$\frac{dQ_{volume\ of\ gas}}{dt} = nC_p\frac{dT_g}{dt}$$

where n is the number of moles of gas in the room subsequent to the explosion, T_g is the gas temperature, and C_p is the heat content of the gas at constant pressure.[1] Thus,

$$nC_p\ \frac{dT_g}{dt} = qA_{walls,\ floor,\ roof} \qquad (1)$$

F.2.0 Moles of Gas

The gas in the panel subsequent to the explosion is a mixture of the combustion products of the explosive gas which is taken to be a mixture of methane, CH_4 and air. Because methane can explode with other than a stoichiometric air/methane mixture (i.e., the methane concentration in air for an explosion to occur is a range as opposed to a single value), it is impossible to determine the number of moles of combustion product gas precisely. Thus, it is assumed that the explosion occurs with a stoichiometric air/methane mixture.

[1]The specific heat at constant volume is used even though the explosion or rapid combustion of the methane-air mixture occurs at constant volume because the rate of change of enthalpy as opposed to internal energy has been used.

F.2.1 Mixture

The stoichiometric reaction for methane is (Bodartha, 1980):

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

with the moles of air given by:

$$n_{air} = 4.77(2) = 9.54 \ mole\ air/mole\ methane$$

or 9.54 moles of air are required to provide 2 moles of oxygen. Using a ratio of 9.54 moles of air per mole of methane, the total moles of gas at the time of the explosion would be:

$$n = (9.54 + 1)n_{CH4}$$

The number of moles of nitrogen in the air and in the combustion products gas is 3.77(2) = 7.54 moles/mole of methane (Bodartha, 1980). Thus,

$$7.54 \text{ moles } N_2 + 2 \text{ moles } O_2 + 1 \text{ mole } CH_4 =$$
$$7.54 \text{ moles } N_2 + 1 \text{ mole } CO_2 + 2 \text{ moles } H_2O$$

On a molar basis the reaction products are 71.5% nitrogen, 9.5% carbon dioxide, and 19% water vapor. This compares with a reaction product that is 72.9% nitrogen, 11.6% carbon dioxide and 15.5% water vapor when propane is burned at a stoichiometric ratio (D'Appolonia, 1978). Also, 10.54 moles of the methane-air mixture produces 10.54 moles of reaction products. Thus, the number of moles of air/methane prior to the explosion is the same as the number of moles of the product gas and the above relation for n will be used to compute the heat content in a panel prior to cooling.

$$n_{gas} = 10.54\ n_{CH4} \qquad (2)$$

Substituting (2) into (1),

$$10.54\ n_{CH4}\ C_p\ \frac{dT_g}{dt} = qA_{walls,\ floor,\ roof}$$

or

$$\frac{dT_g}{dt} = \frac{qA_{walls,\ floor,\ roof}}{10.54\ n_{CH4}\ C_p} \tag{3}$$

is the differential equation for the time rate of change of the gas temperature in the panel following an explosion.

F.2.2 Specific Heat

The specific heat, Cp, of the combustion products of the explosion is required by equation (3). In general, the specific heat is a function of temperature over large temperature ranges. Figure C-1 shows plots of specific heats of the combustion products of stoichiometric propane-air mixtures and methane-air mixtures based on data from D'Appolonia (1978) and Reid, et al., (1977). The curves for propane-air mixtures are shown for comparison between the Reid, et al. data and the D'Appolonia data.

For an explosion temperature on the order of 2400 degrees kelvin (°K), and using an average of the wall temperature and gas temperature to evaluate the specific heat, the temperature dependence curve will be evaluated in the region of 1400 °K which is about the maximum useful temperature for the Reid, et al. data.

As shown on Figure F-1, the Reid et al. (1977) and D'Appolonia (1978) data agree well up to a temperature of approximately 1400 °K. At the greater temperatures Reid et al. (1977), and other data indicate a decrease in specific heat with greater temperatures which is not consistent with expectation.

Figure F-2 shows a comparison of Reid et al. (1977) and the D'Appolonia (1978) data multiplied by 0.961, the ratio of specific heats for a methane-air mixture to a propane-air mixture at 300 °K. Below 1400 °K the agreement is very good. Above 1400 °K the curve based on the D'Appolonia data remains valid. Therefore, the specific heat of the combustion products formed from a stoichiometric methane air mixture as a function of temperature is[2]

$$C_p = 1.29\ x\ 10^{-3}\ T + 7.3353 - \frac{32682}{T^2} \tag{4}$$

[2]Equation (4) was obtained by multiplying Equation (9) of Appendix B of D'Appolonia [1978] by 0.961.

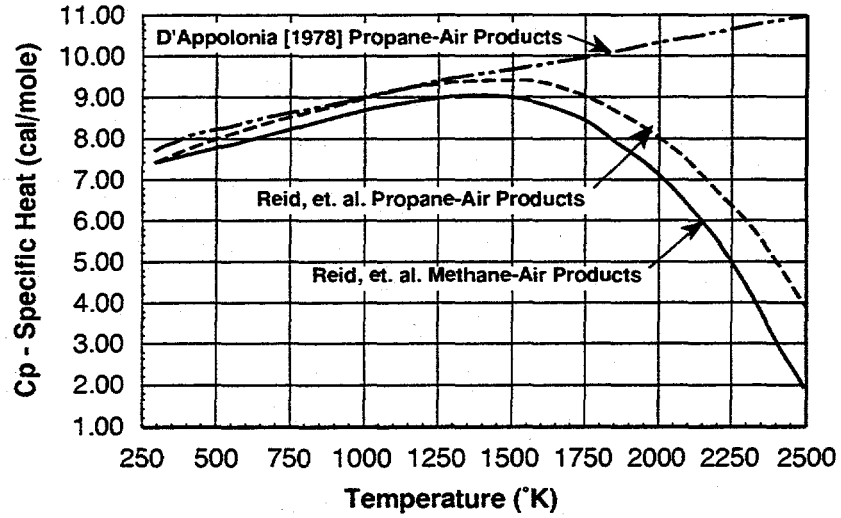


Figure F-1
Specific Heat as a Function of Temperature

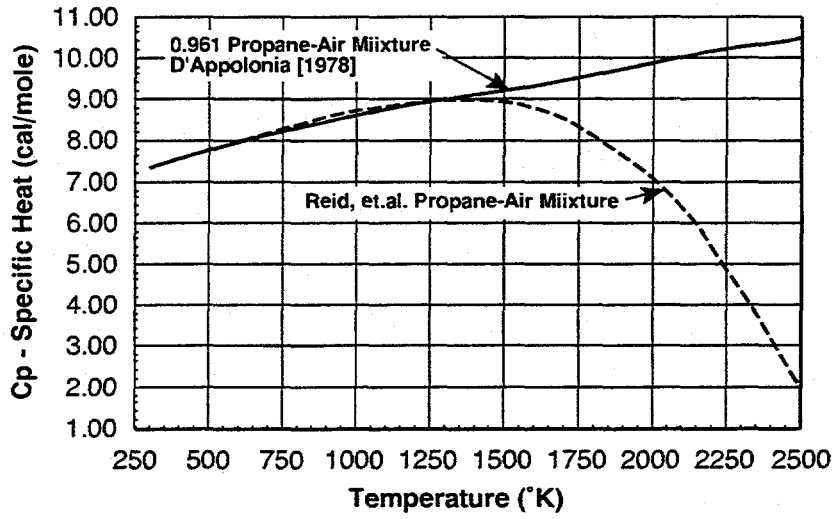


Figure F-2
Specific Heat for Methane-Air Stochiometric Mixture

F.3.0 Heat Transfer to the Walls, Floor, Etc.

Heat is transferred from the gas to the surrounding walls, floor and roof of the panel rooms by both convection and radiation. Heat is then transferred into the walls, floor, roof, via conduction. Thus, the rate of heat conduction into the salt or the wall is governed by the rate at which heat can be conducted into the solids.

F.3.1 Radiation Heat Transfer

Heat transferred from the gas to the walls, floor, roof, is given by:

$$q_{rs} = \sigma\left(T_g^4 - T_w^4\right)$$

where q_{rs} is the heat flux to the walls, floor, roof, σ is the Stefan-Boltzmann constant (1.35×10^{-12} cal/cm^2-sec-°K), and T_w is the temperature of the walls, floor, and roof.

The majority of the surface area of the panel available for heat transfer via both radiation and convection is salt. However, a small portion of the total area will be the inner face of the explosion-isolation wall (or construction-isolation well). Because the wall, floor, roof temperature is controlled by the time dependent conduction of heat into either the walls, floor, roof or the wall faces, and the diffusivities and conductivities of the salt and wall, floor, roof material may be different, the radiation heat transfer is divided into two components.

The radiative heat transfer to the salt (T_{ws}) is:

$$q_{rs} = \sigma\left(T_g^4 - T_{ws}^4\right)$$

and the radiative heat transfer to the explosion-isolation wall (T_{wb}) is:

$$q_{rb} = \sigma\left(T_g^4 - T_{wb}^4\right)$$

The combined radiative heat transfer to the walls, floors, roof is:

$$Q_r = q_{rs}A_s + q_{rb}A_b$$

or

$$Q_r = \sigma\left(A_s\left[T_g^4 - T_{ws}^4\right] + A_b\left[T_g^4 - T_{wb}^4\right]\right) \quad (5)$$

where A_b = Area of the walls, and A_s = area of the salt.

Equation (5) comprises the radiation portion of the right hand side of the differential equation, (3), for the rate of gas temperature in the panel.

F.3.2 Convection Heat Transfer

In addition to radiation, heat is transferred to the walls, floor, roof, and explosion-isolation walls by natural convection. In subsequent discussion, walls denote all exposed surface area of salt within a panel. Explosion-isolation walls denote the surface area of the expendable walls placed in the sealed air-intake and air-exhaust drifts of the panel.

F.3.2.1 Heat Transfer from Gas to the Walls

In addition to radiation, heat is transferred to the walls, floor, roof, and explosion-isolation walls via natural convection. The heat flux due to convection (q_c) is given by:

$$q_c = h\left(T_b - T_w\right)$$

where h = Film coefficient.

As for the case of radiation, the majority of heat transfer by convection will occur to the surrounding salt. However, a portion will be transferred to the explosion-isolation wall. Because the temperature of the explosion-isolation wall may be different from the temperature of the salt, the convective heat transfer is divided into the two components analogous to the radiation heat transfer. For the salt, the convection heat transfer is:

$$q_{cs} = h\left(T_g - T_{ws}\right)$$

and for the explosion-isolation walls:

$$q_{cb} = h\left(T_g - T_{wb}\right)$$

The combined radiative heat transfer (Q_c) to the walls, floors, roof, and explosion-isolation walls is:

$$q_{cb} = h\left(T_g - T_{wb}\right)$$

The combined radiative heat transfer (Q_c) to the walls, floors, roof, and explosion-isolation walls is:
assuming that the heat transfer coefficient does not change with location or material.

$$Q_c = q_{c\ NaCl}\ A_s + q_{cb} A_b$$

Theoretically the convective heat transfer coefficient is different for the face of the explosion-isolation walls, which are vertical compared with the heat transfer coefficient for the roof and floor faces of the panel which are horizontal. Neglecting the difference in heat transfer coefficient due to geometric differences, the above two equations for the heat flow to the walls, floor, roof, and explosion-isolation walls can be combined to give

$$Q_c = h\left(A_s\left[T_g - T_{ws}\right] + A_b\left[T_g - T_{wb}\right]\right) \tag{6}$$

Equation (6) gives the convective heat transfer portion of the right hand side of Equation (3). Combining (3), (5) and (6),

$$\frac{dT_g}{dt} = -\frac{Q_c + Q_r}{10.54\ n_{CH4}\ C_p} \tag{7}$$

where the negative sign indicates that Q_c and Q_r represent heat transferred out of the system consisting of the gas in the room. These same quantities then represent heat transferred into the surrounding salt and explosion-isolation wall.

F.3.2.2 Convection Coefficient

Assuming the convection coefficient is the same at all surfaces and following the methods developed in D'Appolonia (1978), with all units in the centimeter-gram-second (cm-g-sec) system of units,

$$N_u = 0.13[P_r G_r]^{1/3}$$

where P_r is the Prandtl number and G_r is the Grashof number. The Prandtl number is essentially constant and is taken as 0.71 regardless of pressure and temperature. The Grashof number is given by

$$G_r = \frac{g\beta L^3(T_g - T_w)}{\nu^2}$$

where g is the acceleration of gravity, β is the volume coefficient of thermal expansion and ν is the kinematic viscosity of the gas. For ideal gases,

$$\beta = \frac{1}{T_g}$$

and the kinematic viscosity is given by

$$\nu = \frac{\mu}{\rho}$$

where μ is the absolute viscosity ρ = mass density. Substituting for n and β in the expression for the Grashof number,

$$G_r = \frac{g\rho^2 L^3(T_g - T_w)}{T_m \mu^2}$$

where

$$T_m = \frac{T_g + T_w}{2}$$

is the average of the gas and surface temperature.

Substituting for the Grashof number and Prandtl number in the expression for the Nusselt number,

$$N_u = 0.13\left(0.71\frac{g\rho^2 L^3[Tg-T_w]}{T_m\mu^2}\right)^{1/3}$$

$$N_u = 0.146L\left(\frac{g\rho^2}{\mu^2}\left[\frac{T_g-T_w}{T_g+T_w}\right]\right)^{1/3}$$

and substituting for the Nusselt number in the expression for the convection coefficient,

$$h = 0.146k_g\left(\frac{g\rho^2}{\mu^2}\left[\frac{T_g-T_w}{T_g+T_w}\right]\right)^{1/3}$$

Since the thermal conductivity of the gas is given by[3]

$$k_g = 6.4\ x\ 10^{-5}\left(\frac{T_m}{300}\right)^{.75}$$

$$h = 9.34\ x\ 10^{-6}\left(\frac{T_g+T_w}{600}\right)^{.75}\left(\frac{g\rho^2}{\mu^2}\left[\frac{T_g-T_w}{T_g+T_w}\right]\right)^{1/3} \qquad (8)$$

Figure F-3 shows h as a function of surface temperature based on a gas temperature of 2400°K and density and viscosity consistent with conditions at the time of an explosion.

Assuming that no additional gas is generated subsequent to the explosion, the density of the gas after the explosion is the same as before the explosion since mass is conserved. Thus, the gas density after the explosion is the molecular weight of n moles of methane plus 9.54n moles of air divided by the initial volume,

[3]D'Appolonia [1978].

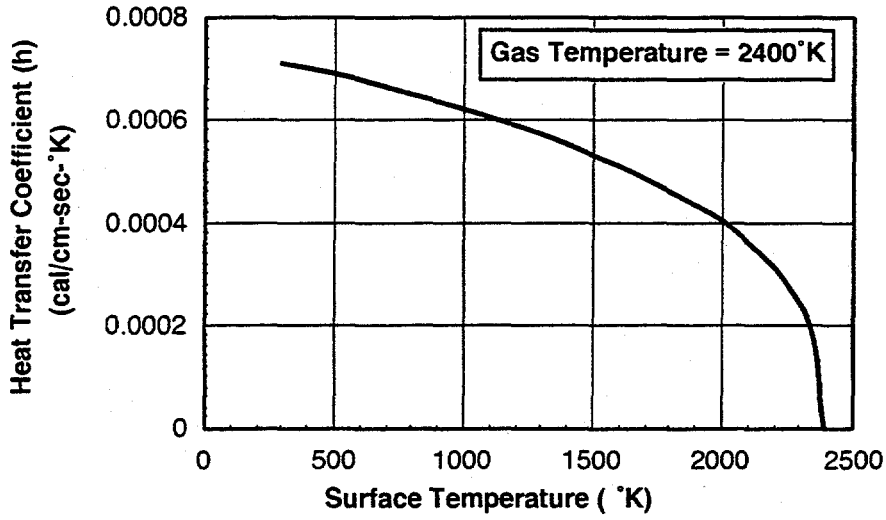


Figure F-3
Convection Heat Transfer Coefficient Versus Temperature

$$\rho = n\left(\frac{M_{w\,CH4} + 9.54M_{w\,air}}{V_{init}}\right)$$

$$\rho = n\left(\frac{16 + 9.54(29)}{V_{init}}\right)$$

$$\rho = \frac{292.66n}{V_{init}} \tag{9}$$

$$\mu = 1.85\ x\ 10^{-4}\left(\frac{T_m}{300}\right)^{0.67} \tag{10}$$

and the viscosity is given by (D'Appolonia, 1978), where the viscosity is evaluated at the average of the surface and gas temperatures.

Because there will be two different surface temperatures, one corresponding to the salt, and one for the explosion-isolation wall, there will be different convective heat transfer coefficients as well.

F.3.3 Conduction Into the Walls, Floor, Roof, and Explosion-Isolation Walls

The temperature which controls the heat transfer from the gas via radiation and convection is controlled by the rate at which heat is conducted into the walls, roof, floor, and explosion-isolation walls. The diffusion of heat into the walls, floor, roof, and explosion-isolation walls is assumed to be governed by a one-dimensional, semi-infinite thermal diffusion model. If the temperature penetrates the explosion-isolation walls, the model is changed to be thermal diffusion across a slab of finite thickness with an ambient gas temperature on the side in the isolation zone.

Thermal diffusion into the walls, floor, roof, and explosion-isolation walls is governed by the partial differential equation,

$$\alpha \frac{\partial^2 T}{\partial x^2} = \frac{\partial T}{\partial t}$$

where α is the thermal diffusivity, T is the temperature, x is the distance into the wall, floors, roof, or explosion-isolation walls, and t is time. At x = 0 the flow of heat into the walls, floor, roof, or explosion-isolation walls is governed by the boundary condition,

$$-k \frac{\partial T}{\partial x} = q_{in}$$

where q_{in} is the heat flux into the walls, etc. from the gas via convection and radiation and k is the thermal conductivity. Because the thermal diffusivity and conductivity for salt is different from that of the explosion-isolation wall, two conduction models are required.

F.3.3.1 Heat Conduction to the Salt

The first involves the heat transferred from the gas to the salt and is governed by the partial differential equation,

$$\alpha_s \frac{\partial^2 T_s}{\partial x^2} = \frac{\partial T_s}{\partial t} \qquad (11i)$$

where α_s is the thermal diffusivity of salt which is a function of temperature. Figure F-3 shows plots of thermal diffusivity for halite, anhydrite, argillaceous halite and polyhalite (Krieg, 1983). Figure F-4 also shows data from D'Appolonia (1978) that used the relation

$$\alpha_s = \frac{10}{T_s}$$

for salt. The D'Appolonia temperature dependence yields slightly higher values compared with the Waste Isolation Pilot Plant (WIPP) data, but indicates a consistency in the data. For purposes of the post-explosion heat transfer analysis the temperature dependent data for salt has been used.

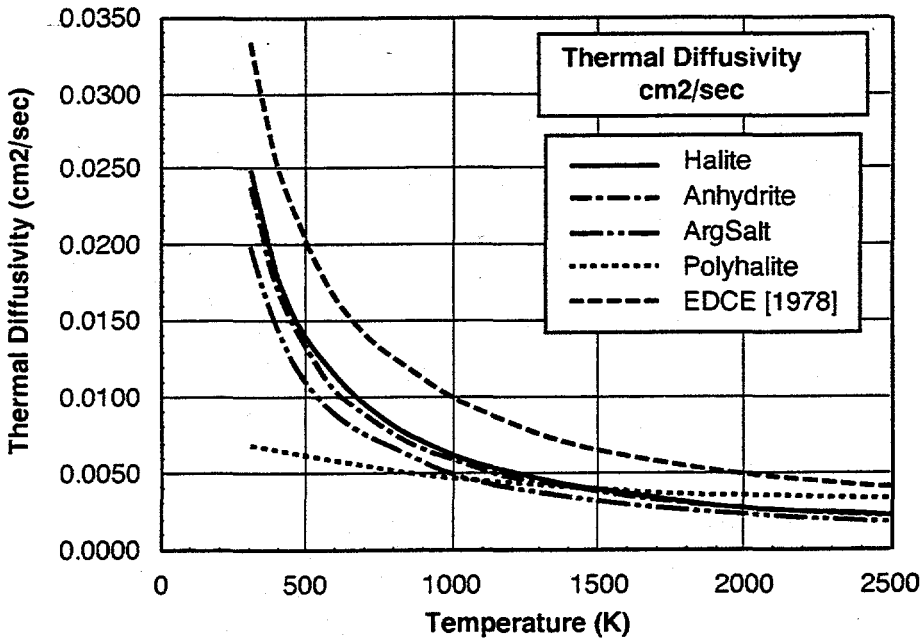


Figure F-4
Thermal Diffusivity of WIPP Geologic Materials

$$\alpha_s = 0.025\left[\frac{300}{T_s}\right]^{1.14} \tag{12i}$$

The boundary condition at the surface of the salt is:

$$-k_s\frac{\partial T_s}{\partial x} = q_{sr}+q_{sc} \tag{13i}$$

where k_s is the thermal conductivity of the salt. Figure F-4 shows plots of thermal conductivities for the same materials as a function of temperature. Again, the thermal conductivity from D'Appolonia (1978):

$$k_s = \frac{4.5}{T_s}$$

is also shown on Figure F-5 to check the consistency of the WIPP data. Again, the thermal conductivity for halite was used for the post-explosion heat transfer analysis.

$$k_s = 0.012\left[\frac{300}{T_s}\right]^{1.14} \tag{14i}$$

The terms q_{sr} and q_{sc} in (13i) couple the heat conduction into the salt with the rate of cooling of the gas via equations (7) through (10). In addition to the boundary conditions given by (12i), initial conditions at time t = 0 are required. It is assumed that at t = 0 the salt is at the ambient temperature in the panel, T_{amb}. Equations (11i) through (14i) with the initial conditions form the complete problem for the temperature in the salt as a function of time as the gas cools following the explosion.

F.3.3.2 Heat Conduction to the Explosion-Isolation Walls

The second model involves the heat transferred from the gas to the explosion-isolation walls and is governed by the partial differential equation,

$$\alpha_b\frac{\partial^2 T_b}{\partial x^2} = \frac{\partial T_b}{\partial t} \tag{11ii}$$

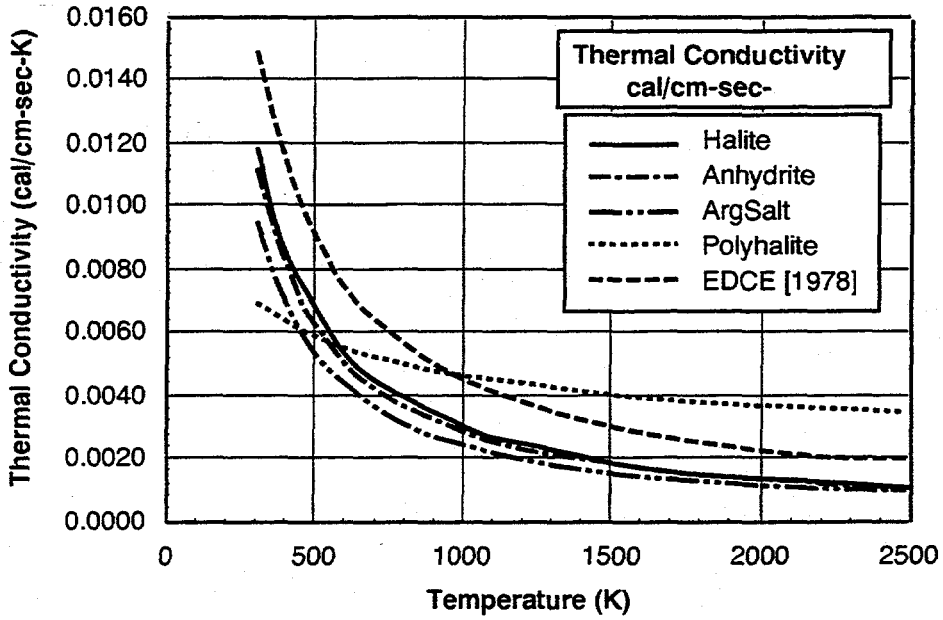


Figure F-5
Thermal Conductivity of WIPP Geologic Materials

where α_b is the thermal diffusivity of explosion-isolation walls. If the explosion-isolation walls are concrete, the thermal diffusivity does not vary with temperature (D'Appolonia, 1978),

$$\alpha_s = 0.005 \tag{12ii}$$

The boundary condition is:

$$-k_b \frac{\partial T_b}{\partial x} = q_{br} + q_{bc} \tag{13ii}$$

where q_{br} = heat flux for the salt, q_{bc} = heat flux for explosion-isolation walls, and k_b is the thermal conductivity of the walls. Again, if the explosion-isolation walls are concrete, the thermal conductivity is constant (D'appolonia, 1978).

$$k_b = 0.002 \tag{14ii}$$

Analogous to the case for salt, the terms q_{br} and q_{bc} in (13ii) couple the heat conduction into the salt with the rate of cooling of the gas via equations (7) through (10). At t = 0 the explosion-isolation walls are at the ambient temperature at the panel level, T_{amb}.

F.4.0 Numerical Model

Equations (1) through (14) were solved using a computer program based on an explicit finite difference representation of the equations. In subsequent discussion the following symbols are used,

τ	=	time step Δt
ε	=	distance between mesh points, Δx, in finite difference representation of semi-infinite solid used to model the explosion-isolation walls.
n	=	subscript denoting the value of a variable at time t.
n+1	=	subscript denoting the value of a variable at time $t+\tau$.
m	=	subscript denoting the value of a variable at mesh point m in a finite difference representation of a semi-infinite solid. m = 0 corresponds to the boundary x = 0.
$T_{g\,n}$	=	gas temperature at time t.
T_{s0}	=	temperature at x = 0 in salt.
T_{b0}	=	temperature at x = 0 in an explosion-isolation wall.
T_{smn}	=	temperature in salt at mesh point m and time n.
T_{bmn}	=	temperature in explosion-isolation walls at mesh point m and time n.
α_{sm}	=	thermal diffusivity in salt at mesh point m (function of temperature).

α_{bm} = thermal diffusivity of explosion-isolation wall material at mesh point m (may be constant or a function of temperature).
q_{rsn} = heat flux to wall (salt) via radiation at time point n.
q_{rbn} = heat flux to explosion-isolation wall via radiation at time point n.
q_{csn} = heat flux to wall (salt) via convection at time point n.
q_{cbn} = heat flux to explosion-isolation wall via convection at time point n.

Where symbols are used for parameters that are a function of temperature and consequently also a function of time, the subscripts n and n+1 refer to whether the parameter is evaluated at t or t + Δt.

F.4.1 Overview of Computer Program

Figure F-6 provides a simplified flow chart of the computer program used to solve the equations in the model in explicit finite difference form.

F.4.2 Finite Difference Formulation

For the first past through the calculational loop n = 0 and the gas temperature is set to T_{g0}, the initial temperature. Based on the assumption of constant volume during the explosion, the temperature is related to the pressure by,

$$T_{g0} = T_{gamb}\left(\frac{P_0}{P_{amb}}\right) = 8T_{gamb} \qquad (15)$$

where

T_{gamb} = the gas temperature prior to the explosion
P^{amb} = the gas pressure prior to the explosion (taken as 2 atm)
P_0 = the gas pressure caused by the explosion (taken as 16 atm)
T_{g0} = the gas temperature caused by the explosion which is the initial gas temperature for the cooling analysis.

The initial temperature of the salt (T_{smo}) and explosion-isolation walls (T_{bmo}) for the heat conduction calculations are set to the ambient temperature at all mesh points.

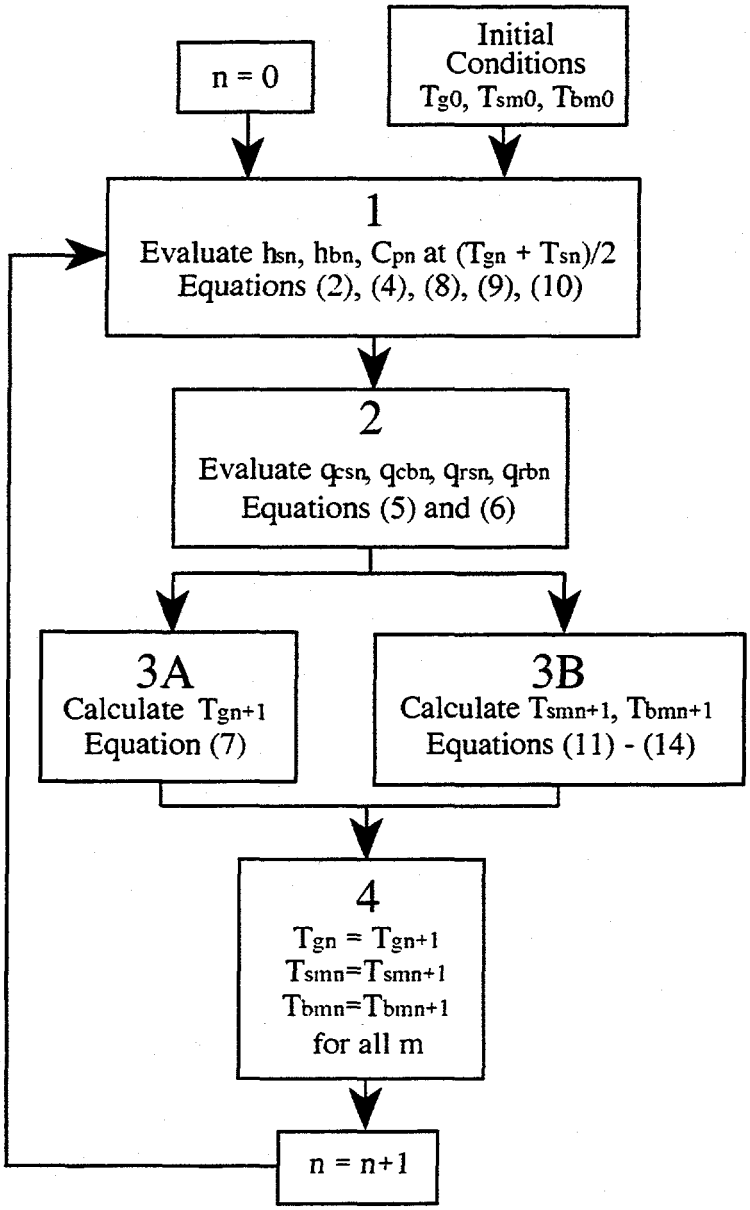


Figure F-6
Program Flow Chart

$$T_{sm0} = T_{amb} \quad m = 1 \ldots M$$
$$T_{bm0} = T_{amb} \quad m = 1 \ldots M \tag{16}$$

where M is the maximum mesh point number used in the finite difference representation of the semi-infinite solid. T_{amb} is the ambient temperature of the salt and explosion-isolation wall at the time of the explosion.

F.4.2.1 Program Section 1

Section 1 of the program (Figure F-3) calculated the parameters required for the determination of the heat fluxes from the hot gas to the cooler walls. These calculations are performed initially based on values for n = 0, initial conditions. Subsequently, they are evaluated based on the temperature values at time point n.

Thus,

$$\mu_{sn} = 1.85 \times 10^{-4} \left(\frac{T_{gn} + T_{s0n}}{600} \right)^{0.67}$$
$$\mu_{bn} = 1.85 \times 10^{-4} \left(\frac{T_{gn} + T_{b0n}}{600} \right)^{0.67} \tag{17}$$

where

μ_{sn} = viscosity of the salt

μ_{bn} = viscosity of the explosion-isolation wall

T_{gn} = gas temperature at time point n

T_{s0n} = wall temperature of the salt at time point n, which is the m = 0 mesh point of the finite difference representation of the semi-infinite solid used to model heat conduction into the salt

T_{b0n} = surface temperature of the explosion-isolation wall.

Since the initial surface temperatures of the salt and the walls are the same, the initial value of μ will be the same at both the salt and the walls. However, with time as the surface temperature of the explosion-isolation walls varies from the surface temperature of the salt, the values of μ will be different for the salt compared with the walls. This plays a role in

having different convection heat transfer coefficients at the salt compared with the explosion-isolation walls.

The convection heat transfer coefficients are given by (8) below.

$$h_{sn} = 9.34 \times 10^{-6}\left(\frac{T_{gn} + T_{s0n}}{600}\right)^{.75}\left(\frac{g\rho^2}{\mu_{sn}^2}\left[\frac{T_{gn} - T_{s0n}}{T_{gn} + T_{s0n}}\right]\right)^{1/3}$$

$$h_{bn} = 9.34 \times 10^{-6}\left(\frac{T_{gn} + T_{b0n}}{600}\right)^{.75}\left(\frac{g\rho^2}{\mu_{bn}^2}\left[\frac{T_{gn} - T_{b0n}}{T_{gn} + T_{b0n}}\right]\right)^{1/3} \qquad (18)$$

The density, ρ, remains constant by virtue of the constant volume and constant number of moles. The acceleration of gravity, g, also remains constant for all time points.

The specific heat of the gas which is required for Section 3A of the program is given by (4) below.

$$C_{pn} = 6.45 \times 10^{-4}\left(T_{gn} + T_{s0n}\right) + 7.3353 - \frac{130728}{\left(T_{gn} + T_{s0n}\right)^2} \qquad (19)$$

Because the specific heat is a bulk property of all of the gas in the panel, it is affected by all of the surface area in the panel. Because the surface area of the salt is orders of magniture larger than the surface area of the explosion-isolation walls, the specific heat at each time is based solely on the surface temperature of the salt.

F.4.2.2 Program Section 2

The heat flux rates to the walls as well as the total heat transfer rates to the walls via convection and radiation are calculated in Section 2 of the program. Flux is required for the boundary condition for the heat conduction analysis of Section 3B and total heat flow is required for the change in gas temperature calculation in Section 3A.

The total heat flow values are given by (5) and (6) which for time step n become where h_{sn} and h_{bn} are given by (18). The total heat flows are used in Section 3A of the program evaluates the time rate of change of the gas temperature using equation (7).

$$Q_{rn} + \sigma\left(A_s\left[T_{gn}^4 - T_{s0n}^4\right] + A_b\left[T_{bn}^4 - T_{b0n}^4\right]\right)$$
$$Q_{cn} = A_s h_{sn}\left(T_{gn} - T_{s0n}\right) + A_b h_{bn}\left(T_{gn} - T_{bn}\right) \quad (20)$$

The total heat flows at time step n given by (20) are heat flow out of the gas occupying the panel volume and into the explosion-isolation walls. For the heat flow into the explosion-isolation walls, the areas, A_s and A_b cancel from the equations representing the boundary conditions at x = 0 for the transient heat conduction problems solved in Section 3B of the program. Thus, for Section 3B, the heat flux values are required. These are the same as (20) without the areas.

$$q_{rn} = \sigma\left(\left[T_{gn}^4 - T_{s0n}^4\right] + \left[T_{gn}^4 - T_{b0n}^4\right]\right)$$
$$q_{cn} = h_{sn}\left(T_{gn} - T_{s0n}\right) + h_{bn}\left(T_{bn} - T_{bn}\right) \quad (21)$$

where q_{rn} and q_{cn} are the heat fluxes due to radiation and convection.

For the total heat flow and heat flux due to radiation, the Stefan-Boltzmann constant is taken to be constand for all values of temperature and hence time.

$$\sigma = 1.355 \times 10^{-12} \quad (22)$$

F.4.2.3 Program Section 3

Section 3 comprises the main body of the program.

F.4.2.3.1 Program Section 3A

Equation (7) governs the rate of change of gas temperature in the panel volume. Using the explicit finite difference approximation,

$$\frac{dT_g}{dt} = \frac{1}{\tau}\left(T_{gn+1} - T_{bn}\right)$$

where $\tau = \Delta t$ is the time increment, Equation (7) becomes

$$T_{gn+1} = T_{gn} - \tau \left(\frac{Q_{cn} + Q_{rn}}{10.54\ n_{CH4}\ C_{pn}} \right) \tag{23}$$

where Q_{cn}, Q_{rn}, and C_{pn} are given by (20) and (19) and n_{CH4} is an input representing the moles of methane in the panel volume at the time of the explosion. Equation (23) gives the gas temperature in the panel at time $t + \Delta t$ in terms of the gas temperature at time t and the total heat flow values at time t.

F.4.2.3.2 Program Section 3B

Section 3B of the program is the most complex. It solves two transient heat conduction problems assuming that the walls, floor, roof, and explosion-isolation walls are semi-infinite solids having thermal conductivities and diffusivities that may or may not be temperature dependent. In the case of the walls, floor and roof, the panel volume the conductivity and diffusivity of salt is dependent on temperature. Assuming that the explosion-isolation wall material is concrete, the conductivity and diffusivity of the explosion-isolation wall are independent of temperature.

Because of the temperature dependence of the conductivity and diffusivity of the salt, and the time-dependent spatial temperature distribution into the walls, floor and roof, the conductivity that is required for the boundary condition at $x = 0$ varies with time and the thermal diffusivity varies in both time and space. The partial differential equation for transient heat conduction when the diffusivity varies spatially is given by:

$$\frac{\partial}{\partial x}\left(\alpha \frac{\partial T}{\partial x} \right) = \frac{\partial T}{\partial t} \tag{a}$$

which can be expanded as:

$$\left(\frac{\partial \alpha}{\partial x} \right)\left(\frac{\partial T}{\partial x} \right) + \alpha \frac{\partial^2 T}{\partial x^2} = \frac{\partial T}{\partial t} \tag{b}$$

Using the finite difference approximations,

$$\frac{\partial \alpha}{\partial x} = \frac{1}{2\varepsilon}\left(\alpha_{m+1} - \alpha_{m-1}\right) \tag{ci}$$

$$\alpha\frac{\partial^2 T}{\partial x^2} = \frac{\alpha_m}{\varepsilon^2}\left(T_{m-1} - 2T_m + T_{m+1}\right) \tag{cii}$$

$$\frac{\partial T}{\partial x} = \frac{1}{2\varepsilon}\left(T_{m+1} - T_{m-1}\right) \tag{cii}$$

where e = Δx, the left hand side of equation (b) becomes

$$\left(\frac{\partial T}{\partial x}\right)\left(\frac{\partial T}{\partial x}\right) + \alpha\frac{\partial^2 T}{\partial x^2} = \frac{1}{4\varepsilon^2}\left(\left[\alpha_{m+1}-\alpha_{m-1}\right]\left[T_{m+1}-T_{m-1}\right]+4\alpha_m T_{m-1}-8\alpha_m T_m+4\alpha_m T_{m+1}\right) \tag{d}$$

or

$$= \frac{1}{4\varepsilon^2}\left(\alpha_{m+1}T_{m+1}-\alpha_{m+1}T_{m-1}-\alpha_{m-1}T_{m+1}+\alpha_{m-1}T_{m-1}\right)+ \frac{1}{4\varepsilon^2}\left(4\alpha_m T_{m-1}-8\alpha_m T_m+4\alpha_m T_{m+1}\right) \tag{e}$$

$$4\varepsilon^2\left(\left[\frac{\partial \alpha}{\partial x}\right]\left[\frac{\partial T}{\partial x}\right]+\alpha\frac{\partial^2 T}{\partial x^2}\right) = v_{m-1}\left(\alpha_{m-1}+4\alpha_m-\alpha_{m+1}\right)-8\alpha_m T_m+T_{m+1}\left(\alpha_{m+1}+4\alpha_m-\alpha_{m-1}\right) \tag{f}$$

Using an explicit finite difference representation of the time derivative as used in Section 3A.

$$\frac{\partial T_m}{\partial t} = \frac{1}{\Delta t}\left(T_{m\,n+1}-T_{m\,n}\right) \tag{g}$$

Substituting (f) and (g) into the partial differential equation (a),

$$T_{m-1\ n}\left(\alpha_{m-1}+4\alpha_m-\alpha_{m+1}\right)-8\alpha_m T_{m\ n}+T_{m+1\ n}\left(\alpha_{m+1}+4\alpha_m-\alpha_{m-1}\right) = \frac{1}{N}\left(T_{m\ n+1}-T_{m\ n}\right) \tag{h}$$

where

$$N = \frac{\Delta t}{4\varepsilon^2} \tag{i}$$

is analogous to the modulus for the case of constant diffusion. Solving (h) for $T_{m\ n+1}$

$$T_{m\ n+1} = T_{m-1\ n}N\left(\alpha_{m-1}+4\alpha_m-\alpha_{m+1}\right)-\left(8N-1\right)\alpha_m T_{m\ n}+T_{m+1\ n}N\left(\alpha_{m+1}+4\alpha_m-\alpha_{m-1}\right) \tag{j}$$

For the case of constant diffusivity,

$$\alpha_{m-1} = \alpha_m = \alpha_{m+1} = \alpha$$

with

$$M = \frac{\alpha\Delta t}{\varepsilon^2} = 4\alpha N \tag{k}$$

equation (j) becomes

$$T_{m\ n+1} = M\left(T_{m+1\ n}+T_{m-1\ n}\right)-\left(2M-1\right)T_{m\ n} \tag{l}$$

which is the finite difference equation for the case of constant diffusivity (Carslaw and Jaeger, 1959). Thus, equation (j) reduces to the correct equation when the diffusivity is constant and is the finite difference equation for the case of variable diffusivity.

For a numerical stability criteria,

$$M<0.5 \tag{m}$$

the corresponding relation for the case of variable diffusivity becomes equation (n) for all m.

$$MAX(\alpha_m N) < 0.125 \qquad \text{(n)}$$

The thermal conductivity and thermal diffusivity at each time point are evaluated from the temperature at that time and space as given previously for the temperature variation of the conductivity and diffusivity.

The boundary condition at x = 0, is the same as for the case of constant diffusivity,

$$-k_n \frac{\partial T_n}{\partial x} = q_{rn} + q_{cn} \qquad \text{(o)}$$

where q_{rn} and q_{rn} are determined in Section 2. Using the finite difference relationship (Carslaw and Jaeger, 1959),

$$\frac{\partial T_n}{\partial x} = \frac{1}{2e}\left(-3T_{0\,n} + 4T_{1\,n} - T_{2\,n}\right) \qquad \text{(p)}$$

equation (o) becomes:

$$-\frac{k_n}{2\varepsilon}\left(-3T_{0\,n} + 4T_{1\,n} - T_{2\,n}\right) = q_{rn} + q_{cn}$$

$$3T_{0\,n} - 4T_{1\,n} + T_{2\,n} = \frac{2\varepsilon}{k_n}\left(q_{rn} + q_{cn}\right) \qquad \text{(q)}$$

Substituting for q_{rn} and q_{cn}:

$$3T_{0\,n} - 4T_{1\,n} + T_{2\,n} = \eta_n\left(T_{gn} - T_{0n}\right) + \gamma_n\left(T_{gn}^4 - T_{0n}^4\right)$$

where

$$\eta_n = \frac{2\varepsilon h_n}{-k_n} \qquad \text{(r)}$$

and

Using the identity
and defining

$$\gamma_n = \frac{2\varepsilon\sigma}{k_n} \tag{s}$$

$$T_{gn}^4 - T_{0n}^4 = (T_{gn} - T_{0n})(T_{gn} + T_{0n})\left(T_{gn}^2 + T_{0n}^2\right)$$

$$f_n = (T_{gn} + T_{0n})\left(T_{gn}^2 + T_{0n}^2\right) \tag{t}$$

$$3T_{0n} - 4T_{1n} + T_{2n} = (\eta_n + \gamma_n f_n)(T_{gn} - T_{0n}) \tag{u}$$

For the case of both convection and radiation equation (u) is a fourth order equation in T_{0n} and has to be solved using a numerical technique such as Newton-Raphson iteration. Since the effect of radiation heating of the walls, floor, roof, and explosion-isolation walls leads to a more rapid cooling of the combustion gas following the explosion, and temperatures effects on the salt or explosion-isolation material is worse for longer durations, it is conservative to neglect radiation heat transfer. In this case, equation (u) becomes linear:

$$3T_{0n} - 4T_{1n} + T_{2n} = \eta_n (T_{gn} - T_{0n}) \tag{v}$$

which can be solved directly for T_{0n}:

$$T_{0n} = \frac{4T_{1n} - T_{2n} + \eta_n T_{gn}}{3 + \eta_n} \tag{w}$$

At each time the field equations are solved based on the previous time. The boundary condition (w) is then applied.

Equations (j) and (u) are formulated for both the salt comprising the walls, floor, and roof and for the explosion-isolation walls. As noted, the field equations for variable diffusivity reduce appropriately to the special case of a constant diffusivity so the above equations are sufficiently general to handle both the material of the explosion-isolation wall and the salt.

F.4.2.4 Program Section 4

In Section 4 of the program, the temperature values at time t+Δt (n+1) become the new values at time t (n). The time counter, n, is incremented by 1 and the program returns to Section 1 to compute the solution at the subsequent time step.

F.4.3 Initial Volume, Surface Area and Number of Moles

The volume of gas to be cooled via heat transfer to the walls, roof, floor, and explosion-isolation walls following an explosion is taken to correspond to the effective panel volume at the time when the air-methane mixture in the panel enters the explosive range. The effective volume is defined as:

$$V_{eff} = \phi V$$

where V is the panel volume considering closure of the panel and Φ is the porosity which accounts for the waste emplaced in the panel. Figure F-7 shows a plot of the effective volume as a function of time.

Based on Figure 4.2 of the Conceptual Design Report (DOE, 1995), the methane-air mixture in the panel volume enters the explosive range at 25 years. From Figure F-7 this corresponds to a panel volume of 1.6×10^{10} cm^3 at the time the postulated explosion occurs.

The surface area at the time of the postulated explosion was obtained from the volume at the time the methane air mixture enters the explosive range at 25 years and the initial ratio of surface area to volume.

$$A_s = \left(\frac{A_{sinit}}{V_{init}} \right) V$$

Figure F-8 shows a plot of panel surface area as a function of time.

Based on the air-methane mixture entering the explosive range at 25 years, the surface area at the time of the explosion is 1.6×10^8 cm^2. The area of two 14 foot x 14 foot explosion-isolation walls is 1.82×10^5 cm^2. Thus the area of the explosion-isolation walls is

$$\frac{1.82 \; x \; 10^5}{1.6 \; x \; 10^8} = 0.0014 = 0.14\%$$

of the total surface area.

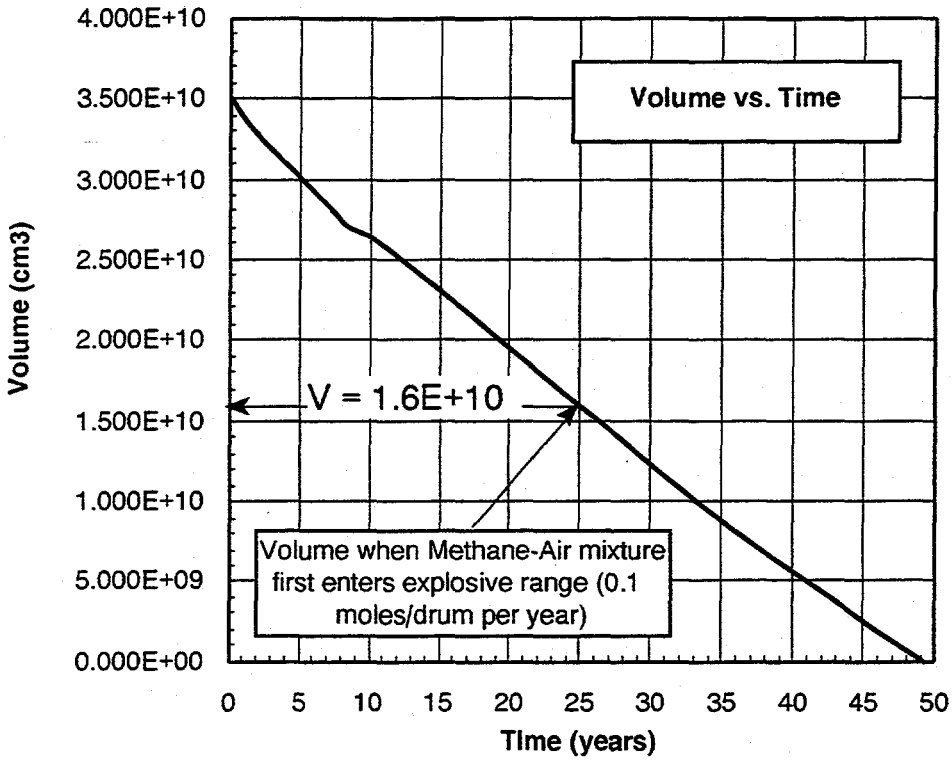


Figure F-7
Effective Panel Volume vs Time

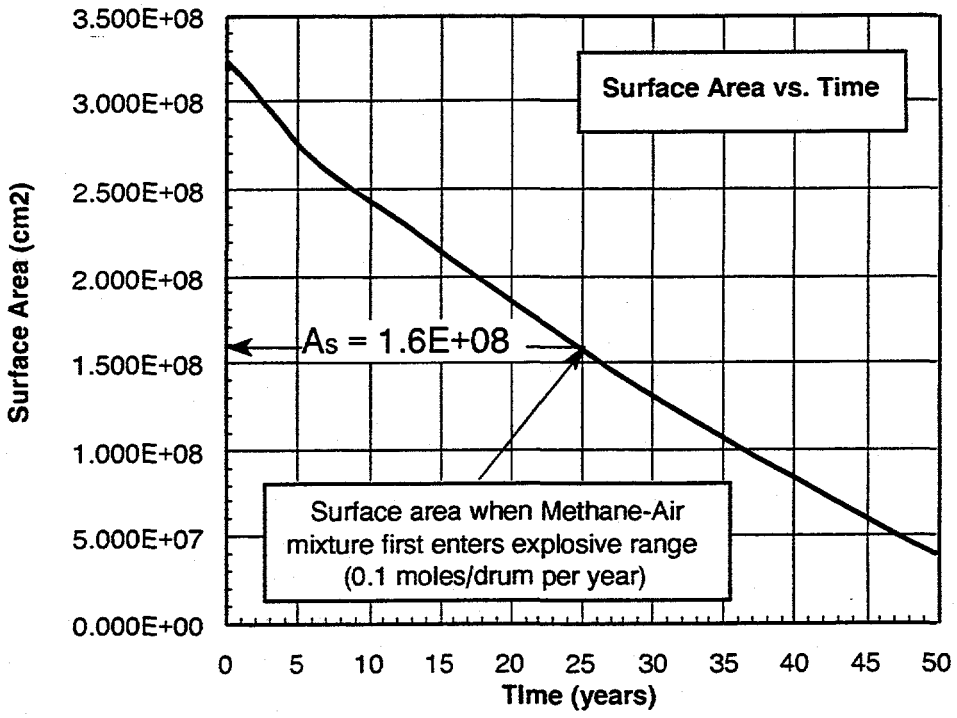


Figure F-8
Surface Area Rooms, Floor and Roof vs Time

The number of moles of combustion gas is found using the ideal gas law based on an initial pressure of 16 atmospheres (atm) and an initial temperature of 2,400 °K.

$$n = \frac{pV}{RT} \tag{24}$$

with

R = 82.06 cm^3-atm/mol-°K (ideal gas law constant)
p = 16 atm
V = 1.6×10^{10}
T = 2400 °K

$$n = \frac{16 \; x \; (1.6 \; x \; 10^{10})}{82.06 \; x \; 2400}$$

$$n = 1.3 \; x \; 10^6 \; moles$$

The program uses the number of moles of methane and air independently to calculate the density. Thus,

$$10.54 \; n_{CH4} = 1.3 \; x \; 10^6 \tag{25}$$

$$n_{CH4} = 1.233 \; x \; 10^5$$

$$n_{air} = 9.54 \; x \; n_{CH4} = 1.176 \; x \; 10^6$$

The density is given by

$$\frac{(1.233 \; x \; 10^5)(16) \; + \; (1.176 \; x \; 10^6)(29)}{1.6 \; x \; 10^{10}} = 0.002255$$

F.5.0 Results

The numerical formulation discussed in Section 4.0 was executed using a spatial grid size, ε - 1 cm and a time increment, τ = 10 seconds. No problems with numerical stability were encountered using these values.

At time t = 0, the initial heat transfer from the combustion gas to the salt and explosion-isolation walls results is a large temperature gradient at the surface. To represent this gradient accurately using a finite difference formulation would require an extremely small grid spacing as the initial temperature gradient extends only an infinitesimal distance into the surface. Using a grid spacing sufficiently small to accurately characterize the initial gradient would be prohibitive, relative to the number of mesh points and time steps required.

The initial conditions for the finite difference calculations were determined by using an exact solution for the case of constant convective heat transfer coefficient and constant gas temperature. The use of the closed form solution to determine the initial conditions assumes that the change in gas temperature over small initial times is small and that the heat transfer coefficient is weakly dependent on the temperature difference between the gas and the surfaces of the salt and explosion-isolation walls. Based on the closed form solution, the initial conditions for the finite difference model were taken at a time of 12.7 seconds following the explosion. For shorter initial times, the gradient had not propagated sufficiently far into the surfaces to be represented with a 1 cm. grid spacing. Thus, the initial time for the finite difference calculations was 12.7 seconds with initial temperatures based on the closed form solution.

Figure F-9 shows the gas temperature, salt temperature (walls, floor, and roof) and explosion-isolation wall temperature as a function of time following the explosion. Figure F-10 shows the temperature distribution into the explosion-isolation walls at various times following the explosion. Figure F-11 shows the temperature distribution into the salt at various times following the explosion.

Figure F-9 shows that the temperature of the gas has nearly reached the initial ambient conditions after about 2 hours. Over that span of time, elevated temperature in the explosion-isolation wall has a maximum extent of 15 cm (about 6 inches) into the explosion-isolation wall. Since the explosion-isolation wall is at least 36 inches (91.4 cm) thick, the elevated temperature will not reach the opposite side of the wall. Thus, the assumption of a semi-infinite body in the numerical model is not violated.

A comparison of the results shown on Figure F-9 with the results given in D'Appolonia (1978) is favorable. The ratios of surface area and volume used in D'Appolonia (1978) as well as the initial pressures are not the same as used for this analysis. The temperatures shown on Figure F-9 are slightly higher than those predicted for a pressure of 9 atm as shown

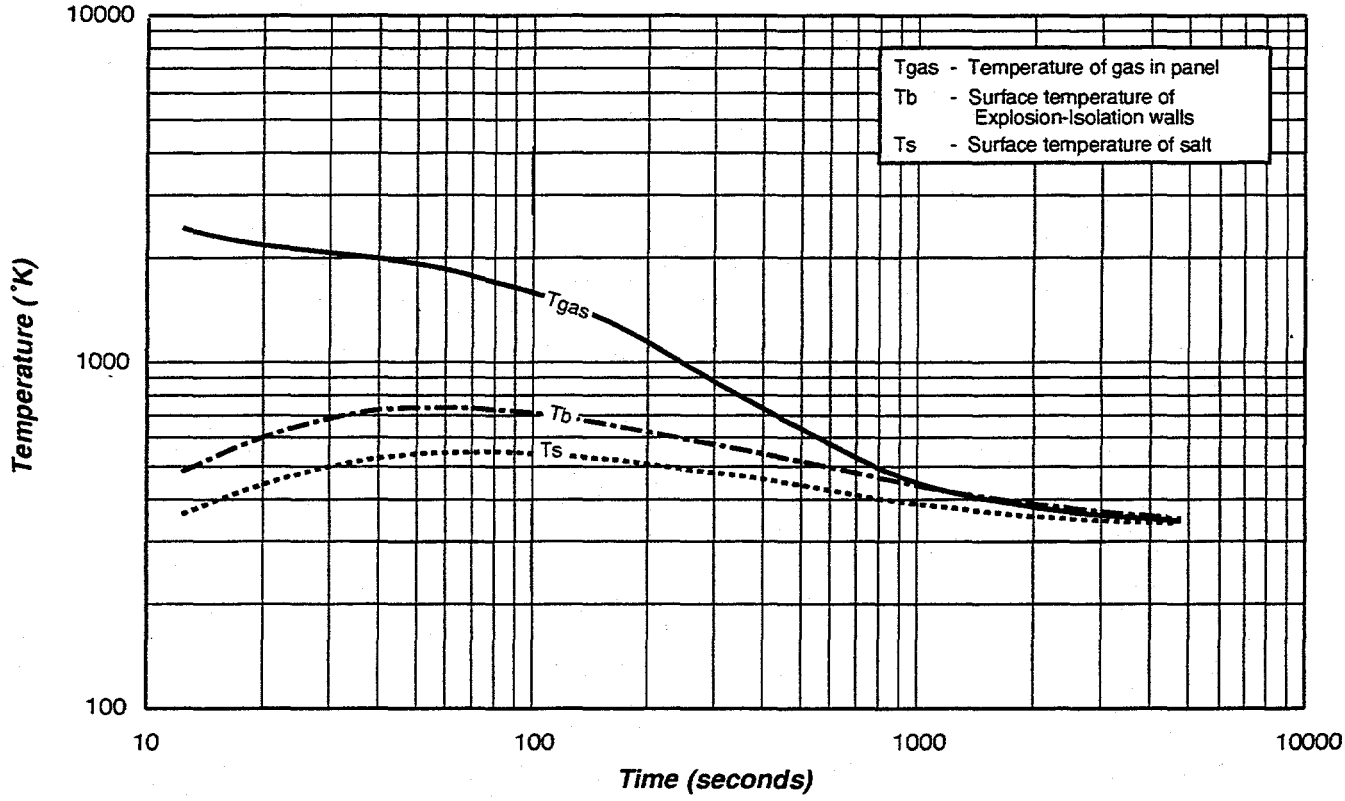


Figure F-9

Temperature Variation with Time for Gas, Salt, and Explosion-Isolation Walls

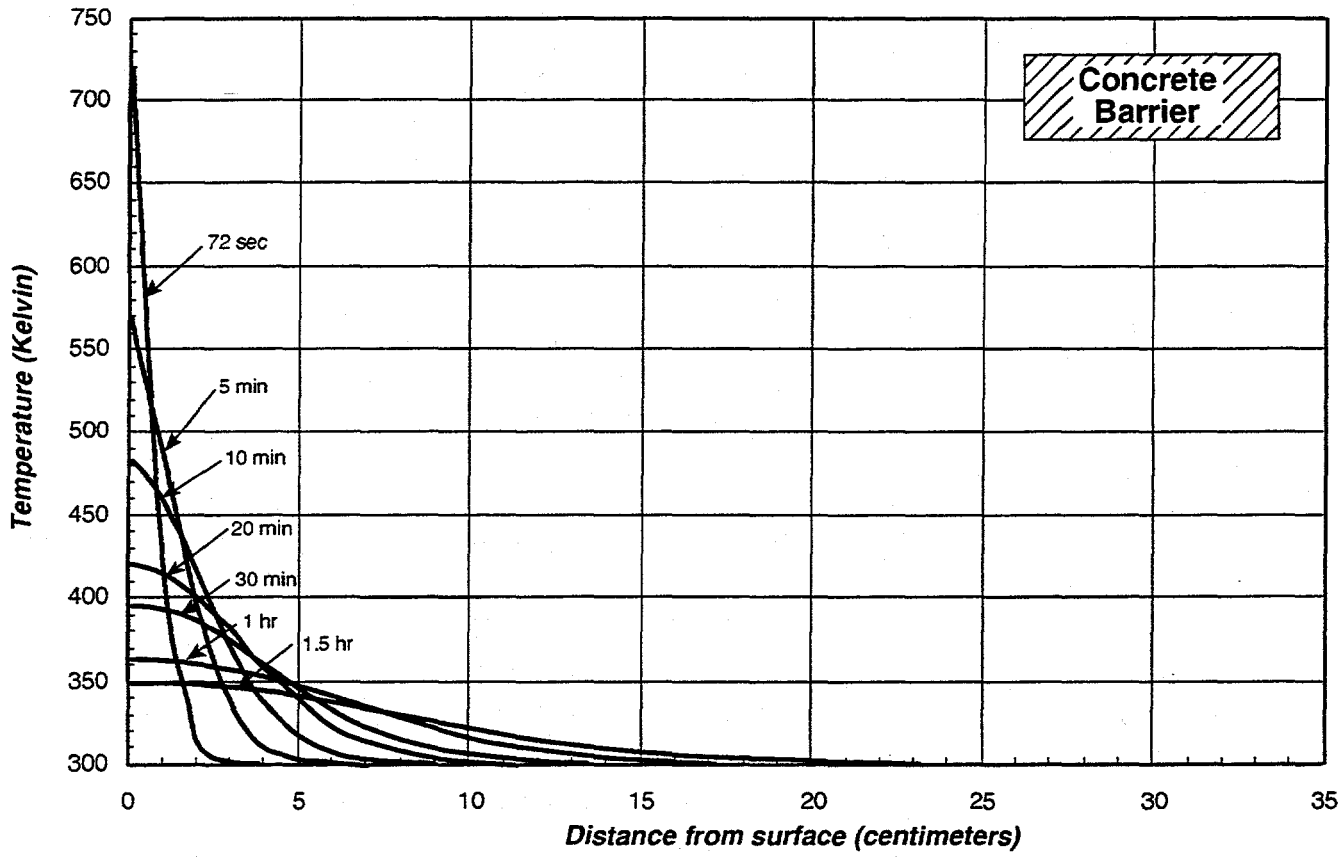


Figure F-10
Temperature Distribution with Time for Concrete Barrier

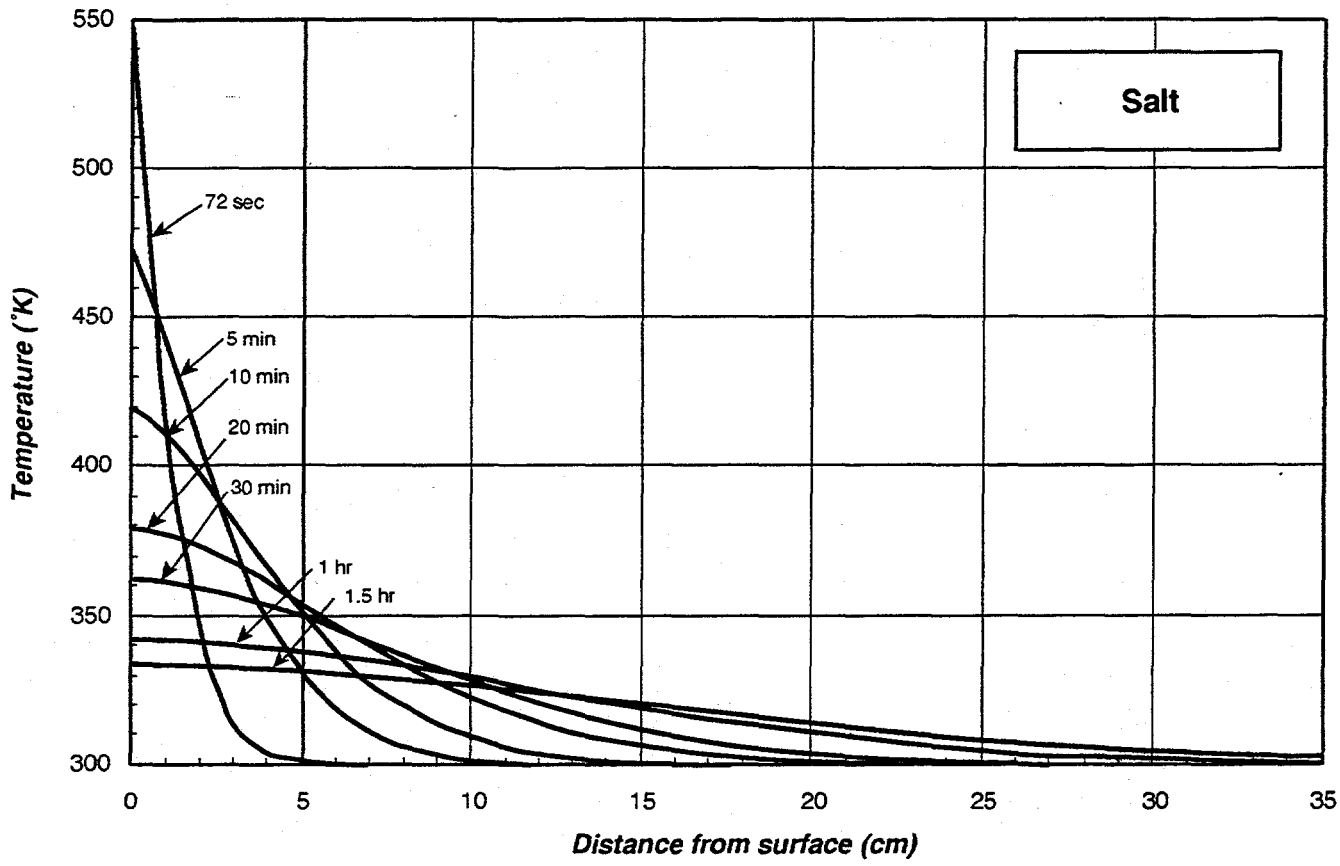


Figure F-11
Temperature Distribution with Time for Salt

in D'Appolonia [1978]. This is as expected since the initial pressure affects the number of moles which determines the rate of temperature decay in the gas. This is illustrated by comparison of the results for 9 atm with those for 27 atm shown in D'Appolonia (1978). The favorable comparison of the results shown on Figure F-9 with those of D'Appolonia (1978) provides verification of the numerical model used in these analyses.

F.6.0 References

Bodurtha, F. T., 1980, *Industrial Explosion Prevention and Control*, McGraw-Hill Book Company, New York, New York.

Carslaw, H. S., and J. C. Jaeger, 1959, *Conduction of Heat in Solids*, 2nd ed., Oxford at the Clarendon Press, Oxford, England.

D'Appolonia Consulting Engineers, 1978, "Potential for Hydrocarbon Explosions and Probable Related Impacts in Mechanically Mined Underground Crude Oil Storage Facilities," D'Appolonia Consulting Engineers, Pittsburg, Pennsylvania.

Krieg, R. D., 1983, "Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project," *SAND83-1908*, Sandia National Laboratories, Albuquerque, New Mexico.

Reid, R. C., J. M. Prausnitz, and T. K. Sherwood, 1977, *The Properties of Gases and Liquids*, 3rd ed., McGraw-Hill Book Company, New York, New York.

U.S. Department of Energy (DOE), 1995, "Conceptual Design for Operational Phase Panel Closure Systems," *DOE-WIPP-95-2957*, U.S. Department of Energy, WIPP Project Office, Carlsbad, New Mexico.

APPENDIX G
TECHNICAL SPECIFICATIONS

SECTION 01010

SUMMARY OF WORK

PART 1 - GENERAL

1.1 Scope

This section includes:

- Scope of Work
- Definitions and Abbreviations
- Drawings
- Work by Others
- Contractors Use of Site
- Contractors Use of Facilities
- Work Sequence
- Work Plan
- Submittals

1.2 Scope of Work

The Contractor shall furnish all labor, materials, equipment and tools to perform operations in connection with the construction of two (2) panel closure systems for each panel, one of each to be installed in the air intake drift and the air exhaust drift of a waste-emplacement panel, as shown on the drawings and called for in these specifications.

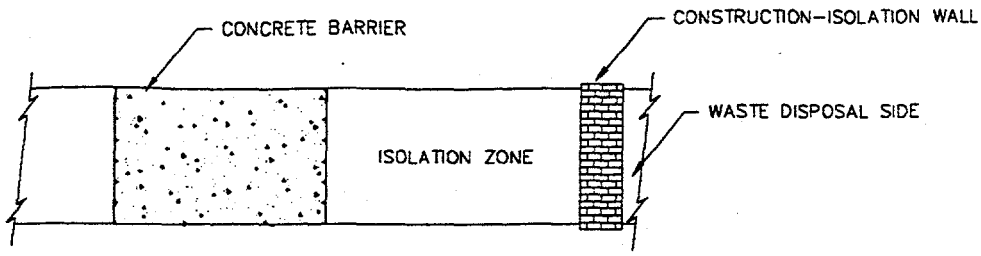
Four (4) possible arrangements of the concrete barrier and isolation walls are shown on the attached Figure 1 "Plan Variations." The specific requirements for the panel closure system will be determined by the Westinghouse WID prior to the time of installation and will be defined in the contract documents.

- Concrete barrier with disturbed rock zone (DRZ) removal up through clay seam G and down through marker bed 139 (MB 139) in combination with a construction isolation wall (Sketch A).

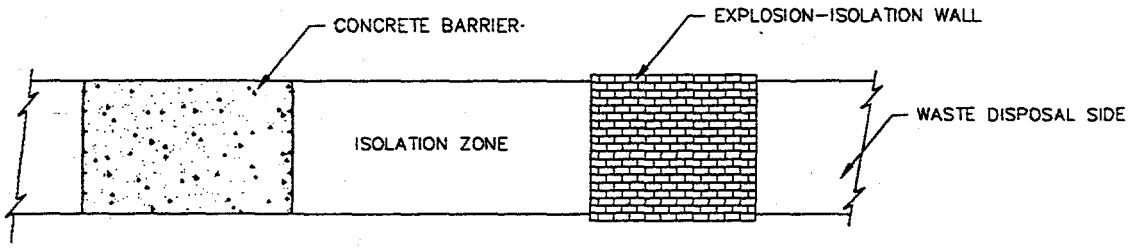
- Concrete barrier with DRZ removal in combination with an explosion isolation wall (Sketch B.)

- Concrete barrier without DRZ removal in combination with construction isolation wall (Sketch C).

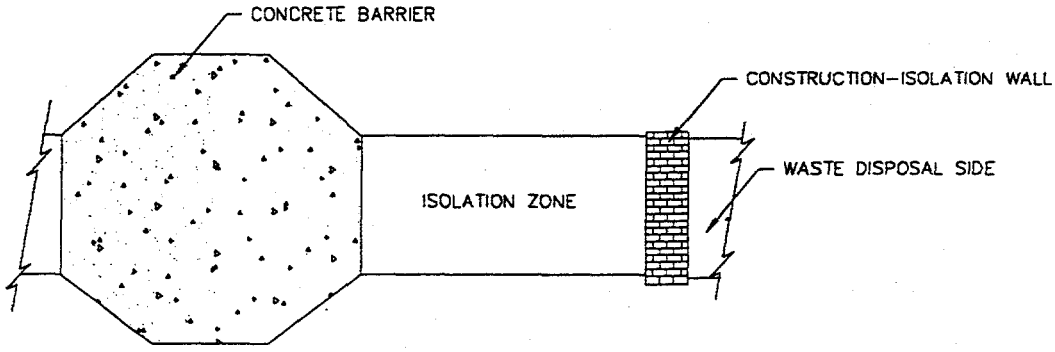
- Concrete barrier without DRZ removal in combination with an explosion isolation wall (Sketch D).



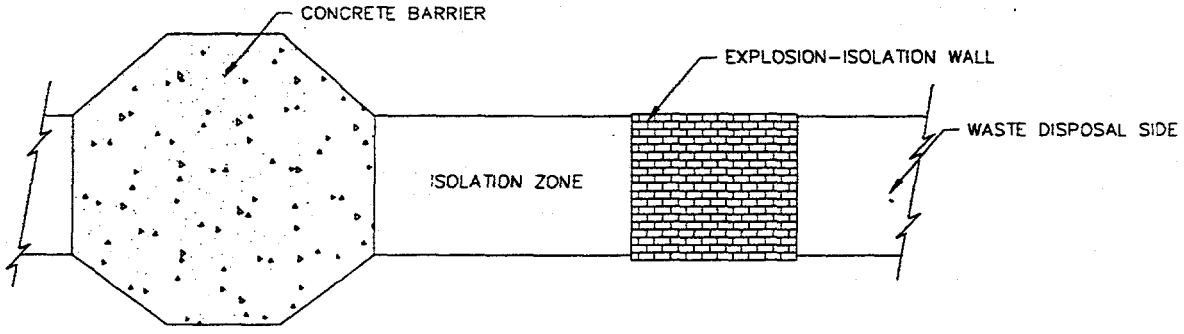
A. CONCRETE BARRIER WITHOUT DRZ REMOVED AND CONSTRUCTION ISOLATION WALL



B. CONCRETE BARRIER WITHOUT DRZ REMOVED AND EXPLOSION ISOLATION WALL



C. CONCRETE BARRIER WITH DRZ REMOVED AND CONSTRUCTION ISOLATION WALL



D. CONCRETE BARRIER WITH DRZ REMOVED AND EXPLOSION ISOLATION WALL

Figure 1
Plan Variations

The scope of work shall include but not be limited to the following units of work:

- Develop work plan, health and safety plan (HASP) and contractors quality control plan (CQCP)
- Prepare and submit all plans requiring approval
- Mobilize to site
- Coordinate construction with operations
- Perform the following for the air intake entry and the air exhaust entry.
  - Excavate the surface preparation for the explosion (or construction) isolation wall
  - Construct the explosion (or construction) isolation wall
  - Excavate the DRZ if required by contract
  - Install the form work for the concrete barrier
  - Place concrete for the concrete barrier
  - Grout the interface of concrete barrier/back wall
  - Provide contact grouting along the contact surface (if required by the engineer)
- Clean up construction areas in underground and above ground
- Submit all required record documents
- Demobilize from site

1.3 Definitions and Abbreviations

Definitions

Contact-handled waste—Contact-handled defense transuranic (TRU) waste with a surface dose rate not to exceed 200 millirem per hour.

Concrete barrier—A barrier placed in the access drifts of a panel to restrict the mass flow rate of volatile organic compounds (VOC).

Concrete block—Concrete used for construction of either an explosion-isolation wall or a construction-isolation wall.

Construction-isolation wall—A wall immediately adjacent to the panel waste-emplacement area that is made of concrete block, with mortar or of steel to isolate construction personnel from coming into contact with the waste.

Creep—Plastic deformation of salt under deviatoric stress.

Design migration limit—A mass flow rate that results in an exposure of the affected individual that is at least 1 order of magnitude below the health-based exposure levels for VOCs during the Waste Isolation Pilot Plant (WIPP) operational period.

Disturbed rock zone (DRZ)—A zone surrounding underground excavations where stress redistribution occurs with attendant dilation and fracturing.

Explosion-isolation wall—A concrete-block wall adjacent to the panel waste-emplacement area with mortar that can sustain the pressure and temperature transients of a methane explosion.

Health-based concentration level—The annual average concentration level for a VOC in air that must not be exceeded at the point of compliance.

Health-based migration limit—The mass flow rate of a VOC from all closed panels that results in the health-based concentration level at the point of compliance.

Hydration temperature—The transient temperature developed by a cementitious material due to the hydration of the cement.

Interface grouting—Grouting performed through grout boxes and pipe lines to fill the void at the concrete barrier/back-wall interface.

Methane explosion—A postulated deflagration caused by the buildup of methane gas to explosive levels.

Partial closure—The process of rendering a part of the hazardous waste management unit in the underground repository inactive and closed according to approved facility closure plans. The partial-closure process is considered complete after partial-closure activities are performed in accordance with approved Resource Conservation and Recovery Act (RCRA) partial closure plans.

Point of compliance—The operating point of compliance for VOC health-based exposure levels at the WIPP, which is the WIPP site boundary.

Remote-handled waste—Any of the various forms of high beta-gamma defense TRU waste requiring remote-handling due to a surface dose rate exceeding 200 millirem per hour.

Standard barrier—A concrete barrier emplaced into the panel-access drifts without major excavation of the surrounding rock.

Volatile Organic Compound (VOC)—Any VOC comprising the land-disposal-restricted indicator VOC constituents in the WIPP waste inventory.

Westinghouse—Westinghouse Electric Corporation, Waste Isolation Division (WID) as the construction management authority.

Abbreviations/Acronyms

ACI	American Concrete Institute
AISC	American Institute for Steel Construction
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
AWS	American Welding Society
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DRZ	disturbed rock zone
EPA	U.S. Environmental Protection Agency
MB 139	Marker Bed 139
MSHA	U.S. Mining Safety and Health Administration
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
RCRA	Resource Conservation and Recovery Act
SMC	Salado Mass Concrete
USACE	U.S. Army Corps of Engineers
WID	Waste Isolation Division
WIPP	Waste Isolation Pilot Plant

1.4 List of Drawings

The following drawings are made apart of this specification:

762447-E1	Panel closure system, air intake and exhaust drifts, title sheet
762447-E2	Panel closure system, underground waste-emplacement panel plan
762447-E3	Panel closure system, air intake drift, construction details
762447-E4	Panel closure system, air exhaust drift, construction details
762447-E5	Panel closure system, construction and explosion walls, construction details
762447-E6	Panel closure system, air intake and exhaust drifts, grouting and miscellaneous details

1.5 Work by Others

Survey

All survey work to locate the barriers and walls, control and confirm excavation, and complete the work will be supplied by Westinghouse. All survey measurements for record purposes will also be performed by Westinghouse. The Contractor shall be responsible for verifying the excavation dimensions to develop the form work to fit the excavation.

Excavation

The Westinghouse WID may elect to perform certain portions of the work, notably the excavation. The work performed by the Westinghouse will be defined prior to the contract.

1.6 Contractor's Use of Site

Site Conditions

The site is located near Carlsbad, New Mexico, as shown on the site location maps and the title sheet drawing. The underground arrangements and location of the WIPP waste-emplacement panels are shown on the plan view drawing. The work described above is to construct the concrete barriers in the air intake and exhaust drifts of one of the panels upon completion of the disposal phase of that panel. The waste-emplacement panels are located approximately 2,150 feet below the ground surface. The Contractor shall visit the site and become familiar with the site and site conditions prior to preparing his bid proposal.

Contractor's Use of Site

Areas at the ground surface will be designated for the Contractor's use in assembling and storing his equipment and materials. The Contractor shall utilize only those areas designated.

Limited space within the underground area will be designated for the Contractor's use for storage of material and setup of equipment.

Coordination of Contractor's Work

The Contractor is advised that on-going waste emplacement and excavation operations are being conducted throughout the period of construction of the panel barrier system. The Contractor shall coordinate his construction operations with that of the waste emplacement and mining operations. All coordination shall be through Westinghouse WID.

1.7 Contractor's Use of Facilities

Existing facilities at the site which are available for use by the Contractor are:

- WIPP roadheader
- Waste shaft conveyance
- Salt skip hoist
- (1) 20 ton forklift

- (1) 40 ton forklift
- 460 volt AC, 3 phase power
- Water (underground, at waste shaft only) (above ground, at location designated by Engineer)

Additional information on these facilities is presented in Section 02010.

1.8 Work Sequence
Work Sequence shall be as shown on the drawings and directed by Westinghouse WID .

1.9 Work Plan
The Contractor shall prepare and submit for approval by Westinghouse WID a Work Plan fully describing his proposed construction operation. The work plan shall define all proposed equipment. The work plan shall also include the method of excavation, grouting, and pumping concrete. The work plan shall also contain such items as control of surface dust emissions. No work shall be performed prior to approval of the Work Plan.

1.10 Health and Safety Plan (HASP)
The Contractor shall obtain, review, and agree to applicable portions of the existing WIPP Safety Manual, WP 12-1. The Contractor shall prepare and submit for approval to Westinghouse, a project-specific HASP taking into account all applicable sections of the WIPP Safety Manual. The Contractor shall also perform a Job Hazard Analysis in accordance with WP 12-111.

1.11 Contractor Quality Control Plan (CQCP)
The Contractor shall prepare and submit for approval to Westinghouse a CQCP identifying all personnel and procedures to produce an end product which complies with the contract requirements. The CQCP shall comply with all Westinghouse WID requirements and Section 01400, Contractor Quality Control, of this specification.

1.12 Submittals
Submittals shall be in accordance with Westinghouse WID Submittal Procedures and as required by the individual specifications.

PART 2 - PRODUCTS

(Not used)

PART 3 - EXECUTION

(Not Used)

SECTION 01010

SUMMARY OF WORK

SECTION 01090

REFERENCE STANDARDS

PART 1 - GENERAL

1.1 Scope

This section includes:

- Provision of Reference Standards at Site.
- Acronyms used in Contract Documents for Reference Standards. Source of Reference Standards.

1.2 Quality Assurance

For products or workmanship specified by association, trade, or Federal Standards, comply with requirements of the standard, except when more rigid requirements are specified or are required by applicable codes.

Conform to reference by date of issue current on the date of the owner-contractor agreement.

The Contractor shall obtain copy of the standards referenced in the individual specification sections. Maintain a copy at jobsite during submittals, planning, and progress of the specific work, until completion of work.

Should specified reference standards conflict with the contract documents, request clarification from the Engineer before proceeding.

1.3 Schedule of References

Various publications are referenced in other sections of the specifications to establish requirements for the work. These referenced are identified by documents number and title. The addresses of the organizations whose publications are referenced are listed below.

ACI	ACI International P.O. Box 19150 Detroit,MI 48219-0150 Ph: 313-532-2600 Fax: 313-533-4747

AITC	American Institute of Timber Construction 7012 So. Revere Parkway, Suite 140 Englewood, CO 80112 Ph: 303-792-9559 Fax: 303-792-0669
AISC	American Institute of Steel Construction One E. Wacker Dr., Suite 3100 Chicago, IL 60601-2001 Ph: 312-670-2400 Fax: 312-670-5403
ANSI	American National Standards Institute 11 West 42nd St. New York NY 10036 pH: 212-642-4900 Fax: 212-302-1286
API	American Petroleum Institute 1220 L. St., NW Washington, DC 20005 Ph: 202-682-8375 Fax: 202-962-4776
ASTM	American Society for Testing and Materials 1916 Race St. Philadelphia, PA 19103 Ph: 610-832-9585 Fax: 215-977-9679
AWS	American Welding Society 550 LeJeune Road Miami, FL 33135 Ph: 800-443-9353 Fax: 305-443-7559
CFR	Code of Federal Regulations Government Printing Office Washington, DC 20402 Ph: 202-783-3238 Fax: 202-223-7703

EPA	Environmental Protection Agency Public Information Center 401 M St., SW Washington, DC 20460 Ph: 202-260-2080
FTM-STO	Federal Test Method Standards Standardization Documents Order Desk Bldg. 4D 700 Robbins Ave. Philadelphia, PA 19111-5094 Ph: 215-697-2179 Fax: 215-697-2978
NRMCA	National Ready-Mixed Concrete Association 900 Spring St. Silver Spring, MD 20910 Ph: 301-587-1400 Fax: 301-585-4219
NTIS	National Technical Information Service U.S. Department of Commerce Springfield, VA 22161 (703) 487-4650
PCA	Portland Cement Association 5420 Old Orchard Road Skokie, IL 60077
USACE	U.S. Army Corps of Engineers U.S. Army Engineer Waterway Experiment Station ATTN: Technical Report Distribution Section, Services Branch, TIC 3909 Halls Ferry Rd. Vicksburg, MS 39180-6199 Ph: 601-634-2355 Fax: 601-634-2506
WID	Westinghouse Electric Corporation Waste Isolation Division Carlsbad, New Mexico 88221

End of Section

SECTION 01090

REFERENCE STANDARDS

SECTION 01400

CONTRACTOR QUALITY CONTROL

PART 1 - GENERAL

1.1 Scope
This section includes:

- Contractor Quality Control Plan (CQCP)
- Reference Standards
- Quality Assurance
- Tolerances
- Testing Services
- Inspection Services
- Submittals

1.2 Related Sections

- 01090 - Reference Standards
- 01600 - Material and Equipment
- 02222 - Excavation
- 02722 - Grouting
- 03100 - Concrete Formwork
- 03300 - Cast-in-Place Concrete
- 04100 - Mortar
- 04300 - Unit Masonry System

1.3 Contractor Quality Control Plan
The Contractor shall prepare and submit for approval by Westinghouse WID, a Quality Control Plan, as described in Section 3.2. No work shall be performed prior to approval of the Contractor's Quality Control Plan.

1.4 References and Standards
Refer to individual specification sections for standards referenced therein, and to Section 01090 - Reference Standards for general listing.

Standards referenced in this section are as follows:

ASTM C1077-95a	Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation

ASTM C1093-88	Practice for Accreditation of Testing Agencies for Unit Masonry
ASTM E329-95	Practice for Use in the Evaluation of Inspection and Testing Agencies as Used in Construction
ASTM E543-95	Practice for Determining the Qualification of Nondestructive Testing Agencies
ASTM E548-94	Practice for Preparation of Criteria for Use in the Evaluation of Testing Laboratories and Inspection Bodies

1.5 Quality Assurance

- Monitor quality control over suppliers, manufacturers, products, services, site conditions, and workmanship, to produce work of specified quality
- Comply with specified standards as minimum quality for the work except where more stringent tolerances, codes, or specified requirements indicate higher standards or more precise workmanship
- Perform work by persons qualified to produce required and specified quality
- Verify that field measurements are as indicated on shop drawings
- Secure products in place with positive anchorage devices designed and sized to withstand stresses, vibration, physical distortion, or disfigurement.

1.6 Tolerances

Monitor excavation fabrication and installation tolerance control of work and products to produce acceptable work. Do not permit tolerances to accumulate.

Adjust products to appropriate dimensions; position before securing products in place.

1.7 Testing Services

Unless otherwise indicated by Westinghouse WID, the Contractor shall employ an independent firm to perform the testing services and other services specified in the individual specification sections, and as required by Westinghouse WID. Testing and source quality control may occur on or off the project site.

The testing laboratory shall comply with applicable sections of the reference standards and shall be authorized to operate in the state in which the project is located.

Testing equipment shall be calibrated at reasonable intervals with devices of an accuracy traceable to either the National Bureau of Standards or accepted values of natural physical constants.

1.8 Inspection Services

The Contractor shall employ an independent firm to perform inspection services as a supplement to the Contractor's quality control as specified in the individual specification sections, and as required by Westinghouse WID. Inspection may occur on or off the project site.

The inspection firm shall comply with applicable sections of the reference standards.

1.9 Submittals

The Contractor shall submit a Contractors' Quality Control Plan as described herein.

Prior to start of work, the Contractor shall submit for approval, the testing laboratory name, address, telephone number and name of responsible officer of the firm. He shall also submit a copy of the testing laboratory compliance with the reference ASTM standards, and a copy of report of laboratory facilities inspection made by Materials Reference Laboratory of National Bureau of Standards with memorandum of remedies of any deficiencies reported by the inspection.

Prior to start of work, the Contractor shall submit for approval the inspection firm name, address, telephone number and name of responsible officer of the firm. He shall also submit the personnel proposed to perform the required inspection, along with their individual qualifications and certifications (Example: Certified AWS Welding Inspector.)

PART 2 - PRODUCTS

Not used.

PART 3 - EXECUTION

3.1 General

The Contractor is responsible for quality control and shall establish and maintain an effective quality control system. The quality control system shall consist of plans, procedures, and organization necessary to produce an end product which complies with the contract requirements. The system shall cover all construction operations, both on site and off site, and shall be keyed to the proposed construction sequence. The project superintendent will be held responsible for the quality of work on the job. The project superintendent in this context shall mean the individual with the responsibility for the overall management of the project including quality and production.

3.2 Quality Control Plan

3.2.1 General

The Contractor shall furnish for review and approval by Westinghouse WID, not later than 30 days after receipt of notice to proceed, the Contractor Quality Control (CQC) Plan proposed to implement the requirements of the Contract. The plan shall identify personnel, procedures, control, instructions, test, records, and forms to be used. Construction will be permitted to begin only after acceptance of the CQC Plan.

3.2.2 Content of the CQC Plan

The CQC Plan shall include, as a minimum, the following to cover all construction operations, both on site and off site, including work by subcontractors, fabricators, suppliers, and purchasing agents:

- A description of the quality control organization, including a chart showing lines of authority and acknowledgment that the CQC staff shall implement the control system for all aspects of the work specified. The staff shall include a CQC System Manager who shall report to the project superintendent.

- The name, qualifications (in resume format), duties, responsibilities, and authorities of each person assigned a CQC function.

- Description of the CQC System Manager's responsibilities and delegation of authority to adequately perform the functions of the CQC System Manager, including authority to stop work which is not in compliance with the contract. The CQC System Manager shall issue letters of direction to all other various quality control representatives outlining duties, authorities, and responsibilities.

- Procedures for scheduling, reviewing, certifying, and managing submittals, including those of subcontractors, off site fabricators, suppliers, and purchasing agents. These procedures shall be in accordance with Westinghouse WID Submittal Procedures.

- Control, verification, and acceptance testing procedures for each specific test to include the test name, specification paragraph requiring test, feature of work to be tested, test frequency, and person responsible for each test. (Laboratory facilities will be subject to approval by Westinghouse WID.)

- Procedures for tracking construction deficiencies from identification through acceptable corrective action. These procedures will establish verification that identified deficiencies have been corrected.

- Reporting procedures, including proposed reporting formats.

- A list of the definable features of work. A definable feature of work is a task which is separate and distinct from other tasks and has separate control requirements. It could be identified by different trades or disciplines, or it could be work by the same trade in a different environment. Although each section of the specifications may generally be considered as a definable feature of work, there are frequently more than one definable feature under a particular section. This list will be submitted to Westinghouse WID for approval.

3.2.3 Acceptance of Plan

Acceptance of the Contractor's plan is required prior to the start of construction. Acceptance is conditional and will be predicated on satisfactory performance during the construction. The Owner reserves the right to require the Contractor to make changes in his CQC Plan and operations including removal of personnel, as necessary, to obtain the quality specified.

3.2.4 Notification of Changes

After acceptance of the CQC Plan, the Contractor shall notify Westinghouse WID in writing of any proposed change. Proposed changes are subject to acceptance by Westinghouse WID.

3.3 Quality Control Organization

3.3.1 General

The requirements for the CQC organization are a CQC System Manager and sufficient number of additional qualified personnel supplemented by independent testing and inspection firms as required by the specifications, to ensure contract compliance. The Contractor shall provide a CQC organization which shall be at the site at all times during progress of the work and with complete authority to take any action necessary to ensure compliance with the contract. All CQC staff members shall be subject to acceptance by Westinghouse WID.

3.3.2 CQC System Manager

The Contractor shall identify as CQC System Manager an individual within his organization at the site of the work who shall be responsible for overall management of CQC and have the authority to act in all CQC matters for the Contractor. The CQC System Manager shall be a graduate engineer, with a minimum of five years construction experience on construction similar to this contract. This CQC System Manager will be employed by the prime Contractor. The CQC System Manager shall be assigned no other duties. An alternate for the CQC System Manager will be identified in the plan to serve in the event of the System Manager's absence. The requirements for the alternate will be the same as for the designated CQC System Manager.

3.3.3 CQC Personnel

In addition to CQC personnel specified elsewhere in the contract, the Contractor shall provide as part of the CQC organization specialized personnel or third party inspectors to assist the CQC System Manager. These individuals shall be employed by the prime Contractor; be

responsible to the CQC System Manager; have the necessary education and/or experience. These individuals shall have no other duties other than quality control.

3.3.4 *Organizational Changes*

The Contractor shall maintain his CQC staff at full strength at all times. When it is necessary to make changes to the CQC staff the Contractor shall revise the CQC Plan to reflect the changes and submit the changes to Westinghouse WID for acceptance at the Contractors' expense.

3.4 Tests

3.4.1 Testing Procedure

The Contractor shall perform specified or required tests to verify that control measures are adequate to provide a product which conforms to contract requirements. Upon request, the Contractor shall furnish to Westinghouse WID duplicate samples of test specimens for possible testing by Westinghouse WID. Testing includes operation and/or acceptance tests when specified. The Contractor shall procure the services of an approved testing laboratory. The Contractor shall perform the following activities and record and provide the following data:

- Verify that testing procedures comply with contract requirements.
- Verify that facilities and testing equipment are available and comply with testing standards.
- Check test instrument calibration data against certified standards.
- Verify that recording forms and test identification control number system, including all of the test documentation requirements, have been prepared.
- Results of all tests taken, both passing and failing tests, will be recorded on the CQC report for the date taken. Specification paragraph reference, location where tests were taken, and the sequential control number identifying the test will be given. If approved by Westinghouse WID, actual test reports may be submitted later with a reference to the test number and date taken. An information copy of tests performed by an off site or commercial test facility will be provided directly to Westinghouse WID. Failure to submit timely test reports as stated may result in nonpayment for related work performed and disapproval of the test facility for this contract.

3.5 Testing Laboratory

The testing laboratory shall provide qualified personnel to perform specified sampling and testing of products in accordance with specified standards, and ascertain compliance of materials and mixes with requirements of Contract Documents. The testing laboratory shall promptly notify Westinghouse WID and Contractor of any observed irregularities or non-conformance of Work or Products.

Reports indicating results of tests, and compliance (or noncompliance) with the contract documents will be submitted in accordance with Westinghouse WID submittal procedures.

The Contractor shall cooperate with the independent testing firm, furnish samples, storage, safe access, and assistance by incidental labor as required. Testing by the independent firm does not relieve the contractor of the responsibility to perform the work to the contract requirements.

The laboratory may not:

- Release, revoke, alter, or enlarge on requirements of the contract
- Approve or accept any portion of the work
- Assume any duties of the Contractor.

The laboratory has no authority to stop the work.

3.6 Inspection Services

The inspection firm shall provide qualified personnel at site to supplement the Contractor's Quality Control Program to perform specified inspection of Products in accordance with specified standards. He shall ascertain compliance of materials and mixes with requirements of Contract Documents, and promptly notify the CQC System Manager, Westinghouse WID and the Contractor of observed irregularities or non-conformance of Work or Products. The inspector does not have the authority to stop the work. The inspector shall refer such cases to the CQC System Manager who has the authority to stop work (see Section 3.2.2).

Reports indicating results of the inspection and compliance (or noncompliance) with the contract documents will be submitted in accordance with Westinghouse WID submittal procedures.

The Contractor shall cooperate with the independent inspection firm, furnish samples, storage, safe access and assistance by incidental labor, as requested.

Inspection by the independent firm does not relieve the Contractor of the responsibility to perform the work to the contract requirements.

3.7 Completion Inspection

3.7.1 Pre-Final Inspection

At the completion of all work the CQC System Manager shall conduct an inspection of the work and develop a "punch list" of items which do not conform to the approved drawings and specifications. Once this is accomplished the Contractor shall notify Westinghouse WID that the facility is complete and is ready for the "Prefinal" inspection. Westinghouse WID will perform this inspection to verify that the facility is complete. A "Final Punch List" will be developed as a result of this inspection. The Contractor's CQC System Manager shall ensure

that all items on this list have been corrected and notify Westinghouse WID so that a "Final" inspection can be scheduled. Any items noted on the "Final" inspection shall be corrected in a timely manner. These inspections and any deficiency corrections required by this paragraph will be accomplished within the time slated for completion of the entire work.

3.7.2 Final Acceptance Inspection

The final acceptance inspection will be formally scheduled by Westinghouse WID based upon notice from the Contractor. This notice will be given to Westinghouse WID at least 14 days prior to the final acceptance inspection and must include the Contractor's assurance that all specific items previously identified to the Contractor as being unacceptable, along with all remaining work performed under the contract, will be complete and acceptable by the date scheduled for the final acceptance inspection.

3.8 Documentation

The Contractor shall maintain current records providing factual evidence that required quality control activities and/or tests have been performed. These records shall include the work of subcontractors and suppliers and shall be on an acceptable form that includes, as a minimum, the following information:

- Contractor/subcontractor and their area of responsibility.
- Operating plant/equipment with hours worked, idle, or down for repair.
- Work performed each day, giving location, description, and by whom.
- Test and/or quality control activities performed with results and references to specifications/drawings requirements. List deficiencies noted along with corrective action.
- Quantity of materials received at the site with statement as to acceptability, storage, and reference to specifications/drawings requirements.
- Submittals reviewed, with contract reference, by whom, and action taken.
- Off-site surveillance activities, including actions taken.
- Instructions given/received and conflicts in plans and/or specifications.
- Contractor's verification statement.

These records shall indicate a description of trades working on the project; the number of personnel working; weather conditions encountered; and any delays encountered. These records shall cover both conforming and deficient features and shall include a statement that equipment and materials incorporated in the work and workmanship comply with the contract. The original and one copy of these records in report form shall be furnished to Westinghouse

WID daily. Reports shall be signed and dated by the CQC System Manager. The report from the CQC System Manager shall include copies of test reports and copies of reports prepared by all subordinate quality control personnel.

3.9 Notification of Noncompliance

Westinghouse WID will notify the Contractor of any detected noncompliance with the foregoing requirements. The Contractor shall take immediate corrective action after receipt of such notice. Such notice, when delivered to the Contractor at the worksite, shall be deemed sufficient for the purpose of notification. If the Contractor fails or refuses to comply promptly, Westinghouse WID may issue an order stopping all or part of the work until satisfactory corrective action has been taken. No part of the time lost due to such stop orders shall be made the subject of claim for extension of time or for excess costs or damages by the Contractor.

End of section.

SECTION 01400
CONTRACTOR QUALITY CONTROL

SECTION 01600

MATERIAL AND EQUIPMENT

PART 1 - GENERAL

1.1 Scope

This section includes:

- Equipment
- Products
- Transportation and handling
- Storage and protection
- Substitutions

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 02010 - Mobilization and Demobilization
- 02222 - Excavation
- 02722 - Grouting
- 03100 - Concrete Formwork
- 03300 - Cast-in-Place Concrete
- 04100 - Mortar
- 04300 - Unit Masonry System

1.3 Equipment

The Contractor shall specify his proposed equipment in the Work Plan. Power equipment for use underground shall be either electrical or diesel engine driven. All diesel engine equipment shall be certified for use underground.

1.4 Products

The Contractor shall specify in the Work Plan, or in subsequently required submittals the proposed products including, but not limited to the grout mix and its components, concrete mix and its components, mortar mix and its components, formwork, and masonry. The proposed products shall be supported by laboratory test results as required by the specifications. All products shall be subject to approval by Westinghouse WID.

1.5 Transportation and Handling

- Transport and handle products in accordance with manufacturer's instructions.
- Promptly inspect shipments to ensure that products comply with requirements, quantities are correct, and products are undamaged.
- Provide equipment and personnel to handle products by methods to prevent soiling, disfigurement, or damage.

1.6 Storage and Protection

- Store and protect products in accordance with manufacturers' instructions.
- Store with seals and labels intact and legible.
- Store sensitive products in weather tight, climate controlled, enclosures in an environment favorable to product.
- For exterior storage of fabricated products, place on sloped supports above ground.
- Cover products subject to deterioration with impervious sheet covering. Provide ventilation to prevent condensation and degradation of products.
- Store loose granular materials on solid flat surfaces in a well-drained area. Prevent mixing with foreign matter.
- Provide equipment and personnel to store products by methods to prevent soiling, disfigurement, or damage.
- Arrange storage of products to permit access for inspection. Periodically inspect to verify products are undamaged and are maintained in acceptable condition.

1.7 Substitutions

1.7.1 Equipment Substitutions

The Contractor may substitute equipment for that proposed in the Work Plan subject to Westinghouse WID's approval. The Contractor shall demonstrate the need for the substitution, and the applicability of the proposed substitute equipment.

1.7.2 Product Substitutions

The Contractor may not substitute products after the proposed products have been approved by Westinghouse WID unless he can demonstrate that the supplier/source of that product no longer exists in which case he shall submit alternate products with lab test results to

Westinghouse WID for approval. In the case that product is a component in a mix, the Contractor shall perform mix testing using that component and submit laboratory test results.

PART 2 - PRODUCTS

Not used.

PART 3 - EXECUTION

Not used.

End of section.

SECTION 01600
MATERIAL AND EQUIPMENT

SECTION 02010

MOBILIZATION AND DEMOBILIZATION

PART 1 - GENERAL

1.1 Scope

This section includes:

- Mobilization of equipment and facilities to site
- Contractor use of site
- Use of existing facilities
- Demobilization of equipment and facilities
- Site cleanup

1.2 Related Sections

- 01010 - Summary of Work
- 01600 - Material and Equipment

PART 2 - PRODUCTS

Not used.

PART 3 - EXECUTION

3.1 Mobilization of Equipment and Facilities to Site

Upon authorization to proceed, the Contractor shall mobilize his equipment and facilities to the jobsite. Equipment and facilities shall be as specified, and as defined in the Contractor's Work Plan. The Contractor shall erect the batch plant and assemble his equipment and materials in the areas designated by Westinghouse WID. Facilities shall be located as near as practical to the existing utilities.

Westinghouse WID will provide utilities (460 volt AC, 3 phase, and water) at designated locations. The Contractor shall be responsible for all hookups and tie-ins required for his operations.

The Contractor shall be responsible for providing his own office, storage, and sanitary facilities.

Areas will be designated for the Contractor's use in the underground area in the vicinity of the panel closure system installation. These areas are limited.

3.2 Use of Site

The Contractor shall use only those areas specifically designated for his use by Westinghouse WID. The Contractor shall limit his on-site travel to the specific routes required for performance of his work, and designated by Westinghouse WID.

3.3 Use of Existing Facilities

Existing facilities at the site which are available for use by the Contractor are:

- WIPP roadheader
- Waste shaft conveyance
- Salt skip hoist
- (1) 20 ton forklift
- (1) 40-ton forklift
- 460 Volt AC, 3 phase power
- Water (in mine, at waste shaft only-above ground at location designated by Westinghouse WID).

The Contractor shall arrange for use of the facilities with Westinghouse WID and coordinate his actions/requirements with that of the ongoing operations.

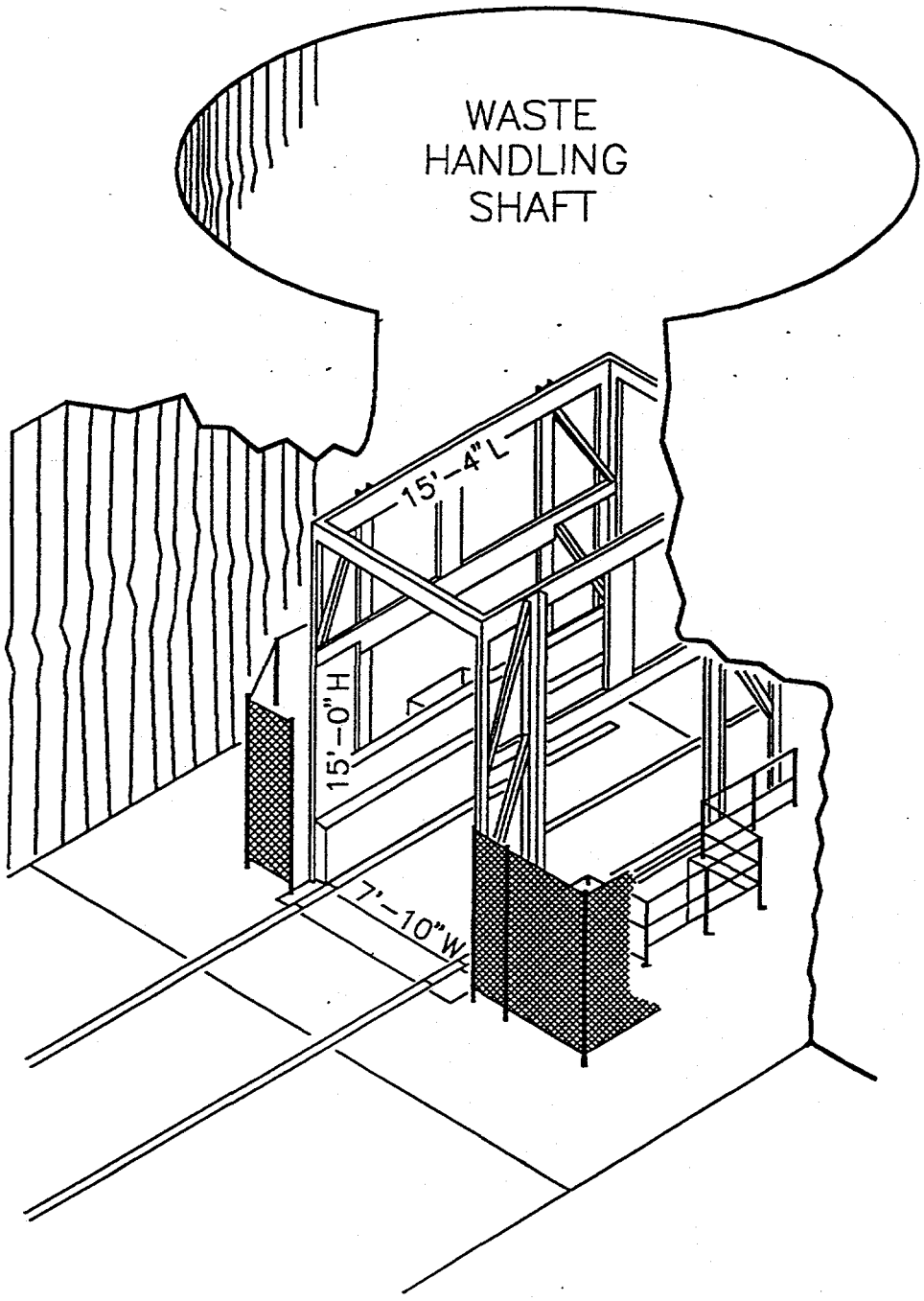
Use of water in the underground will be restricted. No washout or cleanup will be permitted in the underground. Above ground washout/cleanup or equipment will be allowed in the areas designated by Westinghouse WID.

The Contractor is cautioned to be aware of the physical dimensions of the waste conveyance and the air lock (see Figures 2 and 3, attached).

The Contractor shall be responsible for any damage incurred by the existing site facilities as a result of his operations. Any damage shall be reported immediately to Westinghouse WID and repaired at the Contractor's cost.

3.4 Demobilization of Equipment and Facilities

At completion of this work, the Contractor shall demobilize his equipment and facilities from the job site. The batch plant shall be disassembled and removed along with any unused material. All Contractor's equipment and materials shall be removed from the mine and all disturbed areas restored. Utilities shall be removed to their connection points unless otherwise directed by Westinghouse WID.



NOTES

(1) CAGE DIMENSIONS SHOWN ARE INSIDE.

(2) WASTE HOIST DESIGN CAPACITY IS 80,000 LBS.

Figure 2

Waste Handling Shaft Cage Dimensions

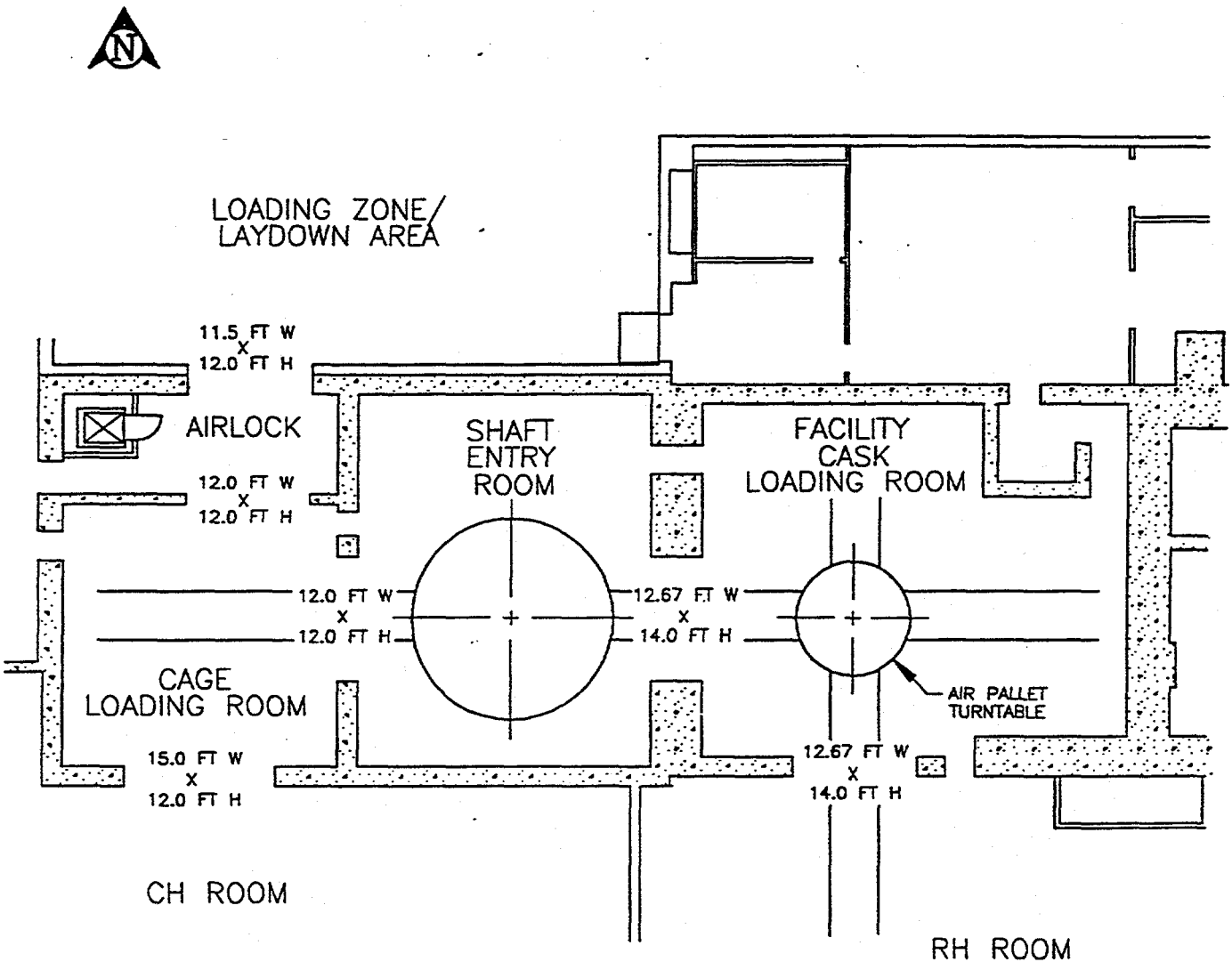


Figure 3

Waste Shaft Collar and Airlock Arrangement

3.5 Site Cleanup

At conclusion of the work, the Contractor shall remove all trash, waste, debris, excess construction materials, and restore the affected areas to its prior condition, to the satisfaction of Westinghouse WID. A final inspection of the areas will be conducted by Westinghouse WID and the Contractor before final payment is approved.

End of section.

SECTION 02010
MOBILIZATION AND DEMOBILIZATION

SECTION 02222

EXCAVATION

PART 1 - GENERAL

1.1 Scope

This section includes:

- Excavation for main concrete barrier
- Excavation for surface preparation and levelling of base areas for isolation walls
- Disposition of excavated materials.

1.2 Related Sections

- 01010 - Summary of Work
- 01600 - Material and Equipment
- 03100 - Concrete Form Work
- 04300 - Unit Masonry System.

1.3 Reference Documents

"Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project" by R.D. Krieg-Sandia National Laboratory Document Sand 83-1908. [Available through National Technical Information Service (NTIS).]

1.4 Field Measurements and Survey

All survey required for performance of the work will be provided by Westinghouse WID. To develop the concrete formwork to fit the excavation, the Contractor shall be responsible for verifying the excavation dimensions.

PART 2 - PRODUCTS

Not used.

PART 3 - EXECUTION

3.1 Excavating for Concrete Barrier

Excavation for the main concrete barrier shall be performed to the lines and grades shown on the drawings. Excavate the back a minimum of 1 inch to 3 inches beyond clay seam G, and the floor a minimum of 1 inch to 3 inches below the anhydride marker bed 139 (MB-139) to

assure removal of the disturbed rock zone (DRZ). Excavation shall be performed utilizing mechanical means such as a cutting head on a suitable boom, by drilling boreholes and using an expansive agent to fragment the rock or other competent equipment or methods submitted to Westinghouse WID for review and approval. The use of explosives is prohibited. The existing WIPP roadheader mining machine may also be available for use. The Contractor is to determine availability and coordinate proposed use of the roadheader with Westinghouse WID. The existing roadheader is capable of excavating the back and the portions of the ribs above the floor level. However, it is not capable of excavating the portion below floor level.

The tolerances for the concrete barrier excavation shall be +6 inches, to 0 inch. In addition, the Contractor is to remove all loose or spalling rock from the excavation surface to provide a sound surface abutting the concrete barrier. The Contractor shall provide and install roof bolts for support as required for personnel protection and approved ground control plans.

3.2 Excavating for Surface Preparation and leveling of Base Areas for Isolation Walls
The Contractor shall excavate a 6-inch surface preparation around the entire perimeter of the isolation walls. The surface preparation in the floor shall be made level to produce a surface for placing the first course of block in the isolation walls. Tolerances for the leveled portion of the surface preparation are ±1 inch. Excavation may be performed by either mechanical or manual means. Use of explosives is prohibited.

3.3 Disposition of Excavated Materials
The Contractor shall remove all excavated materials from the panel-access drift where they are excavated. Excavated materials shall be removed from the mine via the salt skip to the surface, where they will be disposed on site at a location as directed by Westinghouse WID.

3.4 Field Measurements and Survey
All survey required for performance of the work will be provided by Westinghouse WID. The Contractor shall protect all survey control points, bench marks, etc., from damage by his operations. WID will verify by survey that the Contractor has excavated to the required lines and grades. The Contractor shall be responsible for verifying the excavation dimensions to develop concrete formwork to fit the excavation. No form work or block work is to be erected until this survey is completed. The Contractor is to coordinate the survey work with his operations to assure against lost time. The Contractor shall notify Westinghouse WID at least 24 hours prior to the time surveying is required

End of section.

SECTION 02222
EXCAVATION

SECTION 02722

GROUTING

PART 1 - GENERAL

1.1 Scope

This section includes:

- Grouting of concrete barrier.

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 01600 - Material and Equipment
- 03100 - Concrete Form Work
- 03300 - Cast-in-Place Concrete

1.3 References

ASTM C1107-91a Standard Specification for Dry, Hydraulic Cement Grout (Nonshrink)

ASTM C109/ C109M-95 Test Method for Compressive Strength of Hydraulic Cement Mortars

1.4 Submittals for Review and Approval

Thirty days prior to the initiation of grouting, the Contractor shall submit to Westinghouse WID for review and approval, the following:

- Type of grout proposed
- Product data:
  - Manufacturer's specification and certified laboratory tests for the manufactured grout, if proposed
  - Certified laboratory tests for the salt-saturated grout, if proposed, using project-specific materials

- Proposed grouting method, including equipment and materials and construction sequence in Work Plan.

1.5 Submittals for Construction

Daily grouting report indicating the day, date, time of mixing and delivery, quantity of grout placed, water used, pressure required, problems encountered, action taken, quality control data, testing results, etc., no later than 24 hours following construction.

PART 2 - PRODUCTS

2.1 Grout Materials

Grout used for grouting in connection with fresh water/plain cement concrete shall be nonshrink, cement-based grout, Five Star 110 as manufactured by Five Star Products Inc., 425 Stillson Road, Fairfield, Connecticut 06430 or approved equal. Mixing and installation shall be in accordance with the manufacturer's recommendations.

As an alternate to the above grout, in connection with the Salado Mass concrete mix, the Contractor shall use, subject to the approval of Westinghouse WID, a salt saturated grout. The following formulation is suggested to the Contractor as an initiation point for selection of the grout mix. Salt saturated grout strength shall be 4500 psi at 28 days.

Salt-Saturated Grout (BCT-1F)

Component	Percent of total Mass (wt.)
Class H cement	48.3
Class C fly ash	16.2
Cal Seal (plaster - from Halliburton)	5.7
Sodium chloride	7.9
Dispersant	0.78
Defoamer	0.02
Water	21.1

Water for mixing shall be of potable quality, free from injurious amounts of oil, acid, alkali, salt, or organic matter, sediments, or other deleterious substances, as specified for concrete, Section 03300-2.3.

2.2 Product Data

If the Contractor proposes to utilize a manufactured nonshrink cement-based grout, he shall submit complete manufacturer's specifications for the product, along with certified laboratory test results of the material.

If the Contractor proposes to utilize the salt-saturated grout in connection with the Salado Mass concrete mix, he shall submit manufacturer's/supplier's specifications for the component materials, and certified laboratory test results for the resultant mix.

PART 3 - EXECUTION

3.1 General

The Contractor shall furnish all labor material, equipment, and tools to perform all operations in connection with the grouting.

Grout delivery and return lines for interface grouting shall be installed in the form work or in the area to be grouted to provide uniform distribution of the grout as shown on the drawings. The exact location of the boxes and lines shall be determined in the field. Additional grout. delivery and return lines and boxes may be required by Westinghouse WID.

Pumps shall be positive displacement piston type pump designed for grouting service capable of operating at a discharge pressure of 100 psi. The Contractor shall supply a standby pump to be utilized in the event of a breakdown of the primary unit.

Mixers shall be high velocity "colloidal" type with a rotary speed of 1,200 to 1,500 rpm. Grout shall be mixed to a pumpable mix as per the manufacturer's recommendations.

Mixing water shall be accurately metered to control the consistency of the grout.

The Contractor shall provide all necessary valves, gages, and pressure hoses.

Water for mixing is available at the waste shaft. The Contractor is cautioned that no free water discharges or spills are permitted in the mine. All cleanup and washout operations shall be performed at the ground surface.

Potential spill areas in the underground shall be identified by the Contractor in the work plan. The Contractor shall provide measures to contain suitable containment. Isolation measures shall include, but are not limited to, lining with a membrane material (PVC, hypalon, HDPE), draped curtains (polyethylene,PVC, etc.), corrugated sheet metal protective walls or a combination of these and other measures.

If salt-saturated grout is selected for use, the Contractor shall make provisions to accurately proportion the components. Proportioning shall be by weighing. Sufficient quantities of dry

components shall be developed prior to initiation of the grouting to perform the work so as not to incur delays during the mixing/placing sequence.

3.2 Interface Grouting of Concrete Barrier

After each cell of the concrete barrier has been allowed to cure for a period of seven days, or as directed by Westinghouse WID, the Contractor shall interface grout the remaining space between the back wall and the top surface of the concrete barrier.

Each cell of the concrete barrier shall be grouted before the next adjacent cell is formed and concrete placed. Grout delivery and return lines shall be installed with the form work as shown and called for on the drawings, or as directed by Westinghouse WID.

The placing of grout, unless otherwise directed by Westinghouse WID shall be continuous until completed. Grouting shall progress from lower to higher grout pipes. Grouting shall proceed through a single delivery line until grout escapes from the adjacent return line. The Contractor shall then secure these lines and move to the next adjacent set of delivery and return lines. Pressure shall be adjusted to adequately deliver the grout to the forms, as witnessed by grout in the return line.

The grouting operation shall be conducted in a manner such that it does not affect the stability of the concrete barrier structure.

3.3 Contact Grouting

After completion of interface grouting if directed by Westinghouse WID, the Contractor shall contact grout to fill any remaining voids at the concrete barrier/back wall interface. Contact grouting includes all operations to drill, clean, and grout holes installed in the concrete barrier.

The Contractor shall drill and grout the interface zone to the main concrete barrier as directed by Westinghouse WID.

The location, direction, and depth of each grout hole shall be as directed by Westinghouse WID. The order in which the holes are drilled and the manner in which each hole is drilled and grouted, the proportions of the water used in the grout, the time of grouting, the pressures used in grouting, and all other details of the grouting operations shall be as directed by Westinghouse WID.

Wherever required, contact grouting will entail drilling the hole to a limited depth, installing a packer, and performing grouting.

3.3.1 Drilling

The holes shall be drilled with rotary-type drills. Drilling grout holes with percussion-type drills will not be permitted except as approved by Westinghouse WID.

The requirements as to location, depth, spacing, and direction of the holes shall be as directed by Westinghouse WID.

The minimum diameter shall be approximately 11/2 inches.

When the drilling of each hole or stage of has been completed, compressed air will be used to flush out drill cuttings. The hole shall then be temporarily capped or otherwise suitably protected to prevent the hole from becoming clogged or obstructed until it is grouted.

3.3.2 Materials for Contact Grouting

Standard weight black steel pipe conforming to ASTM A-53 shall be set in the concrete in the locations as directed by Westinghouse WID. All pipe and fittings shall be furnished by the Contractor.

The size of the grout pipe for each hole and the depth of the holes for setting pipe for grouting shall be as directed by Westinghouse WID. Care shall be taken to avoid clogging or obstructing the pipes before being grouted, and any pipe that becomes clogged or obstructed from any cause shall be cleaned satisfactorily or replaced.

The packers shall be furnished by the Contractor and shall consist of expansible tubes or rings of rubber, leather, or other suitable material attached to the end of the grout supply pipe. The packers shall be designed so that they can be expanded to seal the drill hole at the specified locations and when expanded shall be capable of withstanding without leakage, for a period of 5 minutes, air pressure equal to the maximum grout pressures to be used.

3.3.3 Grouting Procedures

Different grouting pressures will be required for grouting different sections of the grout holes. Pressures as high as necessary to deliver the grout but which, as determined by trial, are safe against concrete displacement shall be used in the grouting.

If, during the grouting of any hole, grout is found to flow from adjacent grout holes or connections in sufficient quantity to interfere seriously with the grouting operation or to cause appreciable loss of grout, such grout holes and connections shall be capped temporarily. Where such capping is not essential, holes shall be left open to facilitate the escape of air as the grout is forced into other holes. Before the grout has set, the grout pump shall be connected to adjacent capped holes and to other holes from which grout flow was observed, and grouting of all holes shall be completed. If during the grouting of any hole, grout is found to flow from points in the barrier, any parts of the concrete structure, or other locations, such flows or leaks shall be plugged or caulked by the Contractor as directed by Westinghouse WID.

As a safeguard against concrete displacement, excessive grout travel, or while grout leaks are being caulked, Westinghouse WID may require the reduction of the pumping pressure, intermittent pumping, or the discontinuance of pumping.

The consistency of the grout mix shall be varied, as directed by Westinghouse WID, depending on the conditions encountered. Where the grout hole or connection continues to take a large amount of grout after the mix has been thickened, Westinghouse WID may require that pumping be done intermittently, waiting up to 8 hours between pumping periods to allow grout in the barrier to set. After the grouting is complete, the pressure shall be maintained by means of stopcocks, or other suitable valve that it will be retained in the holes or connections being grouted.

3.4 Cleanup

No clean-up or washing of equipment with water is allowed in the underground. No free water spills are permitted. All clean out or wash out requiring water will be performed above ground at the location approved by Westinghouse WID. See note above regarding potential spill areas in Section 3.1 - General.

3.5 Quality Control

The Contractor shall provide a third-party quality control inspector at the site throughout the grout placement operations. The inspector shall determine that the grout mix is properly proportioned and properly mixed to the approved consistency. The inspector shall sample and make one set of grout cubes for compression testing for every 50 cubic feet of grout placed, or fraction thereof, for each day of grout placement.

End of section.

SECTION 02722
GROUTING

SECTION 03100

CONCRETE FORMWORK

PART 1 - GENERAL

1.1 Scope

This section includes:

- Formwork for cast-in-place concrete with shoring, bracing, and anchorage
- Accessory items, grout pipes, concrete delivery pipes.

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 01600 - Material and Equipment
- 02722 - Grouting
- 03300 - Cast-in-Place Concrete
- 04300 - Unit Masonry System

1.3 References

ACI 301-89	Specifications for Structural Concrete for Buildings
ACI 318-89(92)	Building Code Requirements for Reinforced Concrete
ACI 347-94	Recommended Practice for Concrete Formwork
ASTM A-36/ A36M-91	Standard Specification for Structural Steel
ASTM A-53-90b	Standard Specification for Pipe, Steel, Black, and Hot-Dipped Zinc Coated Welded and Seamless
ASTM A-325-91c	Standard Specification for Structural Bolts, Steel, Heat-Treated 120/105 ksi Minimum Tensile Strength
ASTM A-615-95b	Standard Specifications for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
AWS A3.0-94	Welding Terms and Definitions

AWS A5.1-91	Specification for Mild Steel Covered Arc Welding Electrodes
AWS D1.1-94	Structural Welding Code-Steel
AISC	Manual of Steel Construction Latest Edition

1.4 Submittals
The Contractor shall submit the following supporting documentation for the adequacy of the formwork 30 days prior to initiation of work at site:

- Shop detail drawings with appropriate calculations to support the adequacy of the formwork.
- Mill test certification of materials utilized in construction of the forms.
- Details of installation contained in the Contractor's Work Plan.

1.5 Quality Assurance
The design and detail of the formwork shall be conducted under direct supervision of a professional structural Engineer experienced in design of this work. Responsibilities include:

- Fabricating formwork in accordance with AISC manual of steel construction.
- Performing all welding in accordance with AWS D1.1 structural welding code.
- Performing all bolting in accordance with AISC specification for structural joints using ASTM A325 or A490 bolts.
- Performing work in accordance with ACI 301, 318, and 347, AISC and AWS standards. Maintain one copy of all standards at site.

PART 2 - PRODUCTS

2.1 Form Materials
Forms for the concrete barrier shall be constructed of ASTM A-36 steel.

Pipe inserts shall be ASTM A-53 black standard weight pipe.

Form spacers shall be ASTM A-36 round stock.

Bolts shall be ASTM A325 high strength structural bolts.

Grout pipes shall be ASTM A-53 standard weight pipe or flex conduit as shown on the drawings.

Rock anchors shall develop strength equal to or greater than ASTM A-36 round stock.

Welding electrodes shall conform to AWS A5.1.

PART 3 - EXECUTION

3.1 General

The Contractor shall furnish all labor material equipment and tools to perform all operations in connection with the design, detail, fabrication and erection of the formwork and the fabrication and installation of grout pipes for the main concrete barrier. All work shall be performed according to standards referred to in Paragraph 1.3.

The Contractor may, at his option submit an alternate design or modify the design shown on the drawings, subject to the approval of Westinghouse WID. All designs must be supported by design calculations stamped and sealed by a registered professional engineer.

The Contractor shall furnish, fabricate and install all grout pipes and grout boxes for both the concrete barrier and the isolation walls.

3.2 Shop Drawings

The Contractor shall design and detail all formwork for the concrete barrier, complete with any required bracing and shoring for the concrete barrier as shown on the drawings, in accordance with ACI 318 and 347 and the AISC manual of steel construction.

The details shall incorporate provision for adjusting and modifying the formwork to suit the excavation. Excavation tolerances are given in Section 02222 Excavation.

The Contractor shall be responsible for verifying the excavation dimensions to develop the concrete formwork to fit the excavation.

Prior to fabrication, the Contractor shall submit shop drawings complete with supporting calculations for review/approval by Westinghouse WID 30 days prior to initiating work. The contractor shall incorporate all Westinghouse WID's comments, revisions, resolve all questions and resubmit drawings for final approval prior to proceeding with fabrication.

3.3 Fabrication

The Contractor shall fabricate all formwork and ancillary items in accordance with the latest edition of the AISC Manual of Steel Construction and the approved detail drawings.

Formwork shall contain all inserts for grouting and pumping concrete. Sufficient valving shall be provided on inserts to allow shut off of concrete and grout to prevent back flow through the form work.

All welding shall be in accordance with AWS D1.1 structural welding code including operator and procedure certifications. Elements shall be welded using E-7018 low hydrogen electrodes. Panels shall be piece marked to correspond to the erection drawing(s) and sequence at fabrication.

3.4 Installation

3.4.1 Grout Pipes

The Contractor shall furnish, fabricate, and install all grout pipes and boxes as approved by Westinghouse WID. Grout pipes and boxes shall be attached to the back surface using masonry anchors as shown on the drawings or other approved methods. Grout pipes shall be connected to the inserts installed in the permanent forms and securely fastened to the formwork. All grout pipes will be blown out with compressed air after installation and prior to closure of the formwork to assure they are clean and free from debris or obstructions. Grout pipes shall then be temporarily capped to prevent entry of foreign matter until ready for grouting. The Contractor shall apply masking tape to the grout box openings to prevent concrete infiltration during concrete placement.

3.4.2 Formwork

The steel formwork for the concrete barrier is to remain in place at completion of each segment of the barrier, therefore all formwork shall be free from oil, grease, rust, dirt, mud or other material that would prevent bonding by the concrete. Forms will not be oiled or receive application of release agent.

The Contractor shall install formwork at the locations shown on the drawings to the lines and grades shown. Forms are to be mortar tight. The Contractor shall adjust the formwork to suit the contour of the excavation. Rock may be trimmed or chipped to suit where interferences are encountered. Where overexcavation has occurred in excess of the designed-in adjustability of the formwork, modifications shall be proposed to Westinghouse WID for his approval prior to installation. Installation of the formwork shall be reviewed and approved by Westinghouse WID prior to proceeding with concrete installation.

The Contractor shall provide a sealant or gasket material subject to the approval of Westinghouse WID.

3.5 Quality Control

The Contractor shall arrange for and contract with an approved third party inspector to provide inspection/testing services for the fabrication and installation of the formwork and ancillary items, as required by the QA/QC plan.

The Contractor shall furnish certified mill test reports for all materials utilized in the fabrication.

All welding shall be in accordance with AWS D1.1 structural welding code. The Contractor shall furnish welding operator and procedure certifications for all operators and procedures utilized.

Fabricated components shall be inspected for dimension and overall quality. Welds shall be inspected by an AWS certified welding inspector.

The inspector shall visually inspect the installation for fit-up and dimensionally for location.

3.6 Handling, Shipping, Storage

The Contractor shall handle, ship, and store fabricated components with care to avoid damage. Stored components shall be placed on timbers or pallets off the ground to keep the units clean. Components shall be tarped while in outdoor storage. Components that become spattered or contaminated with mud will be thoroughly cleaned during erection, and prior to concrete emplacement. Damaged components will be rejected by the inspector and replaced by the contractor at his cost.

End of section.

SECTION 03100
CONCRETE FORMWORK

SECTION 03300

CAST-IN-PLACE CONCRETE

PART 1 - GENERAL

1.1 Scope

This section includes:

- Cast-in-place concrete for concrete barrier
- Concrete mix design.

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 01600 - Material and Equipment
- 02222 - Excavation
- 02722 - Grouting
- 03100 - Concrete Formwork

1.3 References

ACI 211.1-91	Standard Practice for Selecting Proportions for Normal, Heavy Weight, and Mass Concrete
ACI 318.1-89(92)	Building Code Requirements for Structural Plain Concrete
ACI 304R-89	Guide for Measuring, Mixing, Transporting, and Placing Concrete
ASTM C 33-93	Standard Specification for Concrete Aggregates
ASTM C 39-94	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C 94-94	Standard Specification for Ready-Mixed Concrete
ASTM C 136-95a	Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates
ASTM C 143-90a	Standard Specification for Slump of Hydraulic Cement Concrete

ASTM C 150-95	Standard Specification for Portland Cement
ASTM C 186-94	Standard Test Method for Heat of Hydration of Hydraulic Cement
ASTM C 403/ C 403M-95	Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
ASTM C 494-95	Standard Specification for Chemical Admixtures for Concrete
ASTM C 618-94a	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolam for Use as an Admixutre in Portland Cement Concrete
ASTM C 845-90	Standard Specification for Expansivce Hydraulic Cement
ASTM D 2216-92	Standard Test Method for Laboratory Determination of Water (moisture) Content of Soil and Rock
USACE CRD-C 36	Method of Test for Thermal Diffusivity of Concrete
USACE CRD-C 48	Standard Test Method for Water Permeability of Concrete
API 10	Cements
NRMCA	Check List for Certification of Ready Mixed Concrete Production Facilities
NRMCA	Concrete Plant Standards

Westinghouse WID Standards

WIPP-DOE-71	Design Criteria Waste Isolation Pilot Plant, Revised Mission Concept -- IIA (DOE, 1984)
WP 03-1	WIPP Startup and Acceptance Test Program (Westinghouse, 1993b)
WP 09-010	Design Development Testing (Westinghouse, 1991)
WP 09-CN3021	Component Numbering (Westinghouse, 1994a)
WP 09-024	Configuration Management Board/Engineering Change Proposal (ECP) (Westinghouse, 1994b)

1.4 Submittals for Review/Approval

The Contractor shall submit the following for approval 30 days prior to initiating any work at the site:

Type of concrete proposed

Product Data - Laboratory test data and trial mix data for the proposed concrete to be utilized for the concrete barrier.

Proposed method of installation, including equipment and materials in work plan.

1.5 Submittals at Completion

Laboratory test data developed during the installation of the concrete barrier.

1.6 Quality Assurance

Perform work in accordance with the Contractor's Quality Control Plan and referenced ACI and ASTM standards.

Acquire cement, aggregate and component materials from the same source throughout the work.

PART 2 - PRODUCTS

2.1 Cement

Portland cement shall conform to ASTM C150 Type II modified with Pozzolan or IV for plain cement concrete or API 10 Class H oil well cements. Cement utilized in the mix shall be Portland cement, Type II modified with pozzolan or type IV, to limit the heat of hydration of the resultant mix. The source of the cement to be used shall be indicated and manufacturer's certification that the cement complies to the applicable standard shall be provided with each shipment.

2.2 Aggregates

Aggregates shall be quartz aggregates conforming to the requirements of ASTM C33.

Fine aggregate shall meet the requirements of ASTM C33 having a fineness modulus in the range of 2.80 to 3.00.

Coarse aggregate maximum size shall be 1 1/2 inches and shall be clean, cubical, angular, 100 percent crushed aggregate without flat or elongated particles.

The source of the aggregate is to be indicated and test reports certifying that the aggregate complies with the applicable standard are to be submitted for approval with the trial mix data.

2.3 Water

Water used in mixing concrete shall be of potable quality, free of injurious amounts of oil, acid, alkali, organic matter, or other deleterious substances.

Water shall conform to the provisions in ASTM C94, and in addition, shall conform to the following:

- pH not less 6.0 or greater than 8.0
- Carbonates and/or bicarbonates of sodium and potassium: 1000 ppm maximum
- Chloride ions (Cl): 250 ppm maximum
- Sulfate ions (SO_4): 1000 ppm maximum
- Iron content: 0.3 ppm maximum
- Total solids: 2000 ppm maximum

When ice is used in concrete mix, the water used for making ice shall meet all of the above requirements.

The source of water is to be indicated and certified copies of test data from an approved laboratory confirming that the water to be used meets the above requirements shall be submitted for approval with the trial mix data.

2.4 Admixtures

Pozzolan shall conform to ASTM C618. Sampling and testing of pozzolans shall conform to ASTM C311. Approximately 5 percent by weight of pozzolan may be used to replace cement in the mixes when approved.

All admixtures shall conform to ASTM C-494. The source of any admixtures proposed are to be indicated and certified copies of test data from an approved laboratory shall be submitted for approval with the trial mix.

2.5 Target Properties of the Concrete Mix

The Contractor shall develop and proportion a plain cement concrete mix for use in constructing the concrete barrier. The Contractor shall demonstrate by trial mix that the proposed concrete meets the following properties:

Target properties for Barrier Concrete

Property	Comment
4-hr working time	Indicated by 8-inch slump (ASTM C 142) after 3-hr intermittent mixing. Max 10-inch slump at mixing.
Less than 25 °F heat rise prior to placement	Difference between initial condition and temperature after 4 hr.
4,000 psi compressive strength (f'_c)	At 28 days after casting (ASTM C 39)
Volume stability	Length change between +0.05 percent and -0.02 percent (ASTM C 490)
Minimal entrained air	2 percent to 3 percent air

The Contractor shall use water reducing agents, plasticizers and other admixtures to achieve the slump and workability of the mix without adding excessive mixing water or excessive water-cement ratio. All admixtures shall conform to ASTM C-294.

The Contractor shall provide certified copies of test data from an approved laboratory demonstrating compliance with the above target properties.

In addition to the target properties the Contractor shall provide certified test data for the trial mix for the following properties:

- Heat of hydration ASTM C-186
- Concrete Set ASTM C-403
- Thermal Diffusivity USACE CRD-C36
- Water Permeability USACE CRD-C43

2.6 Salado Mass Concrete

The Contractor may elect to utilize the Salado Mass concrete in preference to developing a plain cement concrete. If Salado Mass concrete is selected, the Contractor shall demonstrate that the Salado Mass concrete meets the target properties shown above. Recommended initial proportioning of the Salado Mass concrete is as follows:

Component	Percent of Total Mass
Class H cement (API 10)	4.93
Chem Comp III (ASTM C-845 Type K)	2.85
Class F fly ash (ASTM C-618)	6.82
Fine aggregate	33.58
Coarse aggregate	43.02
Sodium chloride	2.18
Defoaming agent	0.15
Sodium citrate	0.09
Water	6.38

The Contractor shall prepare a trial mix and provide certified test data from an approved testing laboratory for slump, compressive strength, heat rise, heat of hydration, concrete set time, thermal diffusivity, and water permeability as indicated above for the plain concrete mix.

PART 3 - EXECUTION

3.1 General

The Contractor shall provide all labor material, equipment and tools necessary to develop, supply, mix, transport and place mass concrete in the forms as shown on the drawings and called for in these specifications. All work shall be according to the standard references in paragraph 1.3.

The Contractor will be required to provide and erect on the site a batch plant, suitable to store, handle, weight and deliver the proposed concrete mix. The batch plant shall be certified to NRMCA standards. The batch plant shall be erected on site in the location as directed by Westinghouse WID.

The Contractor shall batch, mix, and deliver to the underground, sufficient quantity of concrete to complete placement of concrete within one form section, as shown on the drawings. Once begun, placement of concrete in a section shall be continuous until completed. Target time for concreting one section is eight to ten hours allowing an additional two hours for clean up of equipment, for a total 10- to 12-hour shift.

It is expected that addition of water to the dry materials and mixing of the concrete will occur at the ground surface with transport of wet concrete to a pump at the underground level where it will be pumped into the forms.

The Contractor is to provide all transport vehicles or means to transfer the wet concrete from the mixer truck to the pump. It is expected that the Contractor will use the waste conveyance hoist to transfer from the ground surface to the mine level. The Contractor is to familiarize himself with the dimensions of the waste conveyance and the airlock in order to provide suitable transport vehicles. The Contractor is also to familiarize himself with the capacity and speed of the conveyance to allow transfer of sufficient concrete to sustain the continuing placement of concrete. (See Figures 2 and 3 attached to Section 02010 - Mobilization and Demobilization).

The Contractor shall determine the horizontal distance to the entry where placement of the concrete barrier is to occur, and develop a route, with the approval of Westinghouse WID for traffic flow within the underground.

Details of the logistics for handling the concrete shall be included in the Contractors' Work Plan, and submitted to Westinghouse WID for approval prior to start of work at the site.

Potential spill areas in the underground shall be identified by the Contractor in the Work Plan. The Contractor shall provide measures to contain and isolate any water from contact with the halite in these areas. Suitable containment isolation measures shall include but are not limited to, lining with a membrane material (PVC, hypalon, HDPE), draped curtains (polyethylene, PVC, etc.), corrugated sheet metal protective walls or a combination of these and other measures.

3.2 Pumping Concrete

The Contractor shall provide pumping equipment suitable for placing the concrete into the forms. The Contractor at a minimum, shall provide an operating and a spare pump, to be used in the event of breakdown of the primary unit. After transporting and prior to pumping the concrete shall be remixed to compensate for segregation of aggregate during transport. The Contractor shall indicate the equipment proposed for pumping (manufacturer, model, type, capacity, pressure and remixing at the point of delivery in the Work Plan).

Each batch of concrete shall be checked at the surface at the time of mixing and again at the point of transfer to the pump for slump and temperature, and shall conform to the following:

- Max. slump at mixing - 10 inches
- Max. slump at delivery to pump - 8 inches
- Max. temperature at placement = 70°F

Note: No water is to be added to the mix after the initial mixing and slump are determined.

The Contractor shall connect to the pipe ports fabricated into the forms for delivery of the concrete, beginning with the lowest ports first. Pumping shall continue until concrete is seen in the adjacent port at which time the delivery hose will be transferred to that port and the first port capped.

Pumping shall continue moving laterally then upward until the entire form is filled and the pour is completed.

3.4 Coordination of Work

The Contractor is to coordinate his work mixing, transporting, and placing the mass concrete with the on-going operations in the underground. Coordination of use of the facilities and existing equipment shall be through Westinghouse WID.

3.5 Clean-Up

No clean up or washing of equipment with water will be allowed in the underground. No free water spills are permitted in the underground. All clean-out or wash-out requiring water will be performed above ground at the location approved by Westinghouse WID.

3.6 Quality Control

The Contractor shall provide a third-party quality control inspector at the site throughout the concrete placement. The inspector shall be responsible for determining that the batch plant is proportioning the mix according to the approved proportions. The batch plant shall provide a print out of batch quantities for each truck delivered to the mine. The inspector shall also determine the slump for each batch as it is mixed and allow additional water to be added until the initial slump is achieved. No additional water is to be added after this time. Temperature will also be recorded at this time.

The inspector shall also determine the slump and temperature following the remixing when concrete is transferred to the pump. Concrete not meeting or exceeding the specification is to be rejected and removed from the underground.

Concrete test cylinders to determine unconfined compression strength shall be taken by the inspection at the delivery from remixer to the pump in the underground. Four (4) cylinders shall be made for each 50 cubic yards of concrete placed. Cylinders shall be sealed with polyethylene and taped and field cured at ambient temperatures in the mine adjacent to the concrete barrier area. Two (2) samples shall be tested at 7 days and the remaining two (2) at 28 days.

End of section.

SECTION 03300
CAST-IN-PLACE CONCRETE

SECTION 04100

MORTAR

PART 1 - GENERAL

1.1 Scope
This section includes:

- Mortar for Isolation Wall Construction.

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 01600 - Material and Equipment
- 04300 - Unit Masonry System

1.3 References

ASTM C91-95	Standard Specification for Masonry Cement
ASTM C144-93	Standard Specification for Aggregate for Masonry Mortar
ASTM C150-95	Standard Specification for Portland Cement
ASTM C207-91	Standard Specification for Hydrated Lime for Masonry Purposes
ASTM C270-94	Standard Specification for Mortar for Unit Masonry
ASTM C780-94	Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry
ASTM C1142-94	Ready-Mixed Mortar for Unit Masonry
ASTM E447-92	Test Methods for Compressive Strength of Masonry Prisms

1.4 Submittals for Review and Approval
The Contractor shall submit for approval the following 30 days prior to the initiation of work at the site.

Design mix.

Certified laboratory tests for the proposed design mix, indicating conformance of mortar to property requirements of ASTM C270, and test and evaluation reports to ASTM C780.

1.5 Submittals at Completion
Certified laboratory test results for the construction testing of mortar mix.

1.6 Quality Assurance
Perform work in accordance with the Contractor's Quality Control Plan and referenced ASTM standards. Acquire cement, aggregate, and component materials from the same source throughout the work.

1.7 Delivery Storage Handling
Maintain packaged materials clean, dry and protected against dampness, freezing and foreign matter.

PART 2 - PRODUCTS

2.1 Mortar Mix
The Contractor shall provide mortar for Isolation Walls, which shall be in conformance with ASTM C270 type M, using the property specification (3,000 psi at 28 days).

Sand for mortar shall conform to ASTM C144.

Water used for mixing mortar shall be of potable quality, free of injurious amounts of oil, acid alkali, organic matter, sediments, or other deleterious substances, as specified for Concrete, Section 03300 2.3.

The supply of materials as defined in the design mix shall remain the same throughout the job.

PART 3 - EXECUTION

3.1 General
The Contractor shall furnish all labor material equipment and tools to perform all operations in connection with supplying and mixing mortar for constructing the isolation walls.

The Contractor shall fully describe his proposed mortar mixing operation, including proposed equipment and materials in the Work Plan.

3.2 Mortar Mixing

Mortar shall be machine-mixed with sufficient water to achieve satisfactory workability. Maintain sand uniformly damp immediately before the mixing process. If water is lost by evaporation, retemper only within one and one half hours of mixing. Use mortar within two hours of mixing at ambient temperature of 85° in the mine.

3.3 Installation

The Contractor shall install mortar to the requirements of Section 04300 Unit Masonry System.

3.4 Field Quality Control

The Contractor shall provide a third party Quality Control Inspector to perform all sampling and testing to confirm that the mortar mix conforms to the proposed mix properties developed in the design mix.

Construction testing of mortar mix shall be in accordance with ASTM C780 for compression strength. Four (4) prism specimens shall be taken for each 50 cu. ft. of mortar or fraction thereof placed each day.

End of Section.

SECTION 04100
MORTAR

SECTION 04300

UNIT MASONRY SYSTEM

PART 1 - GENERAL

1.1 Scope
This section includes:

- Concrete Masonry Units

1.2 Related Sections

- 01010 Summary of Work
- 01400 Contractor Quality Control
- 01600 Material and Equipment
- 02722 Grouting
- 03100 Concrete Formwork
- 04100 Mortar

1.3 References

ASTM C55-94a Standard Specification for Concrete Building Brick

ASTM C140-94a Standard Method of Sampling and Testing Concrete Masonry Units

1.4 Submittals for Revision and Approval
The Contractor shall submit for approval the following 30 days prior to initiation of the work at the site.

Certified laboratory test results for the proposed solid masonry units.

1.5 Quality Assurance
Perform the work in accordance with the Contractor's Quality Control Plan.

PART 2 - PRODUCTS

2.1 Concrete Masonry Units
Concrete masonry units shall be solid (no cavities or cores), load bearing high-strength units having a minimum compressive strength of 3500 psi. Concrete masonry units shall be tested

in accordance with ASTM C140. All other aspects of the concrete masonry units shall comply with ASTM C55, Type I Moisture Controlled.

Nominal modular size shall be 8 x 8 x 16 inches, or as otherwise approved by Westinghouse WID.

Concrete brick shall comply with ASTM C55, Grade N, Type I (moisture controlled) having a minimum compressive strength of 3500 psi (Avg. 3 units) or 3000 psi for individual unit.

2.2 Mortar

Mortar shall be as specified in Section 04100 Mortar.

PART 3 - EXECUTION

3.1 General

The Contractor shall furnish all labor, material, equipment and tools to perform all operations of installing Unit Masonry Isolation Walls to the lines and grades shown on the drawings.

The Contractor shall examine the excavation of the entry to affirm that the keys have been properly leveled and cut to the appropriate depths, at the proper locations prior to any to any work.

3.2 Installation

The Contractor shall install the isolation walls using concrete masonry units as specified above. Masonry units shall be installed with 3/8-inch mortar joints with full mortar bedding and full head joints. Masonry units shall be installed in running bond with headers every third course. Masonry units shall be mortared tight to the ribs and the back wall to provide a seal all around the isolation wall.

Concrete brick may be used as required for fit-up around grout pipes, or minimizing the dimensional fit-up at the top or sides of the isolation walls as approved by Westinghouse WID. The interface between the top of the isolation wall and the back wall shall be completely mortared to provide full contact between the back and the block wall.

3.3 Field Quality Control

The Contractor shall provide a third-party Quality Control Inspector to inspect the installation of the Concrete Masonry Unit Isolation Walls. Inspection and testing of the mortar shall be in accordance with Section 04100 Mortar.

End of Section

SECTION 04300
UNIT MASONRY SYSTEM

APPENDIX H
DESIGN DRAWINGS

NOTICE

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Volume 1

Waste Isolation Pilot Plant

Geotechnical Analysis Report For July 2009 – June 2010

U.S. Department of Energy

March 2011

This document has been submitted as required to:

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FOREWORD AND ACKNOWLEDGMENTS

This report contains an assessment of the geotechnical status of the Waste Isolation Pilot Plant (WIPP). During the excavation of the principal underground access and experimental areas, the status was reported quarterly. Since 1987, when the initial construction phase was completed, reports have been published annually. This report presents and analyzes data collected from July 1, 2009, to June 30, 2010.

This Geotechnical Analysis Report (GAR) was written to meet the needs of several audiences. It satisfies requirements contained in the WIPP Hazardous Waste Facility Permit[1] (HWFP) and the Certification of Compliance[2] with Subparts B and C, Title 40 *Code of Federal Regulations* (CFR) Part 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes." It focuses on the geotechnical performance of the various components of the underground facility, including the shafts, shaft stations, access drifts, and waste disposal areas. The results of investigations of excavation effects and other geotechnical studies are also included.

The report compares the geotechnical performance of the repository to the design criteria. It describes the techniques that were used to acquire the data and the performance history of the instruments. The depth and breadth of the evaluation of the different components of the underground facility vary according to the types and quantities of data available and the complexity of the recorded geotechnical responses. Graphic documentation of data and tabular documentation of instrument history can be provided upon request.

This GAR was prepared by Washington TRU Solutions LLC (WTS) for the U.S. Department of Energy (DOE), Carlsbad Field Office (CBFO), in Carlsbad, New Mexico. Work was supported by the DOE under Contract No. DE-AC29-01AL66444.

[1] New Mexico Environment Department (NMED), 2010, Waste Isolation Pilot Plant Hazardous Waste Facility Permit, NM4890139088-TSDF, Santa Fe, NM

[2] U.S. Environmental Protection Agency, 1998, "Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the Disposal Regulations: Certification Decision," Federal Register, Vol. 63, No. 95, pp. 27354, May 18, 1998, Washington, DC

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ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
bp	before present
bsc	below shaft collar
CAO	Carlsbad Area Office
CBFO	Carlsbad Field Office
CFR	Code of Federal Regulations
CH	contact-handled
cm	centimeter(s)
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ft	foot (feet)
GAR	Geotechnical Analysis Report
GIS	geomechanical instrumentation system
HWFP	Hazardous Waste Facility Permit
in	inch(es)
km	kilometer(s)
kPa	kilopascal(s)
kVA	kilovolt ampere(s)
LANL	Los Alamos National Laboratory
lb	pound(s)
m	meter(s)
Ma	million years
MB	marker bed
µin	10-6 inch(es)
NMED	New Mexico Environment Department
OMB	orange marker bed
psi	pound(s) per square inch
RH	remote-handled

SPDV	Site and Preliminary Design Validation
TRU	transuranic
WIPP	Waste Isolation Pilot Plant
WTS	Washington TRU Solutions LLC
yr(s)	year(s)

1.0 INTRODUCTION

This Geotechnical Analysis Report (GAR) presents and interprets geotechnical data from the underground excavations at the Waste Isolation Pilot Plant (WIPP). The data, which are obtained as part of a regular monitoring program, are used to characterize conditions, to compare actual performance to the design assumptions, and to evaluate and forecast the performance of the underground excavations.

GARs have been available to the public since 1983. During the Site and Preliminary Design Validation (SPDV) Program, the architect/engineer for the project produced these reports quarterly to document the geomechanical performance during and immediately after early excavations of the underground facility. Since completion of the construction phase of the project in 1987, the management and operating contractor for the facility has prepared these reports annually. This report describes the performance and condition of selected areas from July 1, 2009, to June 30, 2010. It is divided into nine chapters.

Chapter 1 provides background information on WIPP, its mission, and the purpose and scope of the geomechanical monitoring program. Chapter 2 describes the local and regional geology of the WIPP site. Chapters 3 and 4 describe the geomechanical instrumentation in the shafts and shaft stations, present the data collected by that instrumentation, and provide interpretation of these data. Chapters 5 and 6 present the results of geomechanical monitoring in the two main portions of the WIPP underground (the access drifts and the waste disposal area). Chapter 7 discusses the results of the Geoscience Program, which include fracture mapping and hole observations. Chapter 8 summarizes the results of geomechanical monitoring and compares the current excavation performance to the design requirements. Chapter 9 lists references.

1.1 Location and Description

WIPP is located in southeastern New Mexico, 26 miles (42 kilometers [km]) east of Carlsbad (Figure 1 - 1). The surface facilities were built on the flat to gently rolling terrain that is characteristic of the Los Medaños area. The underground facility is being excavated approximately 2,150 feet (ft) (655 meters [m]) beneath the surface in the Salado Formation. Figure 1 - 2 shows a plan view of the underground configuration of WIPP as of June 30, 2010.

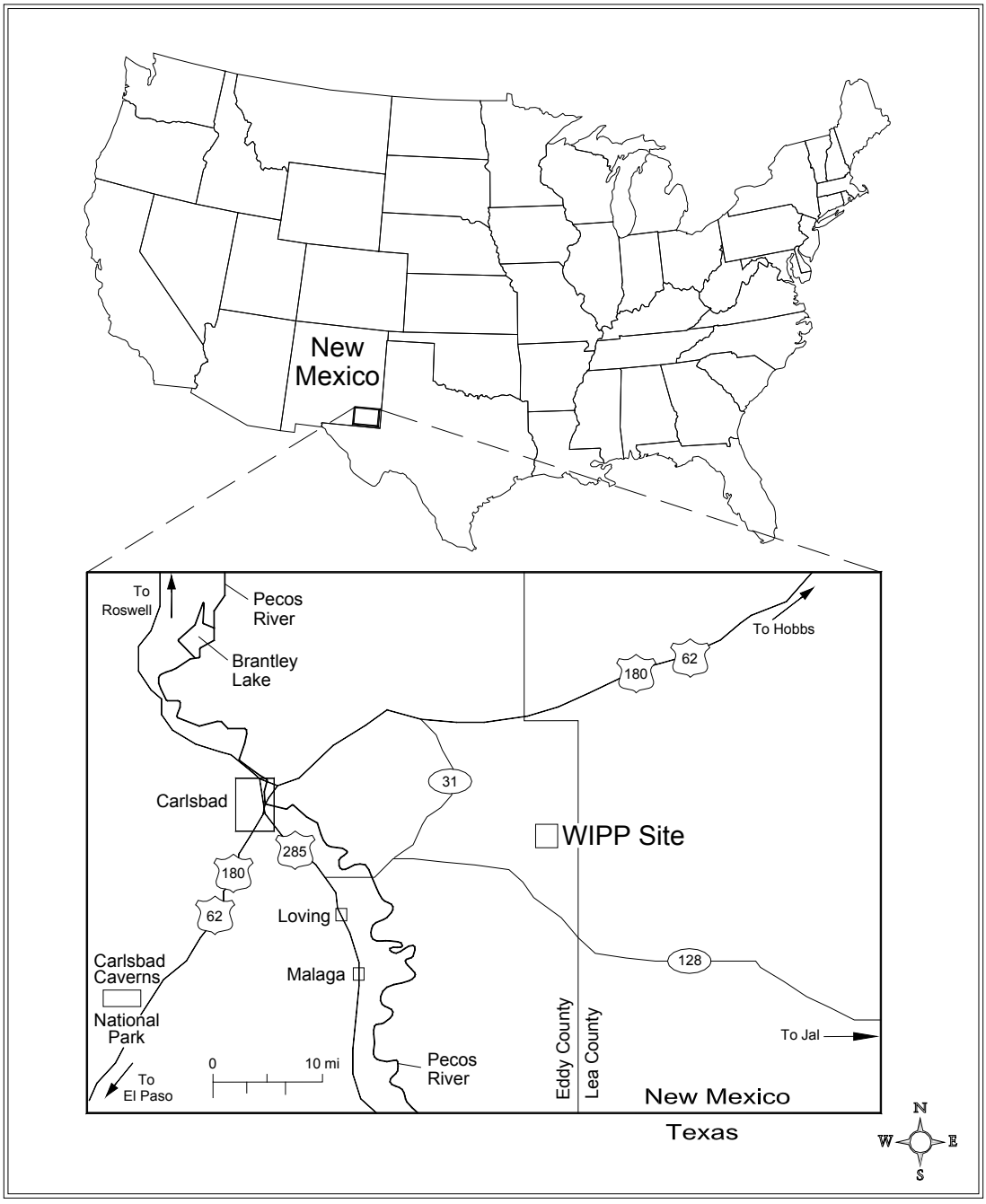

Figure 1 - 1 – WIPP Location

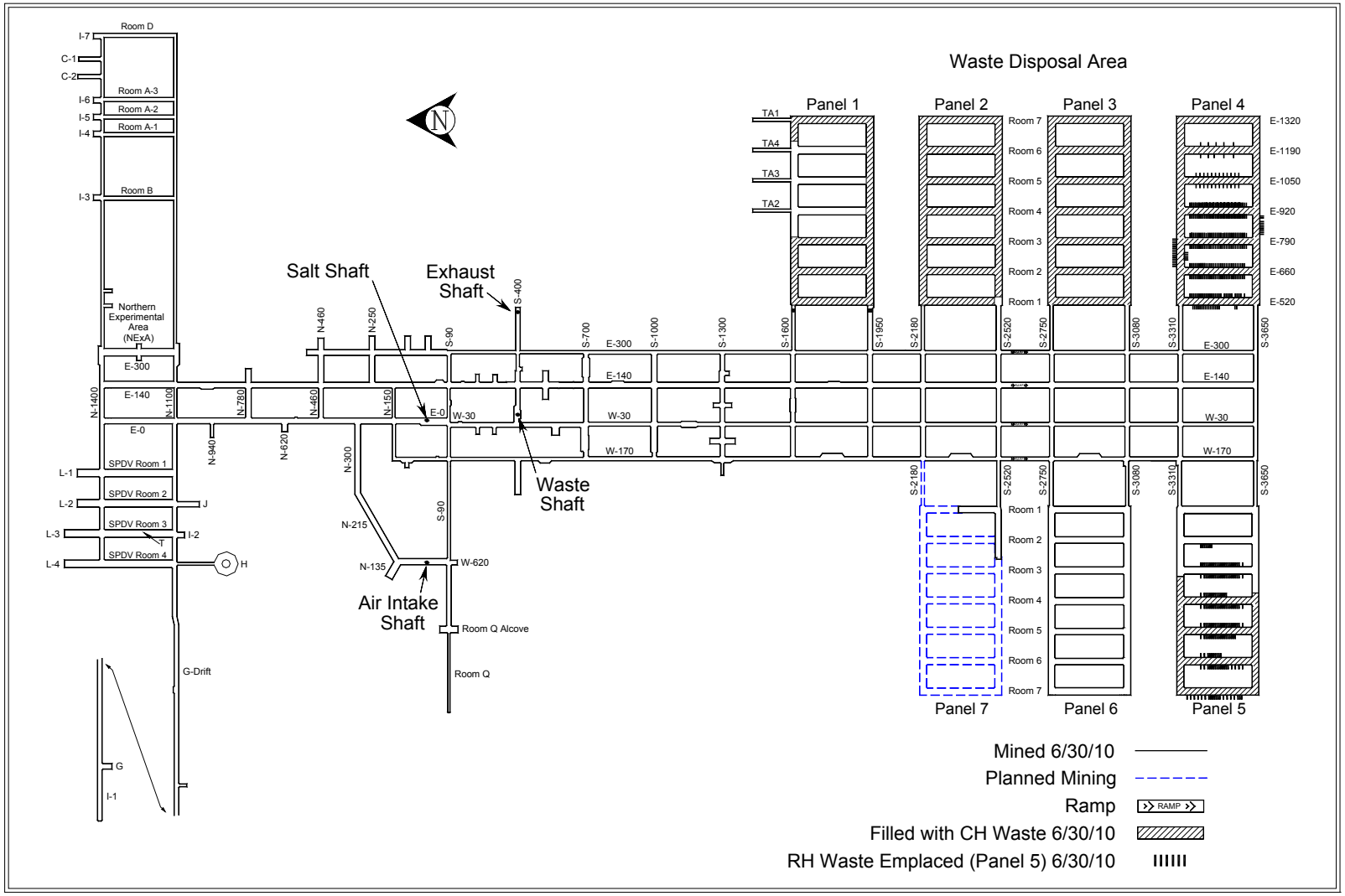

Figure 1 - 2 – Underground Mining and Waste Disposal Configuration as of June 30, 2010

1.2 Mission

In 1979 Congress authorized WIPP (Public Law 96-164, National Security and Military Applications of Nuclear Energy Authorization Act of 1980) to provide ". . . a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission." To fulfill this mission, the DOE constructed a full-scale facility to demonstrate both technical and operational principles of the permanent disposal of transuranic (TRU) and TRU mixed wastes. Technical aspects are those concerned with the design, construction, and performance of the subsurface excavations. Operational aspects refer to the receiving, handling, and emplacement of TRU wastes in the facility. The facility was first used for *in situ* studies and experiments without the use of radioactive waste. WIPP now receives handles, and permanently disposes of TRU waste and TRU mixed waste.

1.3 Development Status

To fulfill its mission, the DOE developed WIPP in a phased manner. The goal of the SPDV phase, begun in 1980, was to characterize the site and obtain *in situ* geotechnical data from underground excavations to determine whether site characteristics and in situ conditions were suitable for permanent disposal. During this phase, the Salt Shaft, a ventilation shaft, a drift to the southernmost extent of the proposed waste disposal area, a four-room experimental panel, and access drifts were excavated. Surface-based geological and hydrological investigations were also conducted. The data obtained from the SPDV investigations were reported in the "Summary of the Results of the Evaluation of the WIPP Site and Preliminary Design Validation Program" (DOE, 1983).

Based upon the favorable results of the SPDV investigations, additional activities were initiated in 1983. These included the construction of surface structures, conversion of the ventilation shaft for use as the Waste Shaft, excavation of the Exhaust Shaft, development of additional access drifts to the waste disposal area, excavation of the Air Intake Shaft, and excavation of additional experimental rooms to support research and development. Geotechnical data acquired during this phase were used to evaluate the performance of the excavations in the context of established design criteria (DOE, 1984). Results of these evaluations were reported in Geotechnical Field Data Reports (DOE, 1985; DOE, 1986a) and were summarized in the Design Validation Final Report (DOE, 1986b).

The Design Validation Final Report concluded that the facility, including waste disposal areas, could be developed and operated to fulfill the long-term mission of WIPP (DOE, 1986b). All available information validated the design of underground openings to safely accommodate the permanent disposal of waste under routine operating conditions.
Panel 1 mining began in 1986 and was completed in 1988. Panel 1 was intended to receive waste for an initial operations demonstration and pilot plant phase that was

scheduled to start in October 1988; however, the demonstration and pilot plant phase was not put into effect because waste could not be emplaced until permits were acquired.

In October 1996, the DOE submitted to the U.S. Environmental Protection Agency (EPA) a compliance certification application in accordance with 40 CFR Parts 191 and 194, which addressed the long-term (10,000-year) performance criteria for the disposal system. On May 18, 1998, the EPA published the final certification that allowed for the receipt of TRU waste at WIPP. Immediately before this certification, the DOE Carlsbad Area Office (CAO) completed an Operational Readiness Review, which is required by the DOE before the start-up or a process change of any nuclear facility. As a result of the review, the CAO notified the Energy Secretary on April 1, 1998, that WIPP was operationally ready to receive waste. On March 26, 1999, the first shipment of TRU waste was received from Los Alamos National Laboratory (LANL). By the end of June 2010, many additional generator sites had shipped waste to WIPP. The cleanup of several small-quantity generator sites, as well as one large-quantity site (Rocky Flats Environmental Technology Site) is now complete.

Waste disposal in Panels 1, 2, 3, and 4 is complete. Panels 1, 2, and 3 contain only CH waste. The first RH waste shipment arrived January 24, 2007. Panel 4 was the first to receive both CH and RH waste. As of June 30, 2010, waste handling activities in Panel 5 included RH disposal in Room 2 and CH disposal in Room 3. Mining operations in Panel 6 (begun June 30, 2008) were completed on March 31, 2010. Panel 6 is now being outfitted. Mining of Panel 7 began April 24, 2010.

1.4 Purpose and Scope of Geomechanical Monitoring Program

As specified in the WIPP HWFP (NMED, 2010), the purpose of the geomechanical monitoring program is to obtain *in situ* data to support the continuous assessment of the design for underground facilities.

Specifically, the program provides for:

- Early detection of conditions that could affect operational safety.
- Evaluation of disposal room closure that ensures adequate access.
- Guidance for design modifications and remedial actions.
- Data for interpreting the behavior of underground openings, in comparison with the established design criteria.

Data taken by or input into the geomechanical instrumentation system (GIS) are evaluated and reported in this GAR. This annual report fulfills the requirements set forth in Part 4.6.1.2, Attachment A3, Section A2-5b (2) of the WIPP HWFP (NMED, 2010),

and 40 CFR §191.14, "Assurance Requirements," implemented through the certification criteria, 40 CFR Part 194.

The Geomechanical Monitoring Program generates the data for four of the compliance monitoring parameters:

- Creep closure and stresses
- Extent of deformation
- Initiation of brittle deformation
- Displacement of deformation features

The instrumentation system for geomechanical monitoring provides data for routine evaluations of safety, stability, and performance of underground openings. *In situ* data are also used to model long-term disposal system performance. Changes resulting from excavations are monitored by routine inspections of selected observation hole arrays and fracture mapping to detect and quantify occurrences of discontinuities such as fractures and bed separations. Analysis of data indicating areas of potential instability allows timely corrective action before they could become safety issues. Other geoscience activities include geologic mapping and sampling, and seismic monitoring.

The GIS provides data that are collected, processed, and stored for analysis. The following subsections briefly describe the major components of the GIS.

1.4.1 Instrumentation

Instrumentation installed for measuring the geomechanical response of the shafts, drifts, and other underground openings includes convergence points, convergence meters, extensometers, rock bolt load cells, pressure cells, strain gauges, piezometers, and joint meters. Table 1 - 1 lists a summary of the specifications for geomechanical instrumentation.

Table 1 - 1 – Geomechanical Instrumentation System

Instrument Type	Measures	Range[a]	Resolution[a]
Sonic probe extensometer	Cumulative deformation	0–2 in	0.001 in
Convergence point (tape extensometer)	Cumulative deformation	2–50 ft	0.001 in
Wire convergence meter	Cumulative deformation	0–3.5 ft	0.001 in
Embedded strain gauge	Cumulative strain	0–3000 μin/in	1 μin/in
Spot-welded strain gauge	Cumulative strain	0–2500 μin/in	1 μin/in
Rock bolt load cell	Load	0–50 tons	40 lb
Earth pressure cell	Pressure	0–1000 psi	1 psi
Piezometer	Fluid pressure	0–500 psi	0.5 psi
Joint meter	Cumulative deformation	0–4 in	0.001 in
Vibrating wire extensometer	Cumulative deformation	0–4 in	0.001 in
Wire extensometer	Cumulative deformation	0–20 in	0.001 in
Linear potentiometric extensometer	Cumulative deformation	0–6 in	0.001 in

a Manual readout boxes for the instruments were manufactured to render measurements in U.S. customary units. Range and resolution measurement units have not been converted to metric units. Measurements from these instruments have been converted for presentation elsewhere in this report.

1.4.2 Data Acquisition

Geomechanical instruments are read either manually, using portable devices, or remotely by electronically polling the stations from the surface in accordance with approved operating procedures. Remotely read instruments are connected to one of the underground data-loggers, and readings are collected by initiating the appropriate polling routine. Upon completion of a verification process, data are transferred to a computer database. Manual readout devices are taken to instrument locations underground. Data are recorded on data sheets and later entered into an electronic database.

The underground data acquisition system consists of instruments, polling devices, and a communications network. Instruments are connected to polling devices that are installed in electrical enclosures near the instrument locations. Polling devices are connected by a data link to a surface computer.

Whether acquired manually or remotely, geomechanical data are entered into the database files of the GIS data processing system. The data processing system consists of computer programs that are used to enter, reduce, and transfer the data to permanent storage files. Additional routines allow access to the permanent storage files for numerical analysis, tabular reporting, and graphical plotting. Copies of the instrumentation database and data plots are available upon request.[3]

1.4.3 Data Evaluation

Rounding and significant digits are used in the data tables of this document. The reference document is American Society for Testing and Materials (ASTM) document ASTM E 29–06b, "Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specification."[4]

Closure measurements are acquired manually from convergence point anchors and remotely from convergence meters. Data are presented in plots of closure versus time. Closure rate data are calculated and presented as part of the data analysis. Extensometers provide displacement data from instrumented rods or wires anchored at various depths. Plots show displacement versus time for individual anchors.

Displacement rate data from the hole collar to the deepest anchor are presented in the data analysis.

[3] Instrumentation data and data plots are presented in "Geotechnical Analysis Report for July 2009-June 2010 Supporting Data" (DOE/WIPP-11-3177 Volume 2).
The document is available upon request from the National Technical Information Service. See page 3 for details and addresses.

[4] Copyright by ASTM, Reproduction authorized per License Agreement with Washington TRU Solutions LLC.

The annual closure rate is calculated as follows:

$$rate(inches/year) = (cfi_2 - cfi_1)/(date_2 - date_1) \times 365.25\,days/year$$
$$where\ cfi = the\ change\ from\ the\ initial\ reading\ (inches)$$
$$cfi_1 = cfi\ reading\ closest\ to\ the\ beginning\ of\ the\ reporting\ period$$
$$cfi_2 = cfi\ reading\ closest\ to\ the\ end\ of\ the\ reporting\ period$$

Comparisons between closure rates of the previous and current reporting periods are presented as percent changes in rate and are calculated as follows:

$$percent\ change\ in\ rate = ((Rate_{Current\ Period} - Rate_{Previous\ Period})/(Rate_{Previous\ Period})) \times 100\%$$

Rock bolt load cells are used to determine bolt support performance. Plots show load versus time for each instrumented bolt.

Earth pressure cells and strain gauges are used to determine the stresses and deformation in and around the shaft liners. Data are depicted in time-based plots.

Piezometers are used to measure the gauge pressure of groundwater and are installed in the shafts at varying elevations to monitor the hydraulic head acting on the shaft liners. Data are plotted as pressure versus time.

Joint meters, installed perpendicular to a crack, monitor the dilation of the crack with time. Data are presented as displacement versus time.

1.4.4 Data Errors

GIS data are processed through a comprehensive database management system. Whether acquired manually or remotely, GIS data are processed and permanently stored according to approved procedures. On occasion, erroneous readings can occur. There are several possible explanations for erroneous readings, including the following:

- The measuring device was misread.
- The reading was recorded incorrectly.
- The measuring device was not functioning within specifications.

When a reading is believed to be erroneous, the suspect reading is evaluated, and a second reading is collected. If the second reading falls in line with the instrument trend, the first reading is discarded and the second reading is entered in the database. If the second reading and subsequent readings remain out of the instrument trend, the ground conditions in the vicinity of the instrument are assessed to determine the reason for the

discrepancy. In addition, the reading frequency may be increased. This process to correct erroneous readings is documented, and the documentation is filed for future reference.

2.0 GEOLOGY

This chapter provides a summary of the stratigraphy of the WIPP region and the site. Readers desiring further geologic information may consult the "Geological Characterization Report, WIPP Site, Southeastern New Mexico" (Powers et al., 1978). This report was developed as a source document on the geology of the WIPP site for individuals, groups, or agencies seeking basic information on geologic history, hydrology, geochemistry, or detailed information, such as physical and chemical properties of repository rocks. A more recent survey of WIPP stratigraphy is included in Holt and Powers (1990).

2.1 Regional Stratigraphy

The stratigraphy in the vicinity of the WIPP site includes rocks of Permian (295 to 250 million years [Ma] before present [bp]), Triassic (250 to 203 Ma), and Quaternary (1.75 Ma to present) ages. The descriptions of formations provided in this section are given in order of deposition (oldest to youngest), beginning with the Castile Formation (Figure 2 - 1).

2.1.1 Permian

The Permian system in southwestern North America is divided into four series. The last of these, the Ochoan Series, contains the host rock in which the WIPP repository is located. The Ochoan Series is of mostly marine origin and consists of four formations: three evaporite formations (the Castile, the Salado, and the Rustler) and one redbeds formation (the Dewey Lake). The Ochoan evaporites overlie marine limestones and sandstones of the Guadalupian Series (Delaware Mountain Group). The younger redbeds represent a transition from the lower evaporite deposition to fluvial deposition on a broad, low-relief, fluvial plain. The Permian rocks are overlain by fluvial deposits of the Triassic and Quaternary periods.

2.1.1.1 Castile Formation

The Castile Formation, lowermost of the four Ochoan formations, is approximately 1,250 ft (380 m) thick in the WIPP vicinity. Lithologically, the Castile is the least complex of the evaporite formations and is composed chiefly of interbedded anhydrite and halite, with limestone present in minor amounts.

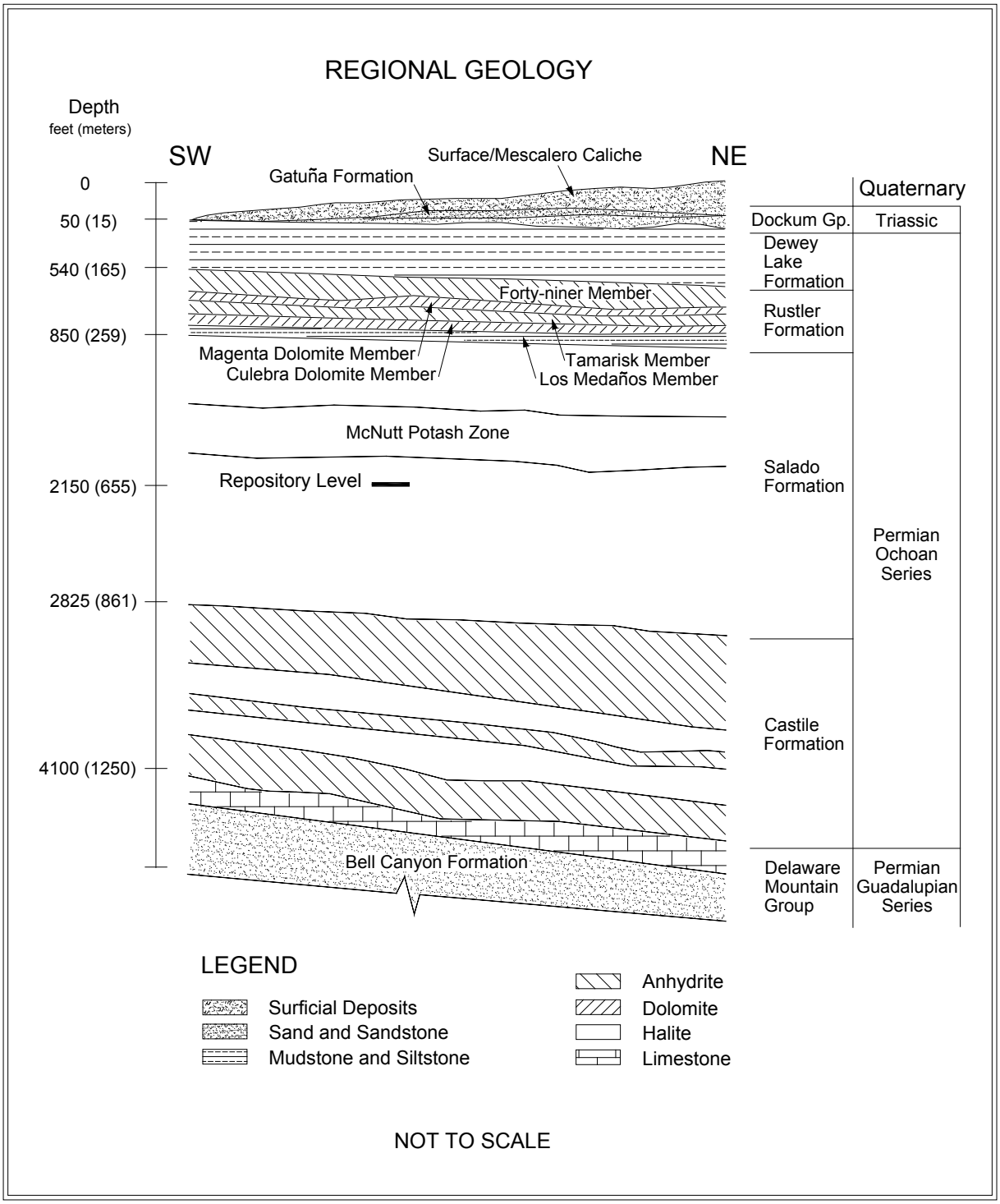

Figure 2 - 1 – Regional Geology

2.1.1.2 Salado Formation

The Salado Formation comprises nearly 2,000 ft (610 m) of evaporites, primarily halite. The formation is subdivided into three informal members: the unnamed lower member, the McNutt potash zone, and the unnamed upper member. Each member contains similar amounts of halite, anhydrite, and polyhalite and is differentiated on the basis of soluble potassium- and magnesium-bearing minerals. The WIPP disposal horizon is located within the unnamed lower member, 2,150 ft (655 m) below the surface.

2.1.1.3 Rustler Formation

The Rustler Formation is subdivided into five members, starting from its base: the Los Medaños Member, the Culebra Dolomite Member, the Tamarisk Member, the Magenta Dolomite Member, and the Forty-niner Member.

In the vicinity of the WIPP site, the Rustler is approximately 310 ft (95 m) thick and thickens to the east. The lower portion (Los Medaños Member) contains primarily fine sandstone to mudstone with lesser amounts of anhydrite, polyhalite, and halite. Bedded and burrowed siliciclastic sedimentary rocks with cross-bedding and fossil remains signify the transition from the strongly evaporitic environments of the Salado to the brackish lagoonal environments of the Rustler (Holt and Powers, 1990).

The upper portion of the Rustler contains interbeds of anhydrite, dolomite, and mudstone. The Culebra Dolomite member is generally brown, finely crystalline, and locally argillaceous. The Culebra contains rare to abundant vugs with variable gypsum and anhydrite filling and is the most transmissive hydrologic unit within the Rustler. The Tamarisk Member consists of lower and upper sulfate units separated by a unit that varies laterally from mudstone to mainly halite. The Magenta Dolomite Member is a gypsiferous dolomite with abundant primary sedimentary structures and well-developed algal features. The Forty-niner Member consists of lower and upper sulfate units separated by a mudstone that displays sedimentary features and bedding. East of the site area, halite correlates with the mudstone. The Culebra and Magenta Dolomite members are persistent and serve as important marker units.

2.1.1.4 Dewey Lake Redbeds

The Dewey Lake Redbeds is the uppermost of the Ochoan Series formations. Within the series, the Dewey Lake represents a transition from the lower marine evaporite deposition to fluvial deposition on a broad, low-relief, fluvial plain. The redbeds, approximately 475 ft (145 m) thick, consist of predominantly reddish-brown interbedded fine-grained sandstone, siltstone, and claystone. This formation is differentiated from others by its lithology and distinctive color (both of which are remarkably uniform), and by sedimentary structures, including horizontal- and cross-laminae and ripple marks. The redbeds also contain locally abundant greenish-gray reduction spots and gypsum-filled fractures. The formation thickens from west to east due to eastward dips and erosion to the west.

2.1.2 Triassic

The only Triassic rocks present in the WIPP region belong to the Dockum Group.

2.1.2.1 Dockum Group

The Dockum Group consists of fine-grained floodplain sediments and coarse alluvial debris of Triassic age. From a pinch-out near the center of the WIPP site it thickens eastward, forming an erosional wedge. Local subdivisions of the Dockum Group are the Santa Rosa Sandstone and the Chinle Formation; however, only the Santa Rosa occurs in the vicinity of the site. It consists primarily of poorly sorted sandstone with conglomerate lenses and thin mudstone partings and contains impressions and remnants of fossils. These rocks have more variegated hues than the underlying uniformly colored Dewey Lake.

2.1.3 Quaternary

Quaternary Period deposits include the Gatuña Formation, Mescalero Caliche, and surficial sediments.

2.1.3.1 Gatuña Formation, Mescalero Caliche, and Surficial Sediments

The Gatuña Formation (ranging in age from approximately 1.3 million to 600,000 years bp) (Powers and Holt, 1993) is a stream-laid deposit overlying the Dockum Group in the WIPP vicinity. At the site center, the formation consists of approximately 13 ft (4 m) of poorly consolidated sand, gravel, and silty clay. The Gatuña Formation is light red and mottled with dark stains. The unit contains abundant calcium carbonate, but is poorly cemented. Sedimentary structures are abundant (Powers and Holt, 1993, 1995).

The Mescalero Caliche (approximately 500,000 years bp) is approximately 4 ft (1.2 m) thick in the WIPP vicinity. The Mescalero is a hard, resistant soil horizon that lies beneath a cover of wind-blown sand. The horizon is petrocalcic (i.e., very strongly cemented with calcium carbonate). Petrocalcic horizons form slowly beneath a stable landscape at the average depth of infiltration of soil moisture and indicate stability and integrity of the land surface. Many of the surface buildings at WIPP are founded on top of the Mescalero Caliche.

Surficial sediments include sandy soils developed from eolian material and active dune areas. The Berino Series (a soil type) covers about 50 percent of the site and consists of deep sandy soils that developed from wind-worked material of mixed origin. Based on sample analyses, the Berino soil from the WIPP site formed 330,000 ± 75,000 years bp.

2.2 Underground Facility Stratigraphy

The WIPP disposal horizon lies near the midpoint of the Salado Formation. The Salado was deposited in a shallow saline lagoon environment, which progressed through numerous inundation and desiccation cycles that are reflected in the formation. An "ideal" cycle progresses upward as follows: a basal layer consisting predominantly of claystone, followed by a layer of sulfate, which is in turn followed by a layer of halite. The entire sequence is capped by a bed of argillaceous (clay-rich) halite accumulated during a period of mainly subaerial exposure.

A regional system used for numbering the more significant sulfate beds within the Salado designates these beds as marker beds (MBs), counted from MB100 near the top of the formation to MB144 near the base. The repository is located between MB138 and MB139 (Figure 2 - 2) within a sequence of laterally continuous depositional cycles as described above. Within this sequence, layers of clay and anhydrite that are locally designated (as shown) can have a significant impact on the geomechanical performance of the excavations. Clay layers provide surfaces along which slip and separation can occur, whereas anhydrites form brittle layers that do not deform plastically.

In the vicinity of WIPP, the stratigraphy is fairly continuous and uniform. Beds generally dip toward the south-southeast at a slope of approximately 3 percent.

2.2.1 Disposal Horizon Stratigraphy of Panels 1, 2, 7, and 8

This disposal horizon contains Panels 1, 2, 7, and 8, all the shaft areas, the shop areas, the SPDV areas (which are now closed), and all the access drifts north of S-2620. Farther south, the four main entries rise in a ramp that starts at S-2620 and ends at S 2740. Panel 7 is currently being excavated, and Panel 8 has not yet been excavated.

Most underground excavations are located within this disposal horizon (Figure 2 - 2). In it, the Orange Marker Bed (OMB) lies near the middle of the rib (i.e., the excavation

wall). The OMB is a laterally consistent unit of moderate to light reddish-orange translucent halite about 6 inches (in) (15 centimeters [cm]) thick that is used as a point of reference during excavation.

MB139 lies approximately 5 ft (1.5 m) below the excavation floor. MB139 is a 20 to 32 in (50-to-80 cm) thick layer of polyhalitic anhydrite. The top of the anhydrite undulates up to 15 in (38 cm), while the bottom is sub-horizontal and is underlain by Clay E.

Above MB139 is a unit of halite that terminates at the base of the OMB. Within this unit, polyhalite is locally abundant and decreases upward, while argillaceous material increases upward.

Above the OMB, a thin band of argillaceous halite gives way to a thick sequence of clear halite that becomes increasingly argillaceous upward and is capped by Clay F. This constitutes a thin layer occasionally interrupted by partings and breaks and is readily visible in the upper ribs. Above Clay F, another sequence of halite begins that, as in lower sequences, becomes increasingly argillaceous upward. This sequence terminates at the Clay G/Anhydrite "b" interface, approximately 6.5 ft (2 m) above the roof of most disposal horizon excavations, forming a roof beam that typically acts as a structural unit. The roof of some disposal horizon excavations (e.g., the E-140 drift between S-1000 and 1950), has been excavated to the upper contact of Anhydrite "b". In this case, a roof beam is formed by the next depositional sequence beginning with Anhydrite "b" and progressing upward to the Clay H/Anhydrite "a" interface, approximately 6.5 ft (2 m) above the upper contact of Anhydrite "b".

2.2.2 Disposal Horizon Stratigraphy of Panels 3, 4, 5, and 6

Field observations and computer modeling indicated that moving the disposal horizon stratigraphically upward (so that the roof was located at Clay G) would improve long-term ground conditions and provide a more stable roof configuration without significantly impacting repository performance. In 2000, the decision was made to implement this change by moving the mining horizon up approximately six feet. Subsequently, in 2000 and 2001, ramps were mined in the W 170, W 30, E 140, and E 300 drifts between S 2620 and S 2750 (Figure 1 - 2). As a result, the disposal horizon for Panels 3, 4, 5, and 6, and the associated connecting drifts lies above the horizon for the other panels (Figure 2 - 3).

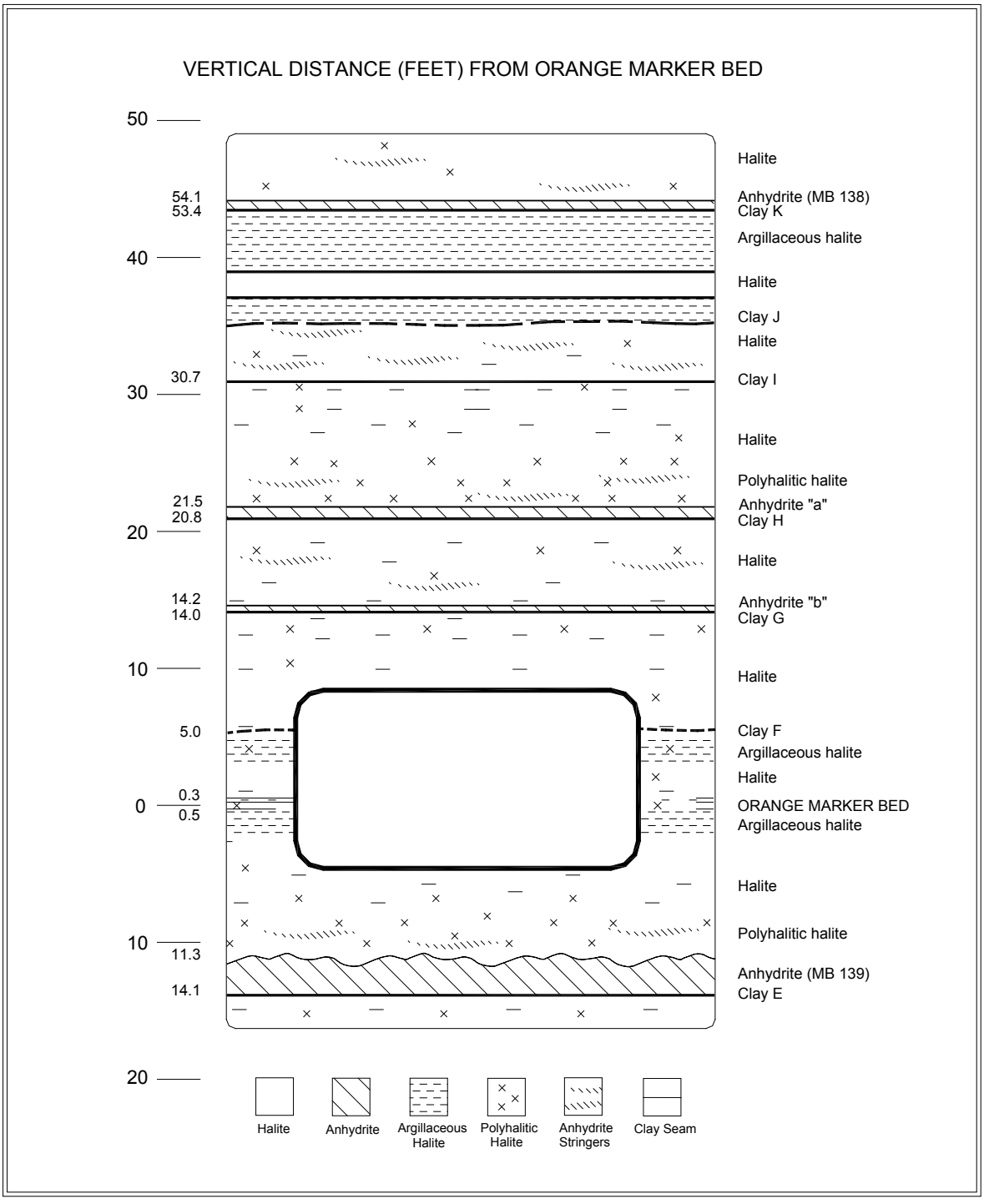

Figure 2 - 2 – Repository Level Stratigraphy of Panels 1, 2, 7, and 8

In this horizon (see Figure 2 - 3), the OMB lies at or below the floor. MB139 lies about 12 ft (3.7 m) below the floor. The roof lies at or slightly above Anhydrite "b". Clay G/ Anhydrite "b" is used as the mining reference during excavation of this disposal horizon.

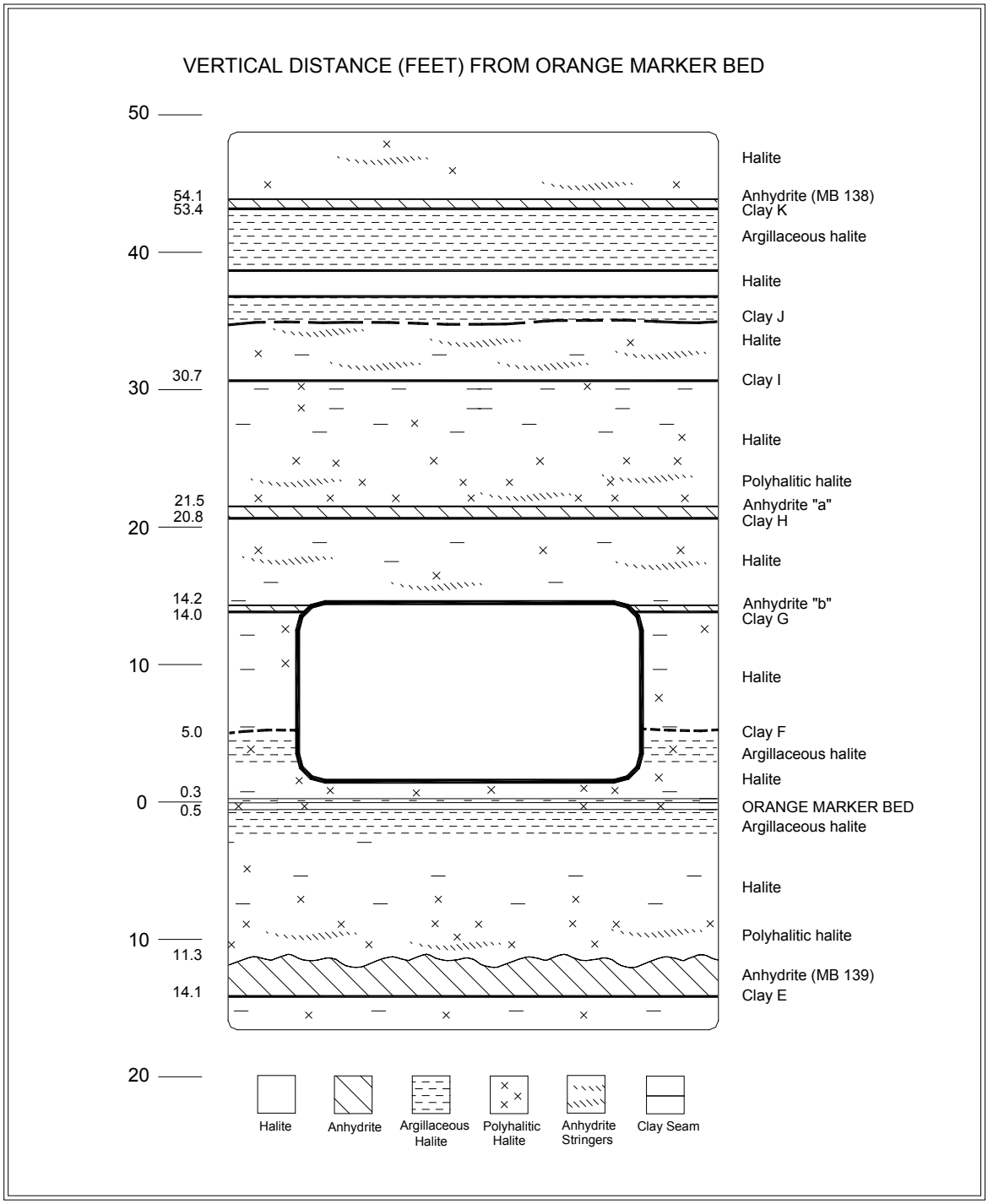

Figure 2 - 3 – Repository Level Stratigraphy of Panels 3, 4, 5, and 6

2.2.3 Northeast Area Stratigraphy

All of the Northeast Area, a former experimental area, is now deactivated and closed to access. These excavations lie at a higher stratigraphic level than the disposal excavations. Floors are at Anhydrite "b". As in the lower units, the halite intervals between the clay seams/anhydrite beds contain relatively pure halite that becomes increasingly argillaceous upward. Above clay I, two more halite intervals complete the underground facility stratigraphy. Clay J, at the top of the first of these intervals, may consist of a distinct seam or merely an argillaceous zone. Clay K tops the second interval and is overlain by MB138.

3.0 PERFORMANCE OF SHAFTS AND KEYS

Four shafts connect the surface with the underground. They are the Salt Shaft, which is used primarily for removing excavated salt from the underground and for transporting personnel and material; the Waste Shaft, which is used primarily for transporting TRU waste to the underground and for transporting personnel and materials; the Exhaust Shaft, which is used to exhaust the ventilation air from the underground; and the Air Intake Shaft, which is the primary source of fresh air ventilation to the underground. This chapter describes the geomechanical performance of these shafts.

Although through the years much of the instrumentation installed in the shafts has failed, there are no plans to replace it. The project has a good understanding of the expected movements in the shafts. Monitoring results up to the point of instrument failure did not indicate unusual shaft movements or displacements. Continued periodic visual inspections confirm the expected shaft performance and provide necessary observations to evaluate shaft performance. Replacement of failed instrumentation will not provide significant additional information.

3.1 Salt Shaft

The first construction activity undertaken during the SPDV Program was the excavation of the Exploratory Shaft. This shaft was subsequently referred to as the Construction and Salt Shaft and is currently designated the Salt Shaft (see Figure 1 - 2). The shaft was drilled from July 4 to October 24, 1981, and geologically mapped in the spring of 1982 (DOE, 1983). Figure 3 - 1 presents the stratigraphy in the shaft.

The Salt Shaft is lined from the surface to 846 ft (258 m) with steel casing having an inside diameter of 10 ft (3-m). The thickness of the steel liner (including external stiffener rings) increases from 0.62 in (1.6 cm) at the top to 1.5 in (3.8 cm) at the key. Cement grout was placed between the liner and the rock face. The 10-ft (3-m) diameter extends through the concrete shaft key to 880 ft (268 m). The shaft key is a 37.5 ft (11.4-m) long, reinforced-concrete structure that begins 3.5 ft (1.07 m) above the bottom of the steel liner. From the key to the bottom at 2,298 ft (700 m), the shaft has a nominal diameter of 12 ft (4 m).

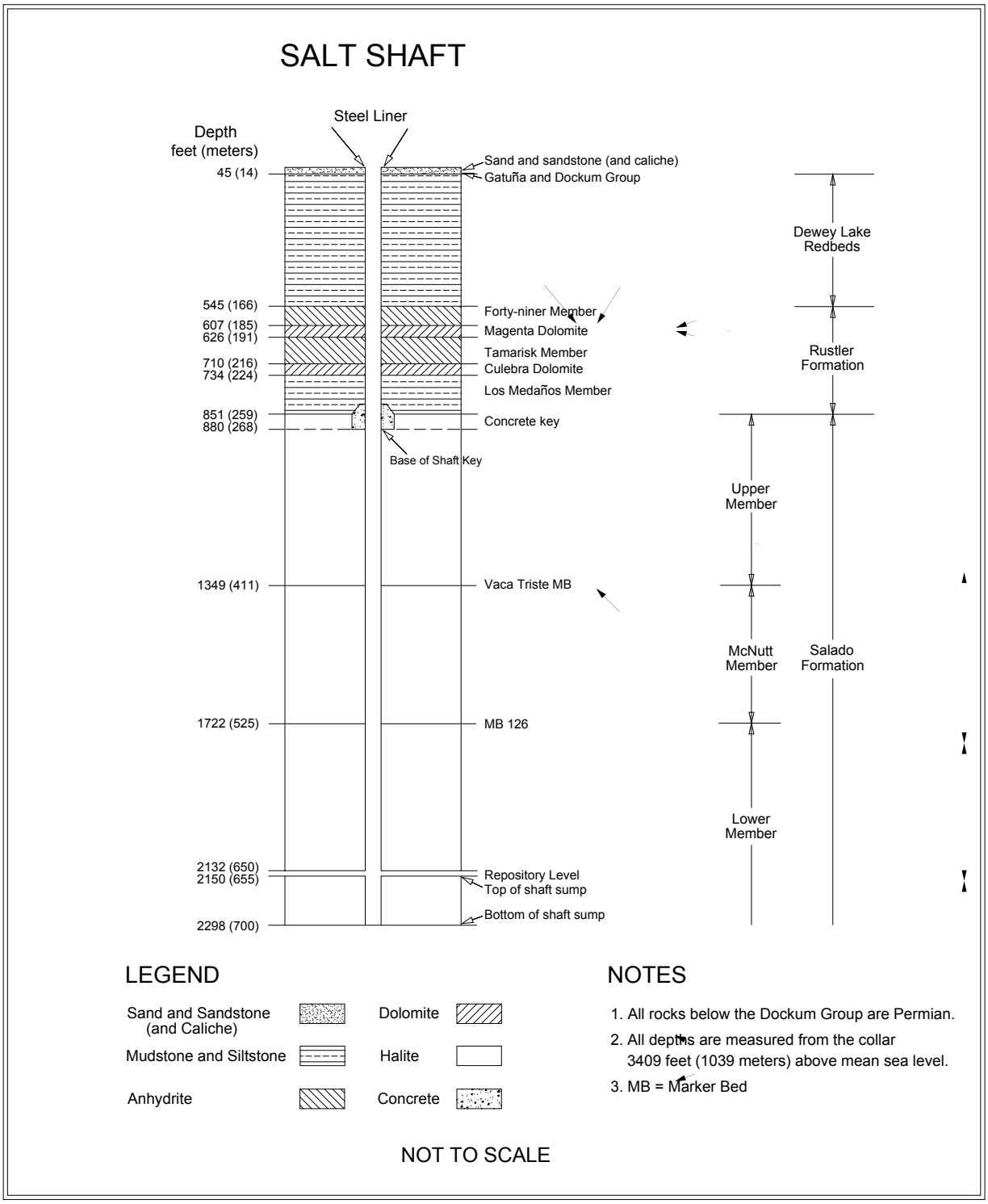

Figure 3 - 1 – Salt Shaft Stratigraphy

Wire mesh anchored by rock bolts is installed in sections of the lower shaft as a safety screen to contain rock fragments that may become detached. The shaft extends approximately 140 ft (43 m) below the repository horizon in order to accommodate the skip loading equipment and a sump.

3.1.1 Shaft Observations

Underground operations personnel conduct weekly visual inspections. These inspections are performed principally to assess the condition of the hoisting and mechanical systems, but they also include examining the shaft walls for water seepage, loose rock, or sloughing. Visual inspections during this reporting period found that the shaft remained in satisfactory condition. Only routine ground control activities were required.

3.1.2 Instrumentation

Geomechanical instruments (radial convergence points, extensometers, and piezometers) were installed at various levels in the shaft from April through July of 1982 (Figure 3 - 2). In the shaft key, instruments included strain gauges, pressure cells, and piezometers. Radial convergence points were installed prior to outfitting. Upon completion of shaft outfitting, no more readings were taken. Figure 3 - 2 and Figure 3 - 3 show the instrument locations.

Ten of the 12 piezometers continue to provide data. The fluid pressures recorded at the end of this reporting period range from approximately 64 pounds per square inch (psi) (441 kilopascals [kPa]) at the 802-ft (244-m) level in the Los Medaños Member to 231 psi (1,593 kPa) at the 691-ft (211-m) level in the Magenta Dolomite Member. The recorded pressures for this reporting period are generally consistent with the readings from the previous reporting period. The fluid pressure on the shaft liner will continue to be monitored on a regular basis.

Four earth pressure cells were installed in the key section during concrete emplacement at the 860-ft (262-m) level. These instruments measure the normal stress between the concrete key and the Salado Formation as salt creep loads up the key structure. Three of the four earth pressure cells continue to provide data. These instruments have indicated essentially no contact pressure since their installation (readings resemble instrument drift at a zero pressure). The contact pressures recorded by the instruments for this reporting period ranged from 24 to 7 psi (-165 to 48 kPa).

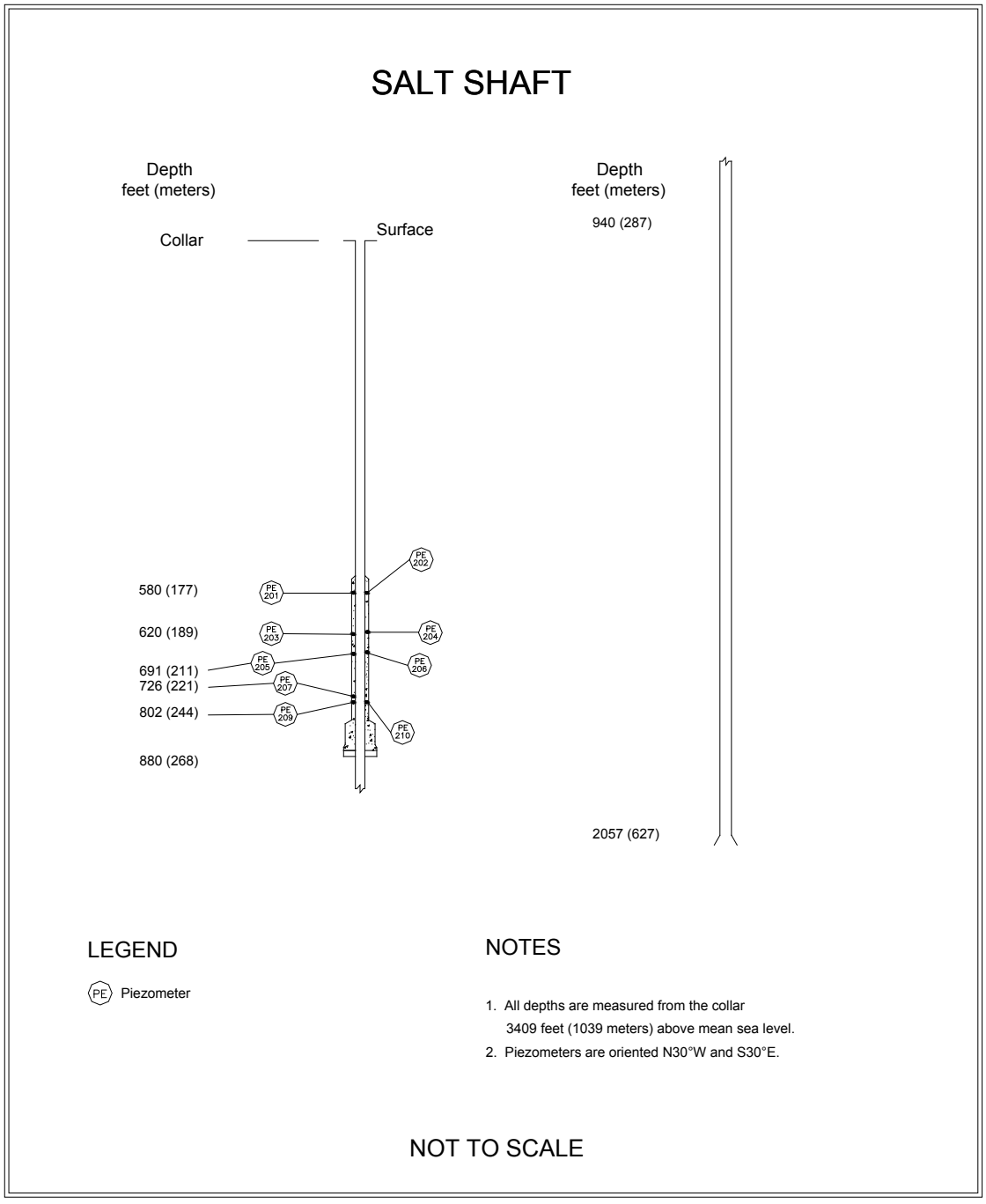

Figure 3 - 2 – Salt Shaft Instrumentation (Without Shaft Key)

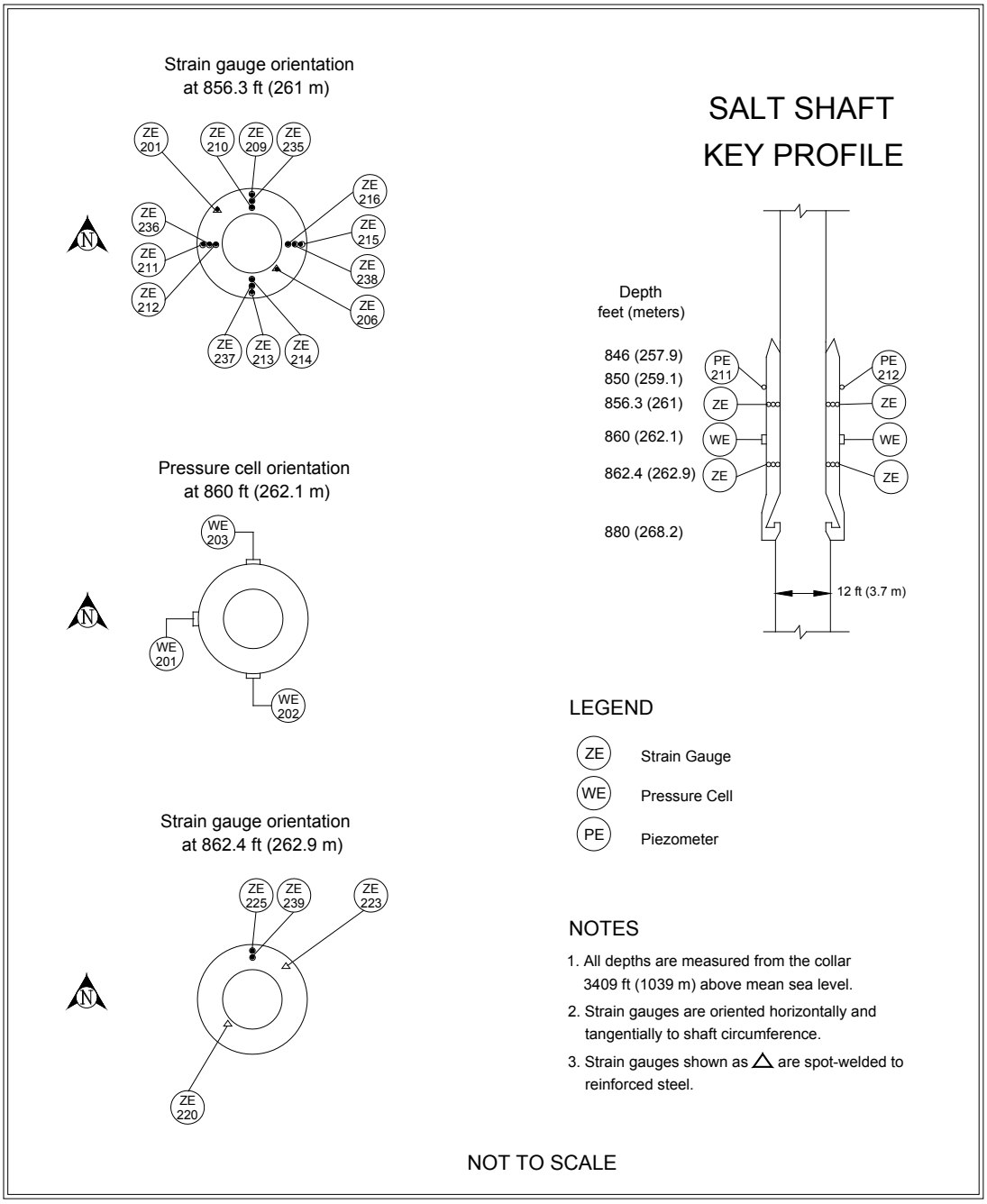

Figure 3 - 3 – Salt Shaft Key Instrumentation

Sixteen spot-welded and twenty-four embedment strain gauges were installed on and in the shaft key concrete at both the 856.3-ft (261-m) level and at the 862.4-ft (263-m) level. Four spot-welded strain gauges are still functioning at these levels. Maximum strains at the 856.3-ft (261-m) level were 649 and 747 microstrain. Strains at the 862.4 ft (263 m) level were 696 and 893 microstrain. The strains from the 12 embedment strain gauges at the 856.3-ft (261-m) level ranged from -818 to 994 microstrain. The strains from the two embedment strain gauges at the 862.4 ft (263-m) level were 256 to 383 microstrain. The strains recorded by the spot-welded strain gauges and the embedment strain gauges during this reporting period are very similar to the strains recorded by these instruments at the end of the previous reporting period.

3.2 Waste Shaft

As part of the SPDV Program, a 6-ft (2-m) diameter ventilation shaft, now referred to as the Waste Shaft, was excavated from December 1981 through February 1982 (see Figure 1 - 2). This shaft, in combination with the Salt Shaft, provided a two-shaft underground air circulation system. From October 11, 1983, to June 11, 1984, the shaft was enlarged to a diameter of 20 to 23 ft (6 to 7 m) and lined above the key. Stratigraphic mapping (Figure 3 - 4) was conducted during shaft enlargement from December 9, 1983, to June 5, 1984 (Holt and Powers, 1984).

The Waste Shaft is lined with non-reinforced concrete having a 19 ft (6 m) inside diameter from the surface to the top of the key at 837 ft (255 m). Liner thickness increases from 10 in (25 cm) at the surface to 20 in (51 cm) at the key. The key is 63 ft (19 m) long and 4.25 ft (1.3 m) thick and is constructed of reinforced concrete. The bottom of the key is 900 ft (274 m) below the surface. The diameter of the shaft is 20 ft (6 m) at the bottom of the key and increases to 23 ft (7 m) just above the shaft station. The shaft below the key is lined with wire mesh anchored by rock bolts. The diameter of 23 ft (7 m) extends to a depth of approximately 2,286 ft (697 m), with the shaft sump comprising the lower 119 ft (36 m) of that interval.

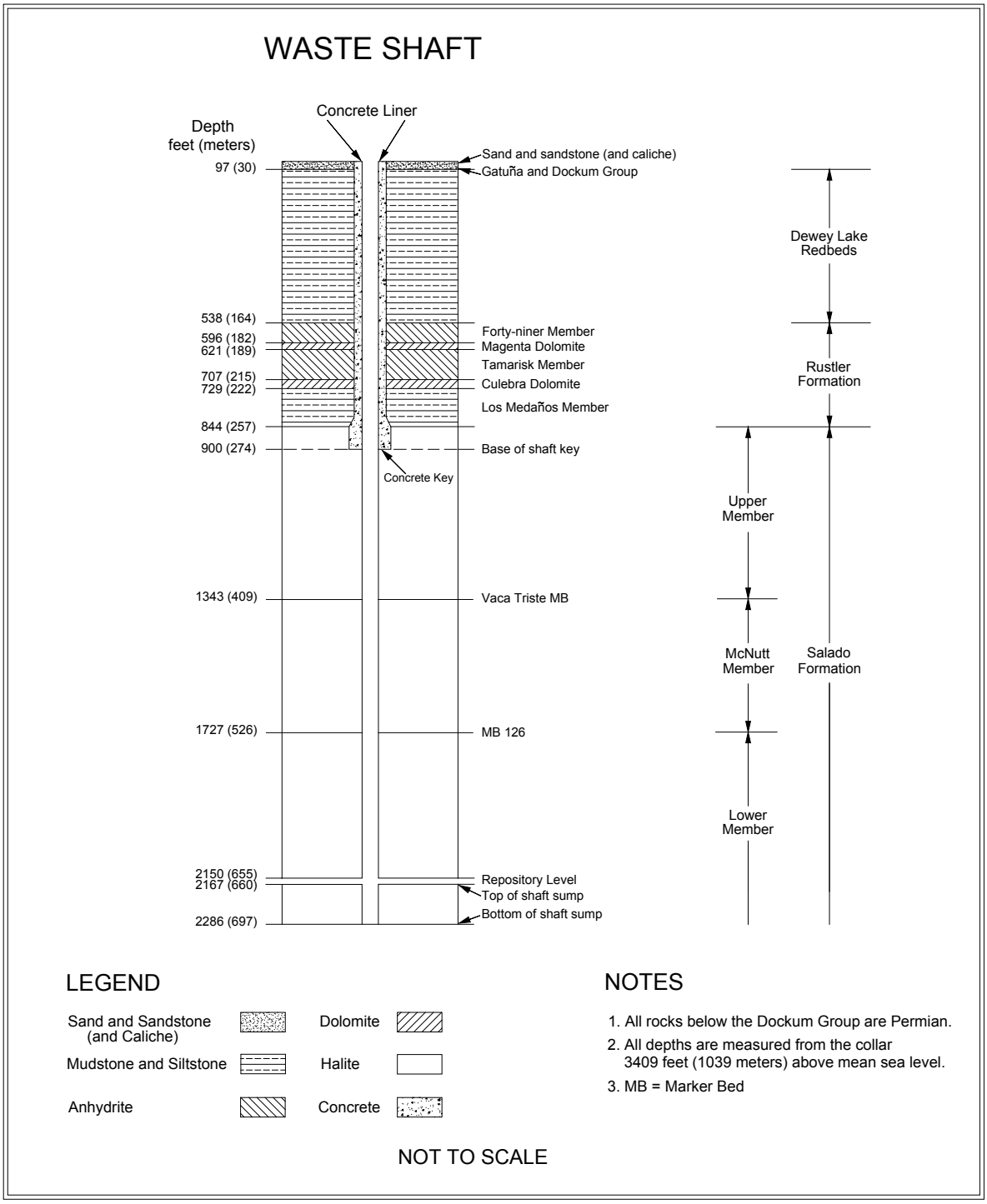

Figure 3 - 4 – Waste Shaft Stratigraphy

3.2.1 Shaft Observations

Underground operations personnel conduct weekly visual inspections, principally to assess the condition of the hoisting and mechanical systems, but also include observation of the shaft walls for water seepage, loose rock, or sloughing. The visual inspections found that the shaft was in satisfactory condition. No ground control activities other than routine maintenance were required.

3.2.2 Instrumentation

Radial convergence points, extensometers, piezometers, and earth pressure cells were installed in the Waste Shaft between August 27 and September 10, 1984. Radial convergence points were installed prior to the outfitting. Upon completion of shaft outfitting, no more radial convergence readings were taken. Figure 3 - 5 and Figure 3 - 6 show the instrument locations.

Nine multi-position extensometers were installed in arrays 1,071 ft (326 m), 1,566 ft (477 m), and 2,059 ft (628 m) below the surface as shown in Figure 3 - 5. Each array consists of three extensometers. No data have been collected during this reporting period due to the malfunction of the data-logger. Since the type of extensometers installed in the shaft 26 years ago is no longer manufactured, remote data acquisition equipment for these extensometers is also unavailable.

Twelve piezometers were installed in the lined section of the Waste Shaft on September 7 and 8, 1984, to monitor fluid pressure behind the shaft liner and the key section. Data continue to be received from 6 piezometers. The maximum recorded fluid pressure during this reporting period was 145 psi (1,000 kPa) at the 717-ft (219-m) level. The pressure readings during this reporting period were consistent with the readings from the previous reporting period with a mean change in pressures of 1 psi (7 kPa).

Four earth pressure cells were installed in the key section of the Waste Shaft during concrete emplacement between March 23 and April 3, 1984. Two are still working. These instruments measure the normal stress between the concrete key and the Salado Formation as salt creep loads the key structure. The contact pressures recorded by the instruments during this reporting period ranged from 83 to 125 psi (572 to 862 kPa).

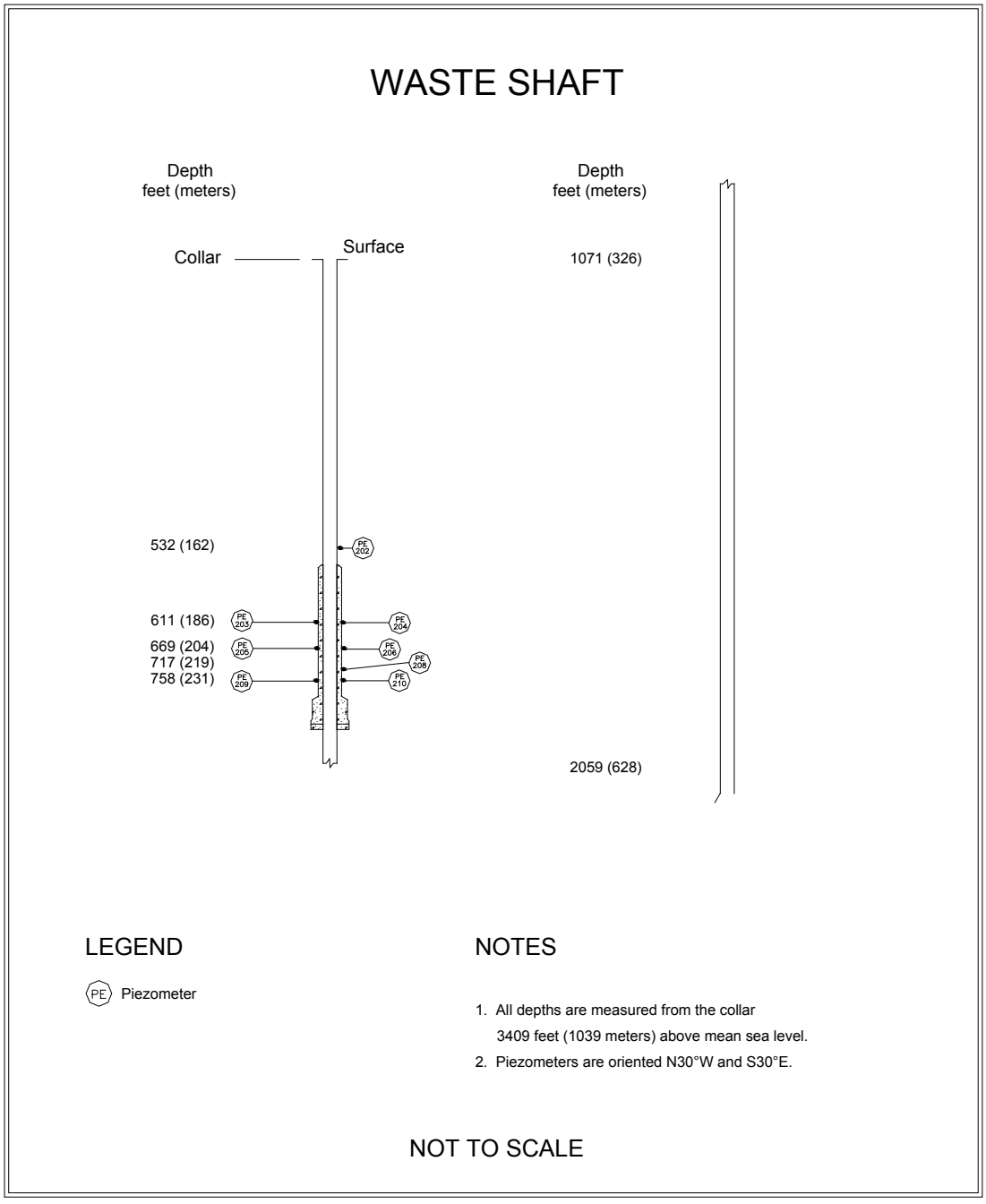

Figure 3 - 5 – Waste Shaft Instrumentation(Without Shaft Key)

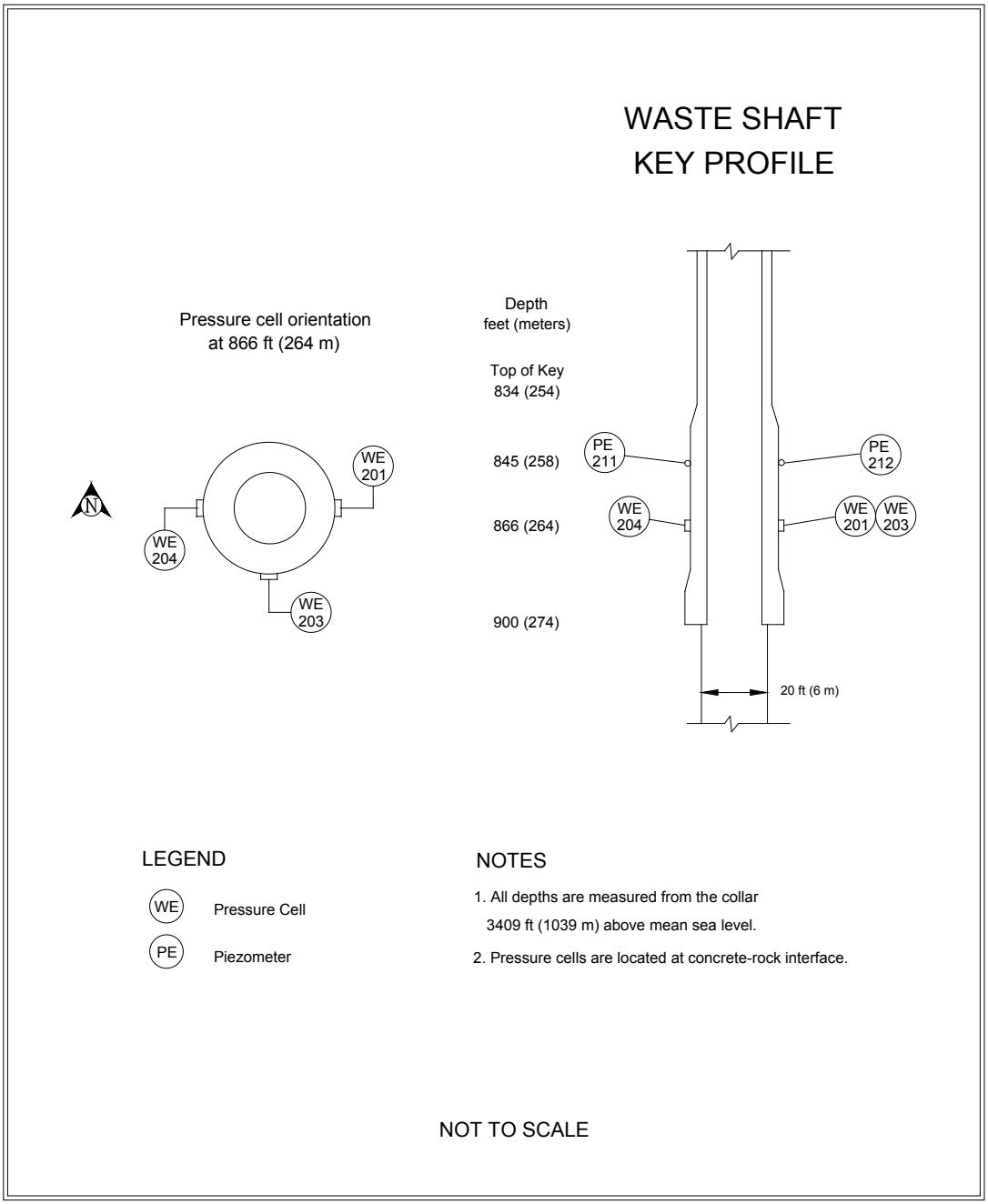

Figure 3 - 6 – Waste Shaft Key Instrumentation

3.3 Exhaust Shaft

The Exhaust Shaft was drilled from September 22, 1983, to November 29, 1984, to establish a route from the underground to the surface for exhaust air (Figure 1 - 2). Stratigraphic mapping was conducted from July 16, 1984, to January 18, 1985 (DOE, 1986c). Figure 3 - 7 illustrates the shaft stratigraphy.

The Exhaust Shaft is lined with non-reinforced concrete from the surface to the top of the shaft key at 844 ft (257 m). The liner thickness increases from 10 to 16 in (25 to 41 cm) over that interval. The key is 63 ft (19 m) long and 3.5 ft (1 m) thick. The shaft diameter below the key is 15 ft (5 m), and the interval below the key is lined with wire mesh anchored by rock bolts. The shaft terminates at the facility horizon, approximately 2,150 ft (655 m) deep. This shaft has no sump.

3.3.1 Exhaust Shaft Observations

Quarterly video inspections were conducted according to approved WIPP procedures. Inspections were performed to evaluate the condition and to verify the integrity of the shaft. The shaft was examined for cracks, corrosion, salt buildup, seeps, and debris. In addition, inspections examined the condition of anchors, brackets, and down-hole equipment. Between July 2009 and June 2010, four quarterly shaft inspections were conducted on August 12, 2009; November 19, 2009; February 24, 2010; and May 26, 2010.

3.3.1.1 Video Camera

Video inspections use a custom-designed vertical-drop color camera in an aerodynamic housing, suspended by a dual-armored cable, with pan, tilt, and zoom capability. The cable contains five copper conductors and two multi-mode optical fibers. It is reeled out by a winch mounted in a control van. Inspections are recorded electronically.

3.3.1.2 Shaft Inspection Observations

Quarterly video inspection observations concentrate on four major areas: air monitoring components, shaft liner, shaft walls, and equipment support and cabling. The air monitoring components consist of one air-velocity and three air-monitoring devices as shown in Figure 3 - 8. The video inspection includes examination of each device, including the transport assembly, guide tubes, the sample intake, and the support brackets that extend from Station "A" above the shaft to the shaft collar. Air monitoring components extend from the collar 21 ft into the shaft. Video inspections indicate that the air-sampling components can accumulate salt buildup of up to several inches thick.

The Exhaust Shaft liner is examined for cracks, seepage, and general shaft stability. Currently, there are three principal zones of seepage in the shaft. The first is about 50 to 55 ft below the shaft collar (bsc). The second is about 60 to 65 ft bsc. The third is about 75 to 80 ft bsc, as shown in Figure 3 - 9. Monitoring of seepage horizons started

before 1995. Water entering the shaft through these cracks is believed to originate from a perched aquifer at the base of the Santa Rosa Formation that is being recharged as the result of surface modifications at the site. The fluid level in the Santa Rosa near the shaft is about 43 to 44 ft below the surface. Based on examination of inspection videos, the flow rate into the shaft during this reporting period is estimated at about 1 to 1 1/2 gallons per minute, most of which is carried out of the shaft by the exhaust air. Seepage cracks are confined primarily to the eastern side of the shaft wall.

When fluid was detected seeping into the shaft, a catch basin was designed and installed at the base of the Exhaust Shaft to intercept water and prevent it from draining into the Waste Shaft Sump. Fluid was removed from the catch basin from March 1996 through October 2005 as needed. The catch basin was damaged in 2004 by fallen debris, either salt or instrumentation cables or both. A new catch basin was fabricated and installed in December 2004. This basin was damaged in August 2005, most likely the result of fallen debris. An interception well system was installed between November 2005 and March 2006 to replace the catch basin. Interception wells were drilled down-gradient in S-400 between E-140 and E 300 (Figure 3 - 10). The interception well system consists of four 30-ft deep 9-7/8-in diameter holes with a submersible pump and pressure transducer in each. Fluid is pumped from each hole to a series of storage containers in S-550. A data-acquisition system monitors the fluid level in each hole, turning the pump on and off between set limits as needed.

Between February 2 and 6, 2008, two additional holes, OH631 and OH632, were drilled in S-400 to improve the total volume of fluid recovered by the interception well system. They replaced OH613 and OH614 which generated little fluid. As with the previous four holes, the additional holes were drilled at 9-7/8-inch diameter to a total depth of 30 feet. Pumps were pulled from OH613 and OH614 and installed in OH631 and OH632. Figure 3 - 10 shows the location of the interception wells system and the 500-gallons storage containers.

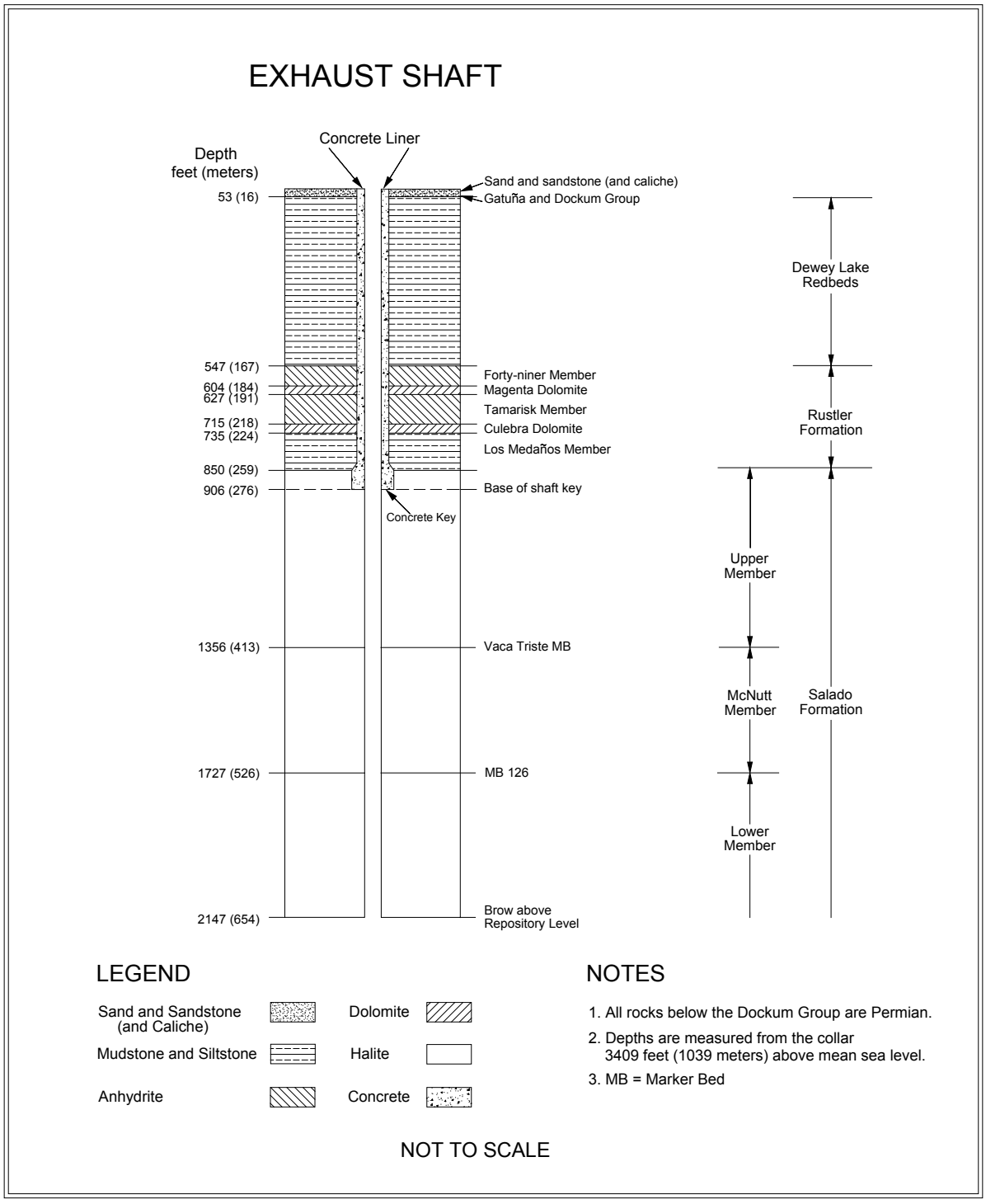

Figure 3 - 7 – Exhaust Shaft Stratigraphy

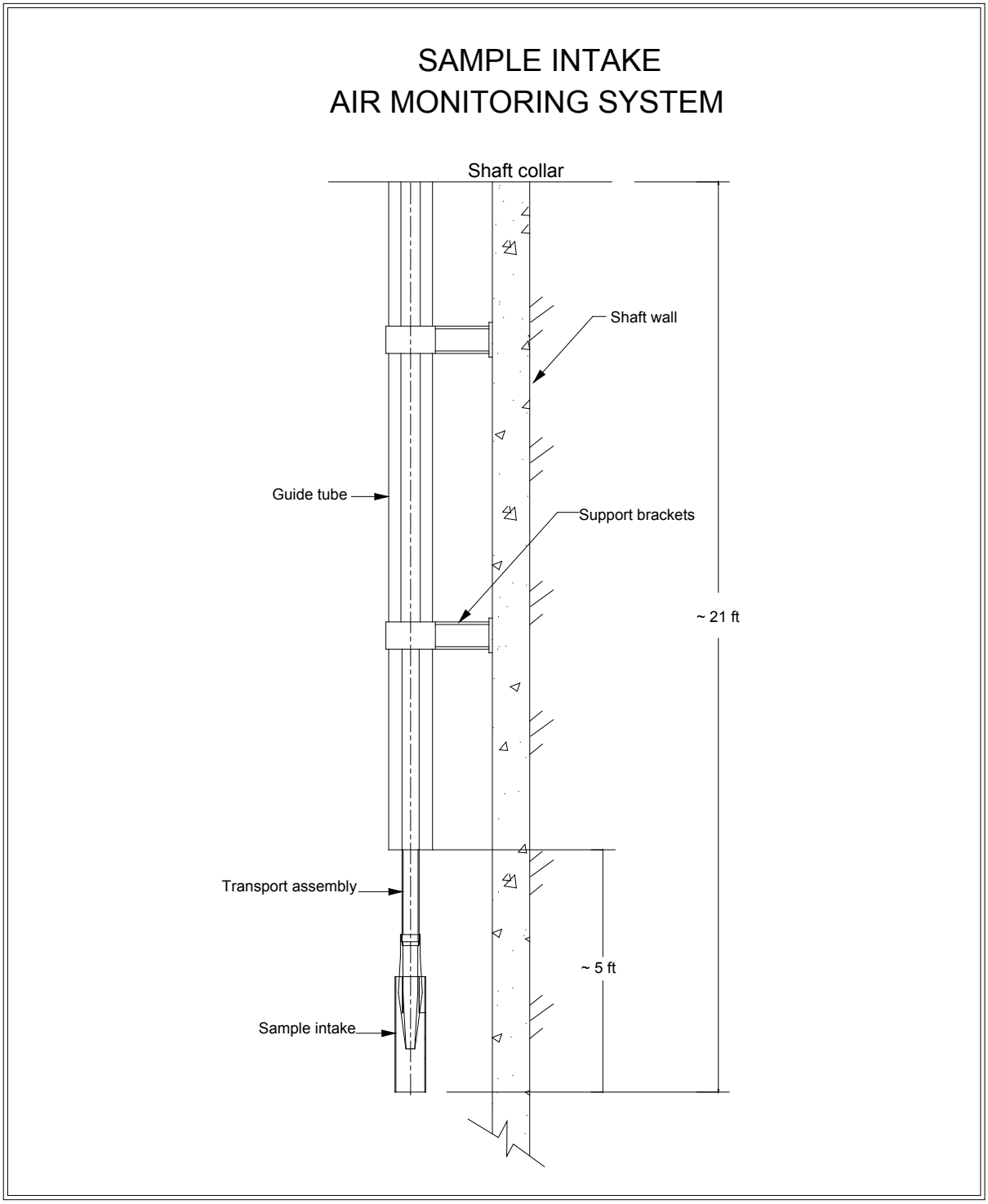

Figure 3 - 8 – Sample Intake of Exhaust Shaft Air Monitoring System

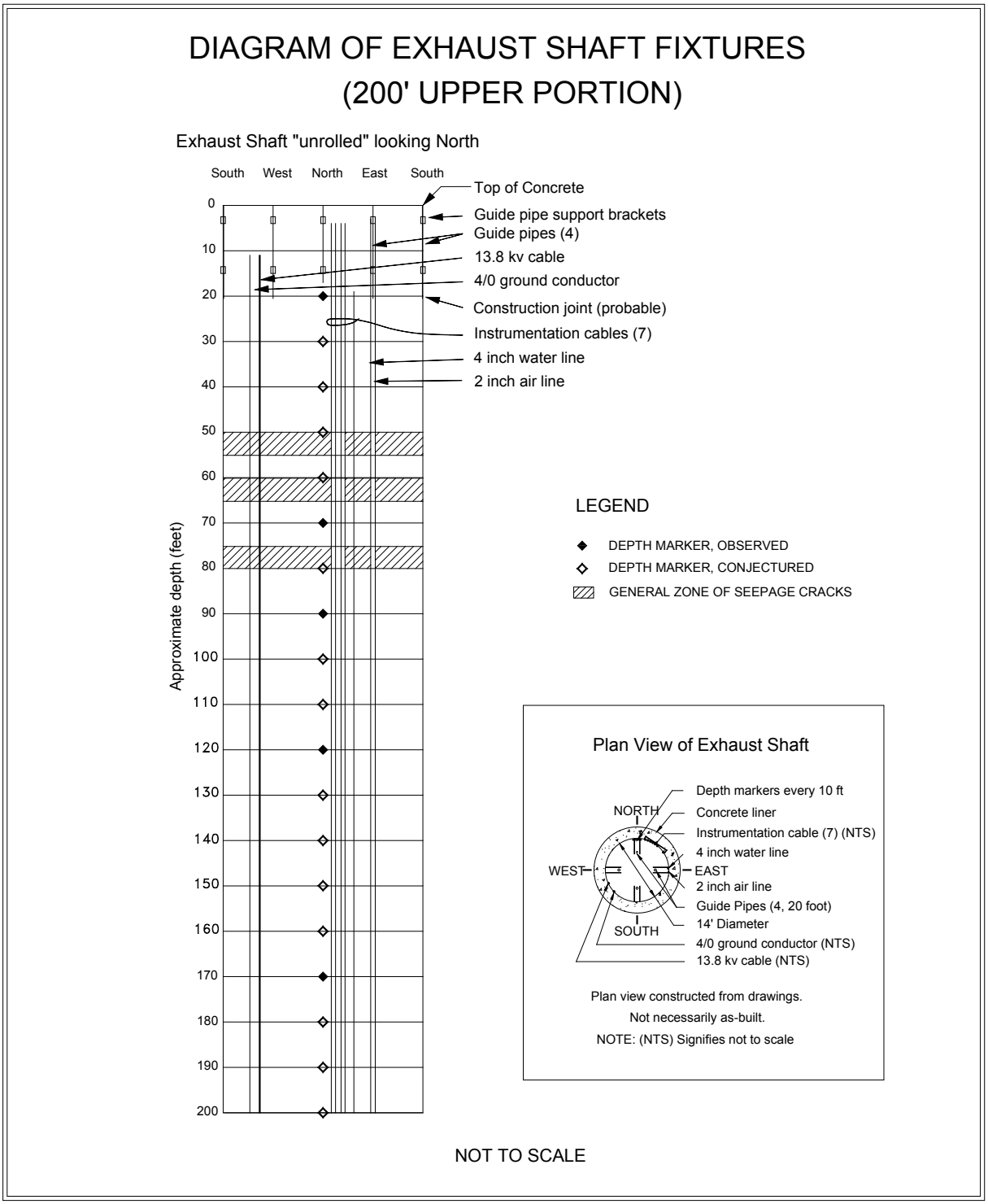

Figure 3 - 9 – Diagram of Exhaust Shaft Fixtures and Seepage Zones (Upper 200 ft)

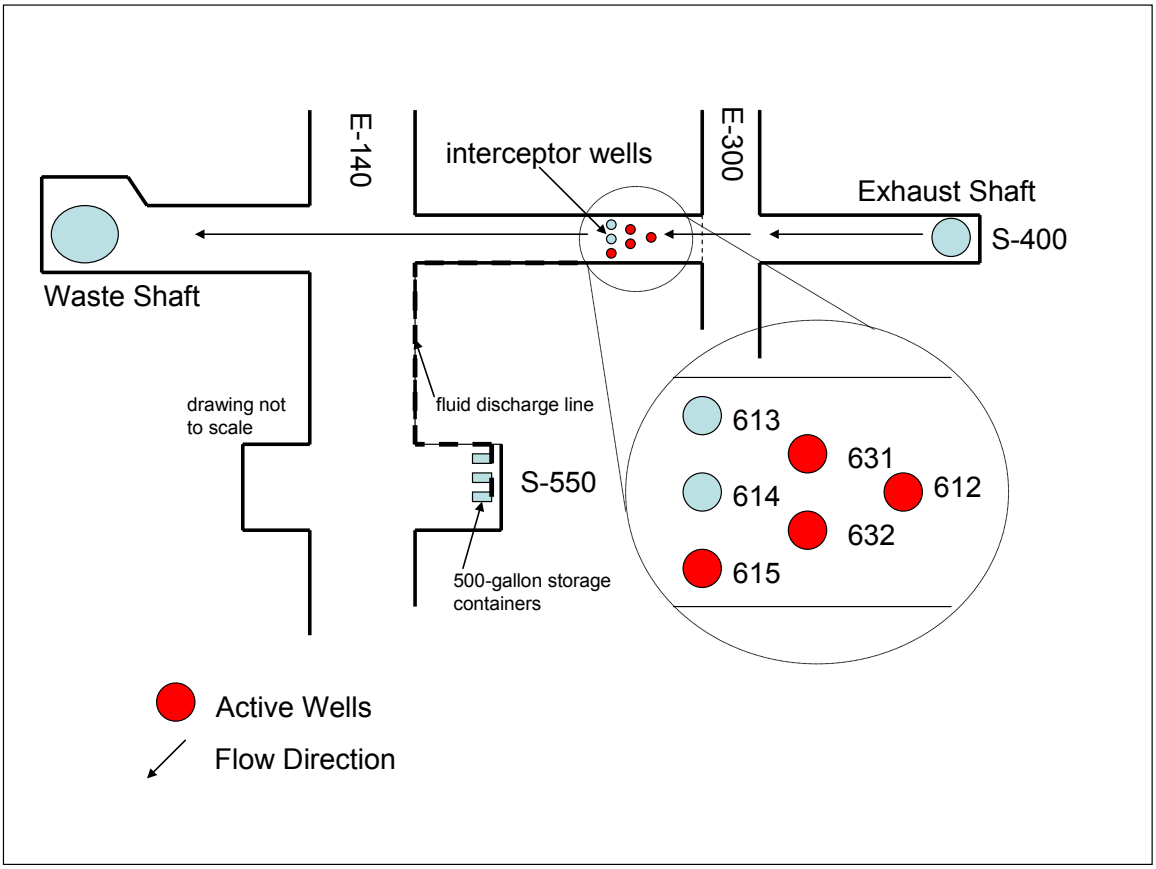

Figure 3 - 10 – Location of Interception Wells and Storage Containers

Table 3 - 1 and Figure 3 - 11 present the volume of fluid removed from the catch basin from July 1997 through June 2006, and by the interception well system from July 2006 through June 2010. The largest reported volumes are typically associated with periods of reduced ventilation and increased humidity. For a discussion of the factors affecting the quantity of fluid produced in the Exhaust Shaft, refer to DOE/WIPP 00-2000, *Brine Generation Study*.

The shaft walls were examined for salt buildup, cracks, moisture, and encrustations, with particular attention paid to power cables, instrument cables, air lines and water-lines, and the three water rings at the base of the Magenta and Culebra members of the Rustler Formation and the bottom of the shaft key. The condition of the shaft wall varies depending on airflow, humidity, temperature, and underground mining activities. During this reporting period, significant mining activity continued in Panels 6 and 7. The principal areas in the shaft with significant salt buildup were the three water rings at the Magenta, the Culebra, and the key, and along upper portions of the shaft generally associated with power cables, support brackets, instrument cables, and the air lines and water-lines.

Though the Magenta and Culebra water rings are encrusted with salt buildup, no water appears to originate from the liner or water rings. Most of the seepage was observed along the east face of the shaft wall near the instrumentation cables and the air lines and water-lines in the upper section of the shaft. Though the presence of water is an inconvenience requiring periodic disposal, at this time it does not appear to have created any hazard or affected the structural integrity of the shaft. However, brine increases the probability of corrosion and deterioration of utility hangers and brackets. There are no visible signs of dissolution of the salt below the key.

The video inspections also focused on the installed utilities and support brackets. These include a 13.8 kVA power cable that is no longer active and the grounding cable on the west wall of the shaft, the instrumentation cables on the northeast wall of the shaft, and the 4 in. air-line and the 2-in. water-line on the east wall of the shaft.

Sporadic salt buildup continues on all cables. The long-term implication of salt buildup is increased loading on cables and cable hangers, accompanied by intermittent falls of debris. The 4-in. compressed air-line and the 2-in. water-line extend from the surface to the bottom of the shaft. At present, neither line is being used. The integrity of the brackets holding the air-line and water-line was difficult to assess because of salt buildup; however, there was no indication that the brackets were broken. Instrumentation cable breaks were observed in the shaft; however, most of these breaks affected abandoned cables, with negligible impact on shaft monitoring and operations.

Table 3-1 – Water Removed from the Exhaust Shaft Catch Basin and the Interception Well System

July 1997 – June 1998		July 1998 – June 1999		July 1999 – June 2000		July 2000 – June 2001		July 2001 – June 2002		July 2002 – June 2003	
Date	Gallons	Date	Gallons	Date	Gallons	Date	Gallons	Date	Gallons	Date	Gallons
7/18/1997	275	7/1/1998	770	7/19/1999	110	7/3/2000	220	7/31/2001	165	7/2/2002	165
7/28/1997	660	7/7/1998	330	12/13/1999	165	7/15/2000	110	8/21/2001	1,595	7/8/2002	440
8/1/1997	550	7/14/1998	220	2/21/2000	110	9/18/2000	330	9/13/2001	330	7/9/2002	495
8/4/1997	715	7/16/1998	275	5/16/2000	715	10/24/2000	110	10/15/2001	770	7/10/2002	660
8/8/1997	770	7/23/1998	165	6/7/2000	165	3/7/2001	110	10/30/2001	220	7/30/2002	220
8/11/1997	660	7/24/1998	220	6/12/2000	275	3/21/2001	165	4/29/2002	275	9/17/2002	165
8/15/1997	475	7/27/1998	825	6/19/2000	440	4/10/2001	220	6/11/2002	550	9/24/2002	330 Sludge
8/18/1997	330	7/28/1998	330	6/22/2000	330	4/17/2001	220	6/22/2002	330	3/25/2003	220 Sludge
8/22/1997	330	8/3/1998	495	6/30/2000	165	4/24/2001	110	**TOTAL**	**4,235**	5/27/2003	55
8/25/1997	1045	8/10/1998	1265	**TOTAL**	**2,475**	5/22/2001	110			6/3/2003	220
8/25/1997	110 Sludge	8/21/1998	330			5/22/2001	440 Sludge			6/25/2003	330
9/2/1997	220	8/24/1998	990			6/12/2001	1100			**TOTAL**	**3,300**
9/15/1997	605	8/27/1998	1155			6/13/2001	110				
9/22/1997	550	9/1/1998	330			6/13/2001	110				
10/13/1997	825	10/5/1998	385			**TOTAL**	**3,465**				
10/20/1997	220	10/26/1998	660								
11/3/1997	275	11/23/1998	110								
11/10/1997	385	2/1/1999	385								
11/17/1997	385	2/10/1999	110								
11/24/1997	330	5/4/1999	330								
12/10/1997	440	5/11/1999	110								
12/12/1997	550	5/24/1999	605								
1/2/1998	220	5/26/1999	165								
1/12/1998	605	5/28/1999	165								
2/2/1998	660	6/1/1999	165								
2/16/1998	605	6/4/1999	165								
3/16/1998	605	6/10/1999	165								
5/4/1998	660	6/10/1999	165 Sludge								
5/11/1998	550	6/16/1999	165								

Table 3-1 – Water Removed from the Exhaust Shaft Catch Basin and the Interception Well System (Continued)

July 1997 – June 1998		**July 1998 – June 1999**		**July 1999 – June 2000**		**July 2000 – June 2001**		**July 2001 – June 2002**		**July 2002 – June 2003**	
Date	Gallons	Date	Gallons	Date	Gallons	Date	Gallons	Date	Gallons	Date	Gallons
5/18/1998	495	6/21/1999	1,705								
5/20/1998	110	6/23/1999	275								
6/1/1998	330	6/30/1999	605								
6/10/1998	90	**TOTAL**	**14,135**								
6/15/1998	385										
6/22/1998	165										
TOTAL	**16,185**										
July 2003 - June 2004		**July 2004 - June 2005**		**July 2005 - June 2006**		**July 2006 - June 2007**		**July 2007 - June 2008**		**July 2008 - June 2009**	
Date	Gallons	Date	Gallons	Date	Date	Gallons	Gallons	Date	Gallons	Date	Gallons
7/8/2003	605	11/29/2004	660 sludge	8/1/2005	1,100	7/11/2006	250	7/11/2007	200	7/31/2008	225
7/9/2003	550	12/6/2004	275 sludge	8/15/2005	880	8/16/2006	420	7/20/2007	400	8/31/2008	50
7/17/2003	165	1/3/2005	440	10/10/2005	715	8/17/2006	400	7/29/2007	420	9/30/2008	115
8/12/2003	275	1/4/2005	220	3/16/2006	55	9/1/2006	420	7/29/2007	410	11/30/2008	65
10/14/2003	165	1/10/2005	385	5/30/2006	400	9/7/2006	420	8/4/2007	410	1/31/2009	65
10/20/2003	440	5/16/2005	660	**TOTAL**	**3,150**	9/18/2007	840	8/14/2007	1000	5/31/2009	927
10/21/2003	330	6/1/2005	660			11/10/2006	150	8/15/2007	820	6/30/2009	425
11/23/2003	220	6/6/2005	220			11/15/2006	400	9/5/2007	820		
11/23/2003	660 sludge	6/20/2005	440			1/30/2007	310	11/8/2007	150		
TOTAL	**3,410**	6/27/2005	220			5/11/2007	75	11/9/2007	110		
		TOTAL	**4,180**			6/20/2007	200	12/4/2007	150		
						TOTAL	**3,885**	6/11/2008	750		
								TOTAL	**5,640**	**TOTAL**	**1,872**

Table 3-1 - Water Removed from the Exhaust Shaft Catch Basin and the Interception Well System (Continued)

July 2009 - June 2010		July 2010- June 2011		July 2011 - June 2012		July 2012 - June 2013		July 2013- June 2014		July 2014 - June 2015	
Date	**Gallons**										
7/2/2009	870										
9/19/2009	180										
1/26/2010	50										
5/3/2010	450										
TOTAL	**1,550**										

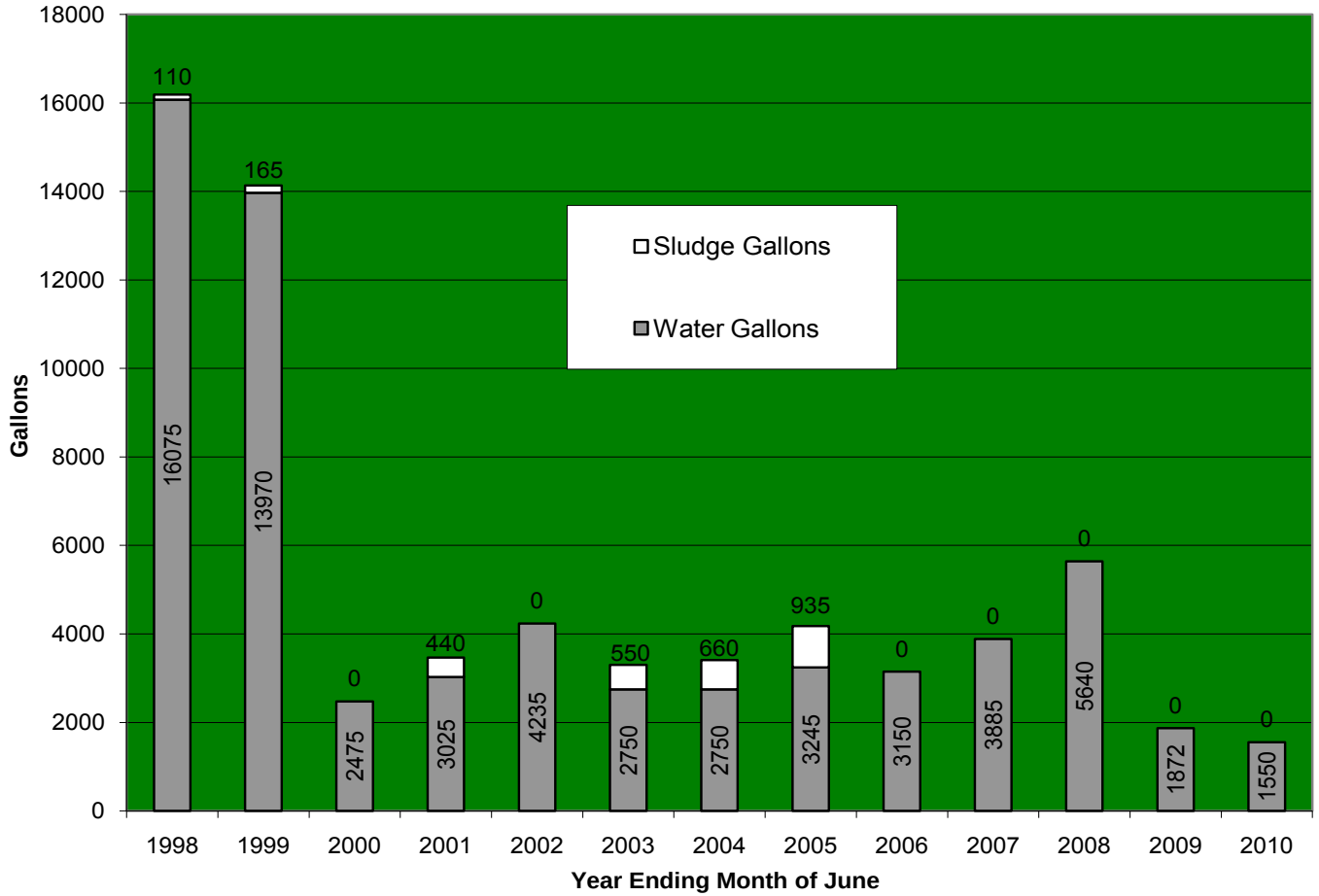

Figure 3 - 11 – Water Removed from the Exhaust Shaft Catch Basin and the Interception Well System

3.3.2 Instrumentation

The Exhaust Shaft was equipped with geomechanical instrumentation in two stages. Earth pressure cells were installed behind the liner key in November 1984. Piezometers and nine multi-position extensometers were installed during November and December 1985. Figure 3 - 12 and Figure 3 - 13 show the instrument locations.

Nine piezometers remain in working condition. The fluid pressure readings from the working piezometers at the end of the reporting period range from -3 psi (-21 kPa) at 544 ft (166 m) to 141 psi (972 kPa) at 721 ft (220 m). Maximum pressure readings from the working piezometers during this reporting period were consistent with maximum readings from the previous reporting period.

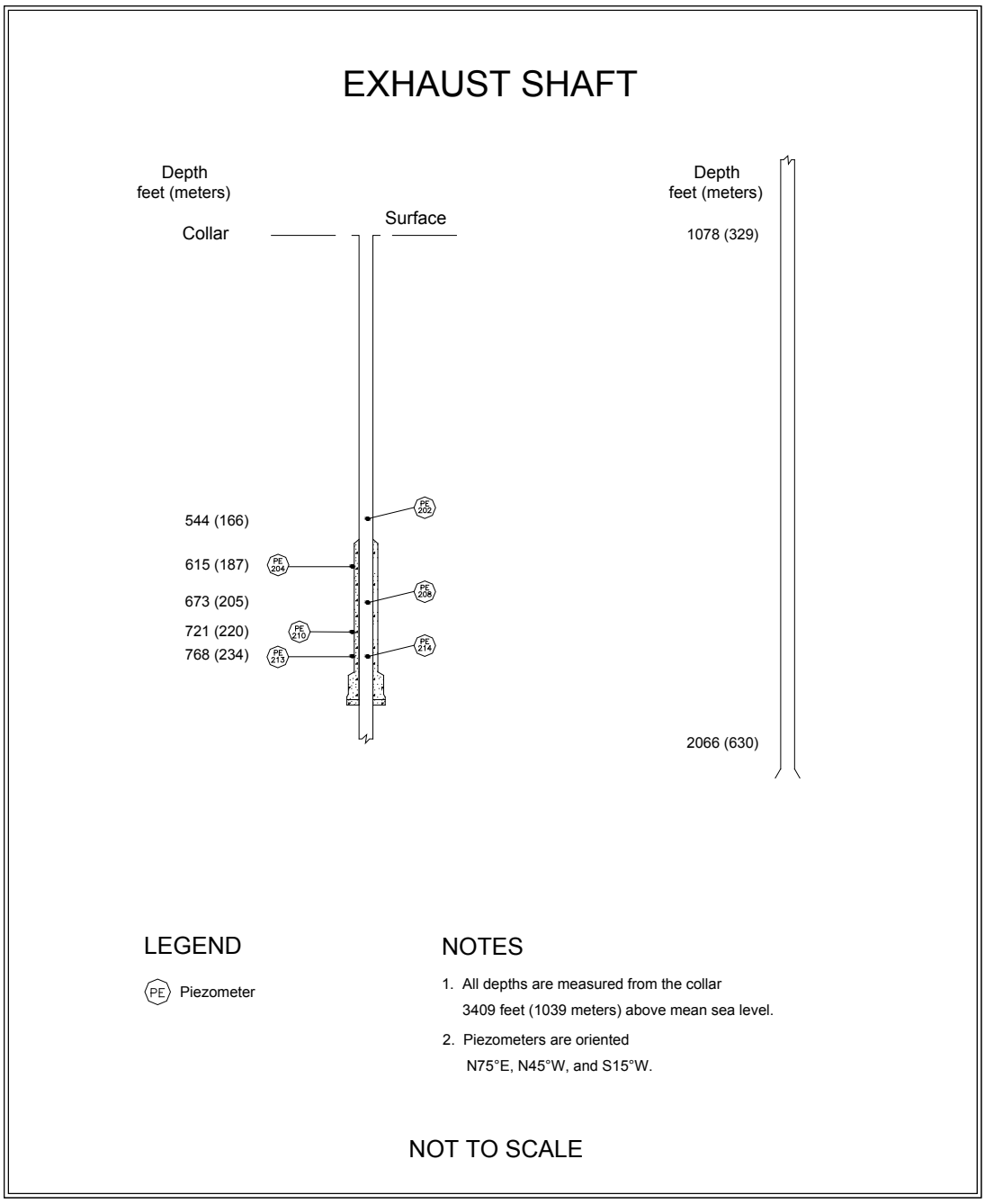

Figure 3 - 12 – Exhaust Shaft Instrumentation (Without Shaft Key)

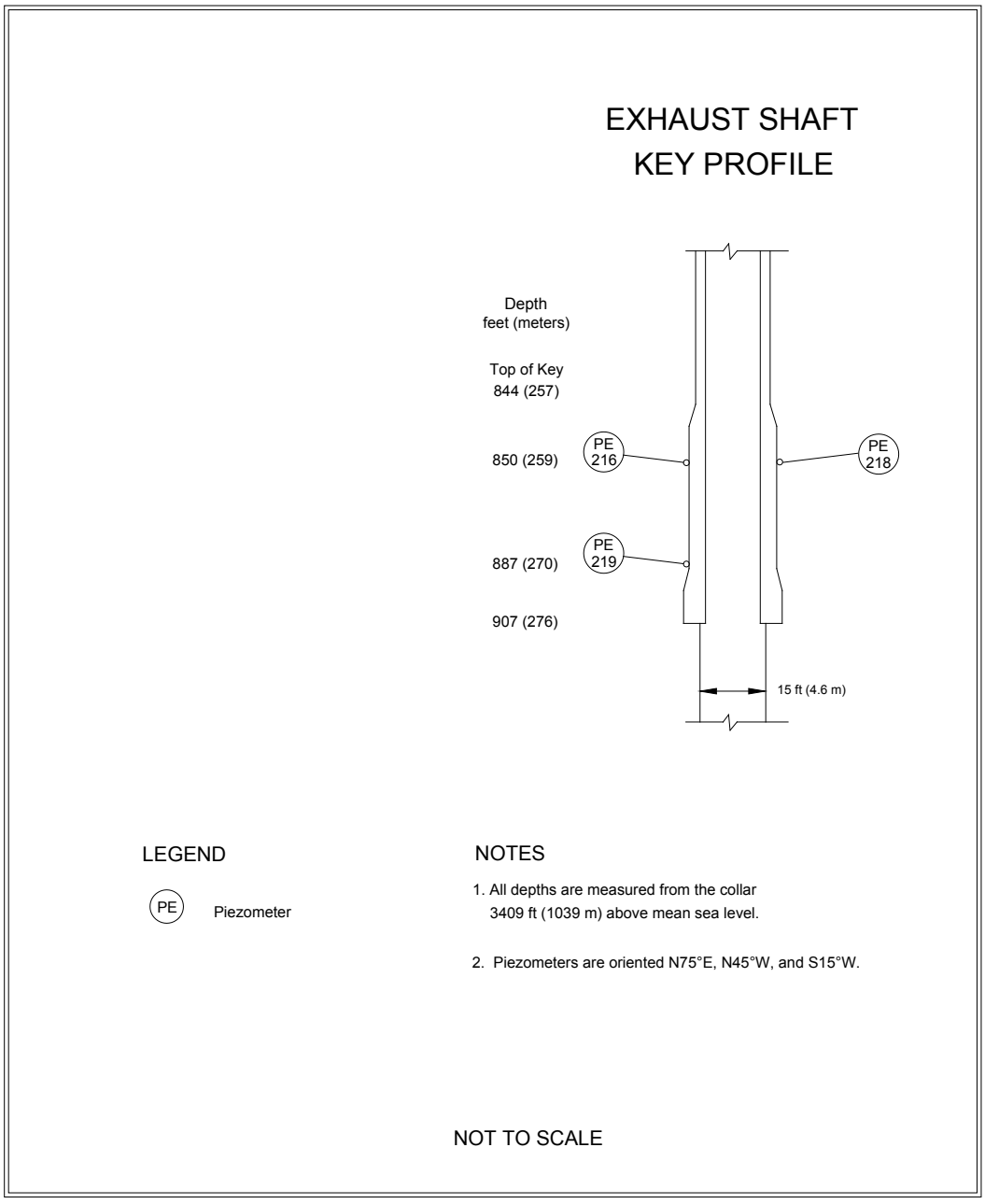

Figure 3 - 13 – Exhaust Shaft Key Instrumentation

3.4 Air Intake Shaft

The Air Intake Shaft was drilled from December 4, 1987, to August 31, 1988, to establish a primary route for surface air to enter the repository (see Figure 1 - 2). The stratigraphy was mapped from September 14, 1988, to November 14, 1989 (Holt and Powers, 1990). Figure 3 - 14 summarizes the shaft stratigraphy.
The Air Intake Shaft is lined with non-reinforced concrete from the surface to the bottom of the shaft key at 903 ft (275 m). The key is 81 ft (25 m) long with an inside diameter of 16 ft (5 m). The shaft diameter below the key is 20 ft (6 m), and the shaft below the key is unlined to the facility horizon at 2,150 ft (655 m). The shaft walls are bolted and meshed from just below the key all the way down to the shaft station. This shaft has no sump.

3.4.1 Shaft Performance

Weekly visual inspections were performed on the Air Intake Shaft during this reporting period, and the shaft was found to be in satisfactory condition. No ground control activities other than routine maintenance were required during this reporting period.

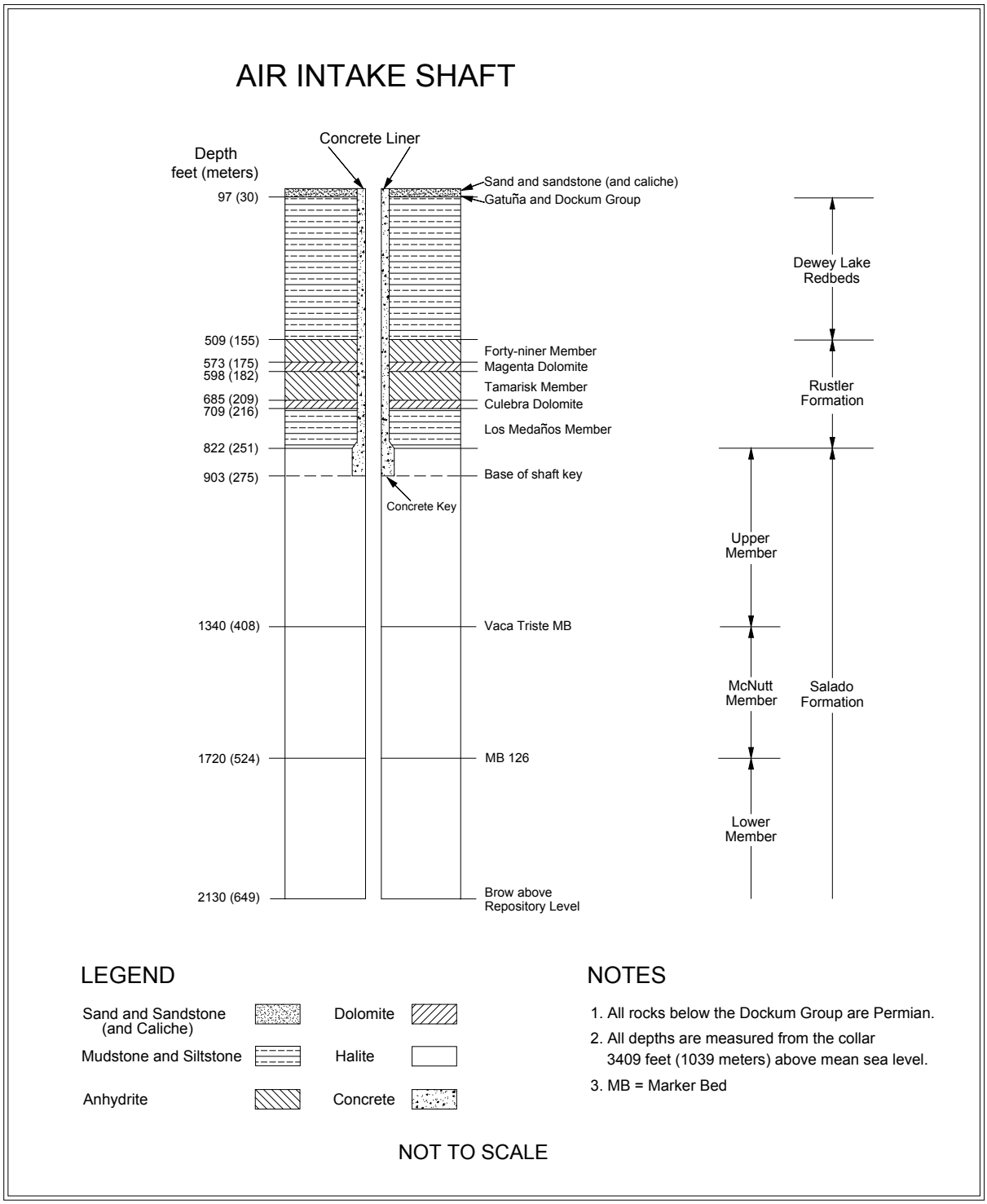

Figure 3 - 14 – Air Intake Shaft Stratigraphy

4.0 PERFORMANCE OF SHAFT STATIONS

This chapter describes the instrumentation and geomechanical performance of the shaft stations at the base of the Salt Shaft, the Waste Shaft, and the Air Intake Shaft. The Exhaust Shaft does not have an enlarged shaft station; therefore, it is not included in this chapter.

4.1 Salt Shaft Station

The Salt Shaft Station was excavated by drilling and blasting between May 2 and June 3, 1982. In 1987 the station was enlarged by removing the roof beam up to Anhydrite "b" between S-90 and N-20 using a mechanical scaler. In 1995, the remaining roof beam at the north end of the station was also removed up to Anhydrite "b". The station area south of the shaft is 90 ft (27.5 m) long and 32 to 38 ft (10 to 12 m) wide. The height of the station south of the shaft is 18 ft (5.5 m). The station dimensions north of the shaft are approximately 30 ft (9 m) long, 32 to 35 ft (10 to 11 m) wide, and 18 ft (5.5 m) high. The shaft extends approximately 140 ft (43 m) below the facility horizon to accommodate the skip loading equipment and a sump. Figure 4 - 1 shows a generalized cross section of the station.

4.1.1 Modifications to Excavation and Ground Control Activities

No significant modifications were performed in the Salt Shaft Station during this reporting period. Ground control activities were limited to routine maintenance.

4.1.2 Instrumentation

Geomechanical instrumentation was installed in the Salt Shaft Station between June 1982 and February 1983, with subsequent reinstallation of extensometers and convergence points as necessary. Figure 4 - 2 shows the instrument locations after the roof beam was taken down.

Five vertical convergence point arrays are currently monitored. Table 4 - 1 summarizes the vertical closure rates in the Salt Shaft Station from July 2009 through June 2010. Salt Shaft Station vertical closure rates indicate that the rates are slightly lower than during the previous reporting period.

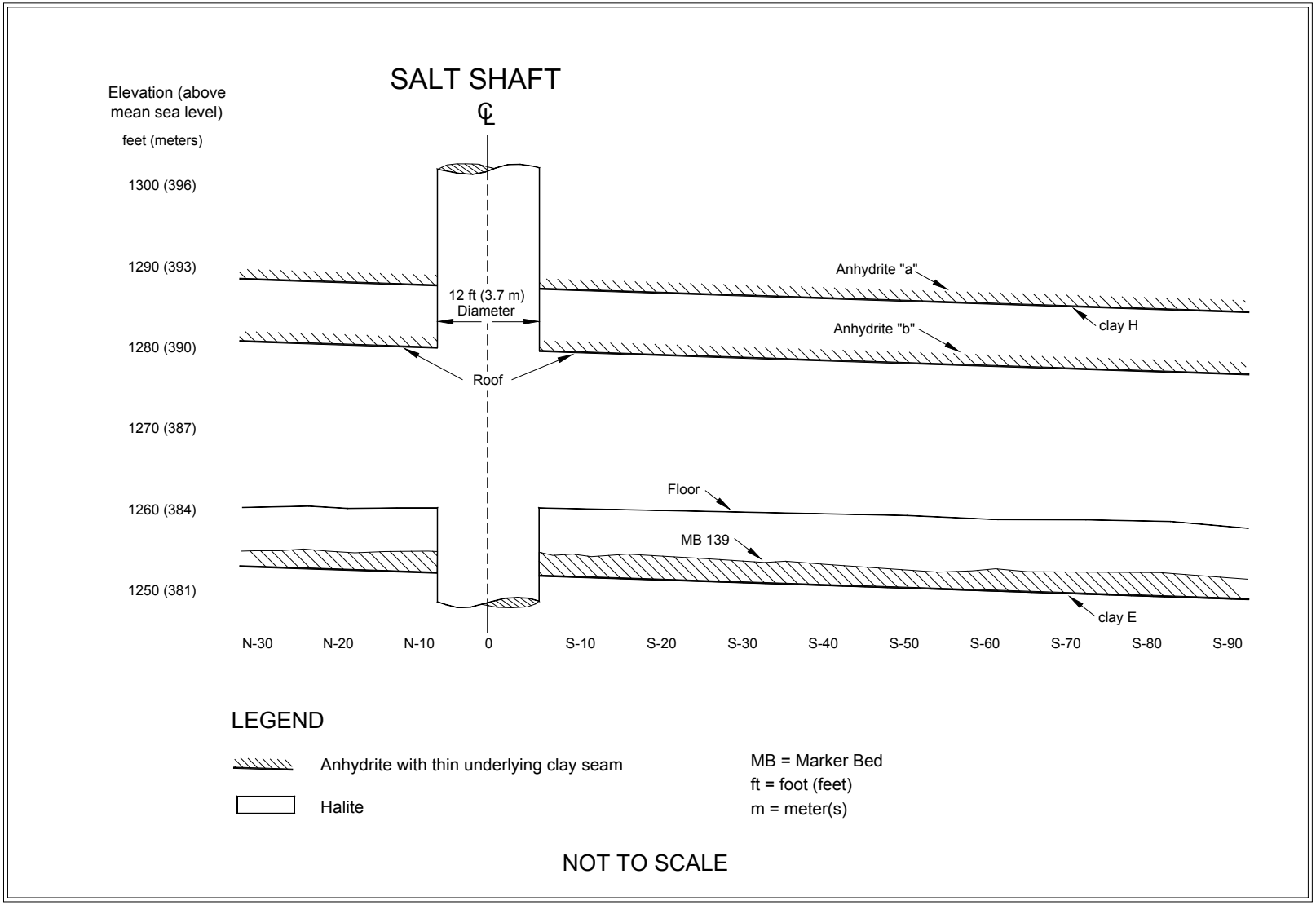

Figure 4 - 1 – Salt Shaft Station Stratigraphy

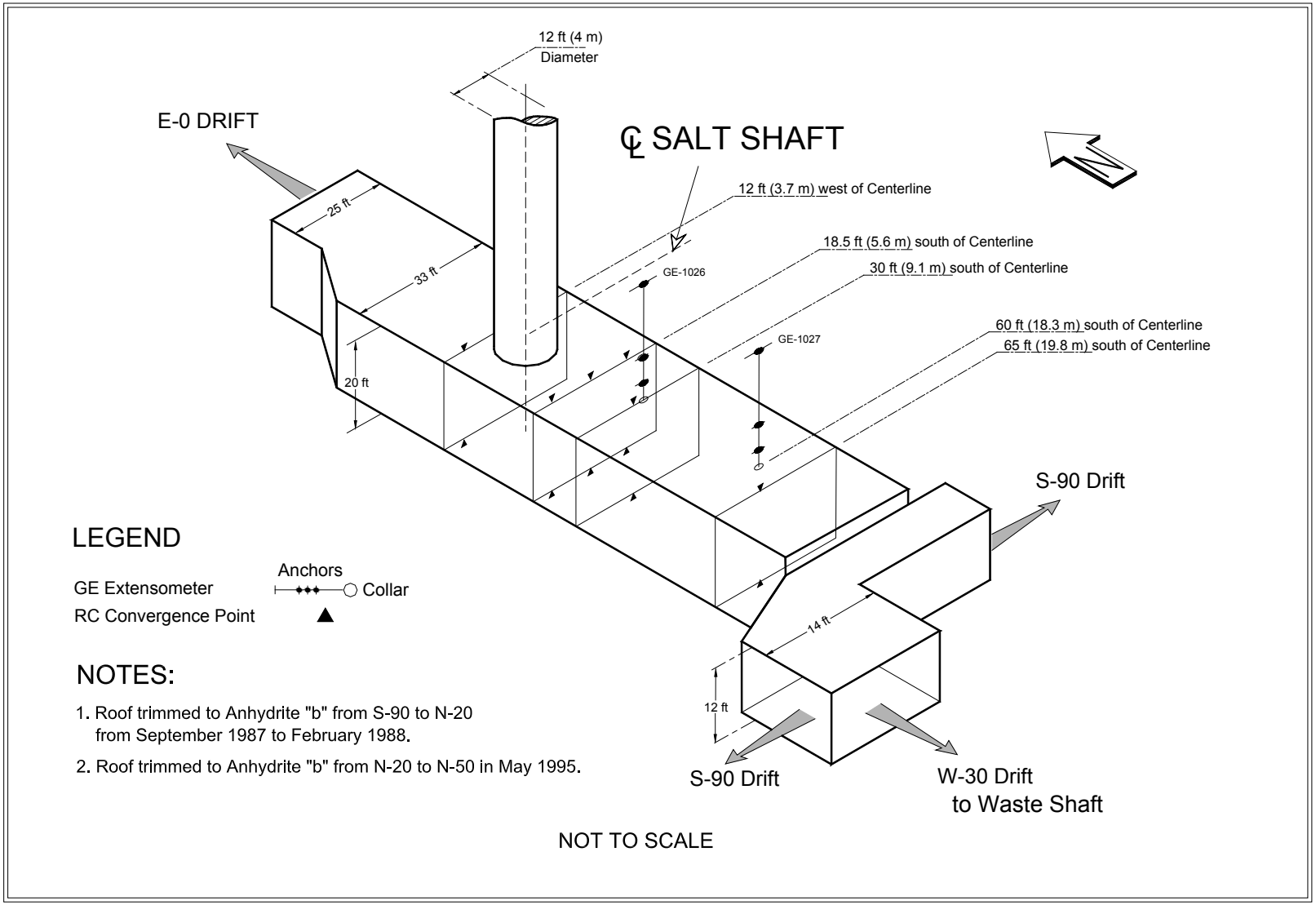

Figure 4 - 2 – Salt Shaft Station Instrumentation after Roof Beam Excavation

Table 4 - 1 – Vertical Closure Rates in the Salt Shaft Station

Table 4-1 – Vertical Closure Rates in the Salt Shaft Station

Location	Chord*	Last Reading	Total Cumulative Displacement in (cm.)	Closure Rate 2009 to 2010 in/yr (cm/yr)	Closure Rate 2008 to 2009 in/yr (cm/yr)	Rate Change Percent
E-0, S-18	A-E	05/18/2010	35.783 (90. 889)	1.37 (3.48)	1.54 (3.90)	-11%
E-0, S-18	B-D	05/18/2010	36.984 (93.939)	1.52 (3.86)	1.79 (4.54)	-15%
E-0, S-18	F-H	05/18/2010	23.216 (58.969)	0.92 (2.34)	1.04 (2.63)	-12%
E-0, S-30	A-C	05/18/2010	50.527 (128.339)	1.40 (3.56)	1.58 (4.01)	-11%
E-0, S-65	A-C	05/18/2010	44.119 (112.062)	1.11 (2.82)	1.14 (2.90)	-3%

* Chord is defined in Section 5.3

4.2 Waste Shaft Station

The Waste Shaft Station was initially excavated with a continuous miner as a ventilation connection to a 6-ft (2-m) diameter exhaust shaft in November 1982. In 1984, the station was enlarged to a height of 15 to 20 ft (4.5 to 6 m) and a width of 20 to 30 ft (6 to 9 m). The station is approximately 150 ft (46 m) long. In 1988, the station walls were trimmed, and concrete was placed on the floor. Since 1988, the Waste Shaft Station has undergone five major floor renovations. A 53-ft (16-m)-long section of the reinforced concrete was removed in February 1991, in 1995 an additional 30-ft (9-m) section was removed, and in 2000 floor maintenance included trimming of the floor and reinstallation of the rails supported by segmented concrete panels on a crushed rock backfill. The roof of the Waste Shaft station was mined up to Clay G in December 2008 to assure adequate operational clearance. 12-ft resin-anchored roof bolts and chain link were installed for ground support. Figure 4 - 3 shows a cross-section of the Waste Shaft Station.

4.2.1 Modifications to Excavation and Ground Control Activities

No modifications were made during this reporting period.

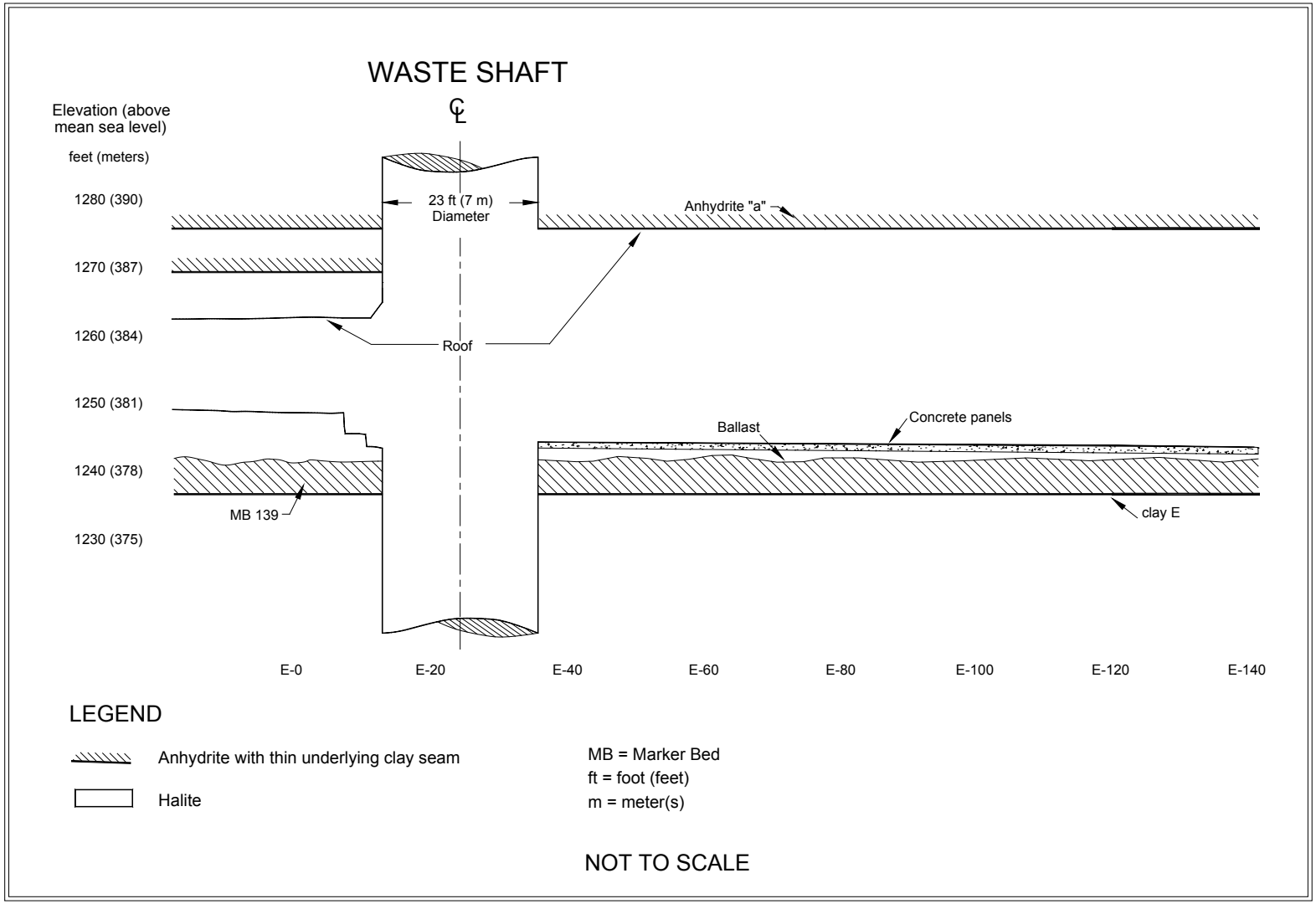

Figure 4 - 3 – Waste Shaft Station Stratigraphy

4.2.2 Instrumentation

Instruments were initially installed in the Waste Shaft Station between November 12 and December 2, 1982. Figure 4 - 4 illustrates the locations after enlargement. Two extensometers in the Waste Shaft Station are currently being monitored. In addition, horizontal convergence is being monitored at E-30 and E 90.

Table 4-2 summarizes the recent history of the roof extensometers in the Waste Shaft Station. Extensometer 51X-GE-00268 (W-30) is installed in a hole drilled into the roof of the station.

Table 4-2 – Summary of Roof Extensometers in Waste Shaft Station

Instrument	Location	Last Reading	Collar Displacement Relative to Deepest Anchor in (cm)	Displacement Rate 2009 to 2010 in/yr (cm/yr)	Displacement Rate 2008 to 2009 in/yr (cm/yr)	Rate Change Percent
51X-GE-00268	S-400, W-30	04/22/2010	10.359 (26.312)	0.27 (0.69)	0.31 (0.79)	-13%
51X-GE-00404	WASTE STATION	06/21/2010	0.354 (0.899)	0.29 (0.74)	0.30 (0.76)	-3%

Table 4 - 3 summarizes the annual closure rates calculated from convergence point data for this reporting period. The data indicate that the horizontal closure rates at both E-32 and E-85 have decreased slightly moderately from the previous reporting period.

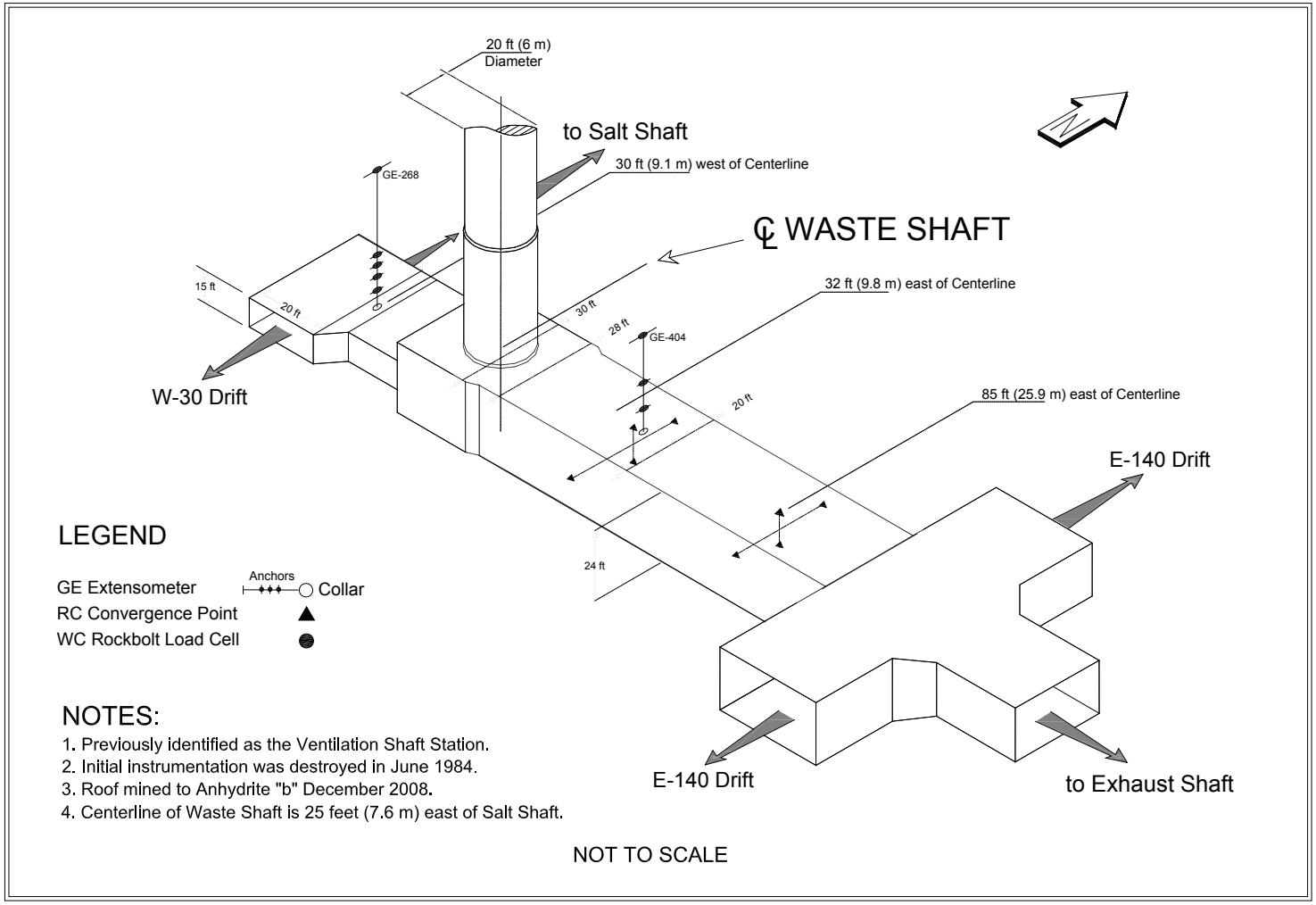

Figure 4 - 4 – Waste Shaft Station Instrumentation after Raising the Roof

Table 4 - 3 - Closure Rates in the Waste Shaft Station

Table 4-3 Closure Rates in the Waste Shaft Station

Location	Chord*	Last Reading	Total Cumulative Displacement in (cm)	Closure Rate 2009 to 2010 in/yr (cm/yr)	Closure Rate 2008 to 2009 in/yr (cm/yr)	Rate change Percent
S-400, E-32	A-C	11/17/2009	1.161 (2.949)	1.55 (3.94)	1.69 (4.28)	-8%
S-400, E-32	B-D	05/04/2010	1.464 (3.719)	1.17 (2.98)	1.46 (3.71)	-20%
S-400, E-85	A-C	11/17/2009	1.068 (2.713)	1.49 (3.79)	1.70 (4.32)	-12%
S-400, E-85	B-D	05/04/2010	1.453 (3.691)	1.16 (2.95)	1.37 (3.49)	-15%

* Chord is defined in Section 5.3

4.3 Air Intake Shaft Station

The Air Intake Shaft Station was excavated in late 1987 and early 1988, using a continuous miner. The Air Intake Shaft is furnished with a work platform and a small cage that can be raised and lowered to perform routine ground maintenance. The principal purpose of that equipment is to provide emergency access.

4.3.1 Modifications to Excavation and Ground Control Activities

The AIS station was not significantly modified during this reporting period. Ground control activities were limited to routine maintenance.

4.3.2 Instrumentation

Radial convergence point and extensometer instrumentation data near the Air Intake Shaft Station are presented in Chapter 5.0 as part of the discussion on the performance of the access drifts. Twenty rock bolt load cells installed in the Air Intake Shaft Station area are monitored regularly.

5.0 PERFORMANCE OF ACCESS DRIFTS

This chapter describes the geomechanical performance of the central underground access drifts. The Waste Disposal Area is discussed in Chapter 6.0. Four major north-south drifts in the WIPP underground are intersected by shorter east-west cross-drifts. Drift dimensions range from 13 ft (4 m) to 21 ft (6.4 m) high and from 14 ft (4.3 m) to 33 ft (9.2 m) wide.

5.1 Modifications to Excavation and Ground Control Activities

Trimming, scaling, and floor milling activities were performed as necessary in many areas. Table 5 - 1 summarizes these activities. It also summarizes ground control activities (e.g., rock bolting and installing wire mesh) in various locations in the access drifts.

5.2 Instrumentation

This section discusses instrumentation details and locations for each instrumentation type.

5.2.1 Extensometers

Thirty extensometers are currently being monitored in the access drifts.

5.2.2 Convergence Points

Convergence points installed during this reporting period were limited to the replacement of arrays in previously mined areas and the installation of new monitoring arrays in newly mined areas. Replacement convergence points were installed in 30 locations throughout the WIPP underground access drifts. Horizontal and vertical convergence point arrays were installed at various locations. Most of these installations were located in E-140 and W-30, where floor trimming activities removed the existing points. Convergence points within the access drifts are read manually at least every two months, with more frequent monitoring in some areas. Table 5 - 2 lists the replacement convergence points that were installed during this reporting period.

Table 5 - 1 – Summary of Modifications and Ground Control Activities in the Access Drifts July 1, 2009 through June 30, 2010

Table 5-1 – Summary of Modifications and Ground Control Activities in the Access Drifts July 1, 2009 through June 30, 2010

Location	Work Activity
N-1100, E-0 (Wash Bay)	Installed 4-ft mechanical bolts and mesh on back and ribs following mining. Supplemented with 12-ft resin bolt pattern
E-140, S-150 (Switch Station 2)	Installed 4-ft mechanical bolts and mesh on back and ribs following mining. Supplemented with 12-ft resin bolt pattern.
S-2520, E-140 to Panel 2 Closure	Installed 4-ft mechanical bolts and mesh on back and ribs following mining. Supplemented with 12-ft resin bolt pattern.
N-460, E-140 to E-300	Installed 4-ft mechanical bolts and mesh on back and ribs following mining. Supplemented with 12-ft resin bolt pattern.
W-170, S-2180 to S-2520	Installed 12-ft resin anchored roof bolts.
W-170, S-2950 to S-3080	Installed 12-ft resin anchored roof bolts.
N-780 Alcove	Installed 12-ft resin anchored roof bolts.
S-3650, E-300 to Panel 4 Closure	Installed 12-ft resin anchored roof bolts.
S-700, W-30 to E-140	Widened and lowered floor. Installed additional bolts and mesh.
W-30, S-2180 to S-3080	Widened and lowered floor. Installed additional bolts and mesh.

Table 5-2 – New and Replace Convergence Points Installed in the Access Drifts July 1, 2009 through June 30, 2010

Table 5-2 – New and Replace Convergence Points Installed in the Access Drifts July 1, 2009 through June 30, 2010

Location	New/Replaced	Field Tag[#]	Chord[*]	Date Installed
E-140, S-700	R	E-140, S-700-6	B-C (Vertical)	6/21/2010
E-140, S-700	R	E-140, S-700-7	A-D (Vertical)	6/21/2010
E-140, S-700	R	E-140, S-700-6	E-F (Vertical)	6/21/2010
E-140, S-850	R	E-140, S-850-9	A-C (Vertical)	6/21/2010
E-140, S-1000	R	E-140, S-1000-3	A-C (Vertical)	6/21/2010
E-140, S-1025	R	E-140, S-1025-4	A-C (Vertical)	6/21/2010
E-140, S-1075	R	E-140, S-1075-4	F-H (Vertical)	6/21/2010
E-140, S-1075	R	E-140, S-1075-4	A-E (Vertical)	6/21/2010
E-140, S-1075	R	E-140, S-1075-4	B-D (Horizontal)	6/21/2010
E-140, S-1150	R	E-140, S-1150-5	L-H (Vertical)	6/22/2010
E-140, S-1150	R	E-140, S-1150-4	A-G (Vertical)	6/22/2010
E-140, S-1150	R	E-140, S-1150-5	B-F (Vertical)	6/22/2010
E-140, S-1225	R	E-140, S-1225-4	A-E (Vertical)	6/22/2010
E-140, S-1225	R	E-140, S-1225-3	B-D (Horizontal)	6/22/2010
W-30, S-850	R	W-30, S-850-4	A-E (Vertical)	6/24/2010
W-30, S-850	R	W-30, S-850-3	H-F (Vertical)	6/24/2010
W-30, S-850	R	W-30, S-850-4	B-D (Horizontal)	6/28/2010
W-30, S-850	R	W-30, S-850-3	C-G (Horizontal)	6/28/2010
W-30, S-1000	R	W-30, S-1000-4	A-C (Vertical)	6/28/2010
W-30, S-1150	R	W-30, S-1150-2	A-C (Vertical)	6/28/2010
W-30, S-1300	R	W-30, S-1300-2	A-C (Vertical)	6/29/2010
W-30, S-1453	R	W-30, S-1453-2	A-C (Vertical)	6/29/2010
W-30, S-1453	R	W-30, S-1453-3	B-D (Horizontal)	6/29/2010
W-30, S-1600	R	W-30, S-1600-3	A-C (Vertical)	6/29/2010
W-30, S-1775	R	W-30, S-1775-2	A-C (Vertical)	6/30/2010
W-30, S-1775	R	W-30, S-1775-3	B-D (Horizontal)	6/30/2010
W-30, S-1950	R	W-30, S-1950-2	A-C (Vertical)	6/30/2010
W-170, S-560	R	W-170, S-560-3	B-D (Horizontal)	10/15/2009
S-700, E-55	R	S-700, E-55-2	A-C (Vertical)	6/24/2010
S-700, E-55	R	S-700, E-55-2	B-D (Horizontal)	6/24/2010

N = New installation.
R = Replacement installation (i.e., instrument replaces older instrument that has failed or has been mined out).
# This column is a combination of the convergence point location followed by a "-X," where X represents the reinstallation number, when applicable,
* A unique letter is assigned to each convergence array element around a particular opening. Chord refers to a particular array pair. The various array lettering schemes are shown in Figure 5-1.

5.3 Analysis of Convergence Point and Extensometer Data

Convergence point data are obtained by measuring the change in distance between fixed points anchored into the rock across an opening, either from rib-to-rib or from roof-to-floor. The measurement end-points constitute a "chord." Figure 5 - 1 shows typical convergence point array configurations along with typical chord designations. Extensometer data are obtained by measuring the displacement from the reference head anchor (collar) to each fixed anchor of the extensometer. These measurements are made, at a minimum, every two months throughout the WIPP underground, except when convergence points are not accessible. Convergence rates and extensometer displacement rates indicate how an excavation is performing; rates that decrease or are relatively constant typify stable excavations, whereas increasing rates may indicate some type of developing instability or may be the response to nearby mining.

Where possible, annual closure rates were calculated from convergence point array data gathered in the access drifts. A complete tabulation of these convergence point data and calculated closure rates is presented in the supporting data document for this report. Locations with increases in annual vertical closure rates of greater than 10 percent are shown in Table 5 - 3.

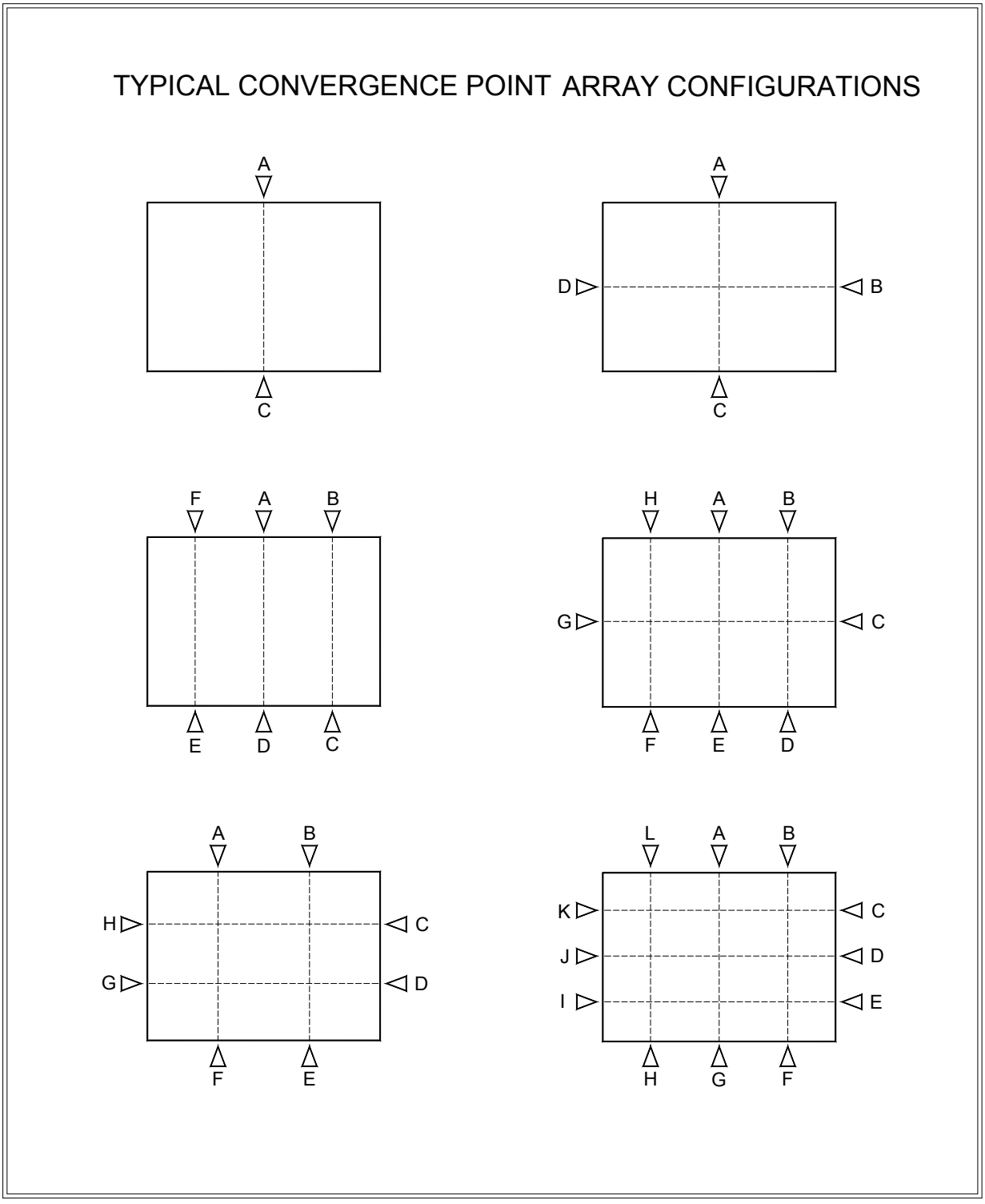

Figure 5 - 1 – Typical Convergence Point Array Configurations Showing Anchor Designations

Extensometer displacement rates and convergence rates are routinely plotted against time, and comparisons are made through time to identify any acceleration. Annual convergence rates are calculated by determining the difference between the first and last readings of the reporting period and dividing the difference by the time between the two readings (in years) (see Section 1.4.3). Instruments that indicate acceleration are analyzed to determine the significance of the acceleration. Factors considered during the analysis include magnitude of the respective rates, percentage increase, convergence history, and any recent excavation in the vicinity.

Thirty extensometers continue to be monitored at various locations in the access drifts. Where displacement data were available, annual displacement rates were calculated for each active installation and compared to the annual displacement rates from the previous reporting period. Approximately 50 percent of the instruments are installed in the E 140 drift to monitor the waste transport route. Many of the E-140 extensometers indicate movement in the roof beam that may be attributed to shallow fracturing and the effects of anhydrite stringer separations in the roof. Lateral deformation in the roof beam may influence the extensometer readings, causing an increase in the measured displacement. Although the extensometer data indicate continued deformation and breakup of the lower beam, the roof bolt anchorage zone remains competent.

Closure rates are variable from year to year; however, locations that exhibit rate increases by more than ten percent are assessed in detail. Further analysis of the convergence rate accelerations has shown many of them to be minor and generally related to roof beam fracturing. Other areas, such as the southern portions of the access drifts, had closure rate increases that can be directly attributed to drift widening and floor trims.

The closure rates observed in E-140 from S-1025 to S-2833 are in an area where the roof beam has been mined to Clay G. The rate of increase in this area may be attributed to roof beam separations formed along shallow anhydrite stringers in the roof. These separations result in the formation of thin roof beams that can easily be deformed toward the opening. Tensile fractures generally develop on the roof surface in areas of maximum deformation.

The rate increases observed in other areas may be attributable to various causes. Rate increases in W-30 and W-170 between S-2750 and S-3080 may be attributed to gradual deterioration of the roof beam along anhydrite stringers. Increases at E-140-S-700 are the result of S-700 crosscut widening completed during the holiday maintenance outage from November 2009 to January 2010.

Table 5 - 3 Greater than 10 Percent Increases in Annual Vertical Convergence Rates in the Access Drifts

Table 5-3 – Greater than 10 Percent Increases in Annual Vertical Convergence Rates in the Access Drifts

Location	Chord*	Last Reading Date	Cumulative Displacement Inches (cm)	Closure Rate 2009 to 2010 in/yr (cm/yr)	Closure Rate 2008 to 2009 in/yr (cm/yr)	Rate Change Percent
E-300, S-700	A-C	5/11/2010	19.284 (48.981)	0.56 (1.42)	0.47 (1.19)	19%
E-300, S-850	A-E	5/11/2010	14.786 (37.556)	0.46 (1.17)	0.33 (0.84)	39%
E-300, S-850	B-D	5/11/2010	11.083 (28.151)	0.38 (0.97)	0.23 (0.58)	65%
E-300, S-850	H-F	5/11/2010	10.251 (26.038)	0.37 (0.94)	0.23 (0.58)	61%
E-300, S-850	C-G	5/11/2010	16.553 (42.045)	0.55 (1.4)	0.4 (1.02)	38%
E-300, S-1150	A-E	5/11/2010	16.722 (42.474)	0.56 (1.42)	0.49 (1.24)	14%
E-300, S-1150	B-D	5/11/2010	11.839 (30.071)	0.41 (1.04)	0.31 (0.79)	32%
E-300, S-1150	H-F	5/11/2010	11.487 (29.177)	0.45 (1.14)	0.32 (0.81)	41%
E300, S-1150	C-G	5/11/2010	19.08 (48.463)	0.66 (1.68)	0.5 (1.27)	32%
E-300, S-3195	A-C	5/11/2010	15.683 (39.835)	2.73 (6.93)	2.38 (6.05)	15%
E-140, S-700	A-D	11/17/2009	28.979 (73.607)	1.69 (4.29)	1.27 (3.23)	33%
E-140, S-700	B-C	11/17/2009	30.032 (76.281)	2.05 (5.21)	1.46 (3.71)	40%
E-140, S-700	E-F	11/17/2009	24.634 (62.57)	0.98 (2.49)	0.85 (2.16)	15%
E-140, S-400	A-C	9/24/2009	1.184 (3.007)	2.4 (6.1)	1.77 (4.5)	36%
W-30, S-2520	A-C	5/18/2010	19.158 (48.661)	2.03 (5.16)	1.75 (4.45)	16%
W-30, S-2685	A-C	5/18/2010	18.89 (47.981)	2.84 (7.21)	1.88 (4.78)	51%
W-30, S-2833	A-C	6/14/2010	14.515 (36.868)	3.11 (7.9)	2.5 (6.35)	24%
W-30, S-2916	A-C	6/28/2010	25.357 (64.407)	5.16 (13.11)	4.64 (11.79)	11%
W-30, S-2998	A-C	6/28/2010	13.404 (34.046)	2.74 (6.96)	2.24 (5.69)	22%
W-30, S-3480	A-C	6/30/2010	10.082 (25.608)	2.25 (5.72)	1.87 (4.75)	20%
W-170, S-2060	B-D	6/28/2010	16.697 (42.41)	1.29 (3.28)	1.12 (2.84)	15%
W-170, S-2180	A-C	6/28/2010	19.183 (48.725)	1.31 (3.33)	1.15 (2.92)	14%
W-170, S-2275	A-C	6/28/2010	11.47 (29.134)	1.22 (3.1)	1.04 (2.64)	17%
W-170, S-2275	B-D	6/28/2010	12.563 (31.91)	1.44 (3.66)	1.23 (3.12)	17%
W-170, S-2350	A-C	6/28/2010	15.287 (38.829)	1.7 (4.32)	1.45 (3.68)	17%
W-170, S-2425	A-C	6/28/2010	13.636 (34.635)	1.53 (3.89)	1.29 (3.28)	19%
W-170, S-2425	B-D	6/28/2010	14.279 (36.269)	1.8 (4.57)	1.41 (3.58)	28%
W-170, S-2833	A-C	6/30/2010	18.951 (48.136)	5.08 (12.9)	4.34 (11.02)	17%
W-170, S-3395	A-C	6/28/2010	12.915 (32.804)	4.19 (10.64)	2.58 (6.55)	62%
W-170, S-3480	A-C	6/28/2010	14.421 (36.629)	4.25 (10.8)	3.24 (8.23)	31%
S-90, W-120	A-C	6/29/2010	6.753 (17.153)	0.63 (1.6)	0.56 (1.42)	13%
S-90, W-120	B-D	6/29/2010	7.199 (18.285)	0.68 (1.73)	0.59 (1.5)	15%
S-90, W-620	A-C	6/29/2010	23.72 (60.249)	1.15 (2.92)	1.00 (2.54)	15%
S-2180, W-100	B-D	4/28/2010	10.325 (26.226)	1.35 (3.43)	1.16 (2.95)	16%
S-2520, W-100	B-D	3/4/2010	15.623 (39.682)	1.94 (4.93)	1.67 (4.24)	16%
S-2750, E-55	A-C	4/27/2010	16.681 (42.37)	3.55 (9.02)	2.99 (7.59)	19%
S-2750, E-410	A-C	4/26/2010	16.326 (41.468)	2.97 (7.54)	2.48 (6.3)	20%
S-2750, W-93	A-C	4/27/2010	18.468 (46.909)	3.91 (9.93)	3.52 (8.94)	11%
S-3080, W-100	A-C	4/27/2010	16.2 (41.148)	3.41 (8.66)	2.78 (7.06)	23%
S-3310, E-220	A-C	4/27/2010	16.02 (40.691)	3.18 (8.08)	2.48 (6.3)	28%
S-3310, W-100	A-C	4/26/2010	17.124 (43.495)	3.6 (9.14)	2.76 (7.01)	30%
S-3650, E-220	A-C	9/16/2009	4.526 (11.496)	2.08 (5.28)	1.63 (4.14)	28%

5.4 Excavation Performance

Approximately 500 readings are collected and assessed regularly from convergence point arrays throughout the WIPP underground. Convergence rates continue to vary seasonally, typically increasing during the warmer and more humid summer months and decreasing during the cooler and drier winter months.

The performance of the access drift excavations during this reporting period was within acceptable criteria. "Acceptable criteria" means that a drift remains accessible, and the ground can be controlled by routine maintenance. Standard remedial ground control in some areas was required to maintain the performance of the excavations. The drifts remain stable and controlled. Most of the annualized rates remain steady, indicating stability. In some locations, where the rates are high, nearby mining activity or gradual deterioration of the roof beam along anhydrite stringers is most likely the cause. Where necessary, additional ground control measures have been or will be installed.

6.0 PERFORMANCE OF WASTE DISPOSAL AREA

The Waste Disposal Area as of June 30, 2010, consisted of Panels 1, 2, 3, 4, and 5. Panels 1, 2, 3, and 4 were closed during previous reporting periods. Waste disposal in Panel 5 was ongoing. Panel 6 has been completed, and Panel 7 mining was under way.

6.1 History

Excavation of Panel 1 began in May 1986 with the mining of the access entries. Initially, the disposal rooms and drifts were developed as pilot drifts that were later excavated to nominal operational dimensions of 13 ft (4 m) high, 33 ft (10 m) wide, and 300 ft (91 m) long. Room 1 was completed to these dimensions in August 1986, and pilot drifts for Rooms 2 and 3 were excavated in January and February 1987. Rooms 2 and 3 were completed in February and March 1988, and Rooms 4 through 7 were completed in May 1988. Four short access drifts designed to lead to smaller test alcoves were excavated north off the S-1600 drift and Rooms 4-7 in June 1989. Only the access drifts to the alcoves were completed; the alcoves themselves were not excavated. Panel 1 waste emplacement (in Rooms 1, 2, 3, 7, adjacent areas of S 1600, and all of S-1950) was completed during a prior reporting period, and the panel is closed to all access. The Panel 1 access entries, S-1600 and S-1950, which extend from the E-300 drift to the isolation walls, remain open, and the instrumentation in this area continues to be maintained and monitored.

Excavation of the Panel 2 waste disposal area began in September 1999 with the mining of access entries. Initially, the disposal rooms and drifts were developed as pilot drifts that were trimmed to finished dimensions. Room 1 was completed in January 2000, and pilot drifts for Rooms 2 and 3 were excavated in February 2000. Pilot drifts were completed for Rooms 4 through 6 in April 2000. The pilot drift for Room 7 was excavated in May 2000. All the rooms were excavated to final dimensions by August 2000. Waste emplacement in Panel 2 was completed during a prior reporting period, and the panel is closed to all access. The Panel 2 access entries, S-2150 and S-2520,

which extend from the E-300 drift to the isolation walls, remain open, and the instrumentation in this area continues to be maintained and monitored.

Excavation of Panel 3 waste disposal rooms began in May 2002 with the mining of access entries to Panel 3. As with Panel 2, initially, the disposal rooms and drifts were developed as pilot drifts that were trimmed to finished dimensions. All the rooms were excavated to final dimensions by the end of March 2004. Waste emplacement in Panel 3 was completed in February 2007. Substantial barriers and bulkheads were installed in the exhaust and intake drifts of Panel 3 to prevent access into the panel and to isolate it from the ventilation circuit.

Panel 4 access drift mining began in January 2005. The disposal rooms were initially developed as pilot drifts and were later trimmed to final dimensions. Mining was completed by June 2006. Waste emplacement in Panel 4 was completed in March 2009. Substantial barriers and bulkheads were installed in the exhaust and intake drifts of Panel 4 to prevent access into the panel and to isolate it from the ventilation circuit.

Waste was being emplaced in Panel 5. Rooms 2 and 3 were currently receiving waste.

Outfitting of Panel 6 was completed, and the panel was almost ready to receive waste.

6.2 Modifications to Excavations and Ground Control Activities

Routine maintenance and ground control activities in the form of trimming, scaling, rock bolt replacement, and installing wire mesh were performed on ribs, floor, and roof throughout accessible areas of the disposal panels. Table 6 - 1summarizes the ground control activities performed in the disposal panels during this reporting period.

6.3 Instrumentation

Remote monitoring of extensometers continues in Panel 4. There were no changes to the Panel 5 instrumentation layout. Convergence monitoring continued in all accessible areas up to the time that the waste stack front passed the instrument location. Remote monitoring of extensometers continues.

Schematics of the geotechnical instrumentation layout in Panels 4, 5, and 6 are shown in Figure 6 - 1 through Figure 6 - 3**.**

Table 6 - 1 – Summary of Modifications and Ground Control Activities in the Waste Disposal Area from July 1, 2009 to June 30, 2010

Table 6-1 – Summary of Modifications and Ground Control Activities in the Waste Disposal Area from July 1, 2009 to June 30, 2010

Location	Work Performed
Panel 6	5-ft resin bolts installed in a 7-wide pattern.

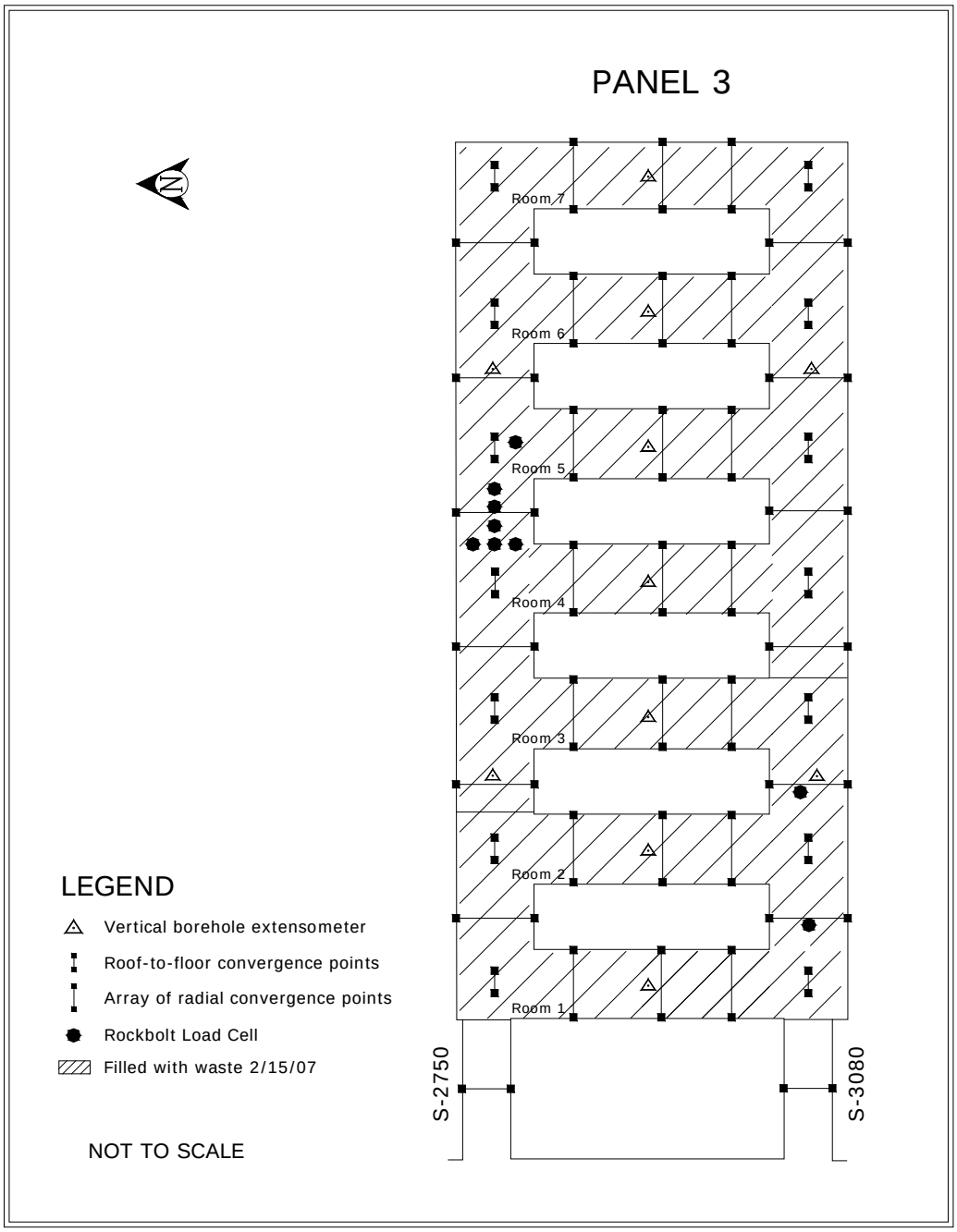

Figure 6 - 1 – Location of Panel 3 Geotechnical Instruments

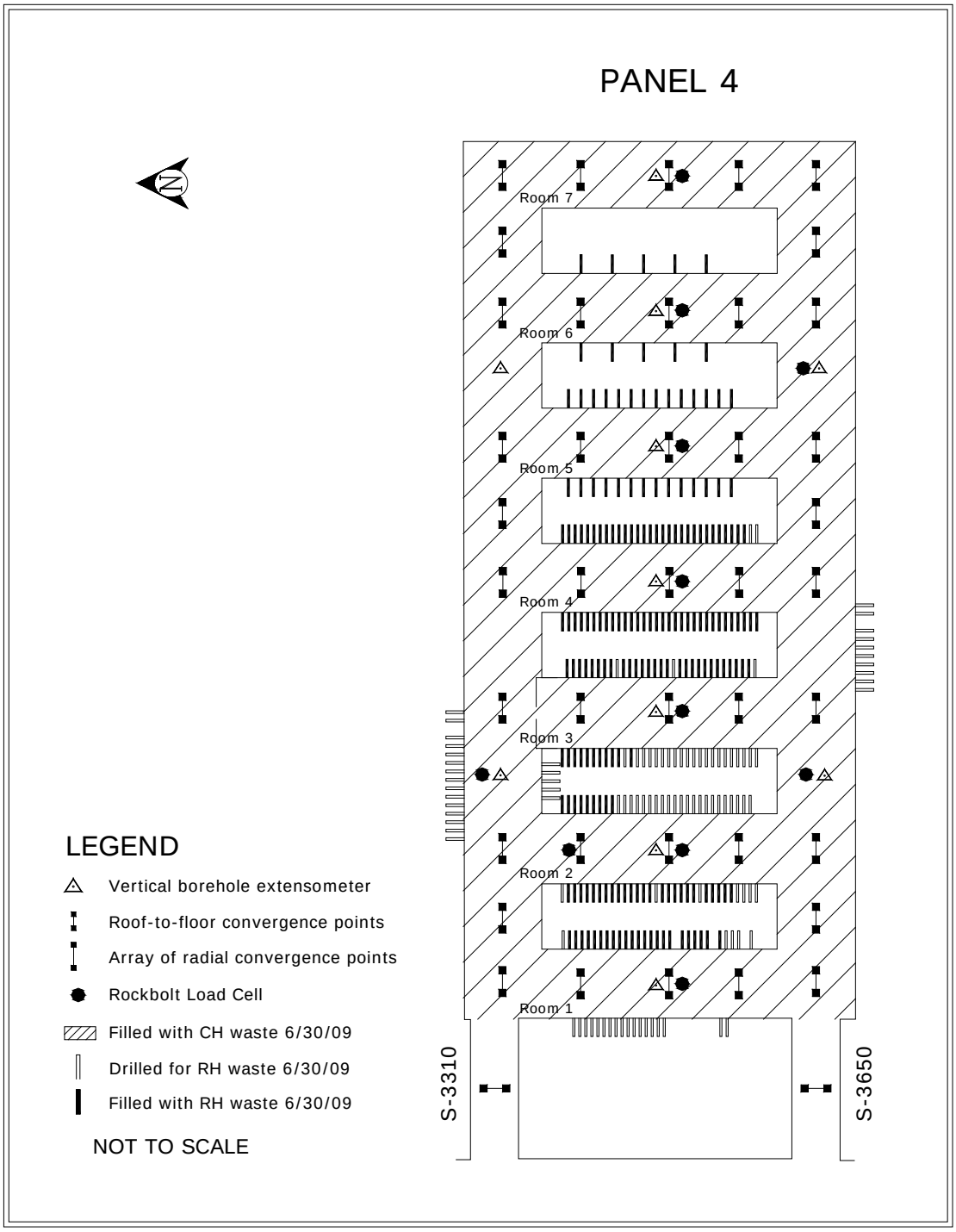

Figure 6 - 2 – Location of Panel 4 Geotechnical Instruments

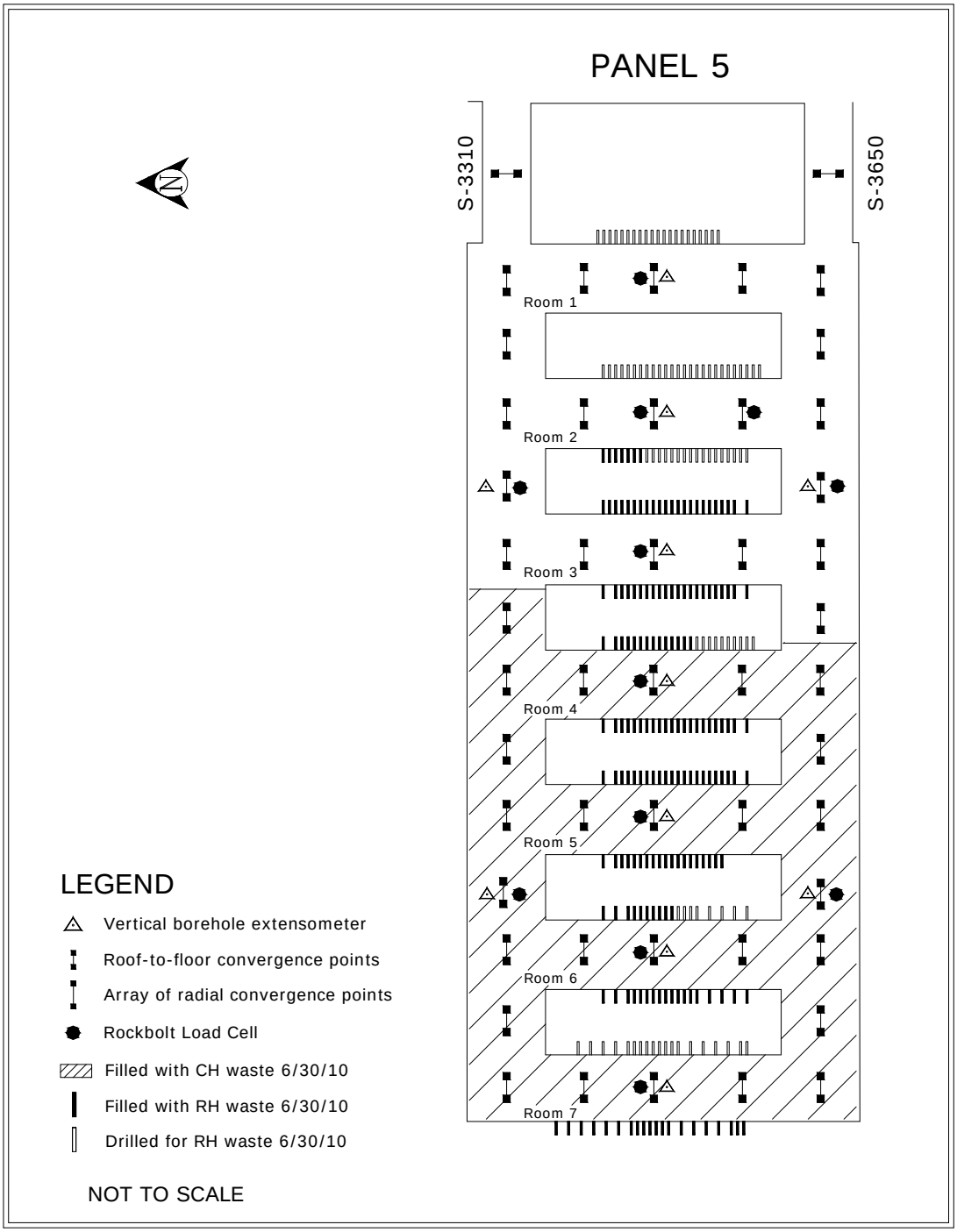

Figure 6 - 3 – Location of Panel 5 Geotechnical Instruments

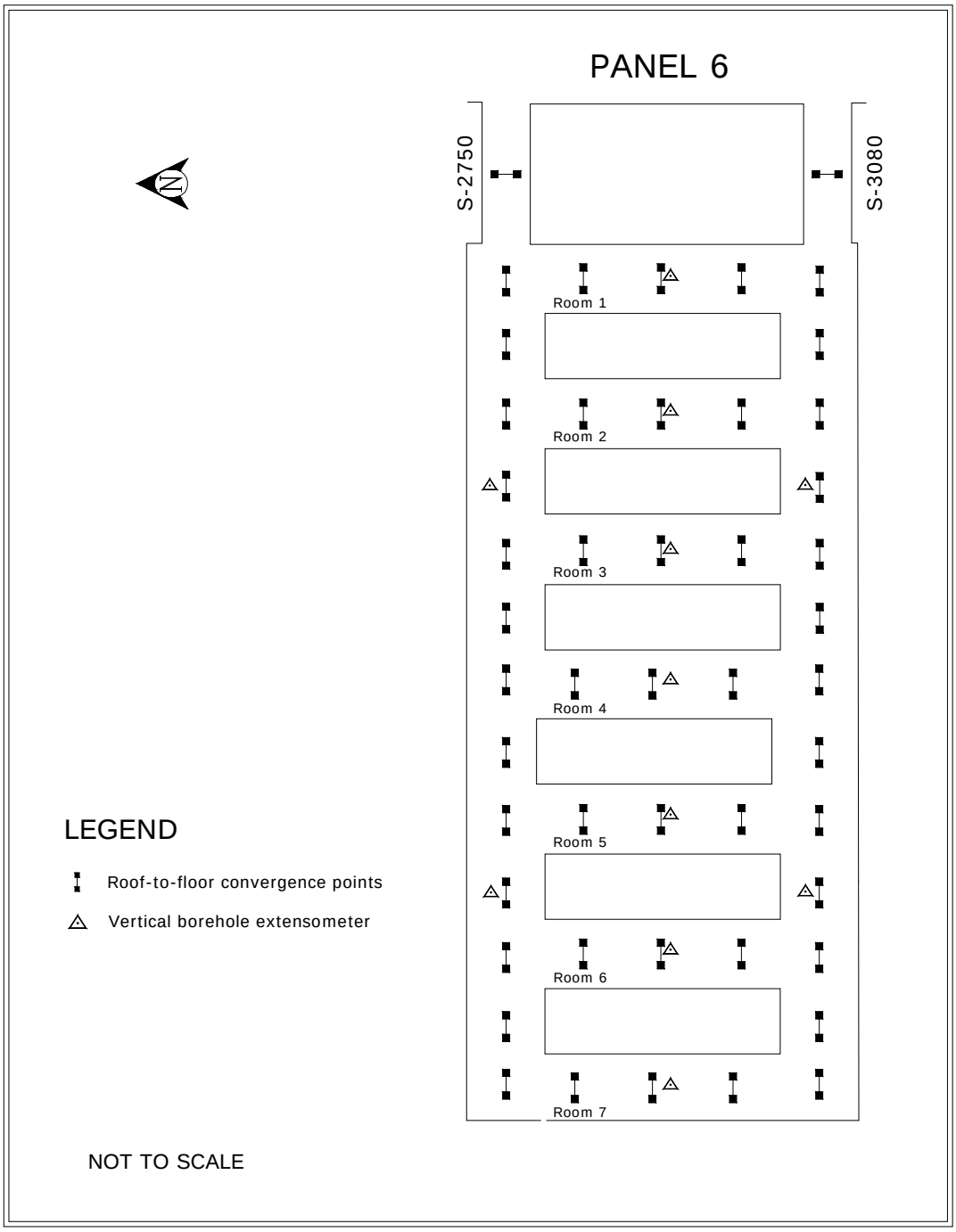

Figure 6 - 4 – Location of Panel 6 Geotechnical Instruments

6.4 Excavation Performance

Waste handling activities in Panels 1, 2, and 3 have been completed, and geotechnical monitoring inside these panels has been discontinued. Waste handling activities have also been completed in Panel 4; however, extensometers continue to be read remotely until the loss of communication with instruments behind the panel closure.
In accessible underground areas, horizontal and vertical convergence rates, calculated at the center of each of the rooms, were compared between this and the previous

reporting period. Generally, convergence rates have declined from initial post-mining levels. Localized increases occur with seasonal creep trends, the presence of continuous anhydrite stringers, and coincident with adjacent mining activities. These increases are addressed, where necessary, with additional ground support selected for conditions prevailing at the specific location of installation.

6.5 Analysis of Extensometer and Convergence Point Data

Geotechnical instrumentation is installed in each disposal room and at select locations in the panel access drifts. As anticipated, these installations showed a general decrease in room closure rate and roof beam deformation with time. At some locations, deformation rates increased as roof sag and roof beam deterioration developed. Supplemental ground control support was installed in these areas and has subsequently reduced the observed rates.

Although Panels 1 through 4 are closed, convergence monitoring continues in the panel entries between E-300 and the explosion isolation walls (Panels 1 and 2) and substantial and isolation barriers (Panels 3 and 4). The monitoring results indicate a steady long-term trend. The lowest closure rates were observed nearest to the explosion isolation walls.

Panel 5 convergence monitoring identified a rate increase toward the end of this reporting period, corresponding to final floor trimming activities in nearby Panel 6. Otherwise, Panel 5 convergence appears to have stabilized.

Panel 6 convergence data rates appear to remain elevated after floor trimming, particularly in the northern portions of the panel. Designed ground support consists of 5 foot-long resin anchored rock bolts, which provide a stiffening effect to the lower portion of the roof beam. Borehole observations indicate that larger separations along anhydrite stringers are occurring above the anchorage zone, where the stress has been redirected.

Panel 7 mining activities commenced at the very end of this reporting period. No data was yet available for those areas.

7.0 GEOSCIENCE PROGRAM

The Geoscience Program confirms the suitability of the site through the collection of various geologic data and excavation characteristics from the underground. These include the inspection of open observation holes for fractures (separations) and offsets (lateral displacements) in roof beams and the mapping of fracture development on roof surfaces. Data collected through these activities support the design and evaluation of ground support systems.

During this reporting period, the following activities were performed:

- Observation hole inspections
- Fracture mapping

Fracture development in the roof is primarily caused by the concentration of compressive stresses in the roof beam and is influenced by the size and shape of the excavation and the stratigraphy in the immediate vicinity of the opening. In a thick roof beam, pillar deformations induce lateral compressive stresses into the immediate roof and floor. With time, the buildup of stress causes differential movement along stratigraphic boundaries. This differential movement is identified as offsets in observation holes and by the bends in failed rock bolts. Large strains associated with lateral movements can induce fracturing in the roof, which is frequently seen near the ribs; however, this process may take a long time (years) to develop.

At the upper repository horizon, clay or anhydrite stringers exert significant influence over the effective thickness of the roof beam. The presence of these stringers causes the roof beam to behave as a series of thin independent beams. Little or no tensile support is provided across the stringer interface. As horizontal end-loading continues, each beam can deflect downward causing a tensile fracture to develop along the bottom of the beam. These tensile fractures can develop in relatively new excavations soon after separation occurs along the stringer interface.

The location and initiation of interface separation is also influenced by the dip of the rock layers. The roofs and floors of the disposal panels are mined level through the sloping beds. At some locations, this may result in a significant difference in roof beam thickness from one side of the excavation to the other. Areas with the thinnest beam are the most likely to develop separations and subsequent fracturing.

7.1 Observation Hole Inspections

Geotechnical observation holes are drilled at various locations throughout the underground facility. A location may contain one or more holes arranged in an array. These holes are drilled to depths that allow the monitoring of fracture development and offsetting and are inspected for the development of those features. Roof observation holes usually extend up past clays G and H (Figure 7 - 1 and Figure 7 - 2).

The clay seams nearest the excavation surfaces define the immediate roof beam. The roof beam is bounded by Clay G in most of the access drifts and Panels 1 and 2. Some areas, such as the Salt Shaft Station, portions of the E-0 and E-140 drifts, the south mains south of S-2620, and Panels 3, 4, 5, and 6 are excavated to Clay G and so have roof beams bounded by Clay H.

The offset in a hole is determined by visually estimating the degree of occlusion. The direction of offset along clay seams is observed as the movement of the strata nearer to the observer relative to the strata farther away. Typically, the nearer strata move toward the center of the excavation (Figure 7 - 3 and Figure 7 - 4). Based on previous observations in the underground, the magnitude of offset is usually greater in holes located near ribs than in those located along excavation centerlines. Offsetting along the clay layers is observable until total offset is reached or visibility is obstructed by intervening offsets at other clay seams or fractures. Holes are inspected for fractures, using an aluminum rod with a flattened steel wire probe attached to one end perpendicular to the rod (referred to as a "scratch rod"). Fractures and clay seams are located by moving the probe along the inside of the hole until it is snagged in one of

these features. Depth to each feature is recorded, as is the magnitude of separations encountered. A fiber scope camera is occasionally used in addition to the scratch rod to visually document features of interest in a hole.

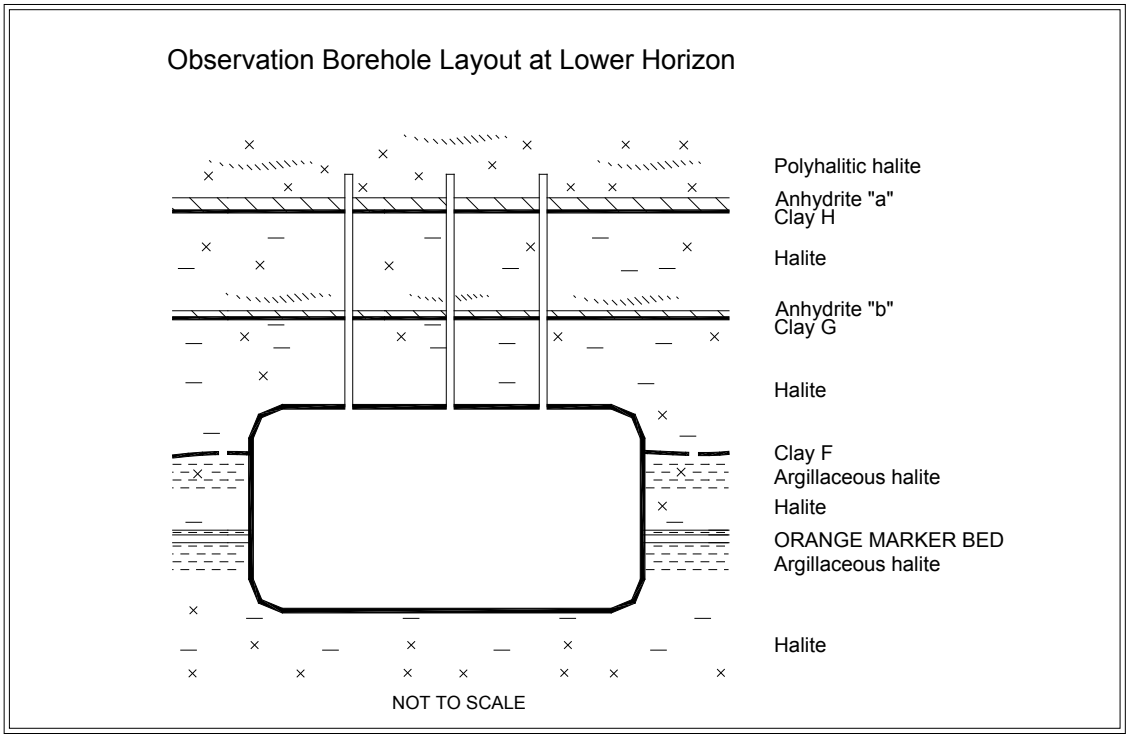

Figure 7 - 1 – Example of Observation Hole Layout at Lower Horizon

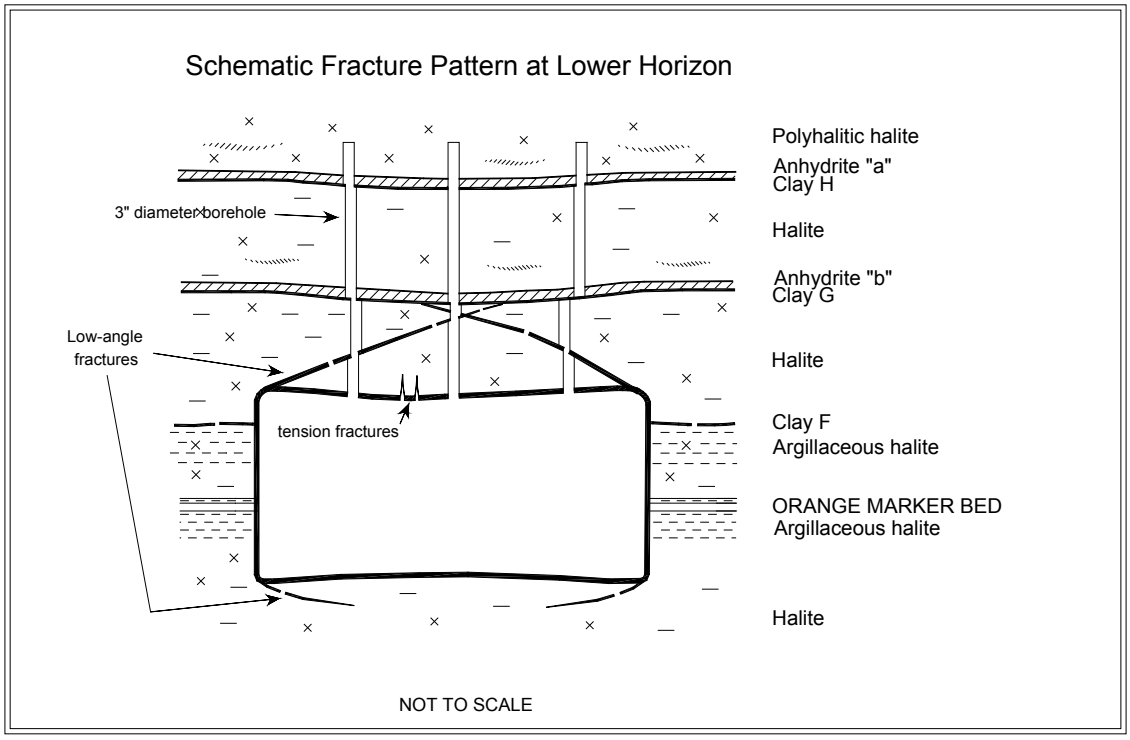

Figure 7 - 2 – Example of Observation Hole Layout at Upper Horizon

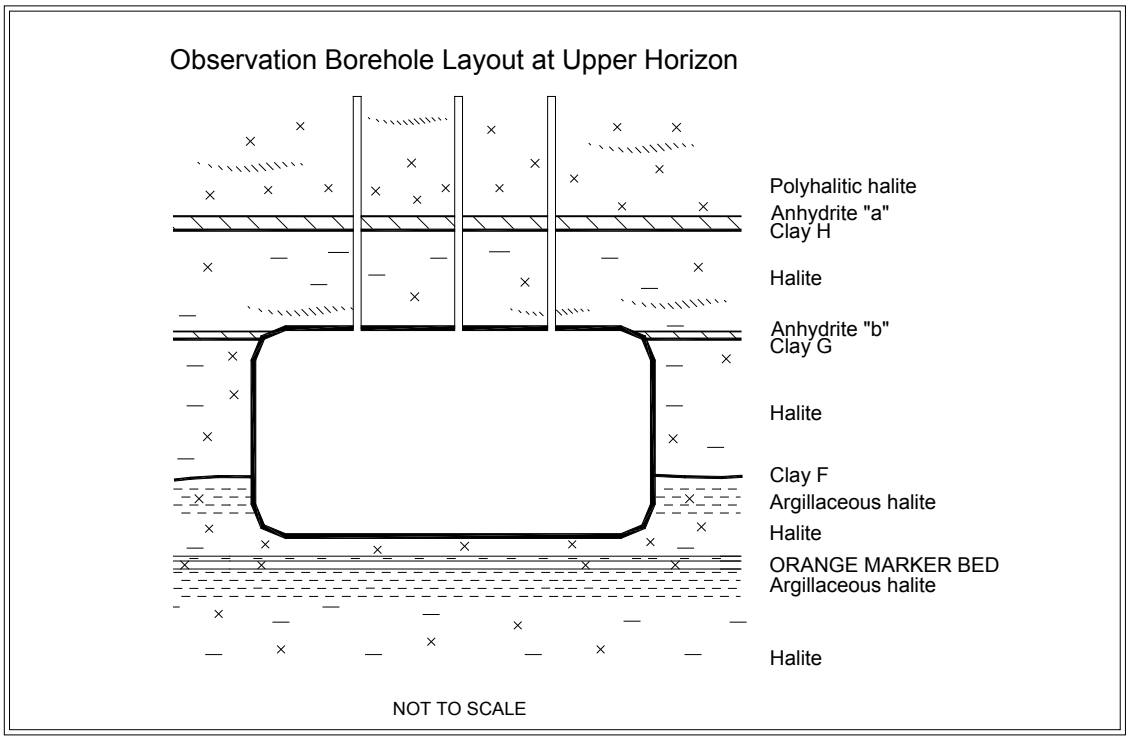

Figure 7 - 3 – Typical Fracture Patterns at Lower Horizon

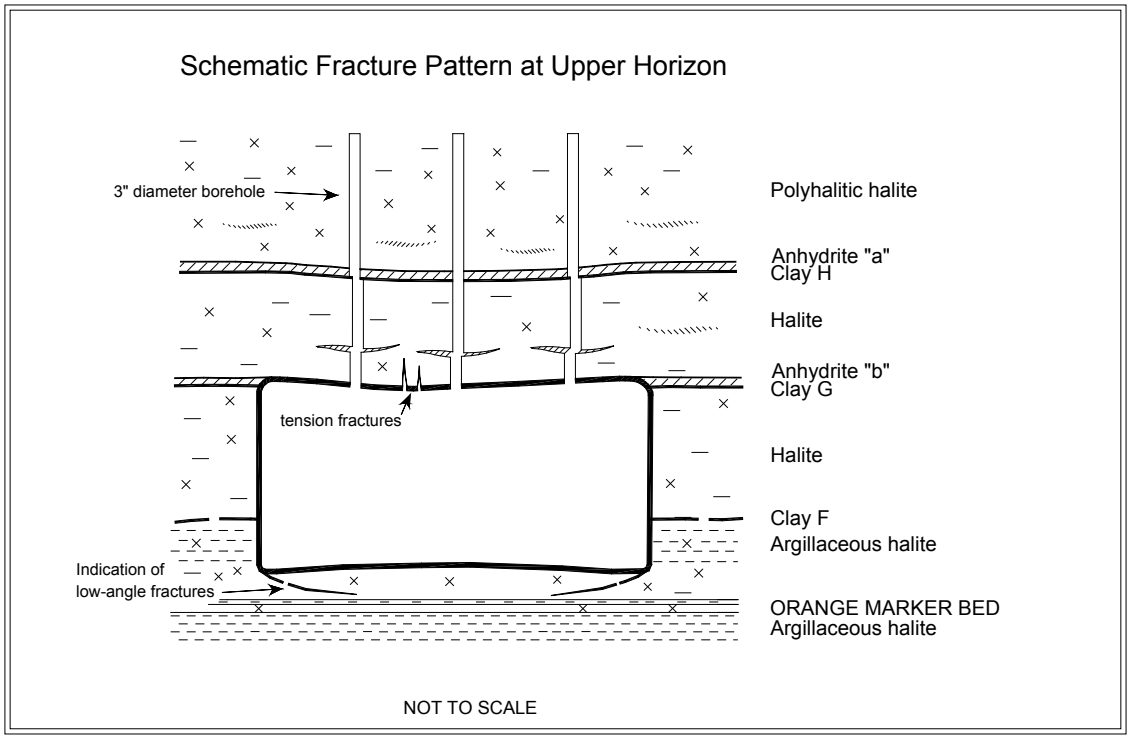

Figure 7 - 4 – Typical Fracture Patterns at Upper Horizon

The separation and offset data observed in accessible holes in the back are presented in the supporting data document for this report. Twenty eight accessible holes were monitored in Panel 5, and 47 in Panel 6. In both Panels 5 and 6, the greatest separations were associated with Clay H and Anhydrite "a". Five holes in Panel 5 and thirteen holes in Panel 6 had fractures associated with anhydrite stringers in the lower portion (first 3 feet) of the roof beam. Twenty-five of 28 holes in Panel 5 and 41 of the 47 holes in Panel 6 showed some offset.

7.2 Fracture Mapping

Routine mapping documents the progression of fractures in the roof exposed on the excavation surfaces of the drifts and rooms in the underground repository. The fracture surveys are generally performed on an annual basis, and the fracture maps are updated. The fracture maps facilitate the analysis of strain in the immediate roof-beam, because they document the development and propagation of fractures through time. The supporting data document contains fracture maps for Panels 5 and 6. During this reporting period, fractures were mapped in Panels 5 and 6.

8.0 SUMMARY

At the inception of WIPP, criteria were developed that address the design requirements (DOE, 1984). They pertained to all aspects of the mined facility and its operation as a pilot plant for the demonstration of technical and operational methods for permanent disposal of contact-handled and remote-handled TRU waste. In 1994, as the WIPP focus moved toward the permanent disposal of TRU waste, these design requirements were reassessed and replaced by a new set of requirements called system design descriptions. Table 8 - 1 shows the comparison of these design requirements with conditions actually observed in the underground from July 2009 through June 2010.

Normal drift and room maintenance continued during this reporting period with rib, roof, and floor scaling and trimming in various locations, and rock bolts and wire mesh installed as needed. Supplemental ground control systems consisting of resin-anchored bolts were installed in select locations. Some of these supplemental systems also included roof mats.

New geomechanical instrumentation was installed in Panel 6 and its access drifts, as well as in various locations throughout the repository to replace mined-out instruments. Monitoring no longer continues in non-accessible areas except in Panel 4. All accessible areas of the underground are connected to data-loggers or are monitored manually.

The *in situ* performance of the excavations generally continues to satisfy the appropriate design criteria, although specific areas are being identified where deterioration resulting from ageing must be addressed through routine maintenance and installation of engineered systems. This deterioration has been identified through the analysis of data acquired from geomechanical instrumentation and the Geoscience Program. If the planned life of some of the openings needs to be extended, changing the geometry of the access drifts (removing unstable roof beam or rib spalls, or milling the floor for added clearance), or additional ground control (roof removal, installing bolts, mesh, or straps) may be necessary. The ground conditions in the waste disposal area and associated waste transport routes continue to slowly deteriorate; however, routine ground control installations and maintenance continue to allow safe access in the underground facility.

In addition to underground instrumentation, qualitative assessments of fracture development are documented through mapping the underground repository and inspecting the observation holes. The information acquired from these programs provides early detection of ground deterioration, contributes to the understanding of the dynamic geomechanical processes in the WIPP underground, and aids in the design of effective ground control and support systems.

Table 8 - 1 – Comparison of Excavation Performance to System Design Requirements

Table 8-1 – Comparison of Excavation Performance to System Design Requirements

Requirement	Comments
"The lining shall be designed for a hydrostatic pressure. . . ."	Water pressure observed on piezometers located behind the shaft liners remains below design levels.
"The key shall be designed to resist the lateral pressure generated by salt creep."	Geomechanical data from the Waste Shaft indicate that the shaft key is minimally loaded and is structurally stable. Visual inspections of all shaft keys do not indicate any deterioration due to creep loading.
"The key shall be designed to retain the rock formation and will be provided with chemical seal rings and a water collection ring with drains to prevent water from flowing down the unlined shaft from the lining above."	Shaft inspection observations and instrumentation show no indication of instability due to salt dissolution. No water has been observed flowing along the rock-liner interface.
"The underground waste disposal facilities shall be designed to provide space and adequate access for the underground equipment and temporary storage space to support underground operations."	Geomechanical instrument data and visual observations indicate that the current design provides adequate access and storage and disposal space. Ground control maintenance is performed as necessary to maintain access.
"Entries and subentries to the underground disposal area and the experimental areas shall be provided and sized for personnel safety, adequate air flow, and space for equipment."	Deformation of excavation remains within the required limits. Normal periodic maintenance consisting of rock bolting, wire meshing, trimming, and scaling continue throughout the repository. Areas such as the waste transport route undergo periodic floor trims in order to maintain adequate operating height.
"Geomechanical instrumentation shall be provided to measure the cumulative deformation of the rock mass surrounding mined drifts. . . ."	Geotechnical instrumentation is operated and maintained to meet this requirement. This annual report provides a summary and analysis of the geomechanical data.

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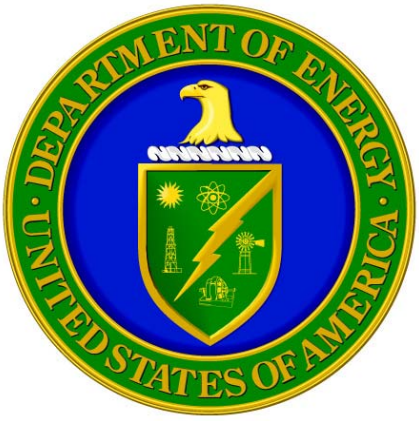
DOE/WIPP-11-3177
Volume 2

Geotechnical Analysis Report for July 2009 - June 2010

Supporting Data

March 2011



Waste Isolation Pilot Plant

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1.0 Introduction

This report is a compilation of geotechnical data presented as plots for each active instrument installed in the underground at the Waste Isolation Pilot Plant (WIPP) through June 30, 2010. A summary of the geotechnical analyses that were performed using the enclosed data is provided in Volume 1 of the Geotechnical Analysis Report (GAR).

1.1 Instrumentation

Geomechanical instrument data included in this report reflect the measurements of the geomechanical response of the underground and shafts. The instruments consist of convergence points, borehole extensometers, rockbolt load cells, pressure cells, strain gages, piezometers, and joint meters.

Closure measurements are taken at convergence points. Rock displacement is calculated by measuring the distance between two opposing points. Displacement is monitored over time and is plotted as closure versus time. Annual rates of closure are calculated for the convergence data and are compared with annual closure rates from previous reporting periods.

Borehole extensometers are used to determine the absolute movements of the ground around the openings. With these instruments, rods or wires are placed into a hole and anchored at various depths. The displacement at the extensometer head (located near the excavation face) is measured relative to each of the fixed anchors. These data are used in the extensometer *displacement* plots presented here. As part of the post-processing of acquired extensometer data a *relative displacement* value is calculated. The deepest anchor is assumed to be fixed in undisturbed ground and a displacement for the remaining anchors relative to the deepest anchor is calculated. Annual rates of collar displacement are calculated for each extensometer and are compared with the annual displacement rate reported during the previous reporting period.

Rockbolt load cells are used to determine the ground loading and the effectiveness of rockbolts. Plots consist of load versus time for each instrumented bolt.

Earth pressure cells and strain gages are used in and around the shaft liners to determine their loads. These are also depicted in time-based plots. Monitoring of these instruments indicates whether there is any stress buildup in the shaft lining systems.

Piezometers are used to measure the gauge pressure of groundwater. They have been installed in the shafts at varying elevations to monitor the hydraulic head acting on the shaft liners. Plots from piezometers are presented as pressure versus time.

Joint meters are installed perpendicular to a crack and monitor any changes in separation of the crack which may occur over time.

1.2 Data Plot Explanation

Data are presented in graphical form for ease in interpretation. Time-based plots are used in this report. Each plot generally consists of a legend in the upper right-hand corner that gives the array name and specific location of the instrument or point evaluated. The legend ties the graphical cross-sectional representation of the drift or shaft typically presented in the lower right-hand corner to the symbols on the curve in the graph. For extensometers, each anchor is designated with an alpha character "A" closest to the collar and "B," "C," "D," or "E" for the furthest point from the collar (the deepest anchor). For convergence points, the horizontal and vertical sections of the drift are referred to as chords. Breaks in the graph for convergence data and a numeric designator added to the legend typically indicate that the convergence point was lost due to normal mine maintenance activities and later reinstalled.

1.3 Report Organization

Chapter 1.0 provides an introduction to this Supporting Data volume of the GAR. Chapter 2.0 provides instrument data analysis for the Salt Handling Shaft, Waste Shaft, and Exhaust Shaft followed by data plots for the extensometers, piezometers, earth pressure cells, spot welded strain gages, and embedment strain gages installed in the shafts. Chapter 3.0 provides instrument data analysis for the Salt Handling Shaft Station and Waste Shaft Station, an instrument data summary only for the area immediately surrounding the Air Intake Shaft, and data plots for extensometers, convergence points, and rockbolt load cells for all three locations. Chapter 4.0 provides instrument data analysis for the access drifts followed by data plots for the extensometers, convergence points, joint meters and rock bolt load cells. Chapter 5.0 provides instrument data analysis for the Waste Disposal Area followed by data plots for the extensometers, rock bolt load cells and convergence points.

Chapter 6.0 provides geologic data collected through the mapping of fractures, stratigraphic mapping and the observed displacements in vertical boreholes.

2.0 Instrumentation Summary for Shafts

Instrumentation data analysis for three of the four shafts at the WIPP follows. Table 2-1 presents data and analysis of the Salt Shaft. Plots of the instrument data are presented as Figures 2-1 through 2-12. Table 2-2 presents data and analysis of the Waste Shaft. Plots of the instrument data are presented as Figures 2-13 through 2-18. Table 2-3 presents data and analysis of the Exhaust Shaft. Plots of the instrument data are presented as Figures 2-19 through 2-25.

Table 2-1
Salt Handling Shaft Data Analysis

PIEZOMETERS

Field Tag	Level feet	Figure Number	Date of 2009-2010 Max. Reading	2009-2010 Maximum Pressure Readings (psi)	Date of 2008-2009 Max. Reading	2008-2009 Maximum Pressure Readings (psi)	Change in Maximum Pressure From Previous Year (psi)	Comments
37X-PE-00201	580	2-1	04/05/10	98.8	11/03/08	82.7	16.1	
37X-PE-00202	580	2-1	04/05/10	106.9	11/03/08	88.9	18	
37X-PE-00203	620	2-2	04/05/10	230.5	06/02/09	163.1	67.4	
37X-PE-00204	620	2-2	04/05/10	187.5	06/02/09	150.3	37.2	
37X-PE-00205	691	2-3	06/03/10	188	05/04/09	176.8	11.2	
37X-PE-00206	691	2-3	06/03/10	183.3	05/04/09	171.4	11.9	
37X-PE-00209	802	2-4	08/03/09	64.4	07/01/08	65.9	-1.5	
37X-PE-00210	802	2-4	09/01/09	65.1	09/02/08	65.5	-0.4	
37X-PE-00211	850	2-5	06/03/10	105.2	08/04/08	100.9	4.3	
37X-PE-00212	850	2-5	06/03/10	121.9	08/04/08	108.8	13.1	

EARTH PRESSURE CELLS

Field Tag	Level feet	Figure Number	Date of 2009-2010 Max. Reading	2009-2010 Maximum Pressure Readings (psi)	Date of 2008-2009 Max. Reading	2008-2009 Maximum Pressure Readings (psi)	Change in Maximum Pressure From Previous Year (psi)	Comments
37X- WE-00201	860	2-6	09/01/09	-6.2	08/04/08	-4.3	-1.9	
37X- WE-00202	860	2-6	07/06/09	-24.3	08/04/08	-23.5	-0.8	
37X- WE-00203	860	2-6	04/05/10	7.4	05/04/09	2.8	4.6	

Table 2-1 (Continued)
Salt Handling Shaft Data Analysis

SPOT WELDED STRAIN GAGES

Field Tag	Level Feet	Figure Number	Date of 2009-2010 Max. Reading	2009-2010 Maximum Pressure Readings (psi)	Date of 2008-2009 Max. Reading	2008-2009 Maximum Pressure Readings (psi)	Change in Maximum Strain From Previous Year	Comments
37X-ZE-00201	856.3	2-7	09/01/09	747	07/01/08	741	6	
37X-ZE-00206	856.3	2-7	08/03/09	646	08/04/08	649	-3	
37X-ZE-00220	862.4	2-8	09/01/09	893	08/21/08	868	25	
37X-ZE-00223	862.4	2-8	08/03/09	696	08/04/08	657	39	

EMBEDMENT STRAIN GAGES

Field Tag	Level feet	Figure Number	Date of 2009-2010 Max. Reading	2009-2010 Maximum Pressure Readings (psi)	Date of 2008-2008 Max. Reading	2008-2009 Maximum Pressure Readings (psi)	Change in Maximum Strain From Previous Year	Comments
37X-ZE-00209	856.3	2-9	01/19/10	-552	02/02/09	-554	-8	
37X-ZE-00210	856.3	2-9	08/03/09	994	08/04/08	1000	-6	
37X-ZE-00211	856.3	2-9	09/01/09	333	07/01/08	328	5	
37X-ZE-00212	856.3	2-9	02/01/10	-818	02/02/09	-769	-49	
37X-ZE-00213	856.3	2-9	07/06/09	365	08/04/08	356	9	
37X-ZE-00214	856.3	2-9	02/01/10	-83	02/02/09	-87	4	
37X-ZE-00215	856.3	2-9	07/06/09	119	08/04/08	110	9	
37X-ZE-00216	856.3	2-9	06/03/10	629	08/04/08	621	8	
37X-ZE-00225	862.4	2-10	09/01/09	256	08/04/08	238	18	
37X-ZE-00235	856.3	2-11	01/19/10	-420	02/02/09	-416	-4	
37X-ZE-00236	856.3	2-11	08/03/09	107	08/04/08	114	-7	
37X-ZE-00237	856.3	2-11	06/03/10	115	08/04/08	102	13	
37X-ZE-00238	856.3	2-11	06/03/10	525	08/04/08	513	12	
37X-ZE-00239	862.4	2-12	09/01/09	383	08/04/08	371	12	

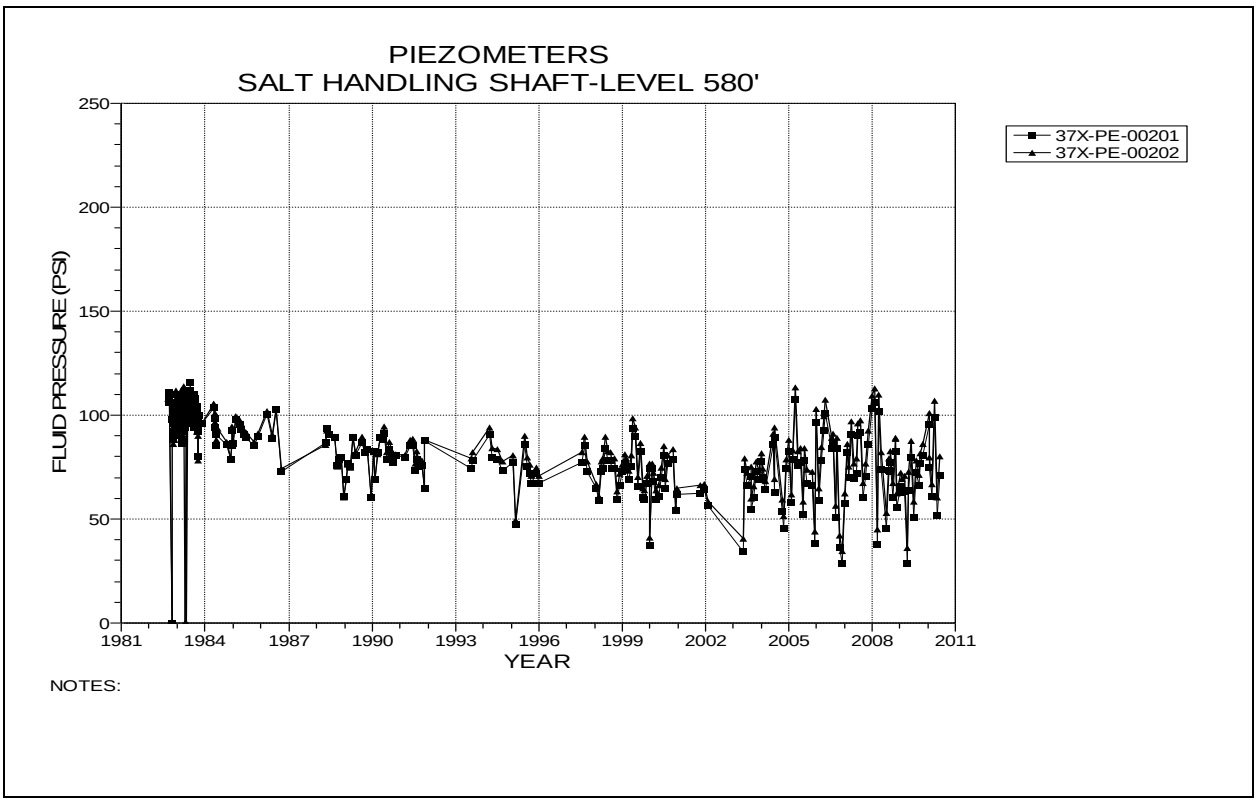


Figure 2-1 Piezometers 37X-PE-00201 and 37X-PE-00202
Salt Handling Shaft – Level 580 at the Forty-niner Member

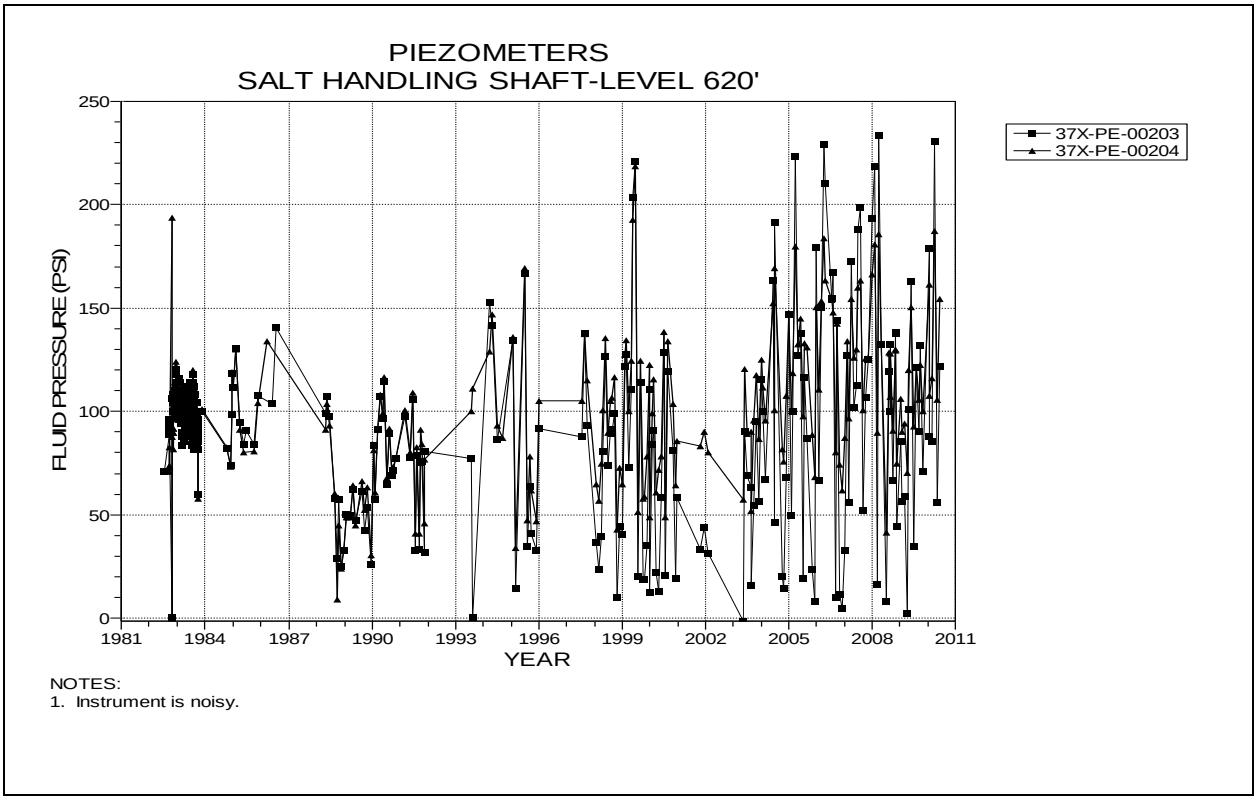


Figure 2-2 Piezometers 37X-PE-00203 and 37X-PE-00204
Salt Handling Shaft – Level 620 at the Magenta Dolomite Member

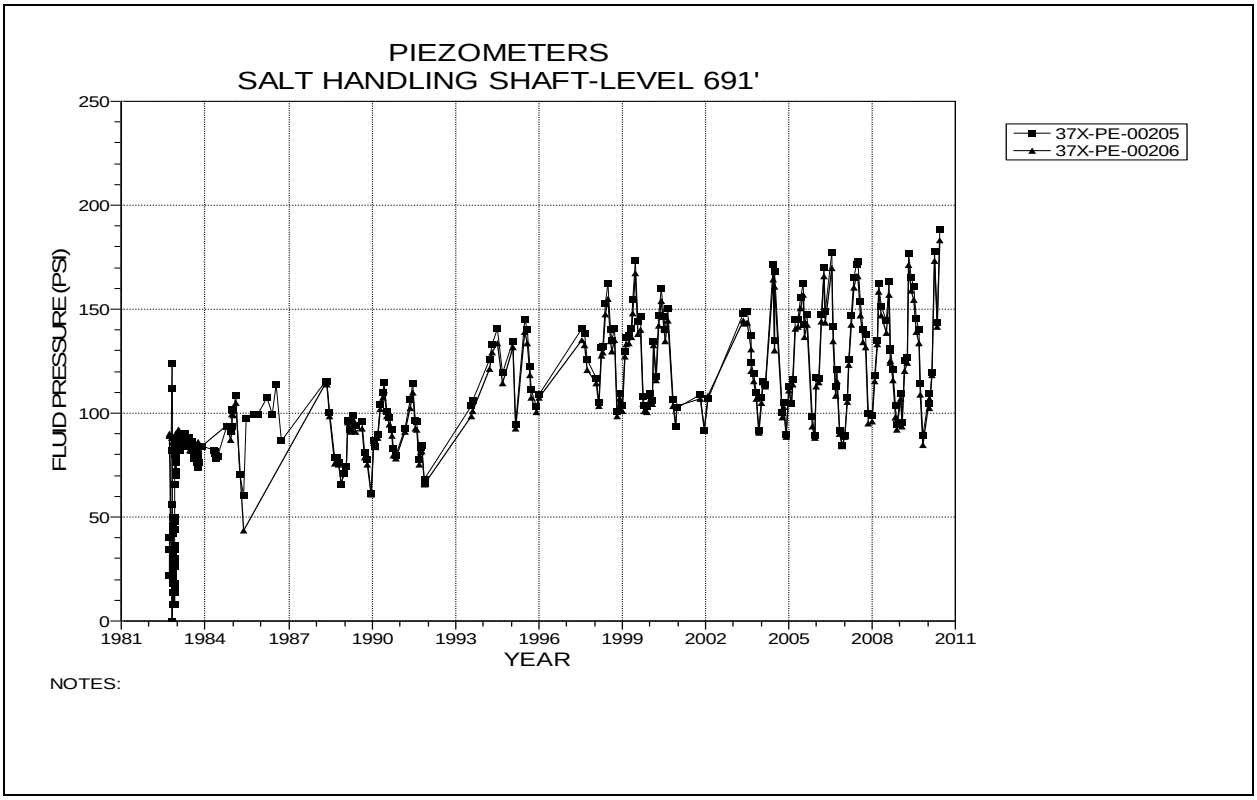


Figure 2-3 Piezometers 37X-PE-00205 and 37X-PE-00206
Salt Handling Shaft – Level 691 at the Tamarisk Member

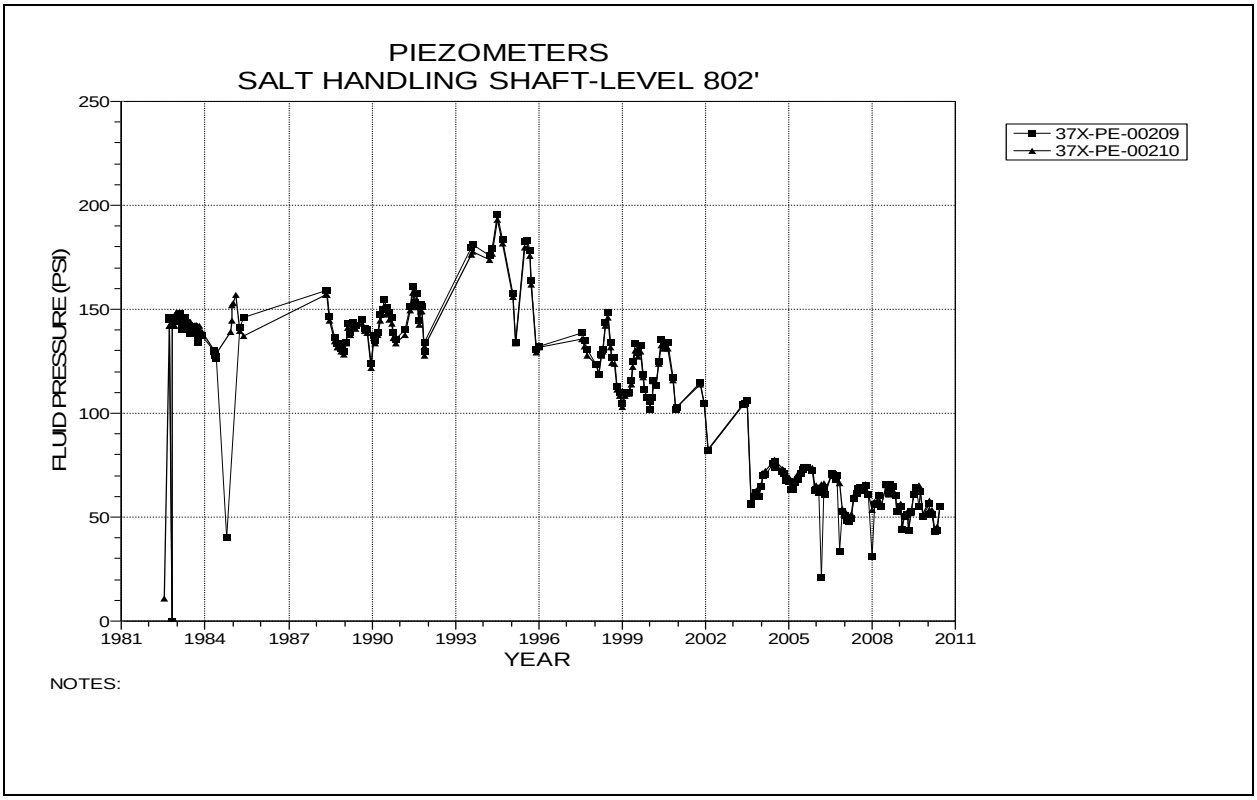


Figure 2-4 Piezometers 37X-PE-00209 and 37X-PE-00210
Salt Handling Shaft – Level 802 at the Los Medaños Member

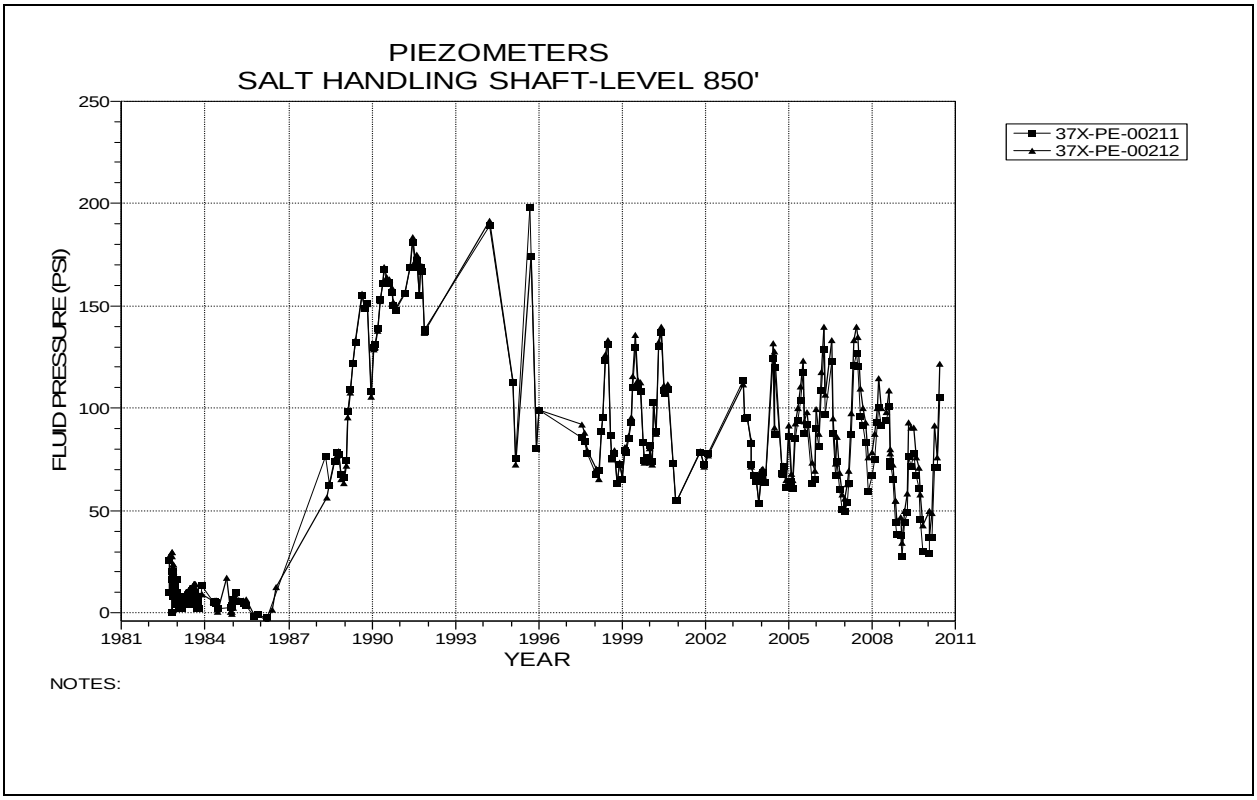


Figure 2-5 Piezometers 37X-PE-00211 and 37X-PE-00212
Salt Handling Shaft – Level 850 at the Rustler-Salado Contact

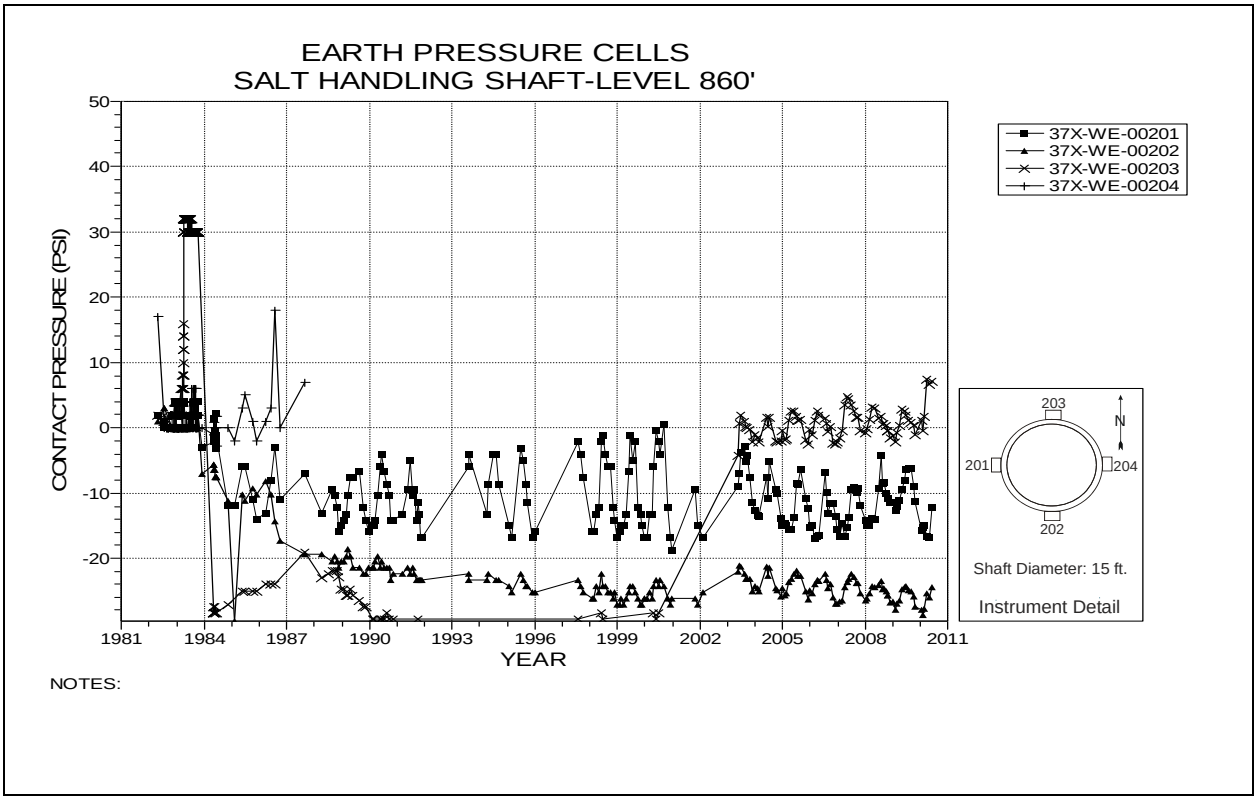


Figure 2-6 Earth Pressure Cells Behind Shaft Key
Salt Handling Shaft Key – Level 860

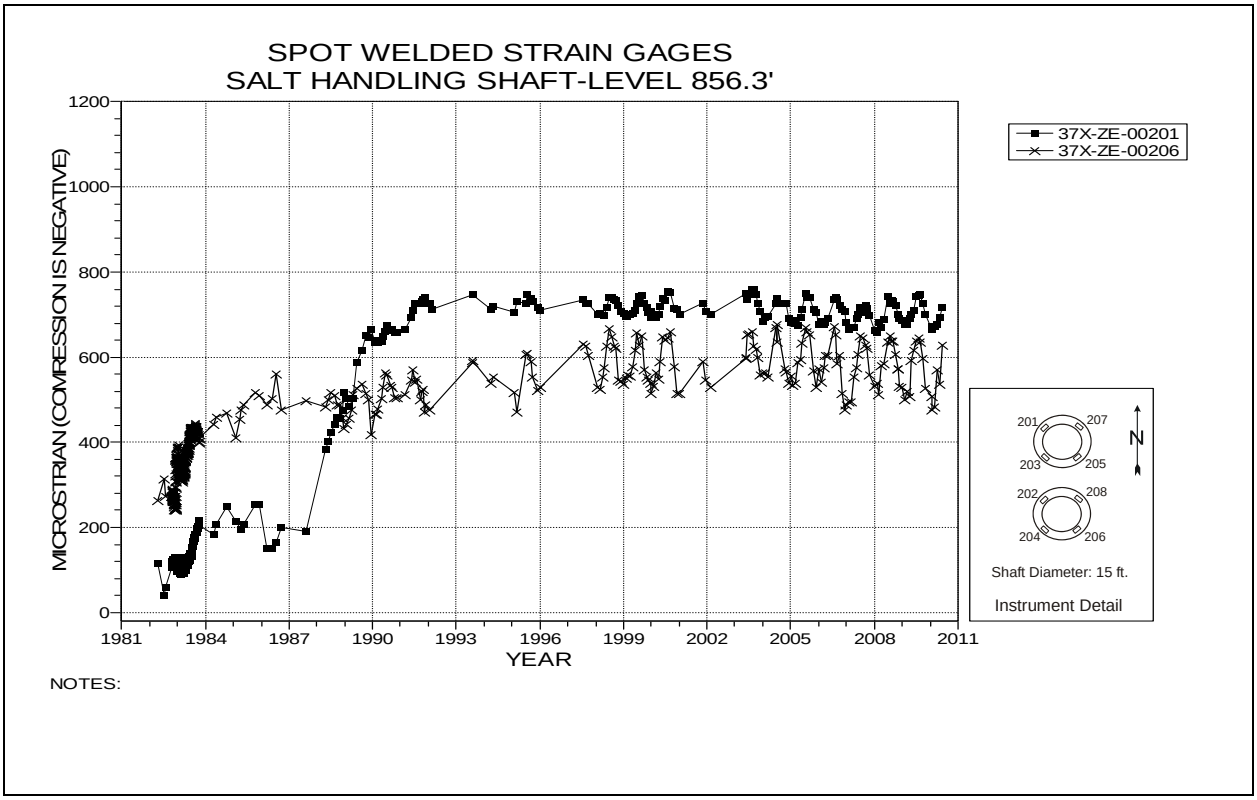


Figure 2-7 Spot-Welded Strain Gages
Salt Handling Shaft Key – Level 856.3

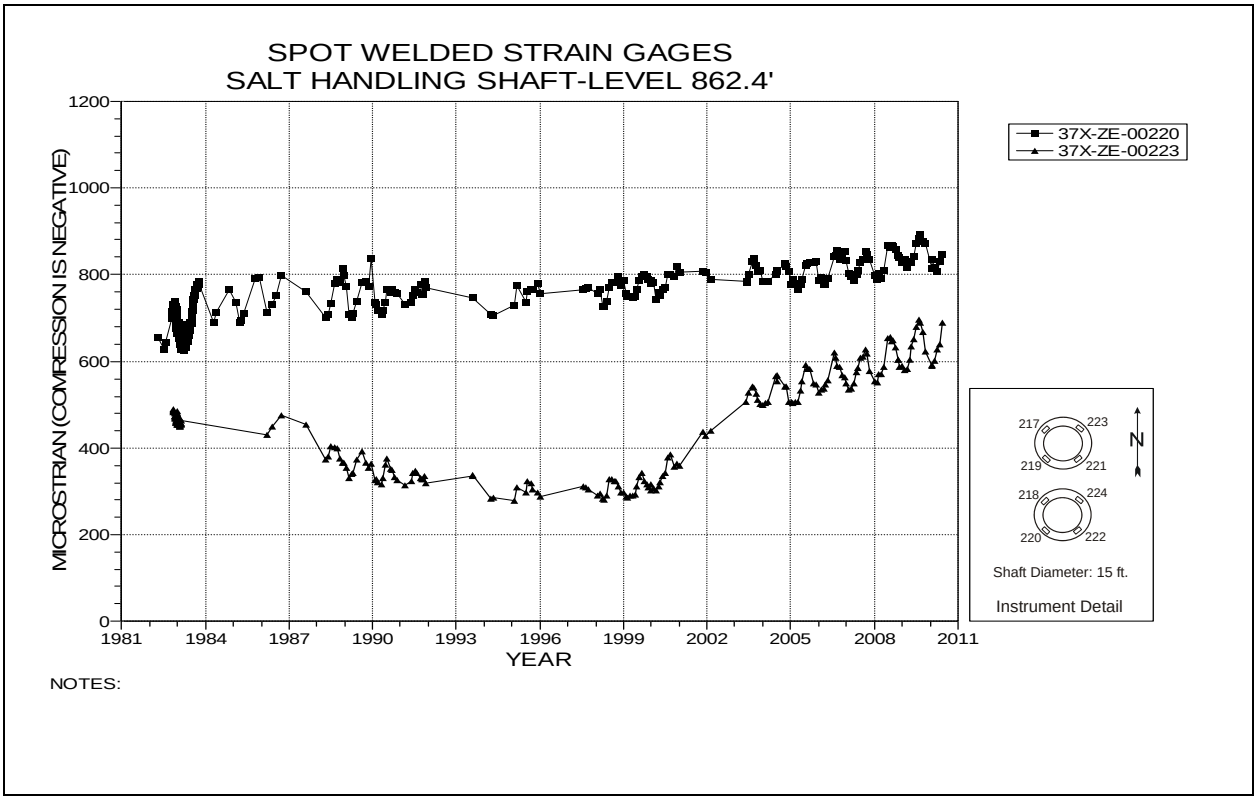


Figure 2-8 Spot-Welded Strain Gages
Salt Handling Shaft Key – Level 862.4

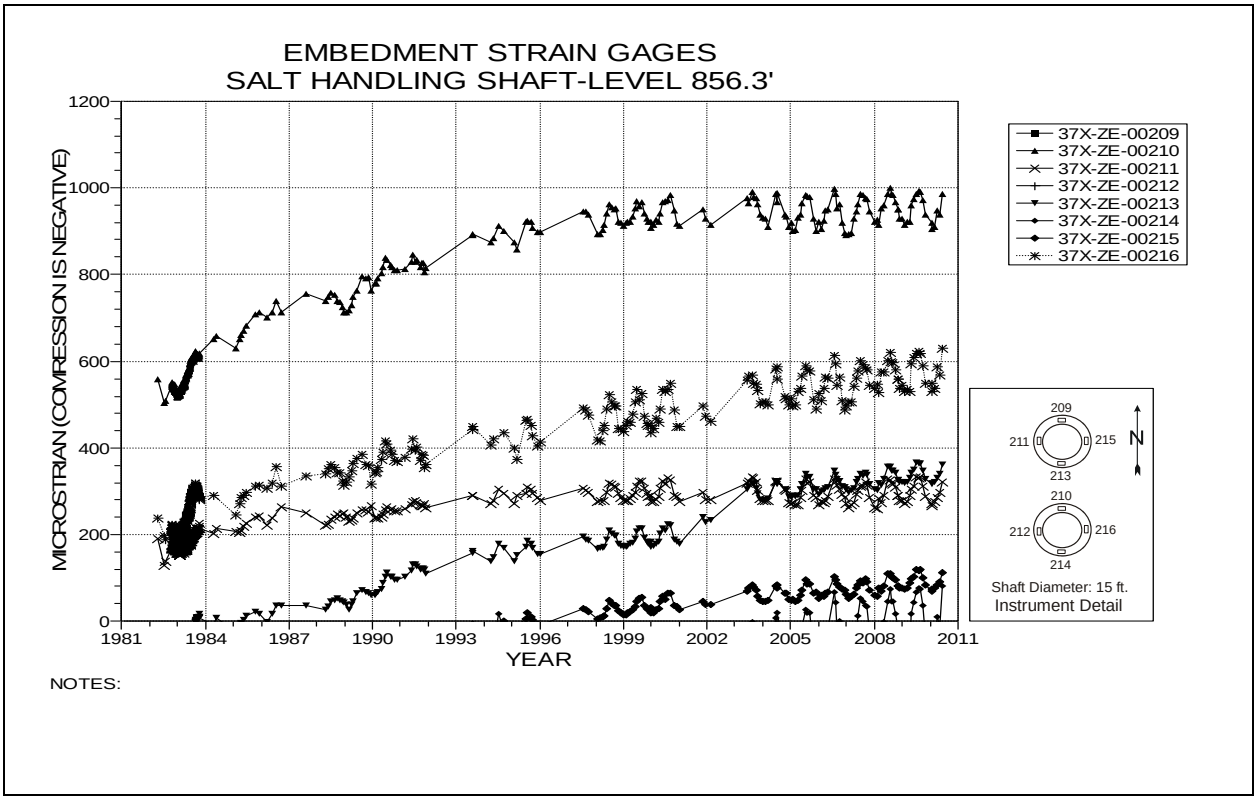


Figure 2-9 Embedment Strain Gages
Salt Handling Shaft Key – Level 856.3

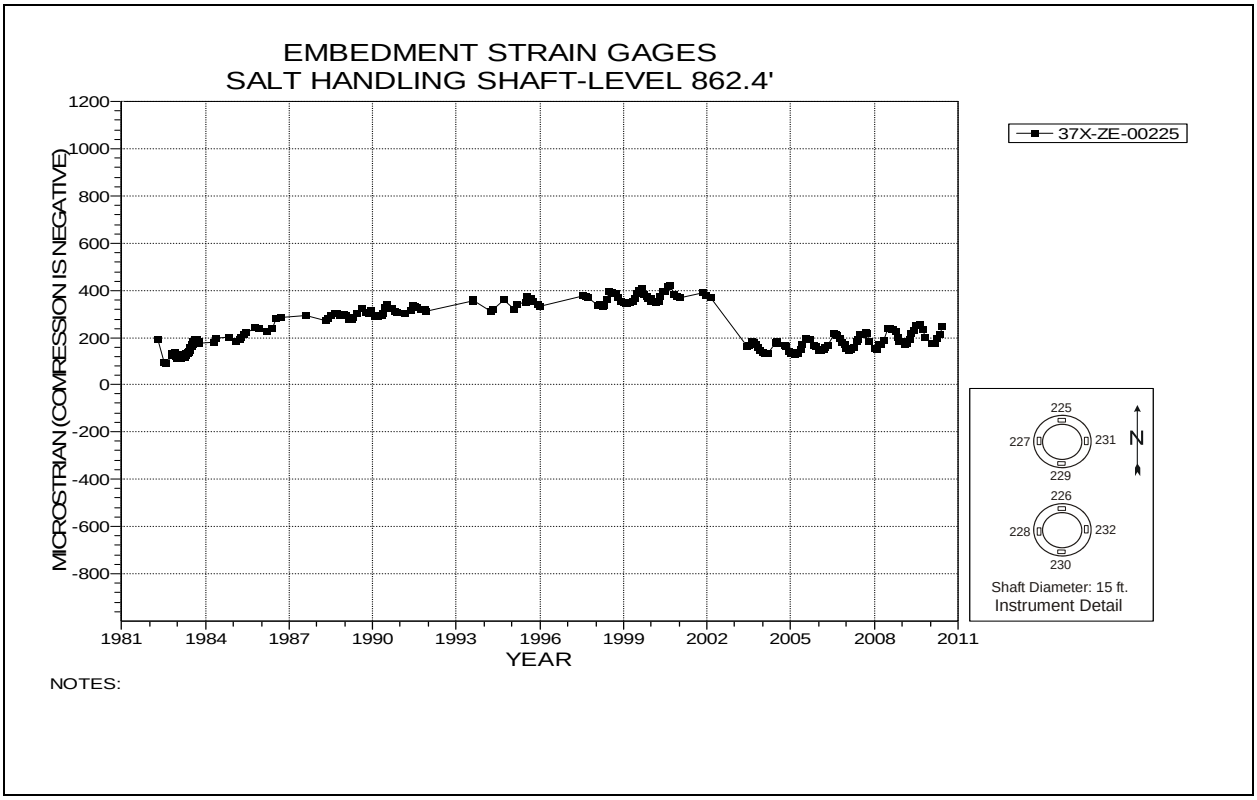


Figure 2-10 Embedment Strain Gage
Salt Handling Shaft Key Level 862.4

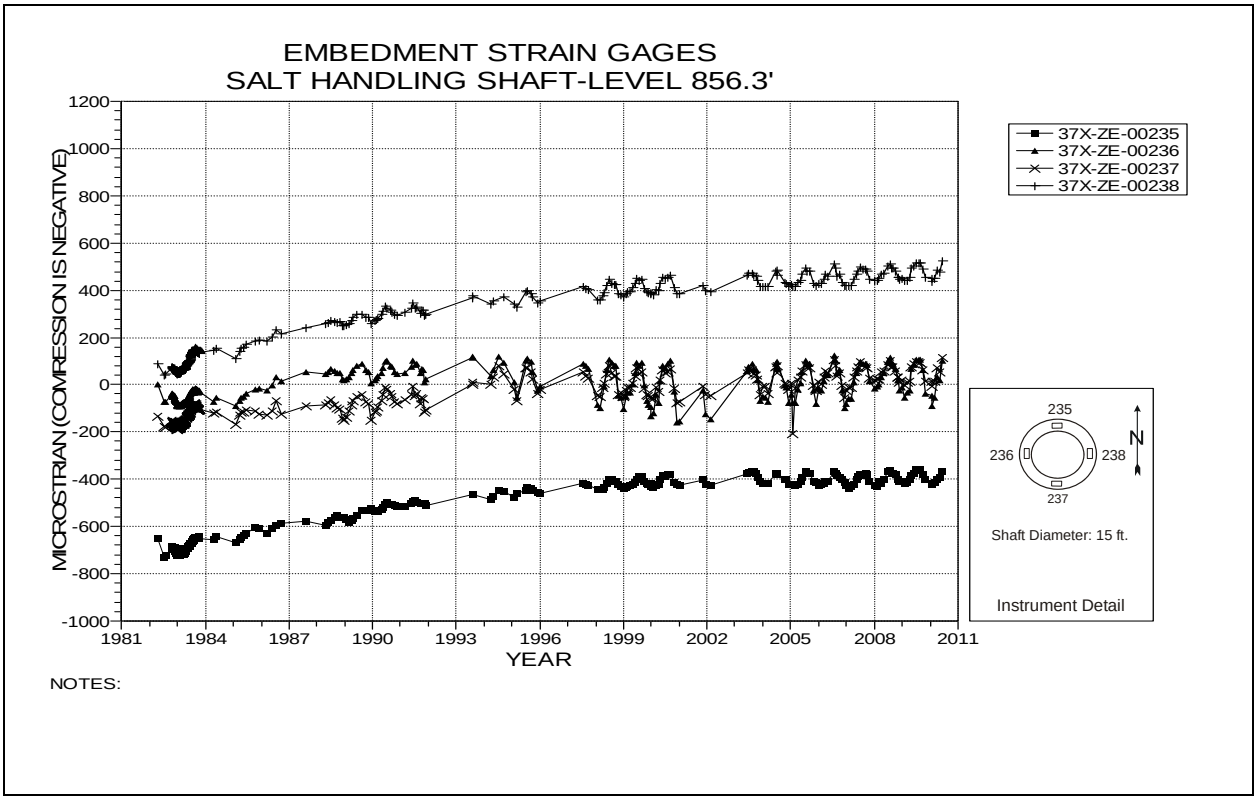


Figure 2-11 Embedment Strain Gages
Salt Handling Shaft Key Level 856.3

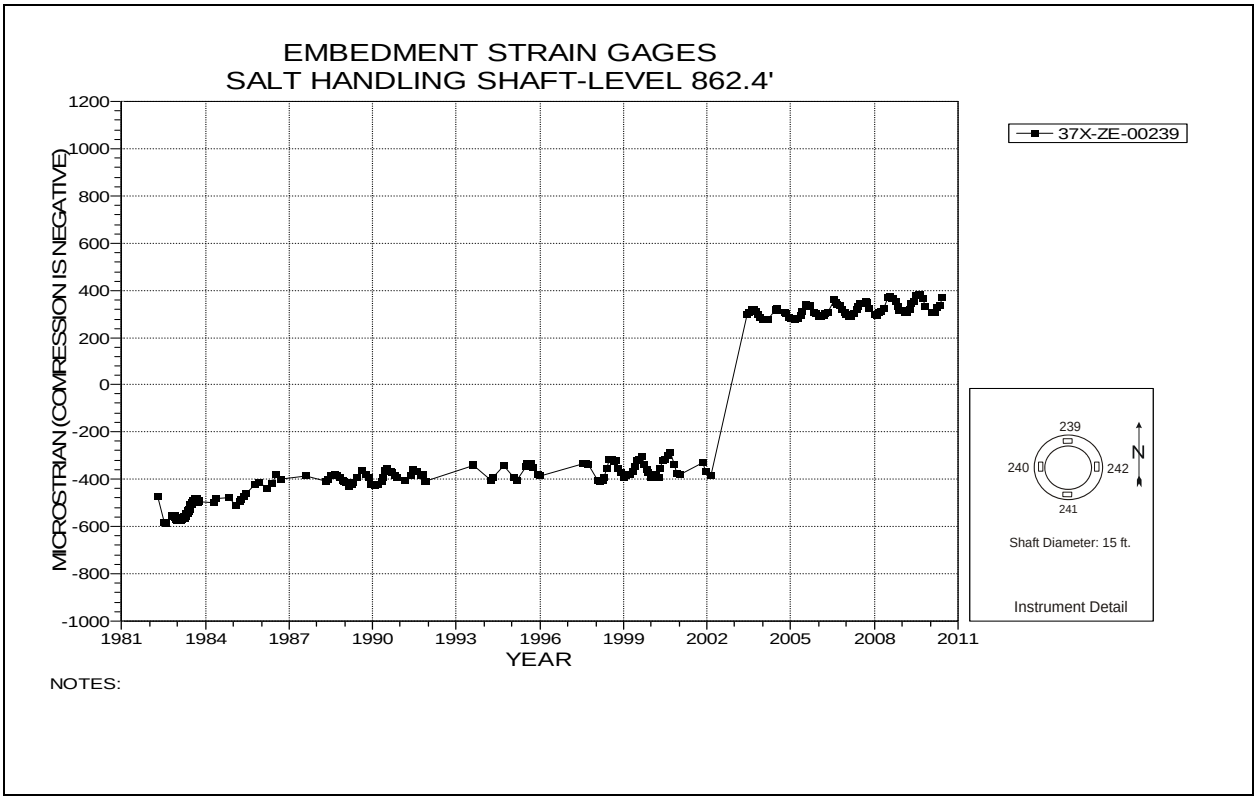


Figure 2-12 Embedment Strain Gages
Salt Handling Shaft Key – Level 862.

Table 2-2
Waste Shaft Data Analysis

PIEZOMETERS

Field Tag	Level feet	Number	Date of Figure Max. Reading	2009-2010 Maximum Pressure Readings (psi)	Date of 2008-2009 Max. Reading	2009-2010 Maximum Pressure Reading (psi)	Change in Maximum Pressure From Previous Year (psi)	Comments
31X-PE-00202	532	2-13	09/25/09	-3.6	08/27/08	-3.6	0	
31X-PE-00205	669	2-14	06/30/09	-1.0	03/11/09	-0.5	-0.5	
31X-PE-00206	669	2-14	02/12/10	-0.7	06/30/09	-0.7	0	
31X-PE-00208	717	2-15	06/16/10	144.8	06/30/09	143.7	1.1	
31X-PE-00209	758	2-16	06/16/10	51.4	06/30/09	50.7	0.7	
31X-PE-00211	845	2-17	09/25/09	67.2	08/27/08	72	-4.8	
31X-PE-00212	845	2-17	07/29/09	72.4	07/22/08	74.2	-1.8	

EARTH PRESSURE CELLS

Field Tag	Level feet	Number	Date of Figure Max. Reading	2009-2010 Maximum Pressure Readings (psi)	Date of 2008-2009 Max. Reading	2009-2010 Maximum Pressure Reading (psi)	Change in Maximum Pressure From Previous Year (psi)	Comments
31X- WE-00203	866	2-18	08/27/09	124.7	08/27/08	119.3	5.4	
31X- WE-00204	866	2-18	11/20/09	71.5	07/22/08	93.4	-21.9	

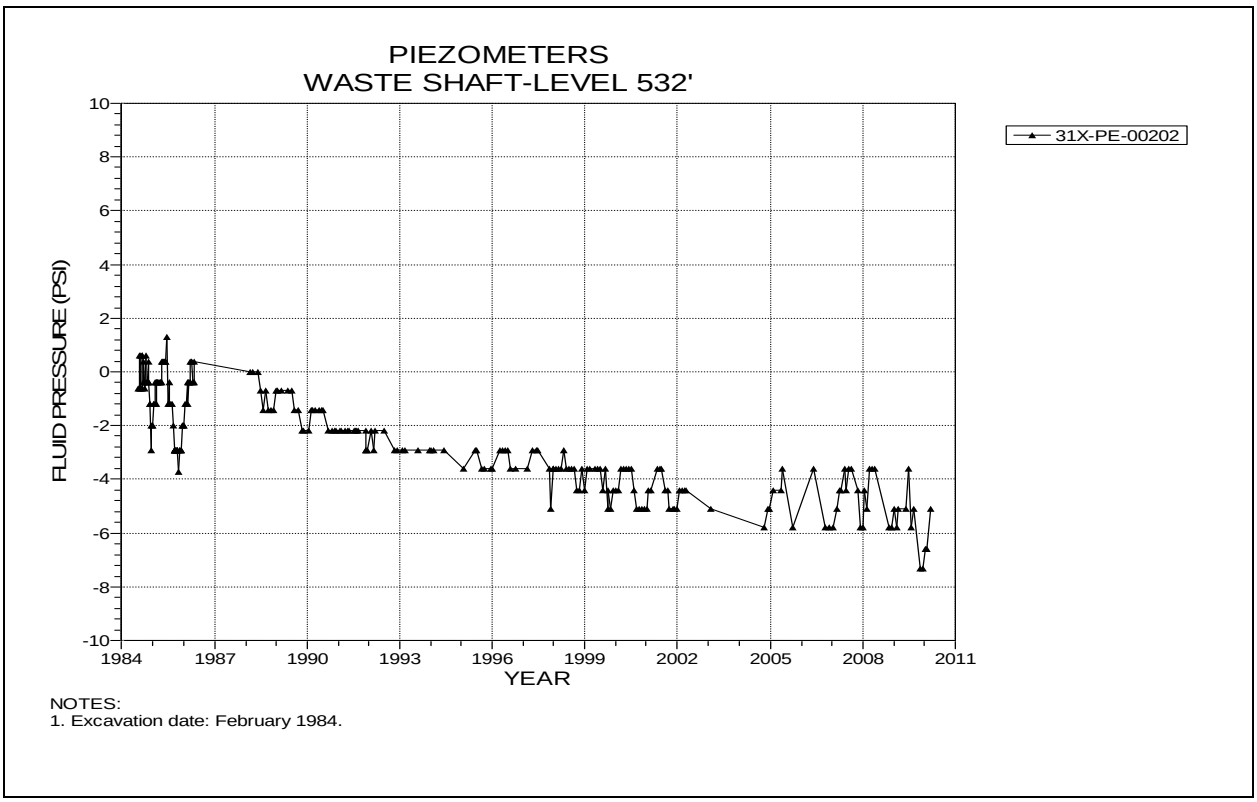


Figure 2-13 Piezometer 31X-PE-00202
Waste Shaft – Level 532 at the Base of Dewey Lake Redbeds

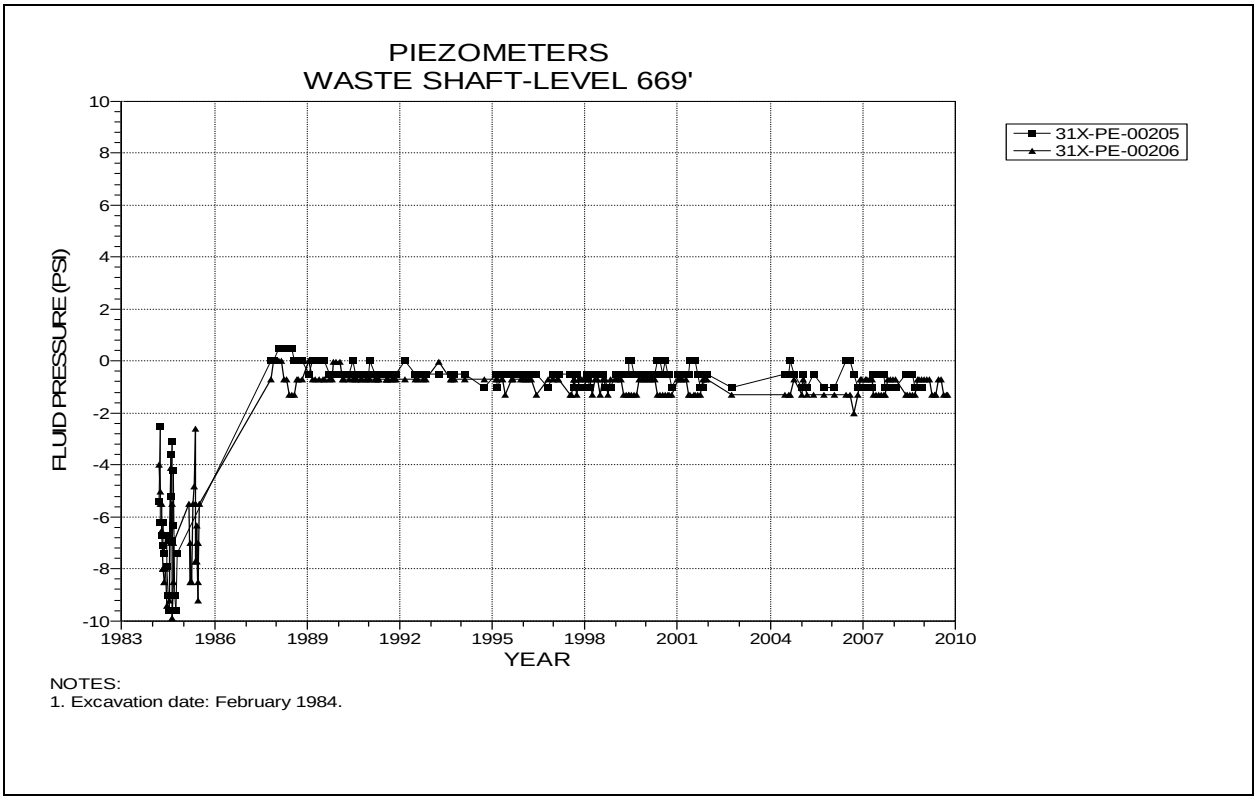


Figure 2-14 Piezometers 31X-PE-00205 and 31X-PE-00206
Waste Shaft – Level 669 at the Tamarisk Member

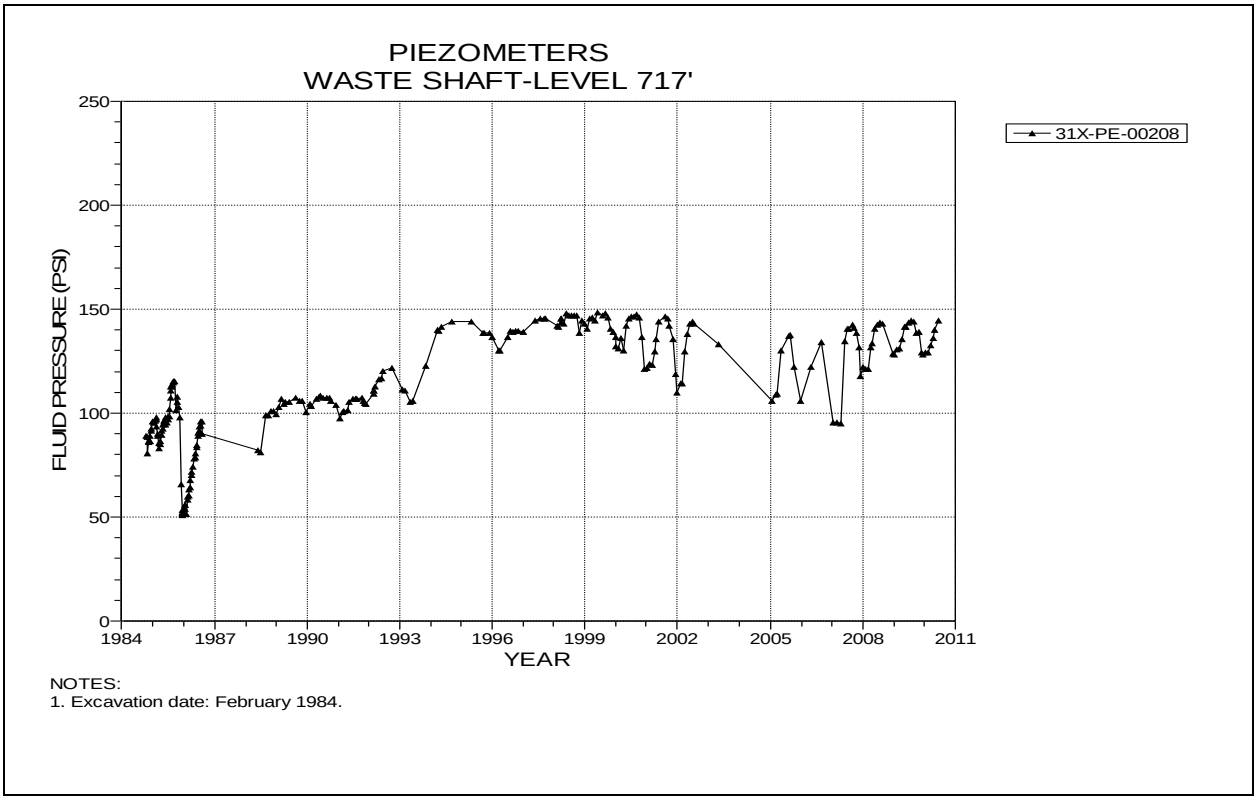


Figure 2-15 Piezometer 31X-PE-00208
Waste Shaft – Level 717 at the Culebra Dolomite Member

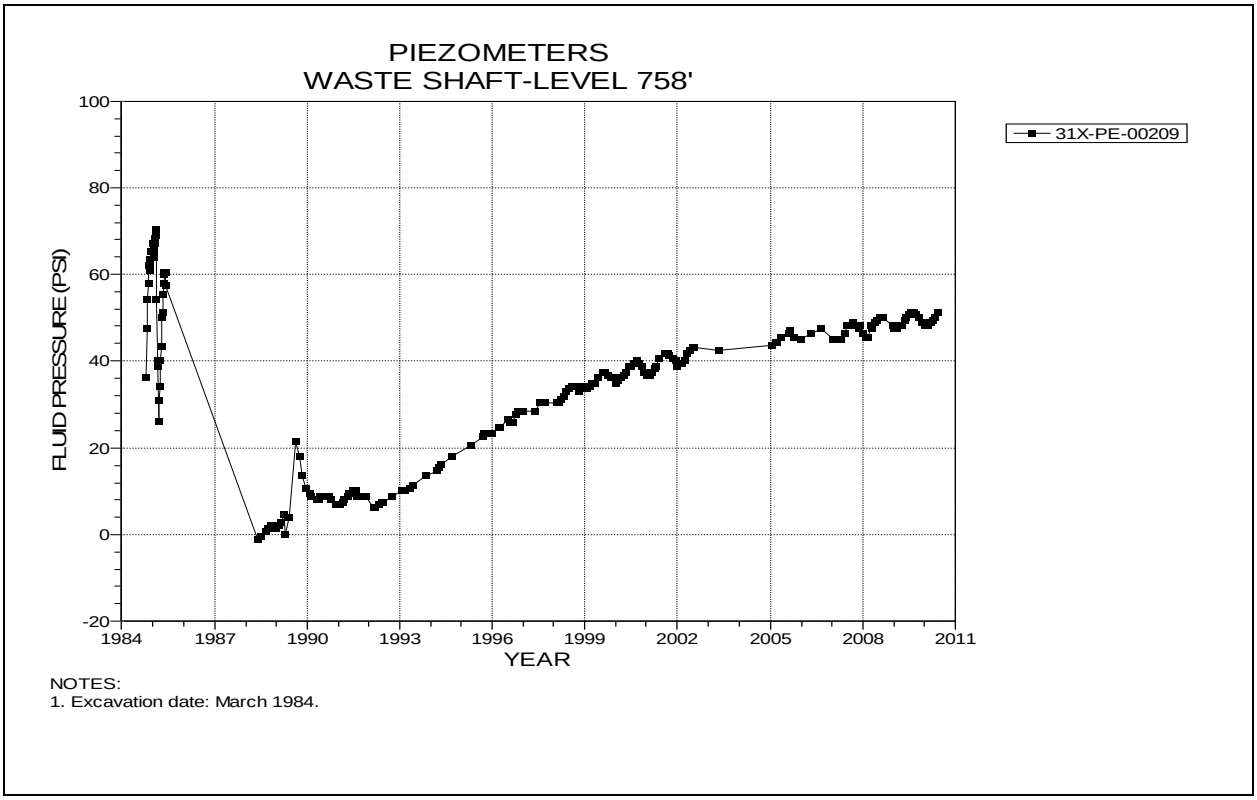


Figure 2-16 Piezometers 31X-PE-00209
Waste Shaft – Level 758 at the Los Medaños Member

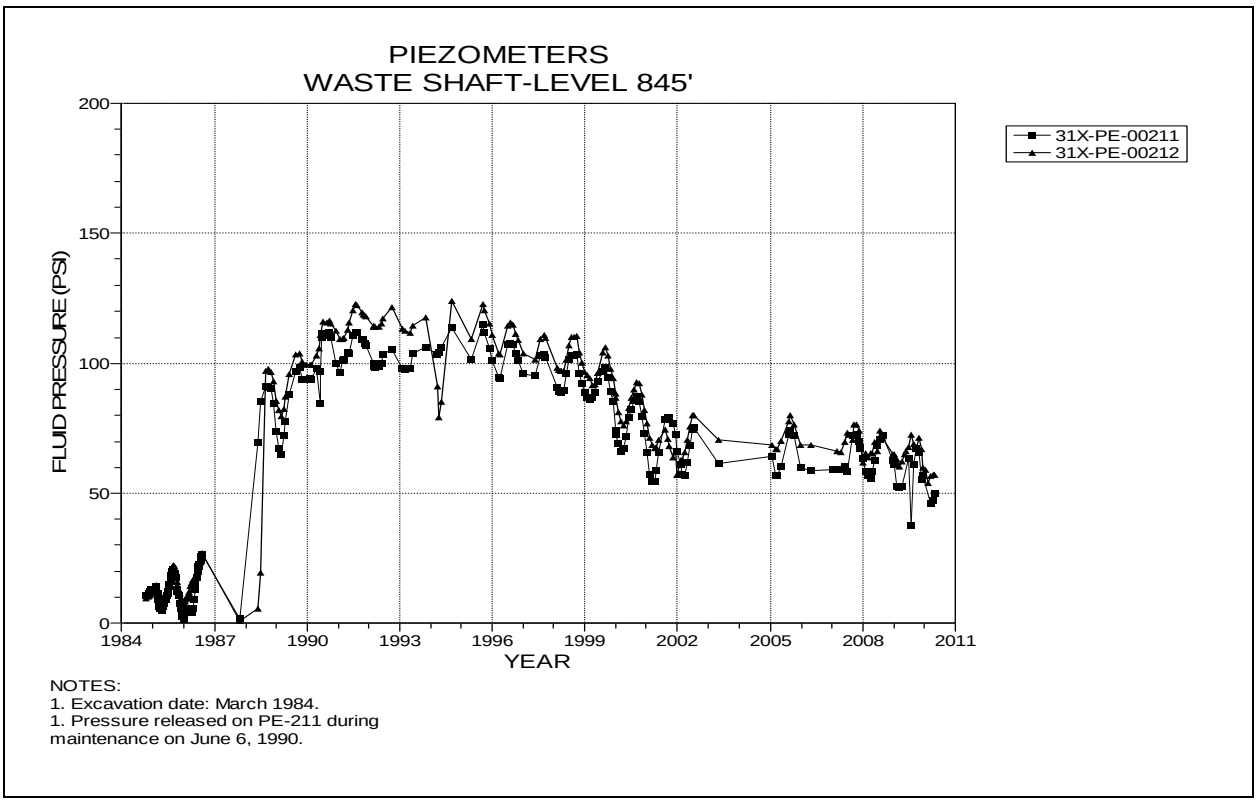


Figure 2-17 Piezometers 31X-PE-00211 and 31X-PE-00212
Waste Shaft – Level 845 at the Rustler-Salado Contact

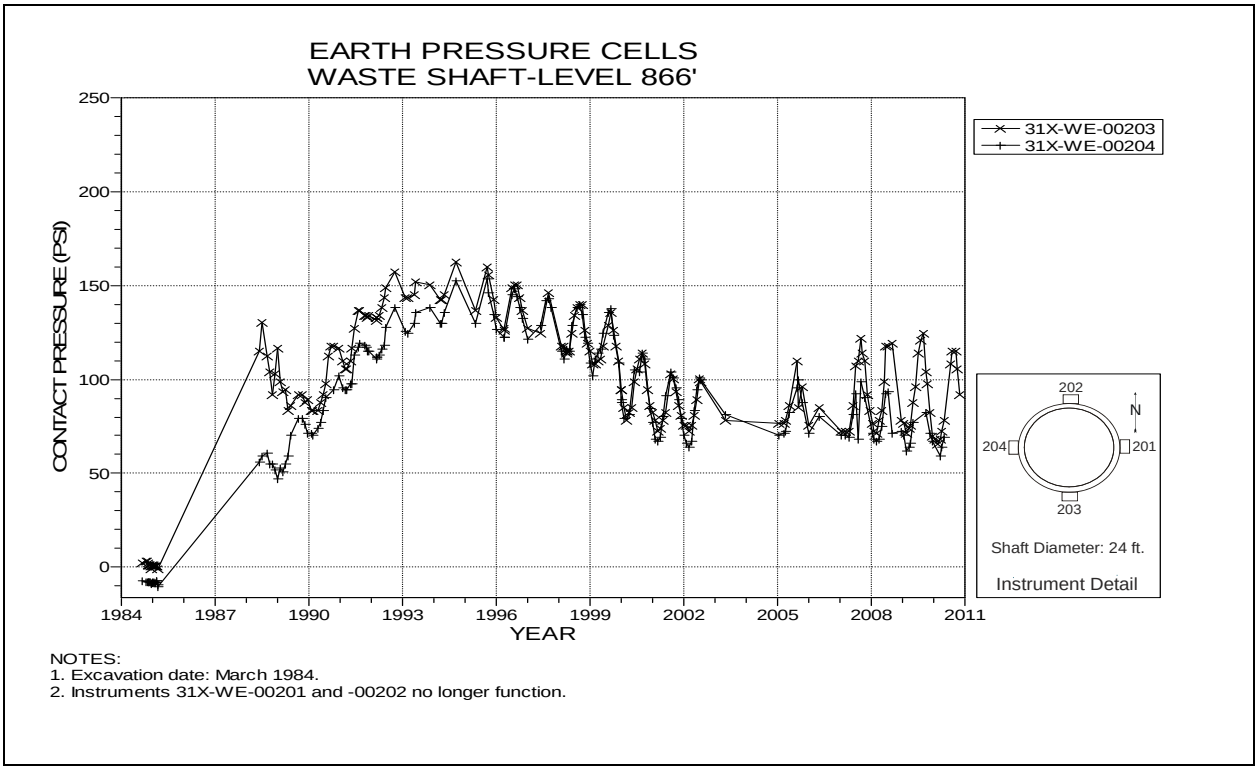


Figure 2-18 Earth Pressure Cells
Waste Shaft Key – Level 866

Table 2-3
Exhaust Shaft Data Analysis

PIEZOMETERS

Field Tag	Level feet	Figure Number	Date of 2009-2010 Max. Reading	2009-2010 Maximum Pressure Readings (psi)	Date of 2008-2009 Max. Reading	2008-2009 Maximum Pressure Readings (psi)	Change in Maximum Pressure From Previous Year (psi)	Comments
35X-PE-00202	544	2-19	06/03/10	-2.6	09/02/08	-2.7	0.1	
35X-PE-00204	615	2-20	10/05/09	125.9	11/03/08	125.8	0.1	
35X-PE-00208	673	2-21	09/01/09	6	11/03/08	5.6	0.4	
35X-PE-00210	721	2-22	09/01/09	141.2	10/06/08	141.6	-0.4	
35X-PE-00213	768	2-23	09/01/09	9.1	09/02/08	8.1	1	
35X-PE-00214	768	2-23	08/03/09	6.7	09/02/08	6.1	0.6	
35X-PE-00216	850	2-24	09/01/09	80.5	10/06/08	89.5	-9	
35X-PE-00218	850	2-24	01/04/10	27.2	11/03/08	44.3	-17.1	
35X-PE-00219	887	2-25	10/05/09	26.7	10/06/08	26.8	-0.1	

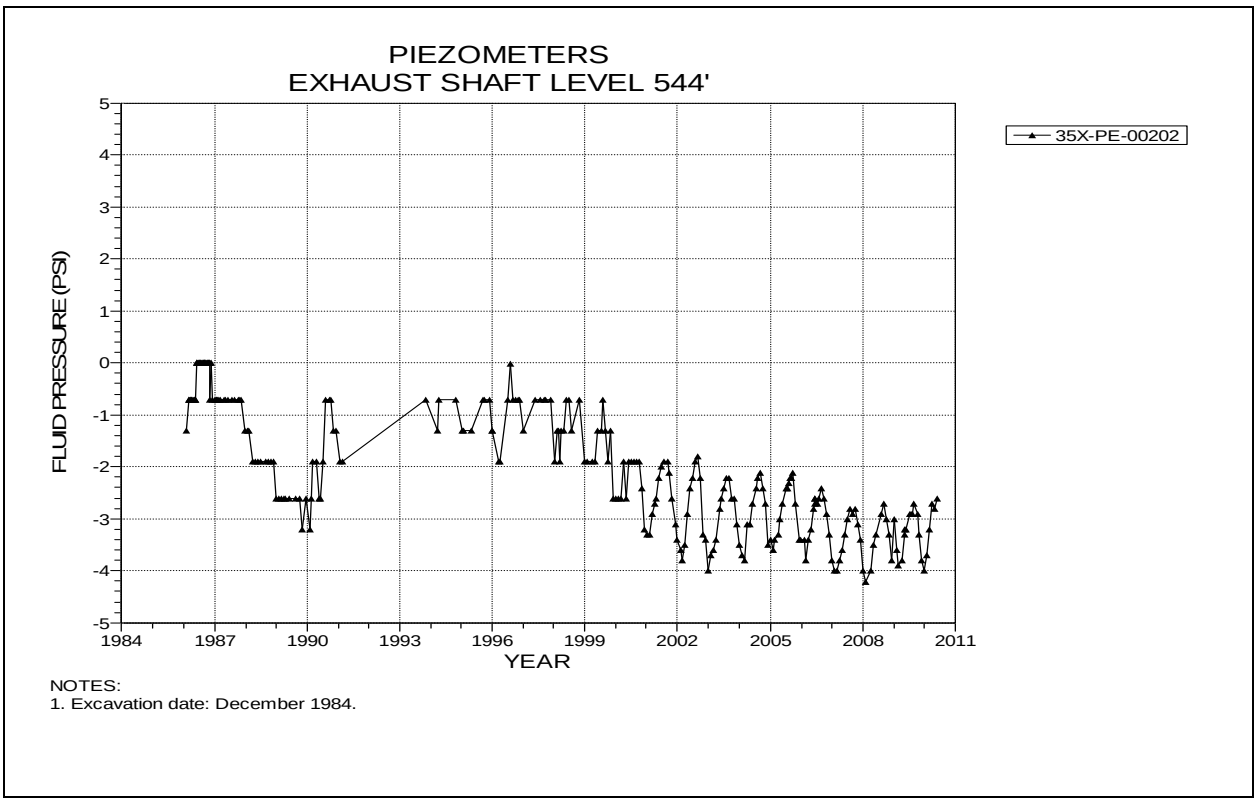


Figure 2-19 Piezometer 35X-PE-00202
Exhaust Shaft – Level 544 at the Base of Dewey Lake Redbeds

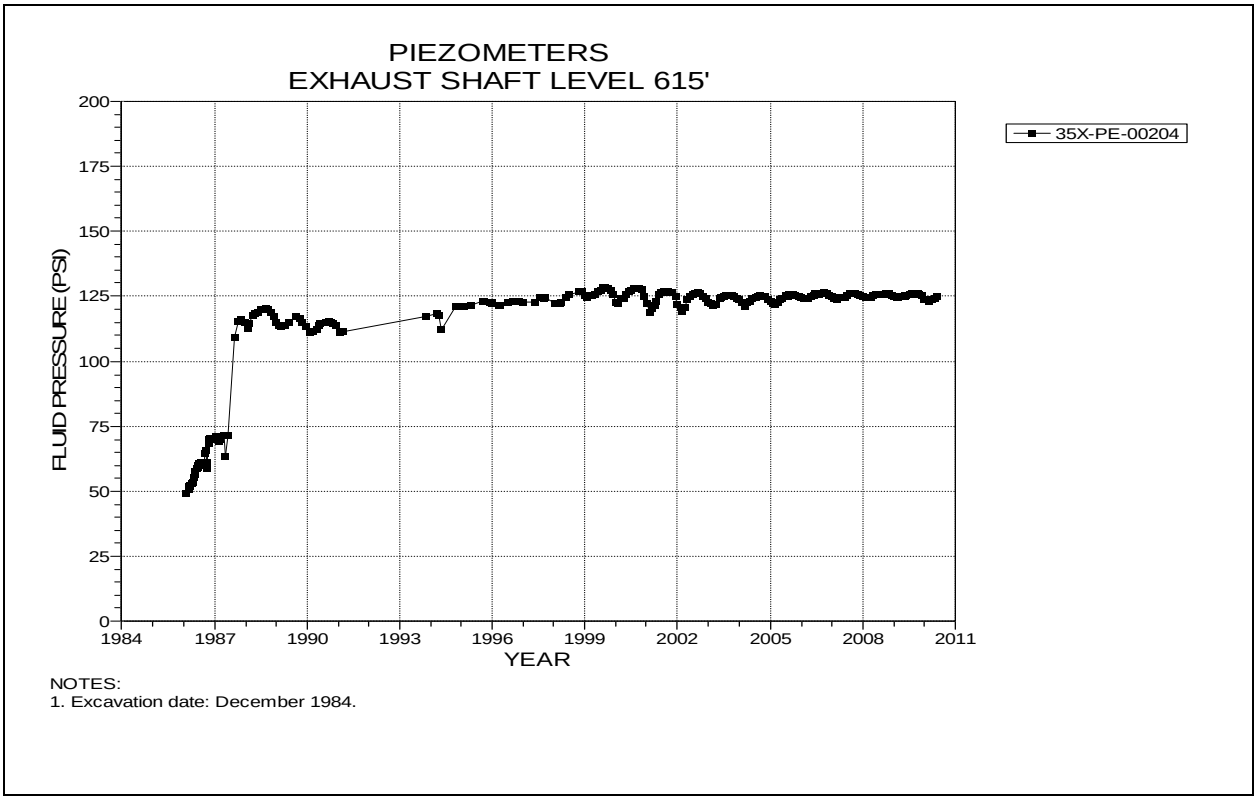


Figure 2-20 Piezometer 35X-PE-00204
Exhaust Shaft – Level 615 at the Magenta Dolomite Member

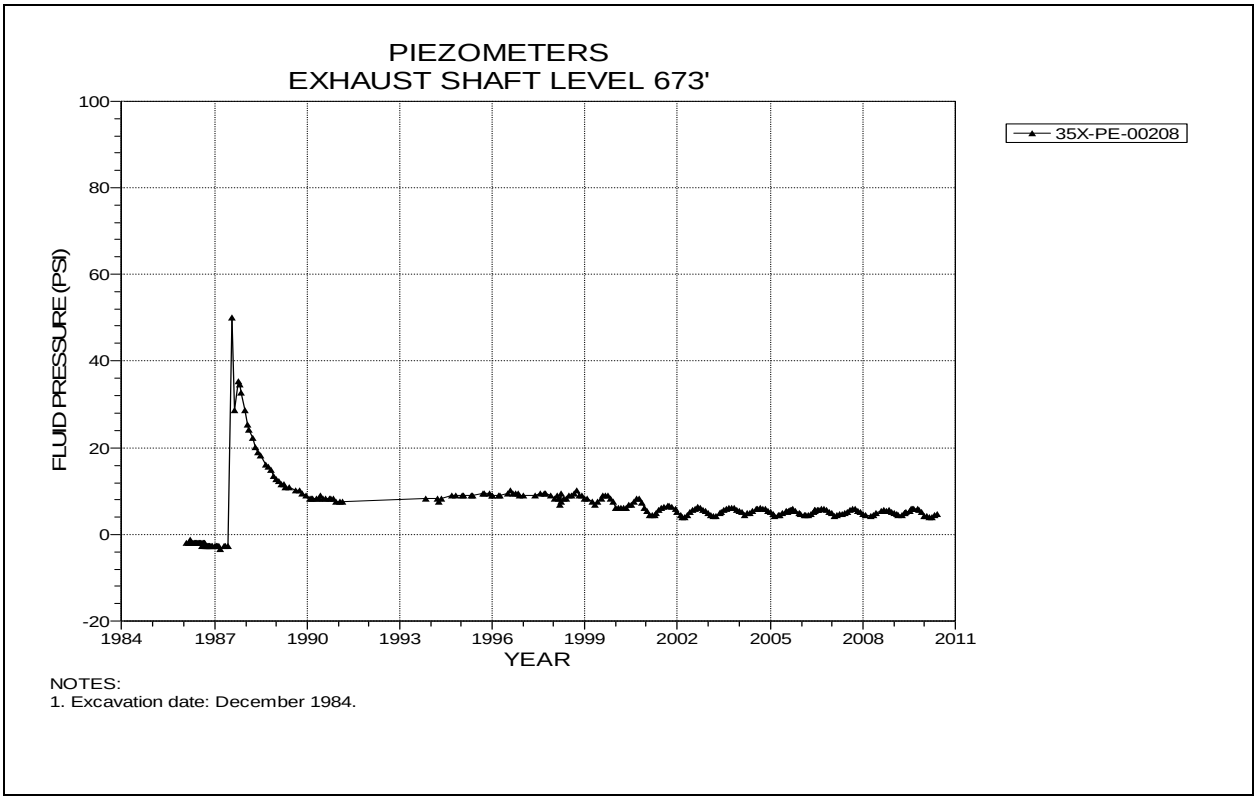


Figure 2-21 Piezometer 35X-PE-00208
Exhaust Shaft – Level 673 at the Tamarisk Member

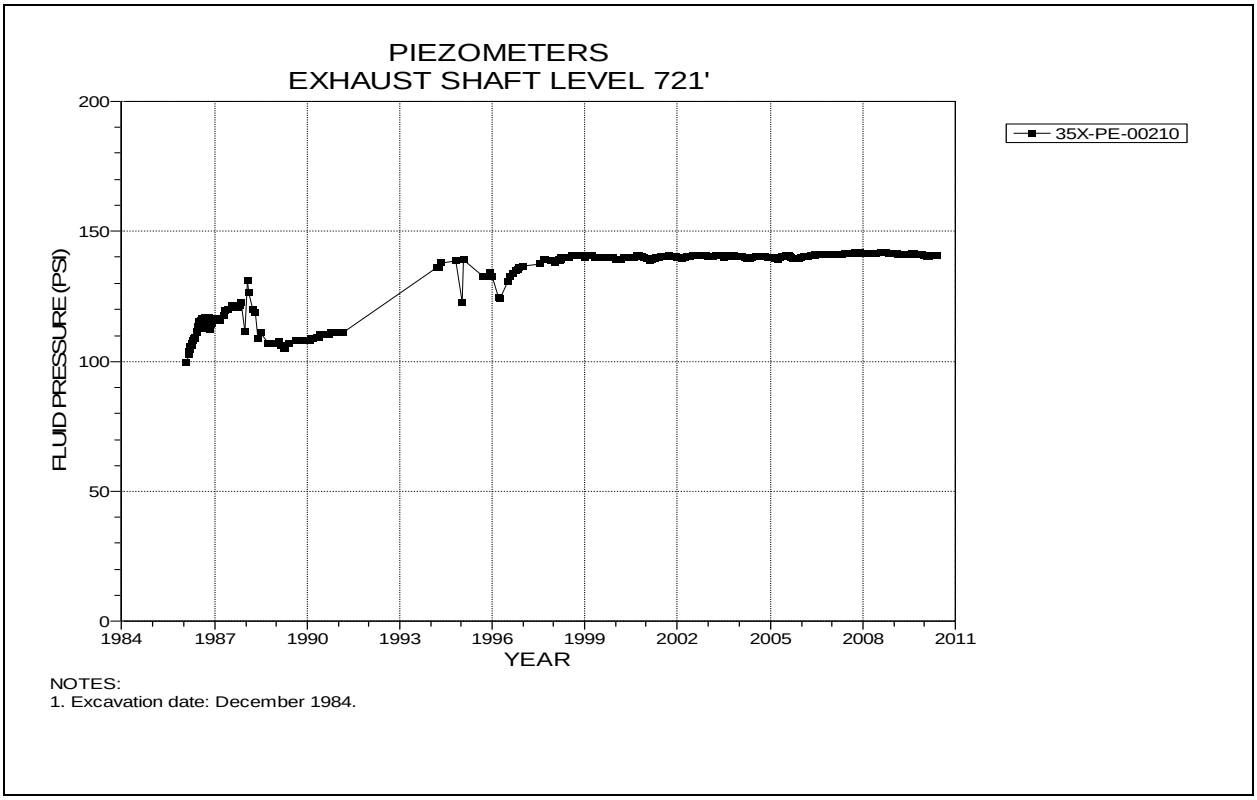


Figure 2-22 Piezometer 35X-PE-00210
Exhaust Shaft – Level 721 at the Culebra Dolomite Member

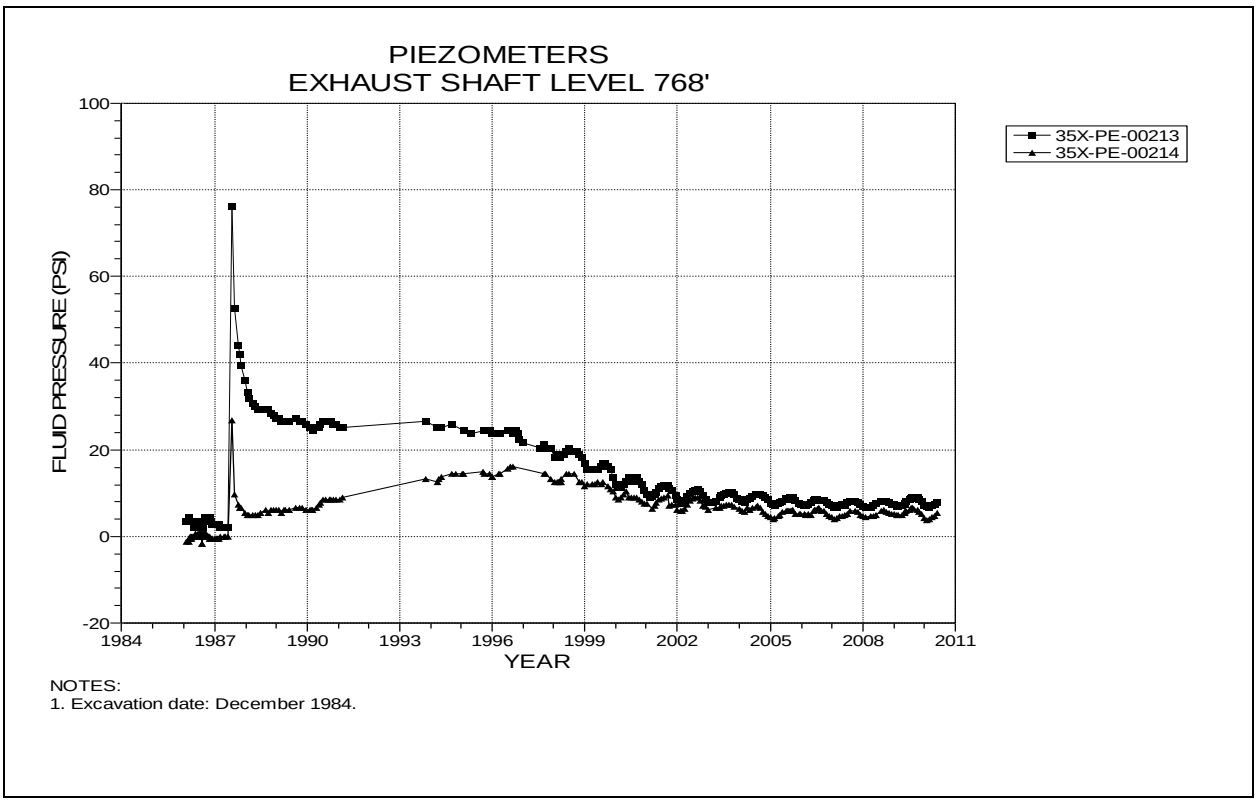


Figure 2-23 Piezometers 35X-PE-00213 and 35X-PE-00214
Exhaust Shaft – Level 768 at the Los Medaños Member

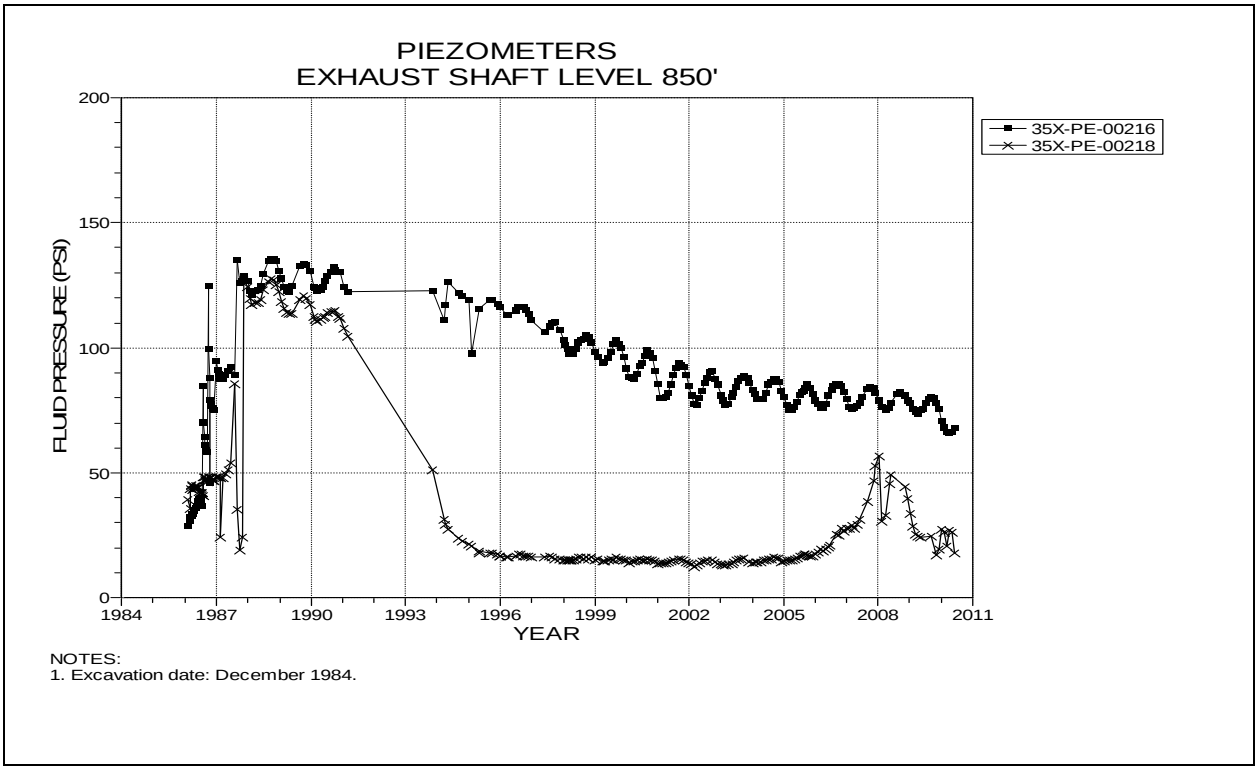


Figure 2-24 Piezometers 35X-PE-00216 and 35X-PE-00218
Exhaust Shaft – Level 850 at the Rustler-Salado Contact

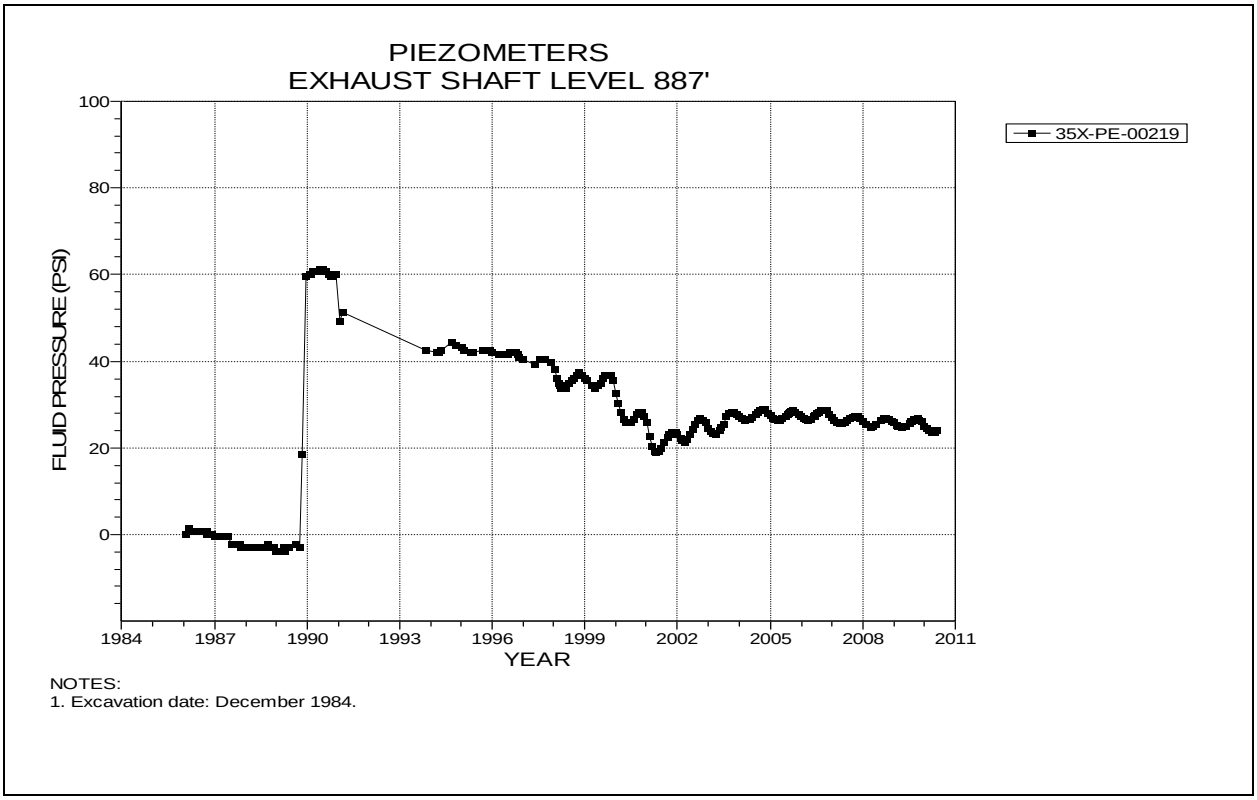


Figure 2-25 Piezometer 35X-PE-00219
Exhaust Shaft – Level 887 below the Lower Chemical Seal

3.0 Instrumentation Summary for Shaft Stations

Instrumentation data analysis for the Salt Handling Shaft Station, Waste Shaft Station, and the area around the Air Intake Shaft follow. Table 3-1 presents data analyses for each of the Salt Handling Shaft Station instruments. Figures 3-1 through 3-3 present plots of the instrumentation data for the Salt Handling Shaft Station. Table 3-2 presents data and analysis for the Waste Shaft Station. Plots from the instrumentation in the Waste Shaft Station are presented as Figures 3-4 through 3-7. Table 3-3 and Figures 3-8 through 3-13 present the data from rock bolt load cells and borehole extensometers located in the immediate area around the Air Intake Shaft.

Table 3-1
Salt Handling Shaft Station Data Analysis

CONVERGENCE POINTS

Field Tag	Location	Figure Number	Last Reading 2009-2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
E0-S18-6 A-E	E0 Drift-S18	3-1	05/18/10	18.266	35.783	1.37	1.54	-11%	
E0-S18-4 B-D	E0 Drift-S18	3-1	05/18/10	19.966	36.984	1.52	1.79	-15%	
E0-S18-4 H-F	E0 Drift-S18	3-1	05/18/10	12.4	23.216	0.92	1.04	-12%	
E0-S30-5 A-C	E0 Drift-S30	3-2	05/18/10	18.958	50.527	1.40	1.58	-11%	
E0-S65-3 A-C	E0 Drift-S65	3-3	05/18/10	13.805	44.119	1.11	1.14	-3%	

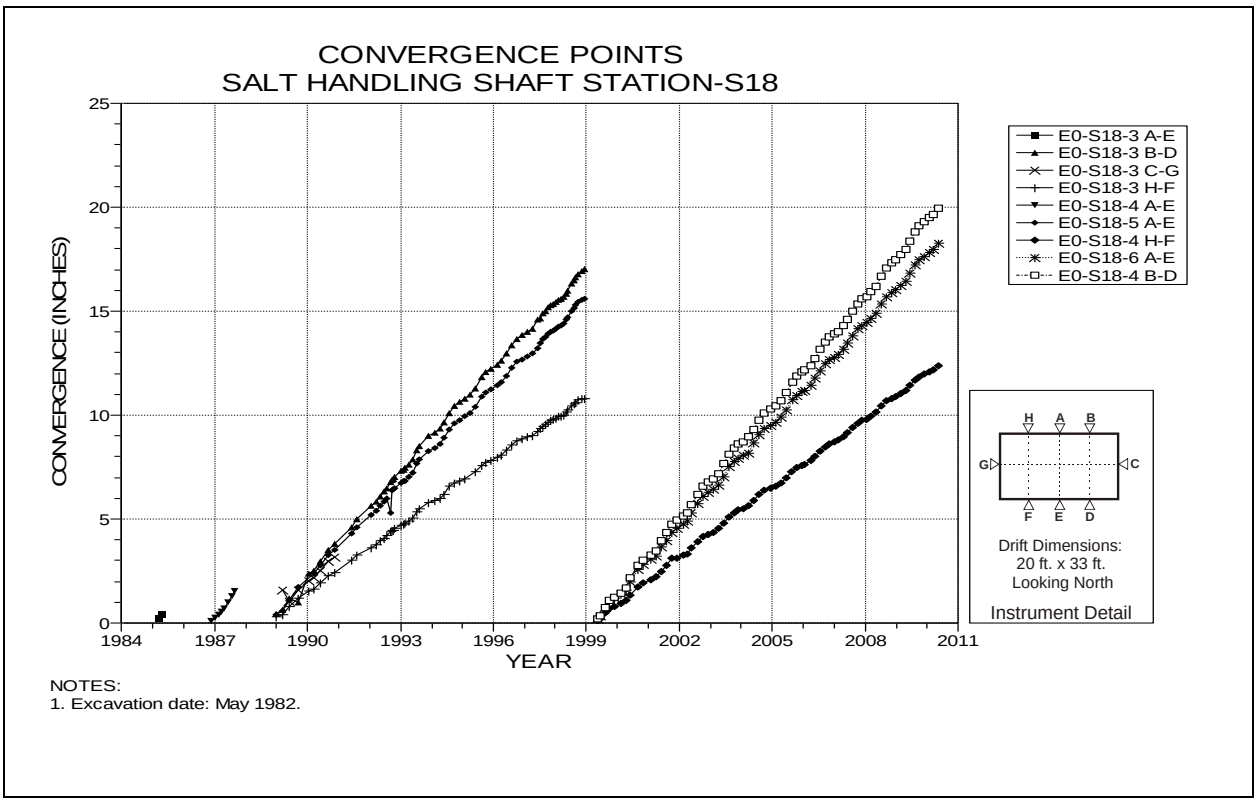


Figure 3-1 Convergence Point Array
Salt Handling Shaft Station at South 18 – All Chords

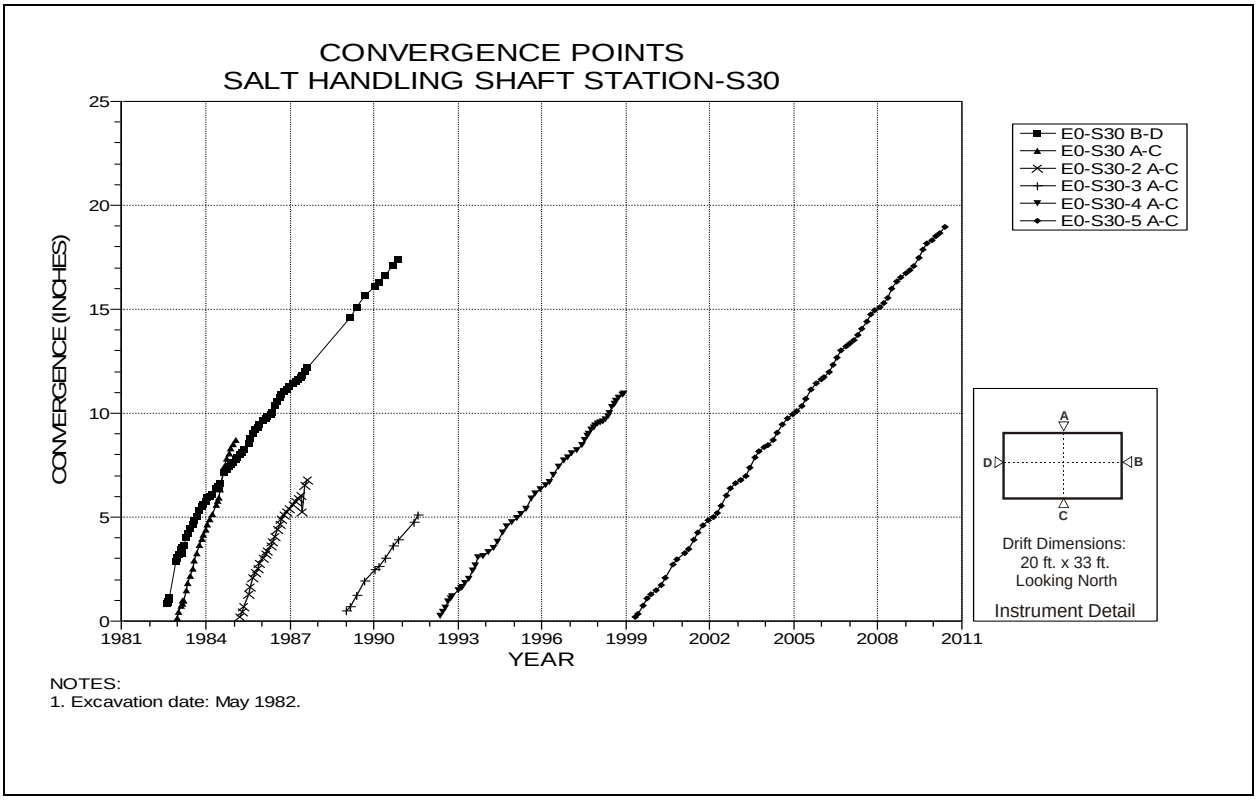


Figure 3-2 Convergence Point Array
Salt Handling Shaft Station at South 30 – All Chords

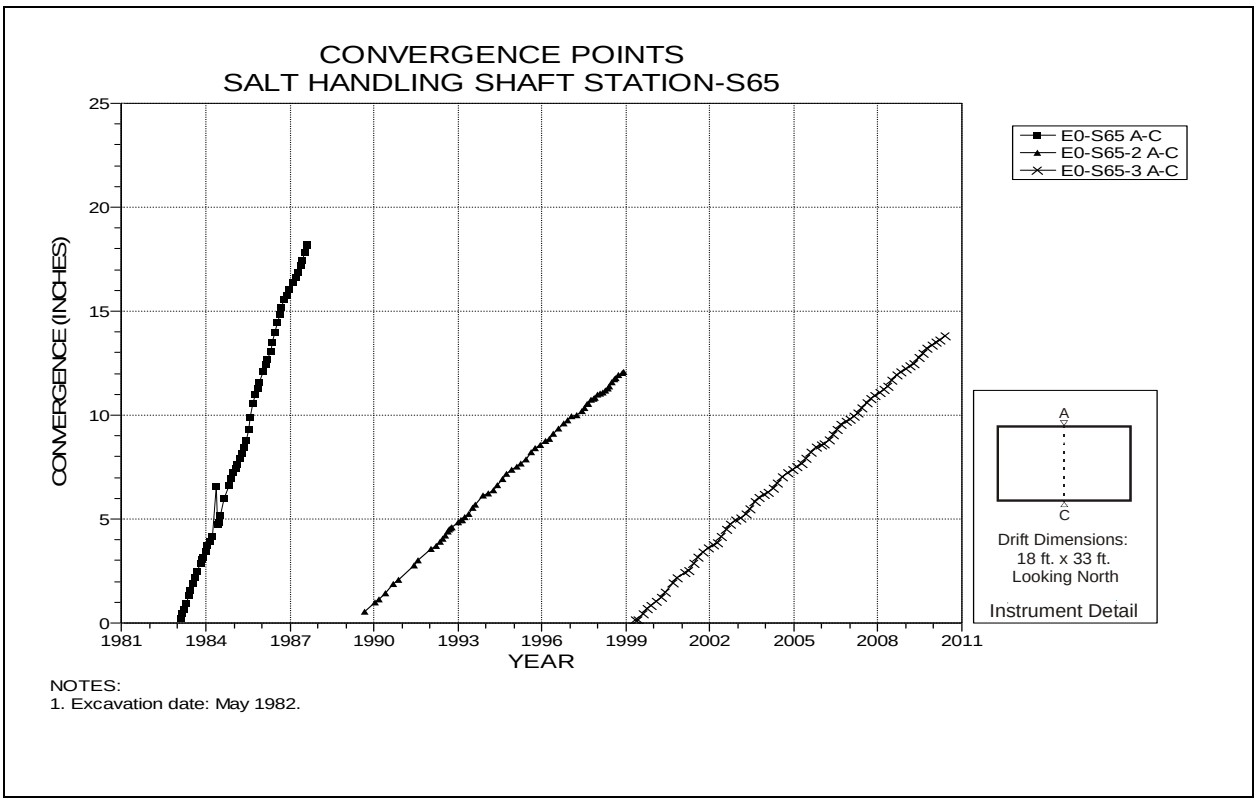


Figure 3-3 Convergence Point Array
Salt Handling Shaft Station at South 65 – Roof to Floor

Table 3-2
Waste Shaft Station Data Analysis

EXTENSOMETERS

Fieldtag	Location		Figure Number	Date of Last Reading	Collar Displacement Relative to Deepest Anchor (inches)	Displacement Rate 2009 to 2010 (in/year)	Displacement Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
51X-GE-00268	W30 Drift-S400	Roof	3-4	04/22/10	10.359	0.27	0.31	-13%	
51X-GE-00404	Waste Station	Roof	3-5	06/21/10	0.354	0.29	0.30	-3%	

CONVERGENCE POINTS

Field Tag	Location	Figure Number	Last Reading 2009-2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent[1]	Comments
			Date	Inches					
S400-E32-2 A-C	S400-E32	3-6	11/17/09	1.161	1.161	1.55	1.69	-8%	
S400-E32-2 B-D	S400-E32	3-6	05/04/10	1.464	1.464	1.17	1.46	-20%	
S400-E85 A-C	S400-E85	3-7	11/17/09	1.068	1.068	1.49	1.70	-12%	
S400-E85 B-D	S400-E85	3-7	05/04/10	1.453	1.453	1.16	1.37	-15%	

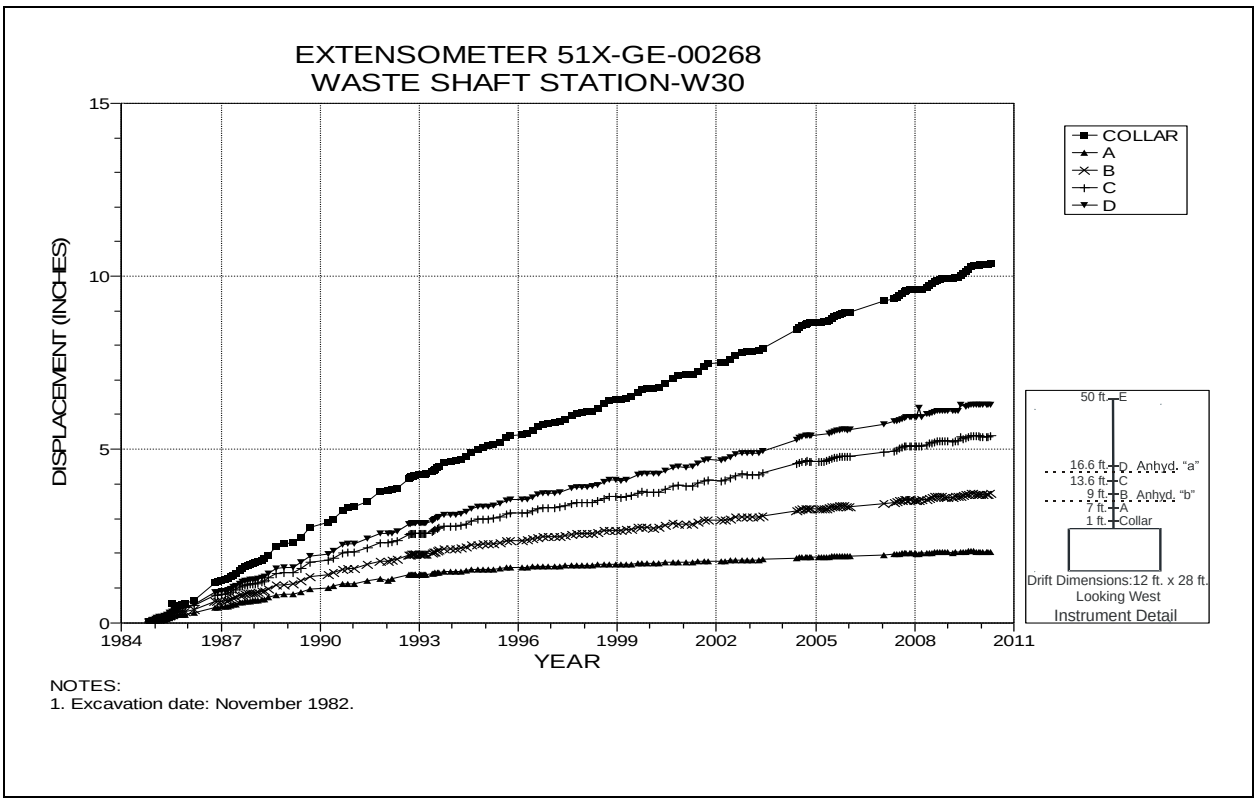


Figure 3-4 Extensometer 51X-GE-00268
Waste Shaft Station at West 30 – Roof

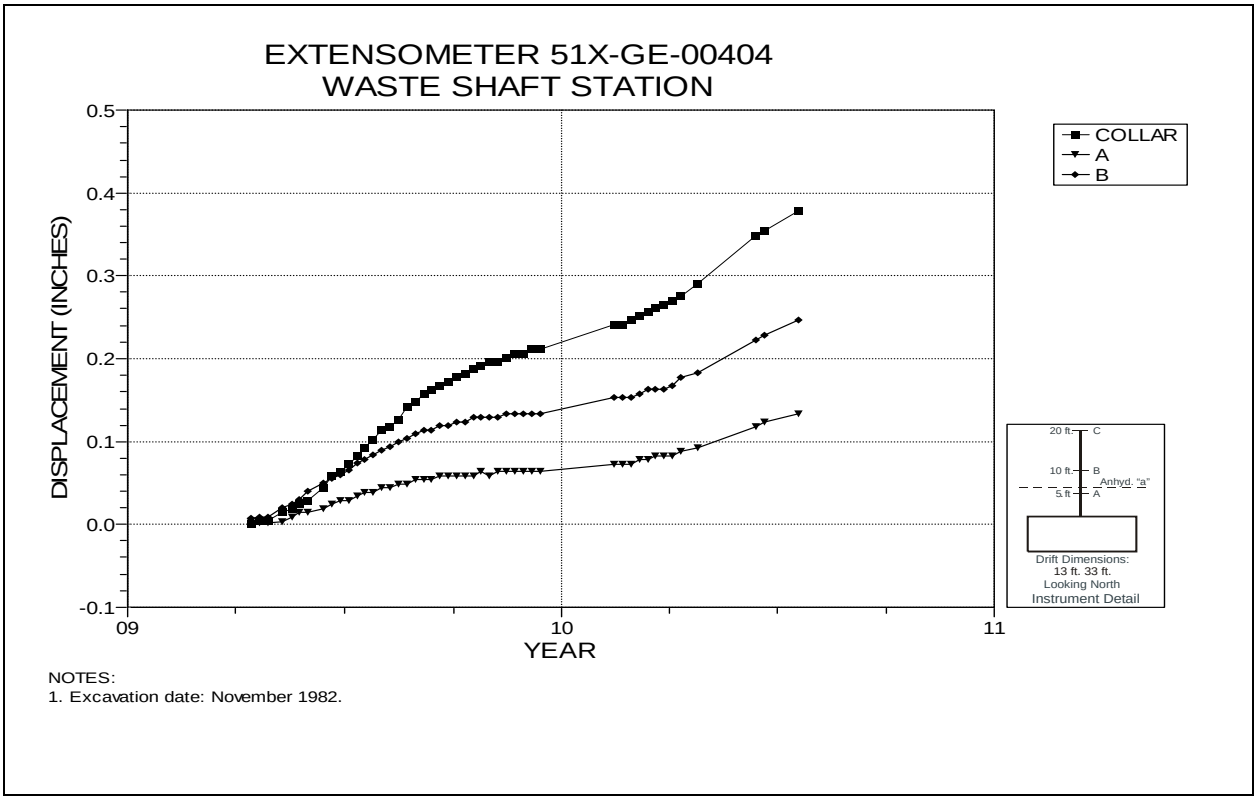


Figure 3-5 Extensometer 51X-GE-00404
Waste Shaft Station – Roof

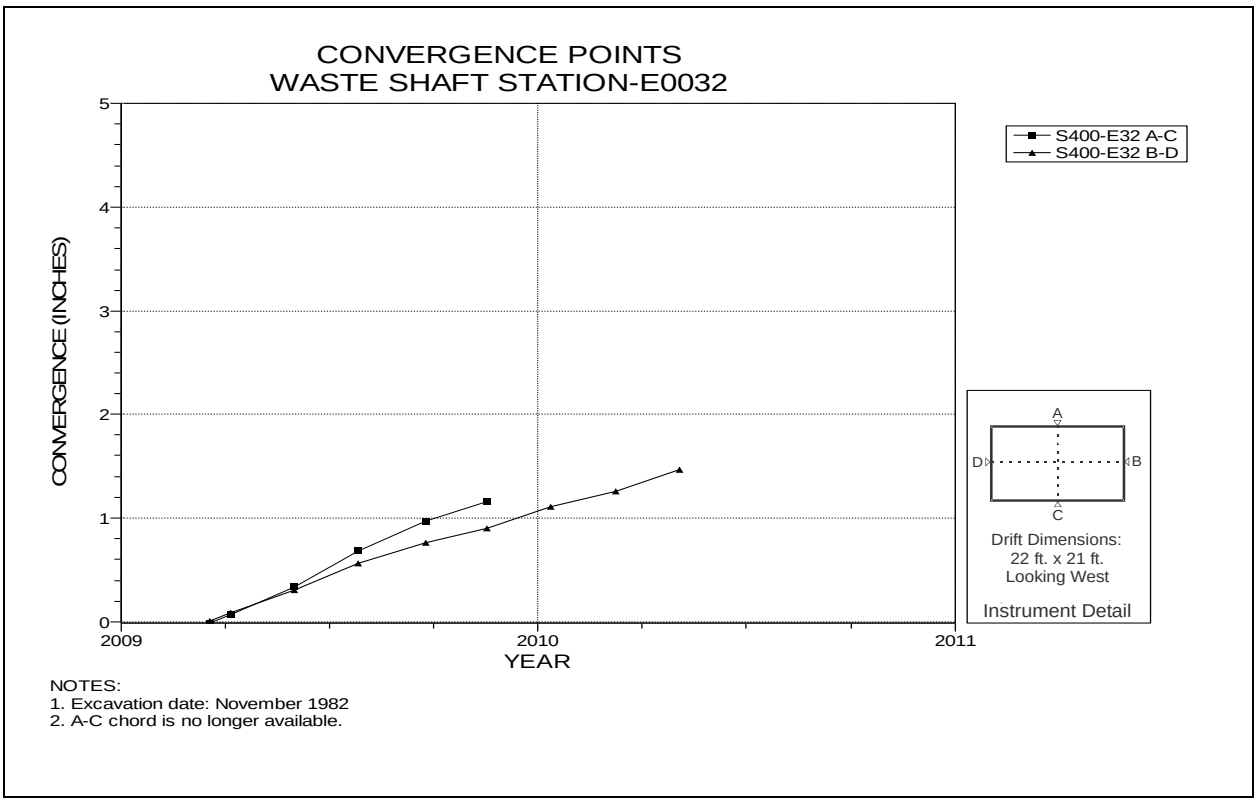


Figure 3-6 Convergence Point Array
Waste Shaft Station at East 32 – All Chords

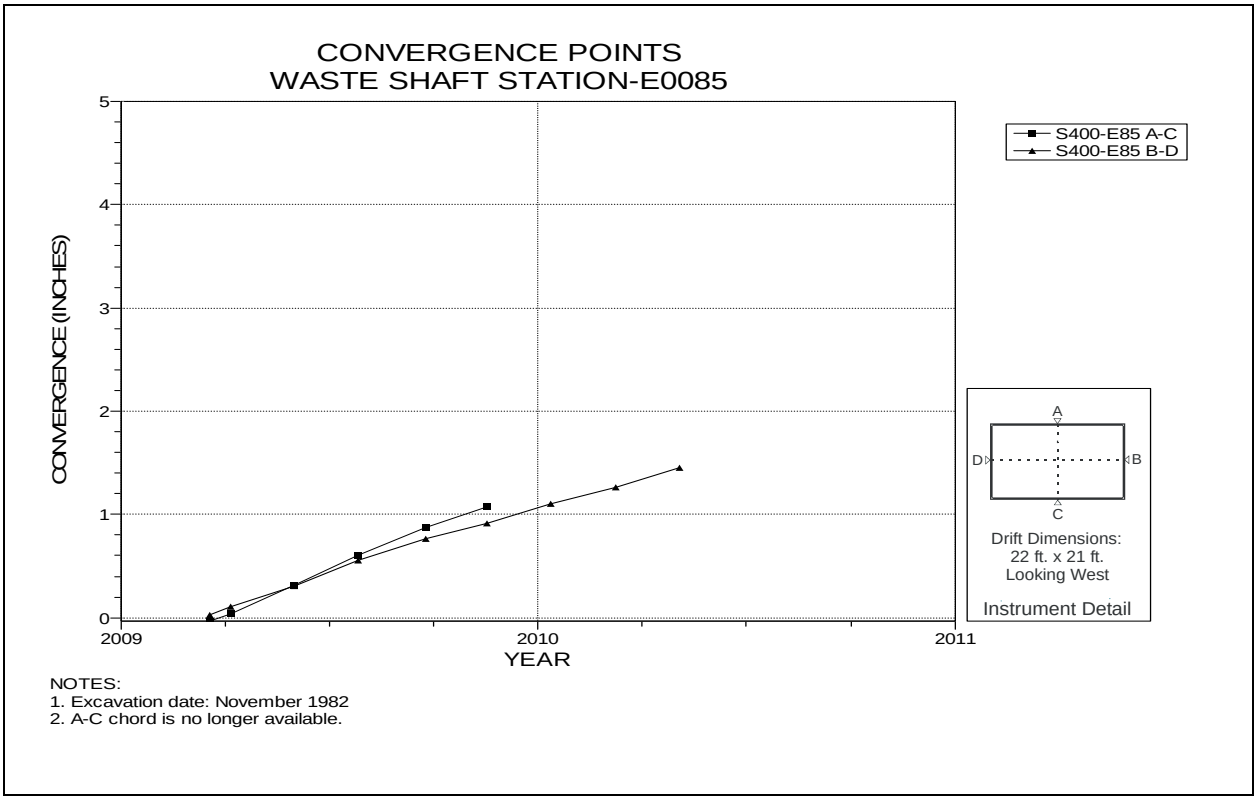


Figure 3-7 Convergence Point Array
Waste Shaft Station at East 85 – All Chords

Table 3-3
Air Intake Shaft Station Data Analysis

EXTENSOMETERS

Field Tag	Location	Figure Number	Date of Last Reading	Collar Displacement Relative to Deepest Anchor (Inches)	Displacement Rate 2009 to 2010 in/year	Displacement Rate 2008 to 2009 in/year	Rate Change Percent	Comments
41X-GE-00122	S65-W620 Roof	3-8	6/28/2010	3.747	0.30	0.30	0%	
41X-GE-00123	N93-W620 Roof	3-9	6/28/2010	5.072	0.35	0.37	-5%	

ROCKBOLT LOAD CELLS

Field Tag	Location	Figure Number	Date of Initial Reading	Date of Last Reading	Load (kips)	Comments
51X-WG-00236	AIS Station Brow – South	3-10	01/19/93	6/28/2010	59.07	
51X-WG-00237	AIS Station Brow – South	3-10	01/19/93	6/28/2010	2.18	
51X-WG-00238	AIS Station Brow – South	3-10	01/19/93	6/28/2010	2.84	
51X-WG-00239	AIS Station Brow – South	3-10	01/19/93	6/28/2010	25.88	
51X-WG-00240	AIS Station Brow – South	3-10	01/19/93	6/28/2010	5.34	
51X-WG-00241	AIS Station Brow – South	3-11	01/19/93	6/28/2010	66.75	
51X-WG-00242	AIS Station Brow – South	3-11	01/19/93	6/28/2010	5.98	
51X-WG-00243	AIS Station Brow – South	3-11	01/19/93	6/28/2010	5.19	
51X-WG-00244	AIS Station Brow – South	3-11	12/24/94	6/28/2010	23.08	
51X-WG-00245	AIS Station Brow – South	3-11	01/19/93	6/28/2010	1.01	
51X-WG-00246	AIS Station Brow – North	3-12	01/19/93	6/28/2010	54.54	
51X-WG-00247	AIS Station Brow – North	3-12	01/19/93	6/28/2010	56.90	
51X-WG-00248	AIS Station Brow – North	3-12	01/19/93	6/28/2010	7.75	
51X-WG-00249	AIS Station Brow – North	3-12	01/19/93	6/28/2010	31.03	
51X-WG-00250	AIS Station Brow – North	3-12	12/24/94	6/28/2010	18.49	
51X-WG-00251	AIS Station Brow – North	3-13	01/19/93	6/28/2010	38.21	
51X-WG-00252	AIS Station Brow – North	3-13	01/19/93	6/28/2010	0.66	
51X-WG-00253	AIS Station Brow – North	3-13	01/19/93	6/28/2010	56.34	
51X-WG-00254	AIS Station Brow – North	3-13	01/19/93	6/28/2010	13.03	
51X-WG-00255	AIS Station Brow – North	3-13	01/19/93	6/28/2010	33.86	

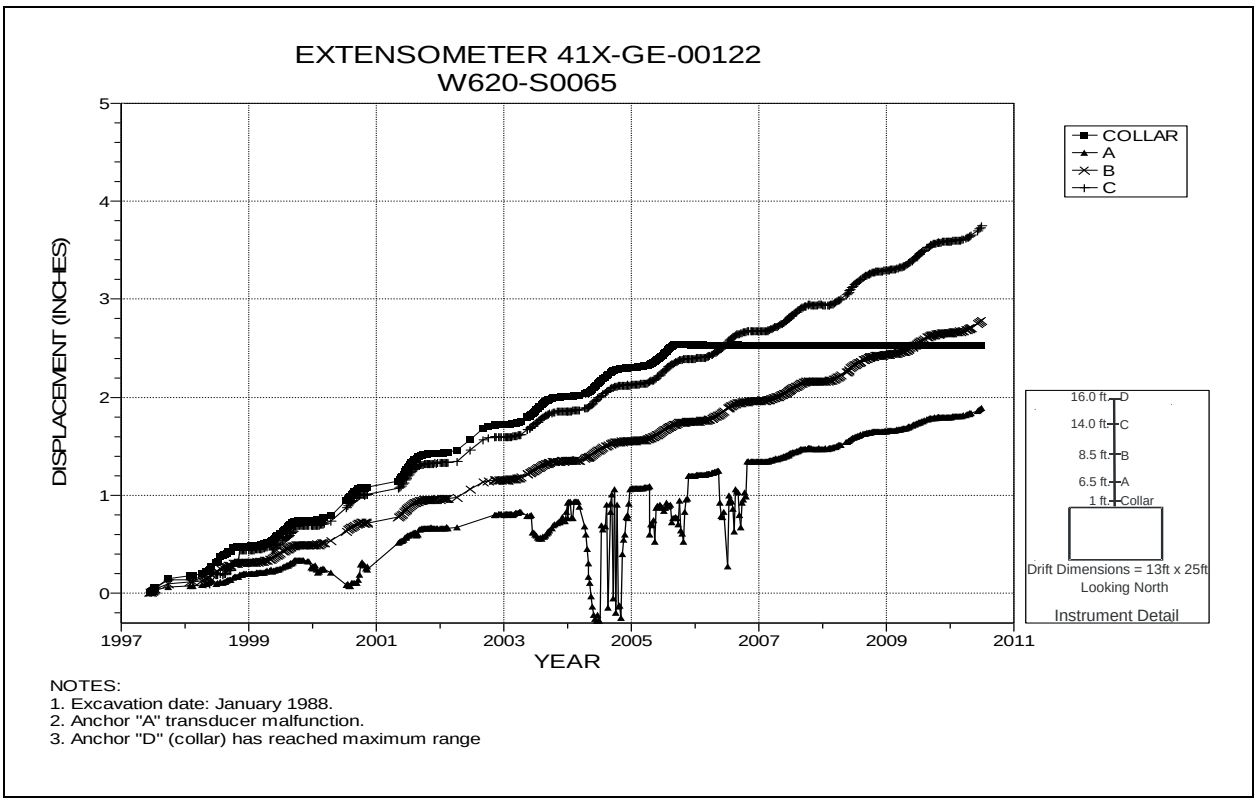


Figure 3-8 Extensometer 41X-GE-00122
Air Intake Shaft Station at South 65 – Roof

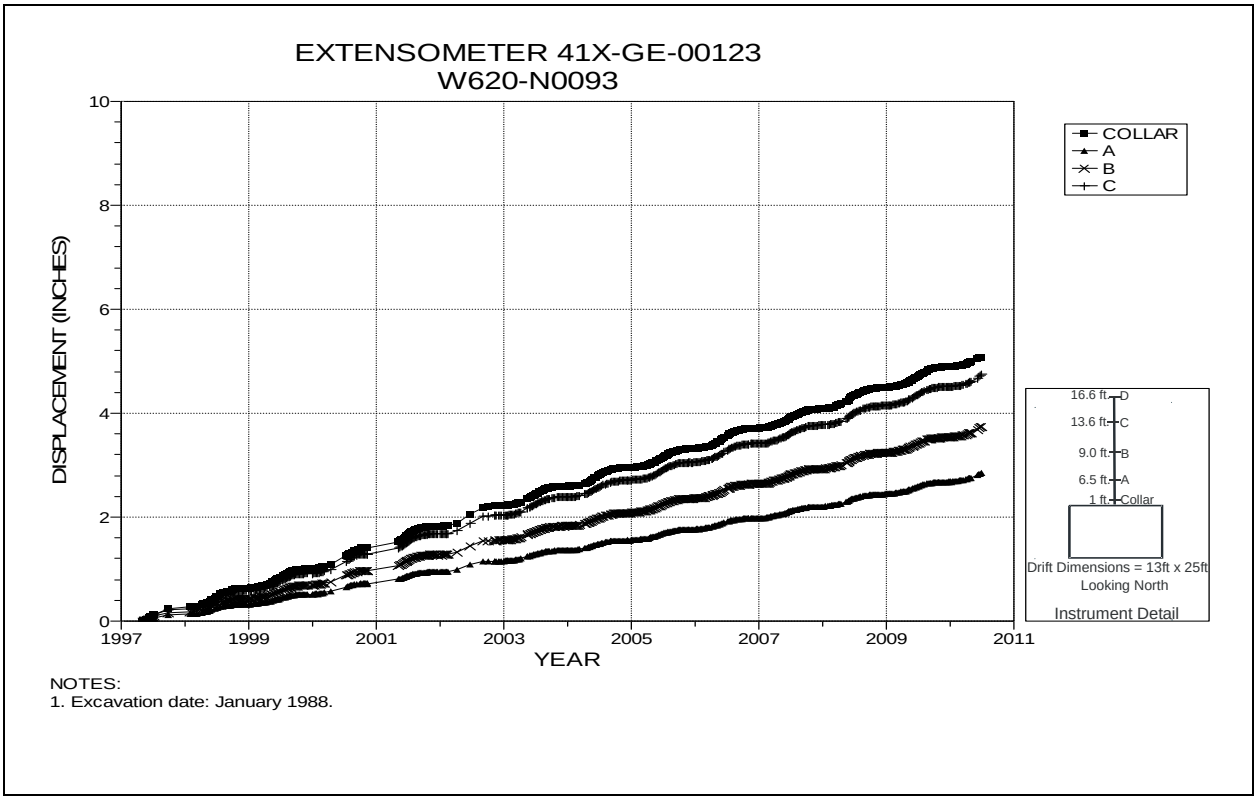


Figure 3-9 Extensometer 41X-GE-00123
Air Intake Shaft Station at North 93 – Roof

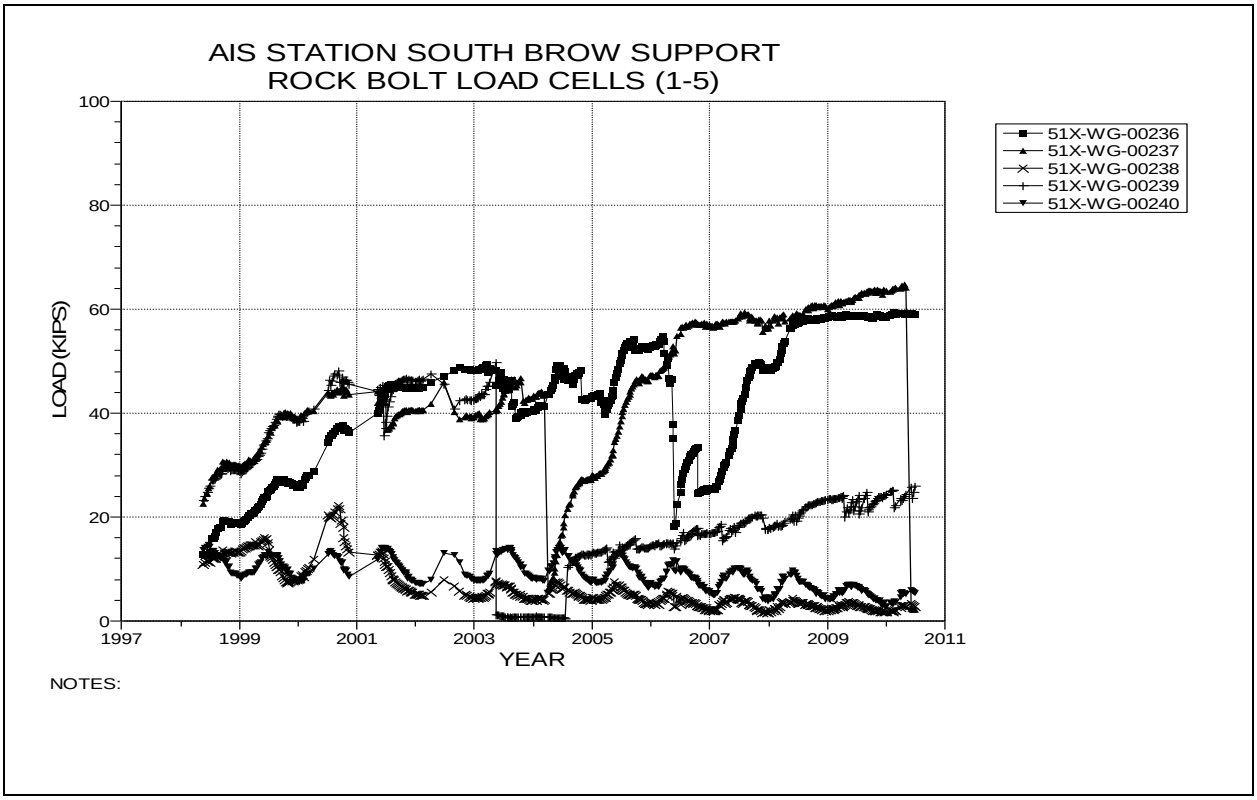


Figure 3-10 Rock Bolt Load Cells
Air Intake Shaft Station Brow – South Side Roof Bolts Set 1

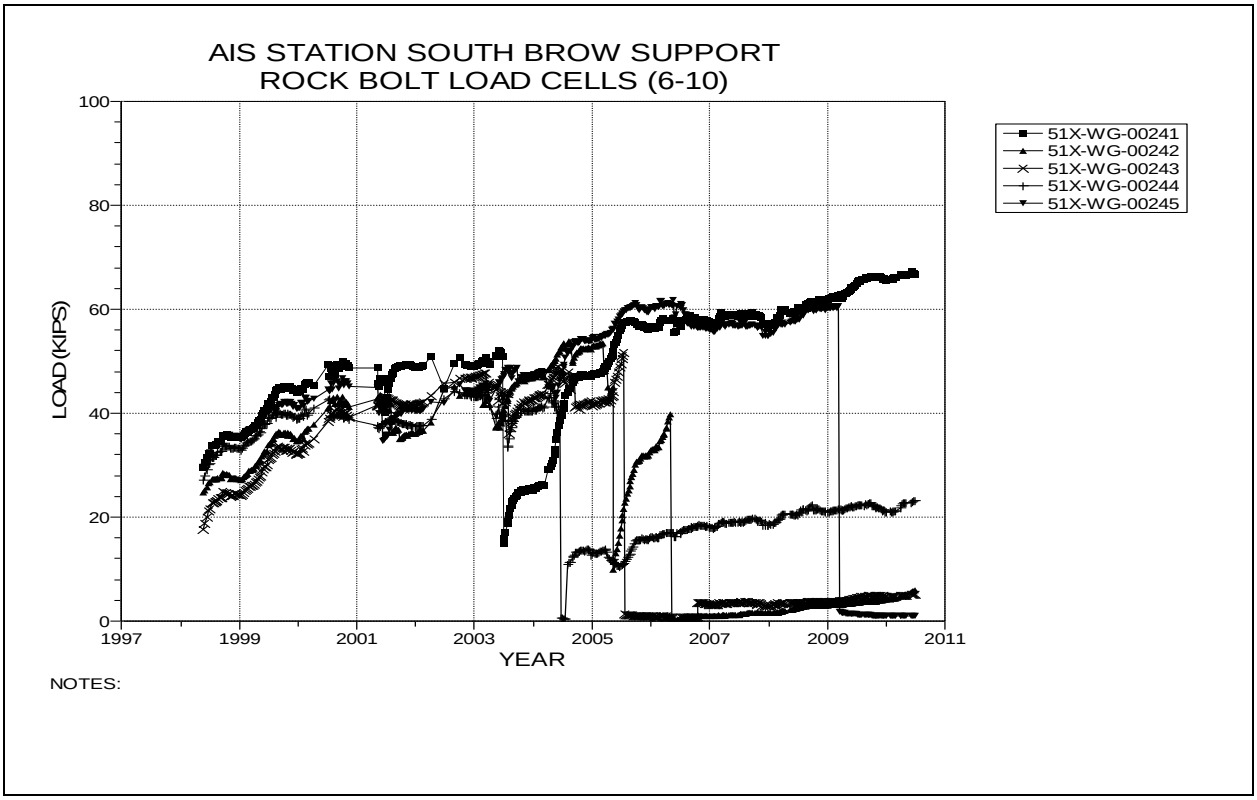


Figure 3-11 Rock Bolt Load Cells
Air Intake Shaft Station Brow – South Side Roof Bolts Set 2

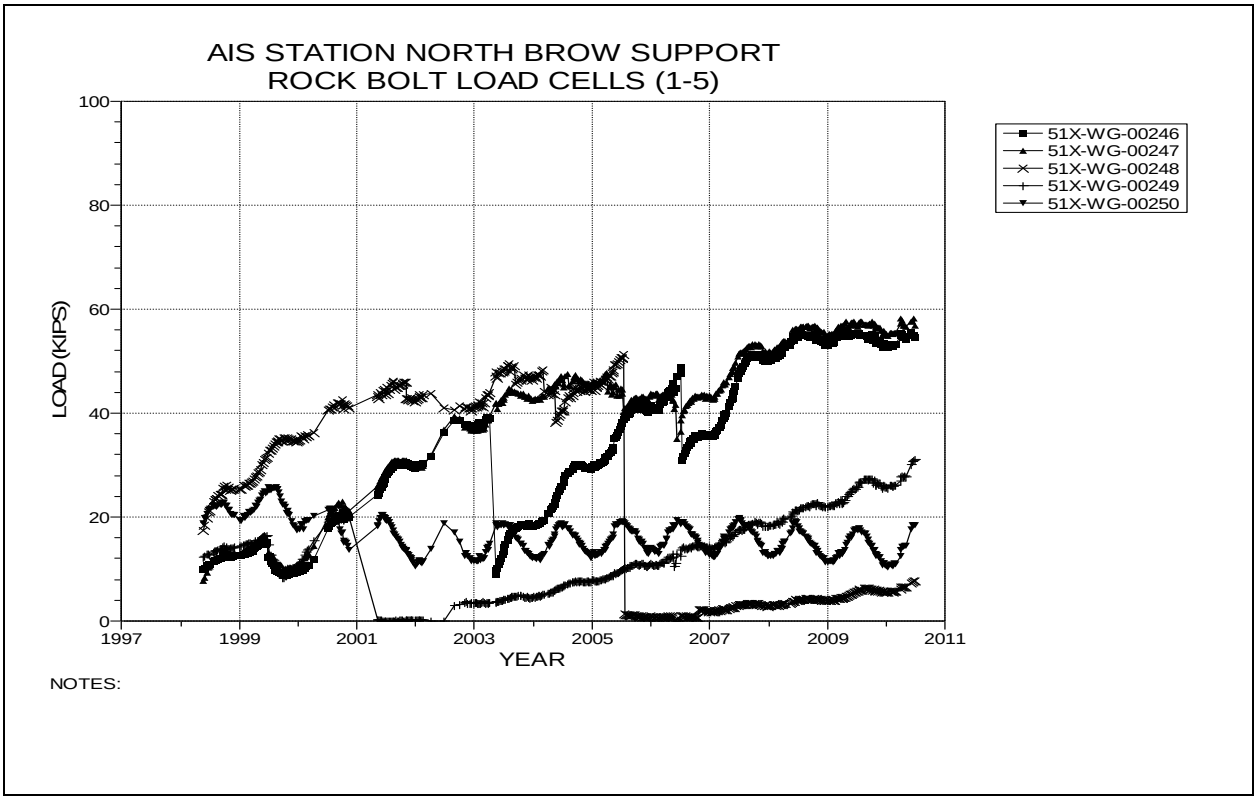


Figure 3-12 Rock Bolt Load Cells
Air Intake Shaft Station Brow – North Side Roof Bolts Set 1

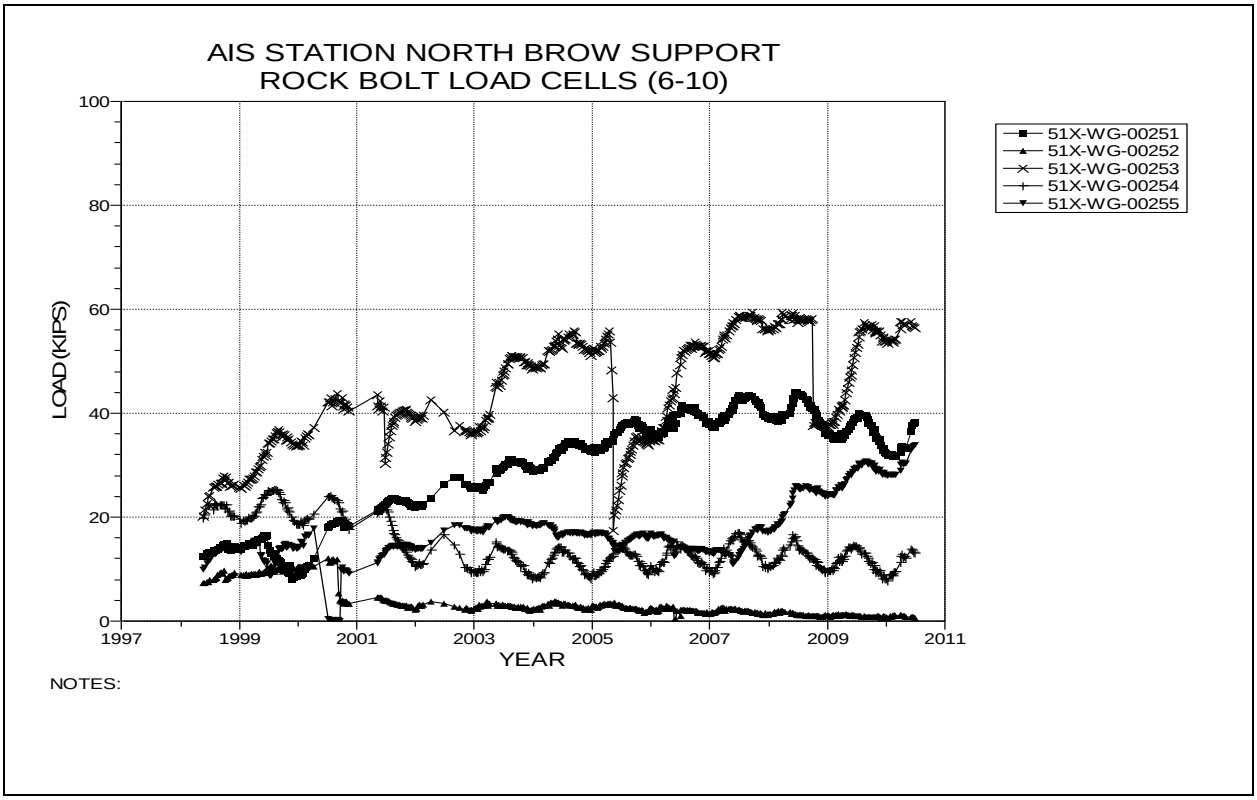


Figure 3-13 Rock Bolt Load Cells
Air Intake Shaft Station Brow – North Side Roof Bolts Set 2

4.0 Instrumentation Summary for the Access Drifts

This chapter presents the instrumentation data and data analyses for the access drifts throughout the WIPP underground. Table 4-1 provides the results of analyses performed on the instrument data including displacement, convergence rates, and rock bolt loading. Figures 4-1 through 4-27-B present data from borehole extensometers installed in the access drifts while Figures 4-28 through 4-245 present the convergence point data. Figure 4-246 through 4-255 presents data from joint meters installed at the S1950/E300 overcast and the access drifts. Figure 4-256 through 4-258 presents the data from rock bolt load cells installed in the E140 drift, the adjacent brows in E140-S1300 and at the E140-S1300 east brow.

Table 4-1 Access Drifts Data Analysis

EXTENSOMETERS

Field Tag	Location		Figure Number	Date of Last Reading	Collar Displacement Relative to Deepest Anchor (inches)	Displacement Rate 2009 to 2010 (in/year)	Displacement Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
51X-GE-00361	E0 DRIFT-N1266	Roof	4-1	06/28/10	8.305	1.01	1.41	-28%	
51X-GE-00352	E0 DRIFT-N940	Roof	4-2	06/28/10	3.997	1.04	0.47	121%	
51X-GE-00353	E0 DRIFT-N626	Roof	4-3	06/28/10	3.949	0.71	0.55	29%	
51X-GE-00355	E0 DRIFT-N300	Roof	4-4	06/28/10	4.079	0.49	0.41	20%	
51X-GE-00364	E140 DRIFT-N1266	Roof	4-5	06/28/10	4.287	0.66	0.73	-10%	
51X-GE-00105-3	E140 DRIFT-N150-3	Roof	4-6	03/31/10	3.011	0.20	0.30	-33%	
51X-GE-00372	E140 DRIFT-S146	Roof	4-7	06/28/10	2.891	0.56	0.57	-2%	
51X-GE-00472	E140/S1000	Roof	4-8	03/10/10	4.697	0.04	0.04	0%	
51X-GE-00464	E140/S1025	Roof	4-9	05/04/10	4.038	0.15	0.07	114%	
51X-GE-00333	E140 DRIFT-S1075	Roof	4-10	06/28/10	6.116	0.64	0.58	10%	
51X-GE-00465	E140/S1300	Roof	4-11	05/04/10	2.556	0.10	0.11	-9%	
51X-GE-00335	E140-S1300	Roof	4-12	05/20/10	4.169	0.27	0.20	35%	
51X-GE-00492	E140 DRIFT-S2750	Roof	4-13	06/14/10	2.874	0.24	0.26	-8%	
51X-GE-00367-2	E140-S2916	Roof	4-14	06/28/10	6.093	1.04	3.04	-66%	
51X-GE-00396	E140-S3493	Roof	4-15	06/28/10	3.094	1.38	1.32	5%	
51X-GE-00373	E300 DRIFT-N1341	Roof	4-16	06/28/10	2.92	0.70	0.50	40%	
51X-GE-00388	E300 DRIFT-N1266	Roof	4-17	06/28/10	2.178	0.54	0.61	-11%	
51X-GE-00374	E300 DRIFT-N1186	Roof	4-18	06/28/10	4.101	0.46	0.53	-13%	
51X-GE-00481	N300/W10 BROW	Roof	4-19	06/01/10	2.782	0.17	0.18	-6%	
51X-GE-00474	S1000-E120 BROW	Roof	4-20	04/28/10	1.185	0.01	0.05	-80%	
51X-GE-00473	S1000-E160 BROW	Roof	4-21	04/28/10	0.991	0.01	0.04	-75%	
51X-GE-00462	S1300-E120 BROW	Roof	4-22	04/28/10	0.663	0.02	0.04	-50%	
51X-GE-00463	S1300-E160 BROW	Roof	4-23	04/28/10	4.075	0.22	0.22	0%	
51X-GE-00442	S1600-E120 BROW	Roof	4-24	04/28/10	0.931	-0.02	0.07	-129%	
51X-GE-00441	S1600-E160 BROW	Roof	4-25	01/07/10	2.203	0.13	0.23	-43%	
51X-GE-00490	W30 DRIFT-S2750	Roof	4-26	06/28/10	2.46	0.46	0.37	24%	
41X-GE-00126	W212-N300	Roof	4-27-A	06/28/10	3.156	0.18	0.21	-14%	
41X-GE-00124	W519-N190	Roof	4-27-B	06/28/10	4.651	0.37	0.31	19%	

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
E300-N250-3 A-C	E300-N250	4-28	05/13/10	5.728	34.682	1.50	1.72	-13%	
E300-N170-2 A-E	E300-N170	4-29	05/13/10	5.857	28.351	1.55	1.69	-8%	
E300-N170-2 H-F	E300-N170	4-29	05/13/10	5.327	25.387	1.42	1.49	-5%	
E300-N170-2 C-G	E300-N170	4-29	05/13/10	7.164	22.008	1.23	1.35	-9%	
E300-N45 A-E	E300-N45	4-30	05/13/10	28.711	28.711	1.26	1.44	-13%	
E300-N45 H-F	E300-N45	4-30	05/13/10	25.663	25.663	1.12	1.43	-22%	
E300-N45 C-G	E300-N45	4-30	05/13/10	20.922	20.922	1.09	1.15	-5%	
E300-S45-2 A-E	E300-S45	4-31	05/13/10	23.061	23.061	1.15	1.20	-4%	
E300-S45-2 B-D	E300-S45	4-31	05/13/10	20.116	20.116	1.40	1.33	5%	
E300-S45-2 H-F	E300-S45	4-31	05/13/10	19.959	19.959	0.96	1.03	-7%	
E300-S45 C-G	E300-S45	4-31	05/13/10	17.551	17.551	0.73	0.83	-12%	
E300-S90 A-C	E300-S90	4-32	05/11/10	17.102	17.102	0.62	0.70	-11%	
E300-S250-2 A-C	E300-S250	4-33	05/11/10	7.756	12.141	0.55	0.59	-7%	
E300-S250-2 B-D	E300-S250	4-33	05/11/10	8.317	12.363	0.55	0.59	-7%	
E300-S700 A-C	E300-S700	4-34	05/11/10	19.284	19.284	0.56	0.47	19%	
E300-S850 A-E	E300-S850	4-35	05/11/10	14.786	14.786	0.46	0.33	39%	
E300-S850 B-D	E300-S850	4-35	05/11/10	11.083	11.083	0.38	0.23	65%	
E300-S850 H-F	E300-S850	4-35	05/11/10	10.251	10.251	0.37	0.23	61%	
E300-S850-2 C-G	E300-S850	4-35	05/11/10	7.275	16.553	0.55	0.40	38%	
E300-S1000 A-C	E300-S1000	4-36	05/11/10	19.141	19.141	0.58	0.53	9%	
E300-S1150-3 A-E	E300-S1150	4-37	05/11/10	11.232	16.722	0.56	0.49	14%	
E300-S1150-3 B-D	E300-S1150	4-37	05/11/10	7.78	11.839	0.41	0.31	32%	
E300-S1150-3 H-F	E300-S1150	4-37	05/11/10	7.867	11.487	0.45	0.32	41%	
E300-S1150-2 C-G	E300-S1150	4-38	05/11/10	8.624	19.08	0.66	0.50	32%	
E300-S1300 A-C	E300-S1300	4-39	05/11/10	13.034	13.034	0.64	0.65	-2%	
E300-S1450 A-C	E300-S1450	4-40	05/11/10	8.524	8.524	0.61	0.66	-8%	
E300-S1450 B-D	E300-S1450	4-40	05/11/10	9.764	9.764	0.71	0.74	-4%	
E300-S1687 A-C	E300-S1687	4-41	05/11/10	9.319	9.319	0.78	0.82	-5%	

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
E300-S1687 B-D	E300-S1687	4-41	05/11/10	9.847	9.847	0.78	0.79	-1%	
E300-S1775 A-C	E300-S1775	4-42	05/11/10	8.388	8.388	0.68	0.67	1%	
E300-S1775 B-D	E300-S1775	4-42	05/11/10	10.008	10.008	0.76	0.80	-5%	
E300-S1862 A-C	E300-S1862	4-43	05/11/10	8.980	8.980	0.74	0.74	0%	
E300-S1862 B-D	E300-S1862	4-43	05/11/10	10.683	10.683	0.84	0.87	-3%	
E300-S2065 A-C	E300-S2065	4-44	05/11/10	10.502	10.502	0.90	0.89	1%	
E300-S2065 B-D	E300-S2065	4-44	05/11/10	13.747	13.747	1.14	1.16	-2%	
E300-S2275 A-C	E300-S2275	4-45	05/11/10	12.683	12.683	1.06	1.07	-1%	
E300-S2275 B-D	E300-S2275	4-45	05/11/10	16.213	16.213	1.46	1.42	3%	
E300-S2350 A-C	E300-S2350	4-46	05/11/10	14.748	14.748	1.22	1.22	0%	
E300-S2350 B-D	E300-S2350	4-46	05/11/10	16.857	16.857	1.44	1.41	2%	
E300-S2425 A-C	E300-S2425	4-47	05/11/10	15.302	15.302	1.37	1.38	-1%	
E300-S2425 B-D	E300-S2425	4-47	03/15/10	16.783	16.783	1.36	1.47	-7%	
E300-S2634 A-C	E300-S2634	4-48	05/11/10	12.332	12.332	1.60	1.64	-2%	
E300-S2634 B-D	E300-S2634	4-48	05/11/10	12.153	12.153	1.49	1.52	-2%	
E300-S2833 A-C	E300-S2833	4-49	05/11/10	14.919	14.919	2.11	2.22	-5%	
E300-S2833 B-D	E300-S2833	4-49	05/11/10	12.727	12.727	1.52	1.54	-1%	
E300-S2916-3 A-C	E300-S2916	4-50	05/11/10	5.620	23.784	2.06	3.87	-47%	
E300-S2916 B-D	E300-S2916	4-50	05/11/10	14.34	14.340	1.67	1.71	-2%	
E300-S2998-3 A-C	E300-S2998	4-51	05/11/10	5.573	32.930	2.67	3.24	-18%	
E300-S2998 B-D	E300-S2998	4-51	05/11/10	13.971	13.971	1.79	1.80	-1%	
E300-S3195 A-C	E300-S3195	4-52	05/11/10	15.683	15.683	2.73	2.38	15%	
E300-S3195 B-D	E300-S3195	4-52	05/11/10	13.784	13.784	1.55	1.59	-3%	
E300-S3480 A-C	E300-S3480	4-23	01/18/10	6.827	6.827	2.01	1.92	5%	
E300-S3480 B-D	E300-S3480	4-53	01/18/10	5.209	5.209	1.58	1.46	8%	
E140-N1420-2 A-C	E140-N1420	4-54	06/01/10	9.588	26.058	1.43	1.68	-15%	
E140-N1266-4 B-D	E140-N1266	4-55	06/01/10	7.295	29.300	1.11	1.20	-7%	
E140-N1266-3 A-C	E140-N1266	4-55	06/01/10	14.744	52.499	2.26	2.55	-11%	

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
E140-N1100-2 A-C	E140 -N1100	4-56	06/01/10	8.690	8.690	1.28	1.57	-18%	
E140-N940-2 A-C	E140-N940	4-57	06/01/10	17.102	17.102	3.25	3.21	1%	
E140-N940-2 B-D	E140-N940	4-57	06/01/10	7.034	7.034	1.11	1.23	-10%	
E140-N780-2 A-C	E140-N780	4-58	06/01/10	20.617	52.374	2.24	2.79	-20%	
E140-N686-2 A-C	E140-N686	4-59	06/01/10	16.707	16.707	2.41	2.56	-6%	
E140-N686-2 B-D	E140-N686	4-59	06/01/10	10.870	21.888	1.38	1.43	-3%	
E140-N626-3 A-C	E140-N626	4-60	06/01/10	21.02	53.590	3.09	3.29	-6%	
E140-N626-4 B-D	E140-N626	4-60	03/29/10	10.58	31.887	1.32	1.48	-11%	
E140-N562-2 A-C	E140-N562	4-61	06/01/10	15.508	15.508	2.35	2.36	0%	
E140-N562-2 B-D	E140-N562	4-61	03/29/10	10.955	19.232	1.47	1.57	-6%	
E140-N460-3 A-C	E140-N460	4-62	06/01/10	16.750	37.581	1.90	2.09	-9%	
E140-N355-2 A-C	E140-N355	4-63	06/01/10	7.182	15.726	1.94	2.13	-9%	
E140-N355 B-D	E140-N355	4-63	06/01/10	13.693	13.693	1.50	1.68	-11%	
E140-N220-3 A-C	E140-N220	4-64	06/01/10	9.261	35.060	2.15	2.56	-16%	
E140-N150-4 A-C	E140-N150	4-65	06/01/10	7.186	26.244	1.69	1.73	-2%	
E140-N5-6 A-C	E140-N5	4-66	06/01/10	8.341	40.183	2.07	2.26	-8%	
E140-N5-3 B-D	E140-N5	4-66	06/01/10	14.781	30.022	1.06	1.17	-9%	
E140-S90-4 A-C	E140-S90	4-67	05/04/10	5.784	23.497	1.40	1.49	-6%	
E140-S262-4 A-C	E140-S262	4-68	05/04/10	11.033	31.944	2.17	2.05	6%	
E140-S262-3 B-D	E140-S262	4-68	05/04/10	18.413	19.766	1.05	1.04	1%	
E140-S460-2 B-D	E140-S460	4-69	05/04/10	24.300	30.244	0.99	0.98	1%	
E140-S460-5 A-C	E140-S460	4-69	05/04/10	6.384	49.628	1.81	1.81	0%	
E140-S550-5 A-C	E140-S550	4-70	05/04/10	5.220	40.979	1.42	1.43	-1%	
E140-S550-4 B-D	E140-S550	4-70	05/04/10	26.052	34.694	1.16	1.13	3%	
E140-S700-6 A-D	E140-S700	4-71	11/17/09	7.439	28.979	1.69	1.27	33%	
E140-S700-5 B-C	E140-S700	4-72	11/17/09	8.742	30.032	2.05	1.46	40%	
E140-S700-5 E-F	E140-S700	4-73	11/17/09	4.637	24.634	0.98	0.85	15%	
E140-S850-8 A-C	E140-S850	4-74	05/04/10	12.428	51.513	2.27	2.19	4%	

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
E140-S850-4 B-D	E140-S850	4-75	05/04/10	16.857	32.804	1.16	1.12	3%	
E140-S1000-2 A-C	E140-S1000	4-76	05/04/10	8.723	35.648	1.31	1.31	0%	
E140-S1025-3 A-C	E140-S1025	4-77	05/04/10	9.364	22.177	1.46	1.72	-15%	
E140-S1075-3 A-E	E140-S1075	4-78	05/04/10	9.880	22.230	1.82	1.90	-4%	
E140-S1075-2 C-G	E140-S1075	4-79	06/15/10	15.178	16.000	1.25	1.18	6%	
E140-S1150-3 A-G	E140-S1150	4-80	05/04/10	16.346	30.742	3.52	4.01	-12%	
E140-S1150-4 B-F	E140-S1150	4-81	05/04/10	3.352	27.041	2.83	4.22	-33%	
E140-S1150-4 L-H	E140-S1150	4-81	05/04/10	9.484	20.193	1.91	2.16	-12%	
E140-S1150 C-K	E140-S1150	4-82	06/15/10	15.682	15.682	1.23	1.16	6%	
E140-S1150-2 D-J	E140-S1150	4-82	06/15/10	16.352	17.266	1.39	1.32	5%	
E140-S1150-2 E-I	E140-S1150	4-82	06/30/10	14.920	15.781	1.28	1.20	7%	
E140-S1225-3 A-E	E140-S1225	4-83	05/04/10	12.240	26.697	2.55	2.51	2%	
E140-S1225-2 C-G	E140-S1225	4-83	06/15/10	20.754	21.661	2.15	2.09	3%	
E140-S1225-2 B-D	E140-S1225	4-84	05/04/10	25.031	27.101	2.45	2.34	5%	
E140-S1225-2 H-F	E140-S1225	4-84	05/04/10	17.876	19.434	1.70	1.69	1%	
E140-S1300-4 A-C	E140-S1300	4-85	06/15/10	16.937	33.520	1.40	1.42	-1%	
E140-S1378-2 A-E	E140-S1375	4-86	05/04/10	23.638	34.437	2.15	2.23	-4%	
E140-S1378-2 B-D	E140-S1375	4-87	05/04/10	15.438	25.102	1.34	1.35	-1%	
E140-S1378-2 H-F	E140-S1375	4-87	05/04/10	26.531	37.770	2.34	2.37	-1%	
E140-S1378 C-G	E140-S1375	4-88	06/15/10	18.631	18.631	1.50	1.44	4%	
E140-S1456-4 A-G	E140-S1450	4-89	05/04/10	36.425	41.350	3.78	4.20	-10%	
E140-S1456-2 B-F	E140-S1456	4-90	05/04/10	29.856	32.829	2.59	2.71	-4%	
E140-S1456-2 L-H	E140-S1456	4-90	05/04/10	25.538	27.739	2.81	2.88	-2%	
E140-S1456-2 D-J	E140-S1456	4-91	06/15/10	19.608	21.085	1.74	1.65	5%	
E140-S1456 K-C	E140-S1456	4-92	06/15/10	17.917	17.917	1.39	1.31	6%	
E140-S1456-2 I-E	E140-S1456	4-92	06/15/10	16.049	17.607	1.31	1.32	-1%	
E140-S1534-2 A-E	E140-S1534	4-93	06/15/10	43.042	46.163	2.97	3.06	-3%	
E140-S1534-2 C-G	E140-S1534	4-93	06/15/10	17.497	18.968	1.47	1.43	3%	
E140-S1534-3 B-D	E140-S1534	4-94	06/15/10	15.510	28.875	2.26	2.33	-3%	

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
E140-S1534-2 H-F	E140-S1534	4-94	06/15/10	28.529	31.559	2.17	2.20	-1%	
E140-S1600-5 A-C	E140-S1600	4-95	06/15/10	19.931	36.737	1.82	1.76	3%	
E140-S1687-2 A-E	E140-S1687	4-96	06/15/10	37.338	40.256	3.56	3.72	-4%	
E140-S1687-2 B-D	E140-S1687	4-96	06/15/10	28.017	30.861	2.65	2.63	1%	
E140-S1687-2 H-F	E140-S1687	4-96	06/30/10	27.501	30.057	3.19	3.01	6%	
E140-S1687 C-G	E140-S1687	4-96	06/15/10	19.296	19.296	1.60	1.57	2%	
E140-S1775-2 A-G	E140-S1775	4-97	06/15/10	54.870	58.058	4.10	4.18	-2%	
E140-S1775-3 B-F	E140-S1775	4-97	06/15/10	23.557	48.088	3.62	3.66	-1%	
E140-S1775-2 L-H	E140-S1775	4-97	06/15/10	24.837	26.983	2.19	2.15	2%	
E140-S1775 C-K	E140-S1775	4-98	06/15/10	18.757	18.757	1.44	1.40	3%	
E140-S1775-2 D-J	E140-S1775	4-98	06/15/10	19.240	20.491	1.75	1.66	5%	
E140-S1775-3 I-E	E140-S1775	4-98	06/15/10	5.207	19.428	1.60	1.54	4%	
E140-S1862-2 A-E	E140-S1862	4-99	06/15/10	41.117	43.683	3.82	3.94	-3%	
E140-S1862-3 C-G	E140-S1862	4-99	06/15/10	12.783	19.088	1.66	1.61	3%	
E140-S1862-2 B-D	E140-S1862	4-100	06/15/10	36.213	39.089	3.48	3.54	-2%	
E140-S1862-2 H-F	E140-S1862	4-100	06/15/10	19.669	21.459	1.88	1.77	6%	
E140-S1950-5 A-C	E140-S1950	4-101	06/15/10	18.127	48.184	2.47	2.56	-4%	
E140-S2007-5 A-C	E140-S2007	4-102	06/15/10	15.992	33.952	3.21	3.05	5%	
E140-S2065-4 A-C	E140-S2065	4-103	06/15/10	22.643	40.363	4.15	4.94	-16%	
E140-S2065-2 B-D	E140-S2065	4-103	06/15/10	12.732	19.380	1.74	1.71	2%	
E140-S2122-3 A-C	E140-S2122	4-104	06/15/10	25.022	38.518	3.81	4.24	-10%	
E140-S2275-3 A-C	E140-S2275	4-105	06/14/10	37.968	63.651	6.90	7.15	-3%	
E140-S2275 B-D	E140-S2275	4-105	06/14/10	20.570	20.570	1.95	2.04	-4%	
E140-S2350-4 A-C	E140-S2350	4-106	06/14/10	31.168	67.074	6.94	6.30	10%	
E140-S2350-2 B-D	E140-S2350	4-106	06/14/10	21.690	28.581	2.11	2.05	3%	
E140-S2425-3 A-C	E140-S2425	4-107	06/14/10	26.666	43.888	5.71	5.26	9%	
E140-S2425 B-D	E140-S2425	4-107	06/14/10	21.310	21.310	2.10	2.00	5%	
E140-S2520-2 A-C	E140-S2520	4-108	06/14/10	23.400	32.021	2.89	3.13	-8%	

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
E140-S2634 A-C	E140-S2634	4-109	06/14/10	41.251	41.251	5.42	5.09	6%	
E140-S2634 B-D	E140-S2634	4-109	06/14/10	15.393	15.393	2.02	2.01	0%	
E140-S2750-2 A-C	E140-S2750	4-110	06/14/10	14.498	18.499	2.37	2.48	-4%	
E140-S2833-3 A-C	E140-S2833	4-111	06/14/10	5.687	26.486	4.04	4.00	1%	
E140-S2833 B-D	E140-S2833	4-111	06/14/10	13.649	13.649	1.79	1.78	1%	
E140-S2915-3 A-C	E140-S2915	4-112	06/14/10	5.198	31.414	3.50	4.13	-15%	
E140-S2915 B-D	E140-S2915	4-112	06/14/10	14.882	14.882	1.94	1.95	-1%	
E140-S2998-3 A-C	E140-S2998	4-113	05/03/10	4.403	31.558	3.43	3.36	2%	
E140-S2998 B-D	E140-S2998	4-113	05/03/10	13.668	13.668	1.74	1.78	-2%	
E140-S3080-2 A-C	E140-S3080	4-114	06/14/10	3.835	19.974	2.58	2.85	-9%	
E140-S3195-2 A-C	E140-S3195	4-115	06/14/10	5.052	31.307	3.47	4.02	-14%	
E140-S3195 B-D	E140-S3195	4-115	06/14/10	13.889	13.889	1.66	1.67	-1%	
E140-S3295-2 A-C	E140-S3295	4-116	06/14/10	3.156	10.861	2.15	2.57	-16%	
E140-S3325 A-C	E140-S3325	4-117	06/14/10	10.673	10.673	2.01	2.10	-4%	
E140-S3395-2 A-C	E140-S3395	4-118	06/14/10	4.896	20.054	3.47	3.75	-7%	
E140-S3395 B-D	E140-S3395	4-118	06/14/10	9.098	9.098	1.55	1.62	-4%	
E140-S3480-2 A-C	E140-S3480	4-119	06/14/10	5.023	19.323	3.59	3.81	-6%	
E140-S3480 B-D	E140-S3480	4-119	06/14/10	9.401	9.401	1.60	1.61	-1%	
E140-S3565-2 A-C	E140-S3565	4-120	06/14/10	3.678	15.006	2.61	2.81	-7%	
E140-S3565 B-D	E140-S3565	4-120	06/14/10	8.770	8.770	1.55	1.59	-3%	
E140-S3650-2 A-C	E140-S3650	4-121	04/27/10	2.359	8.979	1.74	1.92	-9%	
E0-N1266-4 A-C	E0-N1266	4-122	05/18/10	16.610	53.516	1.94	2.56	-24%	
E0-N1110-5 A-C	E0-N1110	4-123	05/18/10	9.256	43.680	1.30	1.76	-26%	
E0-N940-5 A-C	E0-N940	4-124	11/30/09	12.310	12.305	1.15	1.37	-16%	
E0-N780-2 A-C	E0-N780	4-125	05/18/10	12.910	53.630	2.26	2.27	0%	
E0-N686 B-D	E0-N686	4-126	03/23/10	16.270	16.273	2.11	2.39	-12%	
E0-N686 A-C	E0-N686	4-126	05/18/10	14.010	34.430	1.67	1.97	-15%	

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)[1]	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent[1]	Comments
			Date	Inches					
E0-N626-4 A-C	E0-N626	4-127	03/23/10	10.42	10.424	1.24	1.41	-12%	
E0-N562 A-C	E0-N562	4-128	05/18/10	15.61	56.565	1.91	2.12	-10%	
E0-N562 B-D	E0-N562	4-128	05/18/10	12.75	12.745	1.78	1.86	-4%	
E0-N460-3 A-C	E0-N460	4-129	05/18/10	11.22	11.224	1.42	1.57	-10%	
E0-N300-5 A-C	E0-N300	4-130	03/23/10	17.32	37.405	1.52	2.01	-24%	
E0-N225-2 A-C	E0-N225	4-131	05/18/10	10.41	50.029	1.34	1.61	-17%	
E0-N225 B-D	E0-N225	4-131	05/18/10	15.22	15.27	1.60	1.72	-7%	
E0-N75 A-C	E0-N75	4-132	05/18/10	15.49	32.463	1.68	1.71	-2%	
E0-N75 B-D	E0-N75	4-132	05/18/10	10.85	10.849	1.13	1.24	-9%	
W30-S120-2 A-C	W30-S120	4-133	05/18/10	3.543	23.537	0.88	0.98	-10%	
W30-S250-5 A-C	W30-S250	4-134	05/18/10	4.189	30.422	1.08	1.17	-8%	
W30-S250-5 B-D	W30-S250	4-134	05/18/10	15.271	26.225	0.84	0.96	-13%	
W30-S400-2 A-C	W30-S400	4-135	05/18/10	3.545	21.373	0.77	0.96	-20%	
W30-S500 B-D	W30-S500	4-136	05/18/10	24.819	24.819	0.92	0.95	-3%	
W30-S500-2 A-C	W30-S500	4-136	05/18/10	3.61	26.12	1.01	1.01	0%	
W30-S700-4 A-C	W30-S700	4-137	11/30/09	4.774	34.277	1.35	1.47	-8%	
W30-S850-3 A-E	W30-S850	4-138	05/18/10	4.049	21.492	1.07	1.16	-8%	
W30-S850-3 B-D	W30-S850	4-139	05/18/10	3.931	15.83	1.02	1.01	1%	
W30-S850-2 H-F	W30-S850	4-139	05/18/10	2.603	15.568	0.7	0.75	-7%	
W30-S850-2 C-G	W30-S850	4-140	05/18/10	2.894	23.238	1.05	1.15	-9%	
W30-S1950 A-C	W30-S1950	4-141	05/18/10	20.448	20.448	1.35	1.45	-7%	
W30-S2067 A-C	W30-S2067	4-142	05/18/10	16.849	16.849	1.61	1.46	10%	
W30-S2275-2 A-C	W30-S2275	4-143	01/25/10	10.22	11.034	N/A	1.04	N/A	Insufficient data
W30-S2350-2 A-C	W30-S2350	4-144	01/25/10	10.532	11.593	N/A	1.10	N/A	Insufficient data
W30-S2425-2 A-C	W30-S2425	4-145	01/25/10	11.908	12.871	N/A	1.20	N/A	Insufficient data
W30-S2520-2 A-C	W30-S2520	4-146	05/18/10	17.263	19.158	2.03	1.75	16%	
W30-S2685-2 A-C	W30-S2685	4-147	05/18/10	16.776	18.89	2.84	1.88	51%	
W30-S2685-2 B-D	W30-S2685	4-147	10/05/09	12.123	14.27	1.59	1.61	-1%	

[1] N/A-Insufficient data available to perform calculation.

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
W30-S2750 A-C	W30-S2750	4-148	06/14/10	12.350	12.350	1.75	1.69	4%	
W30-S2833 A-C	W30-S2833	4-149	06/14/10	14.515	14.515	3.11	2.50	24%	
W30-S2833 B-D	W30-S2833	4-149	05/07/10	12.006	12.006	2.07	1.90	9%	
W30-S2916 A-C	W30-S2916	4-150	06/28/10	25.357	25.357	5.16	4.64	11%	
W30-S2916 B-D	W30-S2916	4-150	04/19/10	10.384	10.384	1.64	1.57	4%	
W30-S2998 A-C	W30-S2998	4-151	06/28/10	13.404	13.404	2.74	2.24	22%	
W30-S2998 B-D	W30-S2998	4-151	04/19/10	10.717	10.717	1.61	1.59	1%	
W30-S3080 A-C	W30-S3080	4-152	06/28/10	19.853	19.853	2.24	2.37	-5%	
W30-S3195 A-C	W30-S3195	4-153	06/28/10	14.151	14.151	2.03	1.96	4%	
W30-S3195 B-D	W30-S3195	4-153	06/28/10	11.081	11.081	1.42	1.42	0%	
W30-S3310 A-C	W30-S3310	4-154	06/28/10	13.599	13.599	1.64	1.74	-6%	
W30-S3395 A-C	W30-S3395	4-155	06/28/10	8.956	8.956	1.71	1.62	6%	
W30-S3395 B-D	W30-S3395	4-155	06/28/10	7.509	7.509	1.35	1.33	2%	
W30-S3480 A-C	W30-S3480	4-156	06/30/10	10.082	10.082	2.25	1.87	20%	
W30-S3480 B-D	W30-S3480	4-156	06/30/10	7.339	7.339	1.30	1.25	4%	
W30-S3565-2 A-C	W30-S3565	4-157	06/30/10	1.754	7.579	1.37	1.44	-5%	
W30-S3565 B-D	W30-S3565	4-157	06/30/10	7.405	7.405	1.31	1.29	2%	
W30-S3650-2 A-C	W30-S3650	4-158	04/27/10	2.122	7.774	1.59	1.76	-10%	
W170-N150-3 A-C	W170-N150	4-159	06/29/10	1.384	9.736	0.49	0.70	-30%	
W170-S5 A-C	W170-S5	4-160	06/29/10	14.198	14.198	0.58	0.58	0%	
W170-S5-2 B-D	W170-S5	4-160	06/29/10	8.495	16.261	0.70	0.72	-3%	
W170-S90-3 A-C	W170-S90	4-161	06/29/10	7.494	14.696	0.81	0.80	1%	
W170-S232-2 A-C	W170-S232	4-162	06/29/10	5.726	11.315	0.53	0.55	-4%	
W170-S232-2 B-D	W170-S232	4-162	06/29/10	8.946	11.588	0.53	0.60	-12%	
W170-S400 A-C	W170-S400	4-163	06/28/10	13.787	13.787	0.62	0.67	-7%	
W170-S560-4 A-C	W170-S560	4-164	06/28/10	1.481	12.300	0.63	0.65	-3%	
W170-S560-3 B-D	W170-S560	4-164	06/28/10	0.452	13.28	0.66	0.71	-7%	
W170-S700-2 A-C	W170-S700	4-165	06/28/10	1.841	21.634	0.75	0.79	-5%	

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
W170-S850-7 A-E	W170-S850	4-166	06/28/10	1.559	18.548	0.70	0.68	3%	
W170-S850-6 B-D	W170-S850	4-167	06/28/10	1.340	14.08	0.60	0.60	0%	
W170-S850-7 H-F	W170-S850	4-168	06/28/10	1.121	12.742	0.51	0.51	0%	
W170-S850-3 C-G	W170-S850	4-169	06/28/10	10.477	21.29	0.82	0.94	-13%	
W170-S1000-3 A-C	W170-S1000	4-170	06/28/10	2.141	25.054	0.92	0.95	-3%	
W170-S1150-4 A-E	W170-S1150	4-171	06/28/10	1.827	22.256	0.82	0.78	5%	
W170-S1150-4 B-D	W170-S1150	4-171	06/28/10	1.449	15.646	0.66	0.64	3%	
W170-S1150-2 H-F	W170-S1150	4-171	06/28/10	1.451	14.857	0.65	0.64	2%	
W170-S1150-2 C-G	W170-S1150	4-172	06/28/10	11.693	23.27	0.96	0.93	3%	
W170-S1300-4 A-C	W170-S1300	4-173	06/28/10	4.084	25.042	1.71	1.62	6%	
W170-S1445-4 A-C	W170-S1445	4-174	06/28/10	3.063	14.355	1.34	1.32	2%	
W170-S1445-2 B-D	W170-S1445	4-174	06/28/10	10.751	13.409	0.98	0.99	-1%	
W170-S1600-4 A-C	W170-S1600	4-175	06/28/10	1.821	16.586	1.45	1.91	-24%	
W170-S1779-3 A-C	W170-S1779	4-176	06/28/10	2.869	17.84	1.25	1.35	-7%	
W170-S1779-2 B-D	W170-S1779	4-176	06/28/10	12.793	15.928	1.17	1.21	-3%	
W170-S1950-3 A-C	W170-S1950	4-177	06/28/10	1.912	15.093	1.01	0.97	4%	
W170-S2060-2 A-C	W170-S2060	4-178	06/28/10	10.651	16.184	1.06	0.99	7%	
W170-S2060-2 B-D	W170-S2060	4-178	06/28/10	13.373	16.697	1.29	1.12	15%	
W170-S2180-2 A-C	W170-S2180	4-179	06/28/10	13.193	19.183	1.31	1.15	14%	
W170-S2275 A-C	W170-S2275	4-180	06/28/10	11.470	11.470	1.22	1.04	17%	
W170-S2275 B-D	W170-S2275	4-180	06/28/10	12.563	12.563	1.44	1.23	17%	
W170-S2350 A-C	W170-S2350	4-181	06/28/10	15.287	15.287	1.70	1.45	17%	
W170-S2350 B-D	W170-S2350	4-181	04/20/10	12.476	12.476	1.31	1.21	8%	
W170-S2425 A-C	W170-S2425	4-182	06/28/10	13.636	13.636	1.53	1.29	19%	
W170-S2425 B-D	W170-S2425	4-182	06/28/10	14.279	14.279	1.8	1.41	28%	
W170-S2520 A-C	W170-S2520	4-183	04/20/10	15.263	15.263	1.72	1.66	4%	
W170-S2685-2 A-C	W170-S2685	4-184	04/20/10	17.487	19.333	2.08	2.26	-8%	
W170-S2685-2 B-D	W170-S2685	4-184	04/20/10	12.751	14.614	1.82	1.88	-3%	

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
W170-S2833 A-C	W170-S2833	4-185	06/30/10	18.951	18.951	5.08	4.34	17%	
W170-S2833 B-D	W170-S2833	4-185	06/30/10	11.883	11.883	2.40	2.35	2%	
W170-S2916 A-C	W170-S2916	4-186	06/30/10	20.445	20.445	3.03	3.06	-1%	
W170-S2916 B-D	W170-S2916	4-186	06/30/10	11.722	11.722	2.10	2.18	-4%	
W170-S2998 A-C	W170-S2998	4-187	06/30/10	24.964	24.964	6.31	5.03	25%	
W170-S2998 B-D	W170-S2998	4-187	04/19/10	12.693	12.693	2.60	2.61	0%	
W170-S3080 A-C	W170-S3080	4-188	06/30/10	16.841	16.841	3.24	4.68	-31%	
W170-S3195 A-C	W170-S3195	4-189	06/28/10	15.963	15.963	2.87	2.78	3%	
W170-S3195 B-D	W170-S3195	4-189	06/28/10	11.760	11.760	1.82	1.87	-3%	
W170-S3310 A-C	W170-S3310	4-190	06/28/10	15.535	15.535	2.10	2.18	-4%	
W170-S3395 A-C	W170-S3395	4-191	06/28/10	12.915	12.915	4.19	2.58	62%	
W170-S3395 B-D	W170-S3395	4-191	06/28/10	8.286	8.286	1.83	1.67	10%	
W170-S3480 A-C	W170-S3480	4-192	06/28/10	14.421	14.421	4.25	3.24	31%	
W170-S3480 B-D	W170-S3480	4-192	06/28/10	11.036	11.036	2.27	2.28	0%	
W170-S3565 A-C	W170-S3565	4-193	06/16/10	9.109	9.109	1.86	1.77	5%	
W170-S3565 B-D	W170-S3565	4-193	06/30/10	7.945	7.945	1.47	1.44	2%	
W170-S3650-2 A-C	W170-S3650	4-194	04/27/10	2.147	9.792	1.61	1.80	-11%	
N780-E70 A-C	N780-E70	4-195	05/18/10	9.881	9.881	1.24	1.30	-5%	
N780-E70 B-D	N780-E70	4-195	05/18/10	9.866	9.866	1.23	1.32	-7%	
N460-E70-3 A-C	N460-E70	4-196	03/23/10	13.631	30.077	1.38	1.38	0%	
N460-E70-2 B-D	N460-E70	4-196	05/18/10	12.954	24.652	1.42	1.45	-2%	
N300-W170-2 A-C	N300-W170	4-197	06/01/10	10.927	33.187	1.41	1.63	-13%	
N300-W170-2 B-D	N300-W170	4-197	06/01/10	14.219	22.414	1.09	1.24	-12%	
N250-E220-2 A-E	N250-E220	4-198	05/13/10	9.259	32.886	2.27	2.74	-17%	
N250-E220-2 B-D	N250-E220	4-198	05/13/10	6.422	31.364	1.60	1.98	-19%	
N250-E220-2 H-F	N250-E220	4-198	05/13/10	5.601	24.026	1.33	1.64	-19%	
N250-E220 C-G	N250-E220	4-198	05/13/10	22.860	22.860	1.29	1.48	-13%	
N215-W500-2 A-C	N215-W500	4-199	06/01/10	9.066	27.395	1.19	1.33	-11%	

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
N215-W500-2 B-D	N215-W500	4-199	06/01/10	10.884	17.702	0.74	0.86	-14%	
N215-W620-2 A-C	N215-W620	4-200	06/01/10	6.588	22.806	0.85	1.03	-17%	
N140-E90-2 A-C	N140-E90	4-201	03/29/10	1.605	15.742	0.77	0.81	-5%	
N140-E90 B-D	N140-E90	4-201	03/29/10	16.966	16.966	0.79	0.87	-9%	
S90-W120 A-C	S90-W120	4-202	06/29/10	6.753	6.753	0.63	0.56	13%	
S90-W120 B-D	S90-W120	4-202	06/29/10	7.199	7.199	0.68	0.59	15%	
S90-W400-2 A-C	S90-W400	4-203	06/29/10	3.520	16.869	0.63	0.66	-5%	
S90-W400-2 B-D	S90-W400	4-203	06/29/10	8.436	16.33	0.61	0.64	-5%	
S90-W590-2 A-C	S90-W590	4-204	06/29/10	3.285	12.614	0.56	0.57	-2%	
S90-W590-2 B-D	S90-W590	4-204	06/29/10	7.934	11.741	0.51	0.55	-7%	
S90-W620 A-C	S90-W620	4-205	06/29/10	23.720	23.720	1.15	1.00	15%	
S90-W770 A-C	S90-W770	4-206	06/29/10	16.403	16.403	0.87	0.81	7%	
S90-W770-3 B-D	S90-W770	4-206	06/29/10	1.566	14.887	0.82	0.82	0%	
S90-W905 A-C	S90-W905	4-207	06/29/10	12.520	12.52	1.24	1.34	-7%	
S105-W920 A-C	S105-W920	4-208	06/29/10	1.702	1.702	1.17	1.68	-30%	
CORE-W10 A-C	CORE STORAGE	4-209	06/29/10	21.023	21.023	0.83	0.84	-1%	
CORE-W101 A-C	CORE STORAGE	4-209	04/20/10	24.335	24.335	1.24	1.24	0%	
CORE-W117 A-C	CORE STORAGE	4-209	06/29/10	22.109	22.109	1.10	1.07	3%	
CORE-W133 A-C	CORE STORAGE	4-209	06/29/10	18.611	18.611	0.85	0.84	1%	
CORE-W20 A-C	CORE STORAGE	4-209	06/29/10	19.840	19.84	0.84	0.85	-1%	
CORE-W30 A-C	CORE STORAGE	4-209	06/29/10	20.819	20.819	0.94	0.94	0%	
CORE-W51 A-C	CORE STORAGE	4-209	06/29/10	23.931	23.931	1.26	1.20	5%	
CORE-W62 A-C	CORE STORAGE	4-209	06/29/10	25.081	25.081	1.37	1.33	3%	
CORE-W73 A-C	CORE STORAGE	4-209	06/29/10	25.324	25.324	1.36	1.32	3%	
S700-E205-3 A-C	S700-E205	4-210	04/28/10	7.306	24.735	1.70	1.64	4%	
S700-E180 A-C	S700-E180	4-211	04/28/10	7.401	7.401	1.73	1.60	8%	
S700-E180 B-D	S700-E180	4-211	04/28/10	4.317	4.317	0.93	0.67	-4%	
S700-E55 A-C	S700-E55	2-212	11/12/09	4.134	4.134	0.85	0.78	9%	

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
S700-E55 B-D	S700-E55	2-212	11/12/09	4.142	4.142	0.83	0.80	4%	
S700-W98-2 A-C	S700-W98	4-213	04/28/10	7.215	21.697	1.45	1.36	7%	
S1000-E160 -3 A-C	S1000-E0160	4-214	04/28/10	1.853	1.853	0.72	0.73	-1%	
S1000-E120-3 A-C	S1000-E120	4-215	04/28/10	5.617	14.057	0.91	0.90	1%	
S1000-E58-4 A-C	S1000-E58	4-216	04/28/10	6.261	21.727	1.14	1.13	1%	
S1000-E58-2 B-D	S1000-E58	4-216	04/28/10	15.915	17.459	0.91	0.97	-6%	
S1000-W98-2 A-C	S1000-W98	4-217	04/28/10	11.207	29.955	1.79	1.79	0%	
S1300-E160 A-C	S1300-E160	4-218	04/28/10	19.042	19.042	1.45	1.41	3%	
S1300-E120 A-C	S1300-E120	4-219	04/28/10	12.763	12.763	0.82	0.83	-1%	
S1300-E24 A-C	S1300-E24	4-220	04/28/10	19.981	19.981	1.15	1.16	-1%	
S1300-W100-3 A-C	S1300-W100	4-221	04/28/10	7.884	31.887	1.93	1.95	-1%	
S1600-E170 A-C	S1600-E170	4-222	04/28/10	14.865	14.865	0.94	0.95	-1%	
S1600-E110 A-C	S1600-E110	4-223	04/28/10	13.588	13.588	0.86	0.89	-3%	
S1950-E113-4 A-C	S1950-E113	4-224	04/26/10	6.765	10.641	0.71	0.69	3%	
S1950-E281-3 A-C	S1950-E281	4-225	04/26/10	12.573	19.115	0.99	1.02	-3%	
S1950-E284-3 A-C	S1950-E284	4-226	04/26/10	12.775	19.387	1.03	1.04	-1%	
S2180-E55-3 A-C	S2180-E55	4-227	04/28/10	1.949	12.796	1.81	2.25	-20%	
S2180-E55 B-D	S2180-E55	4-227	04/28/10	11.563	11.563	1.66	2.20	-25%	
S2180-E220 A-C	S2180-E220	4-228	04/26/10	12.423	12.423	1.32	1.27	4%	
S2180-E220 B-D	S2180-E220	4-228	04/26/10	13.357	13.357	1.47	1.46	1%	
S2180-W100-2 A-C	S2180-W100	4-229	04/28/10	17.028	17.154	2.31	2.17	6%	
S2180-W100-2 B-D	S2180-W100	4-229	04/28/10	10.184	10.325	1.35	1.16	16%	
S2520-E220 A-C	S2520-E220	4-230	04/26/10	16.683	16.683	1.49	1.43	4%	
S2520-E220 B-D	S2520-E220	4-230	04/26/10	16.877	16.877	1.53	1.54	-1%	
S2520-W100 A-C	S2520-W100	4-231	04/28/10	16.166	16.166	1.78	1.67	7%	
S2520-W100 B-D	S2520-W100	4-231	03/04/10	15.623	15.623	1.94	1.67	16%	
S2750-E55 A-C	S2750-E55	4-232	04/27/10	16.681	16.681	3.55	2.99	19%	
S2750-E55 B-D	S2750-E55	4-232	04/27/10	11.728	11.728	1.91	1.78	7%	

Table 4-1 (Continued) Access Drifts Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
S2750-E220 A-C	S2750-E220	4-233	04/26/10	17.971	17.971	2.03	4.65	-56%	
S2750-E220 B-D	S2750-E220	4-233	04/26/10	11.534	11.534	1.53	1.52	1%	
S2750-E410 A-C	S2750-E410	4-234	04/26/10	16.326	16.326	2.97	2.48	20%	
S2750-E410 B-D	S2750-E410	4-234	04/26/10	12.675	12.675	1.90	1.82	4%	
S2750-E485 A-C	S2750-E485	4-235	09/15/09	3.710	3.71	1.93	1.83	5%	
S2750-W93 A-C	S2750-W93	4-236	04/27/10	18.468	18.468	3.91	3.52	11%	
S2750-W93 B-D	S2750-W93	4-236	04/27/10	9.246	9.246	1.52	1.57	-3%	
S3080-E55 A-C	S3080-E55	4-237	04/27/10	15.329	15.329	2.14	2.22	-4%	
S3080-E55-2 B-D	S3080-E55	4-237	04/27/10	8.613	10.272	1.34	1.44	-7%	
S3080-E220-2 A-C	S3080-E220	4-238	04/26/10	11.494	14.199	2.20	2.08	6%	
S3080-E220 B-D	S3080-E220	4-238	04/26/10	11.794	11.794	1.46	1.39	5%	
S3080-W100 A-C	S3080-W100	4-239	04/27/10	16.200	16.2	3.41	2.78	23%	
S3080-W100 B-D	S3080-W100	4-239	04/27/10	11.166	11.166	1.91	1.88	2%	
S3310-E55 A-C	S3310-E55	4-240	04/26/10	15.690	15.69	2.26	2.12	7%	
S3310-E55 B-D	S3310-E55	4-240	04/26/10	11.415	11.415	1.44	1.41	2%	
S3310-E220 A-C	S3310-E220	4-241	04/27/10	16.020	16.02	3.18	2.48	28%	
S3310-E220 B-D	S3310-E220	4-241	04/27/10	13.514	13.514	1.62	1.66	-2%	
S3310-W100-3 A-C	S3310-W100	4-242	04/26/10	10.846	17.124	3.60	2.76	30%	
S3310-W100 B-D	S3310-W100	4-242	04/26/10	11.87	11.87	1.68	1.73	-3%	
S3650-E0055-2 A-C	S3650-E55	4-243	04/27/10	2.086	5.419	1.58	1.75	-10%	
S3650-E220-2 A-C	S3650-E220	4-244	09/16/09	1.169	4.526	2.08	1.63	28%	
S3650-W100-2 A-C	S3650-W100	4-245	04/27/10	2.284	8.301	1.78	1.82	-2%	
S3650-W100 B-D	S3650-W100	4-245	04/27/10	7.121	7.121	1.42	1.58	-10%	

Table 4-1 (Continued) Access Drifts Data Analysis

JOINT METERS

Field Tag	Location	Figure Number	Date of Last Reading	Cumulative Displacement (inches)	Dilation Rate 2009 to 2010 (in/year)	Dilation Rate 2008 to 2009 (in/year) [1]	Rate Change Percent[1]	Comments
51X-CG-02703	S1950-E300 Overcast-NE	4-246	06/16/10	0.683	0.02	0.02	0%	
51X-CG-02706	S1950-E300 Overcast-SW	4-246	06/16/10	1.591	0.10	0.09	11%	
51X-CG-02707	S1950-E300 Overcast-NW	4-246	06/16/10	1.600	0.08	0.09	-11%	
51X-CG-02708	S1950-E300 Overcast-SE	4-246	06/16/10	0.758	0.02	0.02	0%	
51X-CG-02713	E140-S2964	4-247	06/16/10	0.590	-0.25	-0.10	150%	
51X-CG-02876-2	E140-S1505	4-248	06/16/10	0.029	0.03	N/A	N/A	Instrument installed this reporting period.
51X-CG-02883-2	E140-S1529	4-249	06/16/10	0.181	0.33	N/A	N/A	Instrument installed this reporting period.
51X-CG-02885-2	E140-S1545	4-250	06/16/10	0.296	0.32	N/A	N/A	Instrument installed this reporting period.
51X-CG-02875-2	E140-S1795	4-251	06/16/10	0.081	0.13	N/A	N/A	Instrument installed this reporting period.
51X-CG-02714	W30-S2920	4-252	06/28/10	0.598	0.76	N/A	N/A	Instrument installed this reporting period.
51X-CG-02715	W30-S2932	4-253	06/28/10	0.693	0.89	N/A	N/A	Instrument installed this reporting period.
51X-CG-02716	W170-S2678	4-254	06/21/10	0.043	0.07	N/A	N/A	Instrument installed this reporting period.
51X-CG-02717	W170-S2687	4-255	06/21/10	0.559	0.82	N/A	N/A	Instrument installed this reporting period.

[1] N/A-Insufficient data available to perform calculation.

ROCKBOLT LOAD CELLS

Field Tag	Location	Figure Number	Date of Initial Reading	Date of Last Reading	Load (kips)	Comments
51X-WG-00221	S1300-E120	4-256	10/23/96	06/28/10	9.512	
51X-WG-00222	S1300-E160	4-256	10/23/96	06/28/10	46.731	
51X-WG-00223	S1600-E150	4-257	02/18/96	06/28/10	9.429	
51X-WG-00218	E140-S775	4-258	06/26/97	06/28/10	43.094	
51X-WG-00215-2	E140-S901	4-258	10/21/09	06/28/10	26.054	
51X-WG-00219	E140-S975	4-258	06/26/97	06/28/10	38.785	
51X-WG-00214	E140-S910 EAST	4-258	06/26/97	06/28/10	47.503	
51X-WG-00216	E140-S910 EAST	4-258	06/26/97	06/28/10	44.136	
51X-WG-00217	E140-S910 WEST	4-258	06/26/97	06/28/10	61.183	

Table 4-1 (Continued) Access Drifts Data Analysis

ROCKBOLT LOAD CELLS (Continued)

Field Tag	Location	Figure Number	Date of Initial Reading	Date of Last Reading	Load (kips)	Comments
51X-WG-00220	E140-S1023	4-258	10/23/96	06/28/10	58.249	
51X-WG-00293	E140-S1550	4-259	03/17/04	06/16/10	50.312	
51X-WG-00294	E140-S1775	4-260	03/17/04	06/16/10	43.721	
51X-WG-00295-2	E140-S2916	4-261	03/18/10	06/16/10	6.786	
51X-WG-00296-2	E140-S2916	4-261	03/18/10	06/16/10	39.441	

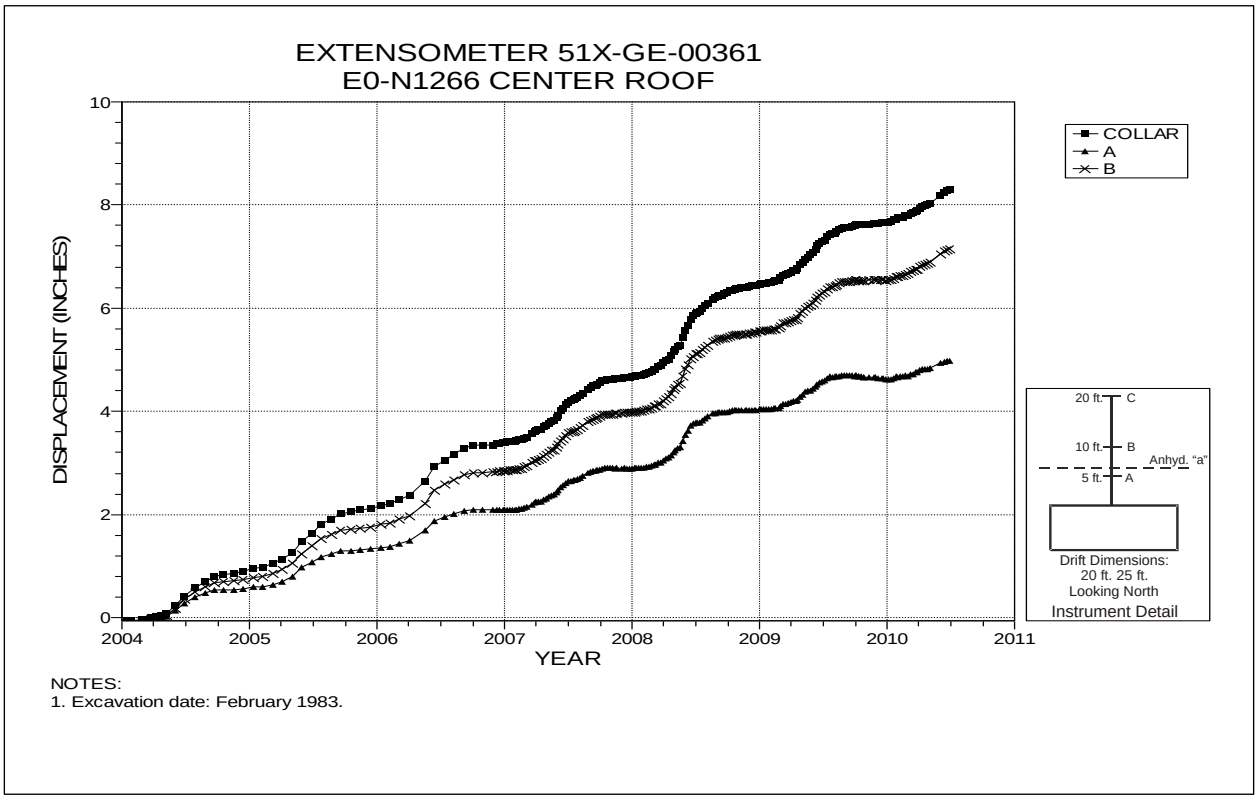


Figure 4-1 Extensometer 51X-GE-00361
E0 N1266 – Roof

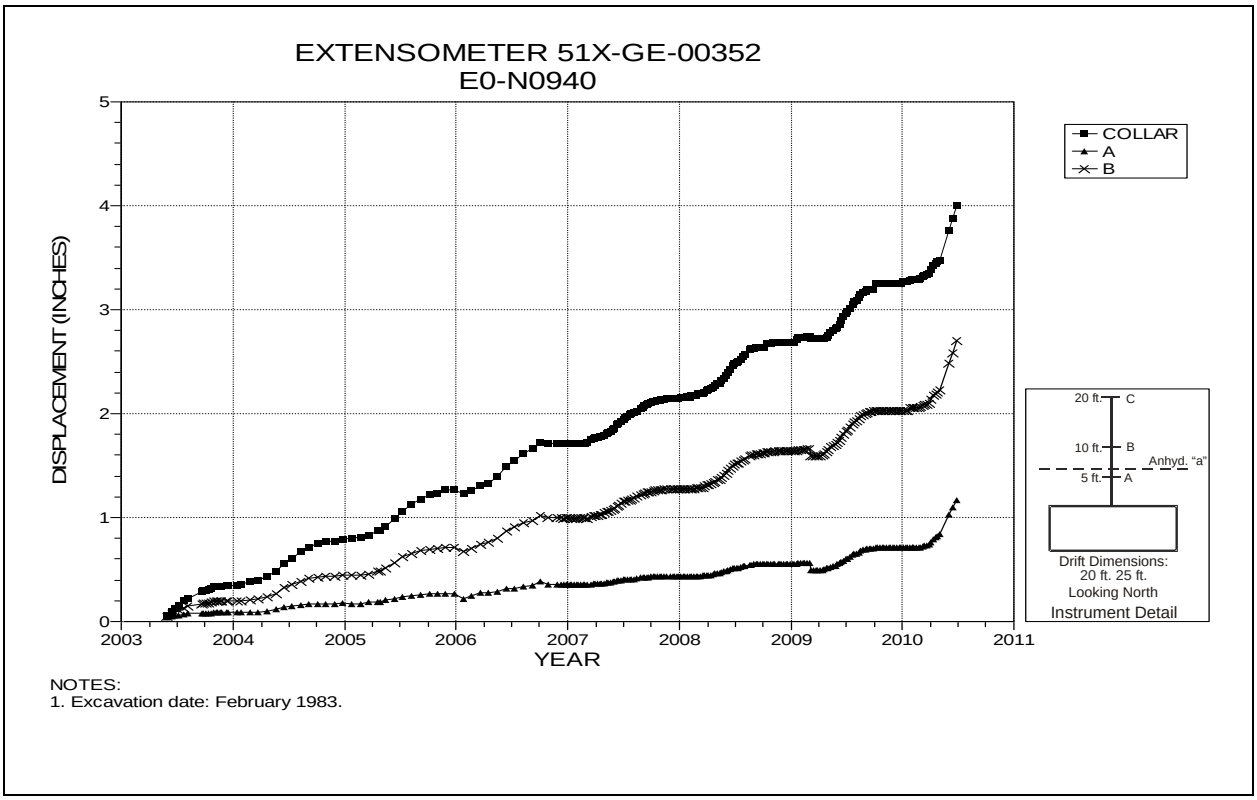


Figure 4-2 Extensometer 51X-GE-00352
E0 N940 – Roof

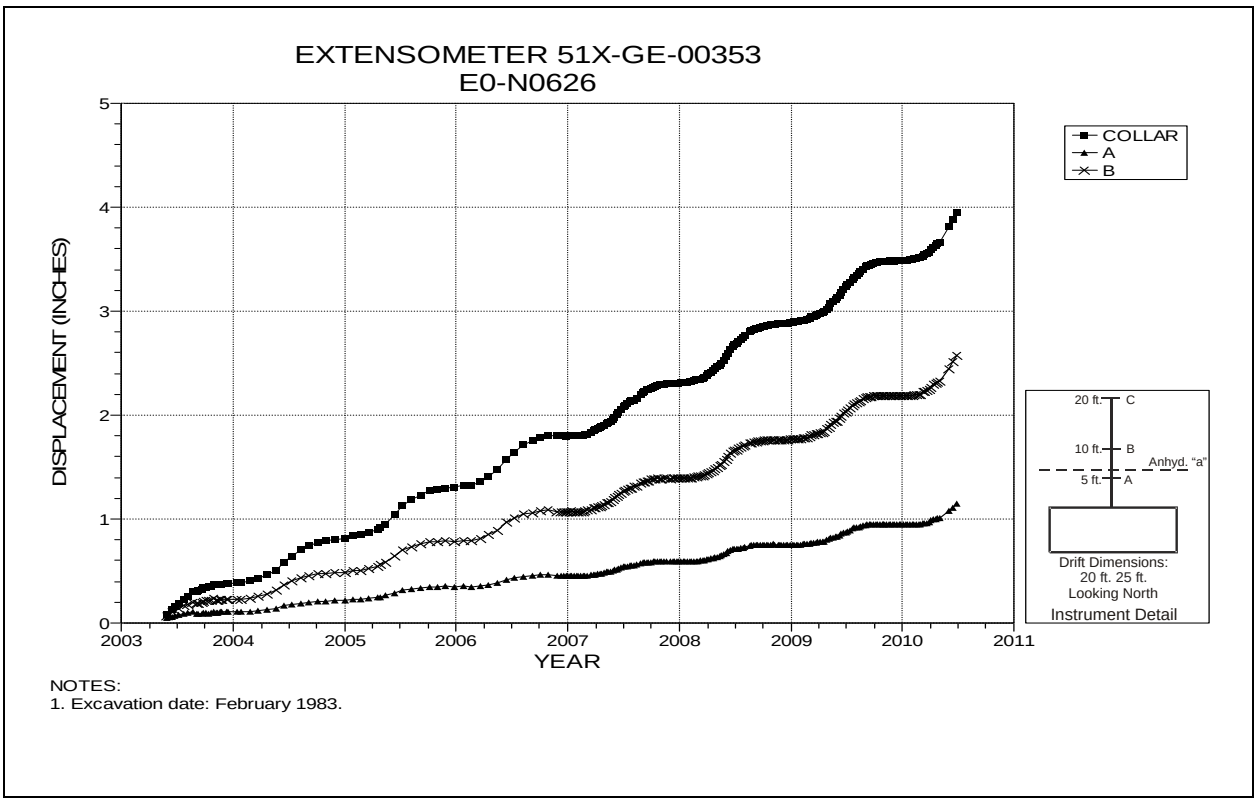


Figure 4-3 Extensometer 51X-GE-00353
E0 N626 – Roof

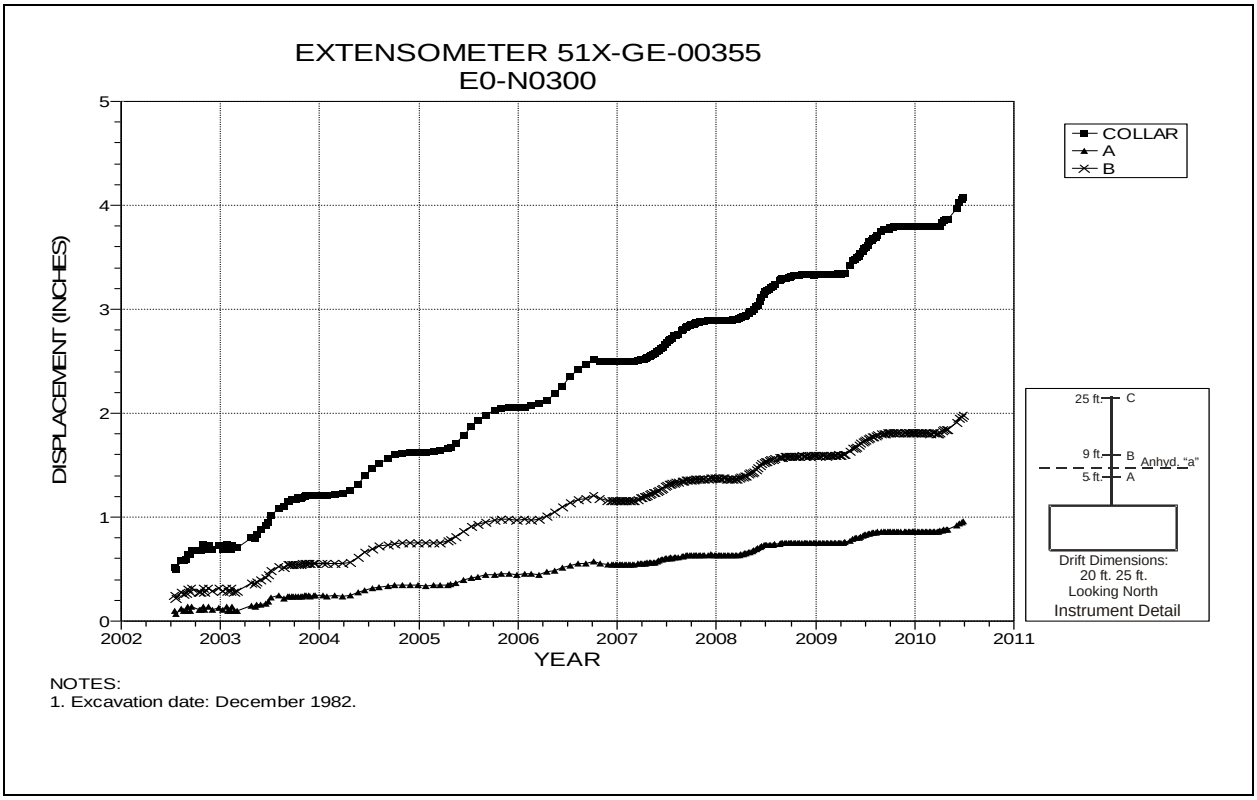


Figure 4-4 Extensometer 51X-GE-00355
E0 N300 – Roof

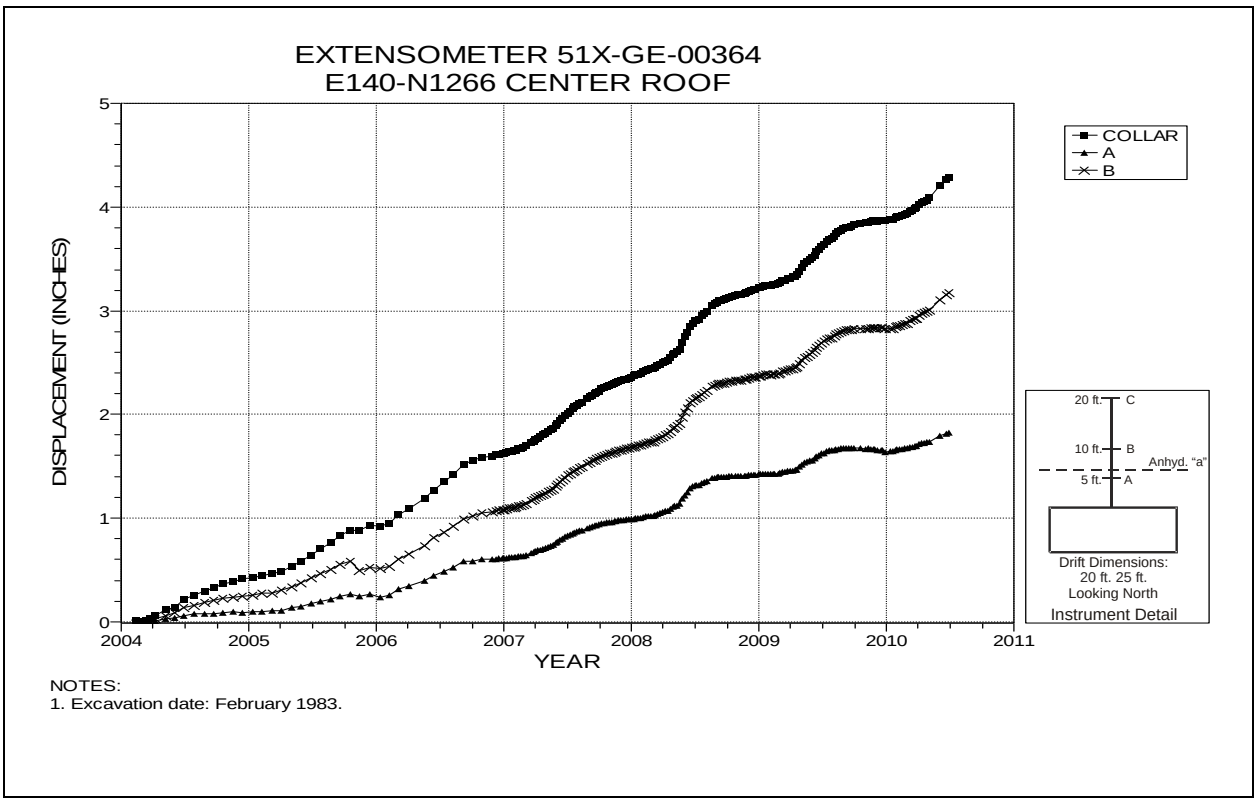


Figure 4-5 Extensometer 51X-GE-00364
E140 N1266 – Roof

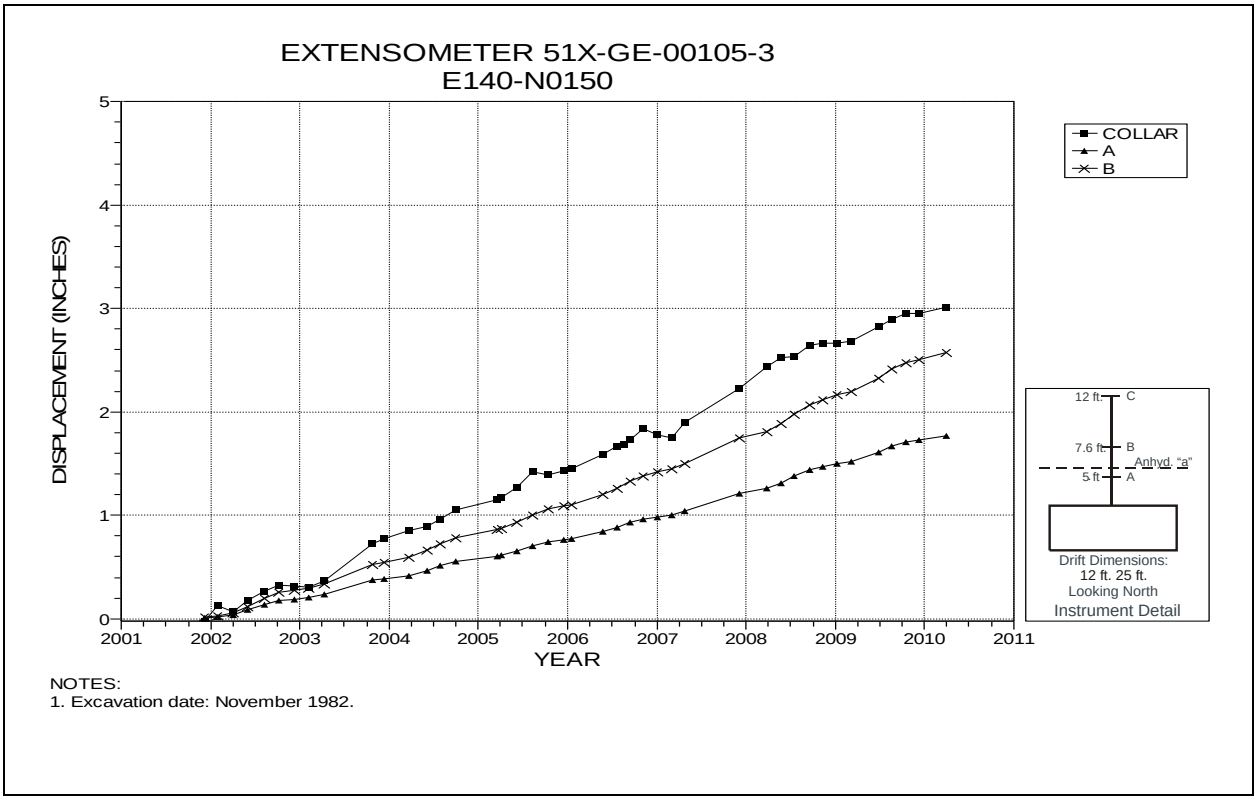


Figure 4-6 Extensometer 51X-GE-00105-3
E140 N150 – Roof

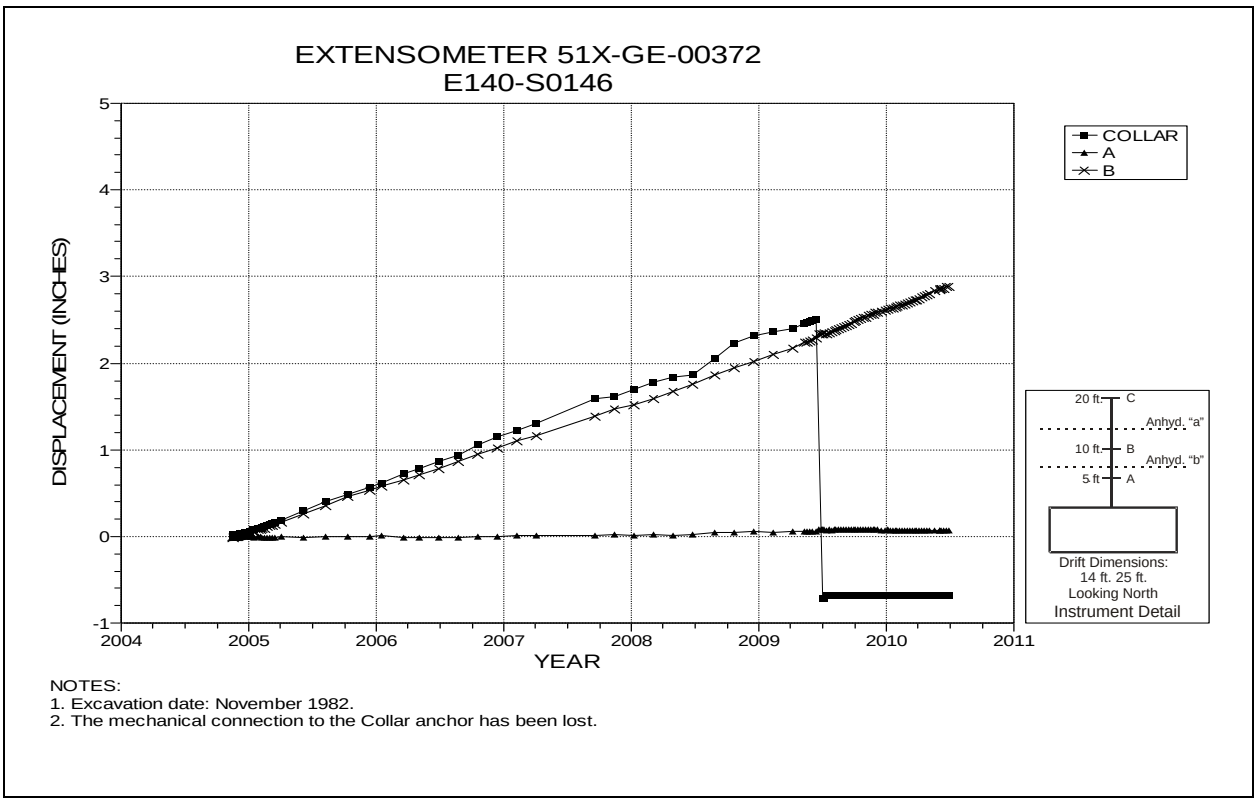


Figure 4-7 Extensometer 51X-GE-00372
E140 at S146 – Roof

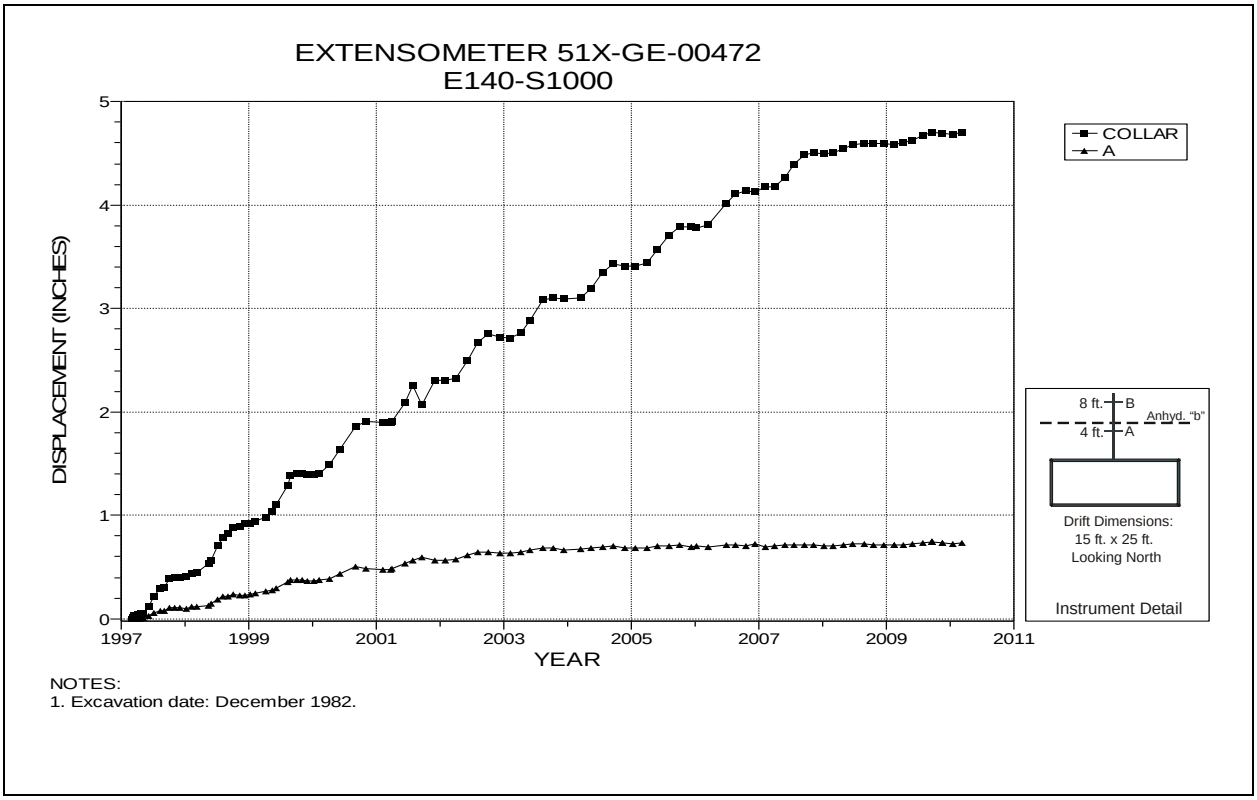


Figure 4-8 Extensometer 51X-GE-00472
E140 S1000 – Roof

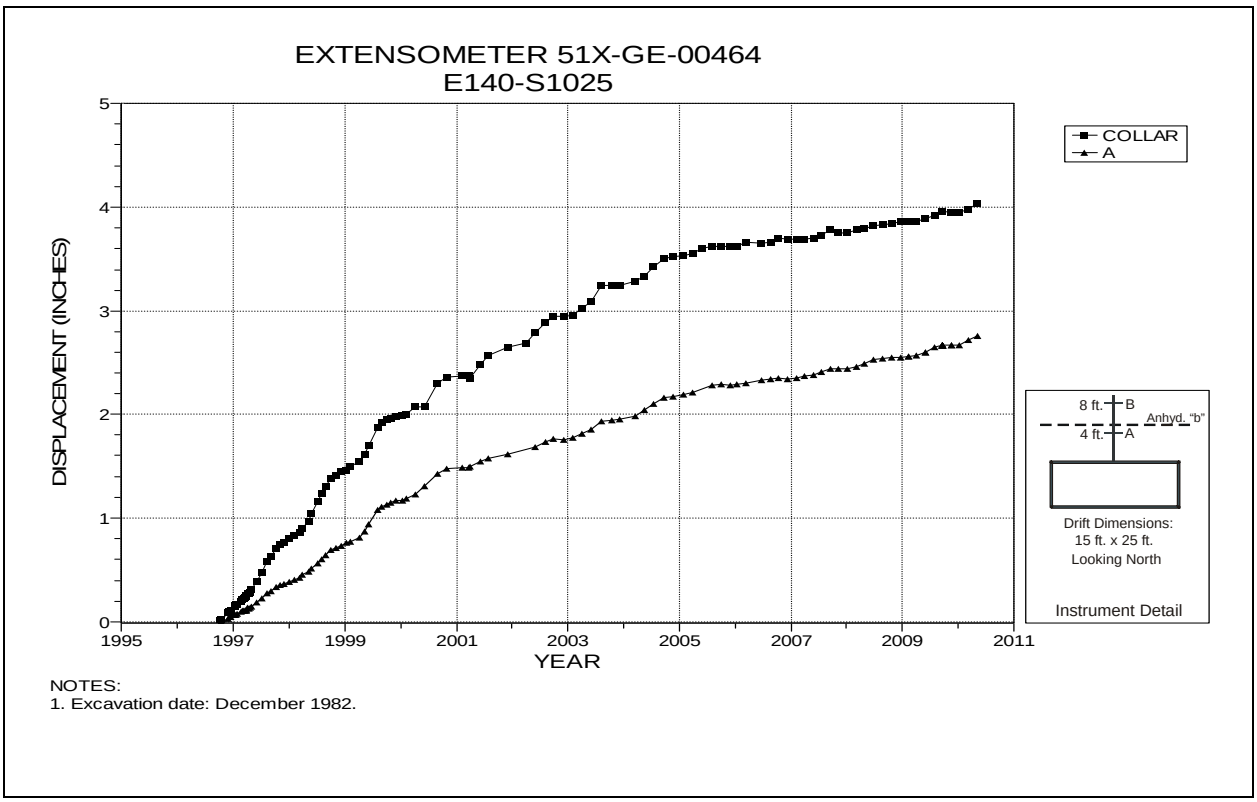


Figure 4-9 Extensometer 51X-GE-00464
E140 S1025 – Roof

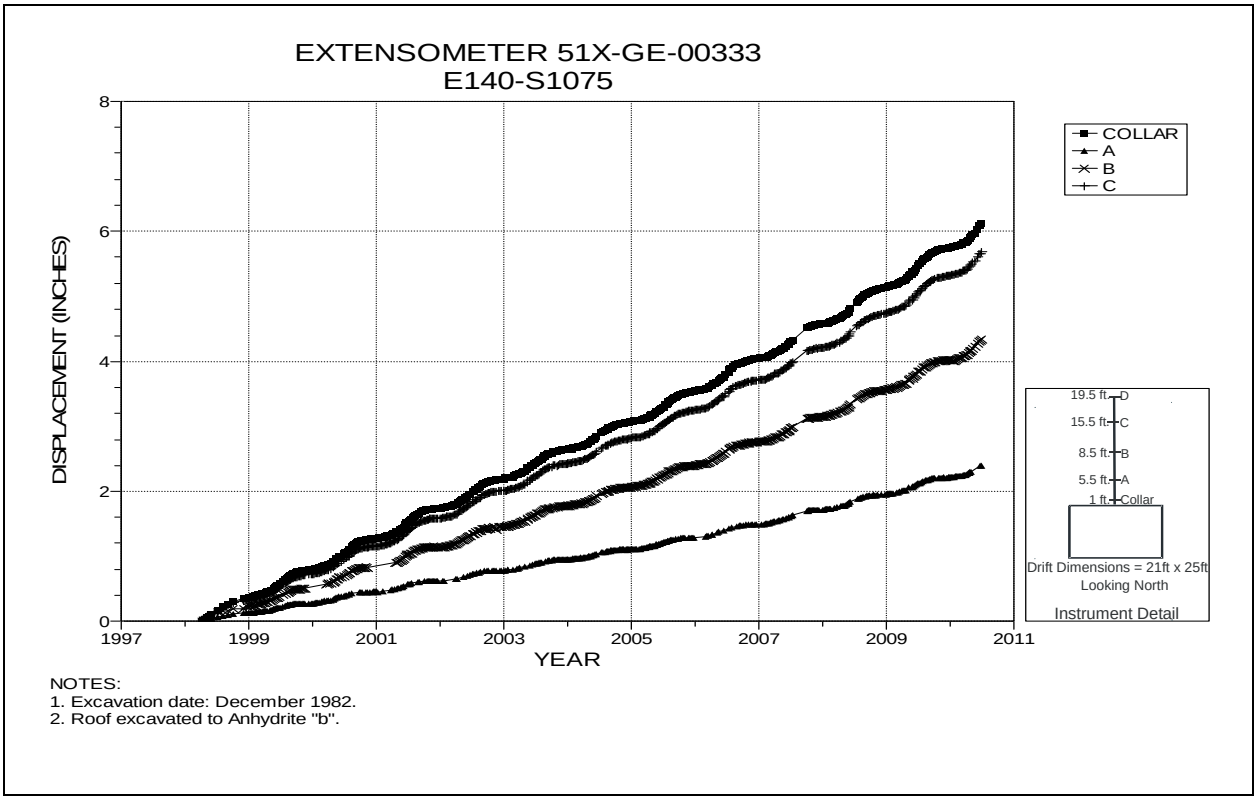


Figure 4-10 Extensometer 51X-GE-00333
E140 S1075 – Roof

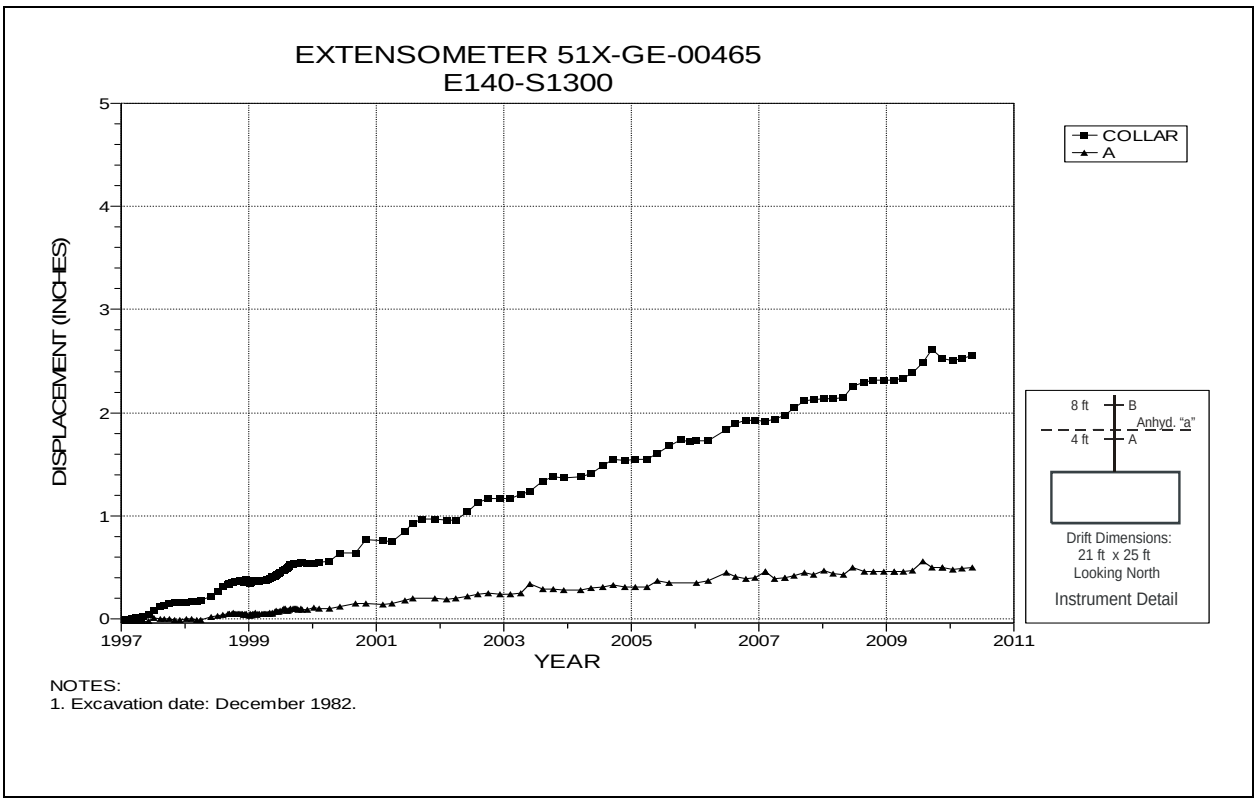


Figure 4-11 Extensometer 51X-GE-00465
E140 S1300 – Roof

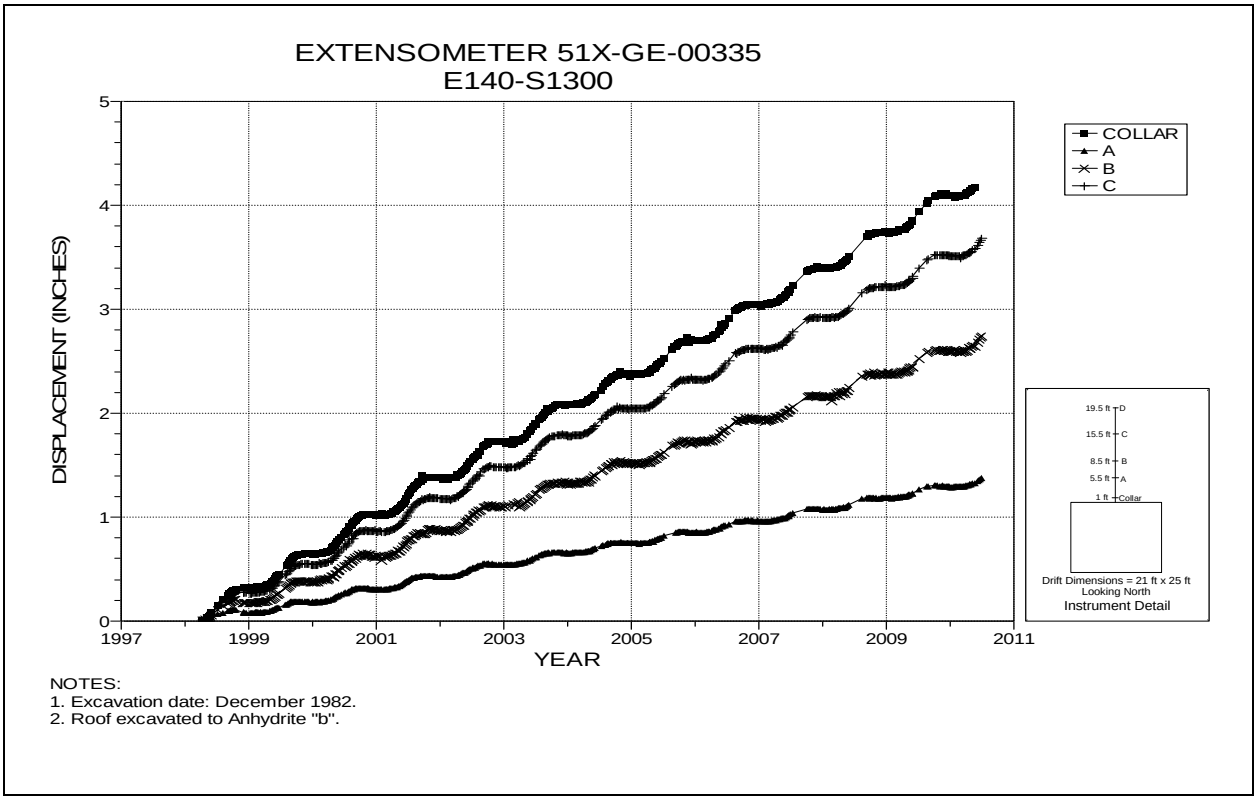


Figure 4-12 Extensometer 51X-GE-00335
E140 S1300 – Roof

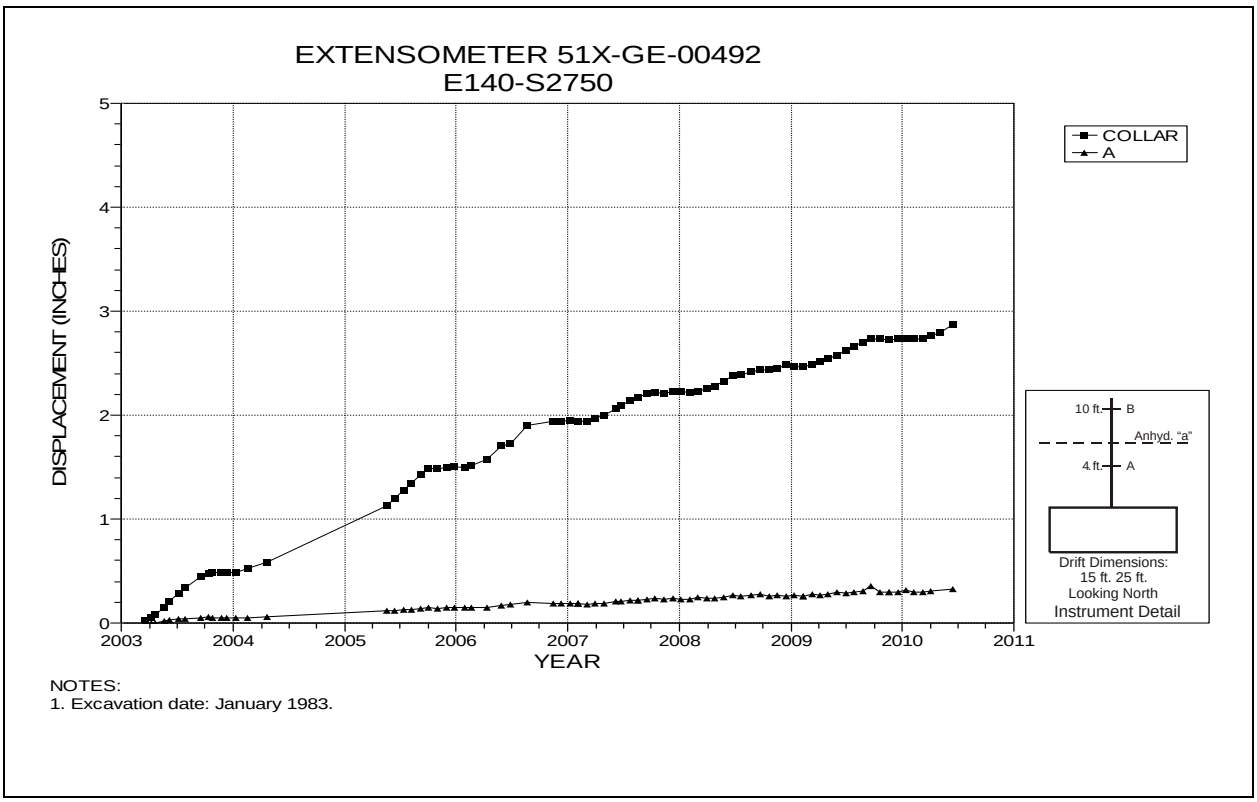


Figure 4-13 Extensometer 51X-GE-00492
E140 S2750 – Roof

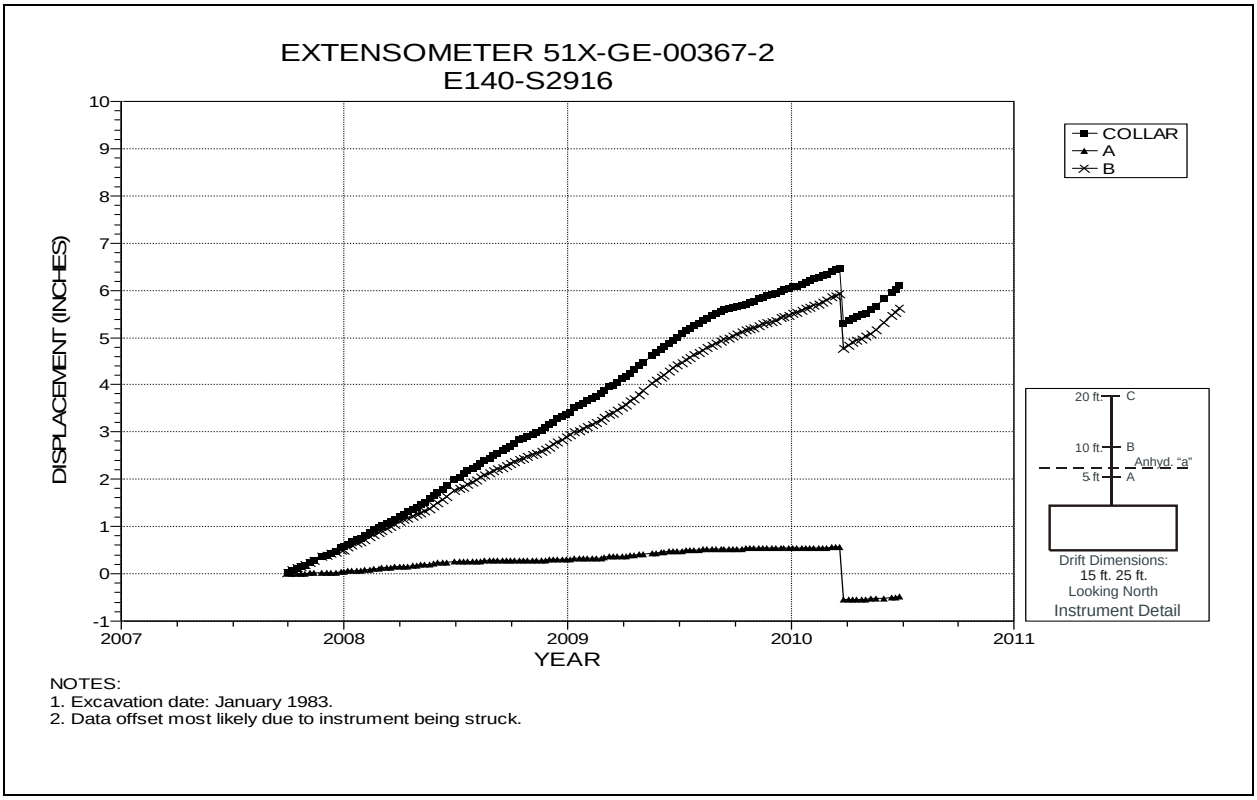


Figure 4-14 Extensometer 51X-GE-00367-2
E140 S2916 – Roof

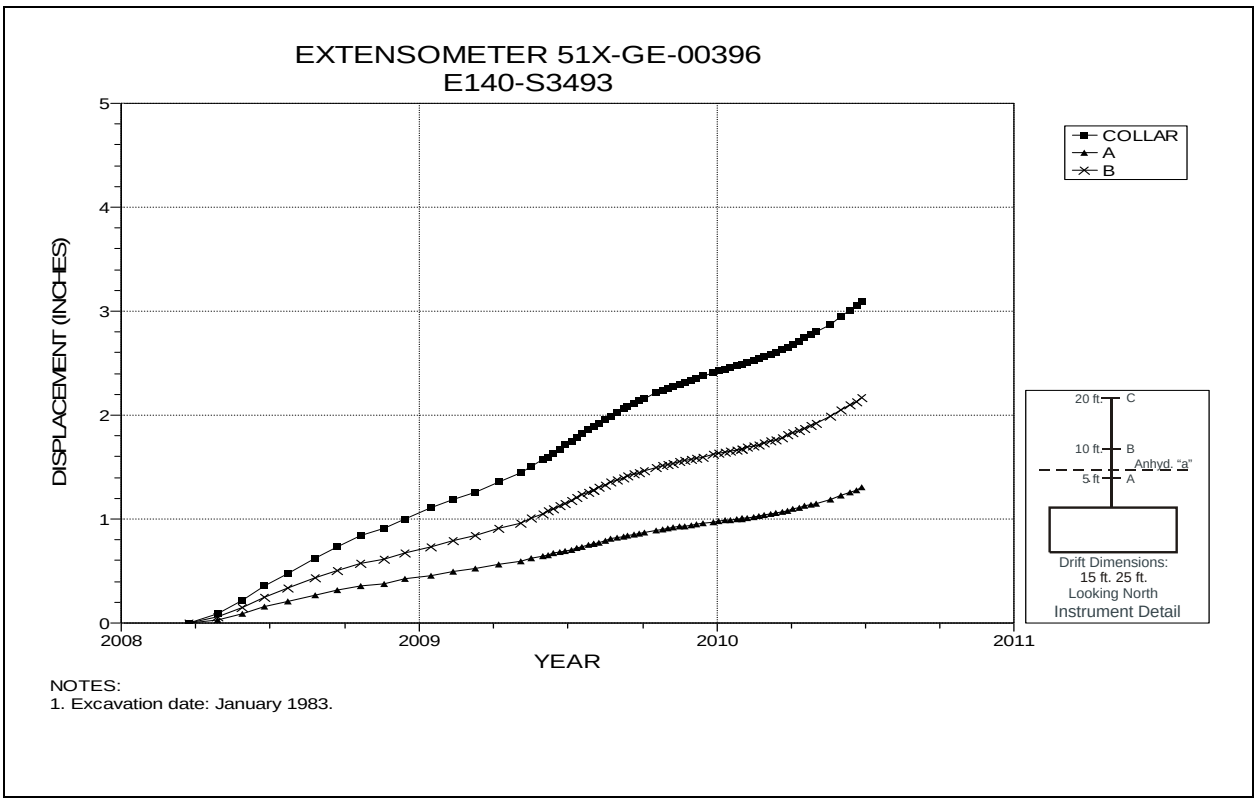


Figure 4-15 Extensometer 51X-GE-00396
E140 S3493 – Roof

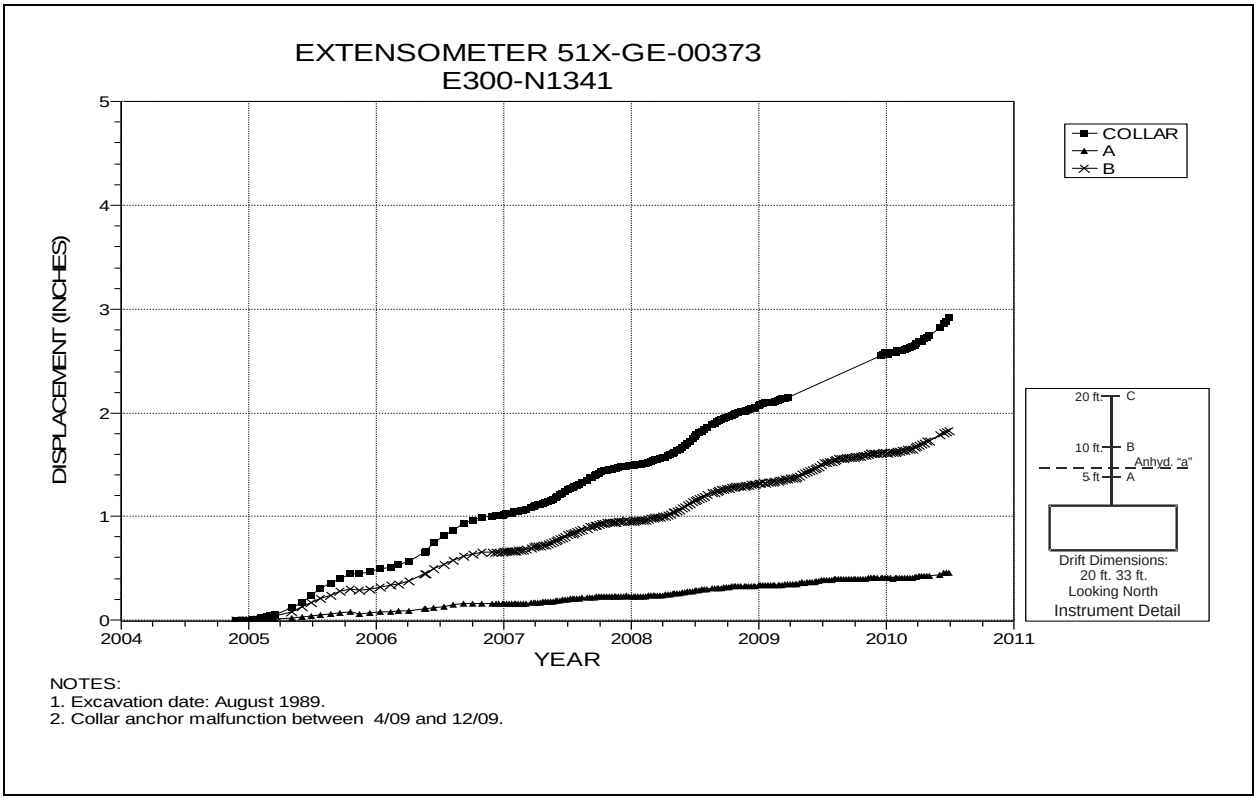


Figure 4-16 Extensometer 51X-GE-00373
E300 N1341 – Roof

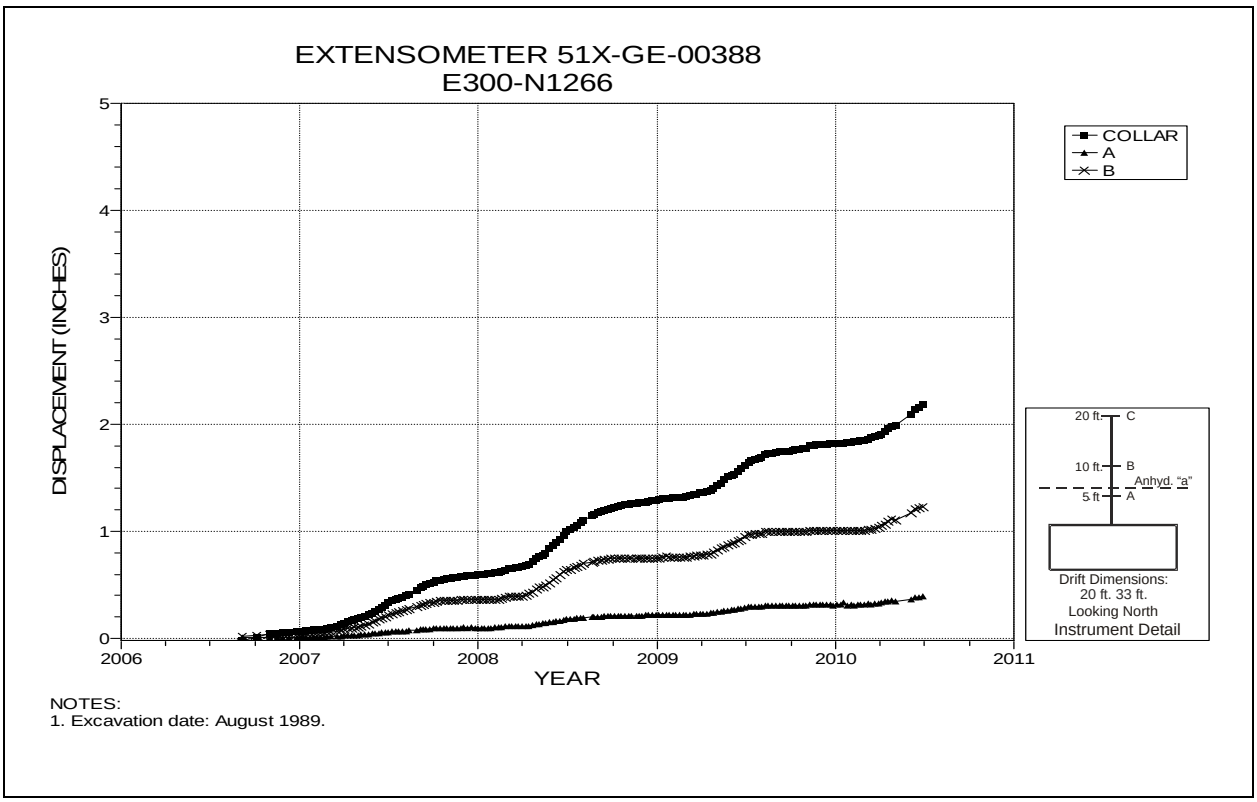


Figure 4-17 Extensometer 51X-GE-00388
E300 N1266 – Roof

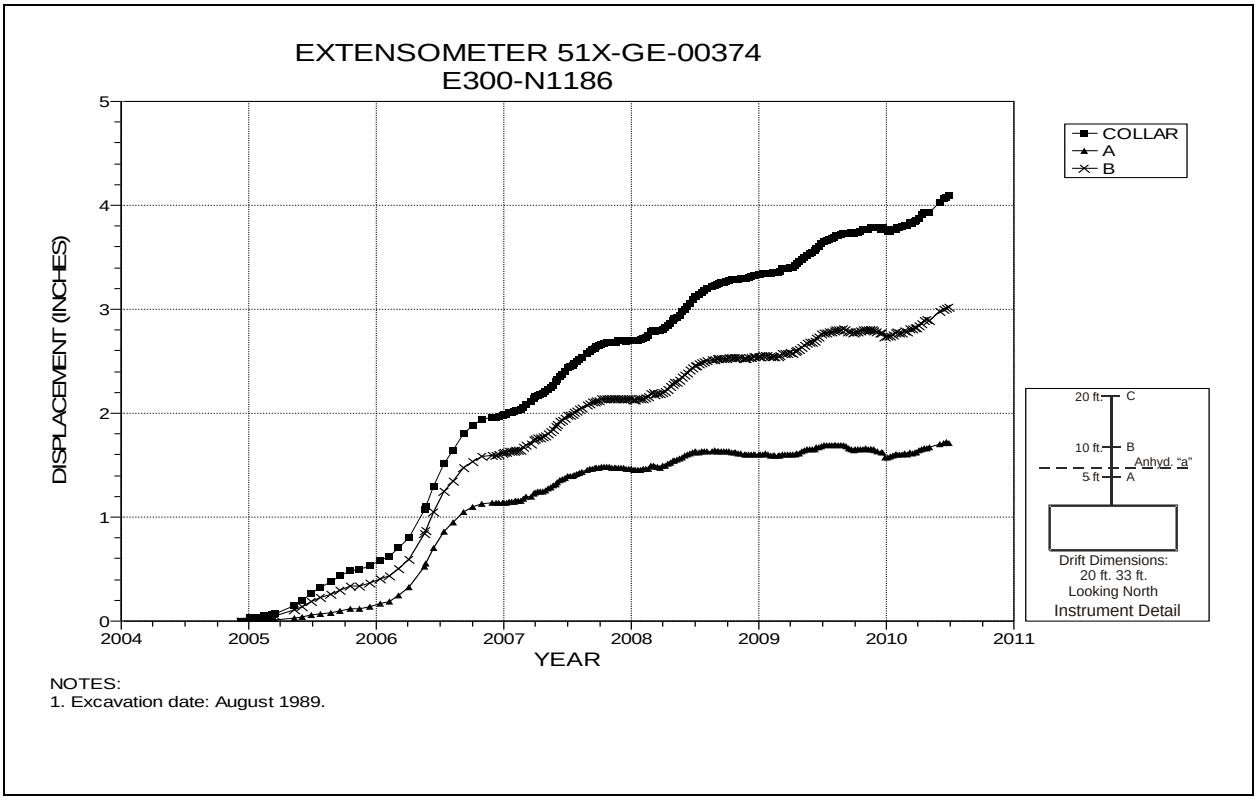


Figure 4-18 Extensometer 51X-GE-00374
E300 N1186 – Roof

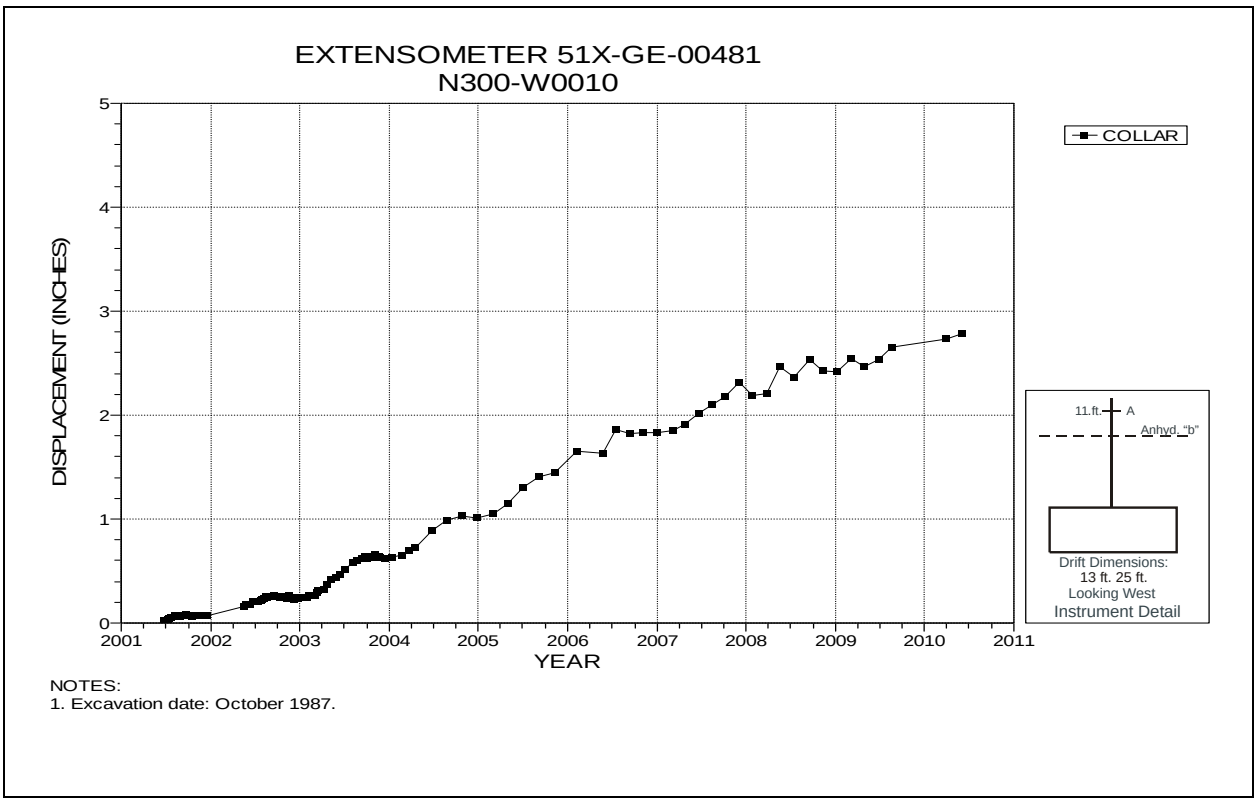


Figure 4-19 Extensometer 51X-GE-00481
N300 W10 – Roof

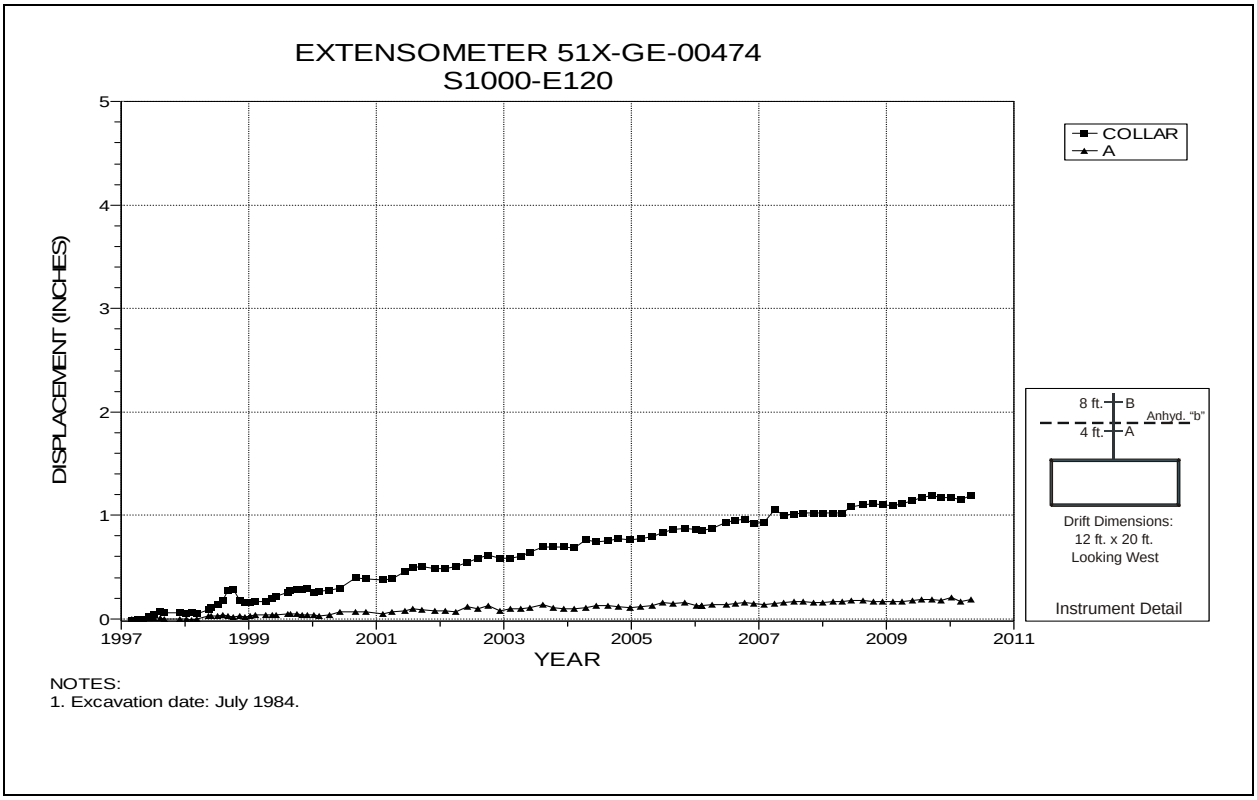


Figure 4-20 Extensometer 51X-GE-00474
S1000 E120 – Roof

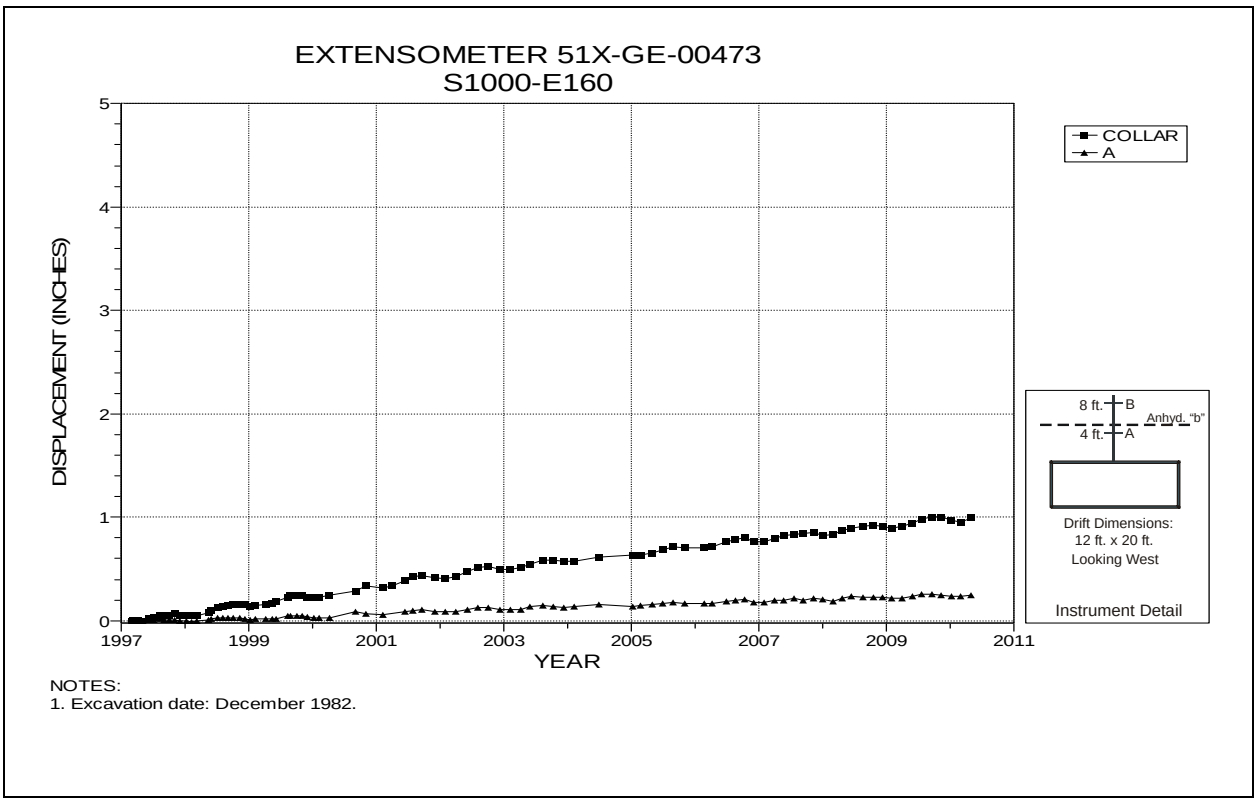


Figure 4-21 Extensometer 51X-GE-00473
S1000 E160 – Roof

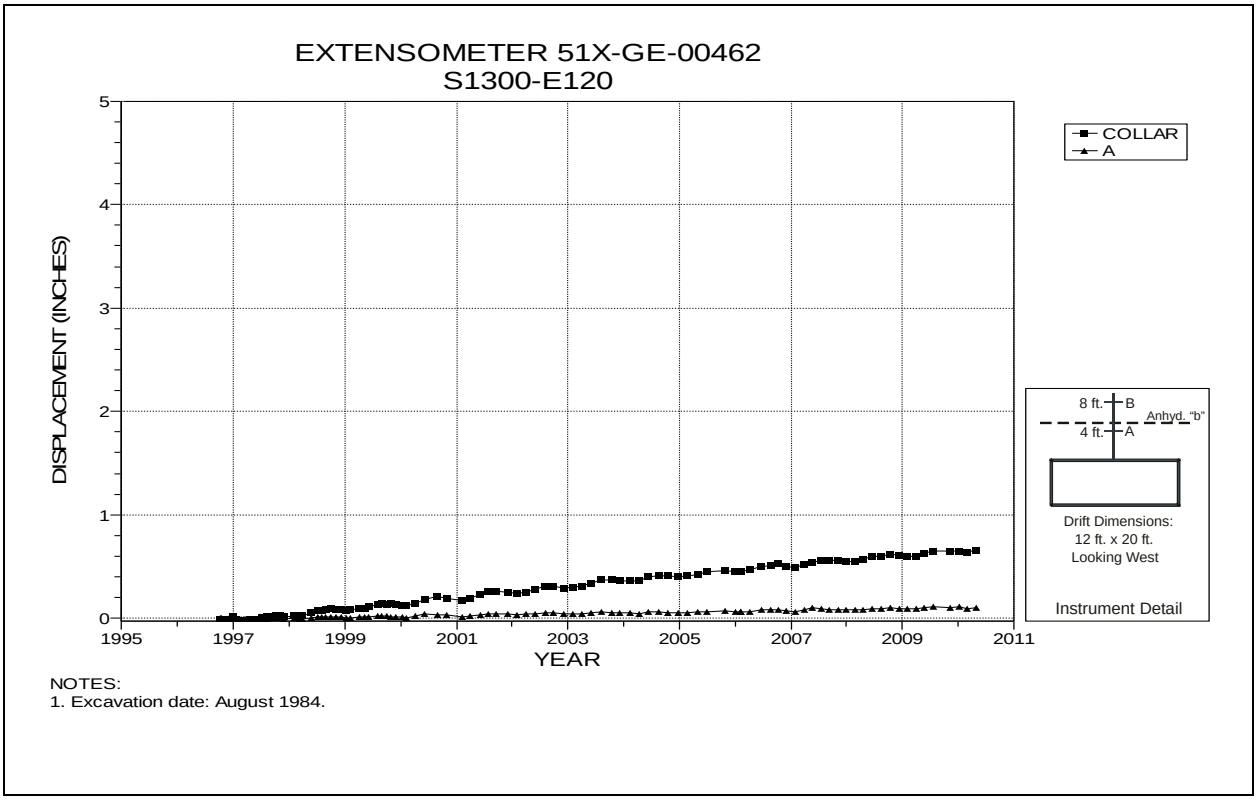


Figure 4-22 Extensometer 51X-GE-00462
S1300 E120 – Roof

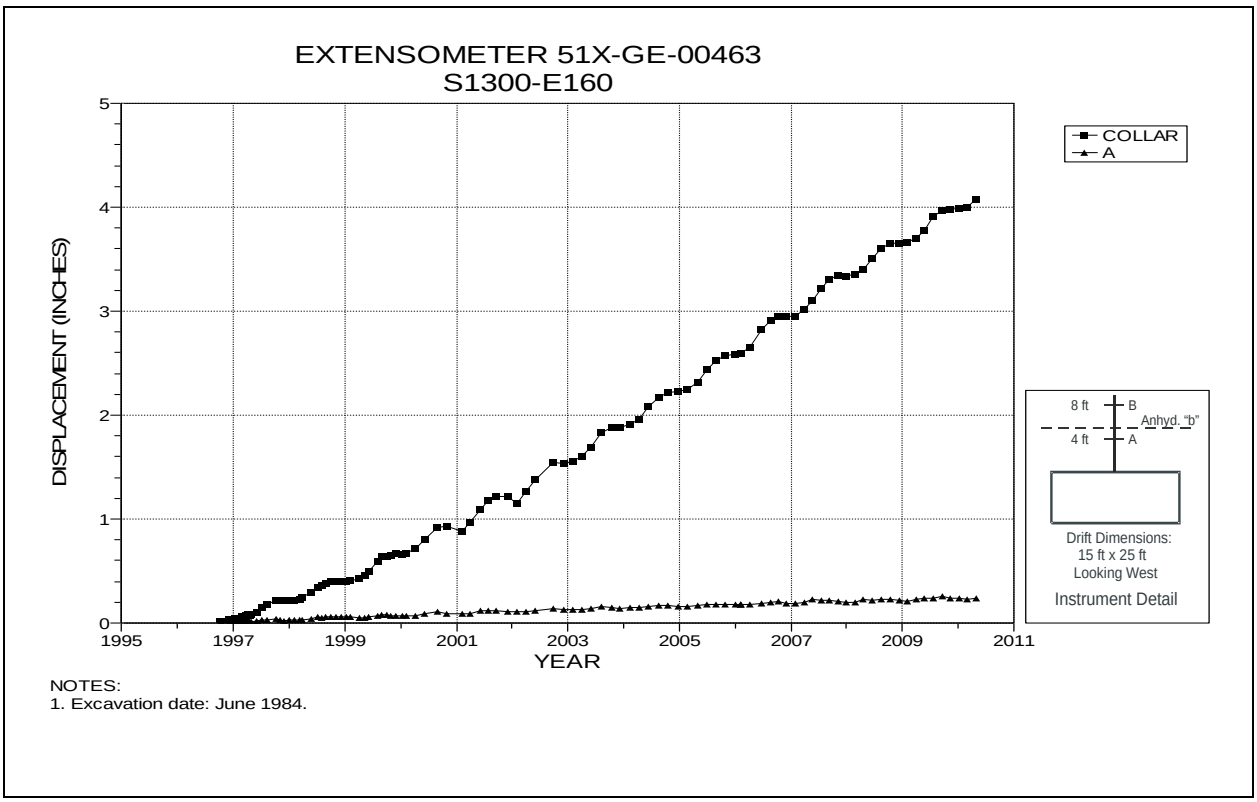


Figure 4-23 Extensometer 51X-GE-00463
S1300 E160 – Roof

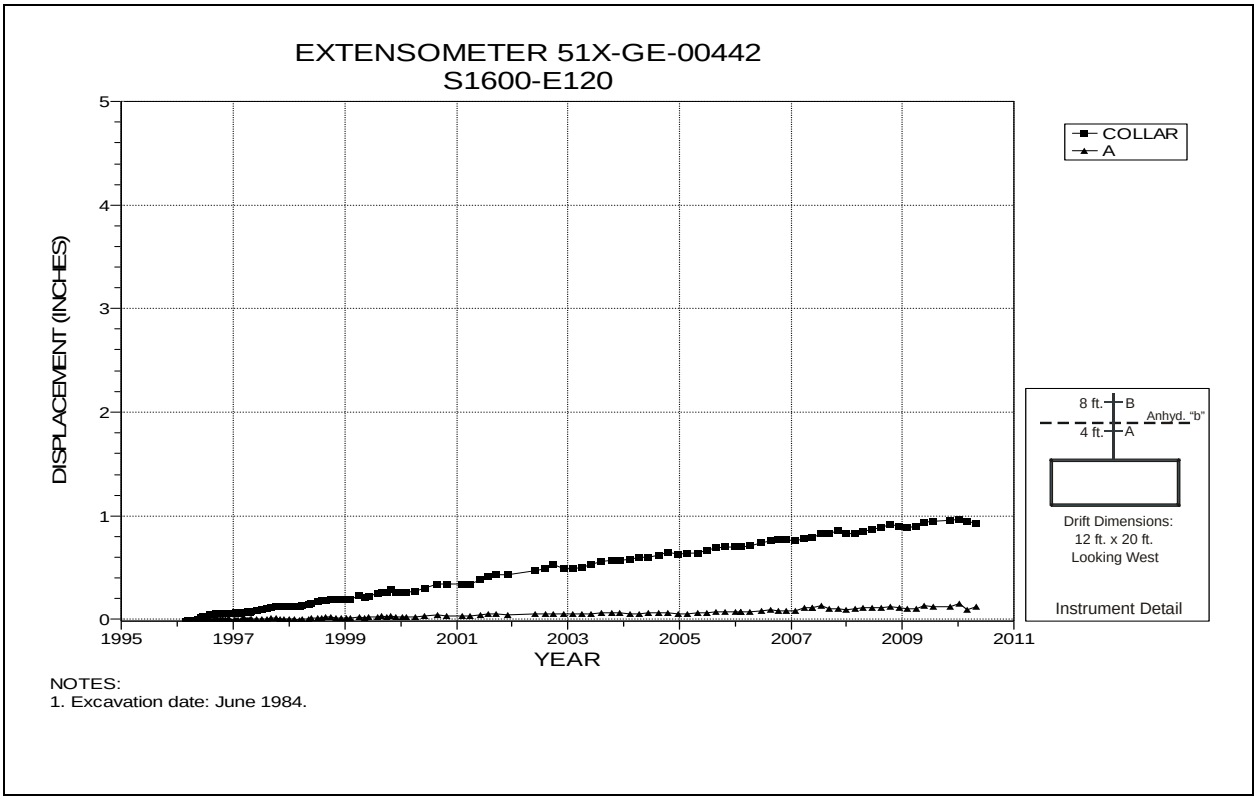


Figure 4-24 Extensometer 51X-GE-00442
S1600 E120 – Roof

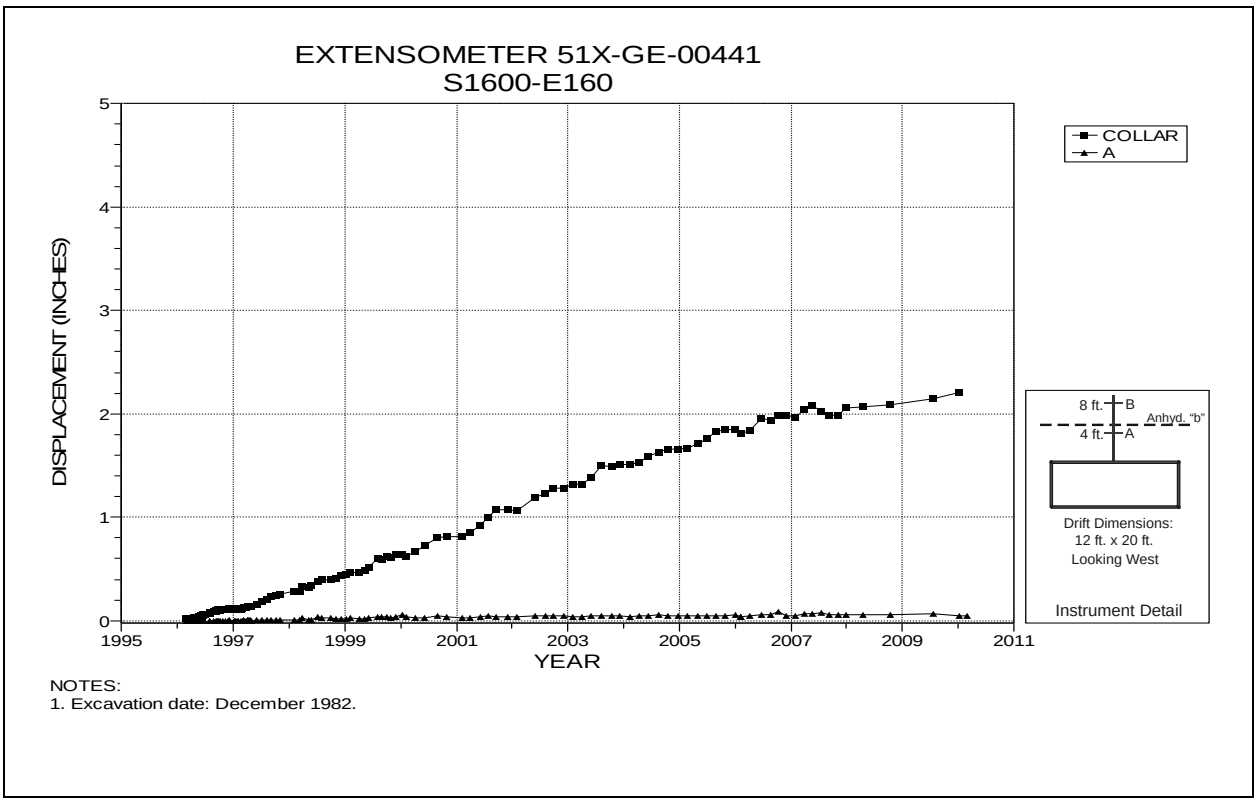


Figure 4-25 Extensometer 51X-GE-00441
S1600 E160 – Roof

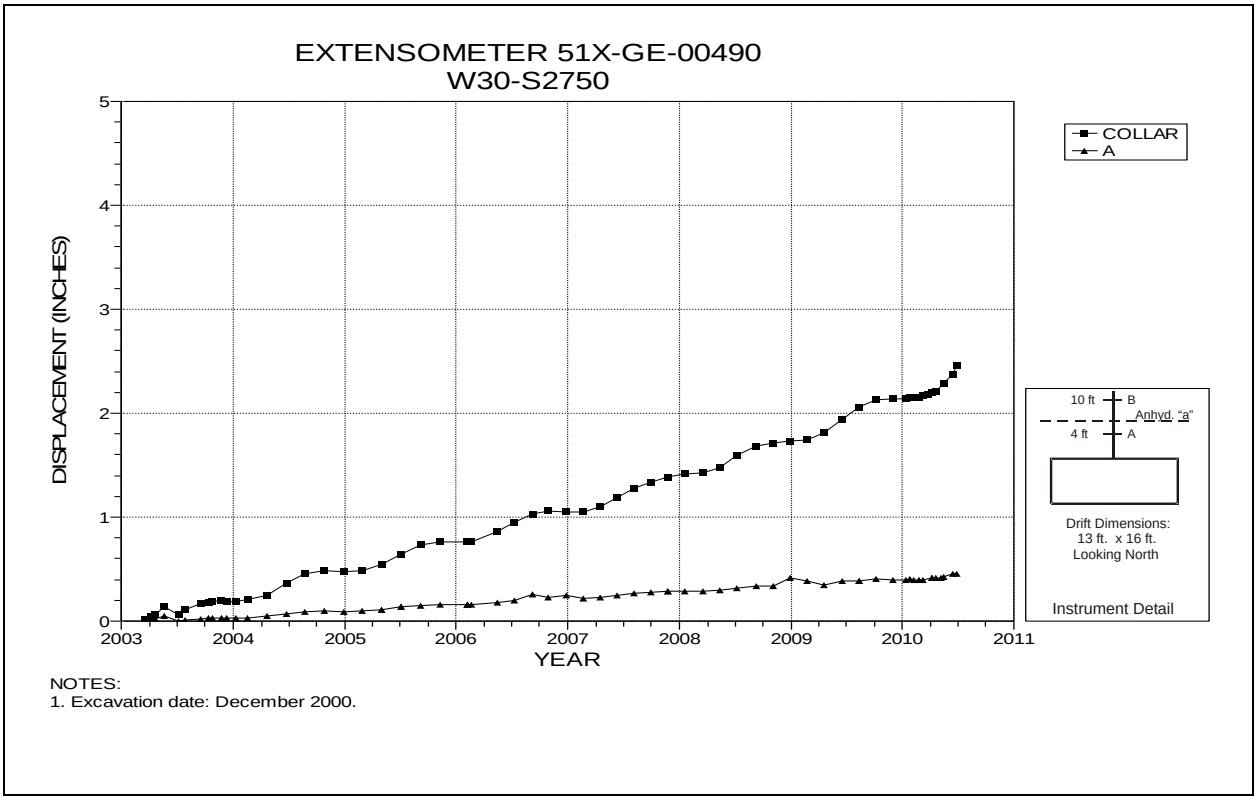


Figure 4-26 Extensometer 51X-GE-00490
W30 S2750 – Roof

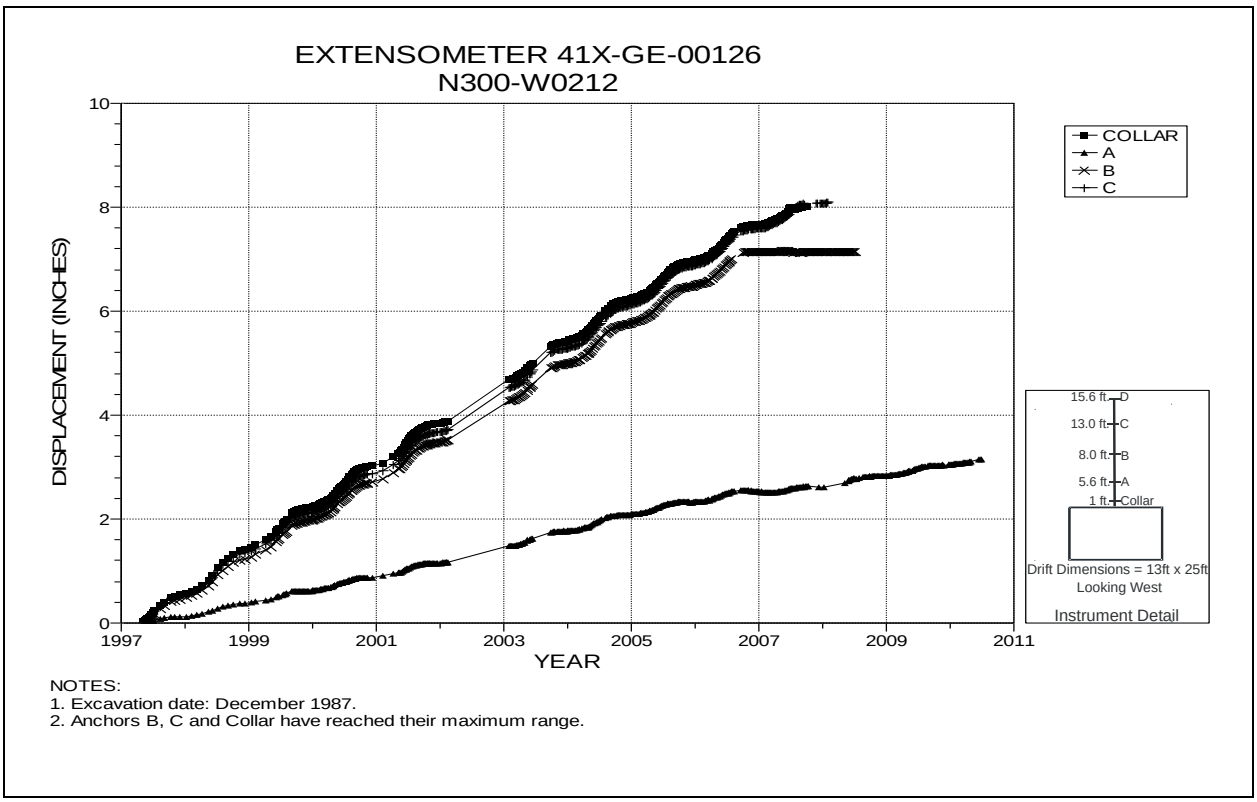


Figure 4-27-A Extensometer 41X-GE-00126
N300 W212 – Roof

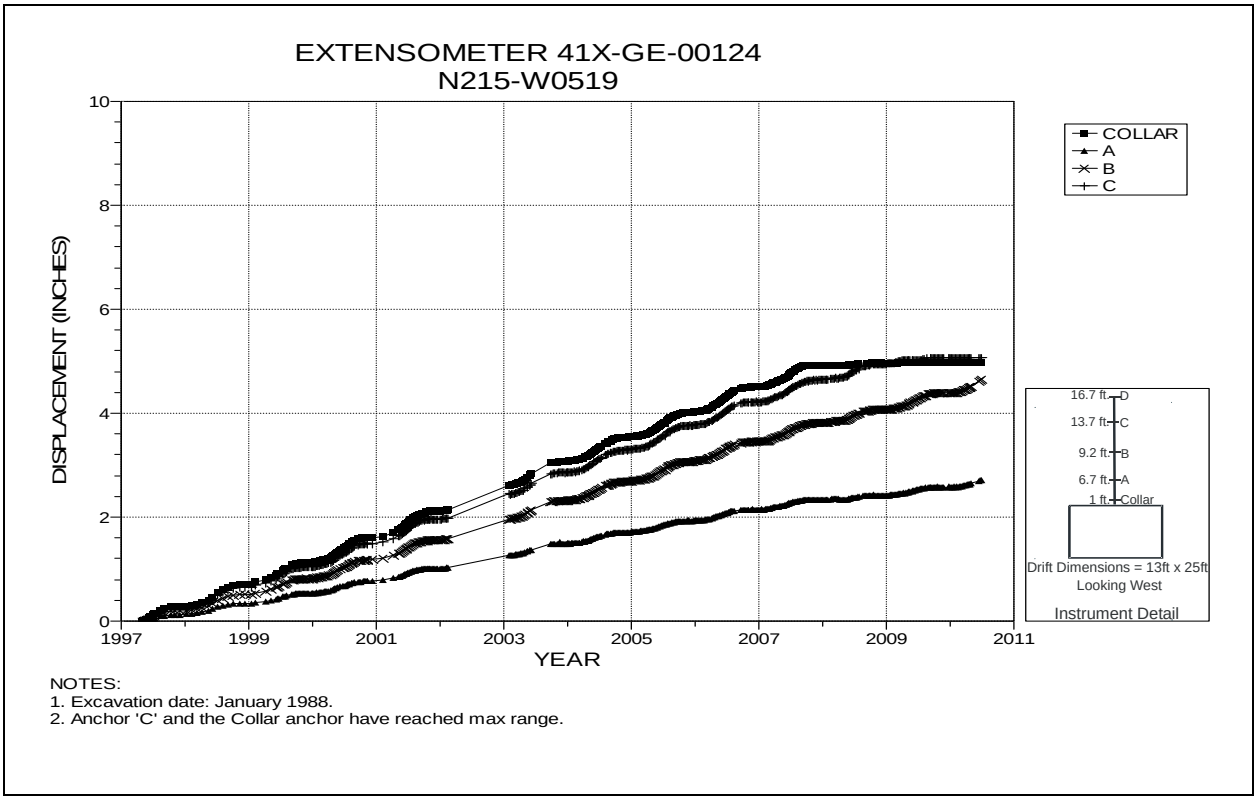


Figure 4-27-B Extensometer 41X-GE-00124
N215 W519 – Roof

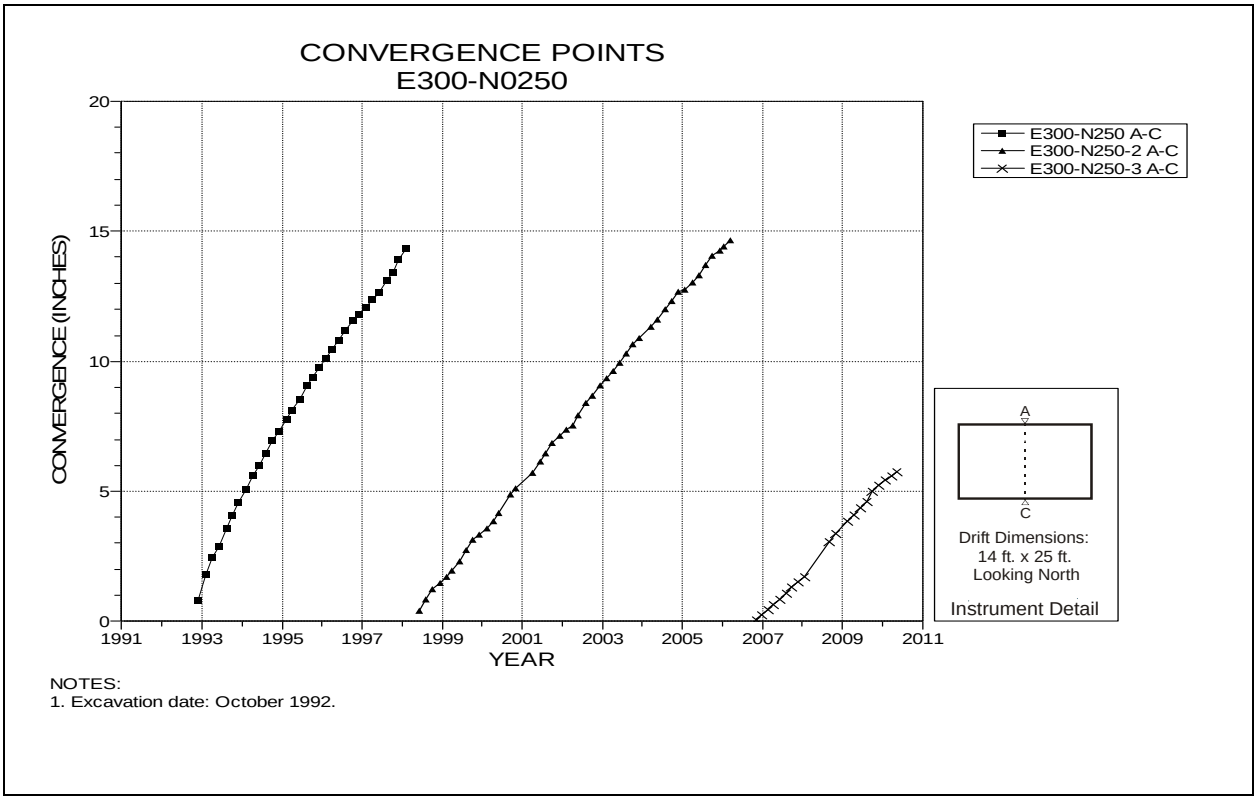


Figure 4-28 Convergence Point Array
E300 Shop N250 – Roof to Floor

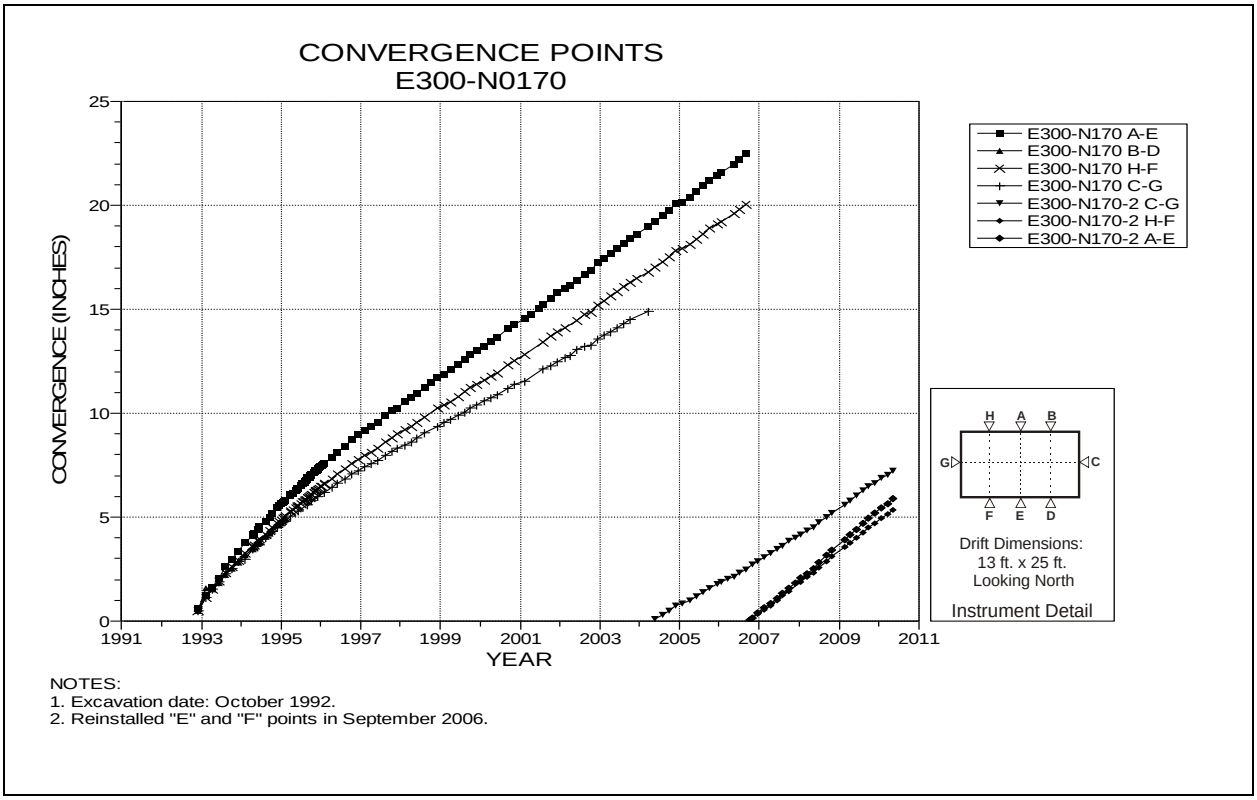


Figure 4-29 Convergence Point Array
E300 Shop N170 – All Chords

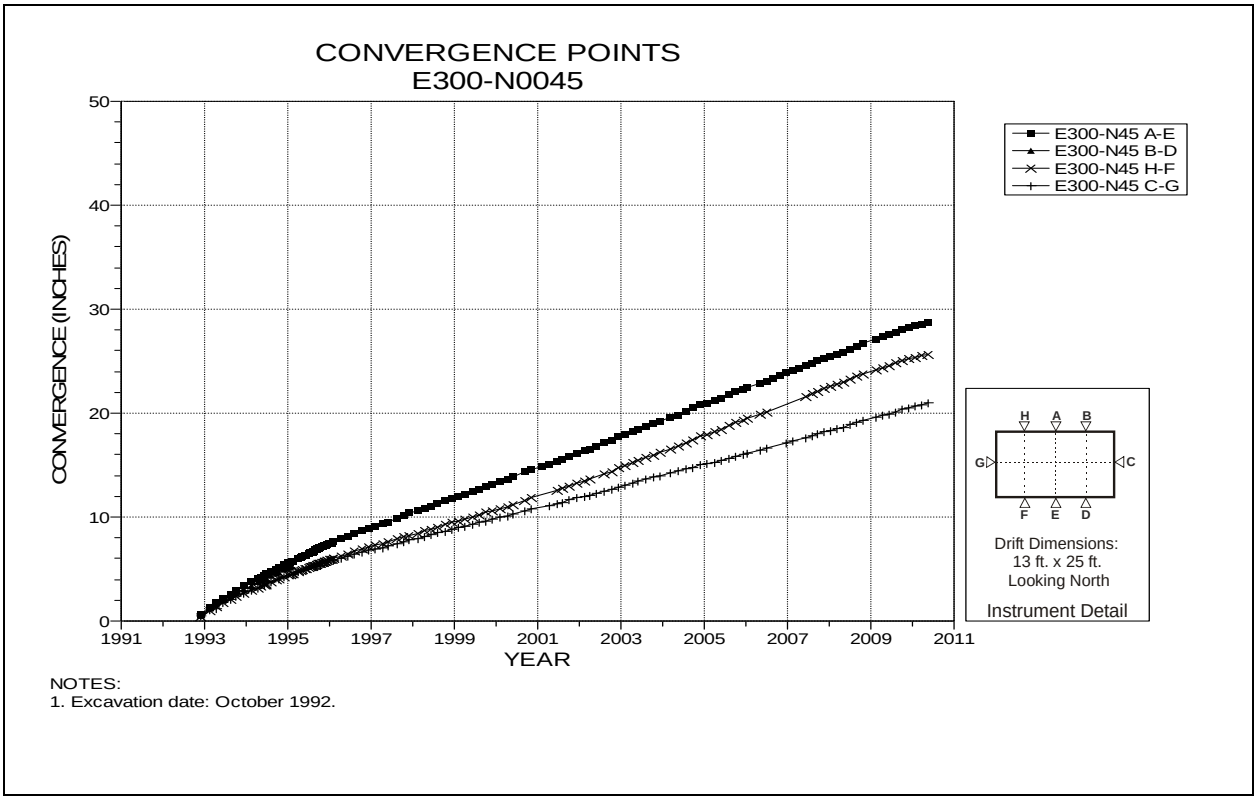


Figure 4-30 Convergence Point Array
E300 Shop N45 – All Chords

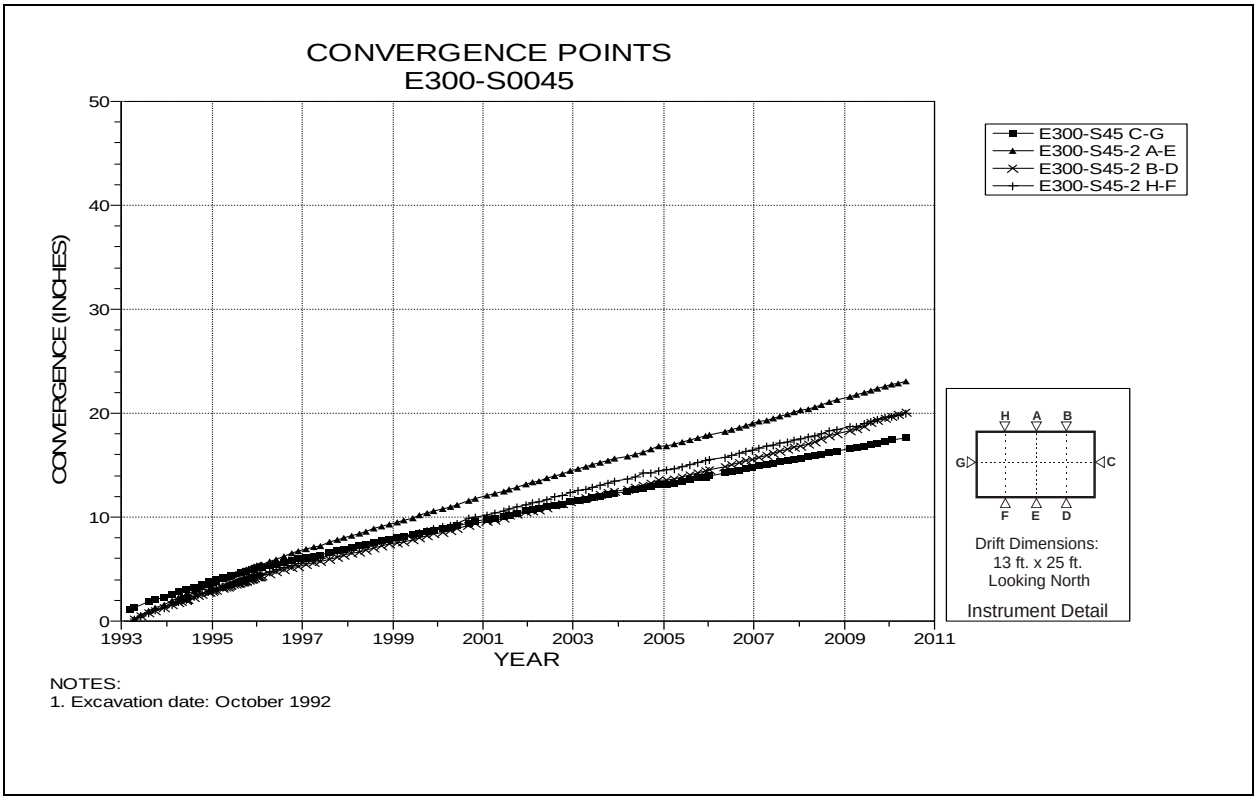


Figure 4-31 Convergence Point Array
E300 Shop S45 – All Chords

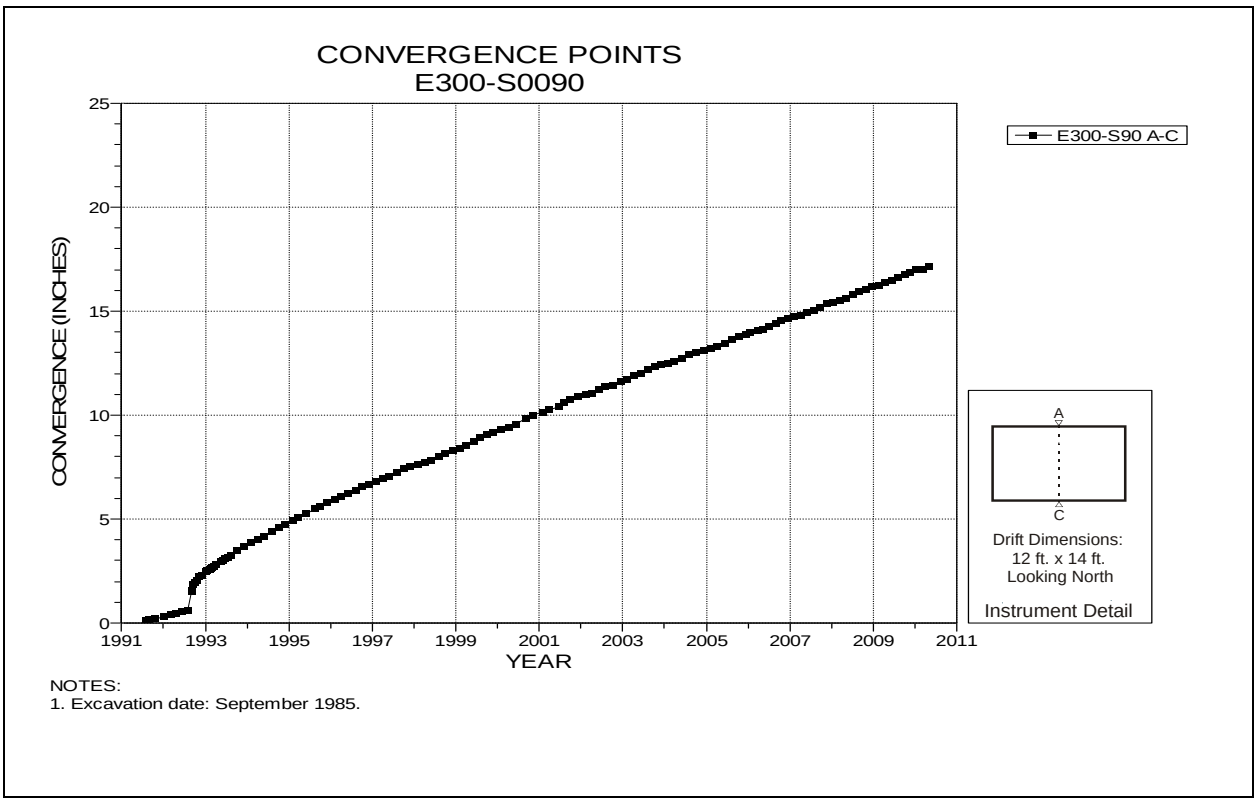


Figure 4-32 Convergence Point Array
E300 S90 – Roof to Floor

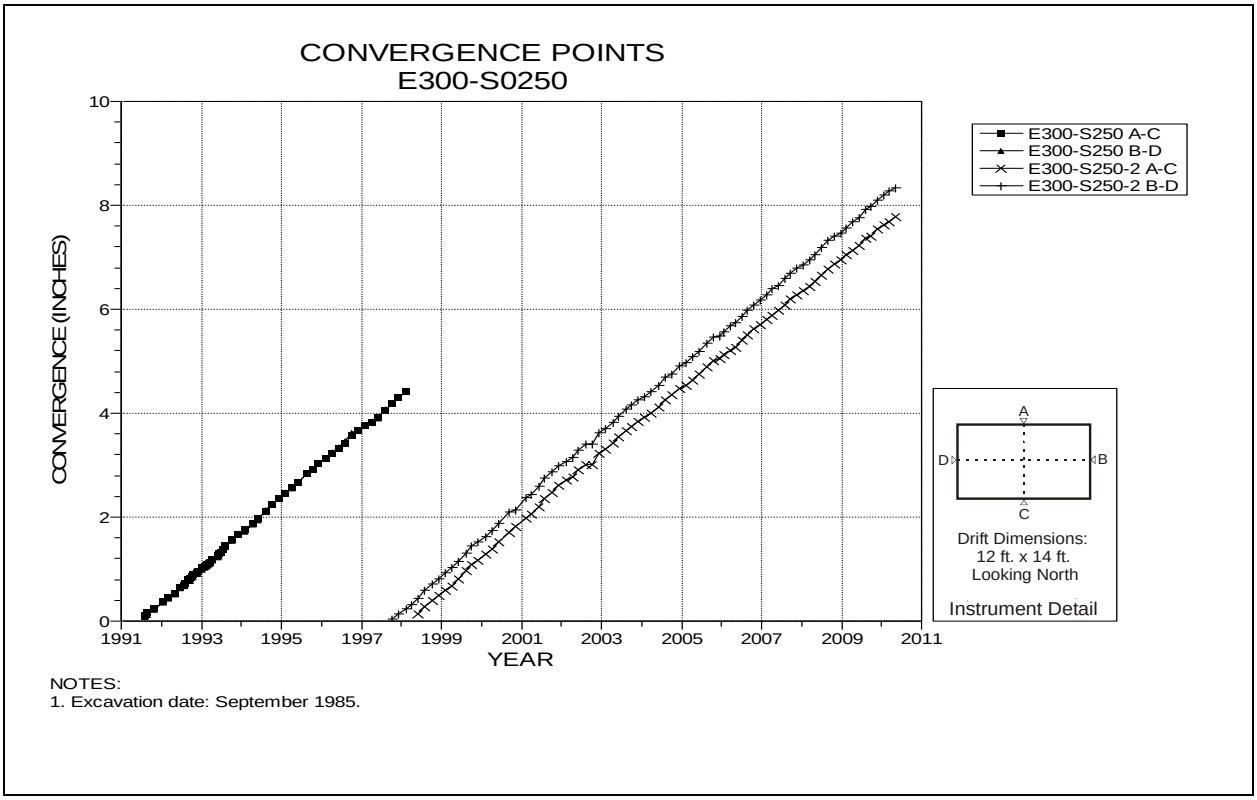
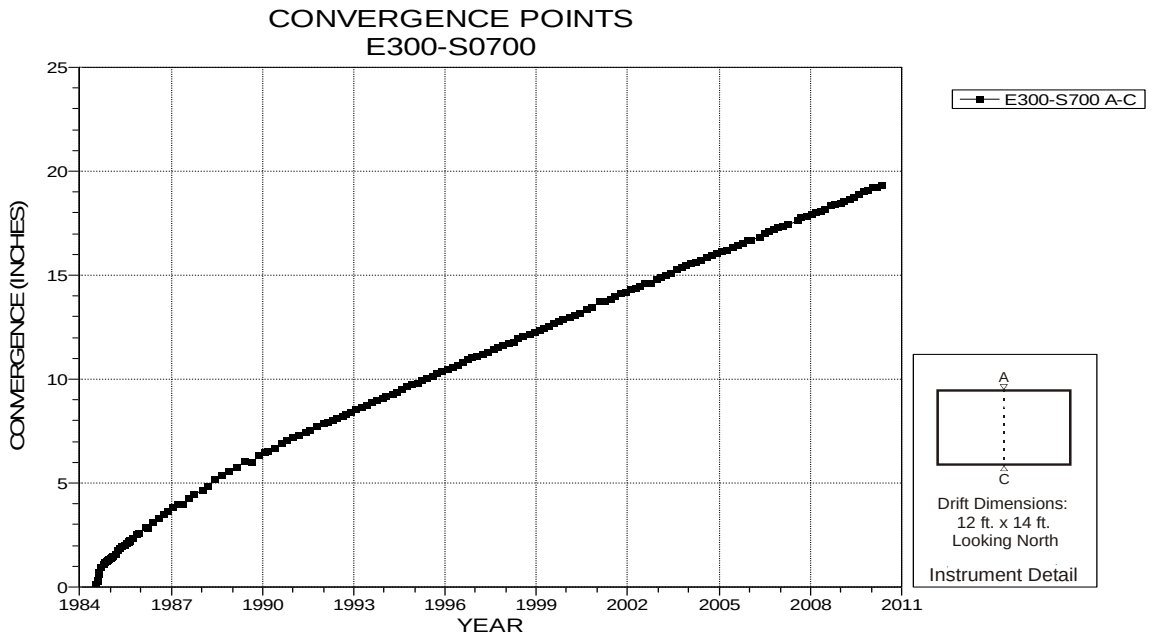
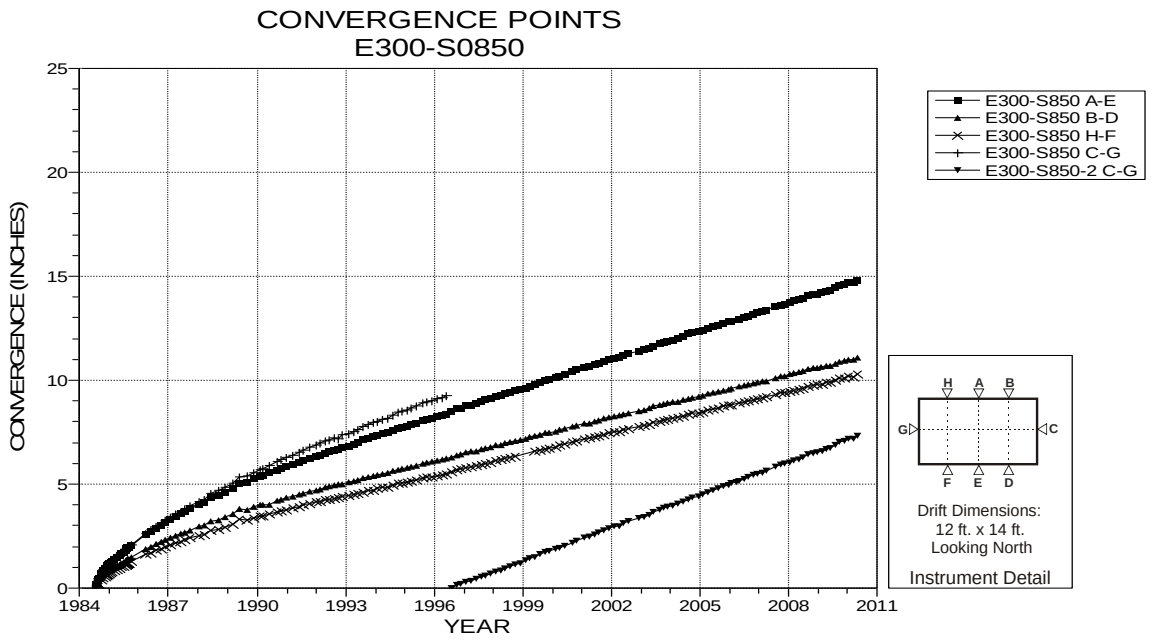


Figure 4-33 Convergence Point Array
E300 S250 – All Chords



NOTES:
1. Excavation date: May 1984.

Figure 4-34 Convergence Point Array
E300 S700 – Roof to Floor



NOTES:
1. Excavation date: July 1984.

Figure 4-35 Convergence Point Array
E300 S850 – All Chords

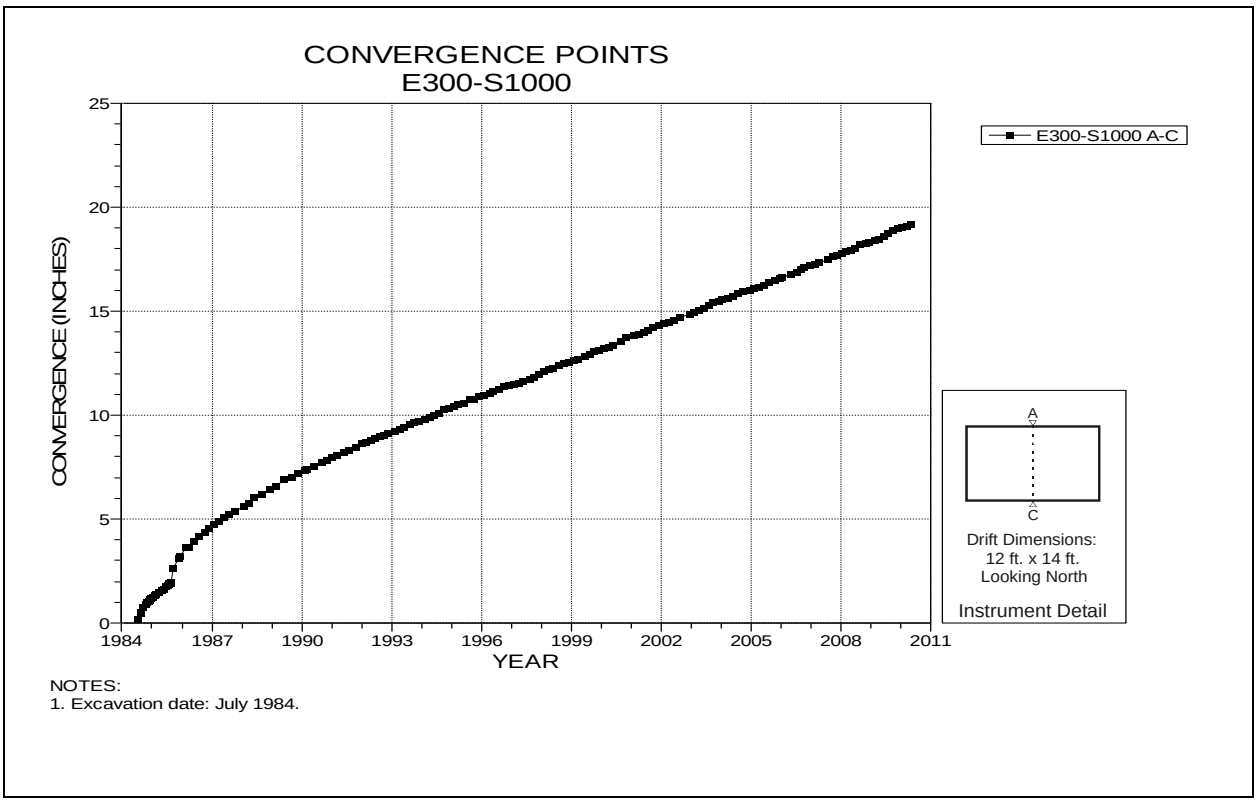


Figure 4-36 Convergence Point Array
E300 S1000 – Roof to Floor

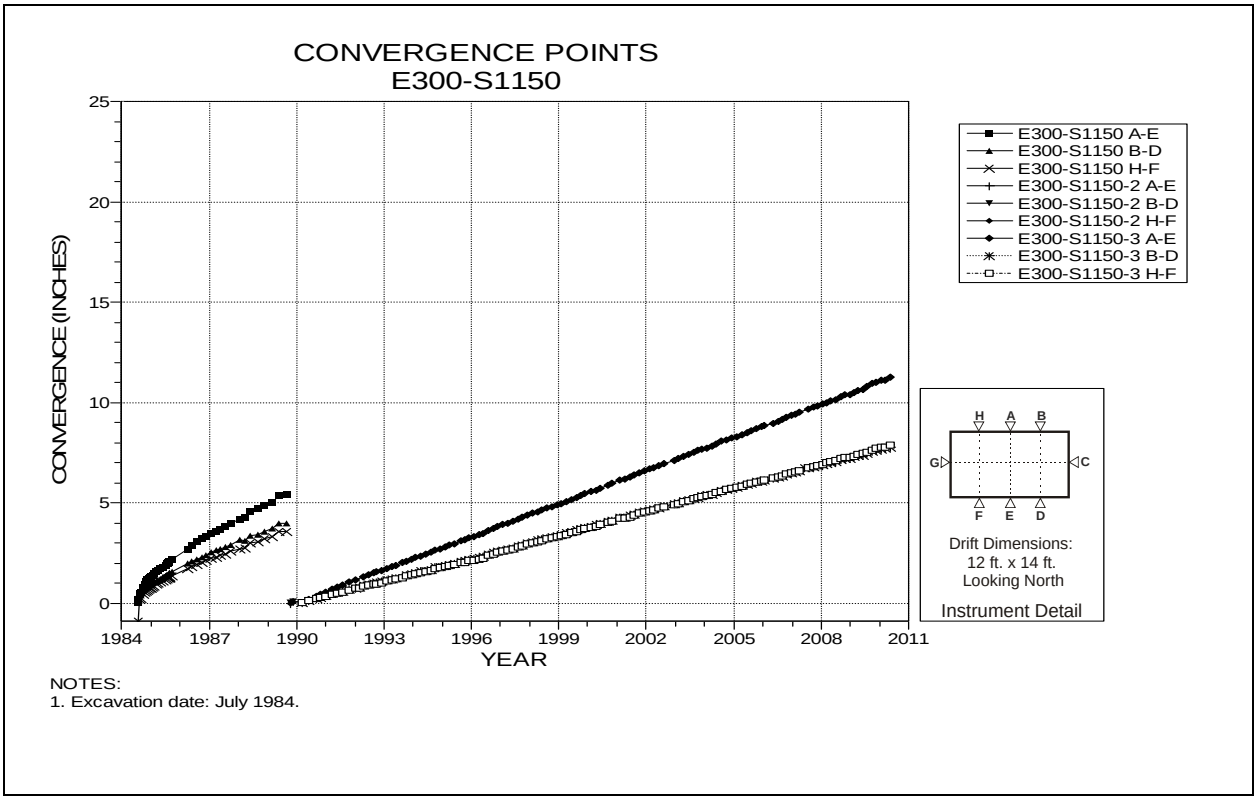


Figure 4-37 Convergence Point Array
E300 S1150 – Roof to Floor

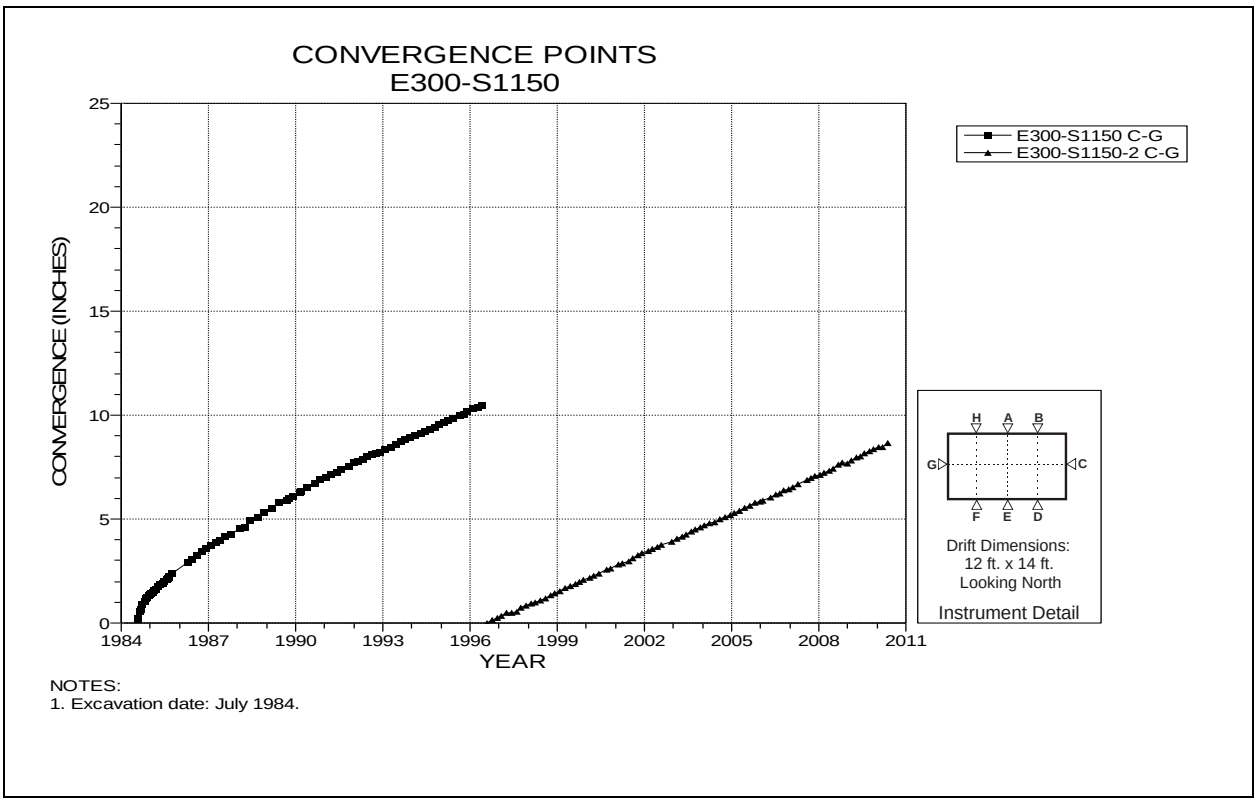


Figure 4-38 Convergence Point Array
E300 S1150 – Rib to Rib

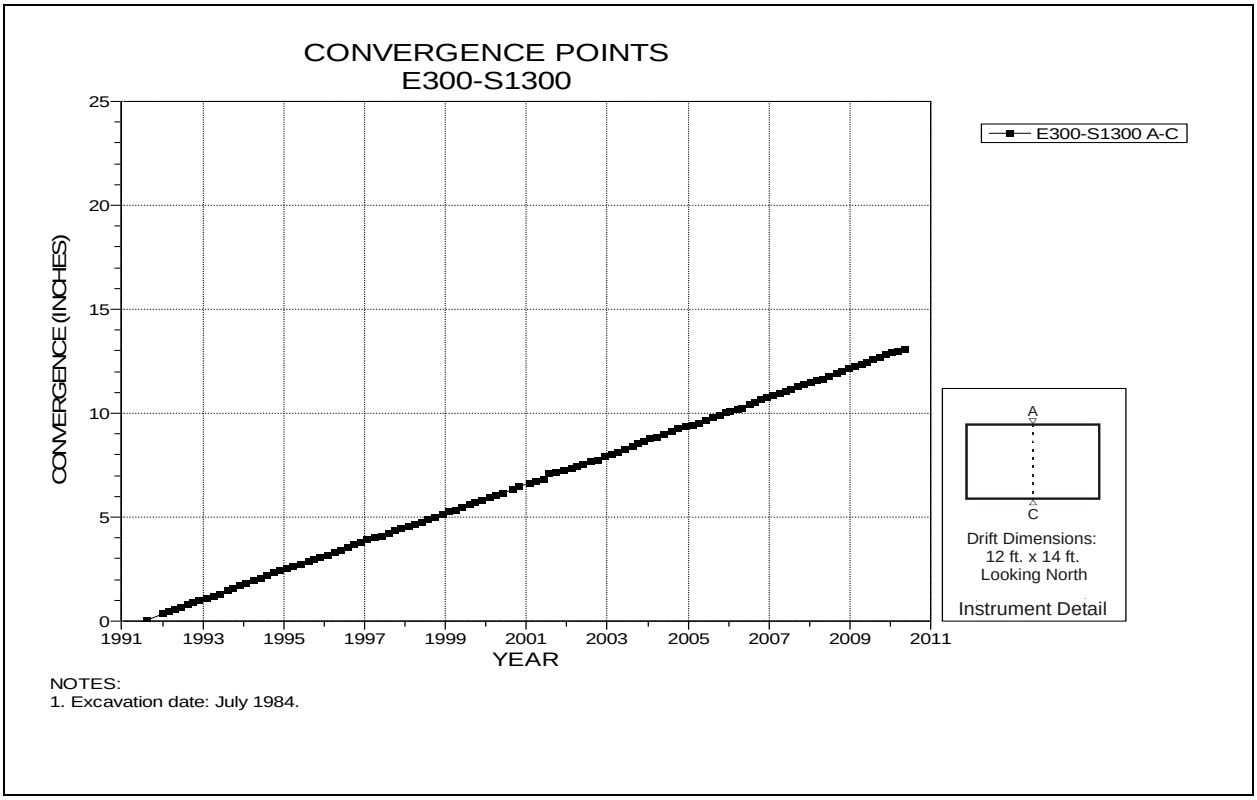


Figure 4-39 Convergence Point Array
E300 S1300 – Roof to Floor

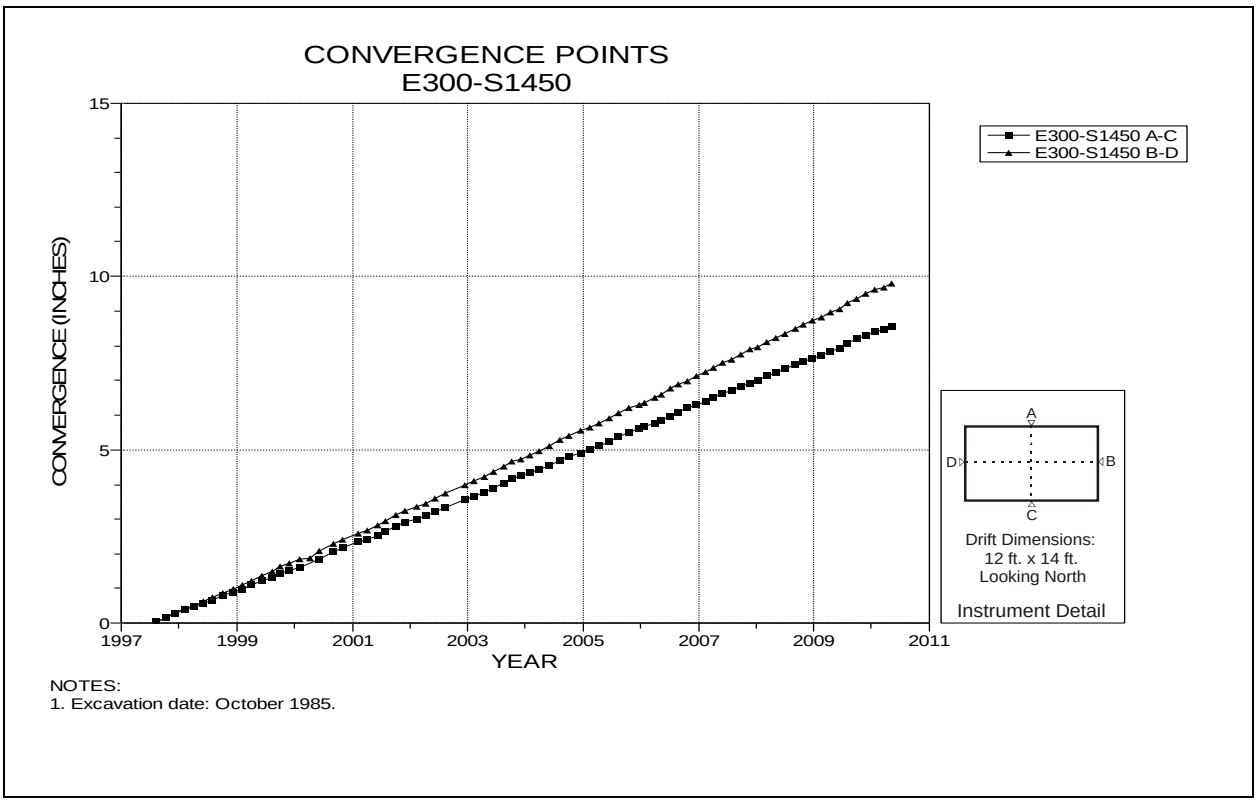


Figure 4-40 Convergence Point Array
E300 S1450 – All Chords

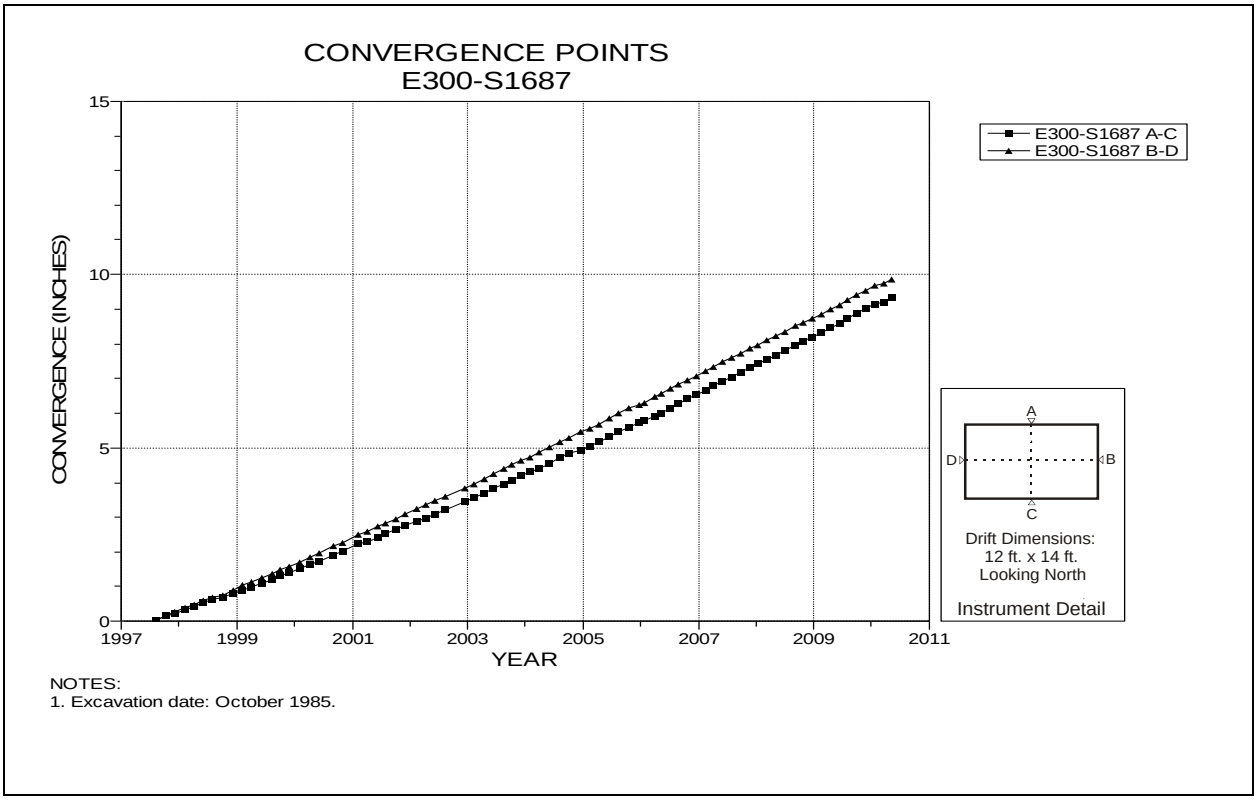


Figure 4-41 Convergence Point Array
E300 S1687 – All Chords

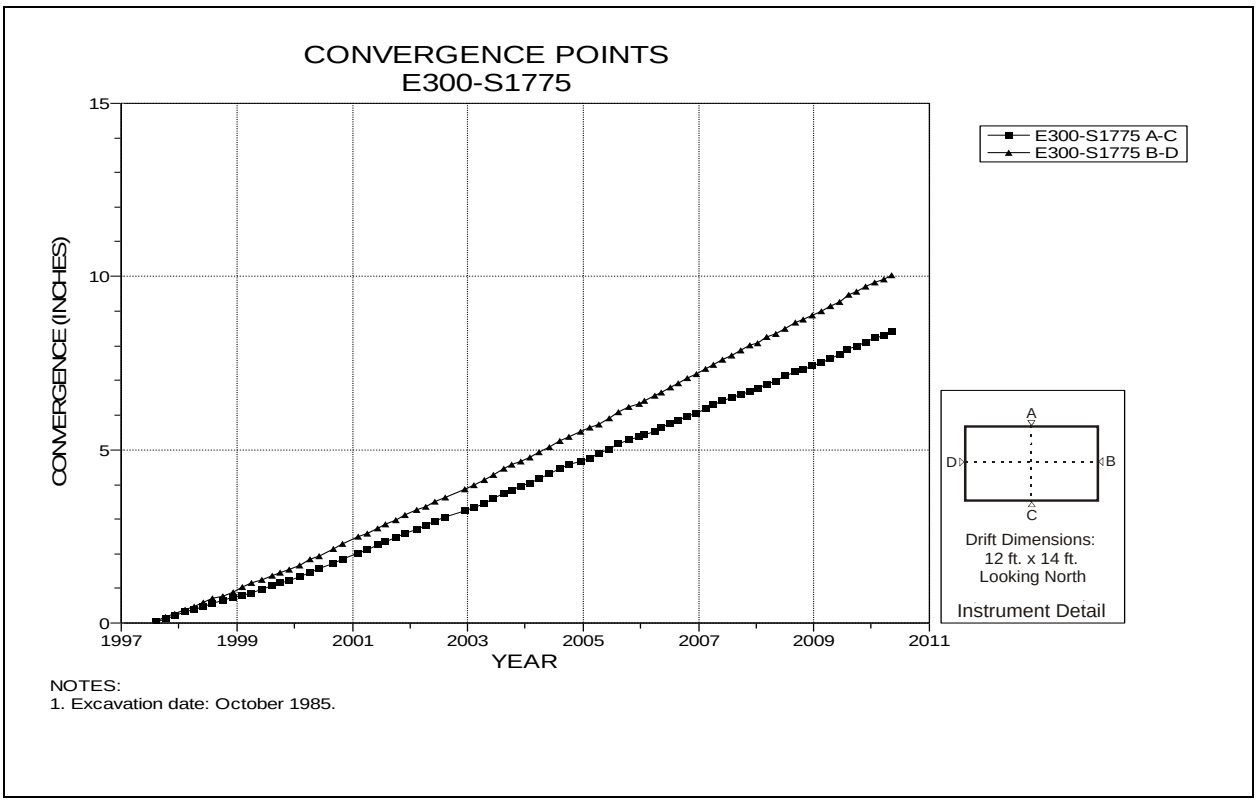


Figure 4-42 Convergence Point Array
E300 S1775 – All Chords

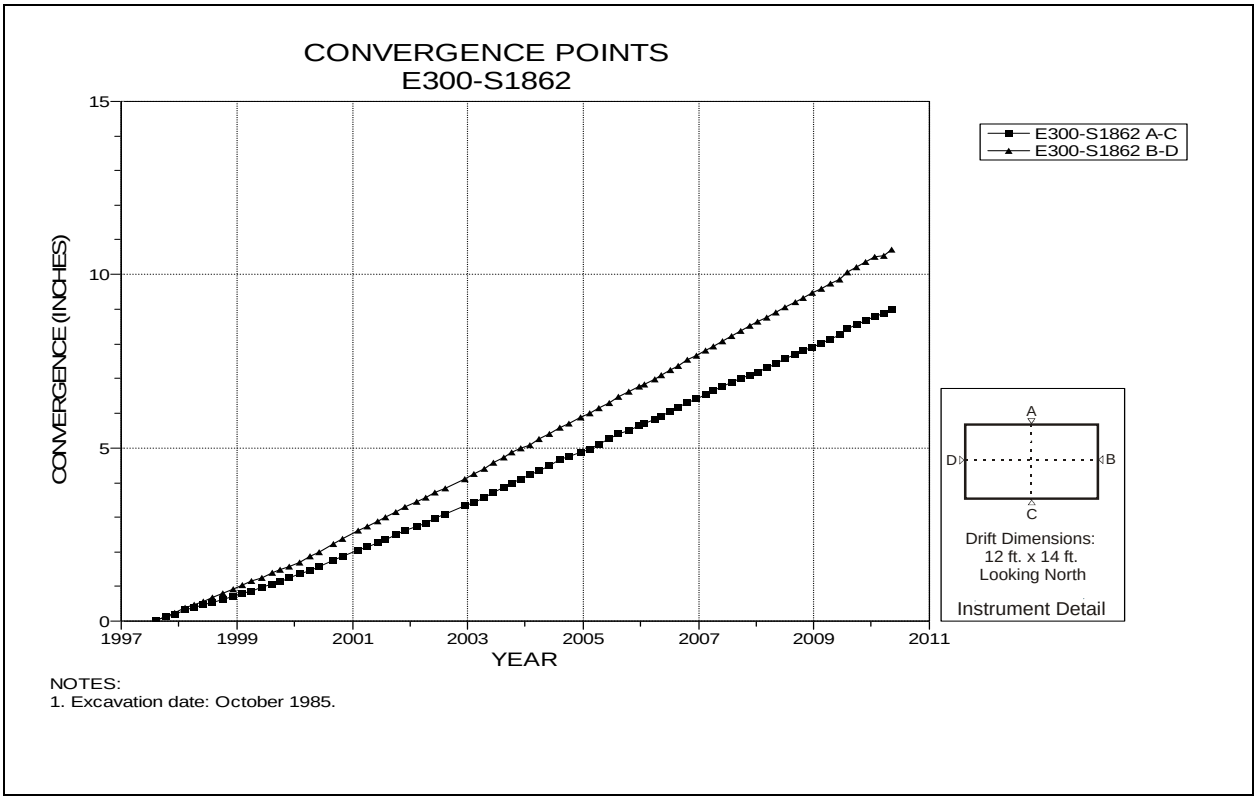


Figure 4-43 Convergence Point Array
E300 S1862 – All Chords

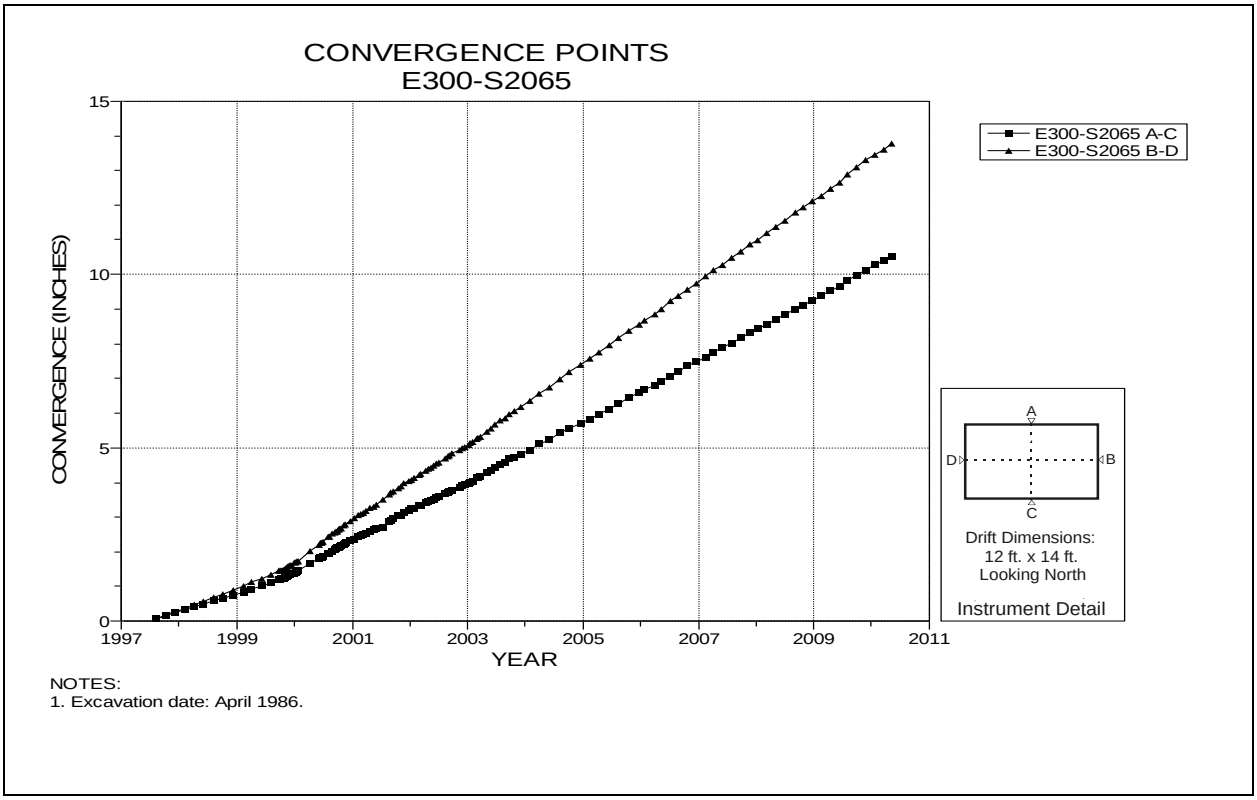


Figure 4-44 Convergence Point Array
E300 S2065 – All Chords

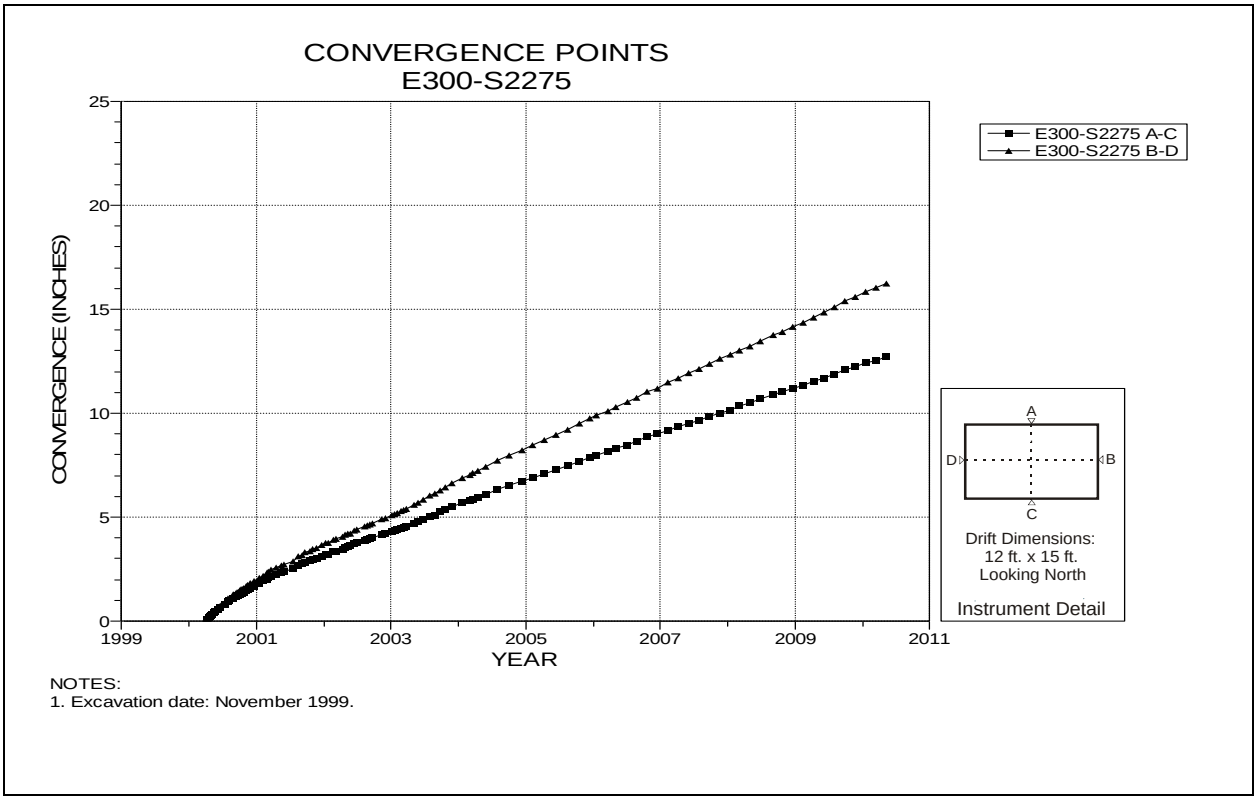


Figure 4-45 Convergence Point Array
E300 S2275 – All Chords

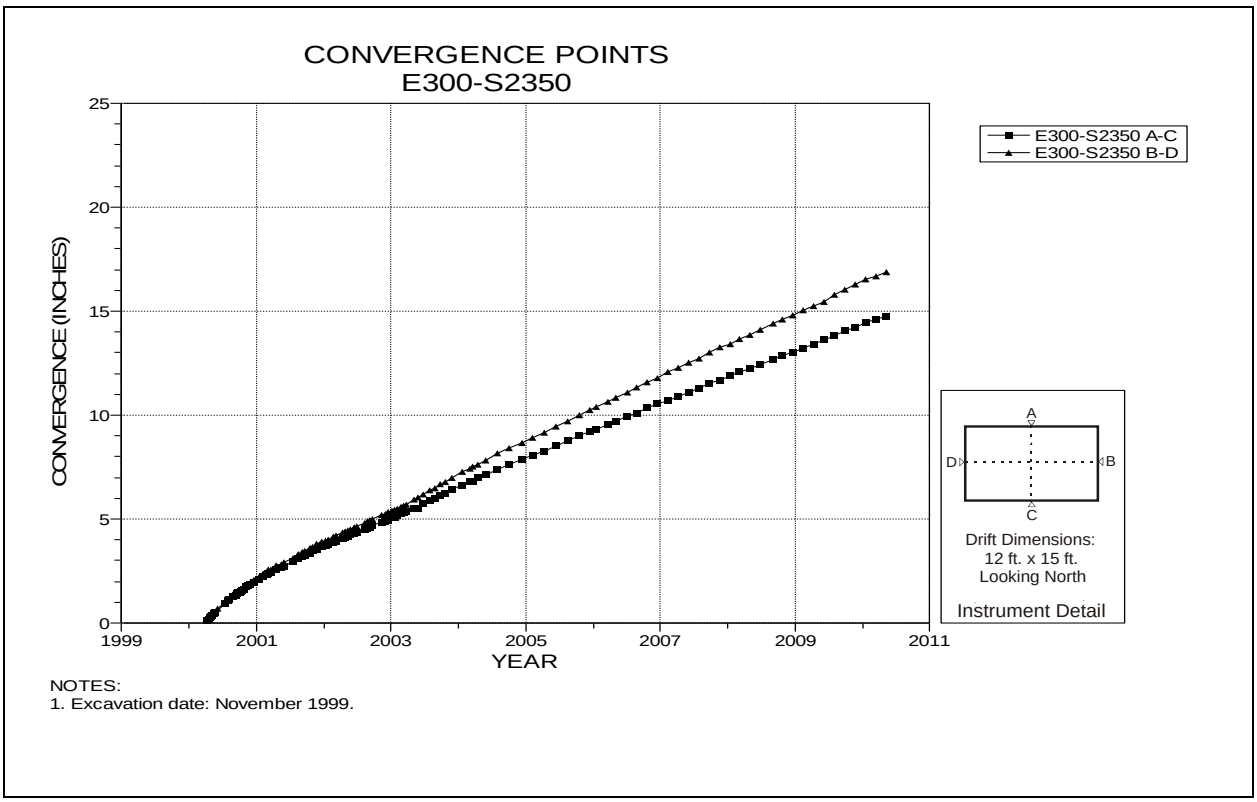


Figure 4-46 Convergence Point Array
E300 S2350 – All Chords

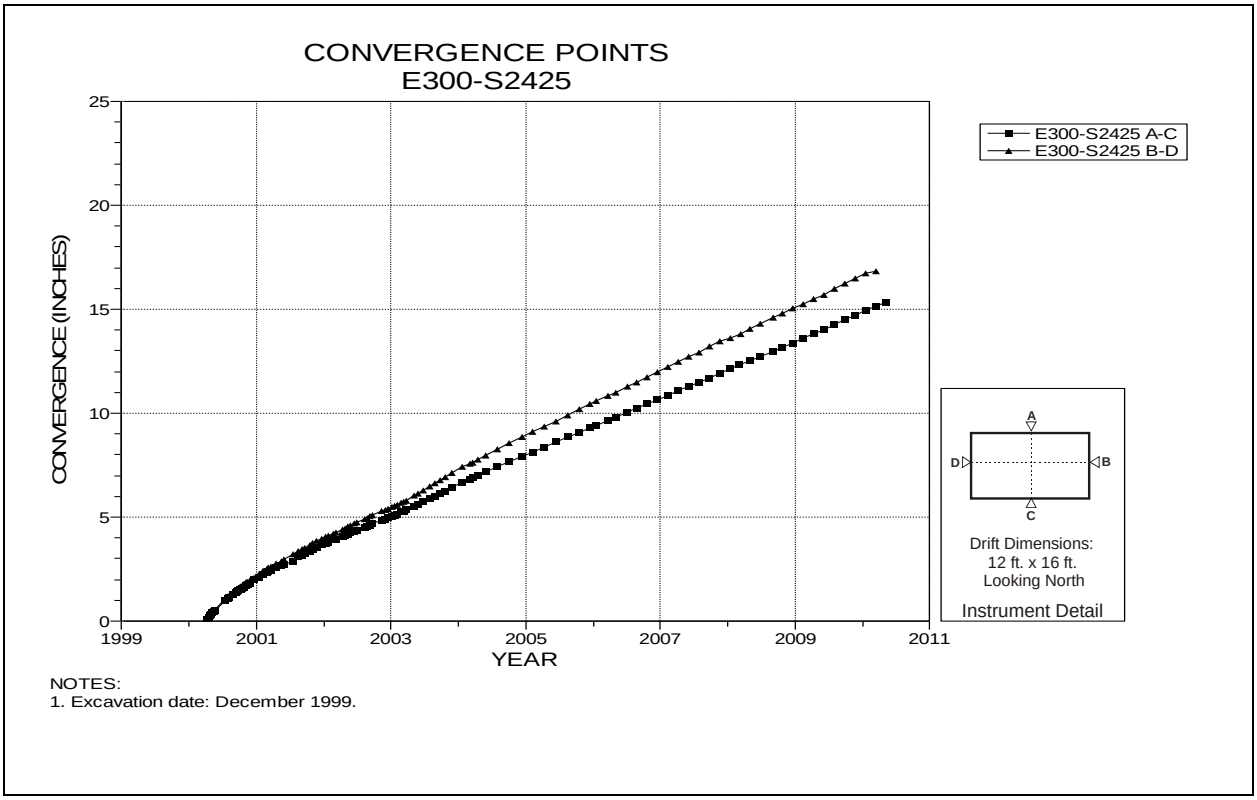


Figure 4-47 Convergence Point Array
E300 S2425 – All Chords

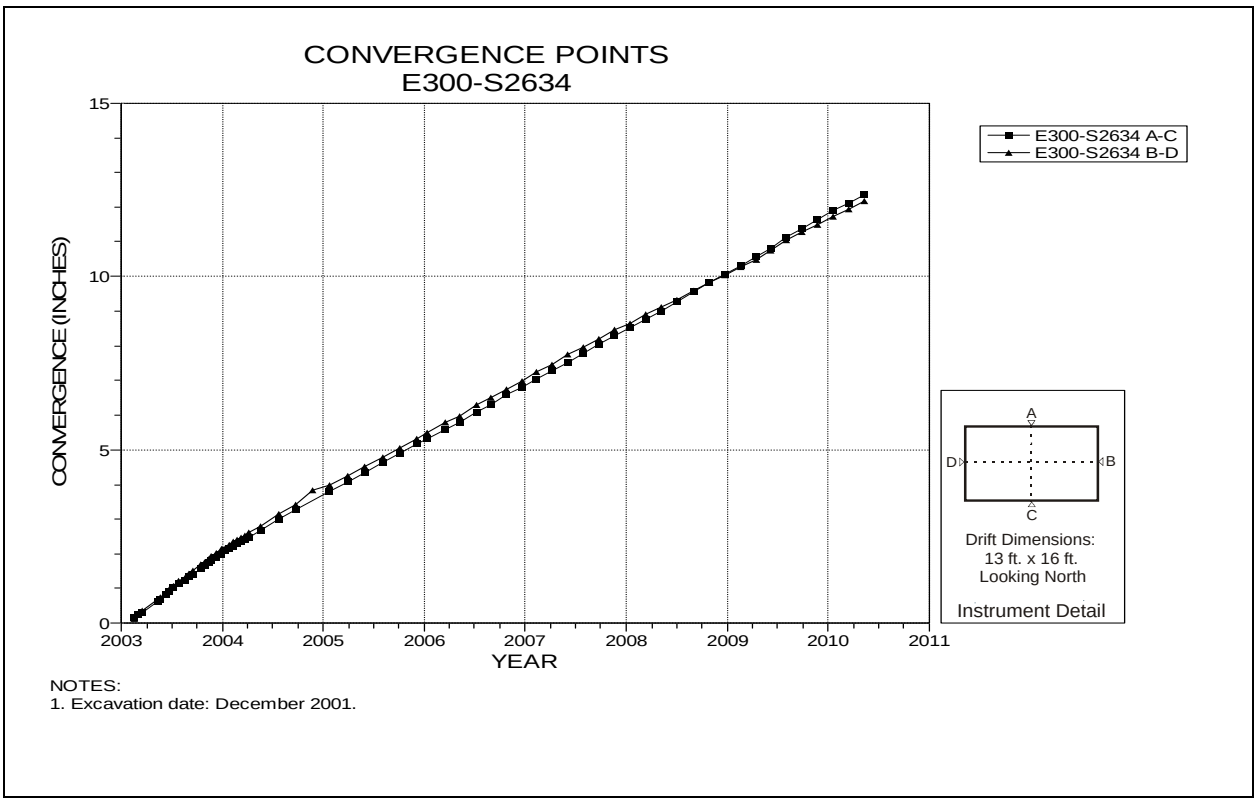


Figure 4-48 Convergence Point Array
E300 S2634 – All Chords

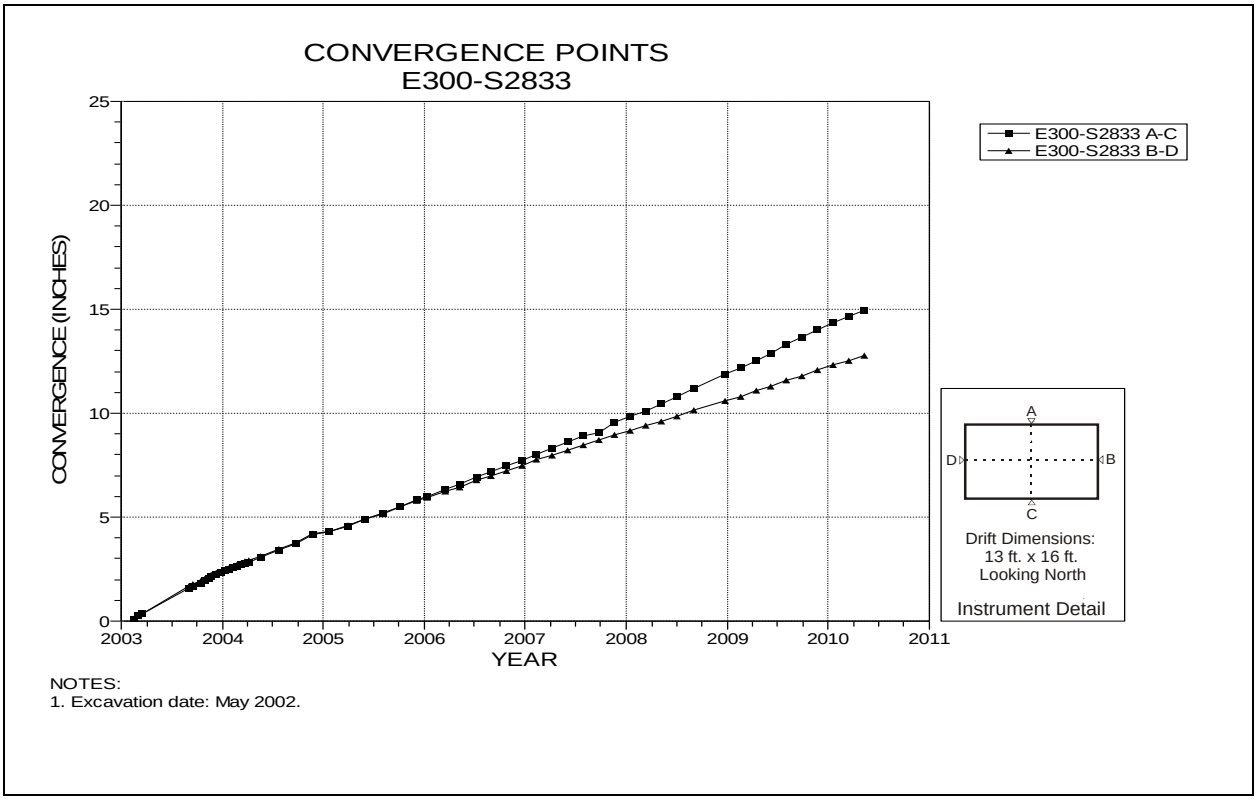


Figure 4-49 Convergence Point Array
E300 S2833 – All Chords

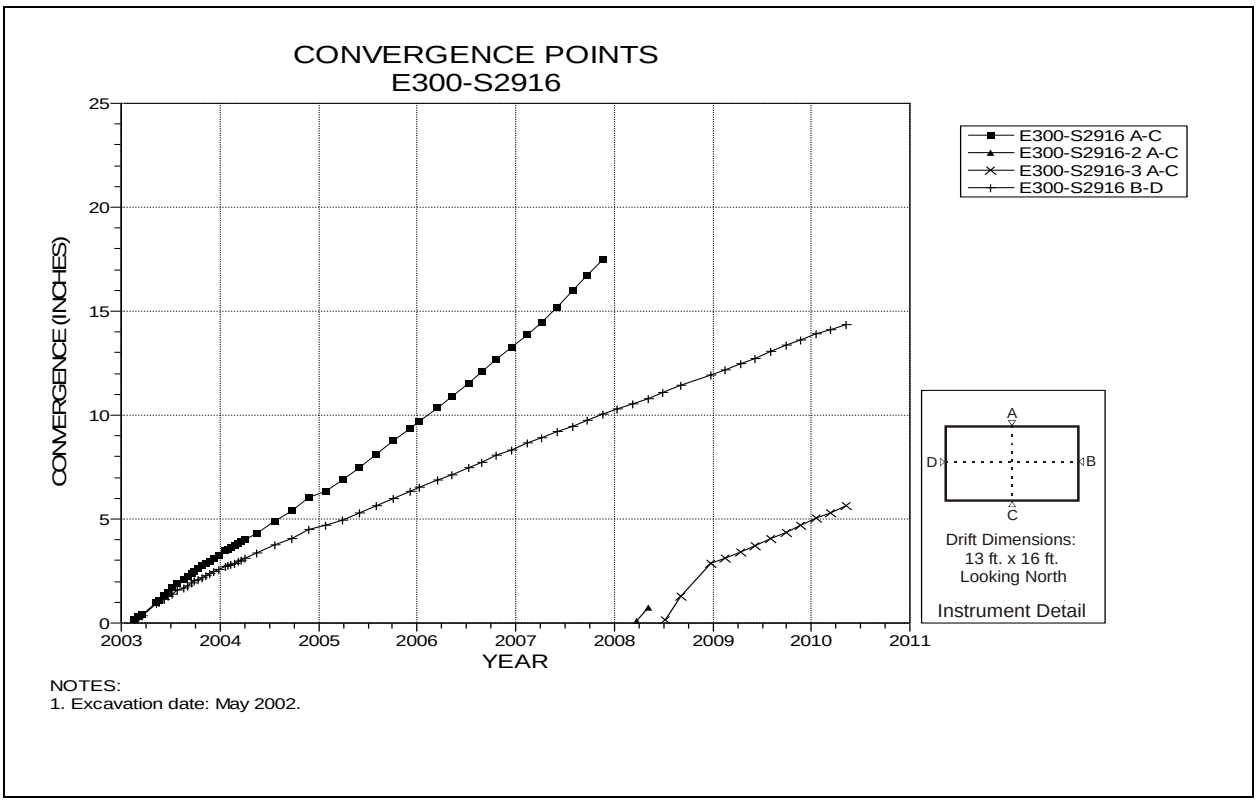


Figure 4-50 Convergence Point Array
E300 S2916 – All Chords

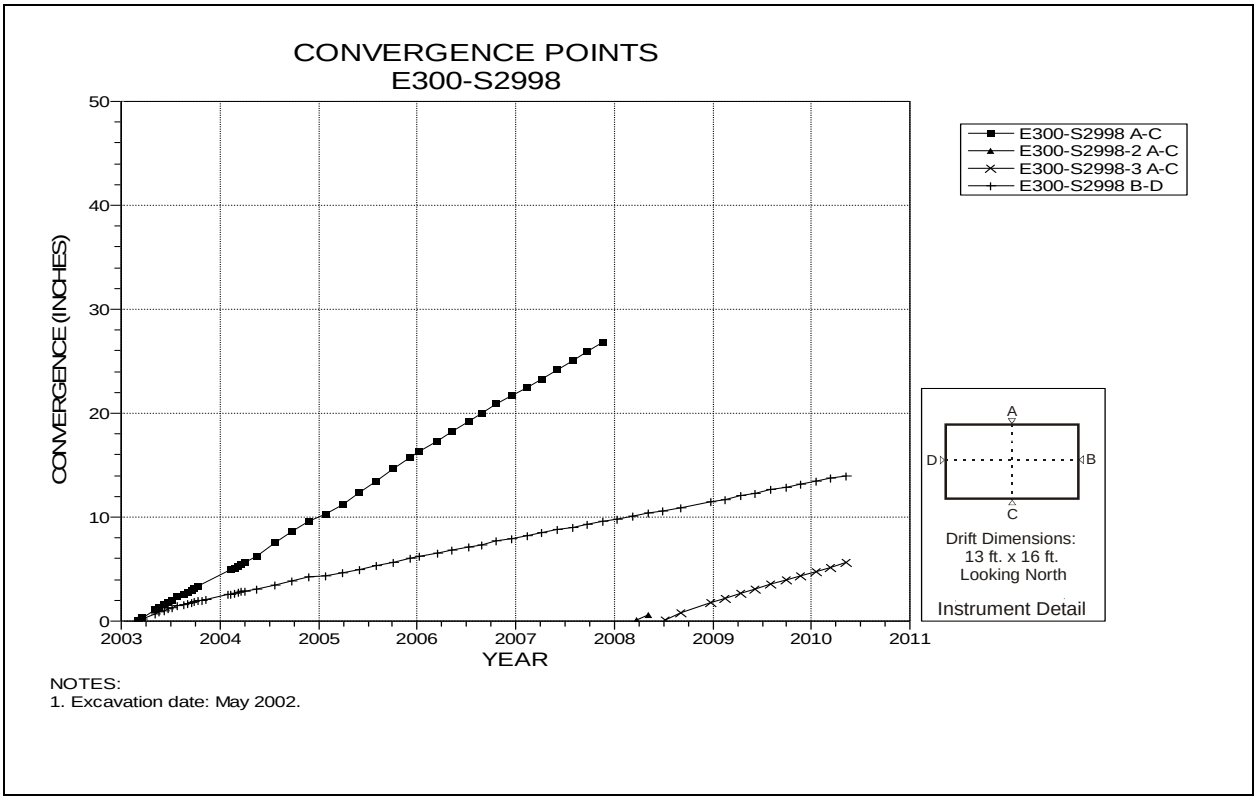


Figure 4-51 Convergence Point Array
E300 S2998 – All Chords

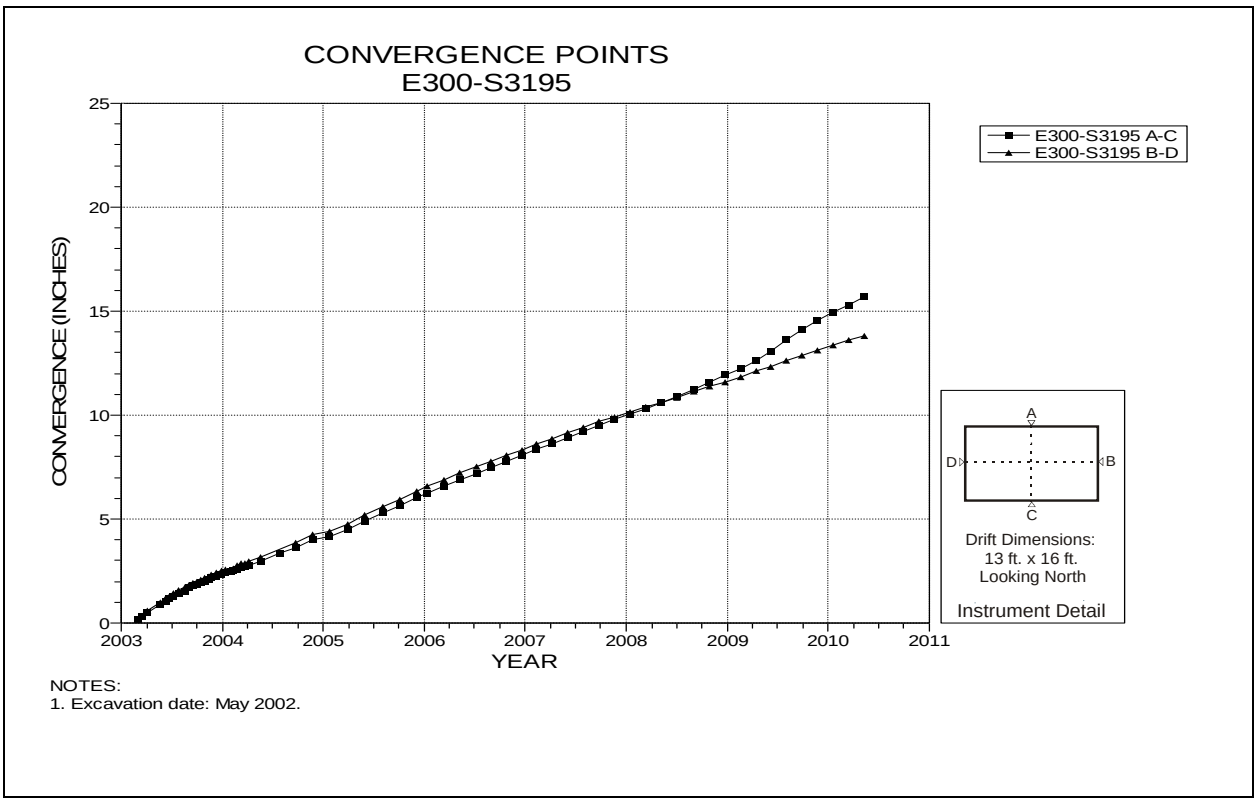


Figure 4-52 Convergence Point Array
E300 S3195 – All Chords

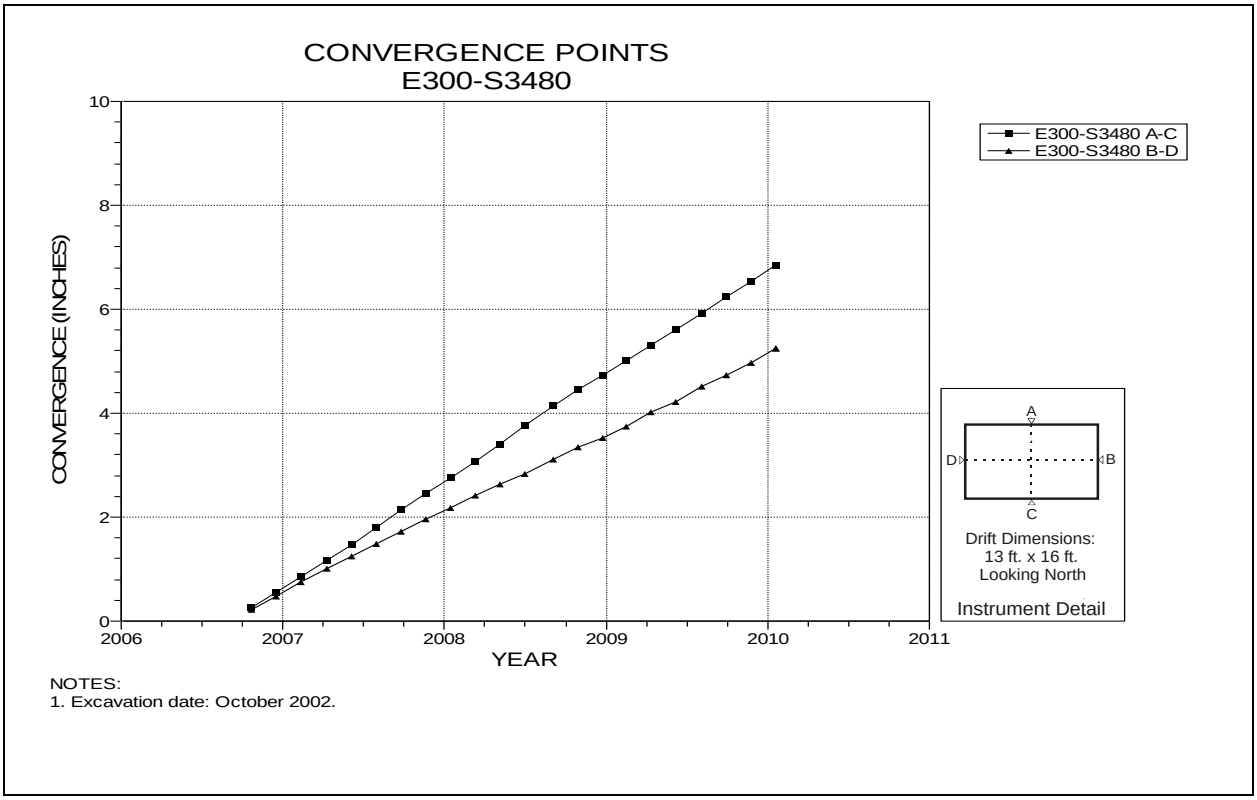


Figure 4-53 Convergence Point Array
E300 S3480 – All Chords

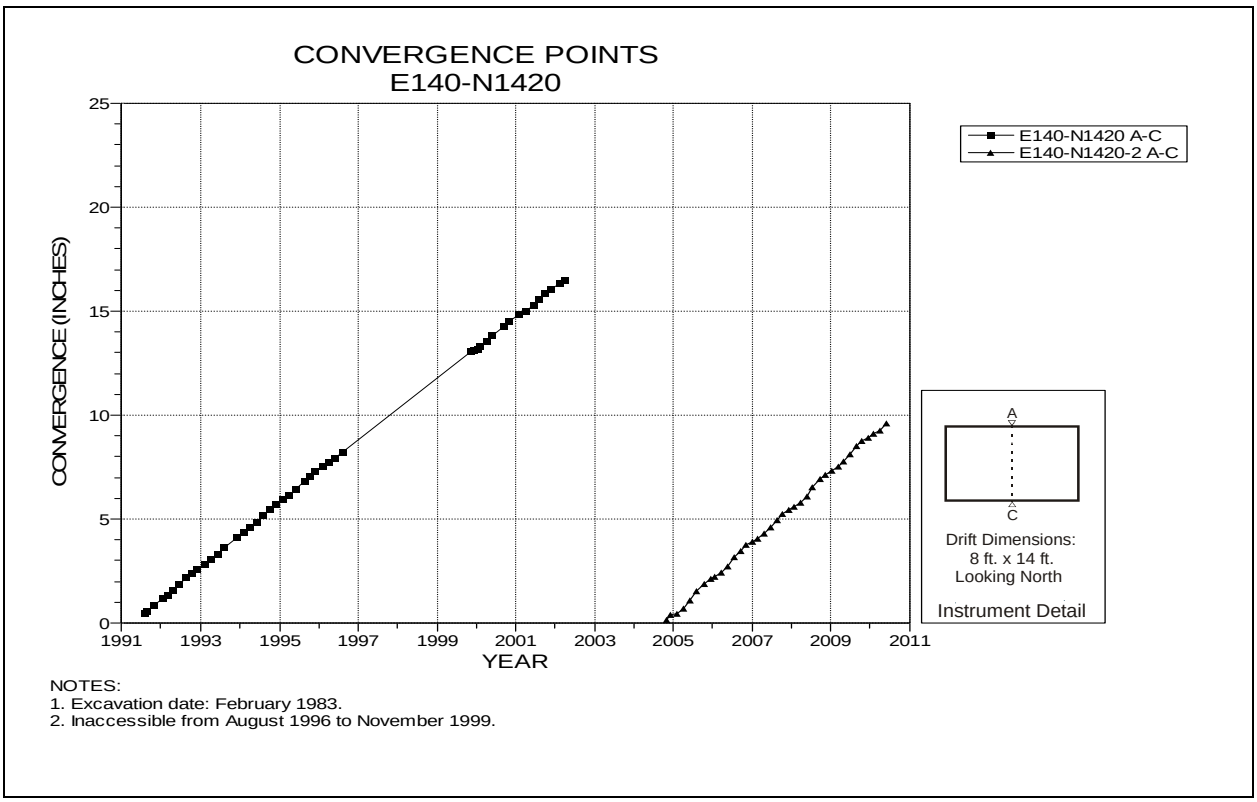


Figure 4-54 Convergence Point Array
E140 N1420 – Roof to Floor

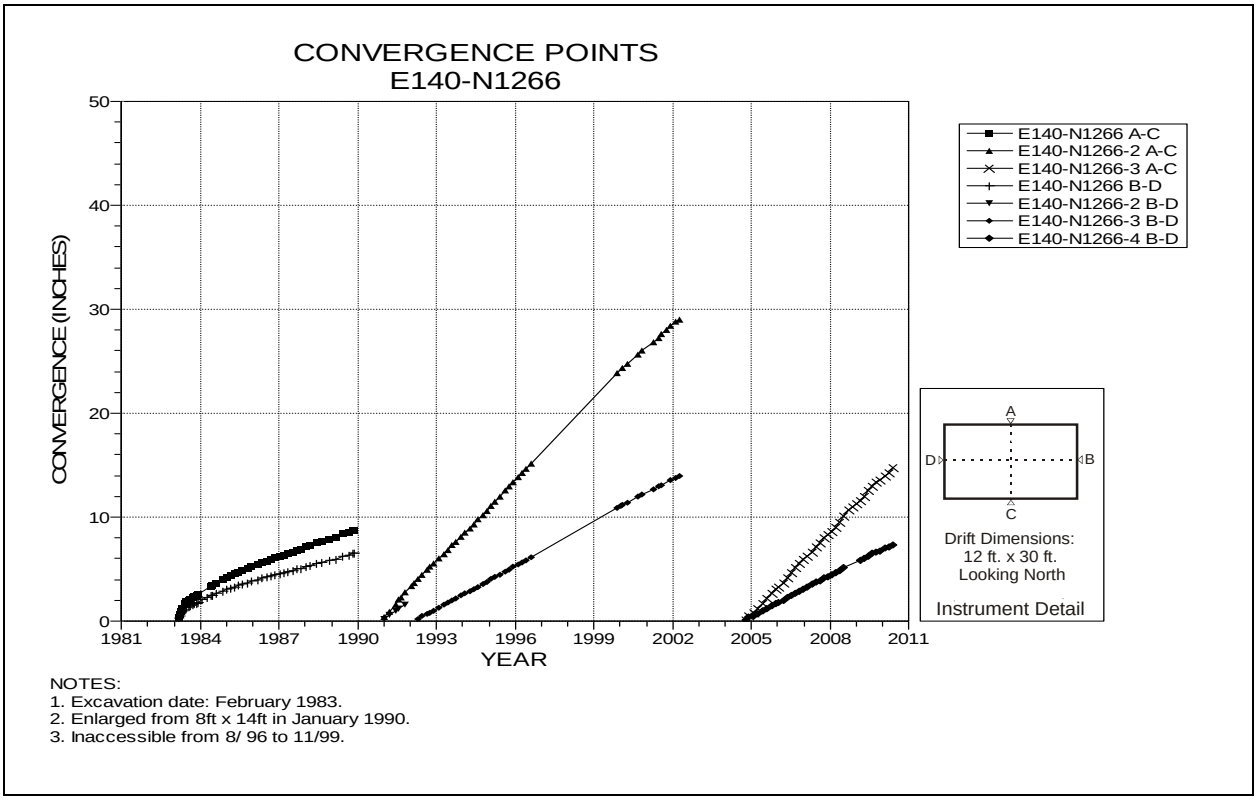


Figure 4-55 Convergence Point Array
E140 N1266 – All Chords

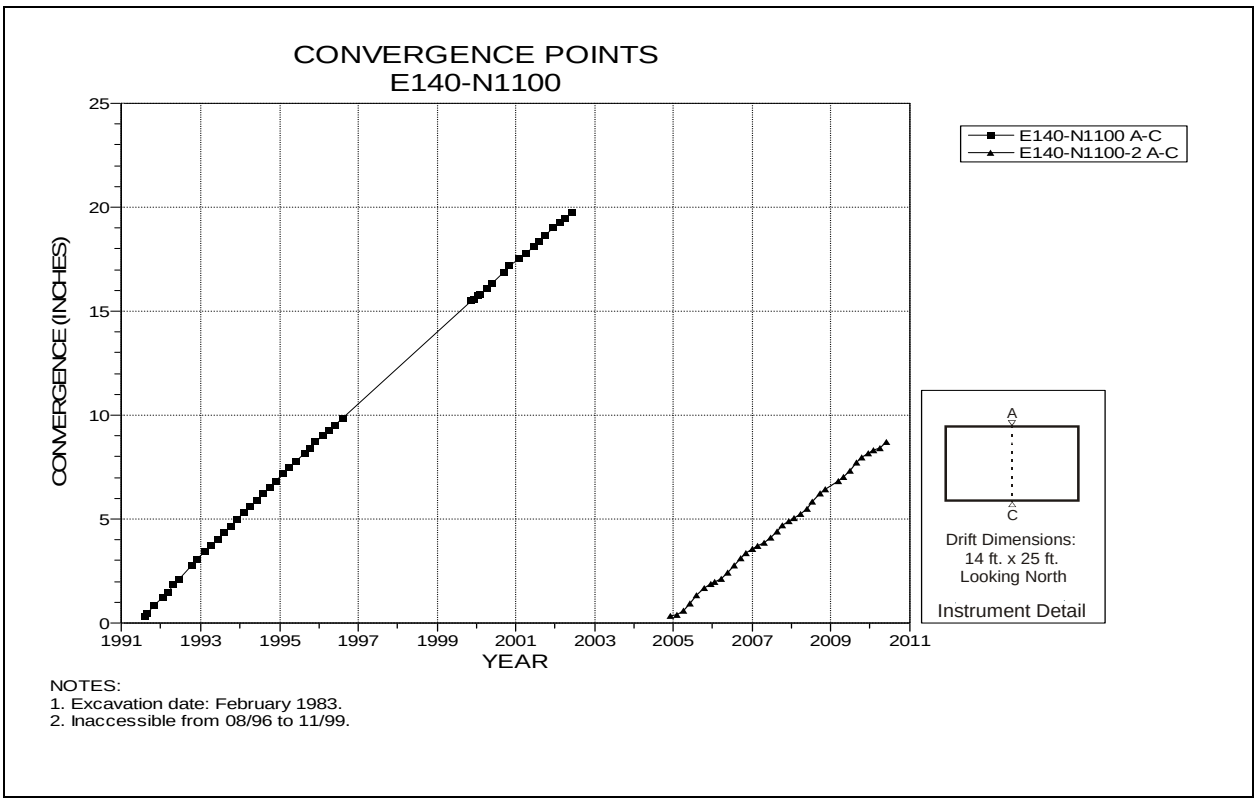


Figure 4-56 Convergence Point Array
E140 N1100 – Roof to Floor

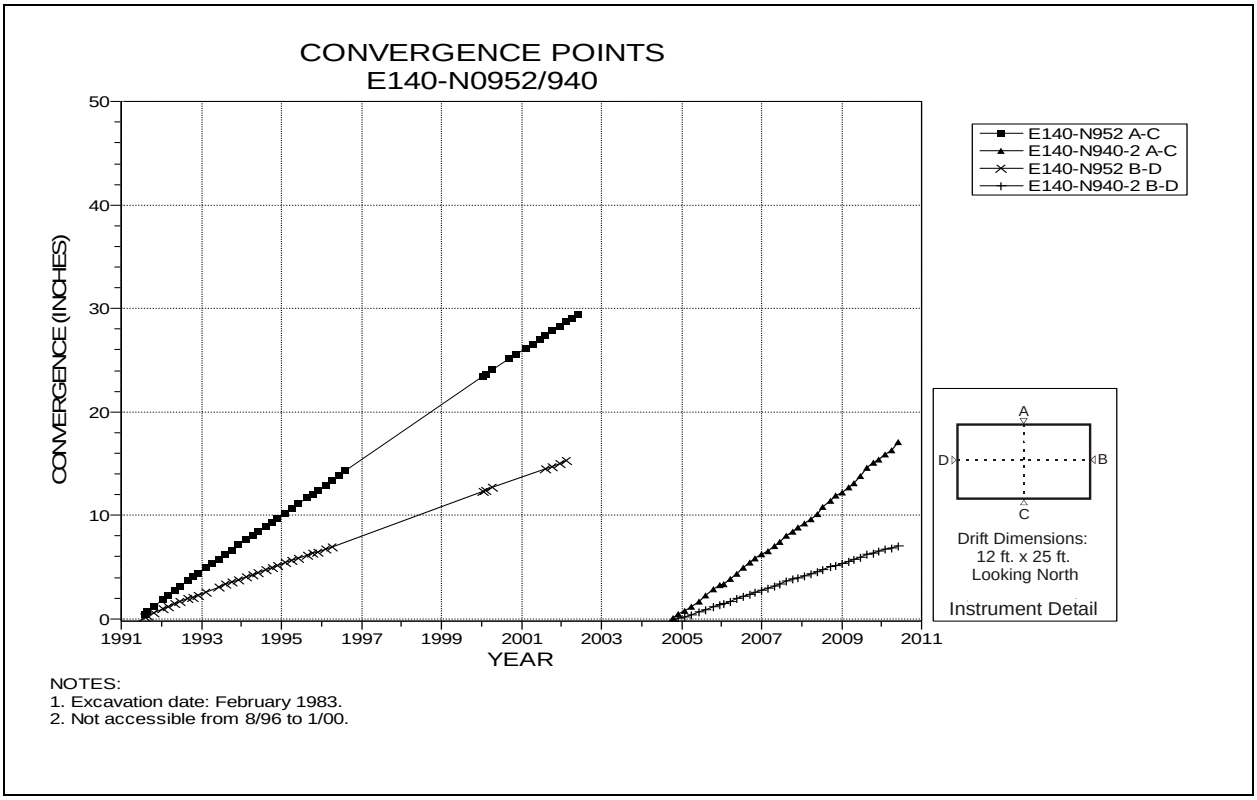


Figure 4-57 Convergence Point Array
E140 N952/940 – All Chords

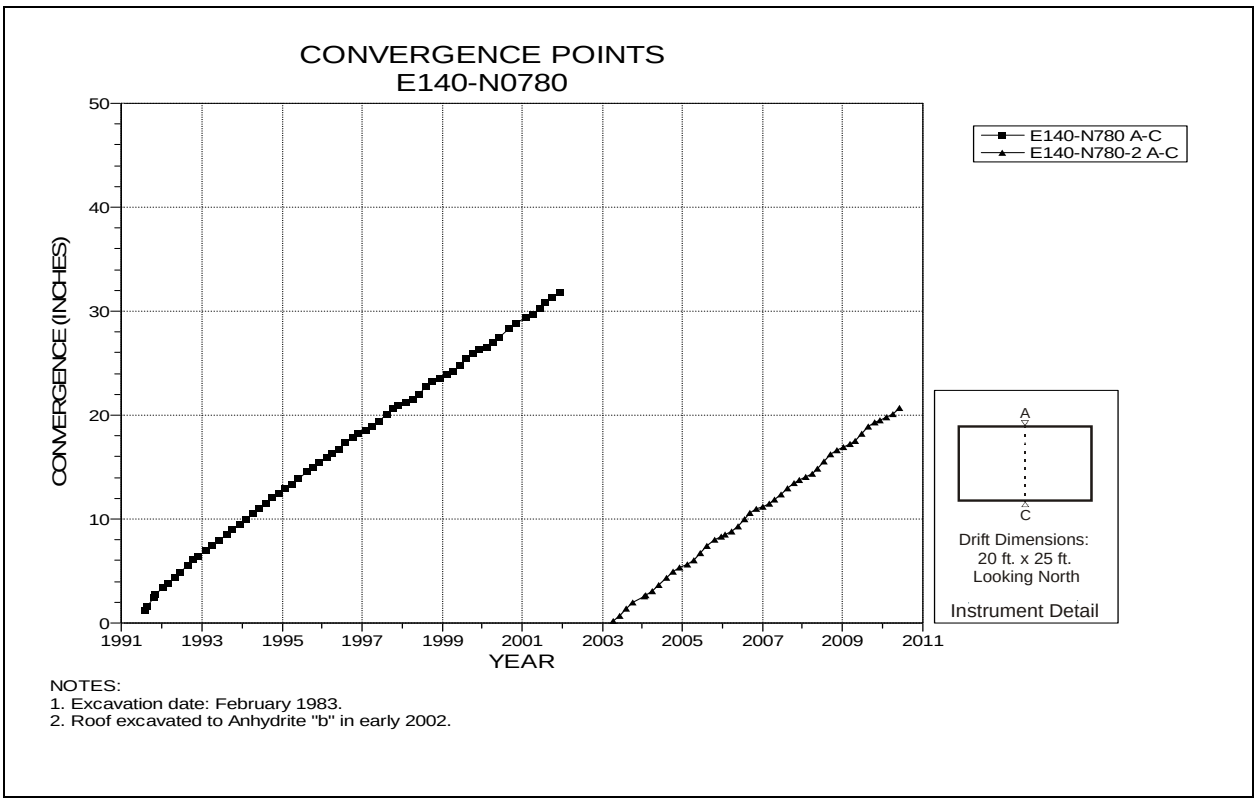


Figure 4-58 Convergence Point Array
E140 N780 – Roof to Floor

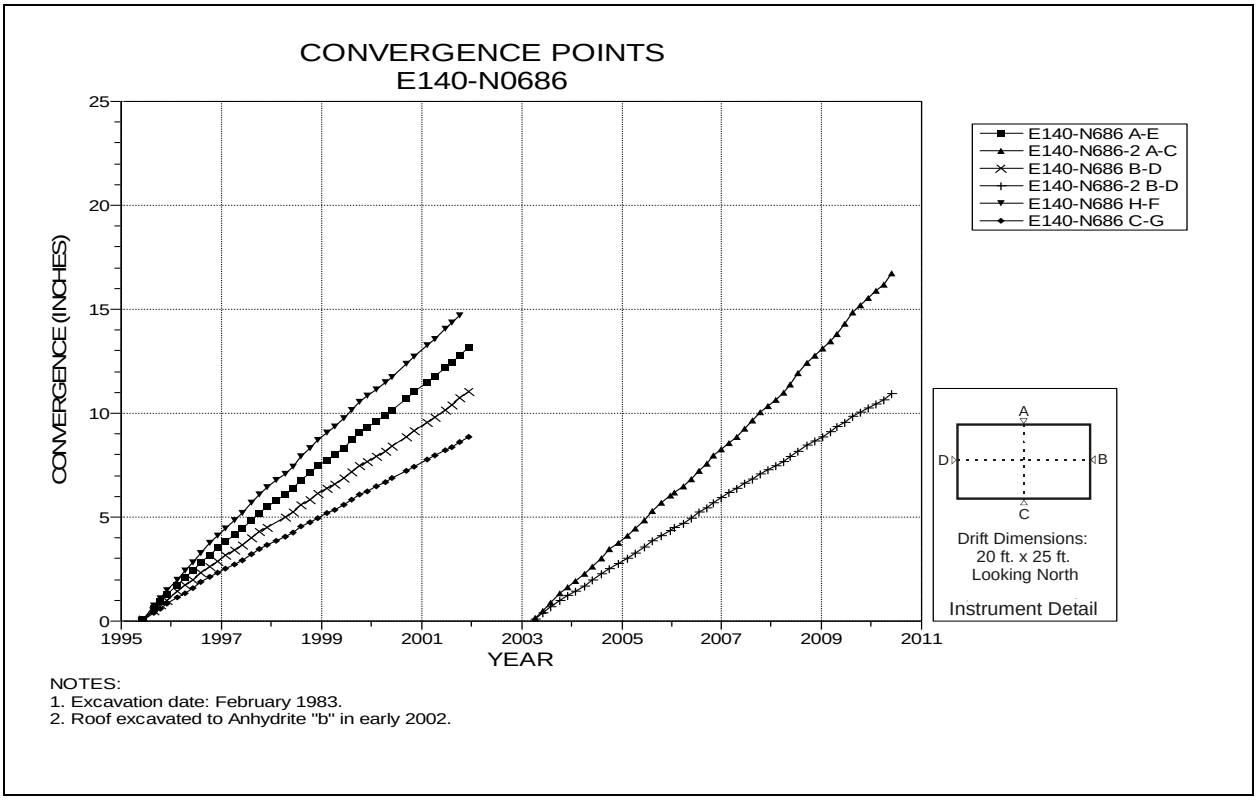


Figure 4-59 Convergence Point Array
E140 N686 – All Chords

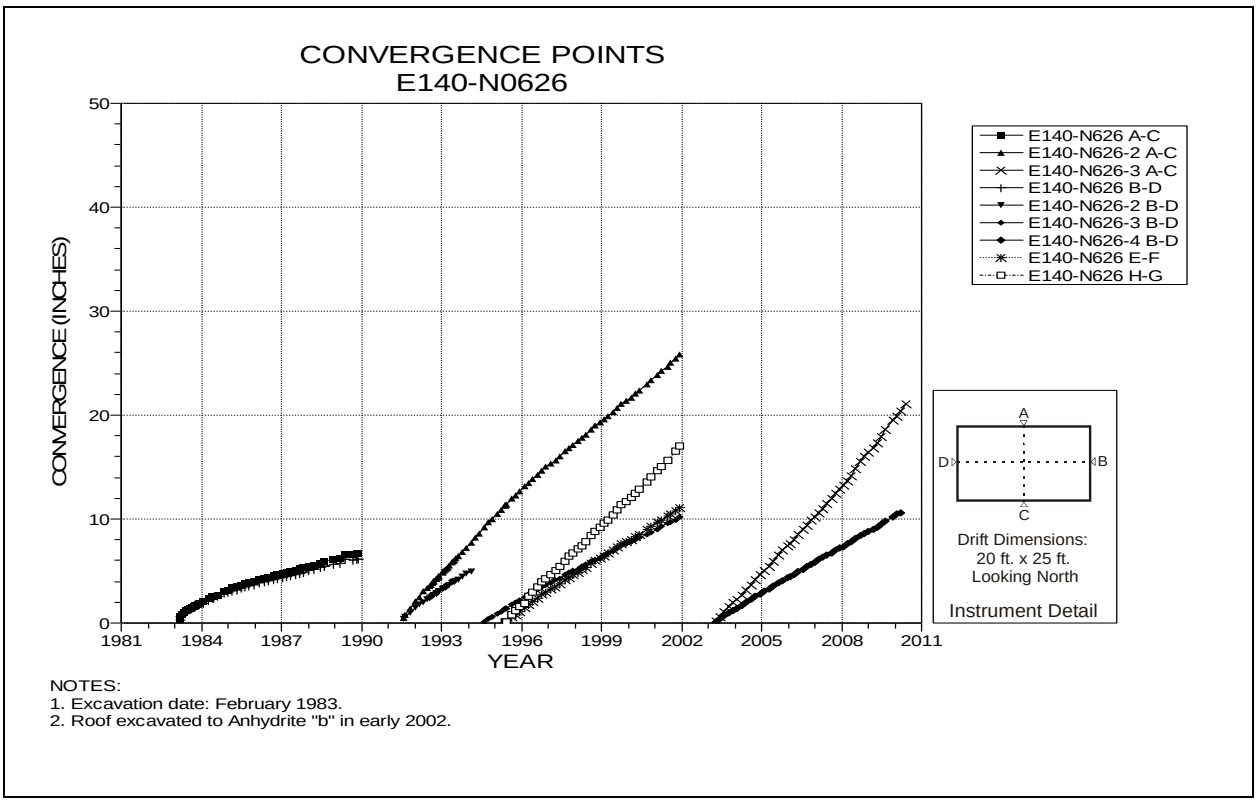


Figure 4-60 Convergence Point Array
E140 N626 – All Chords

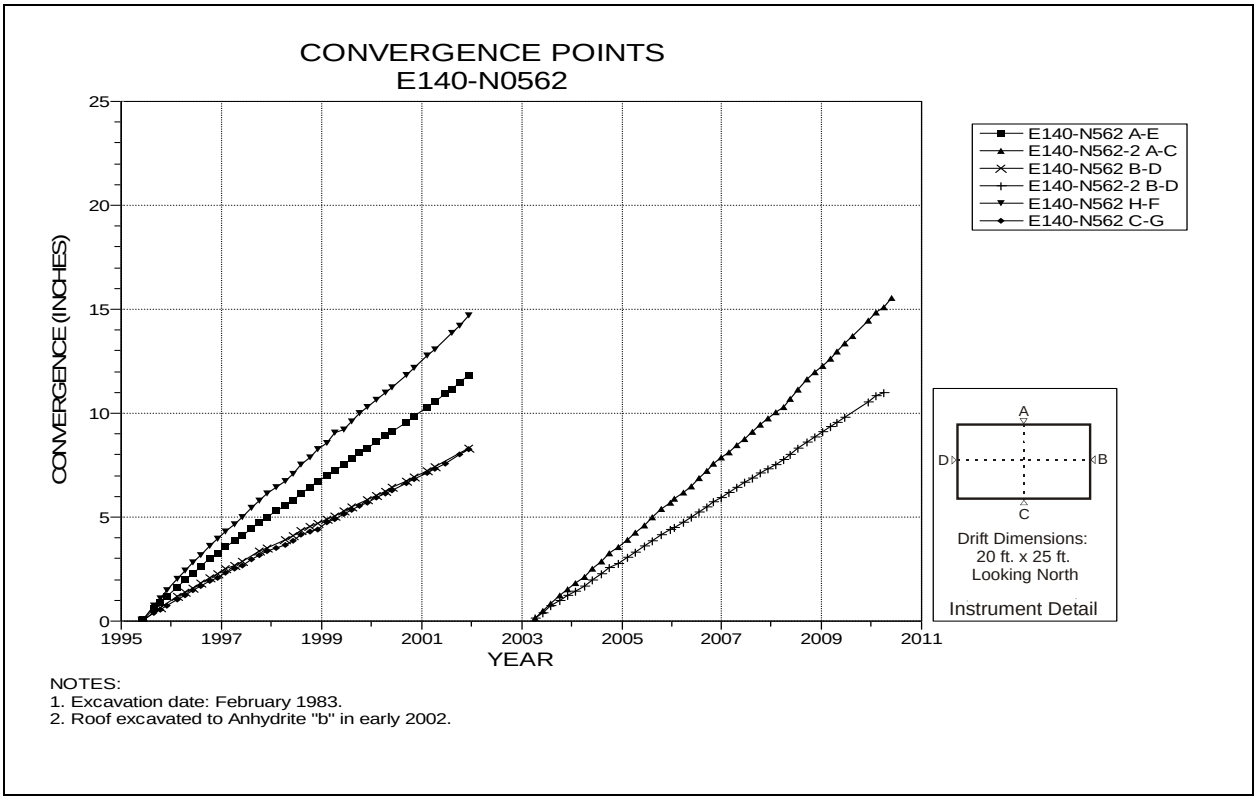


Figure 4-61 Convergence Point Array
E140 N562 – All Chords

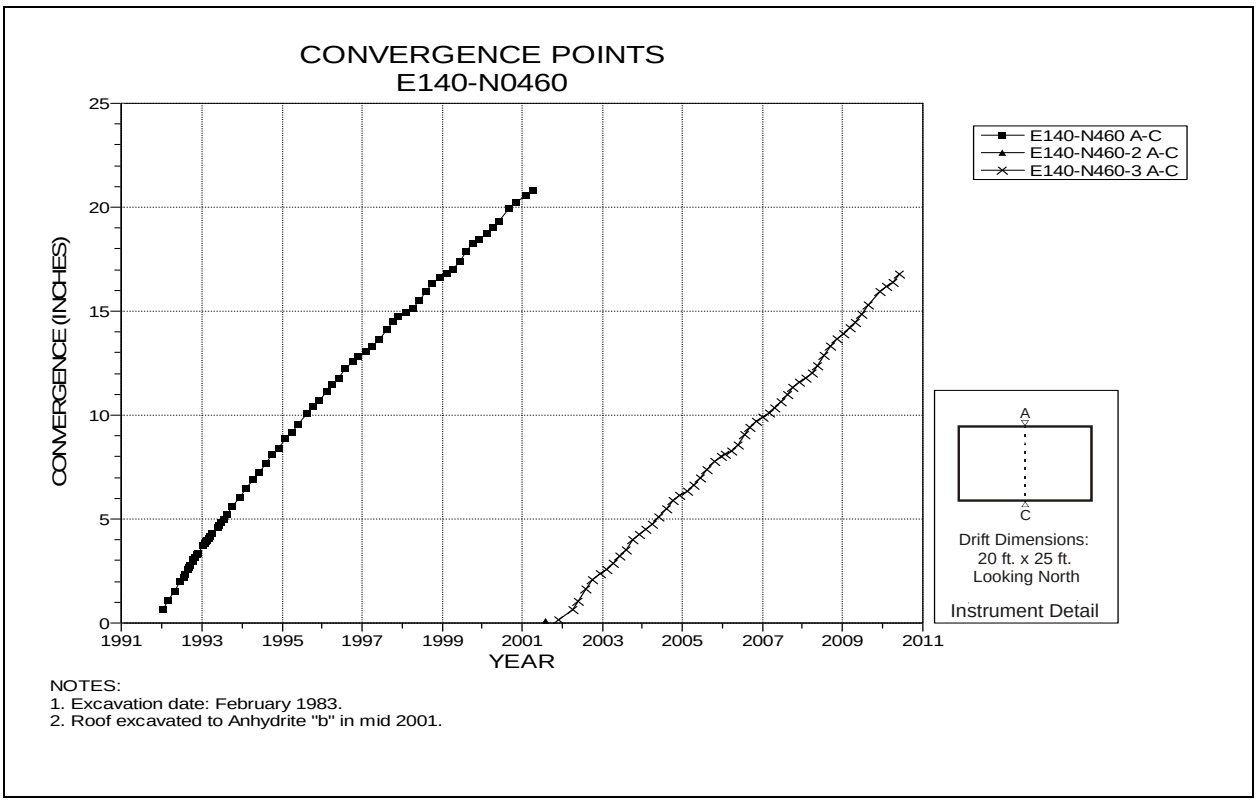


Figure 4-62 Convergence Point Array
E140 N460 – Roof to Floor

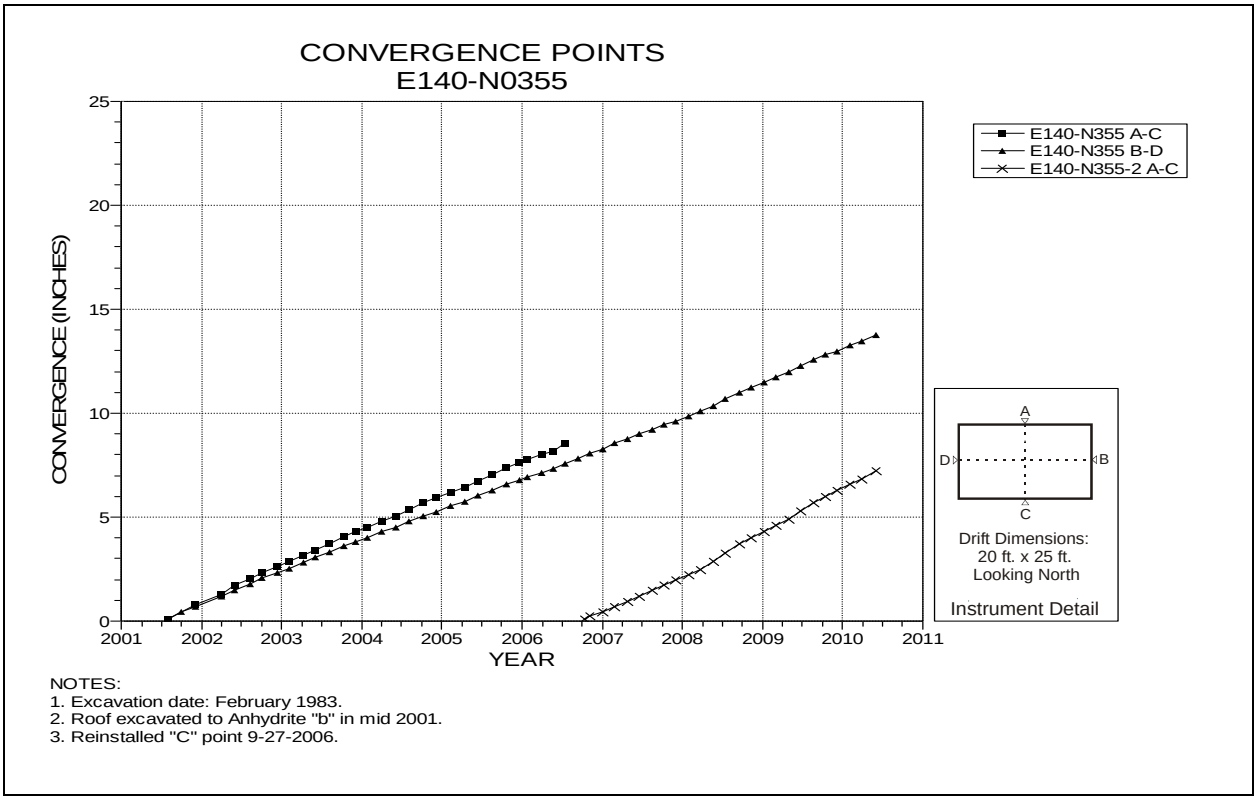


Figure 4-63 Convergence Point Array
E140 N355 – All Chords

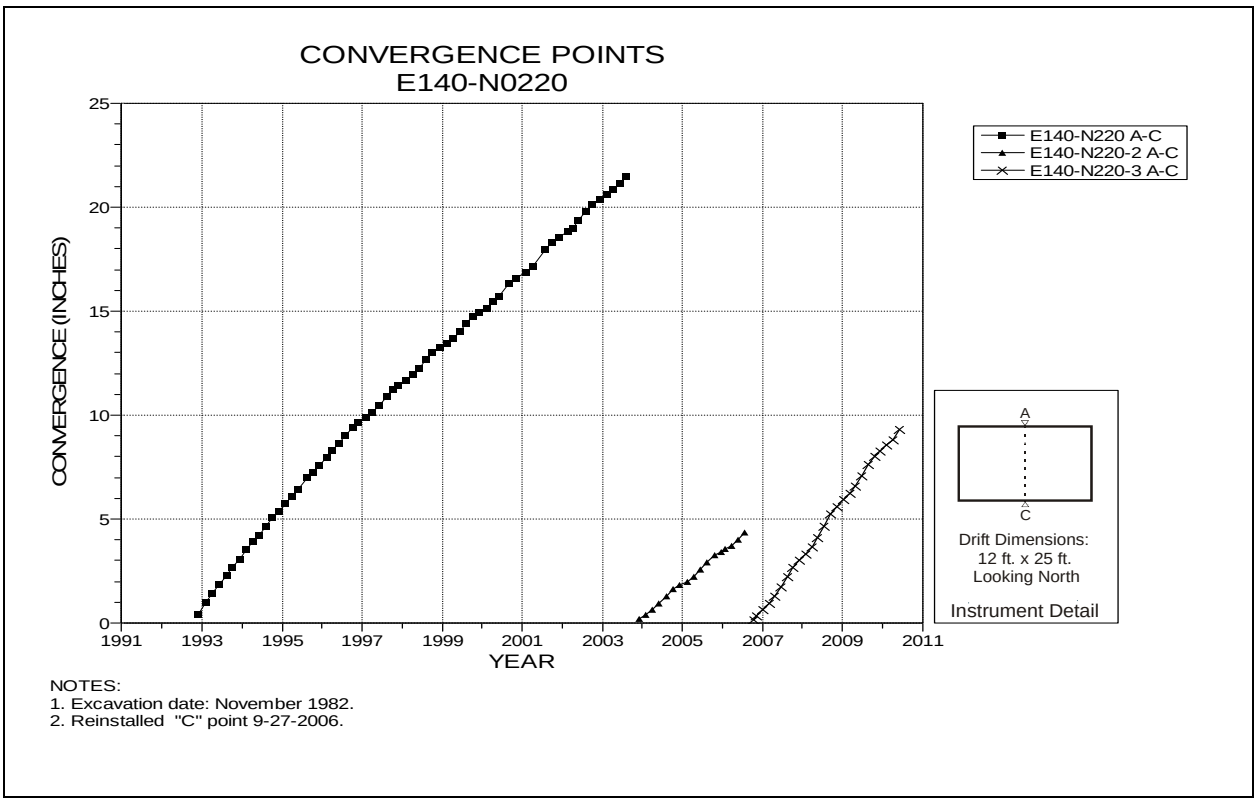


Figure 4-64 Convergence Point Array
E140 N220 – Roof to Floor

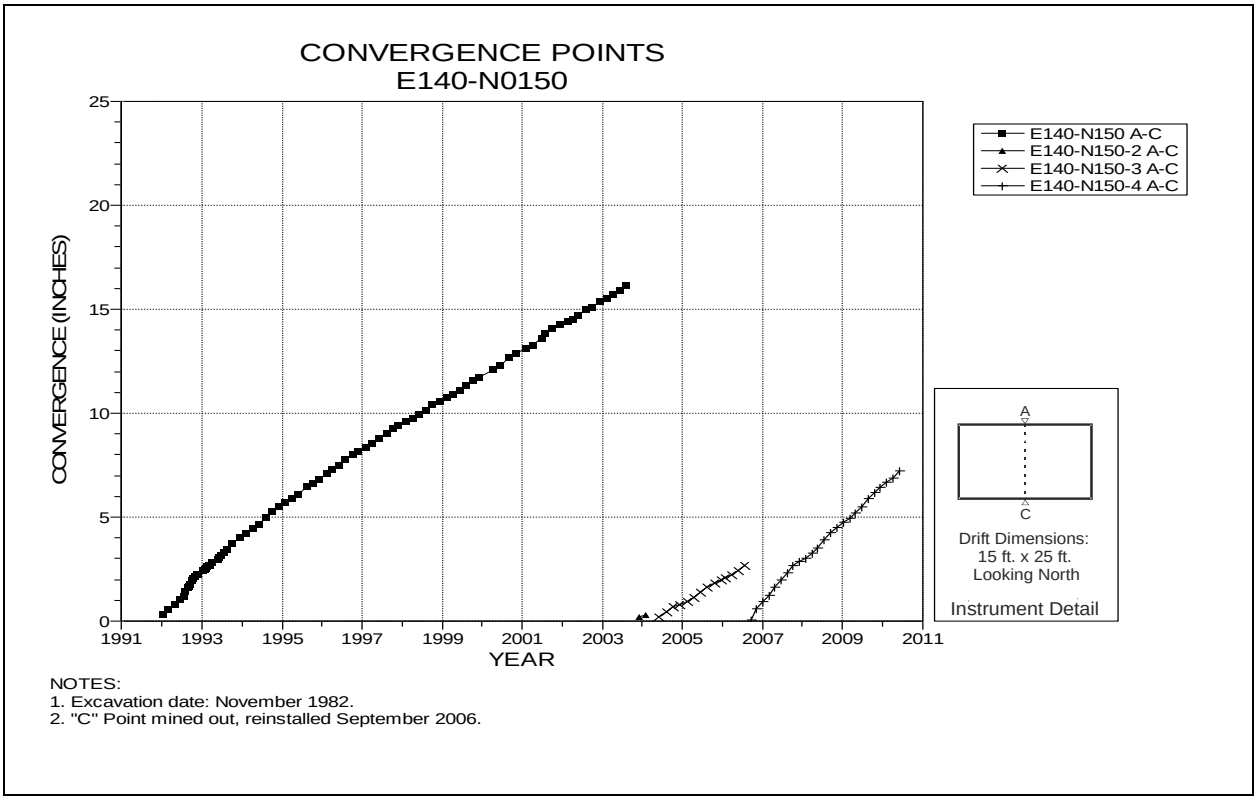


Figure 4-65 Convergence Point Array
E140 N150 – Roof to Floor

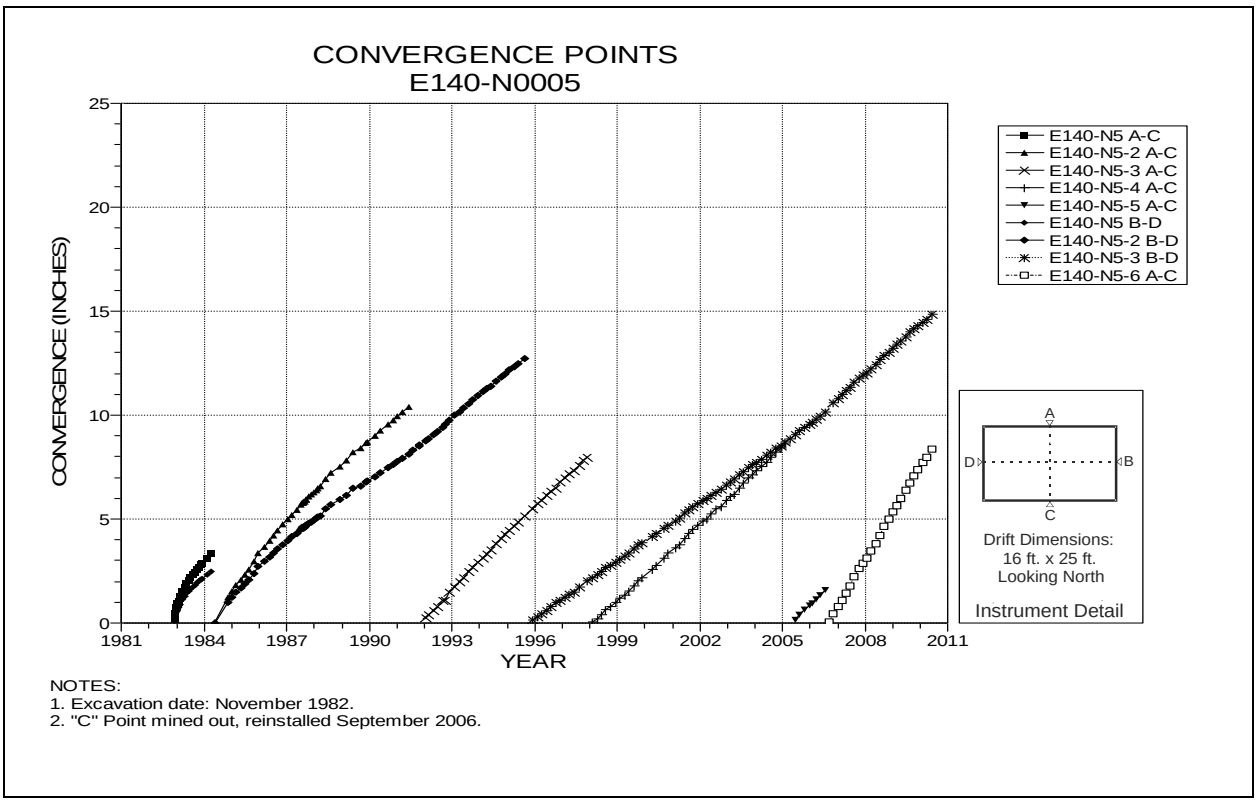


Figure 4-66 Convergence Point Array
E140 N5 – All Chords

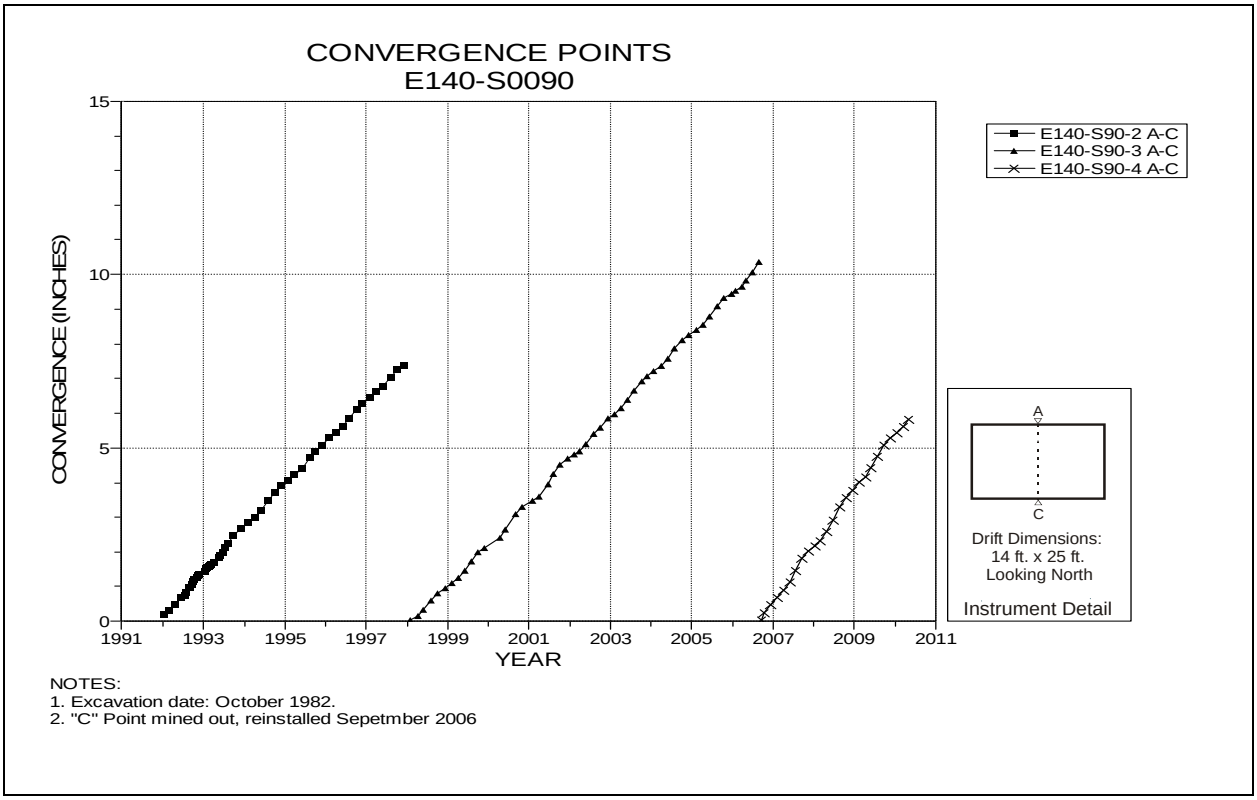


Figure 4-67 Convergence Point Array
E140 S90 – Roof to Floor

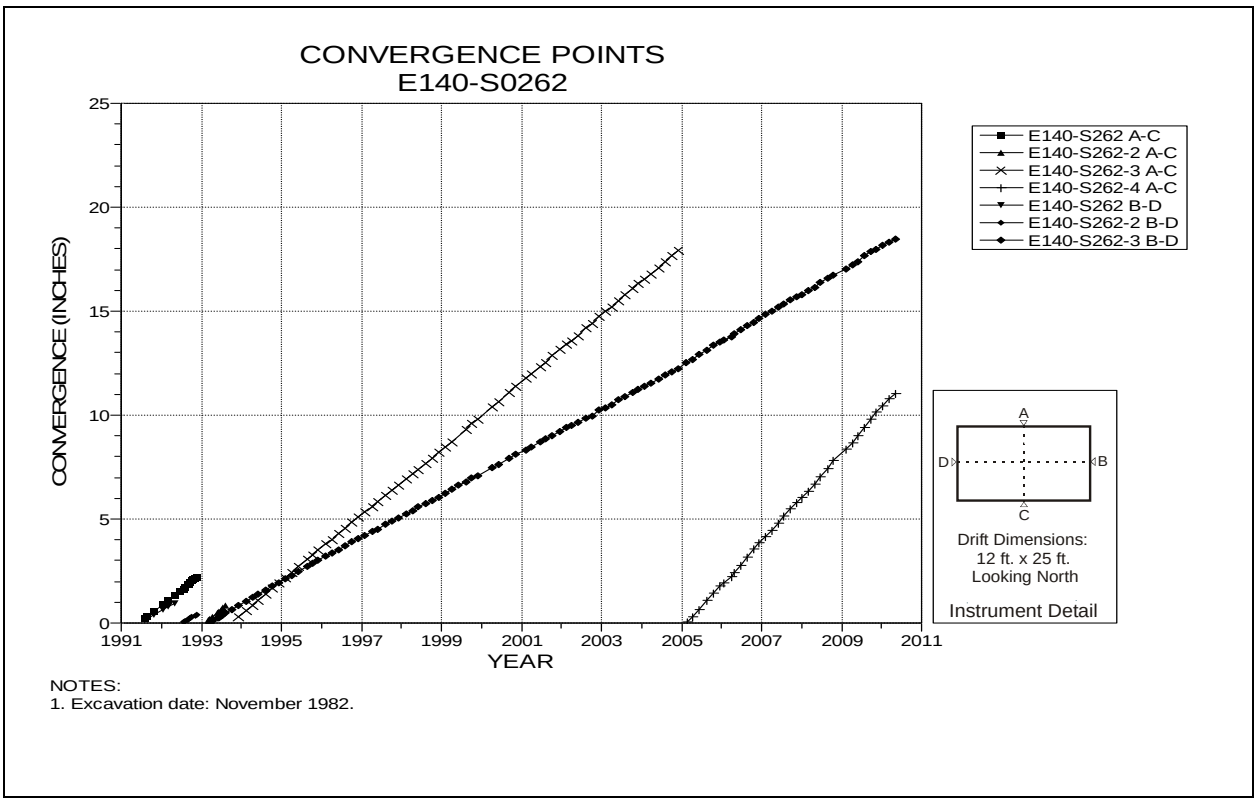


Figure 4-68 Convergence Point Array
E140 S262 – All Chords

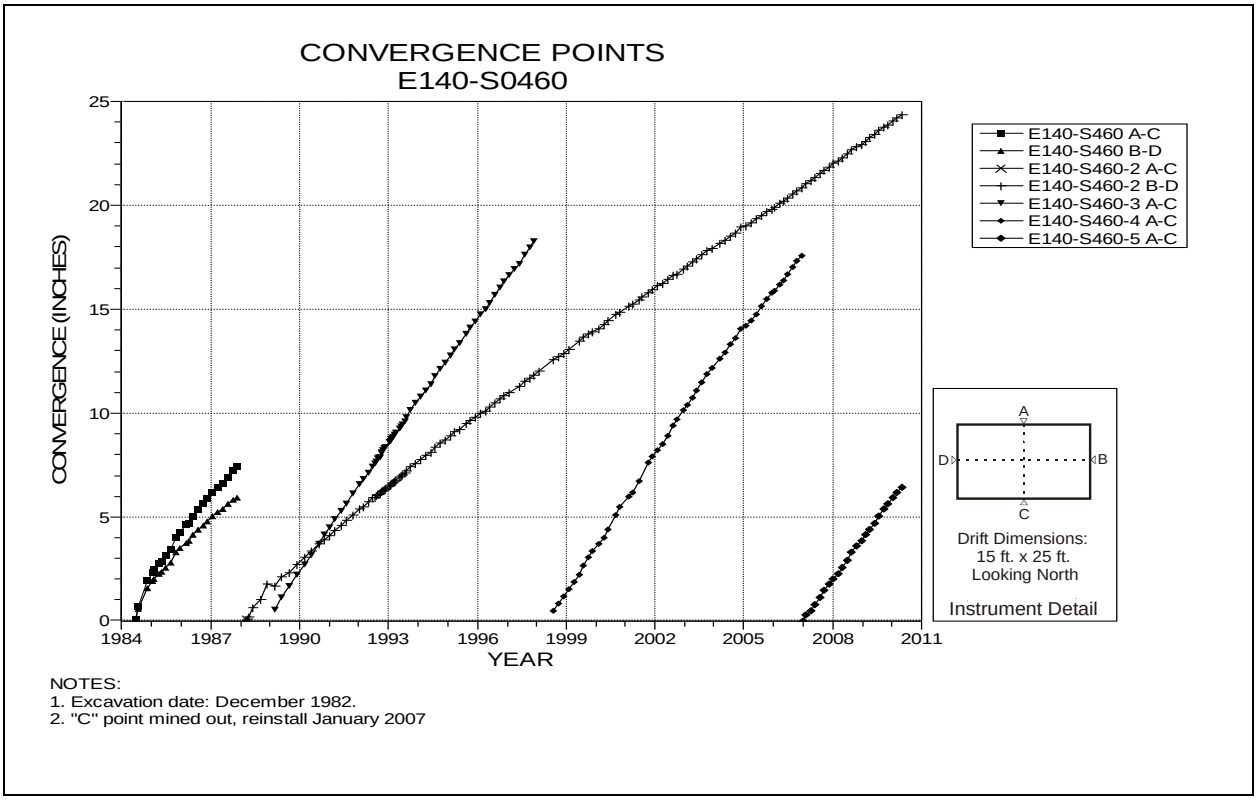


Figure 4-69 Convergence Point Array
E140 S460 – All Chords

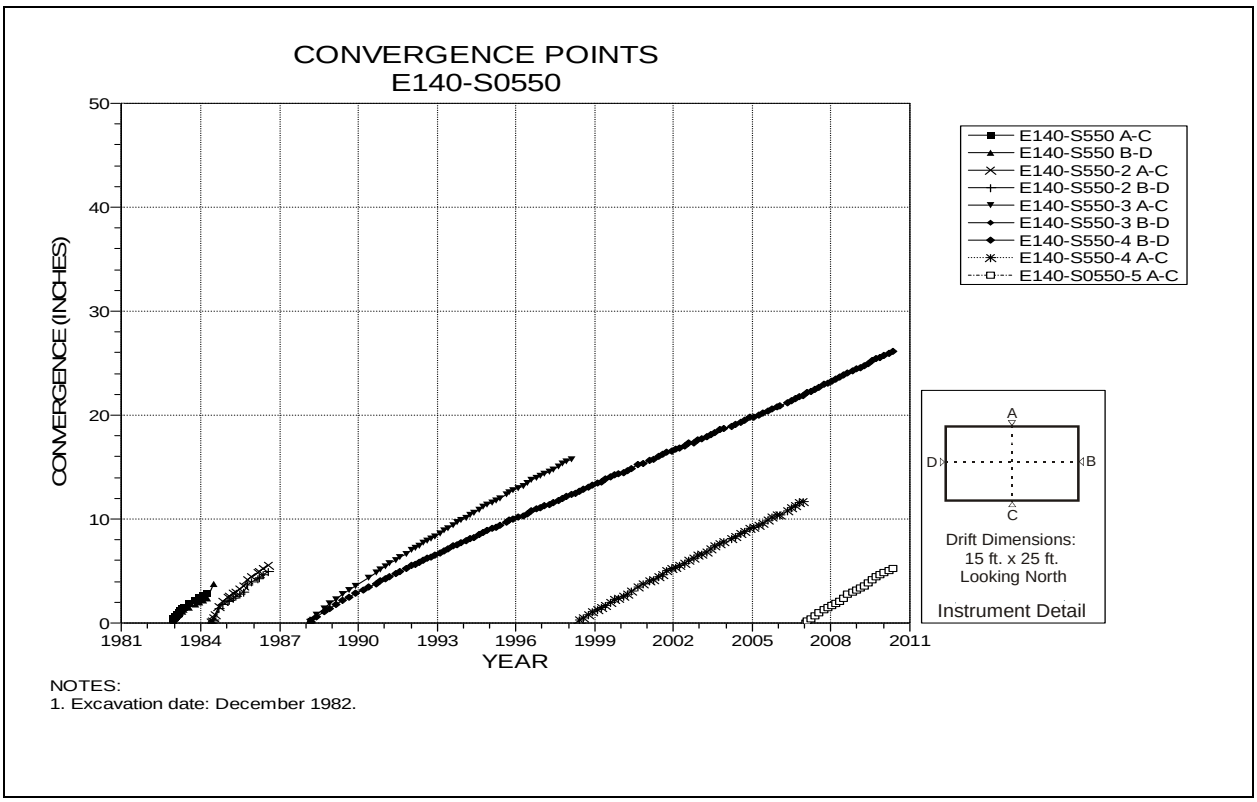


Figure 4-70 Convergence Point Array
E140 S550 – All Chords

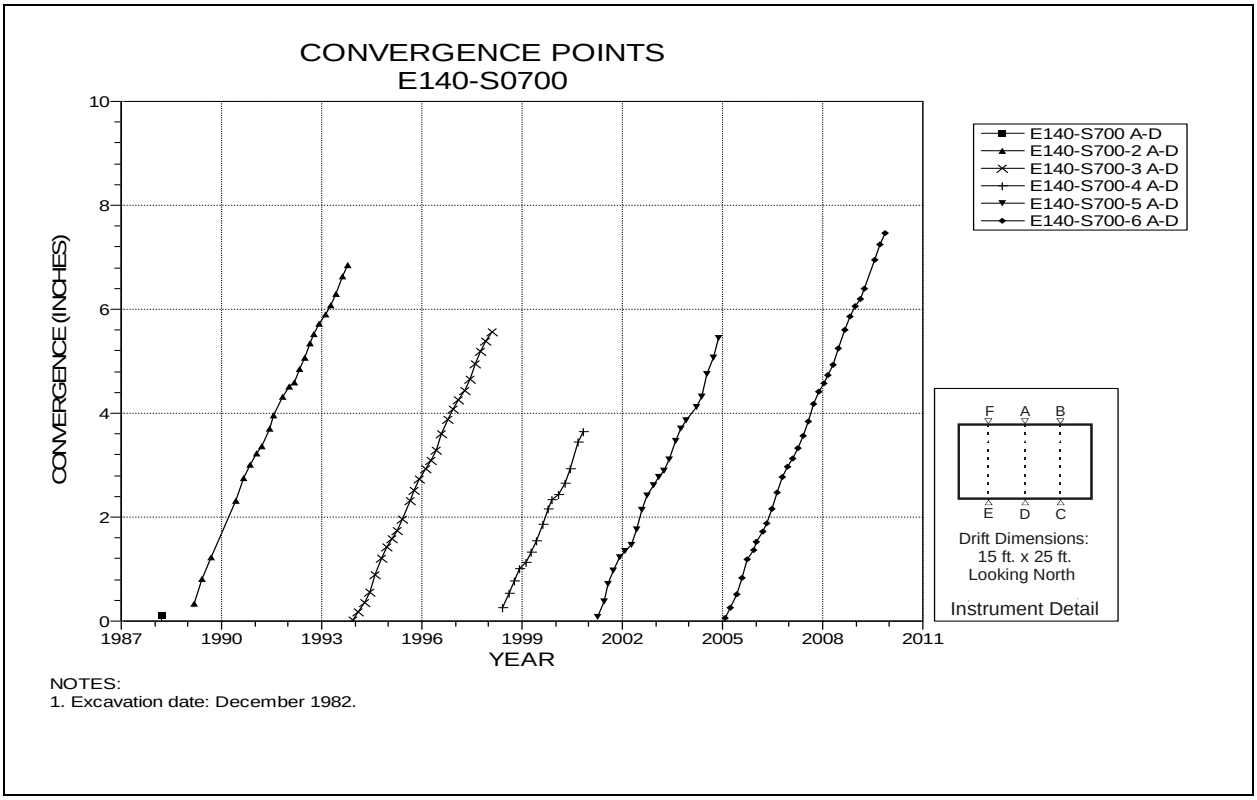


Figure 4-71 Convergence Point Array
E140 S700 – Roof to Floor – Centerline

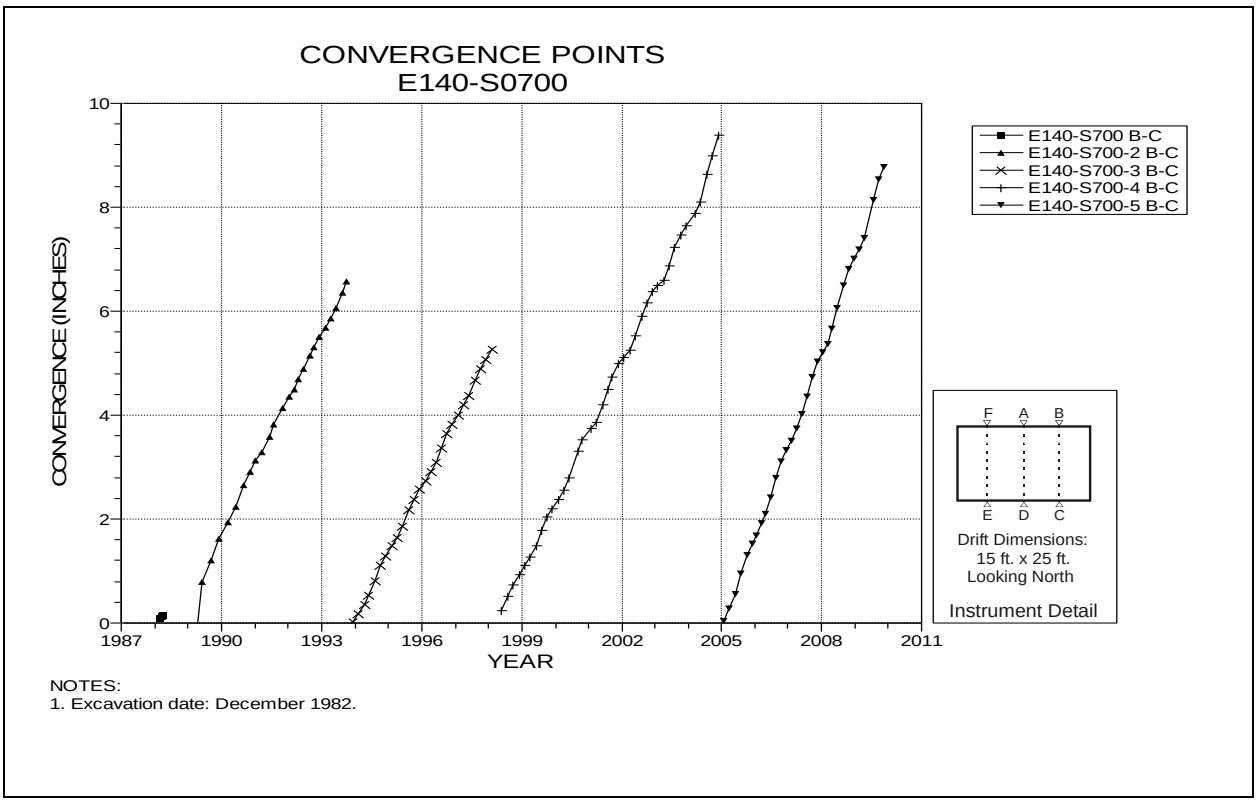


Figure 4-72 Convergence Point Array
E140 S700 – Roof to Floor – Quarter Point

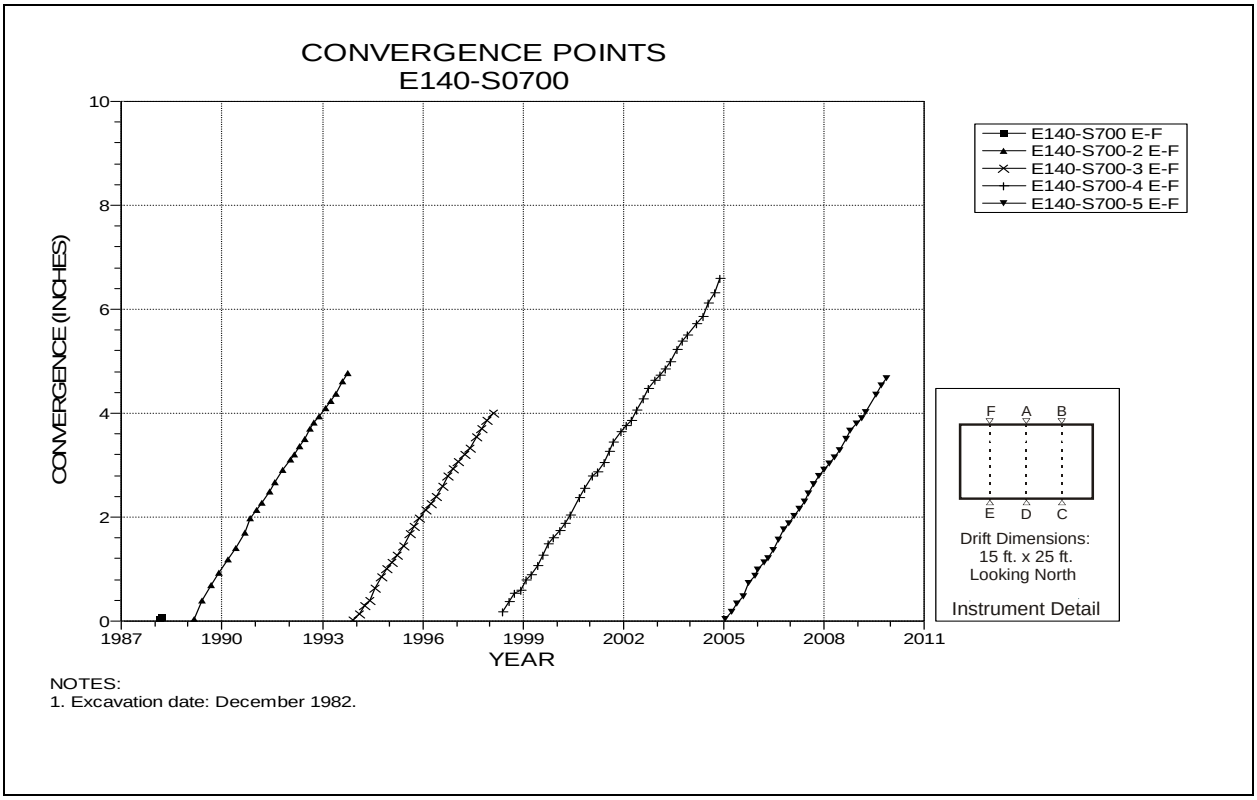


Figure 4-73 Convergence Point Array
E140 S700 – Roof to Floor – Quarter Point

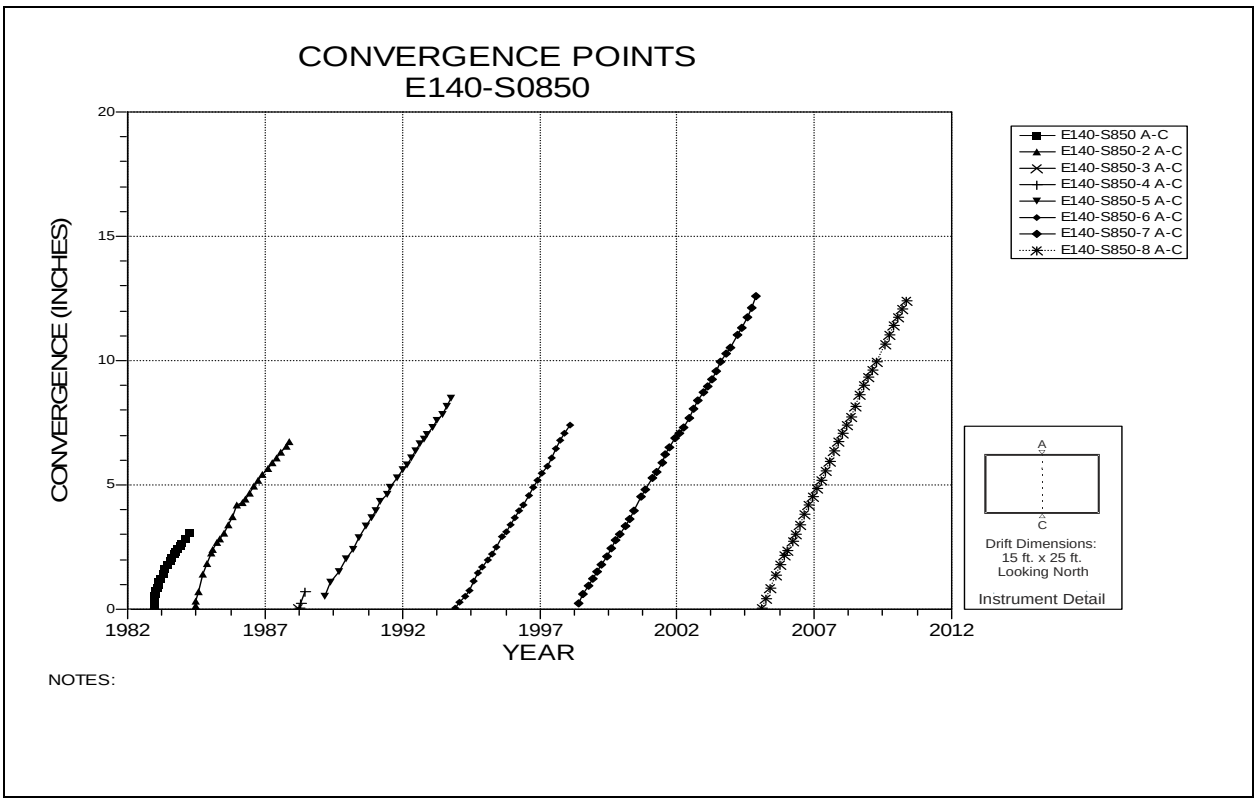


Figure 4-74 Convergence Point Array
E140 S850 – Roof to Floor

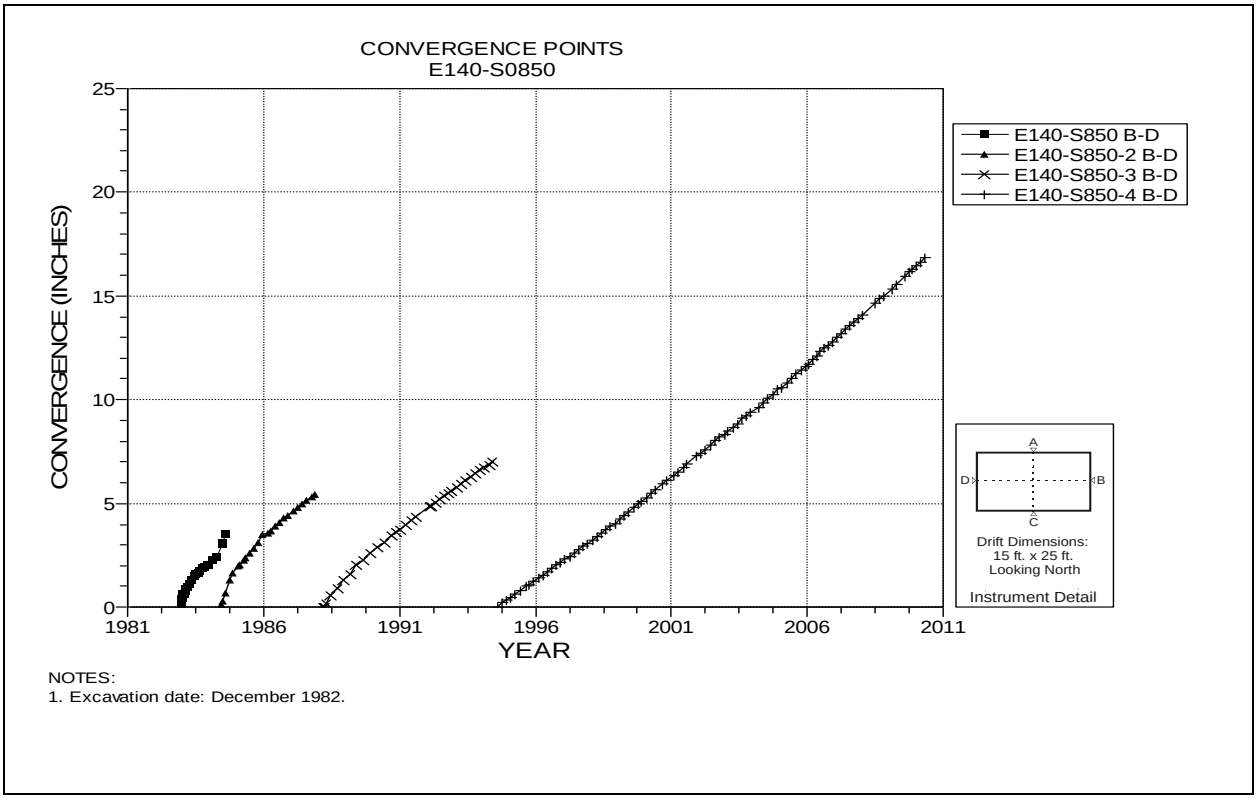


Figure 4-75 Convergence Point Array
E140 S850 – Rib to Rib

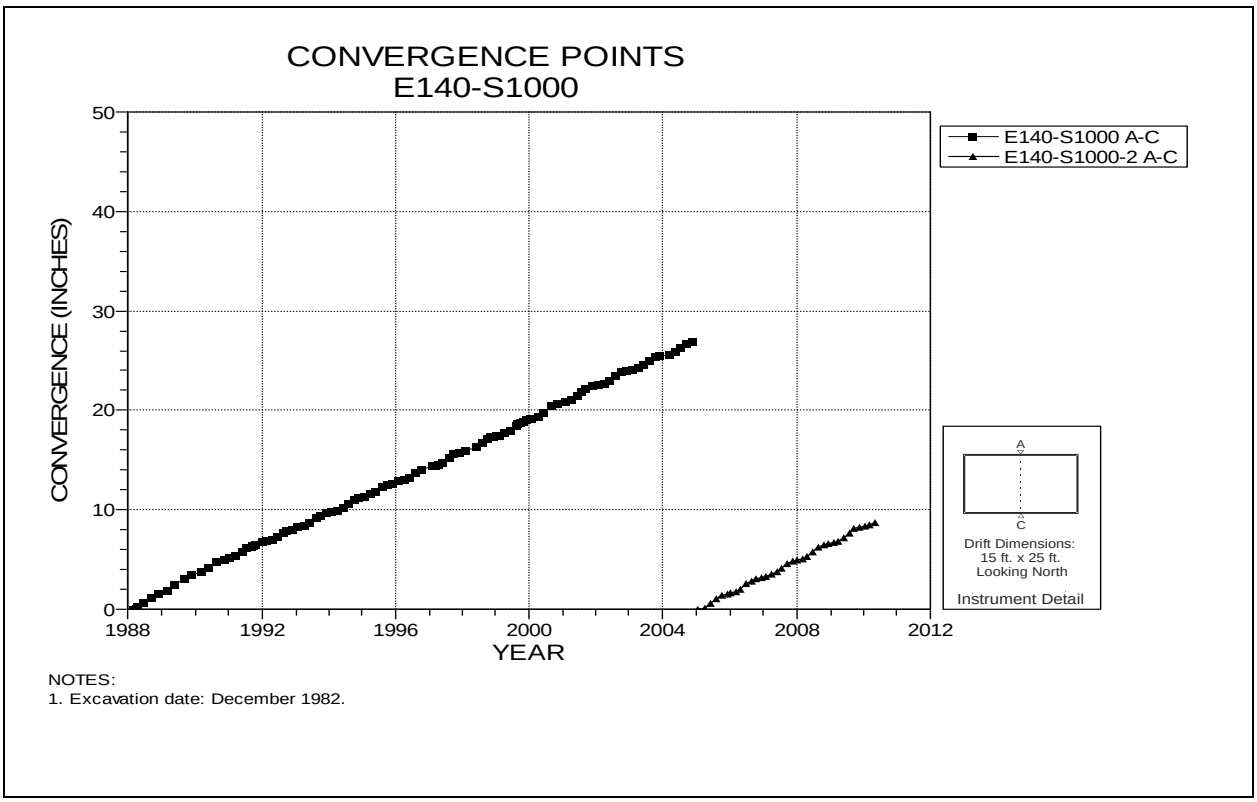


Figure 4-76 Convergence Point Array
E140 S1000 – Roof to Floor

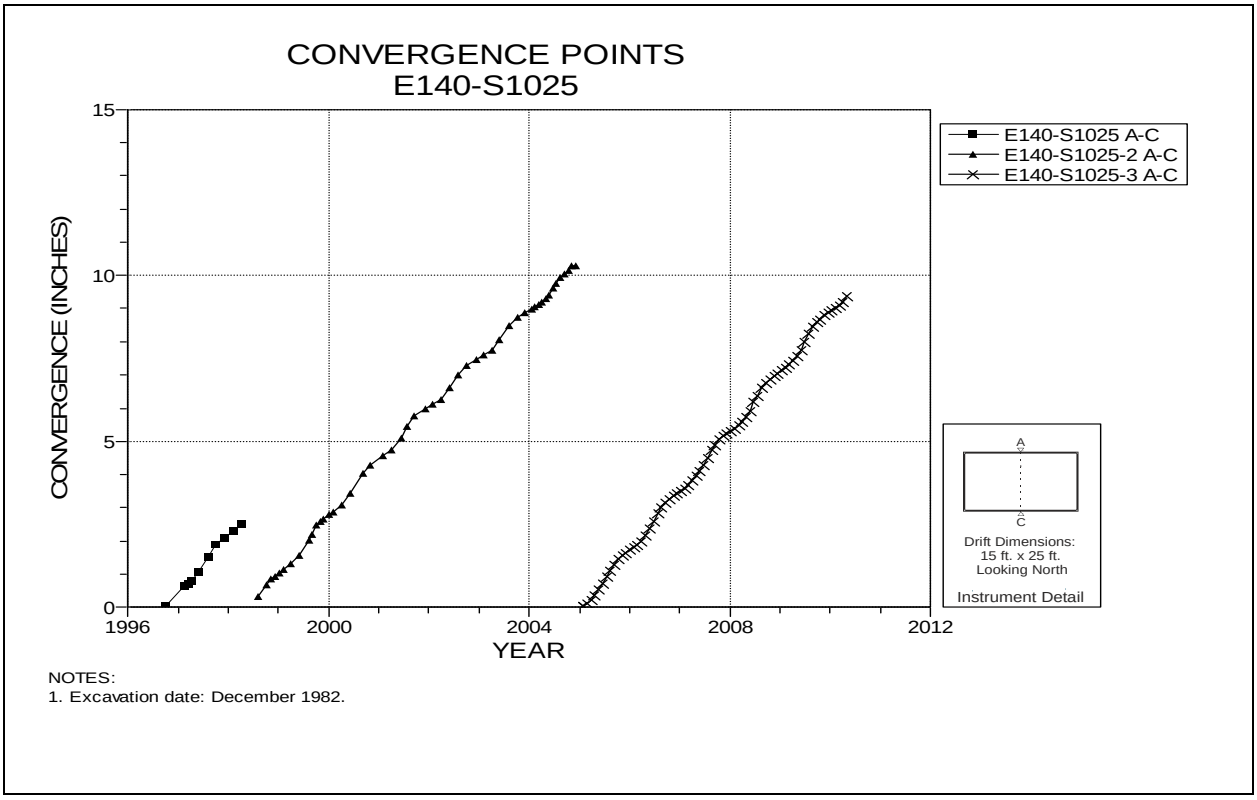


Figure 4-77 Convergence Point Array
E140 S1025 – Roof to Floor

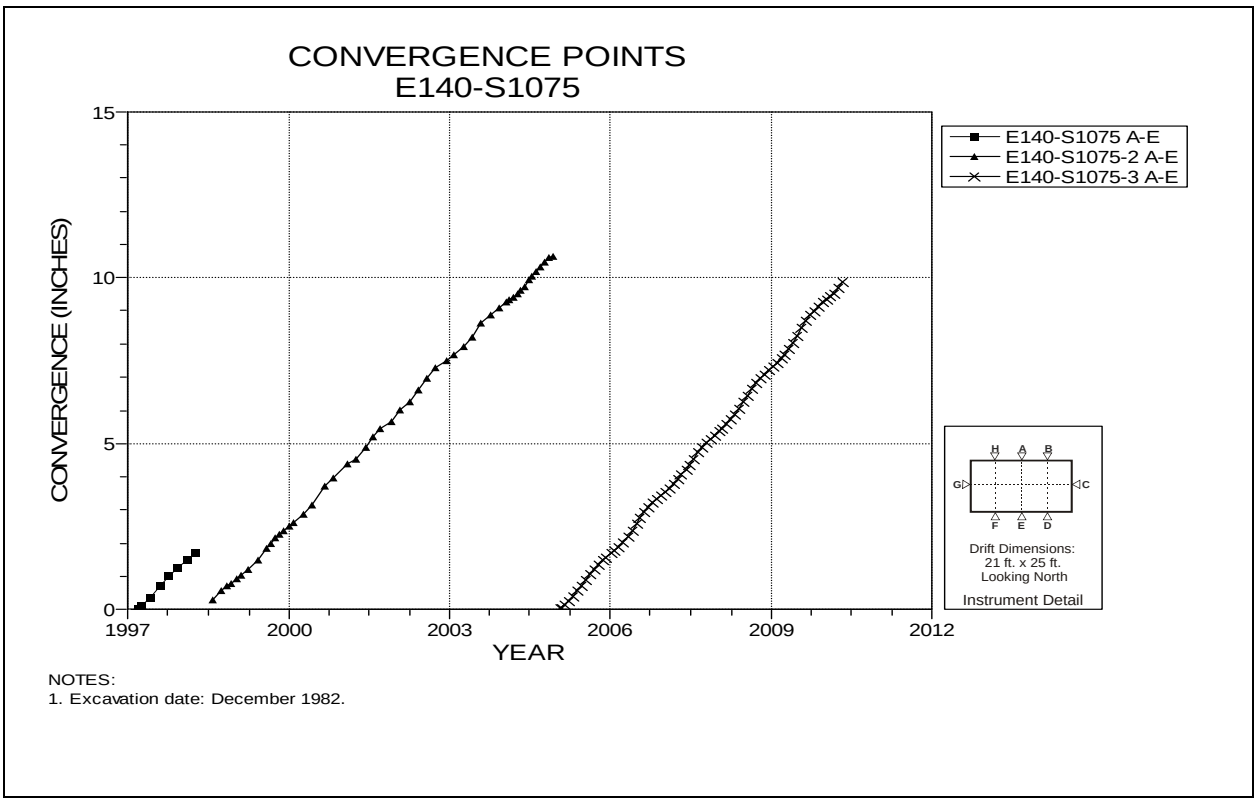


Figure 4-78 Convergence Point Array
E140 S1075 – Roof to Floor

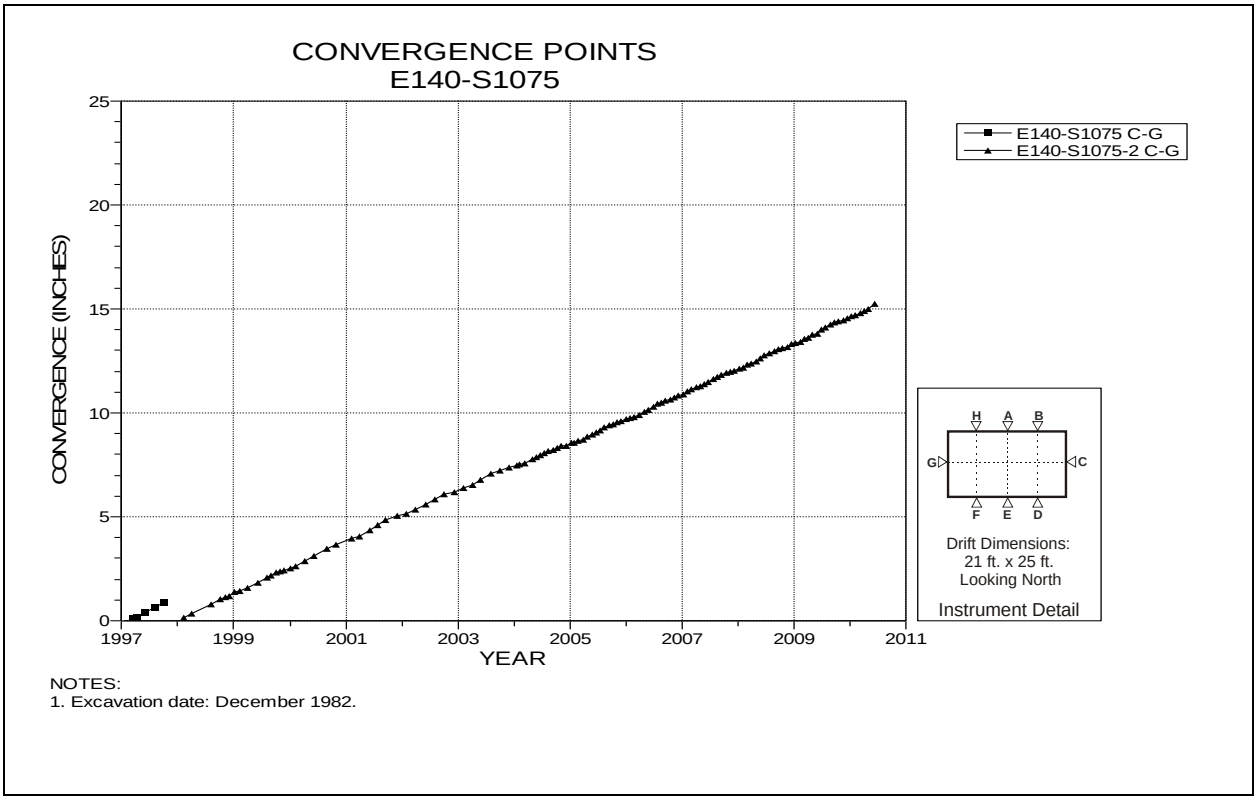


Figure 4-79 Convergence Point Array
E140 S1075 – Rib to Rib

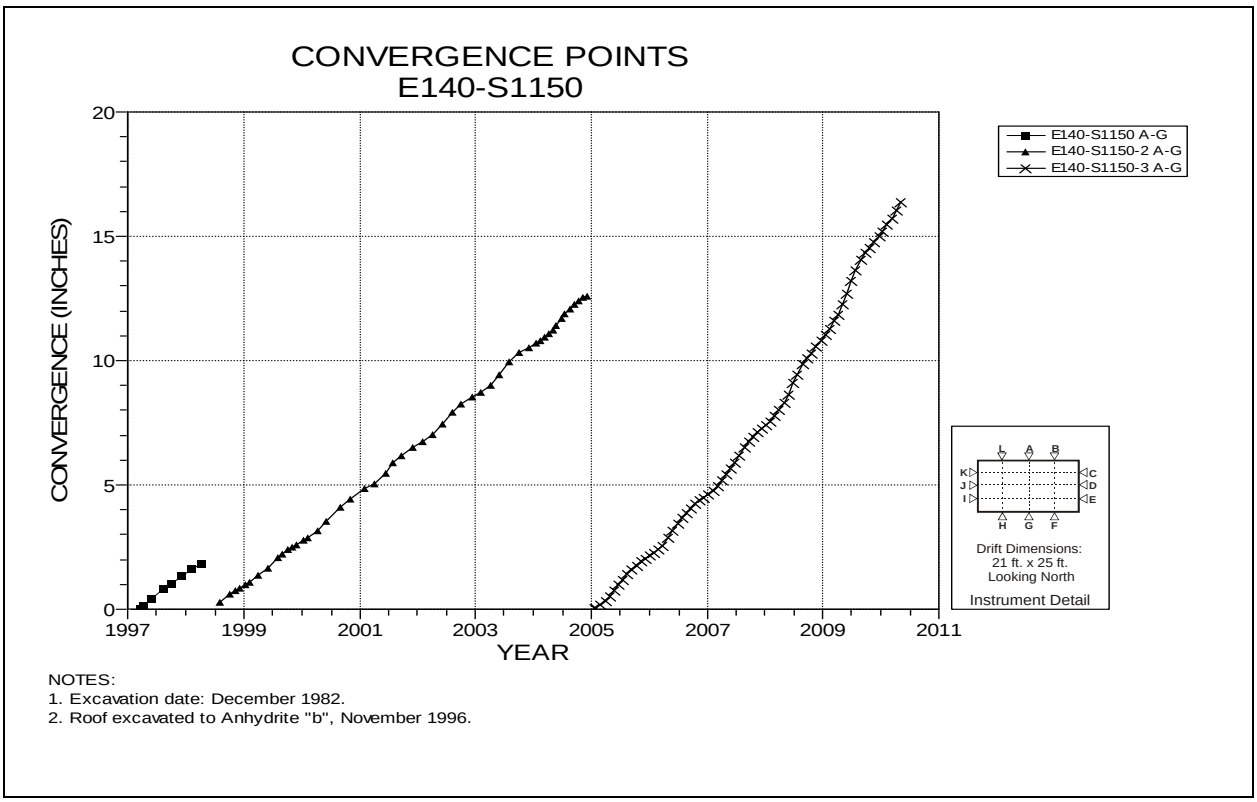


Figure 4-80 Convergence Point Array
E140 S1150 – Roof to Floor

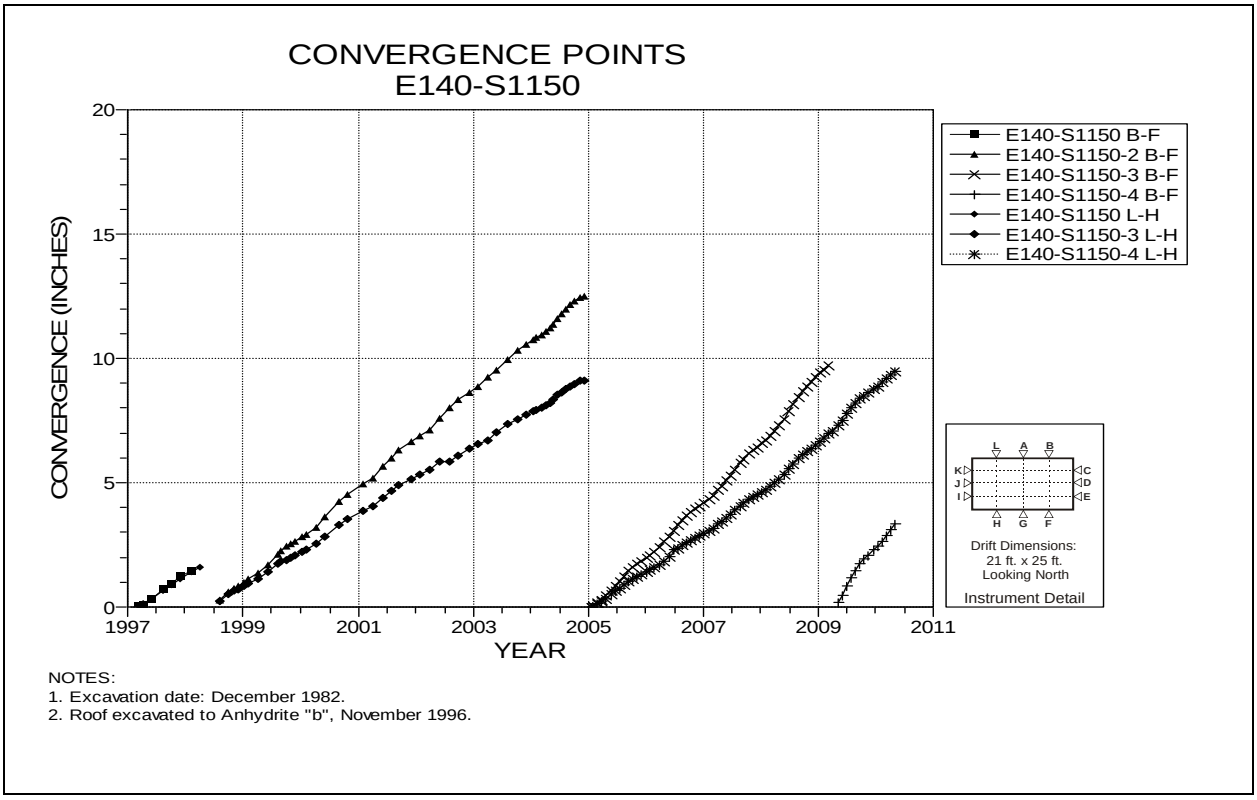


Figure 4-81 Convergence Point Array
E140 S1150 – Roof to Floor – Quarter Points

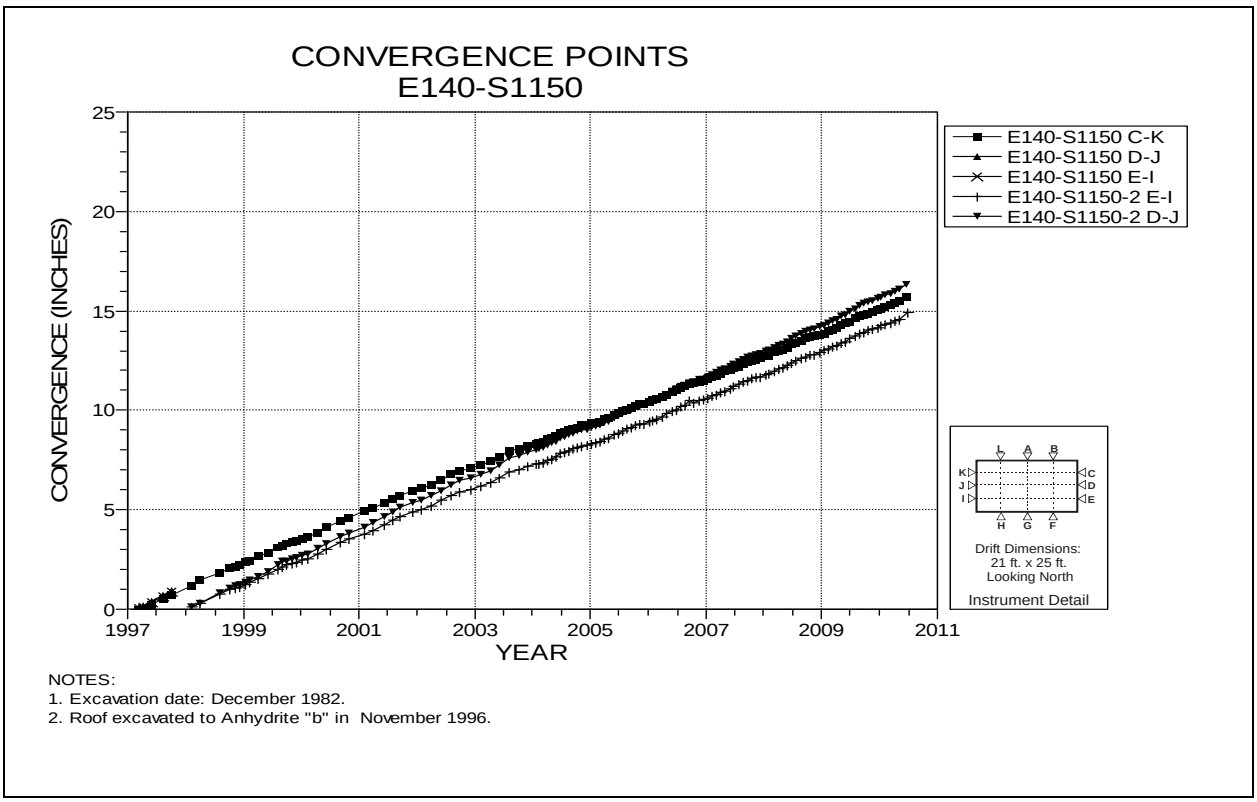


Figure 4-82 Convergence Point Array
E140 S1150 – Rib to Rib – Quarter Points

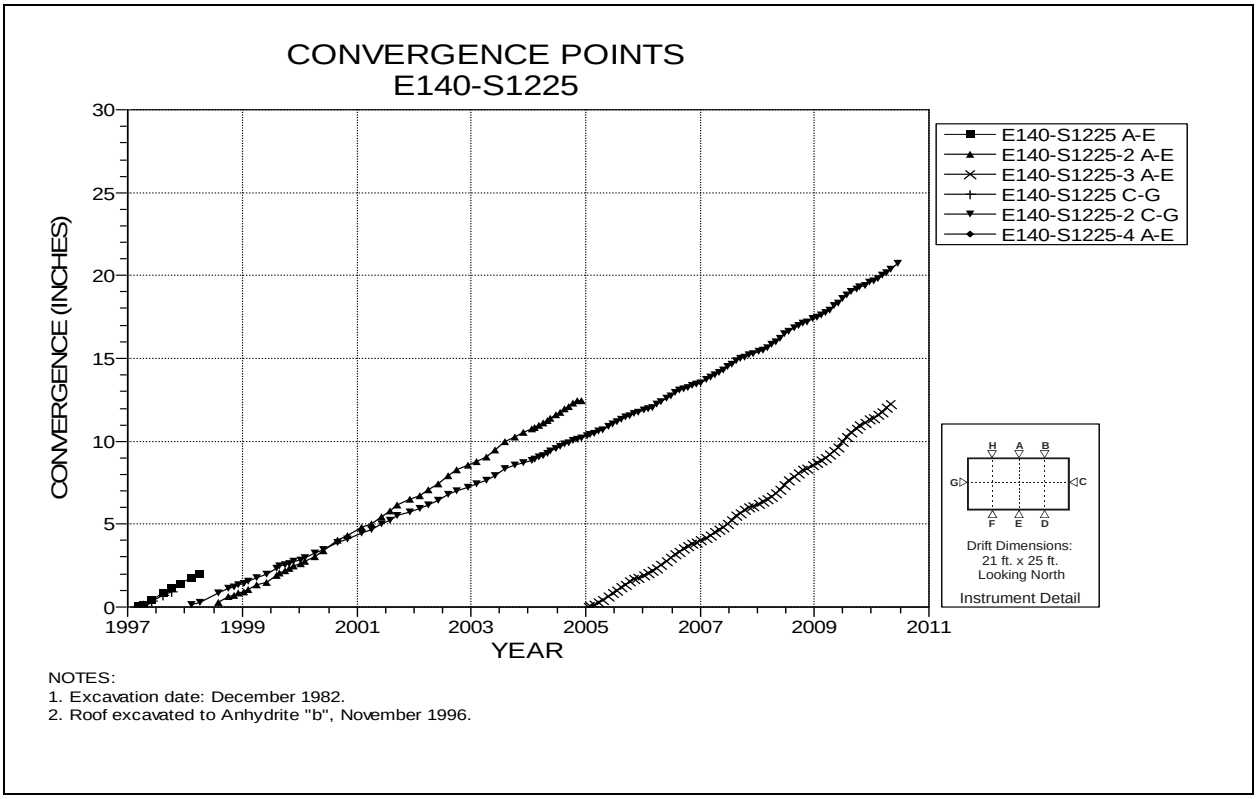


Figure 4-83 Convergence Point Array
E140 S1225 – Roof to Floor

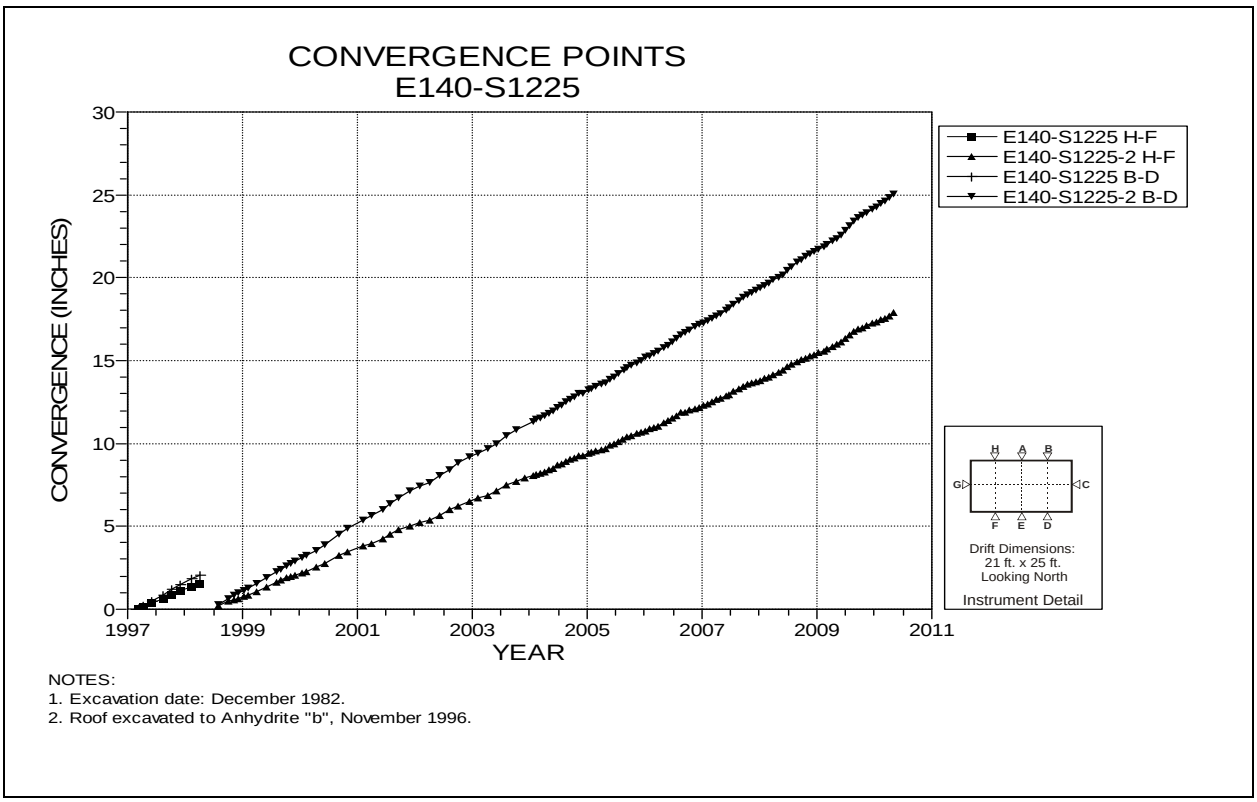


Figure 4-84 Convergence Point Array
E140 S1225 – Roof to Floor – Quarter Points

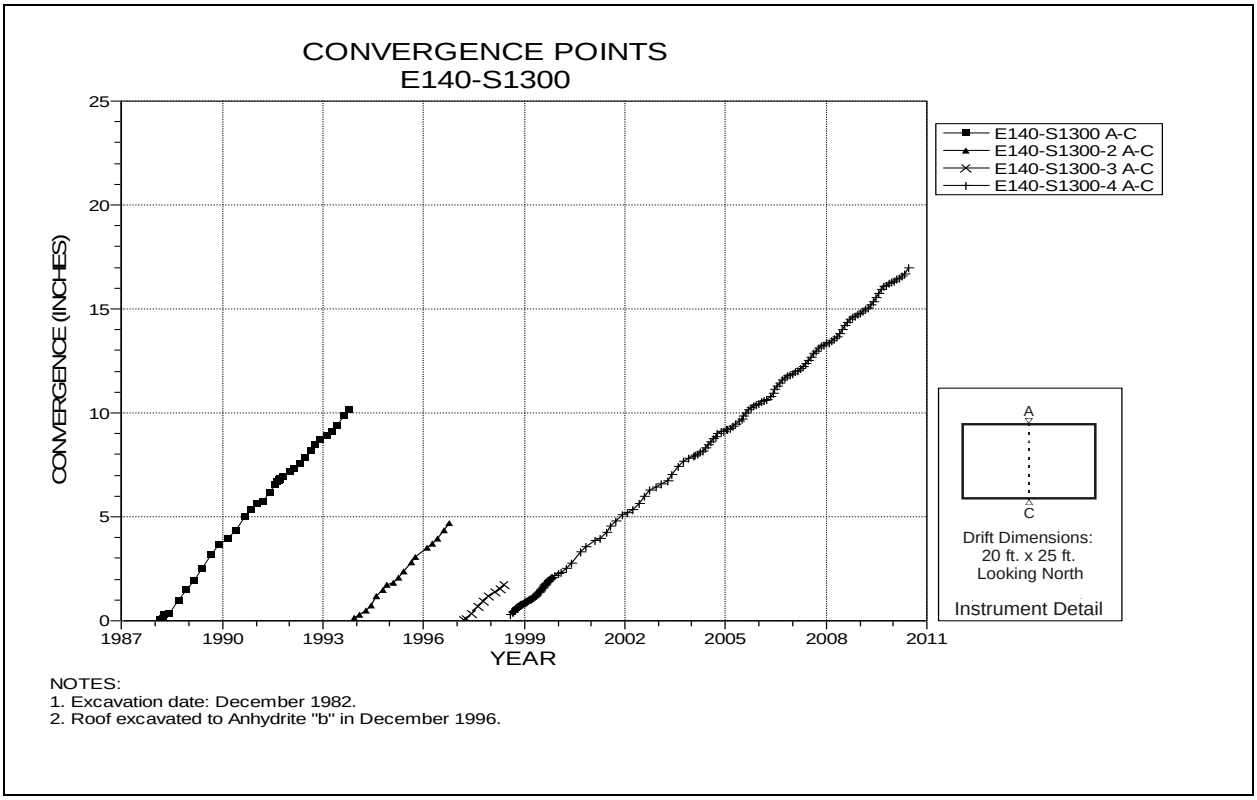


Figure 4-85 Convergence Point Array
E140 S1300 – Roof to Floor

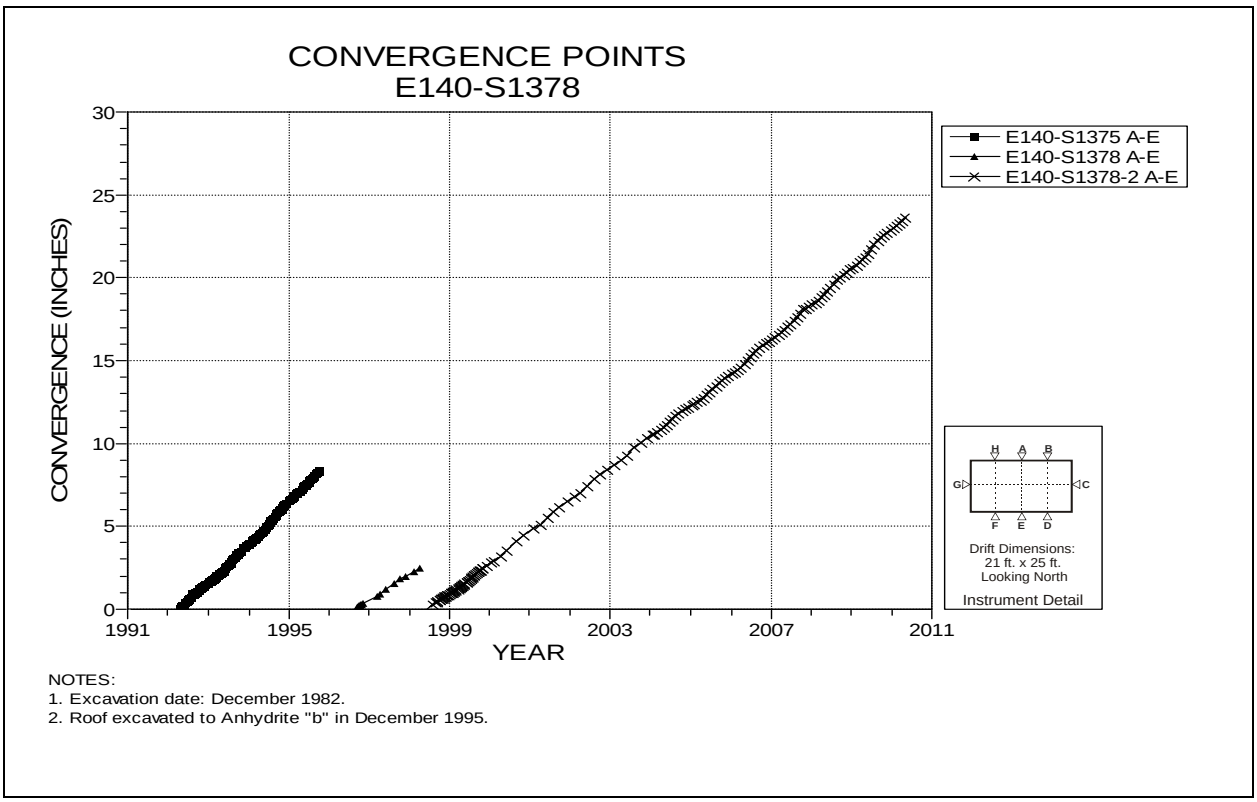


Figure 4-86 Convergence Point Array
E140 S1378 – Roof to Floor

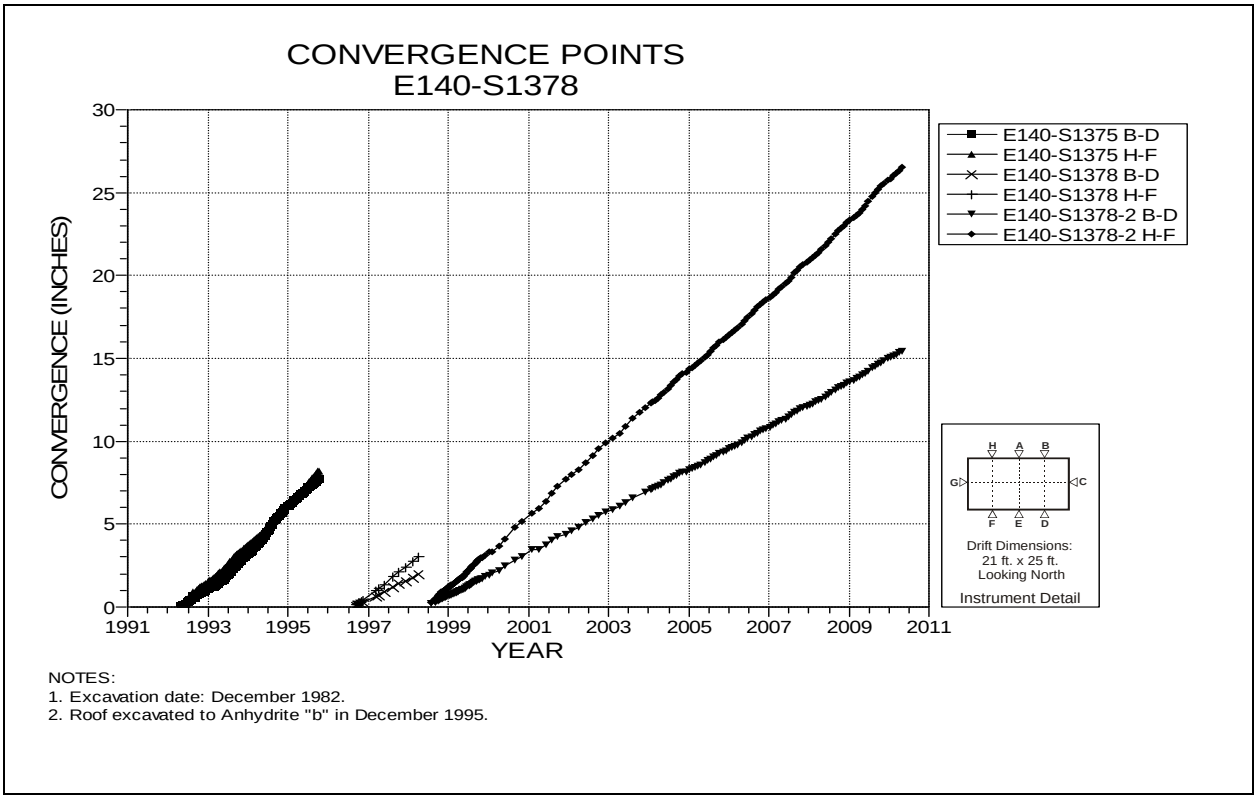


Figure 4-87 Convergence Point Array
E140 S1378 – Roof to Floor – Quarter Points

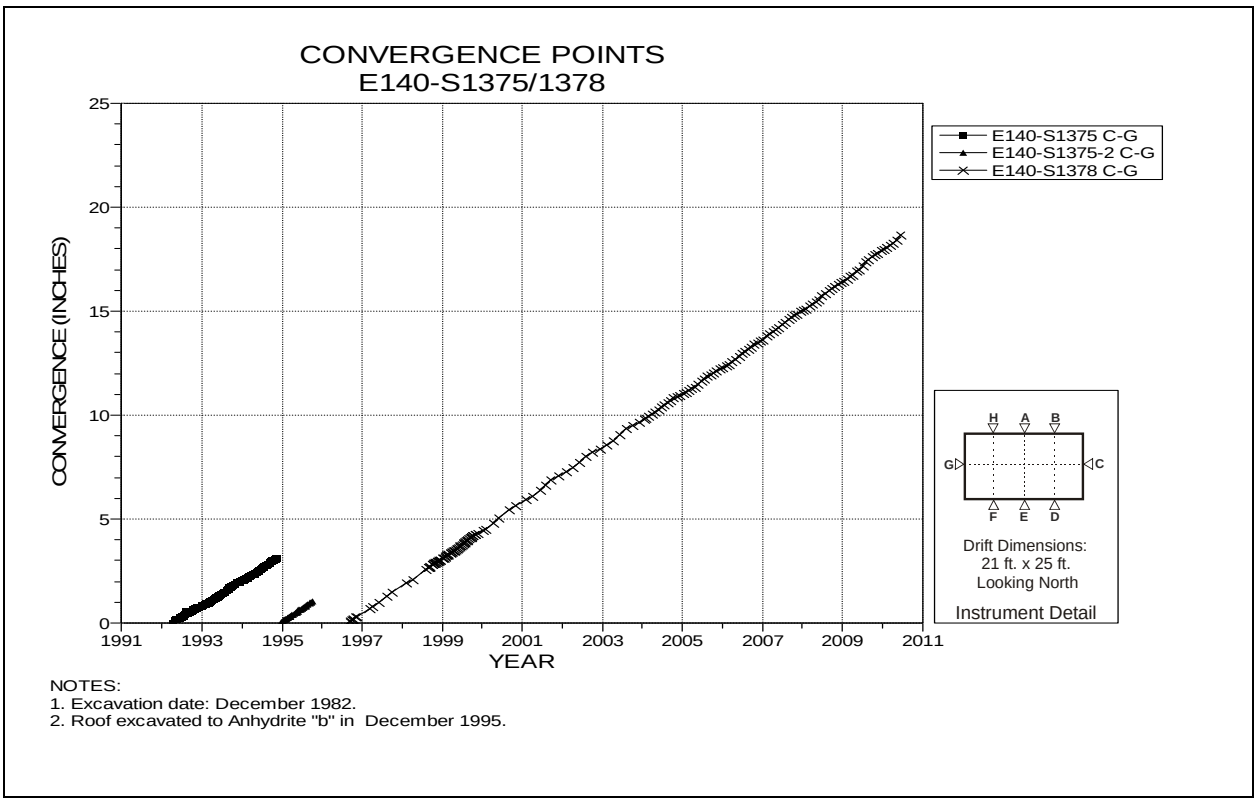


Figure 4-88 Convergence Point Array
E140 S1375/1378 – Rib to Rib

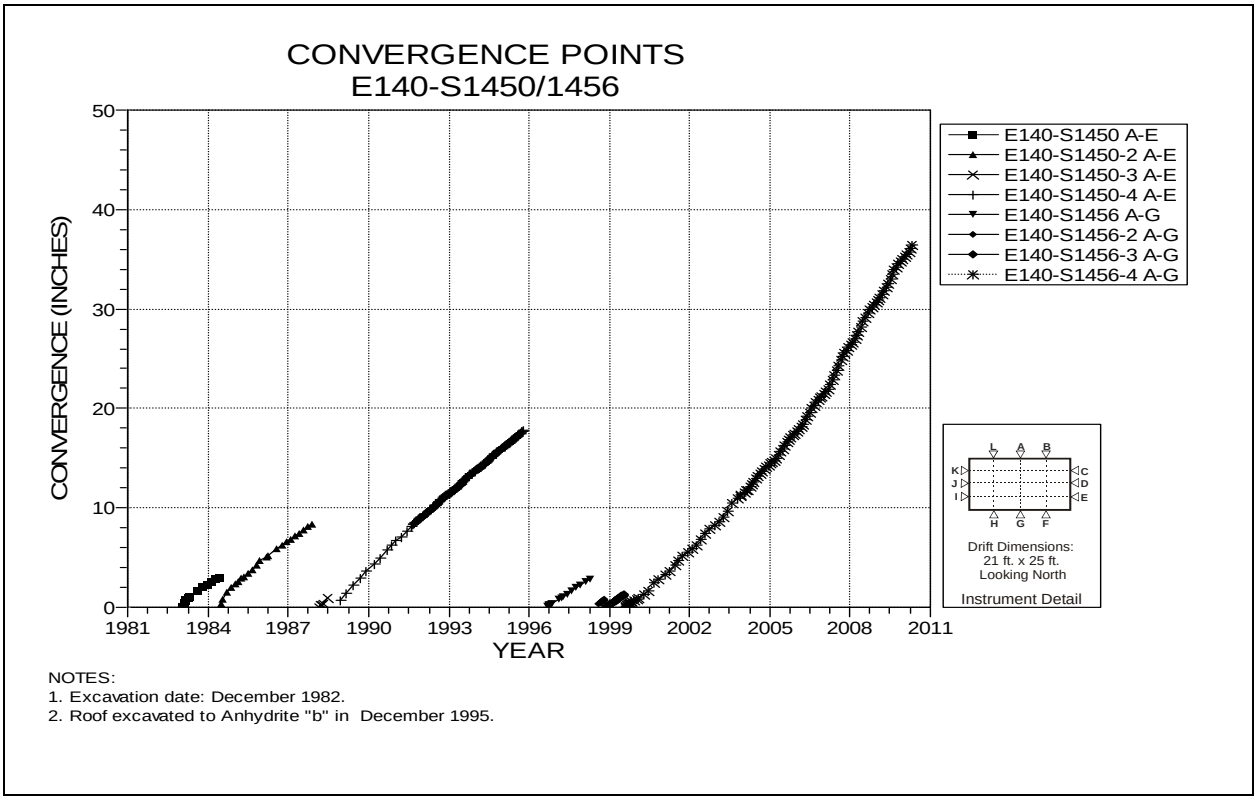


Figure 4-89 Convergence Point Array
E140 S1450/1456 – Roof to Floor

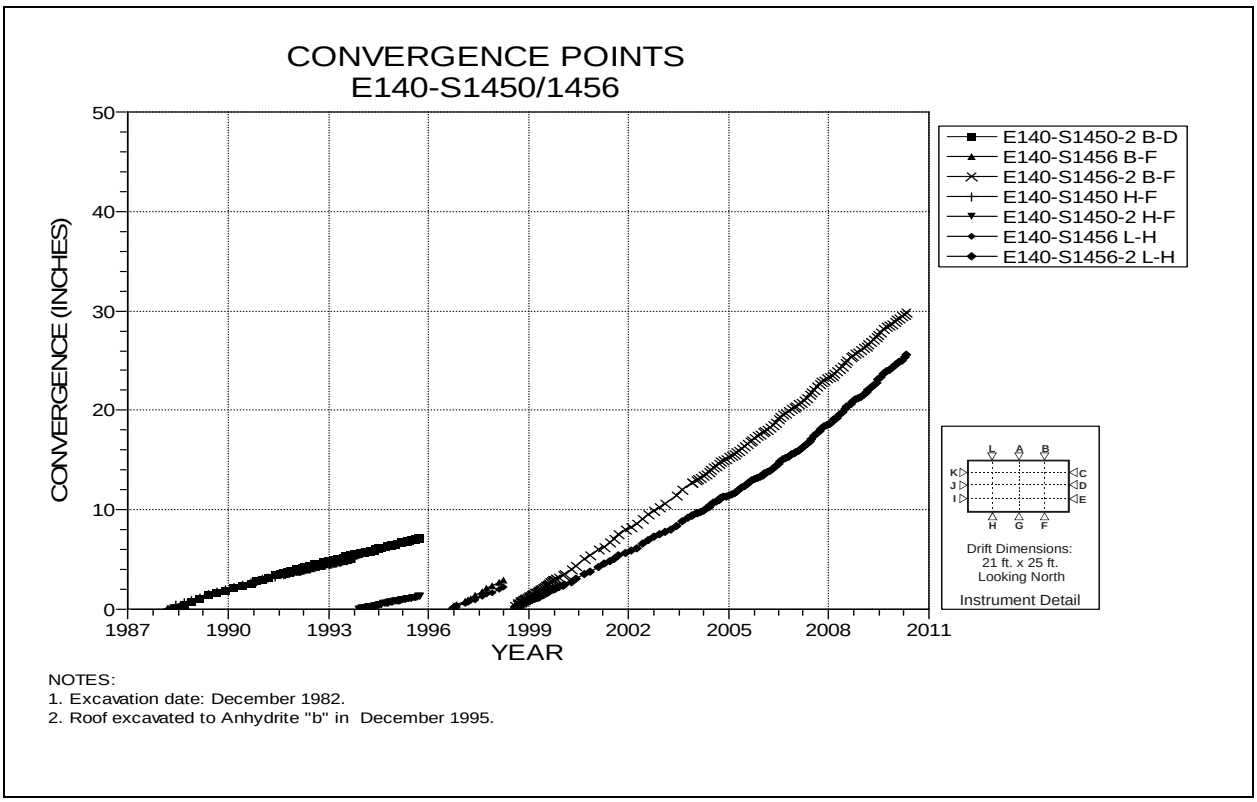


Figure 4-90 Convergence Point Array
E140 S1450/S1456 – Roof to Floor – Quarter Points

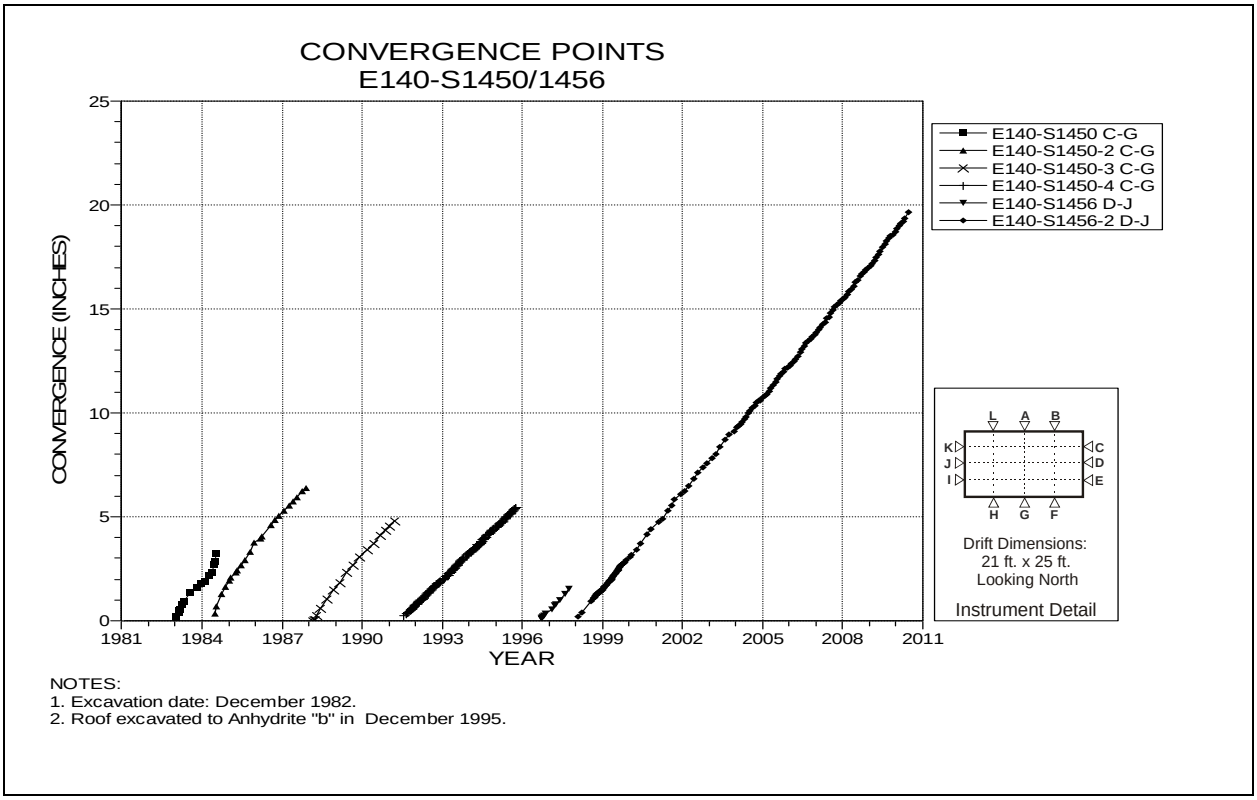
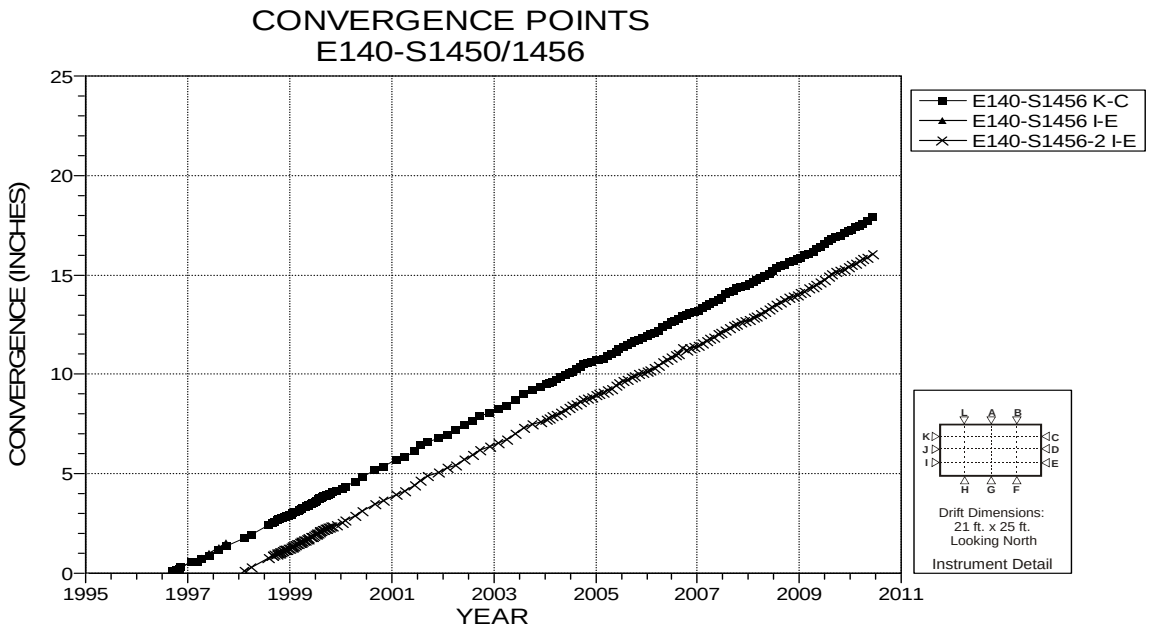
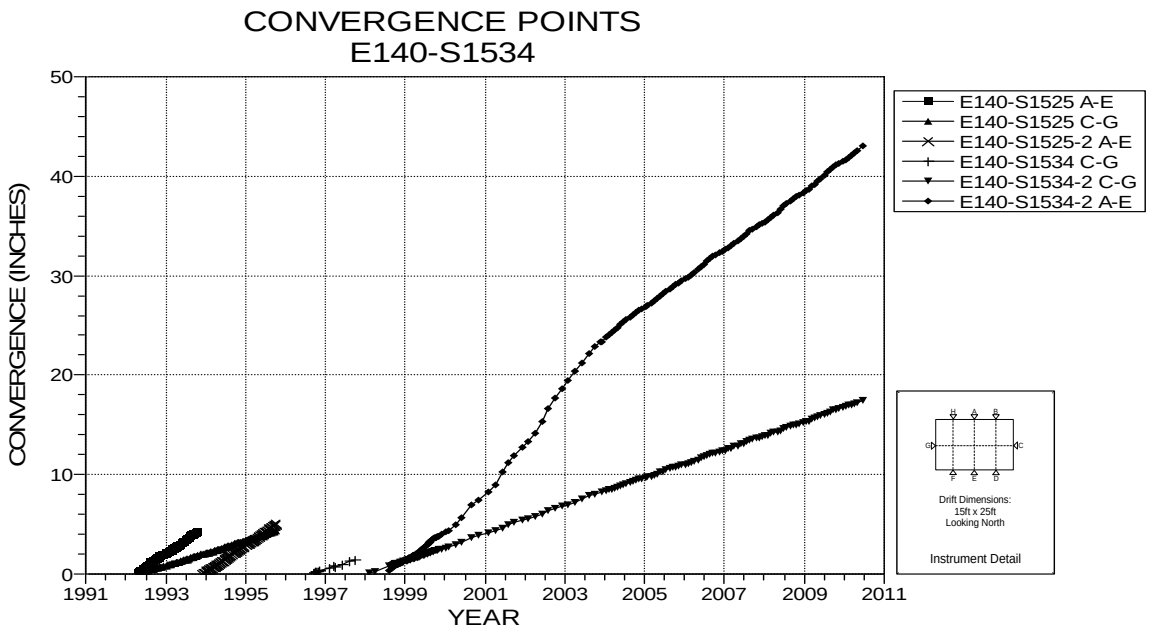


Figure 4-91 Convergence Point Array
E140 S1450/S1456 – Rib to Rib – Midheight



NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b" in December 1995.

Figure 4-92 Convergence Point Array
E140 S1450/S1456 – Rib to Rib



NOTES:
1. Excavation date: December 1982.
2. Roof excavated to Anhydrite "b" in December 1995.
3. Replaced by E140-S1534.

Figure 4-93 Convergence Point Array
E140 S1534 – Roof to Floor – Rib to Rib

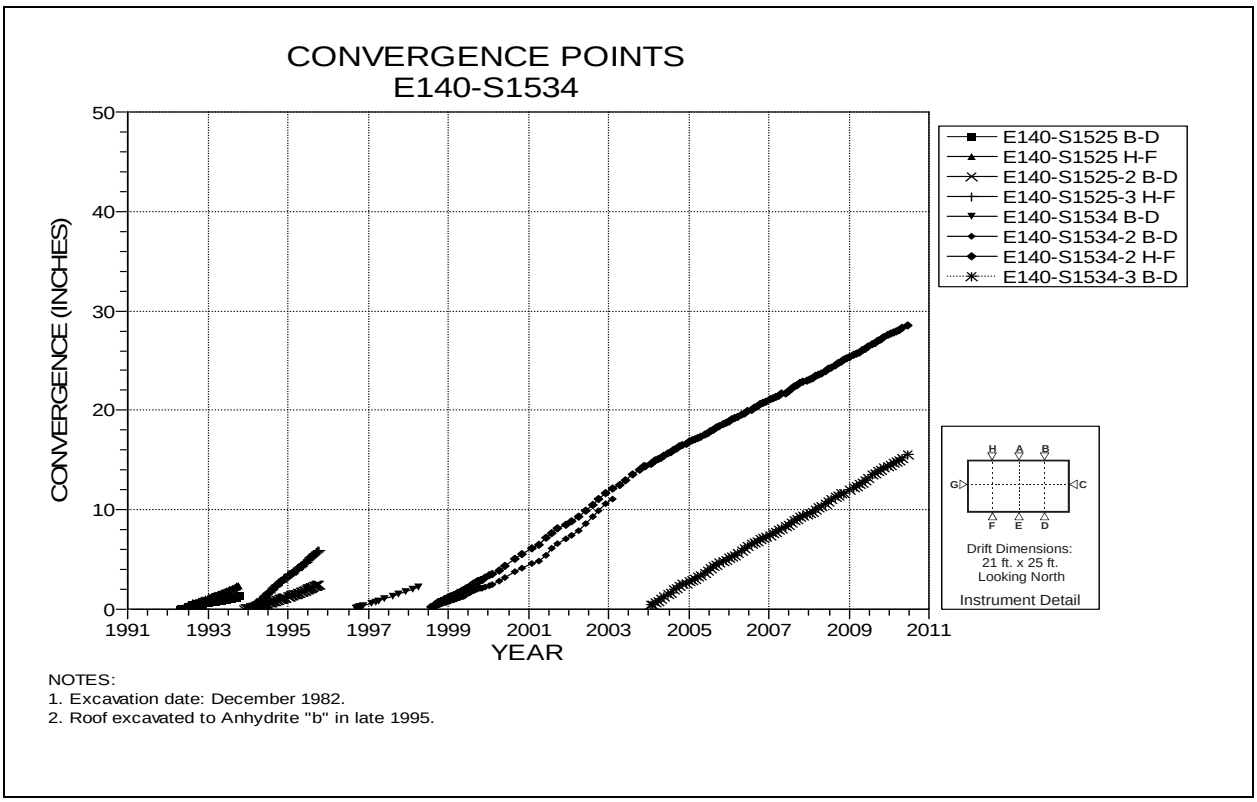


Figure 4-94 Convergence Point Array
E140 S1534 – Roof to Floor – Quarter Points

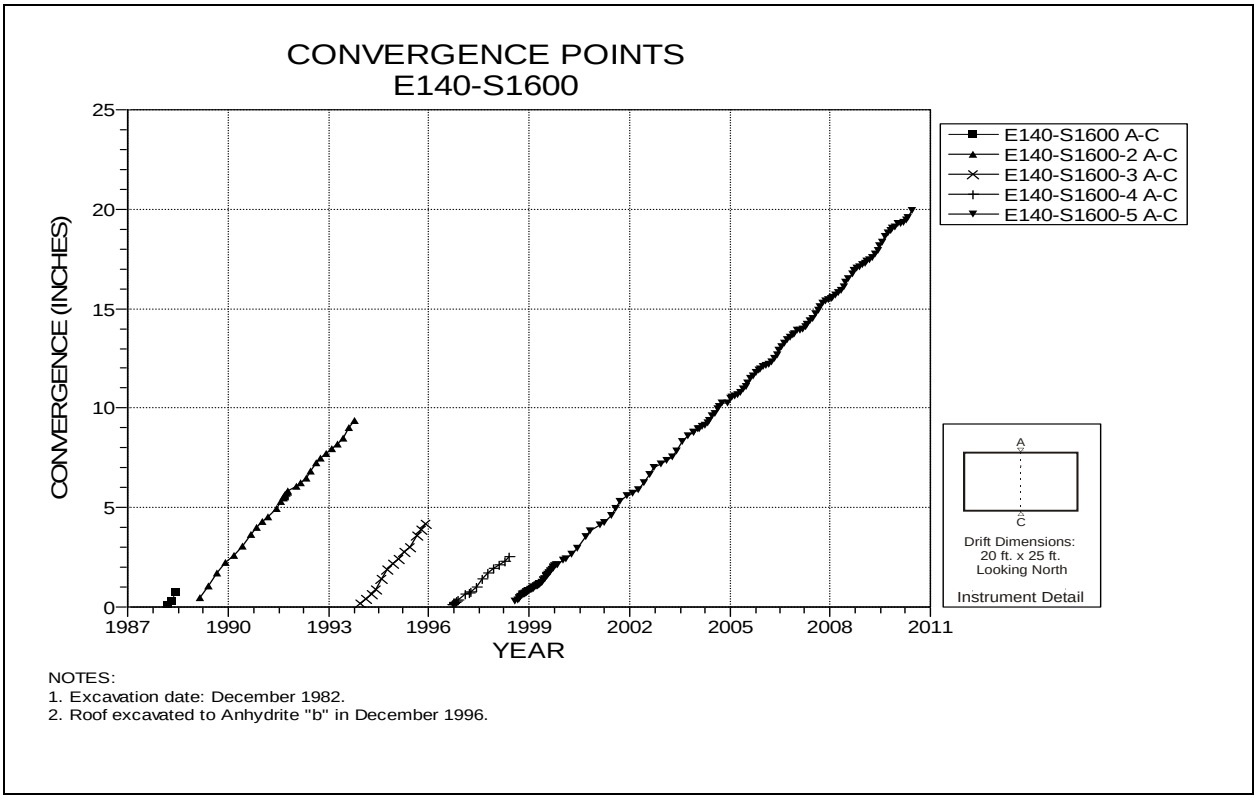


Figure 4-95 Convergence Point Array
E140 S1600 – Roof to Floor

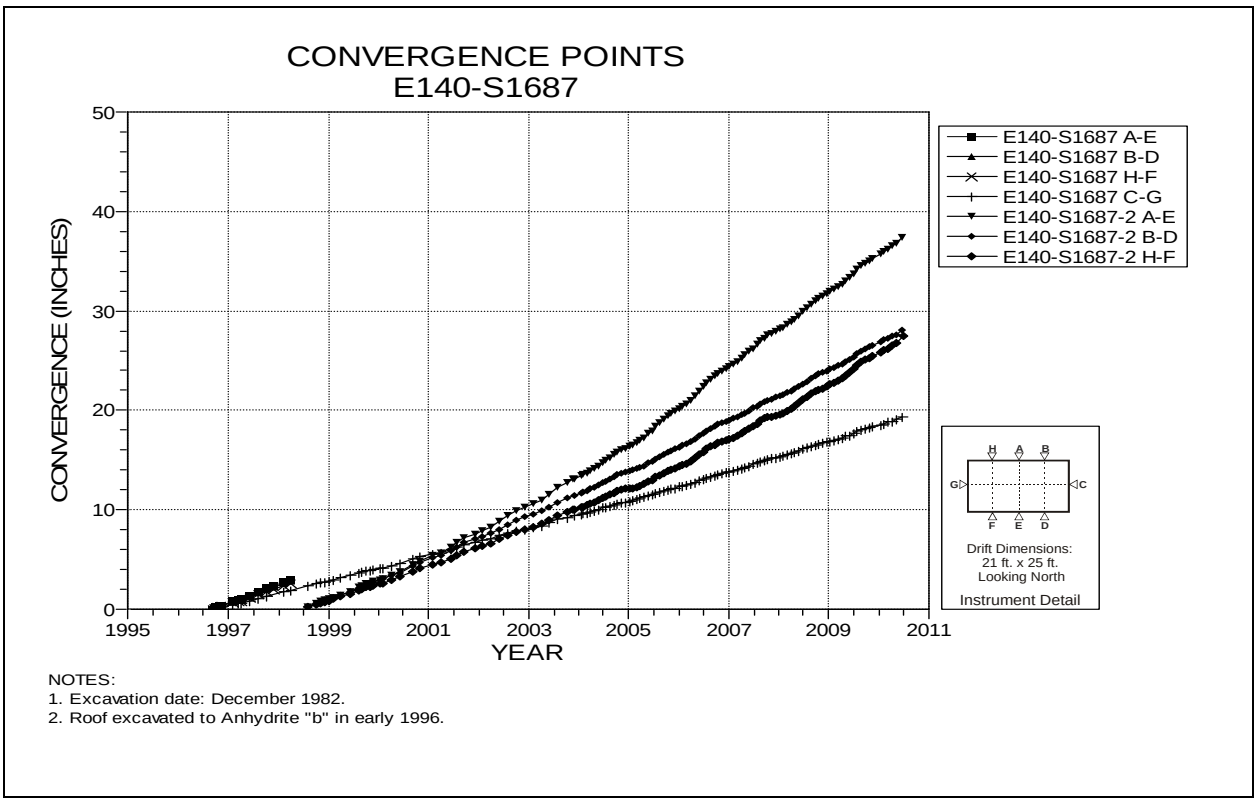


Figure 4-96 Convergence Point Array
E140 S1687 – All Chords

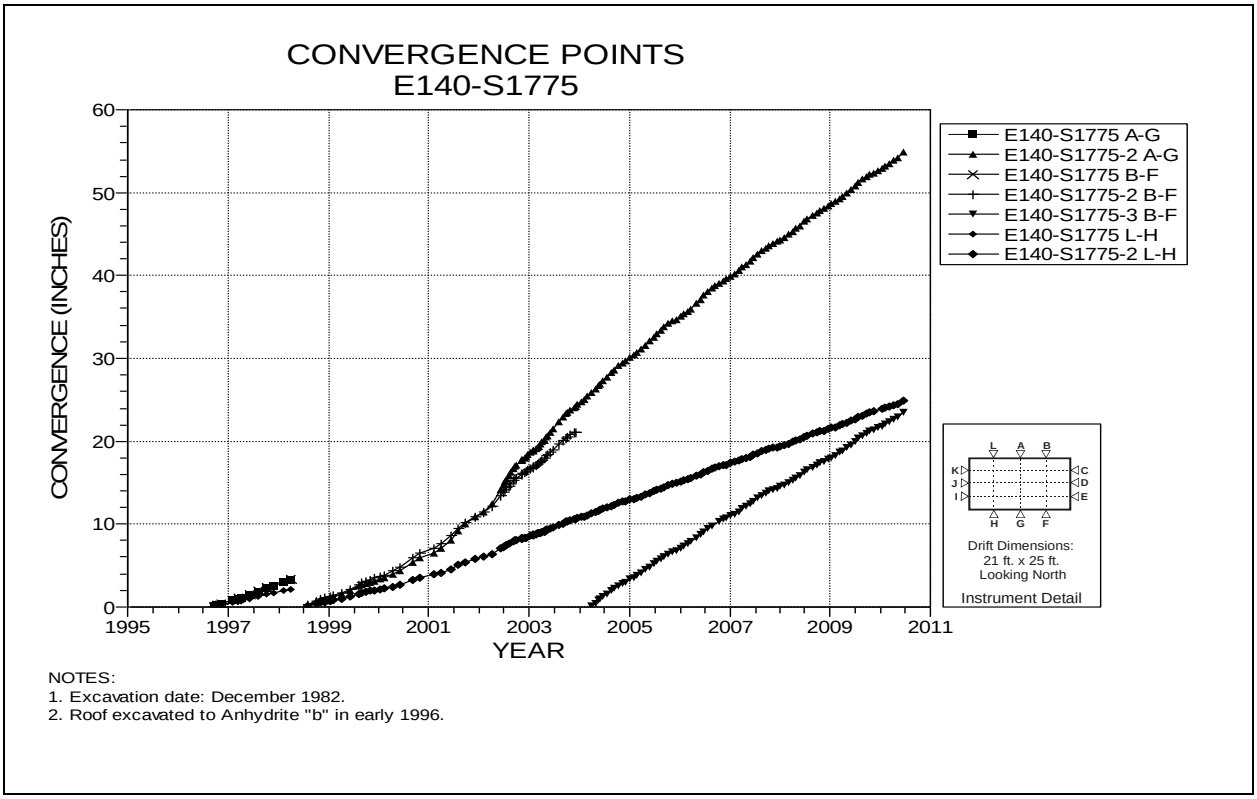


Figure 4-97 Convergence Point Array
E140 S1775 – Roof to Floor – Quarter Points

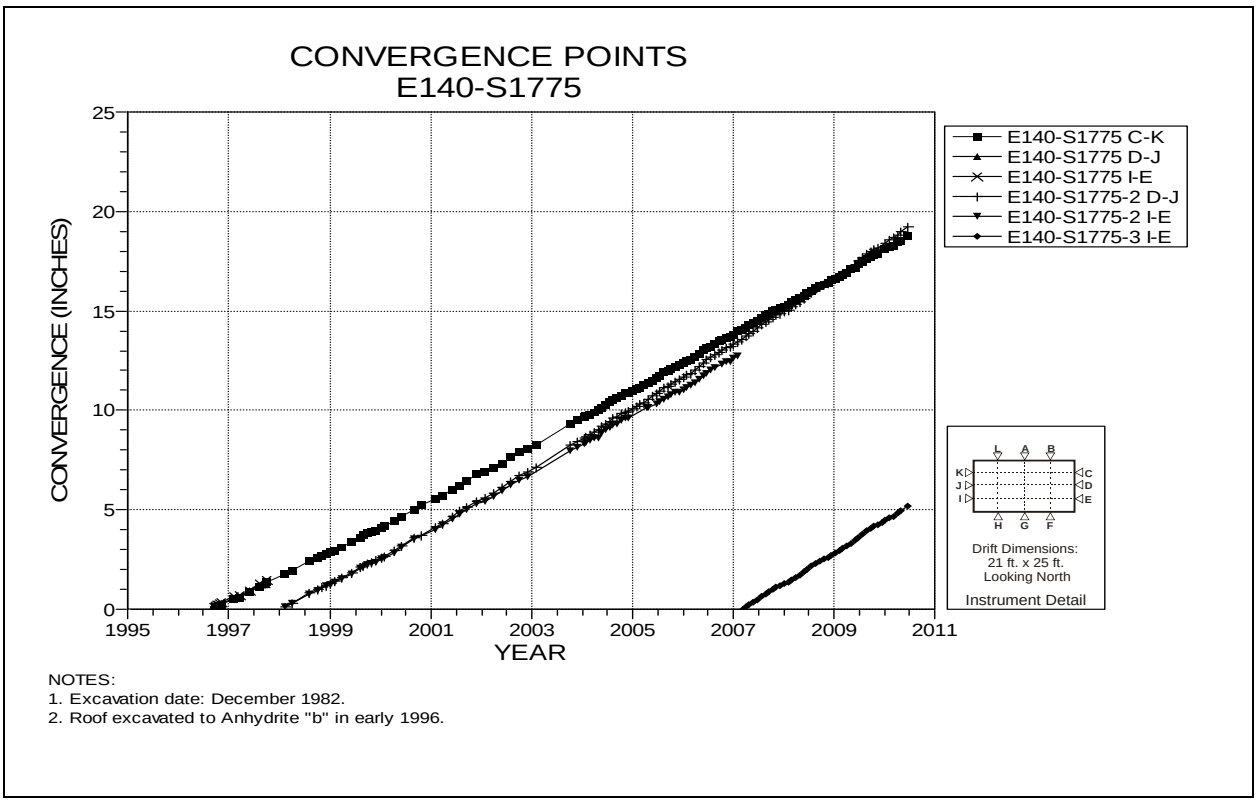


Figure 4-98 Convergence Point Array
E140 S1775 – Rib to Rib

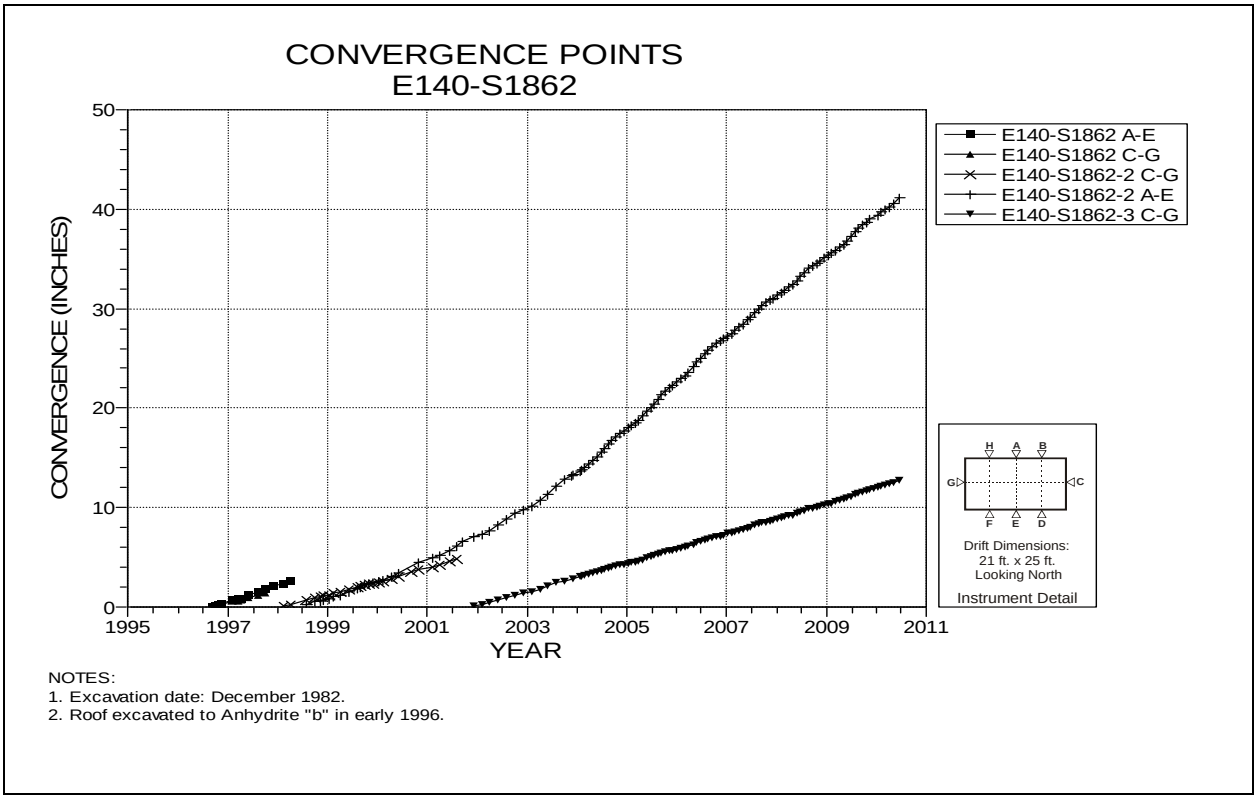


Figure 4-99 Convergence Point Array
E140 S1862 – Roof to Floor – Rib to Rib

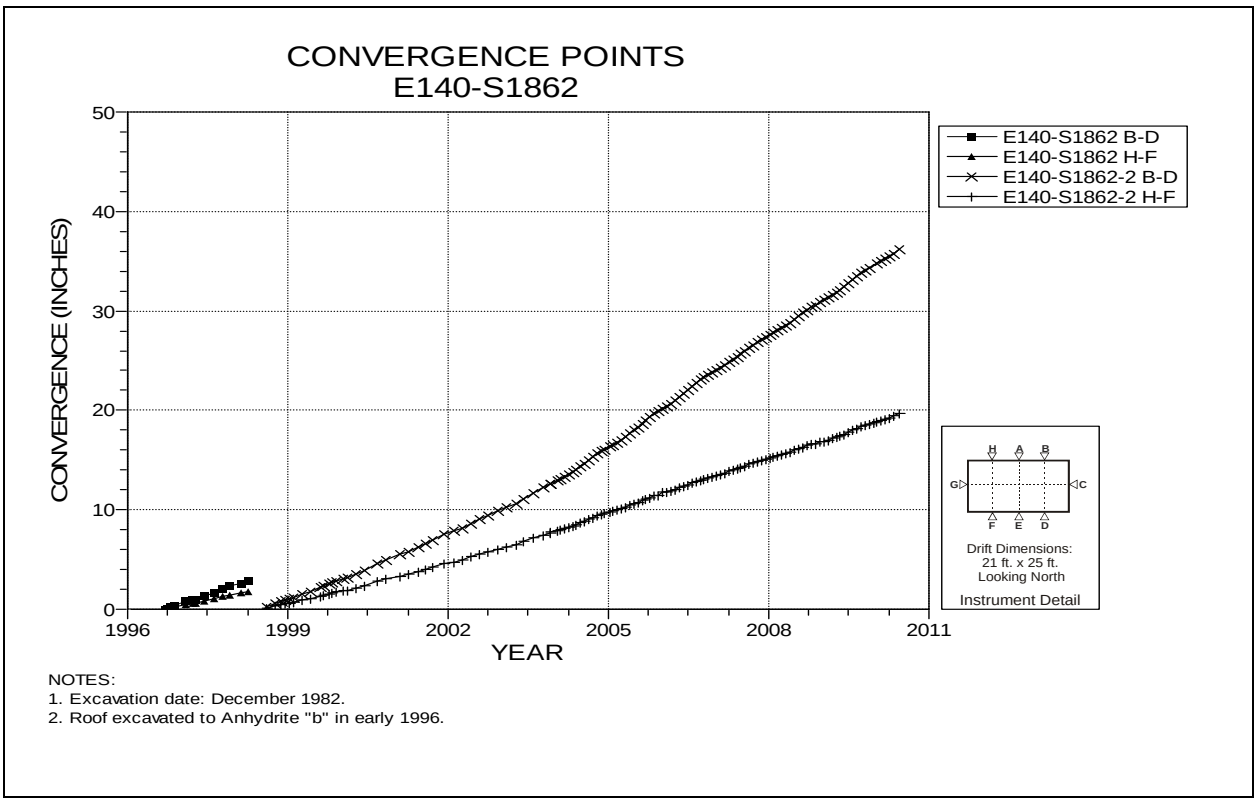


Figure 4-100 Convergence Point Array
E140 S1862 – Roof to Floor – Quarter Points

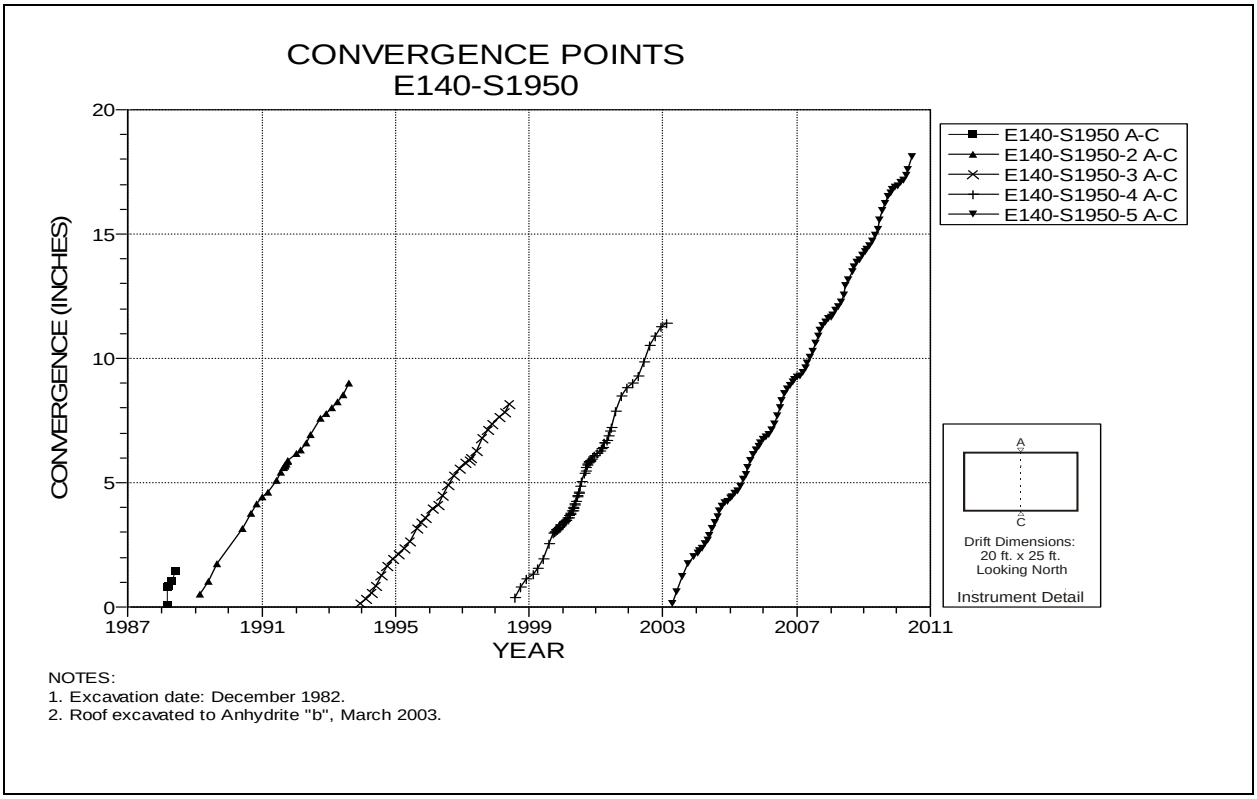


Figure 4-101 Convergence Point Array
E140 S1950 – Roof to Floor

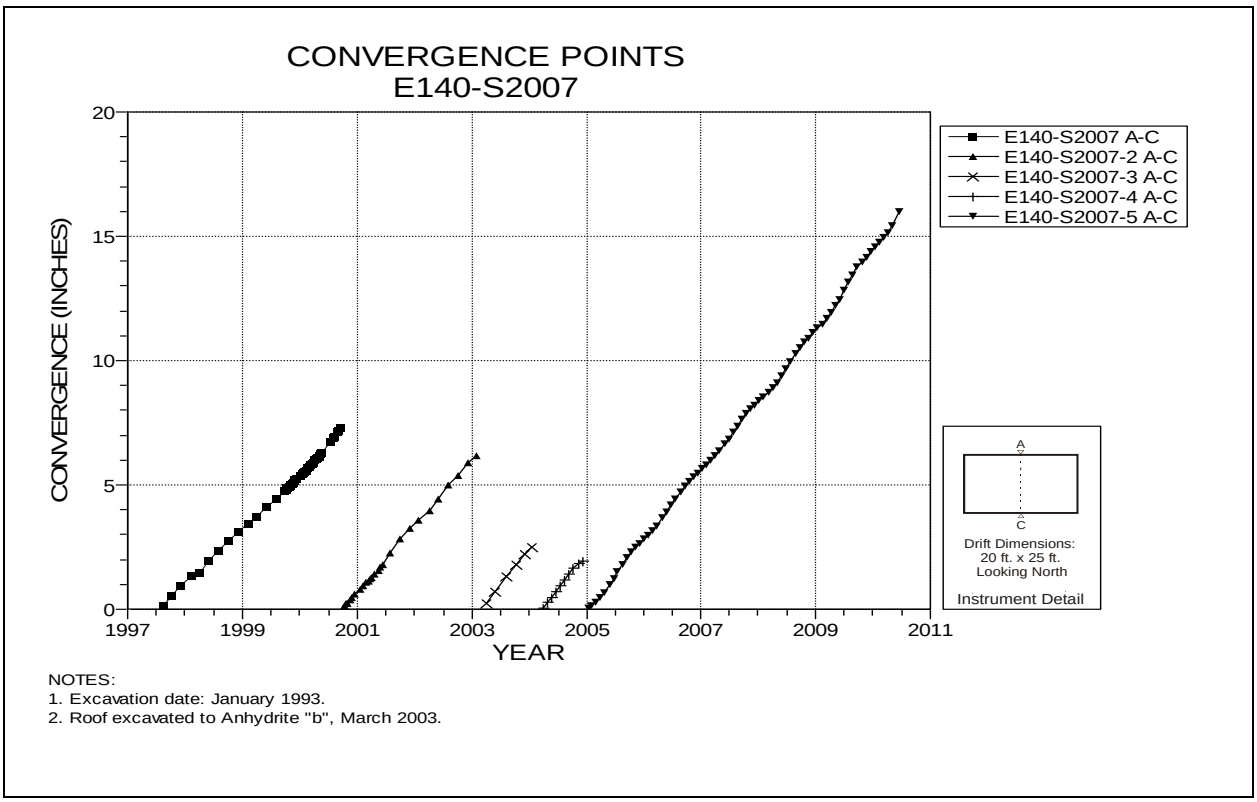


Figure 4-102 Convergence Point Array
E140 S2007 – Roof to Floor

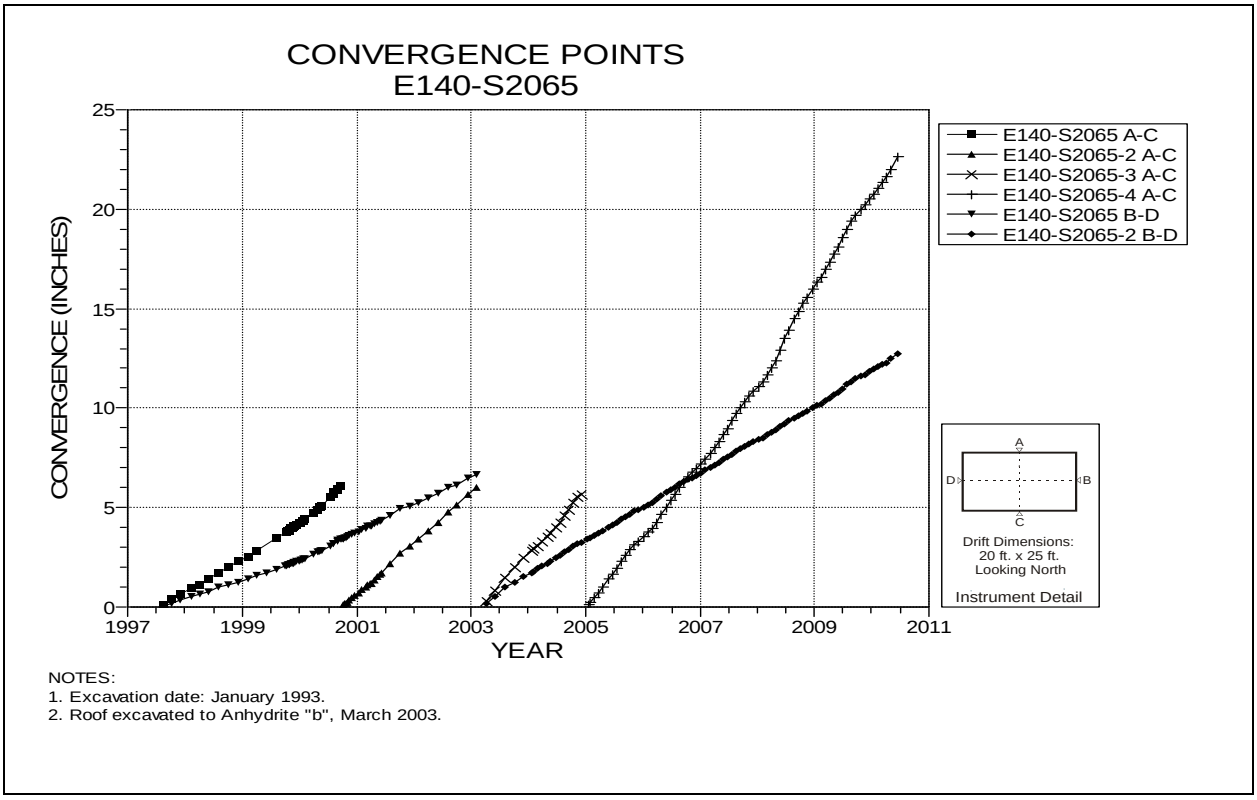


Figure 4-103 Convergence Point Array
E140 S2065 – All Chords

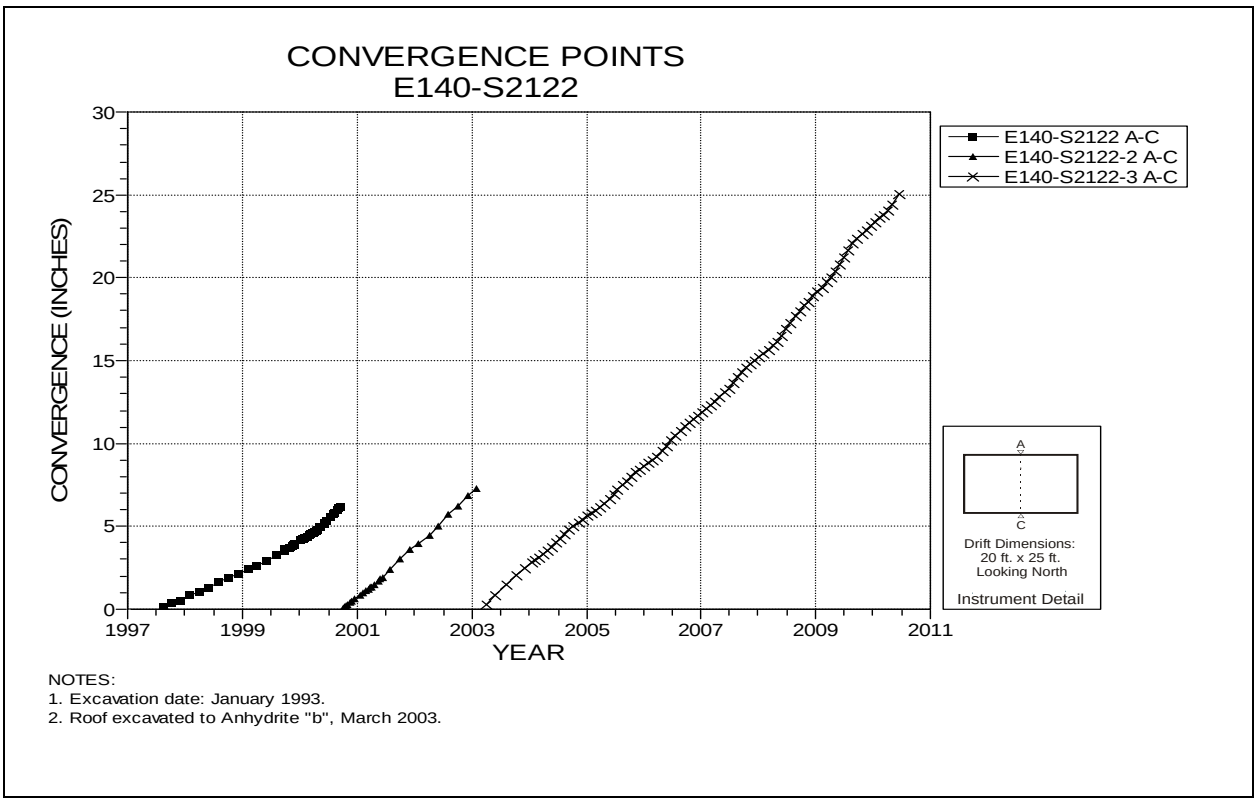


Figure 4-104 Convergence Point Array
E140 S2122 – Roof to Floor

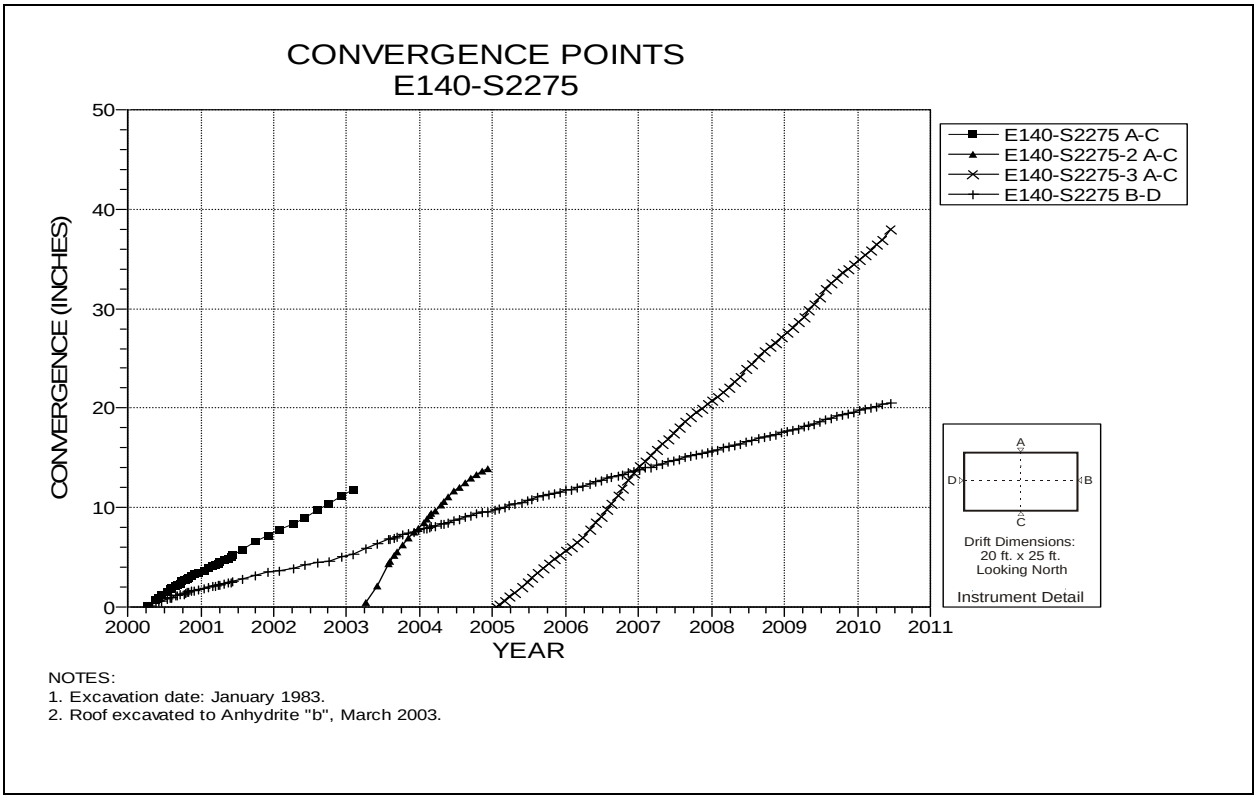


Figure 4-105 Convergence Point Array
E140 S2275 – All Chords

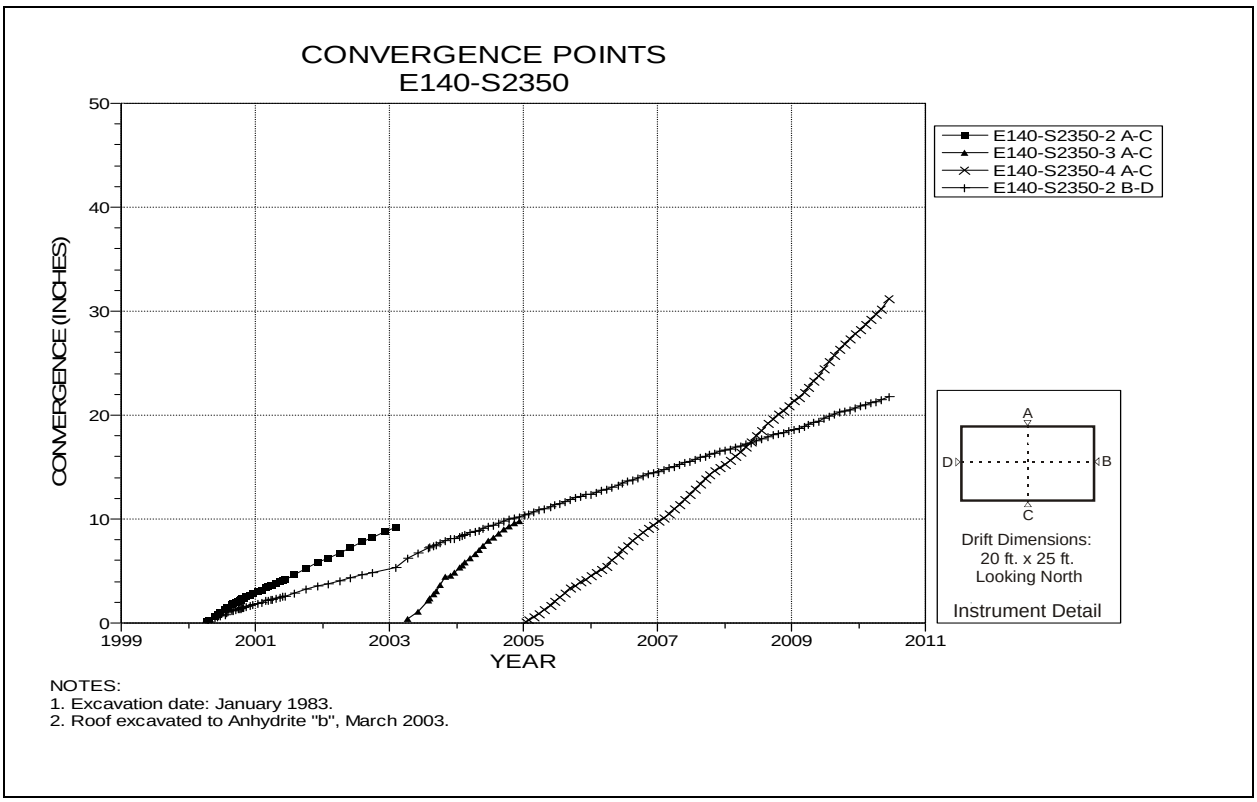


Figure 4-106 Convergence Point Array
E140 S2350 – All Chords

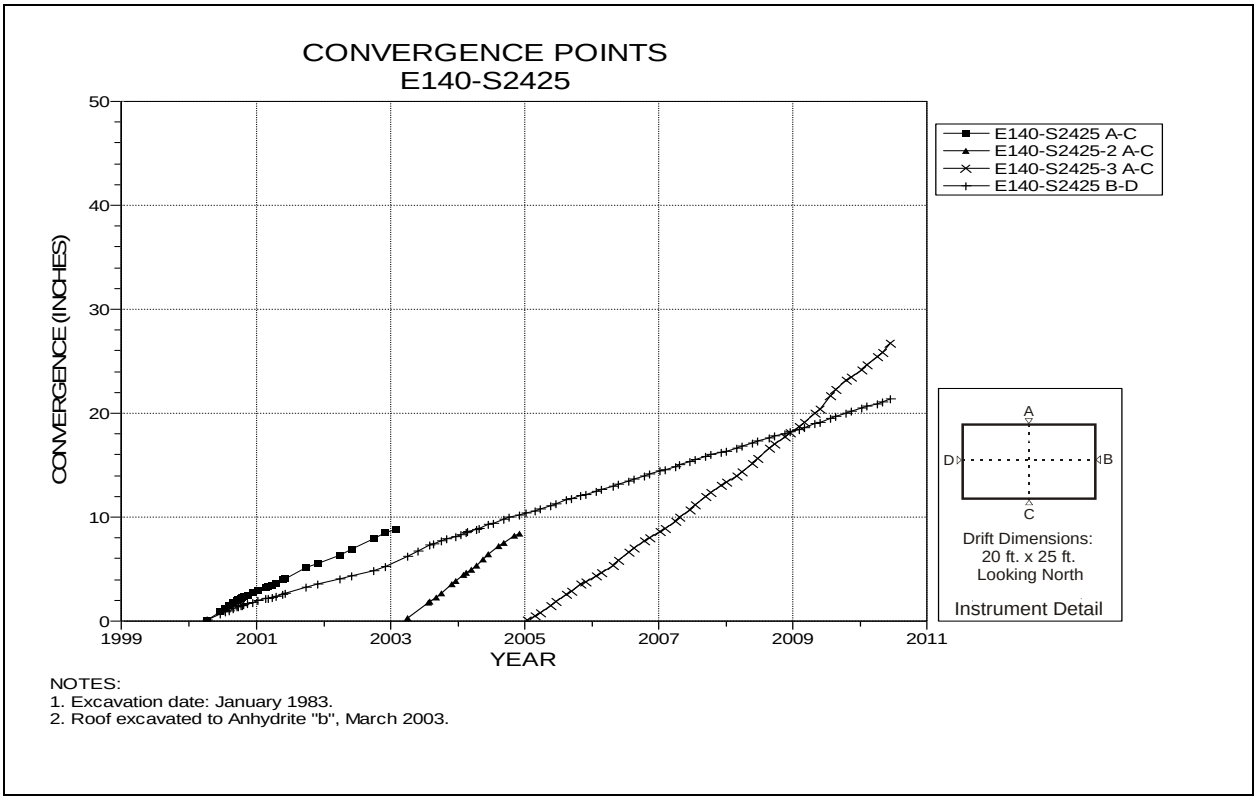


Figure 4-107 Convergence Point Array
E140 S2425 – All Chords

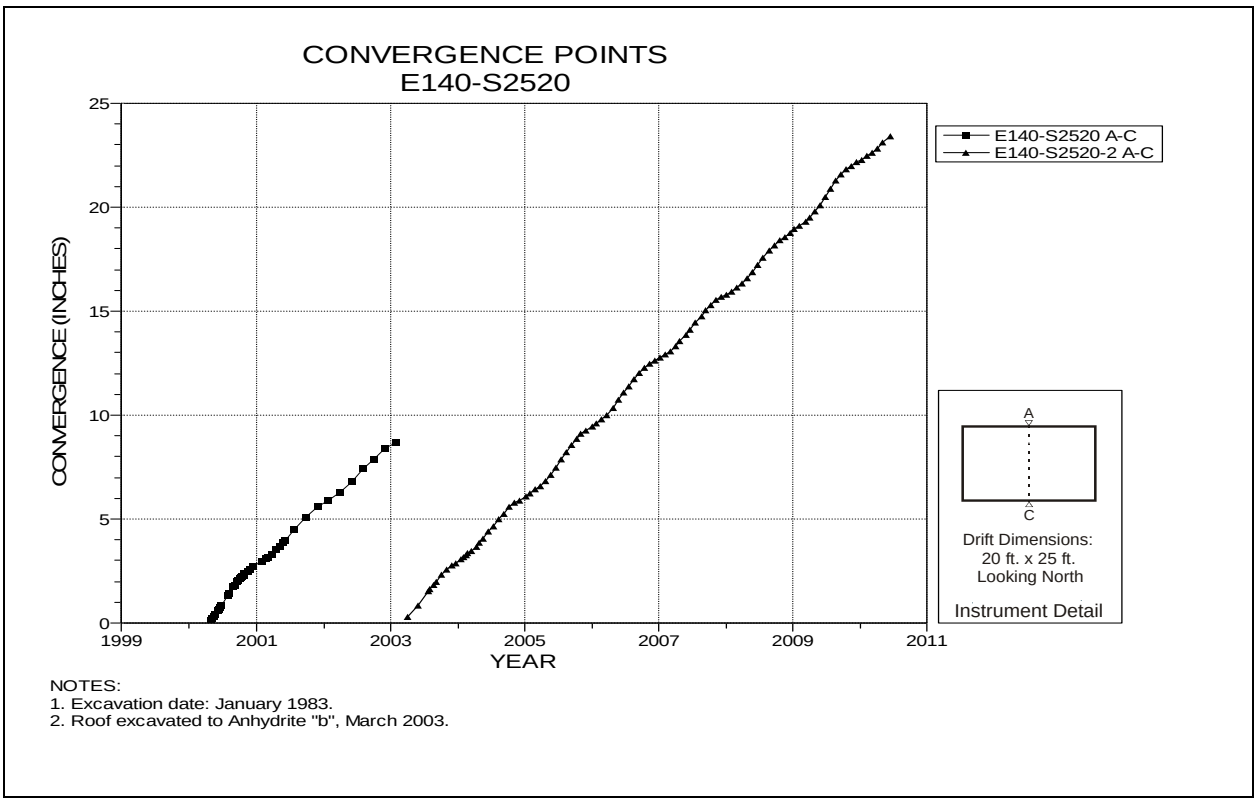


Figure 4-108 Convergence Point Array
E140 S2520 – Roof to Floor

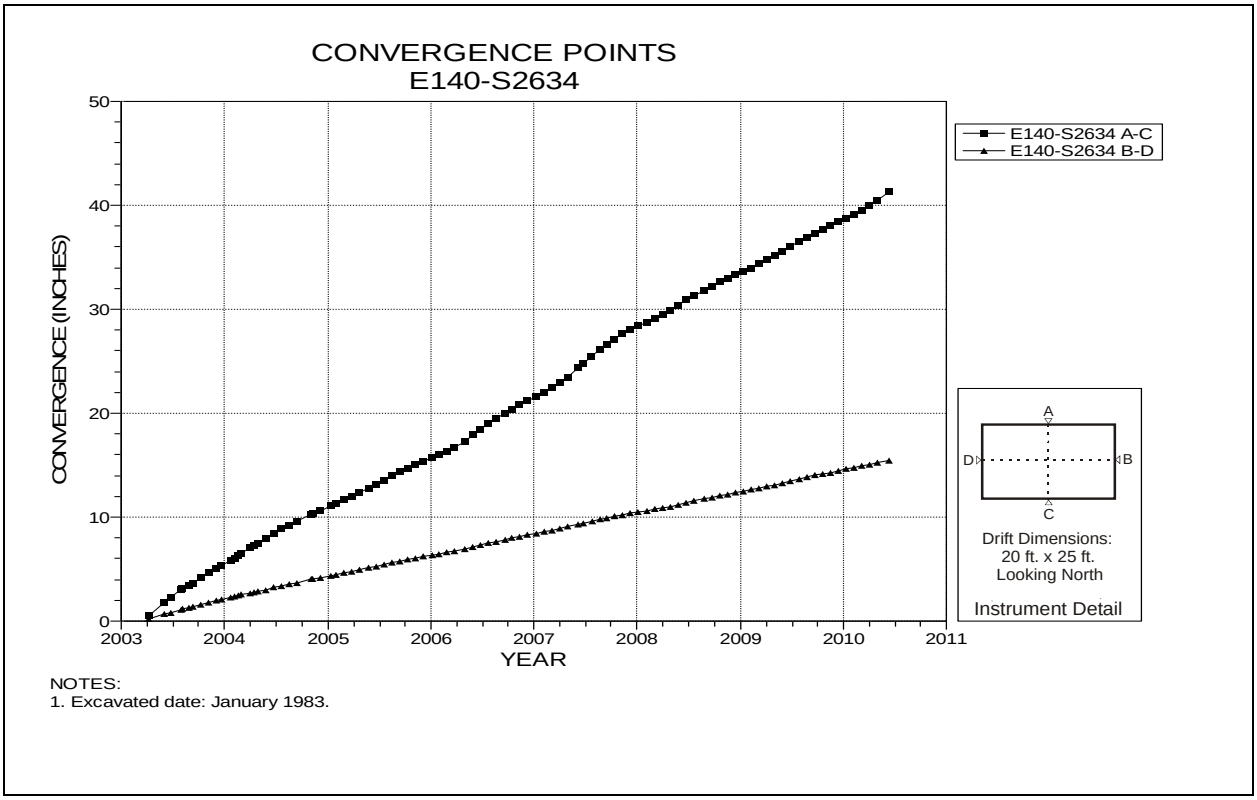


Figure 4-109 Convergence Point Array
E140 S2634 – All Chords

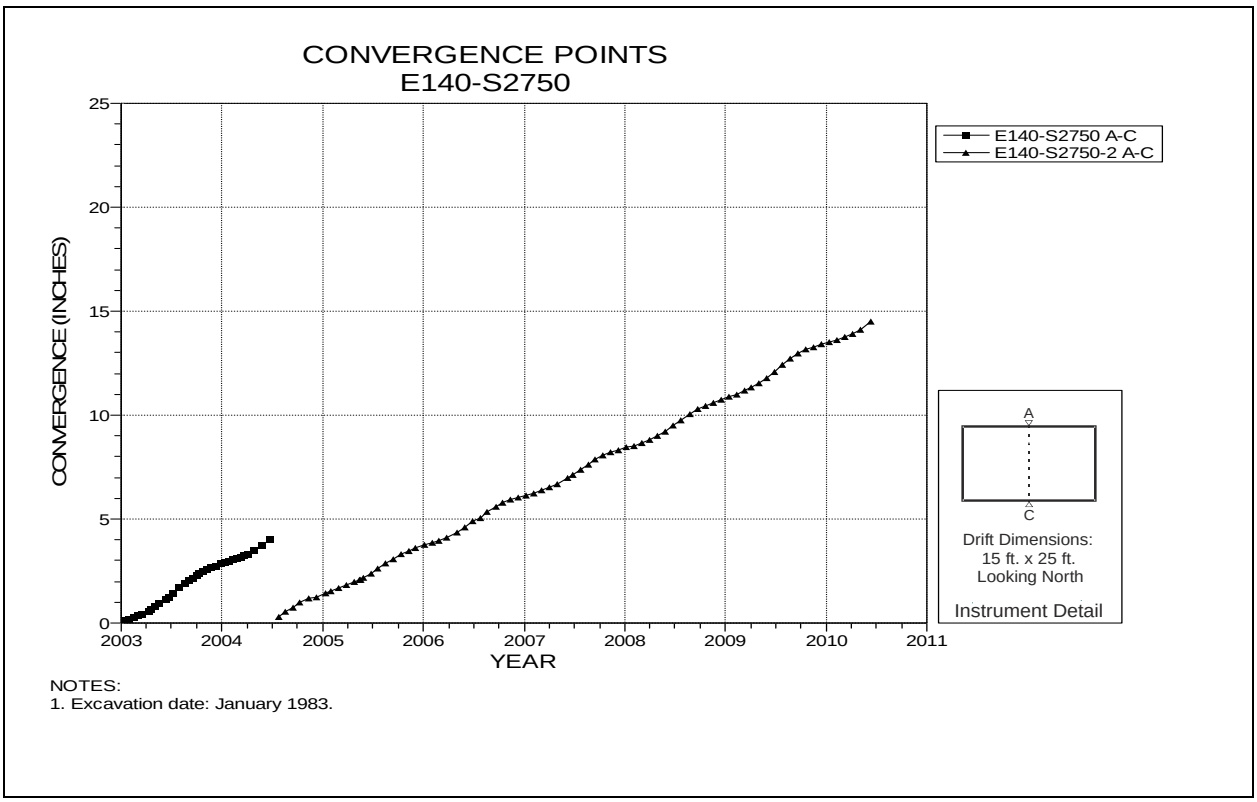


Figure 4-110 Convergence Point Array
E140 S2750 – Roof to Floor

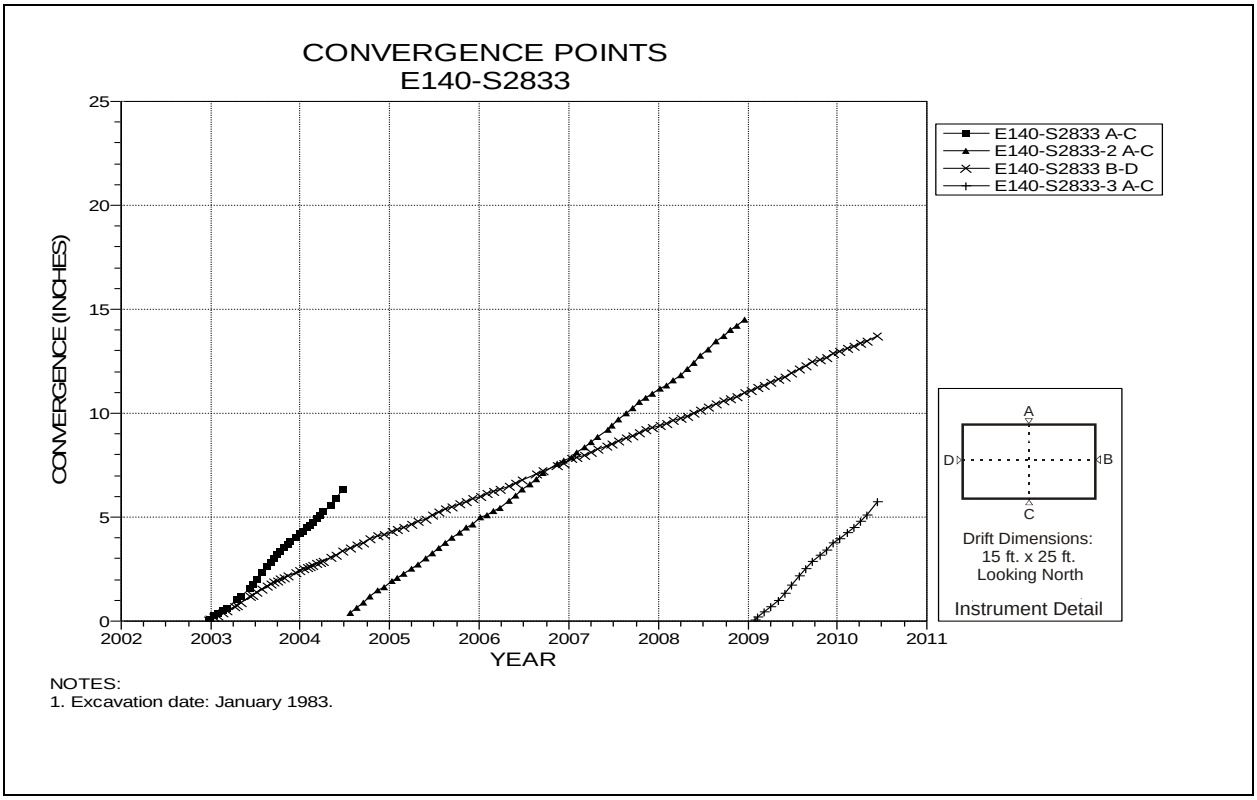


Figure 4-111 Convergence Point Array
E140 S2833 – All Chords

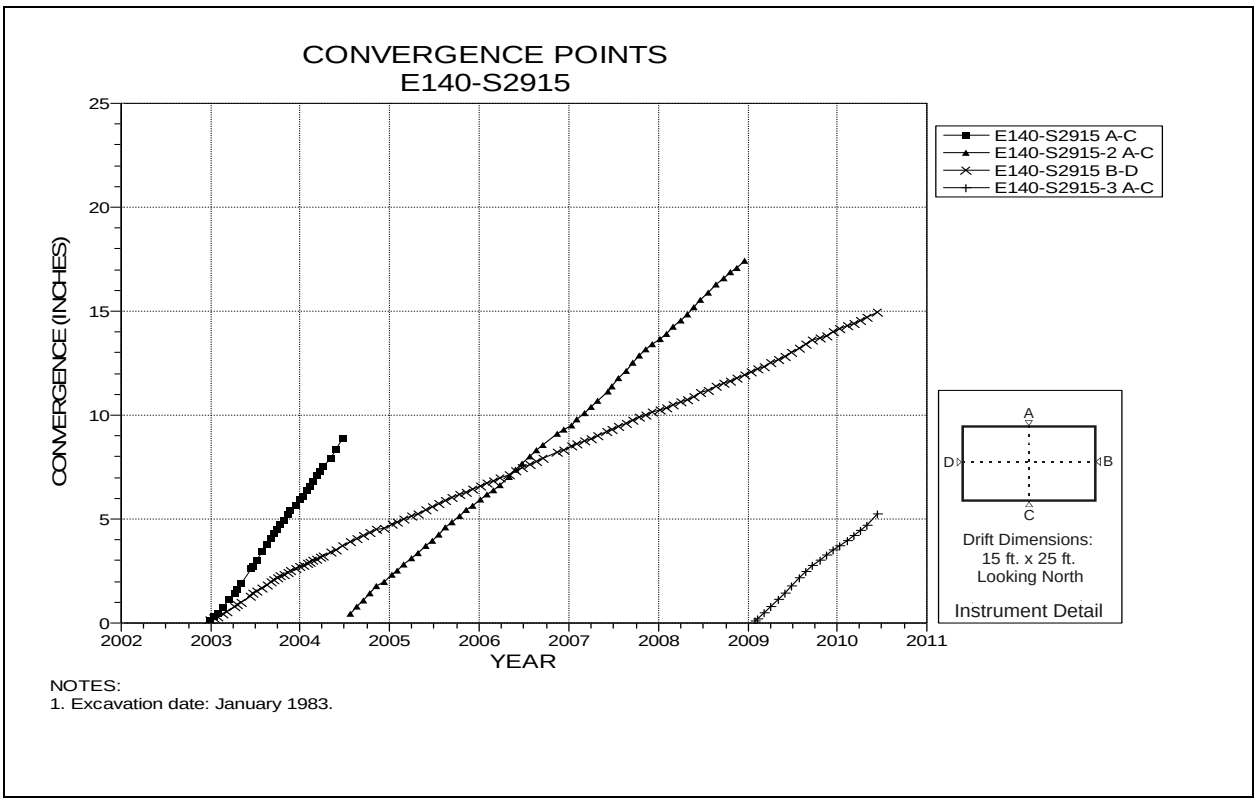


Figure 4-112 Convergence Point Array
E140 S2915 – All Chords

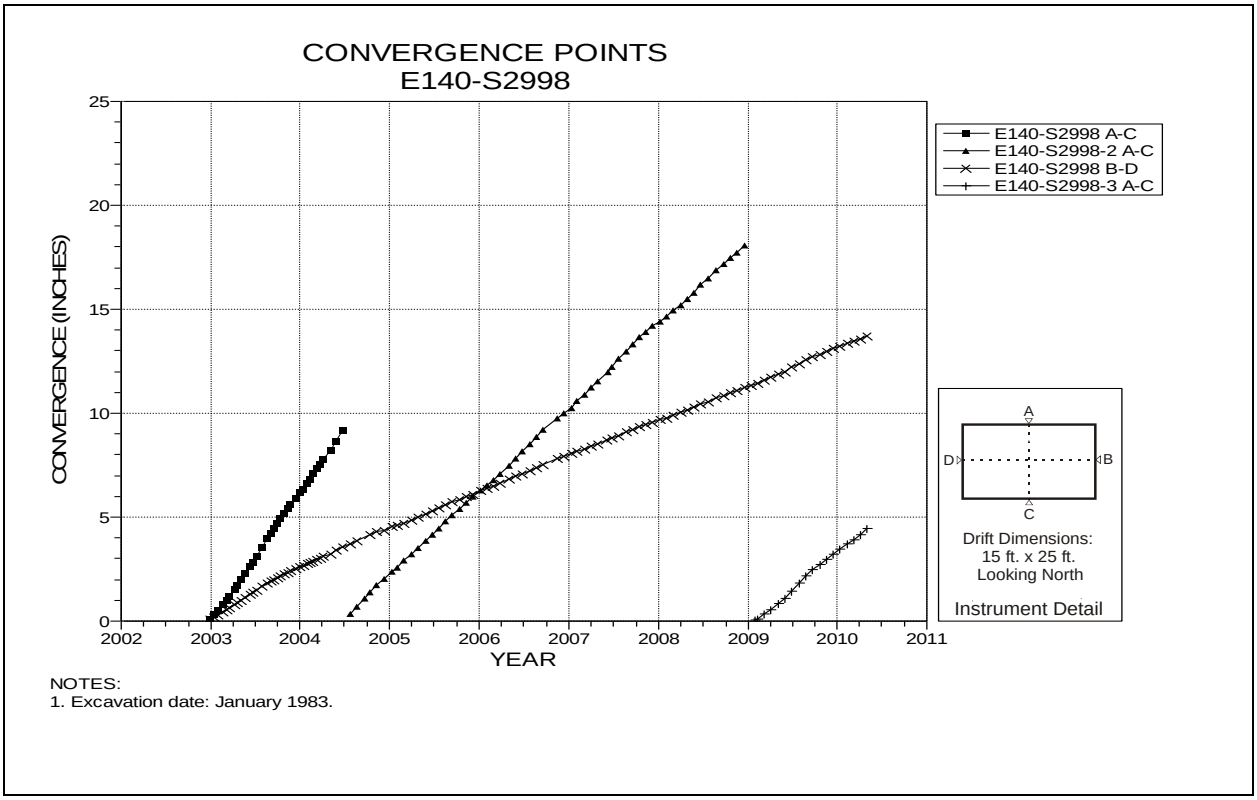


Figure 4-113 Convergence Point Array
E140 S2998 – All Chords

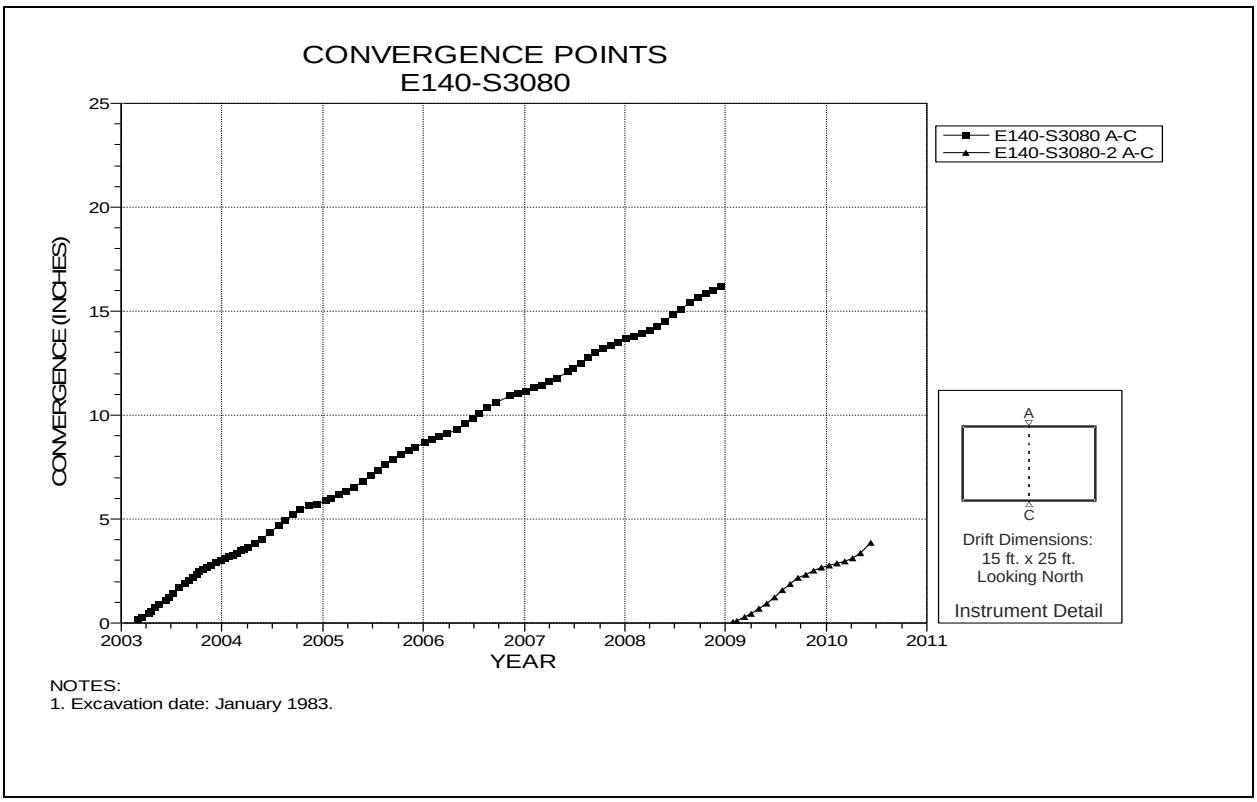


Figure 4-114 Convergence Point Array
E140 S3080 – Roof to Floor

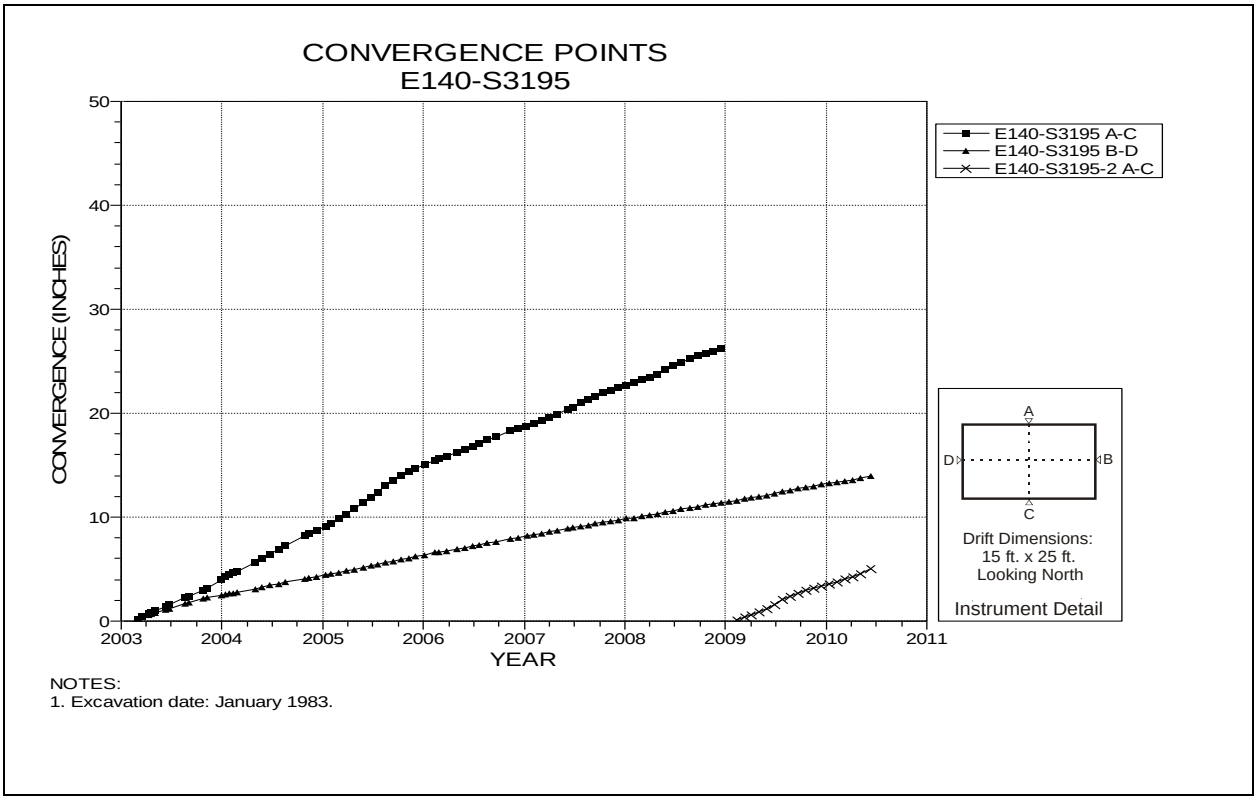


Figure 4-115 Convergence Point Array
E140 S3195 – All Chords

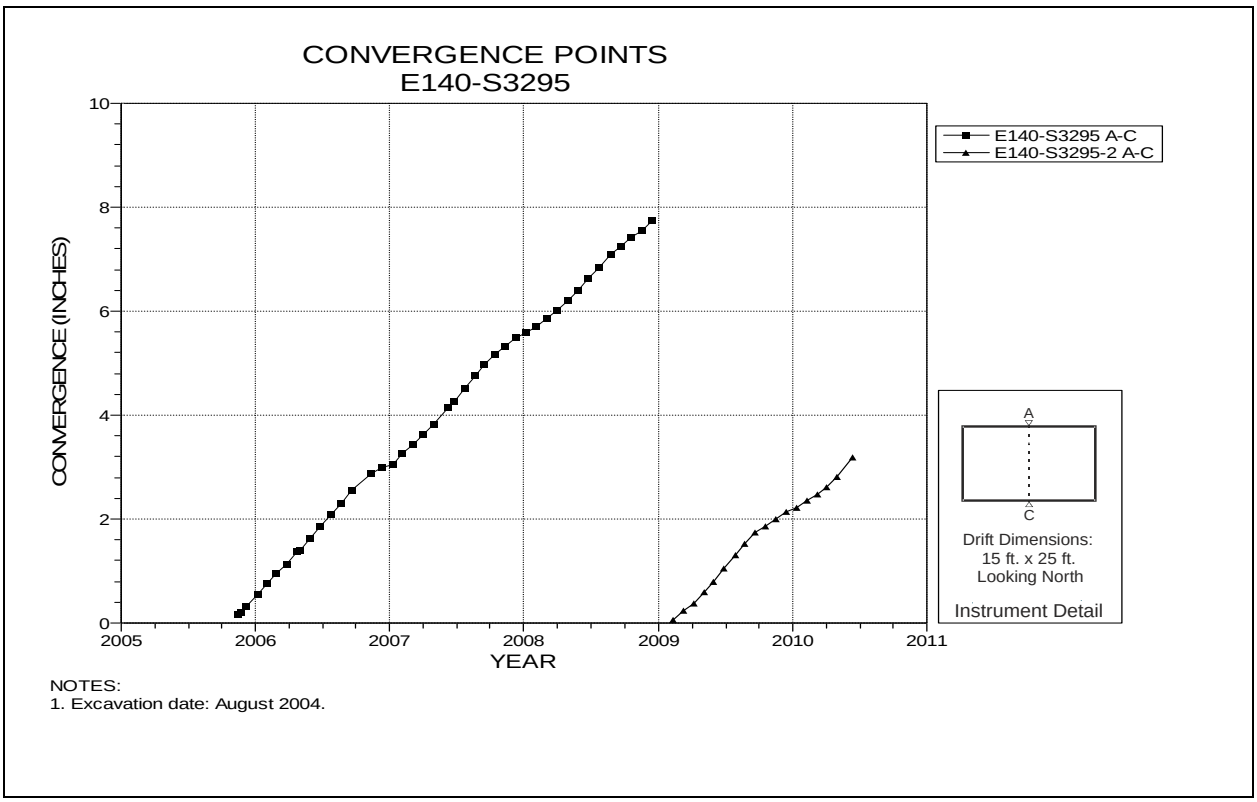


Figure 4-116 Convergence Point Array
E140 S3295 – Roof to Floor

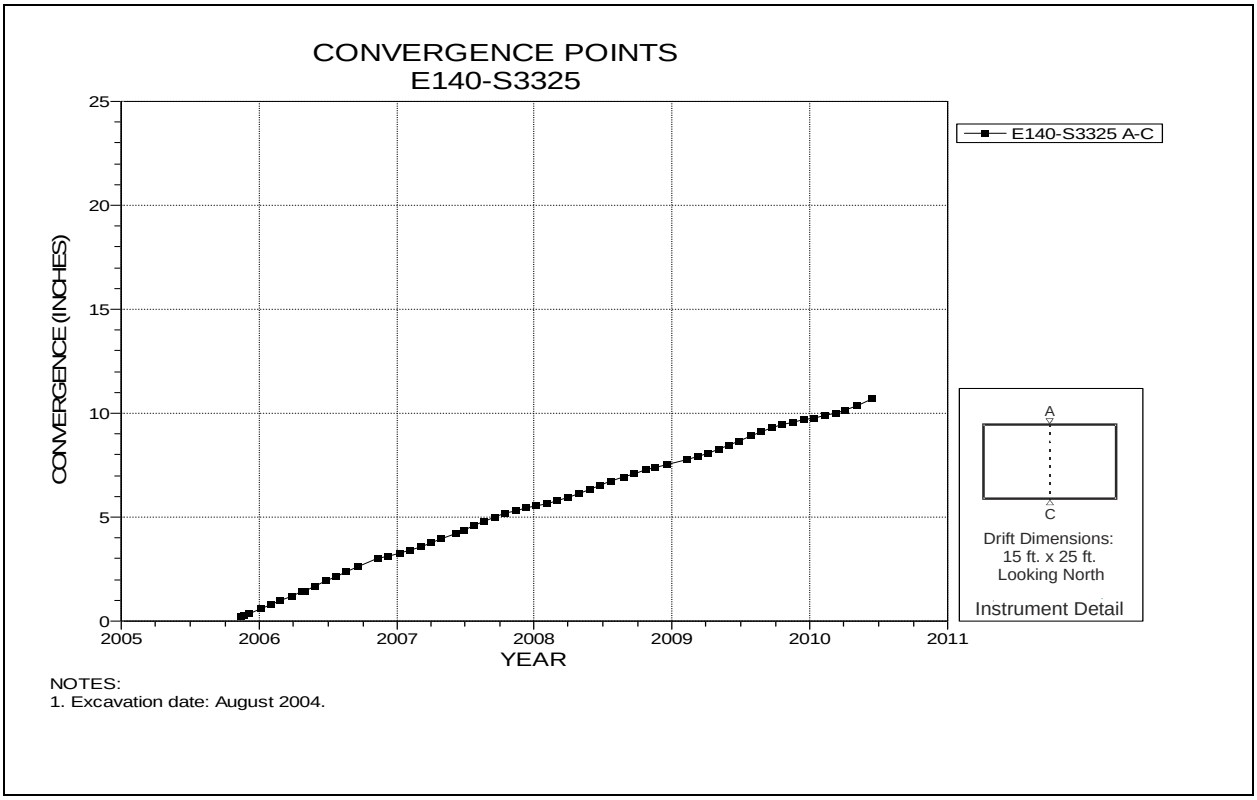


Figure 4-117 Convergence Point Array
E140 S3325 – Roof to Floor

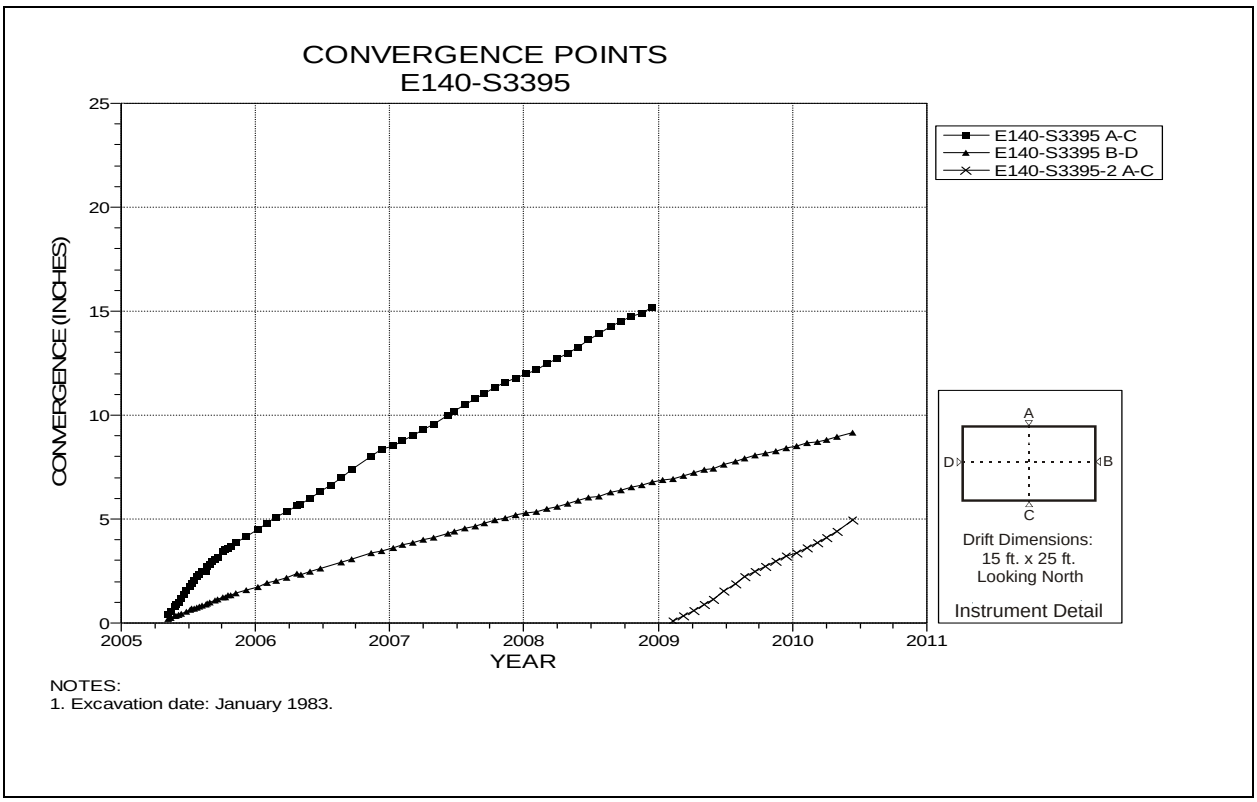


Figure 4-118 Convergence Point Array
E140 S3395 – All Chords

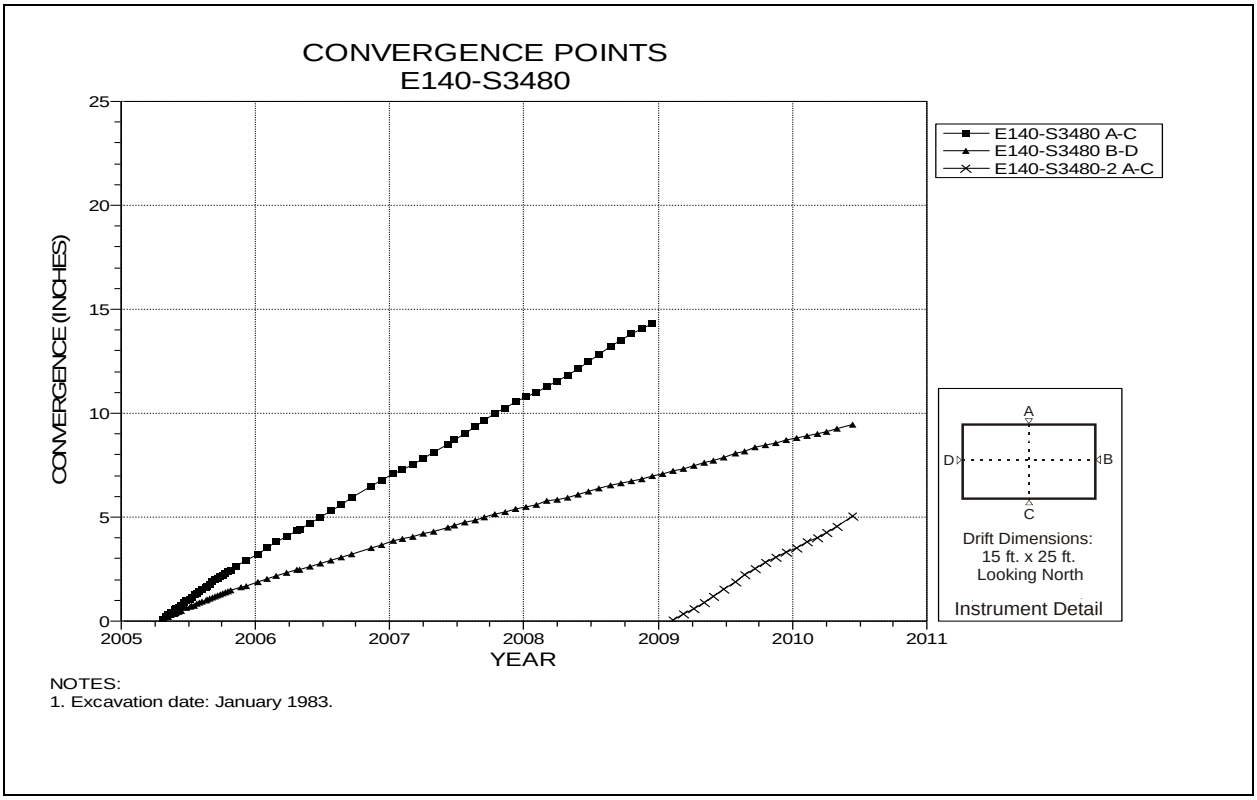


Figure 4-119 Convergence Point Array
E140 S3480 – All Chords

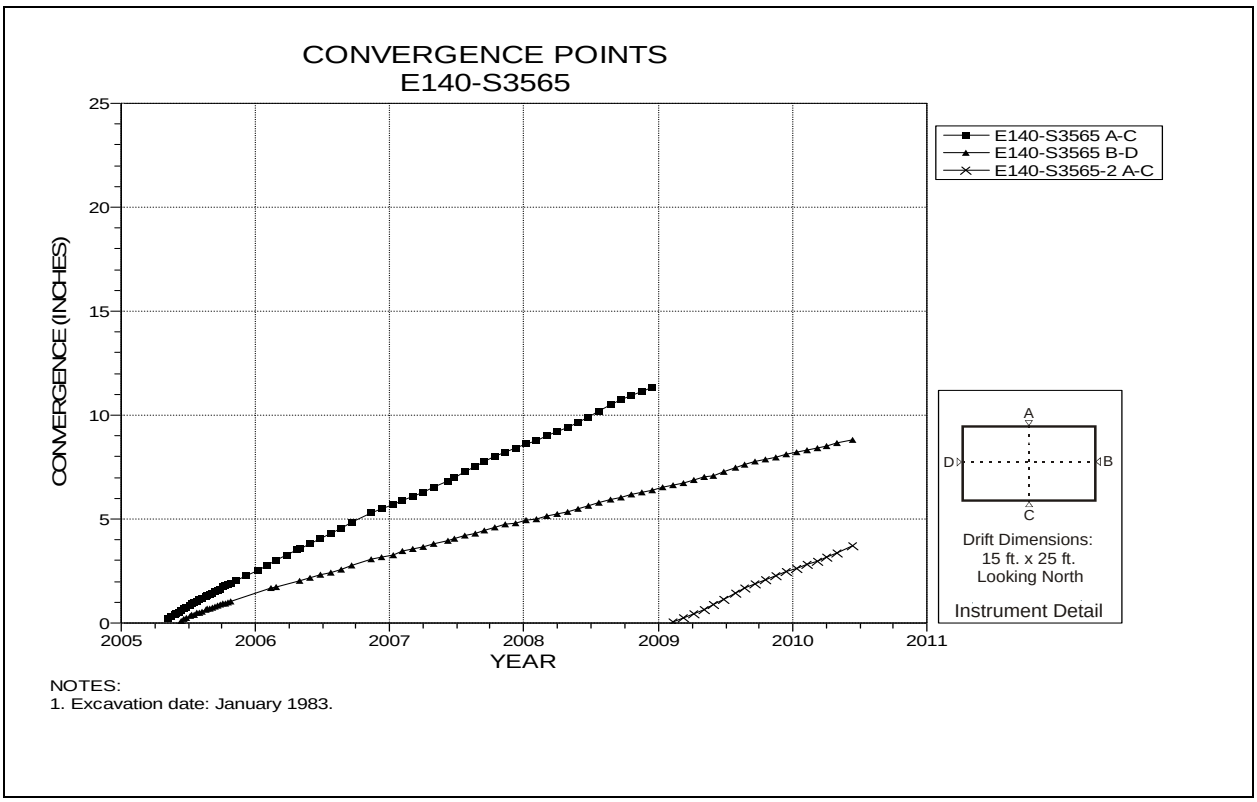


Figure 4-120 Convergence Point Array
E140 S3565 – All Chords

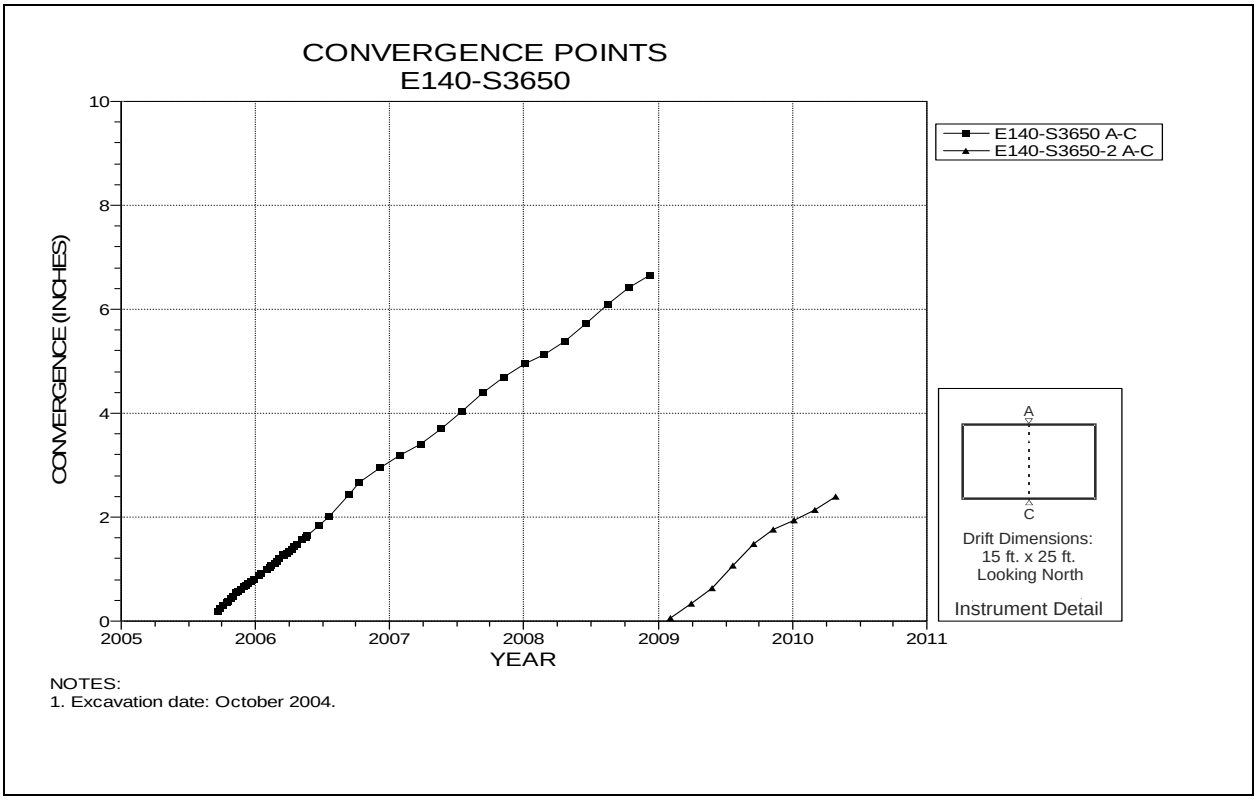


Figure 4-121 Convergence Point Array
E140 S3650– Roof to Floor

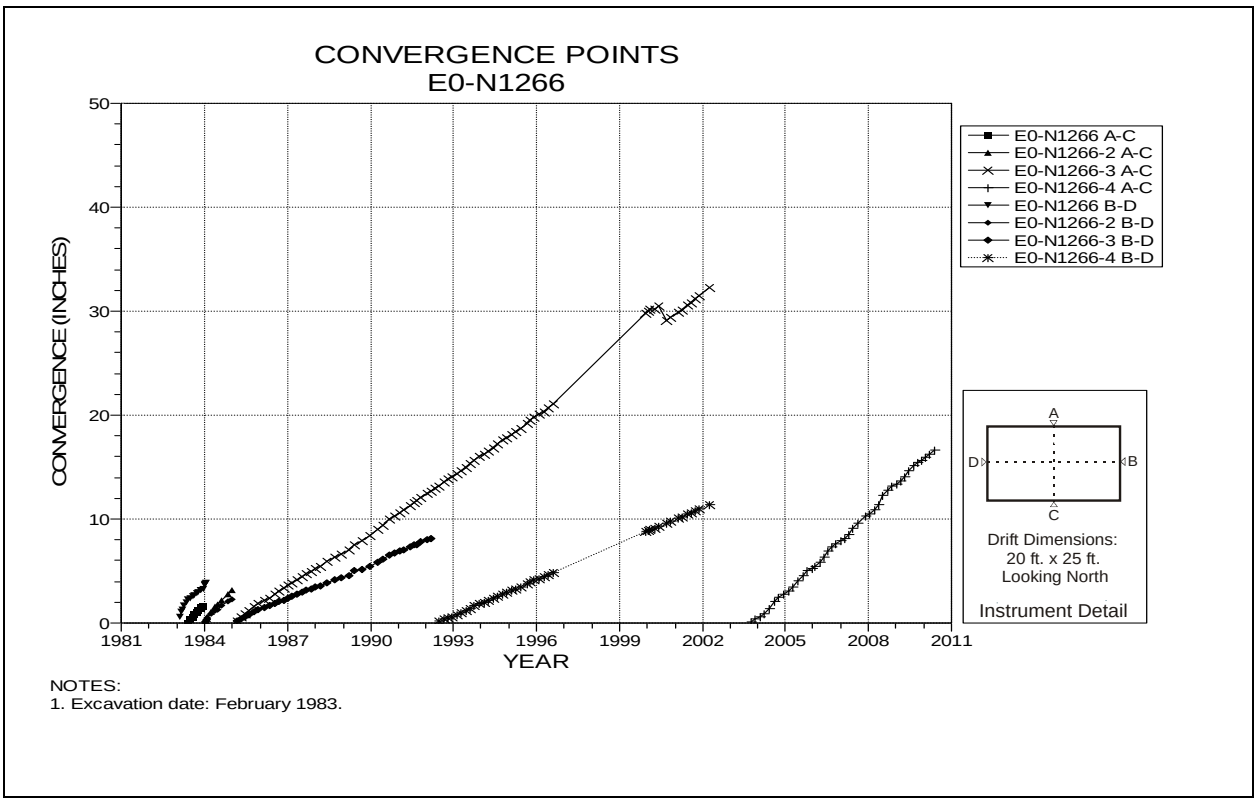


Figure 4-122 Convergence Point Array
E0 N1266 – All Chords

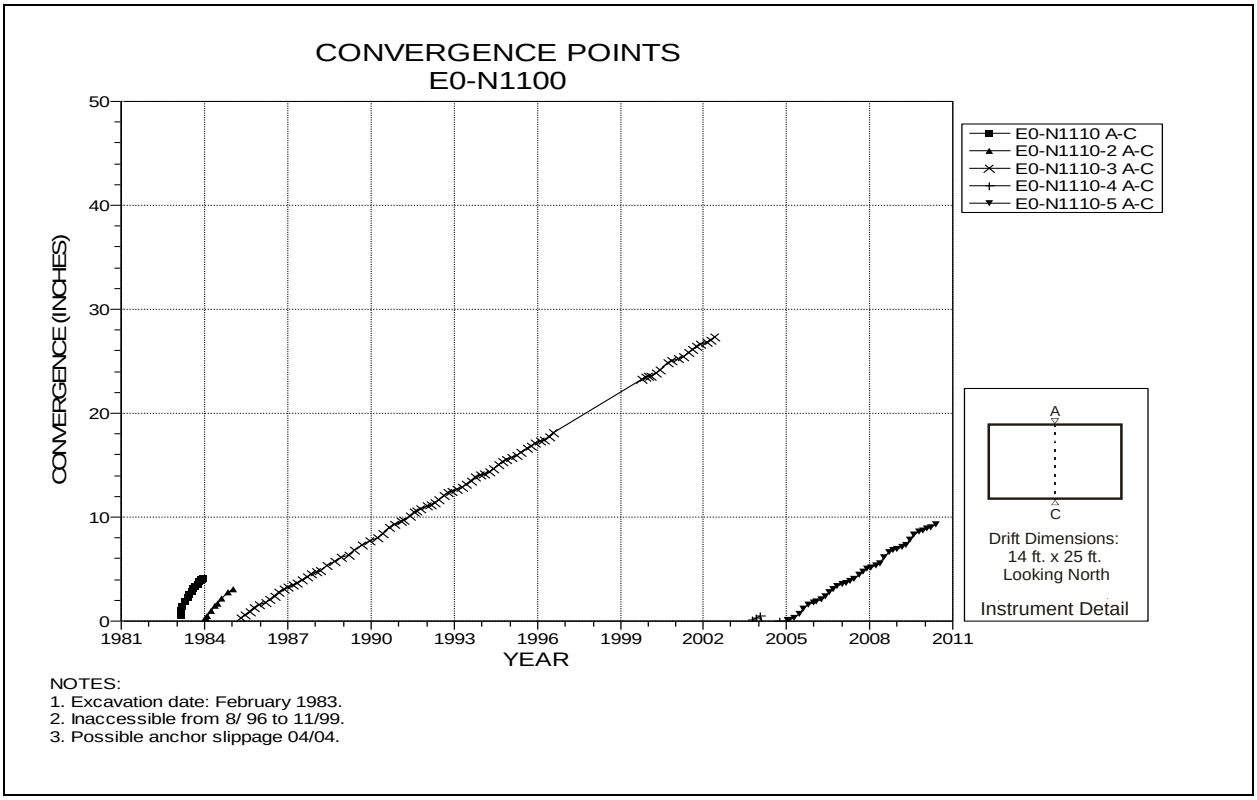


Figure 4-123 Convergence Point Array
E0 N1100 – Roof to Floor

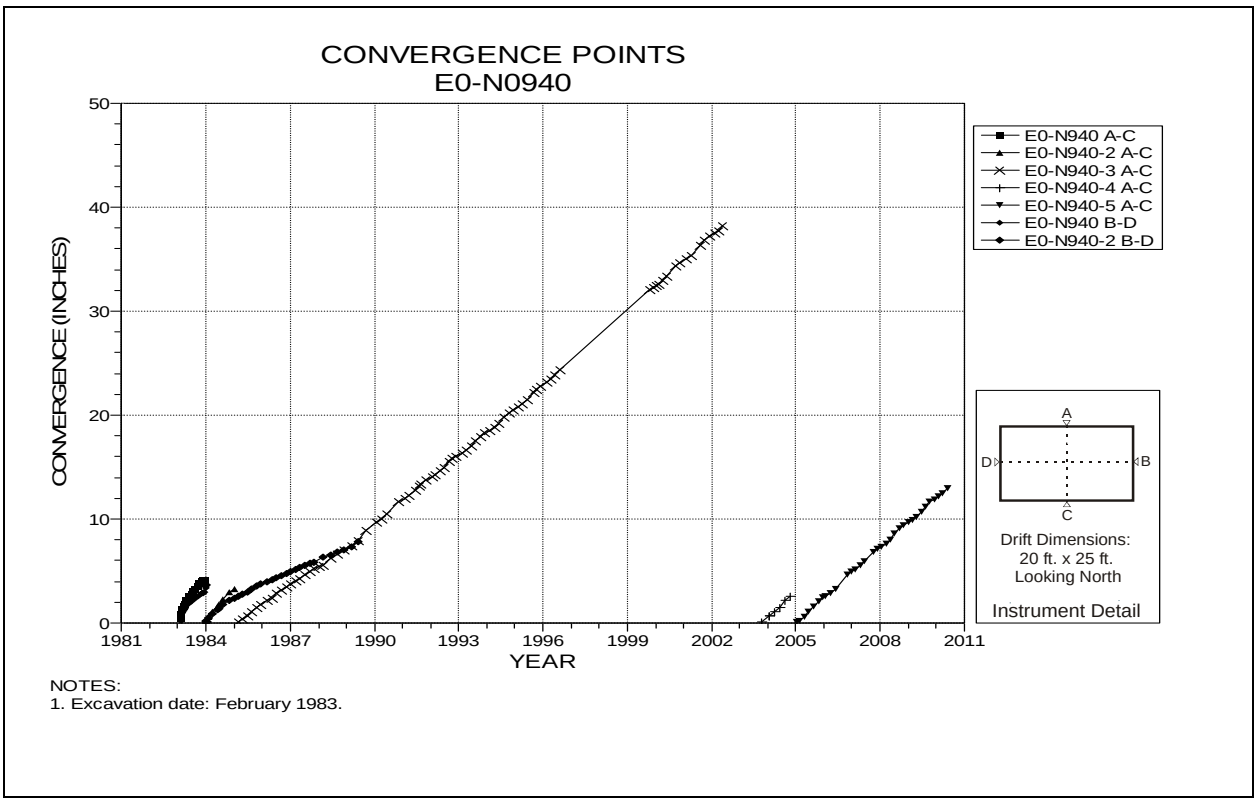


Figure 4-124 Convergence Point Array
E0 N940 – All Chords

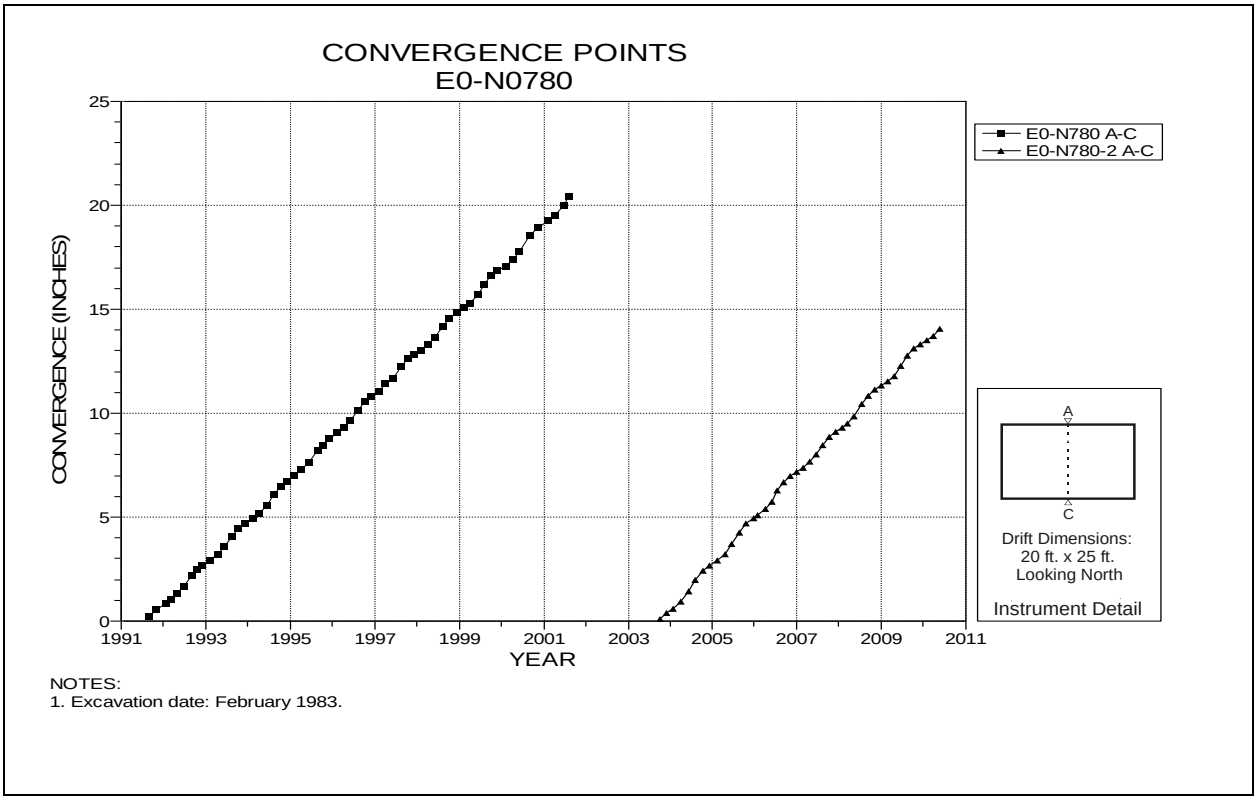


Figure 4-125 Convergence Point Array
E0 N780 – Roof to Floor

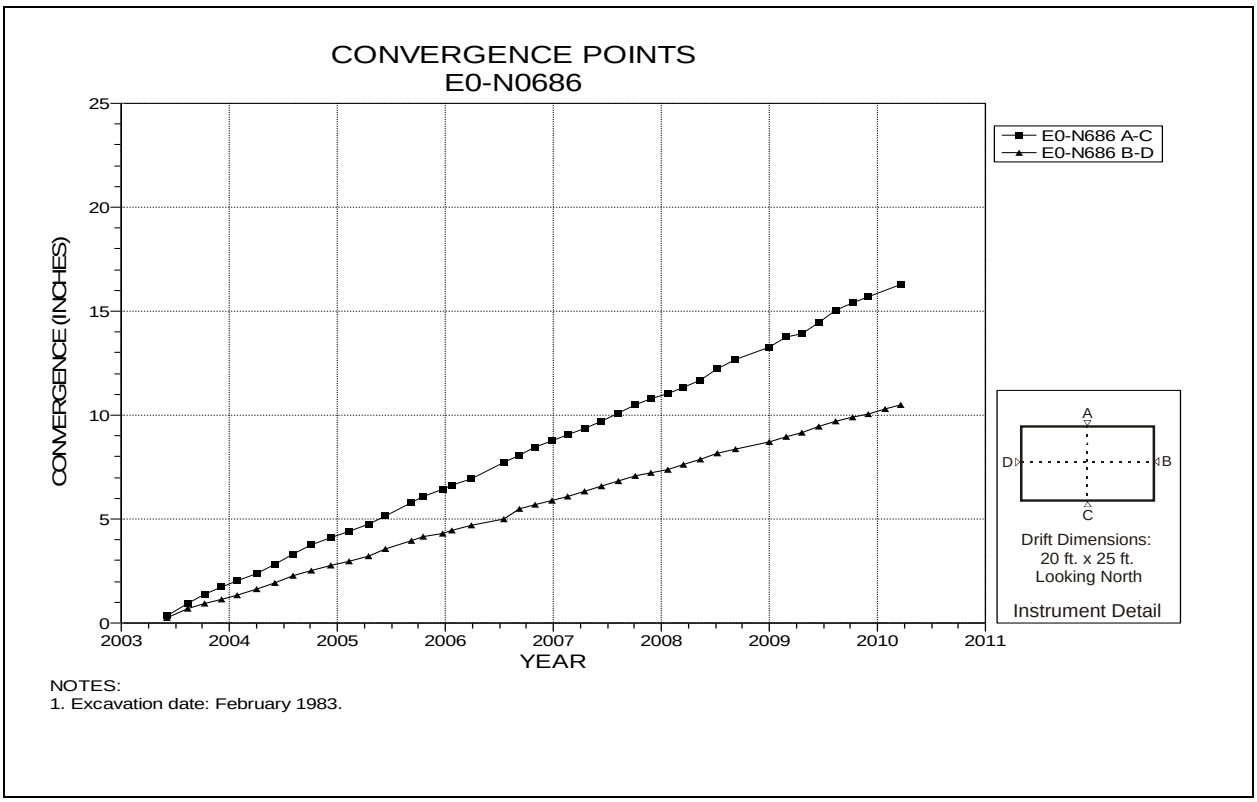


Figure 4-126 Convergence Point Array
E0 N686 – All Chords

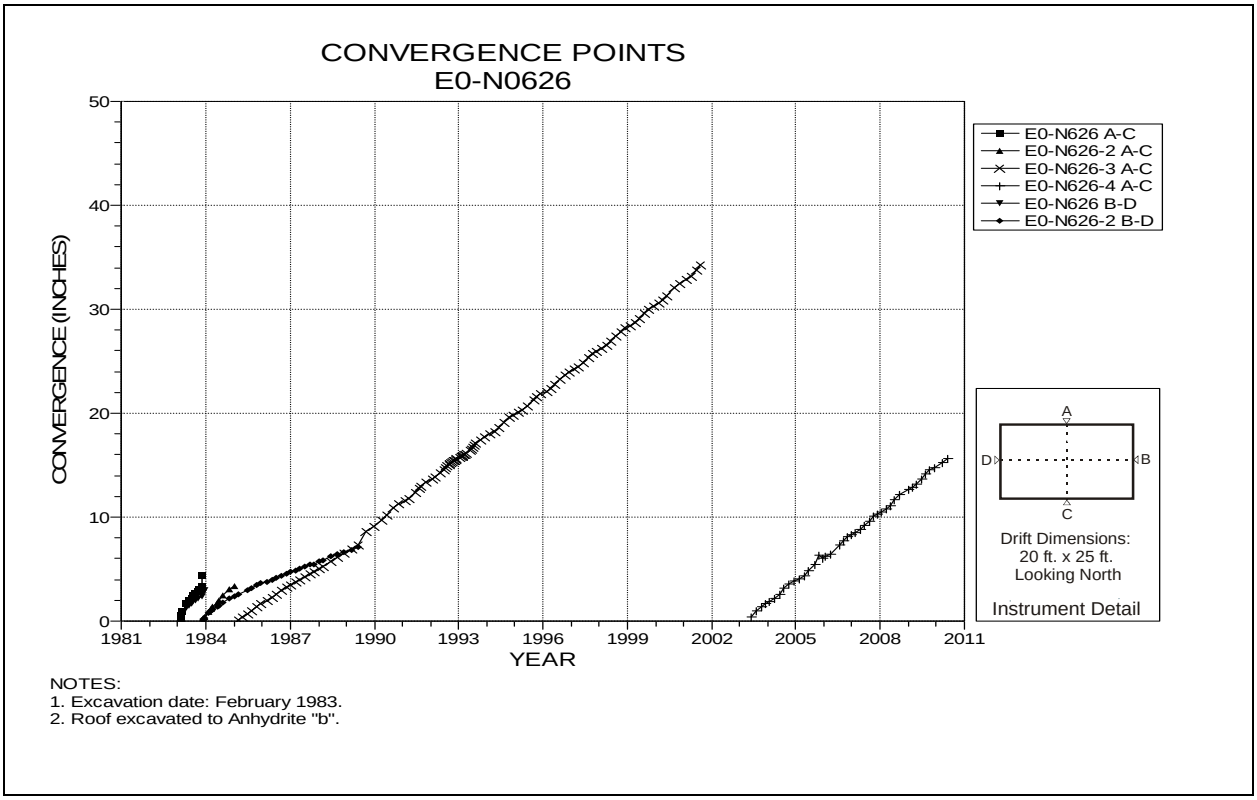


Figure 4-127 Convergence Point Array
E0 N626 – All Chords

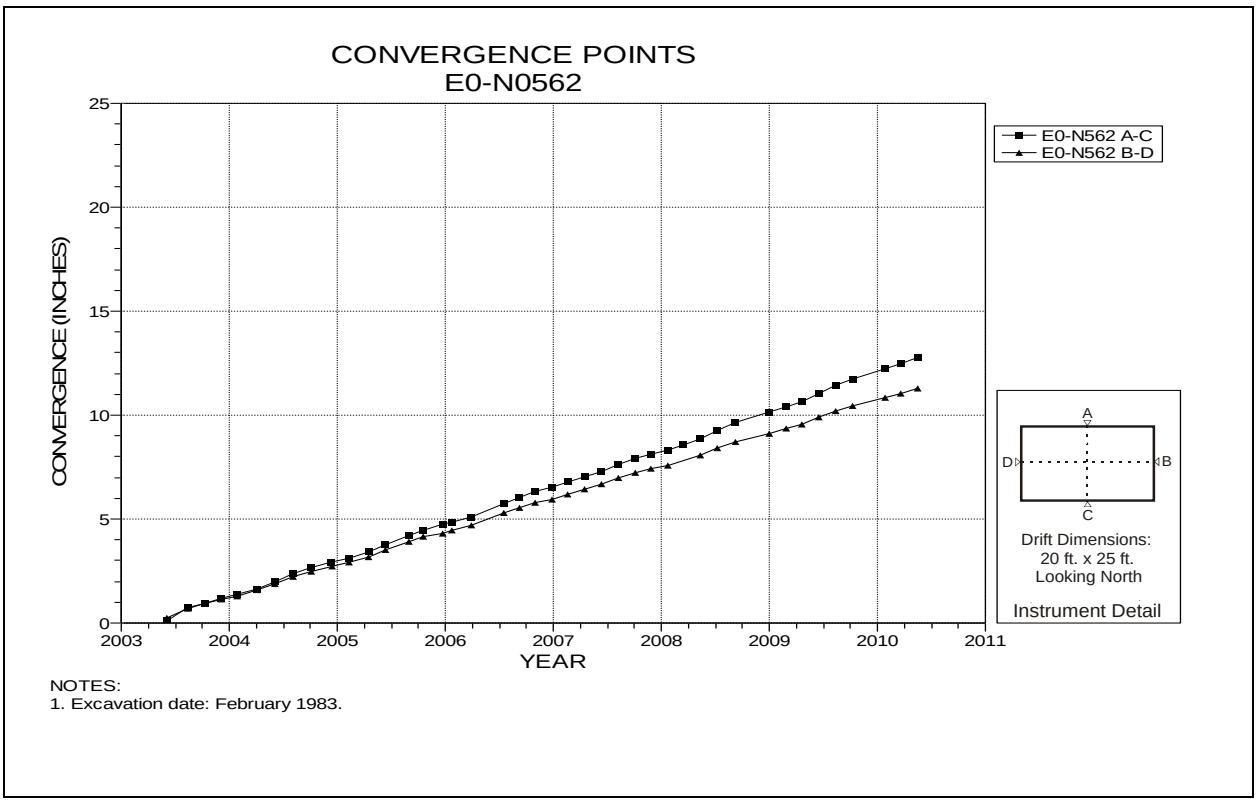


Figure 4-128 Convergence Point Array
E0 N562 – All Chords

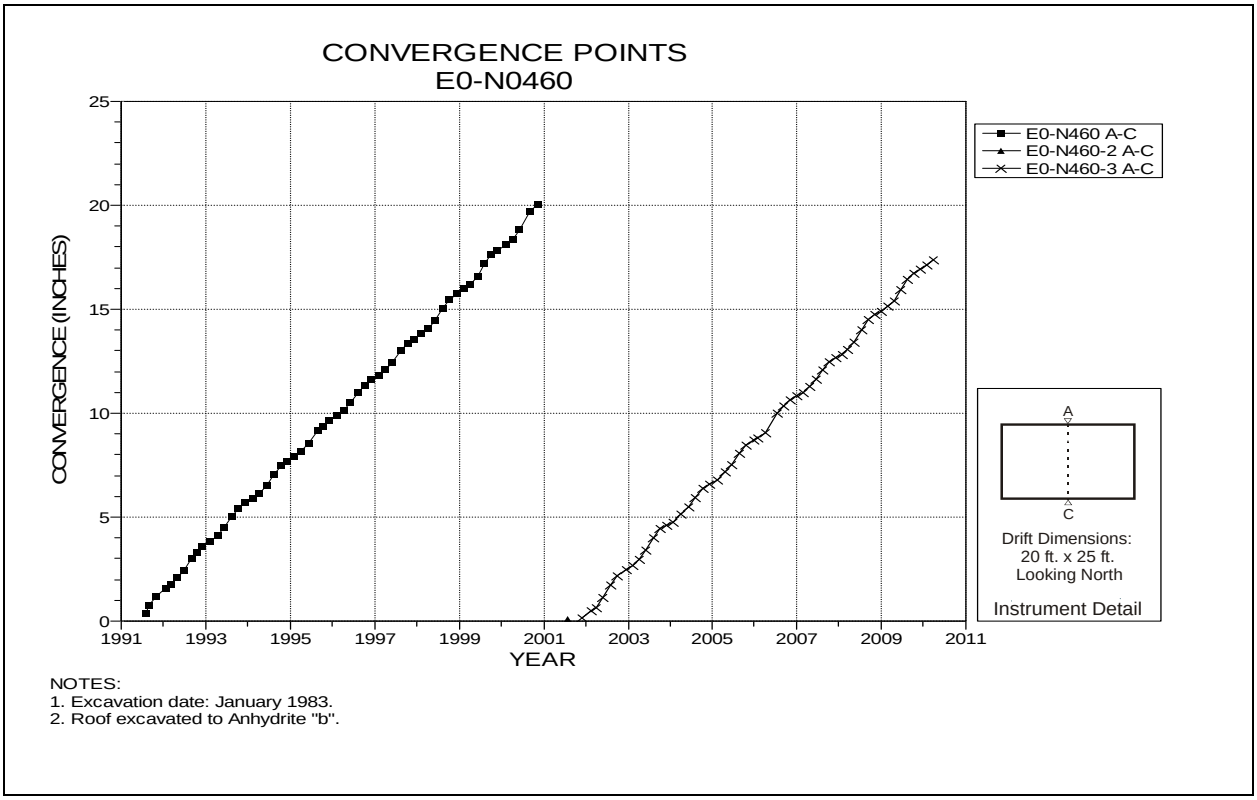


Figure 4-129 Convergence Point Array
E0 N460 – Roof to Floor

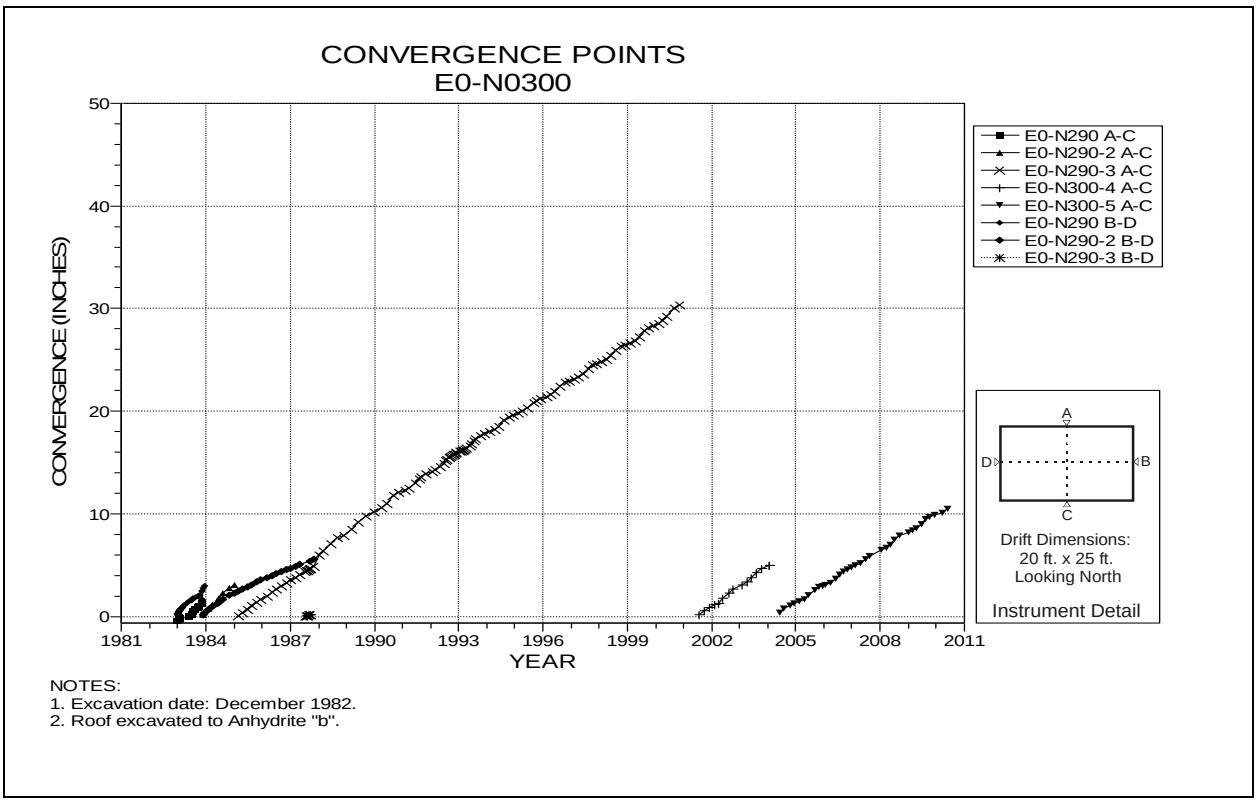


Figure 4-130 Convergence Point Array
E0 N300 – All Chords

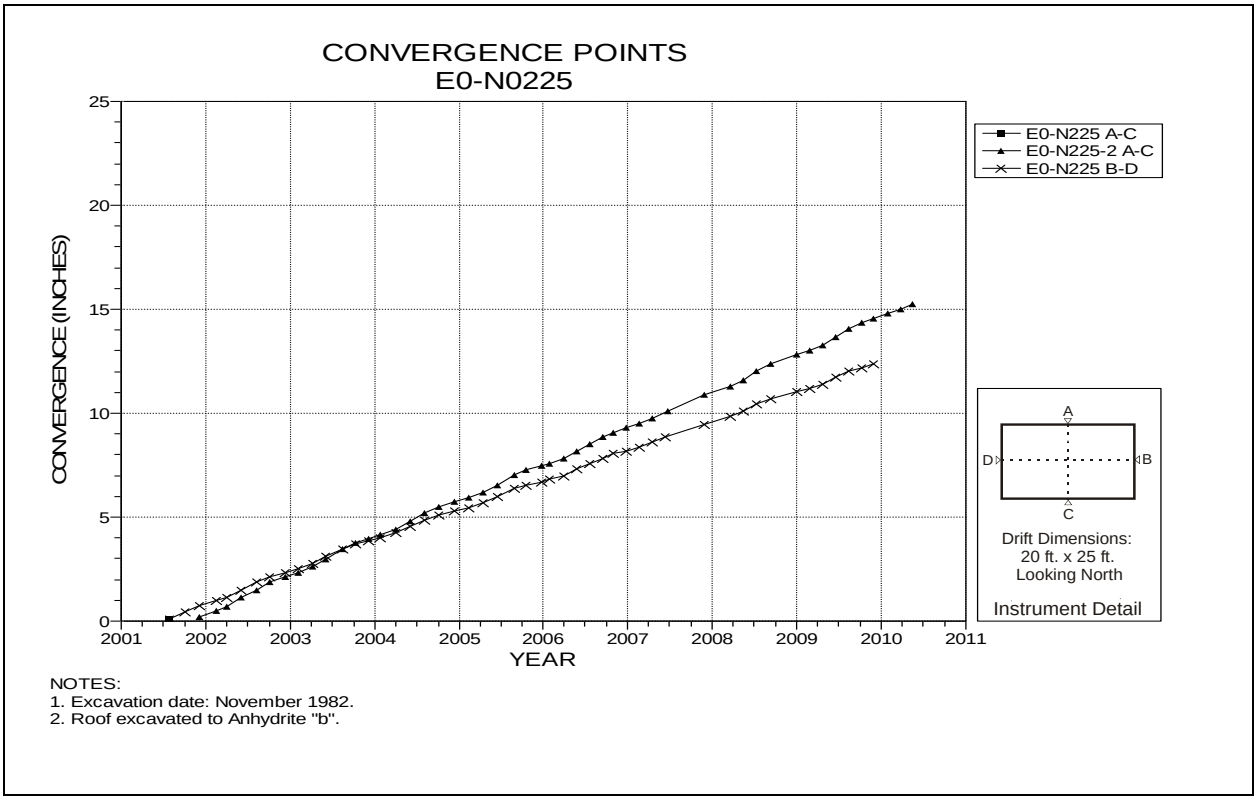


Figure 4-131 Convergence Point Array
E0 N225 – All Chords

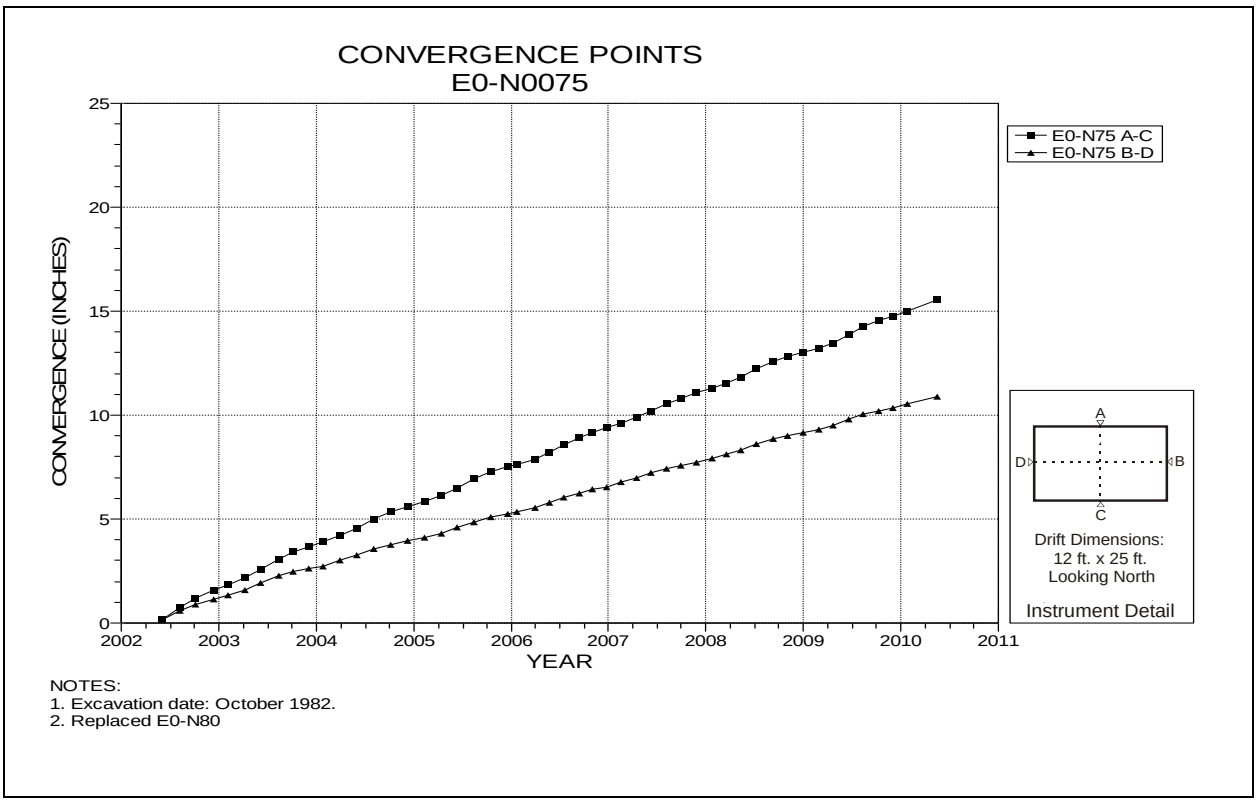


Figure 4-132 Convergence Point Array
E0 N75 – All Chords

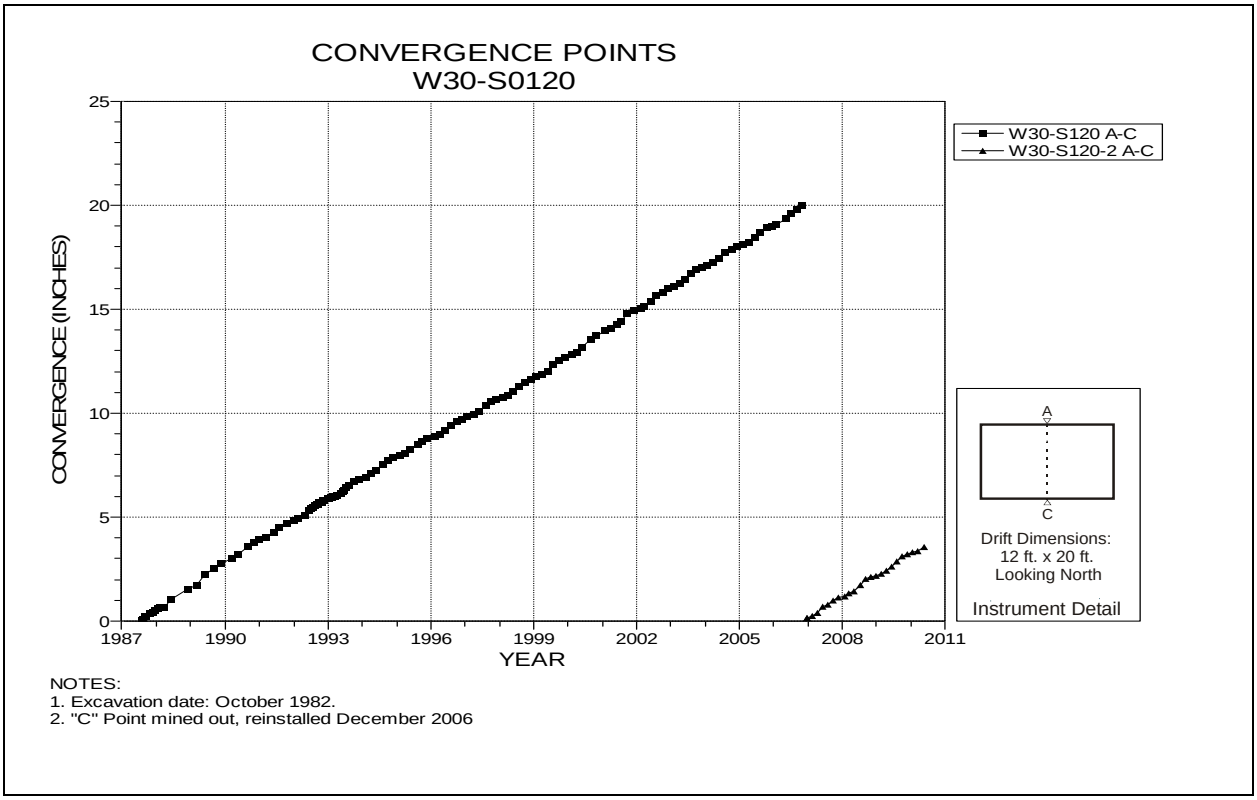


Figure 4-133 Convergence Point Array
W30 S120 – Roof to Floor

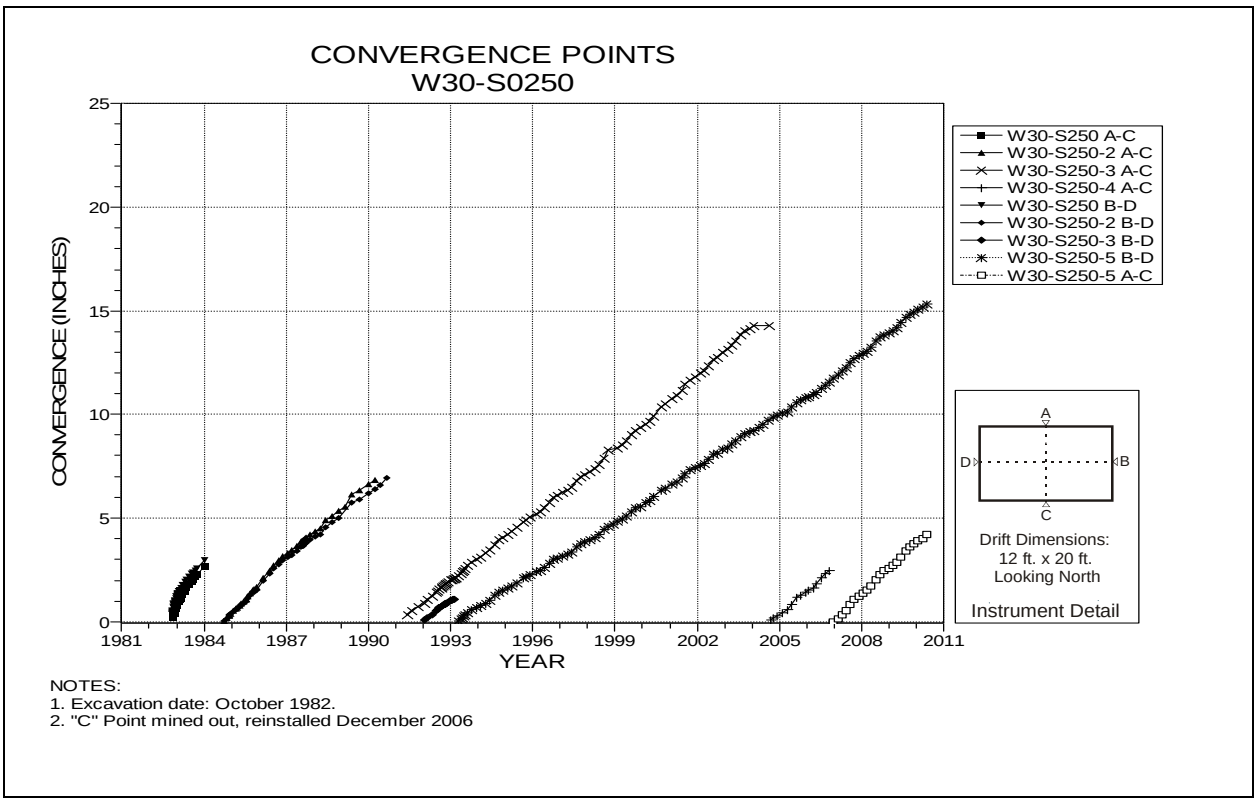


Figure 4-134 Convergence Point Array
W30 S250 – All Chords

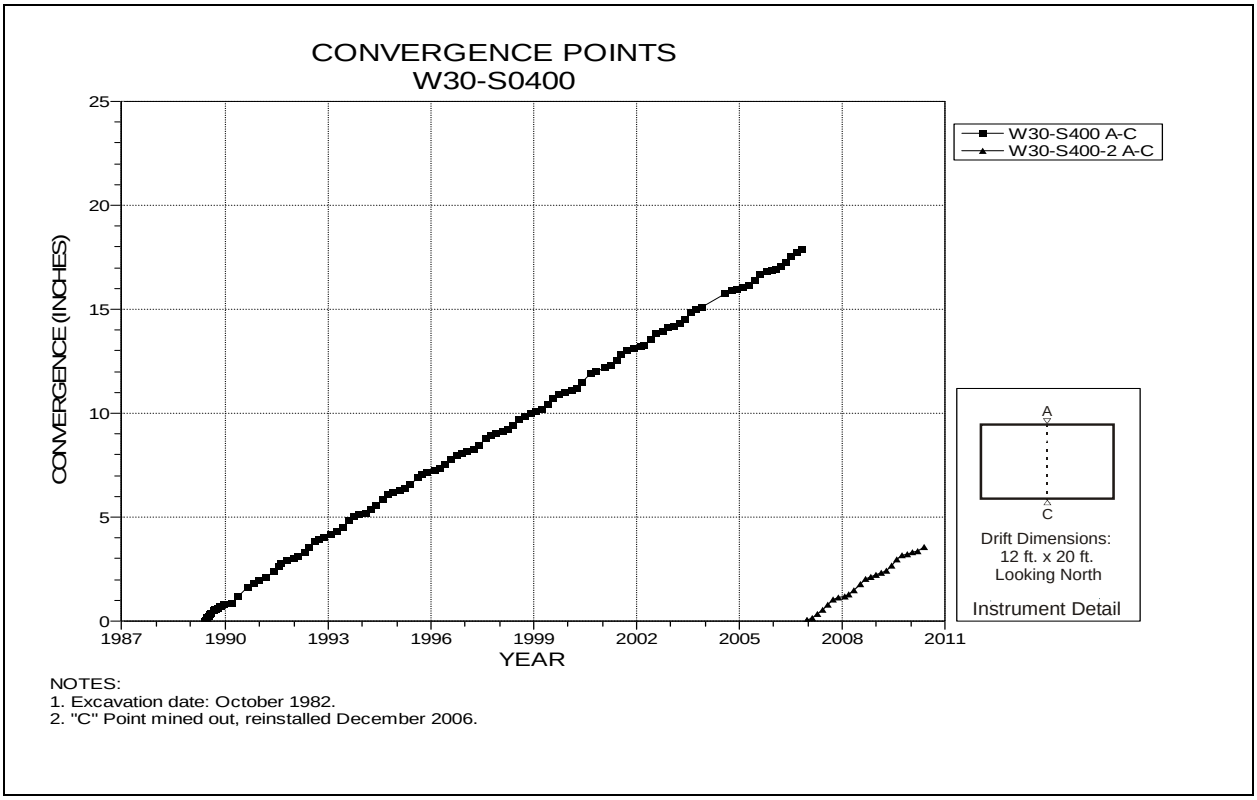


Figure 4-135 Convergence Point Array
W30 S400 – Roof to Floor

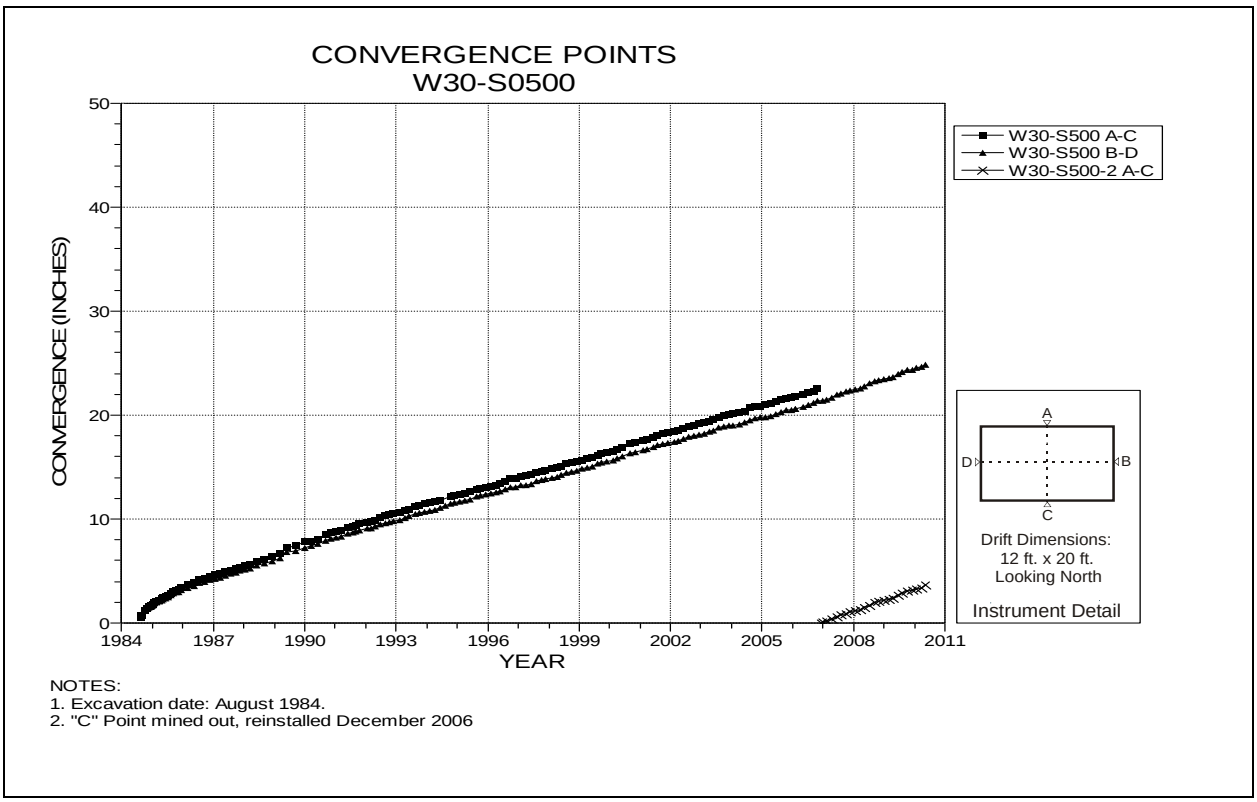


Figure 4-136 Convergence Point Array
W30 S500 – All Chords

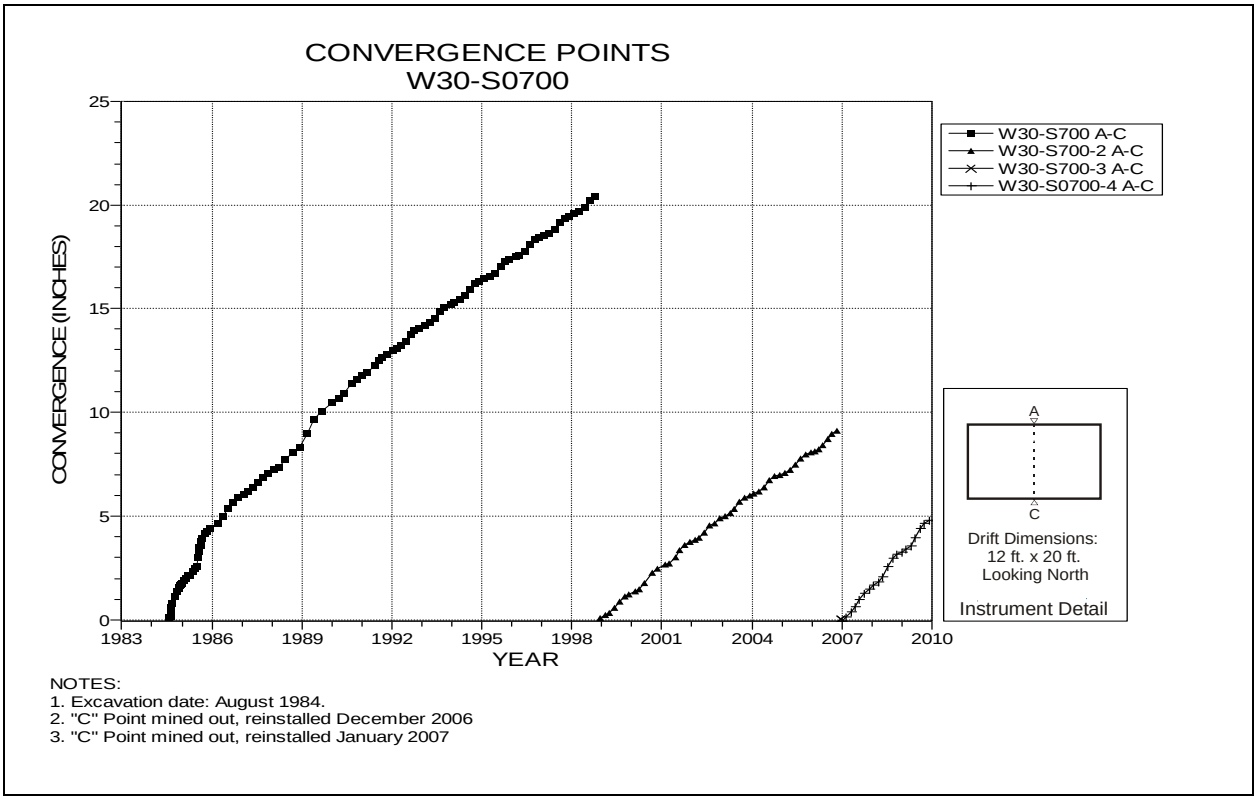


Figure 4-137 Convergence Point Array
W30 S700 – Roof to Floor

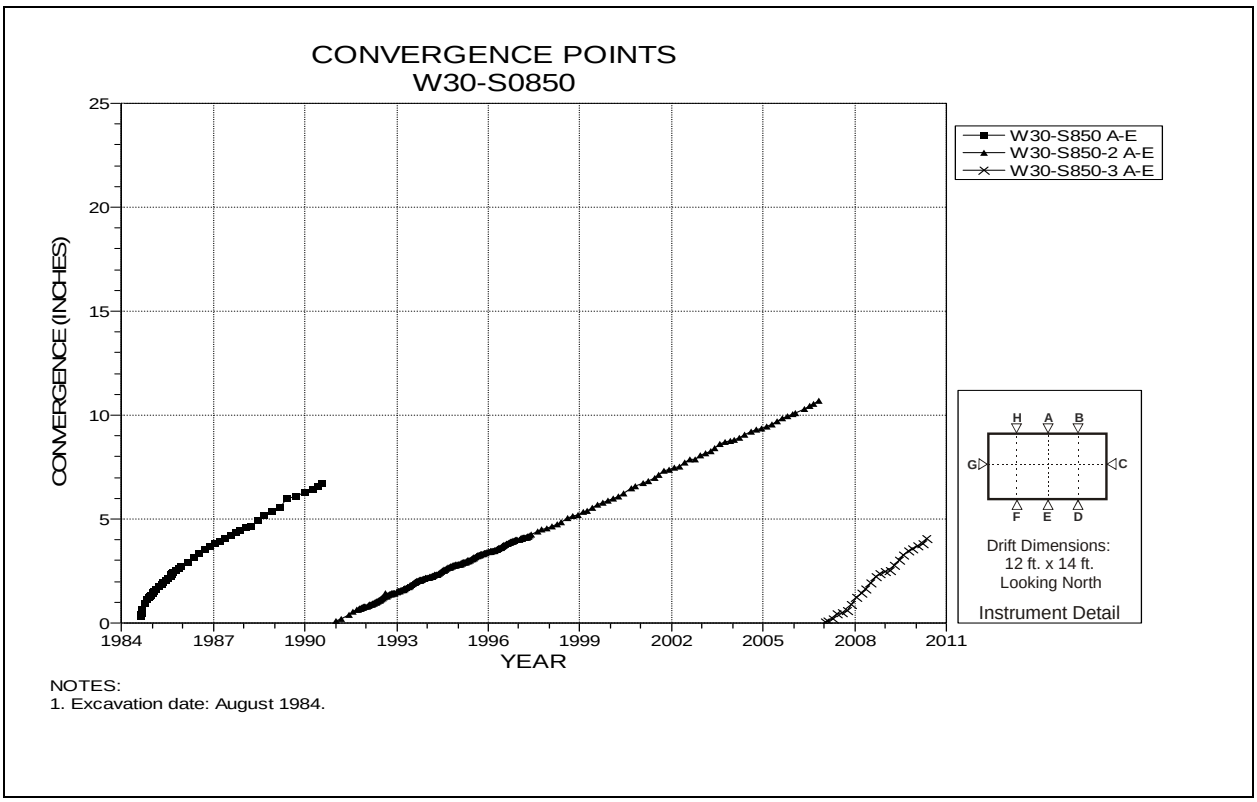


Figure 4-138 Convergence Point Array
W30 S850 – Roof to Floor – Centerline

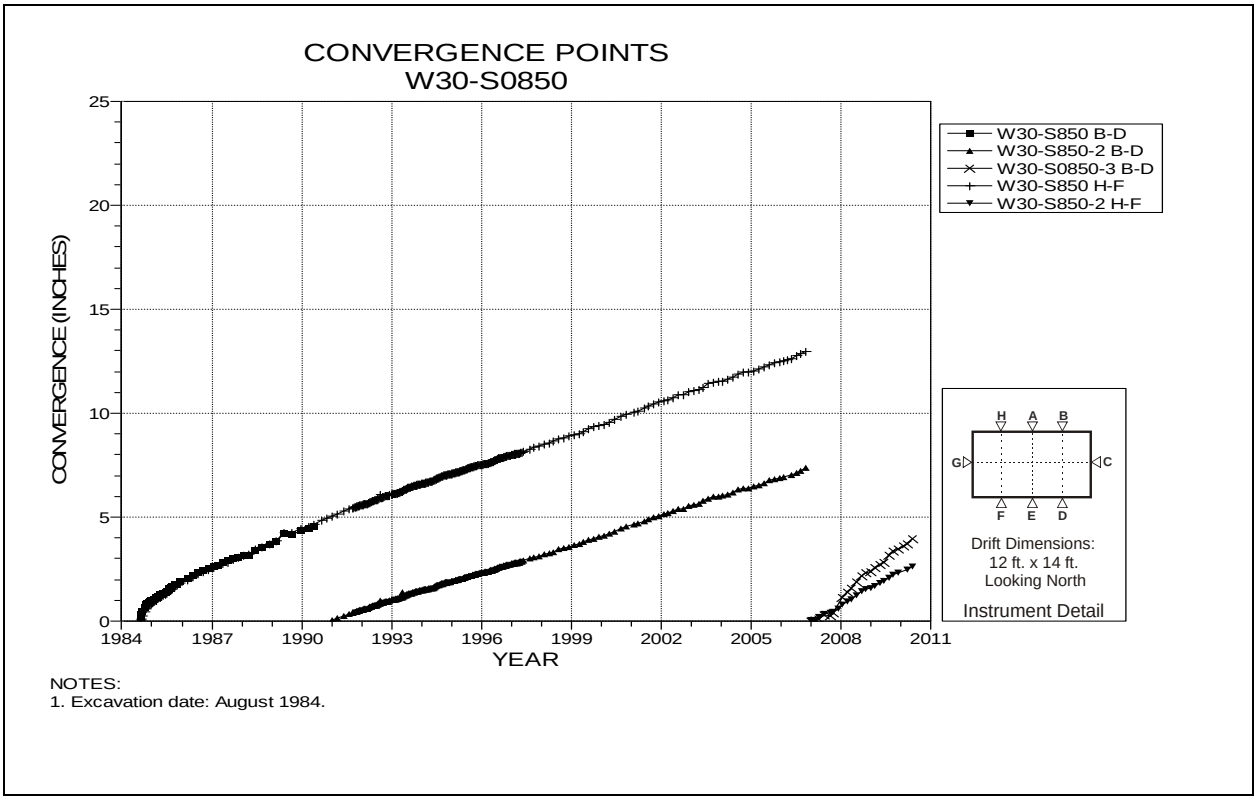


Figure 4-139 Convergence Point Array
W30 S850 – Roof to Floor – Quarter Points

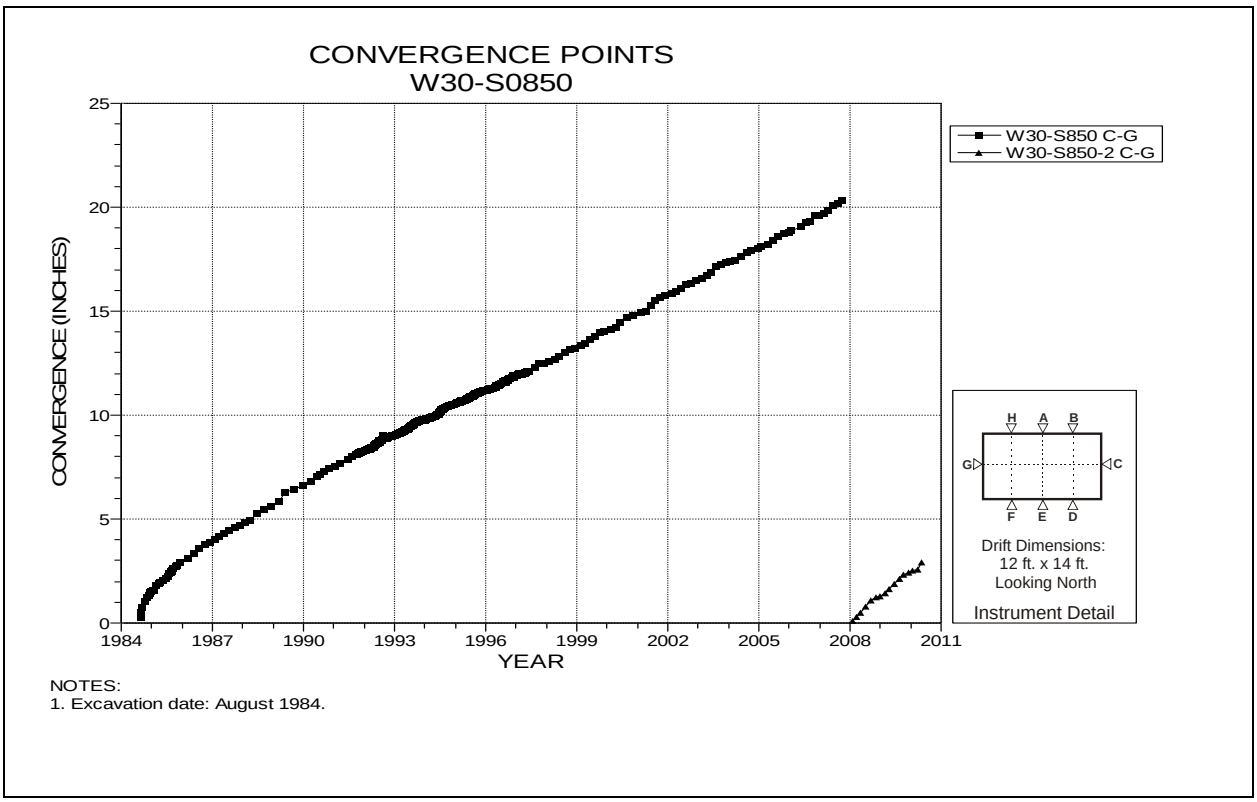


Figure 4-140 Convergence Point Array
W30 S850 – Rib to Rib

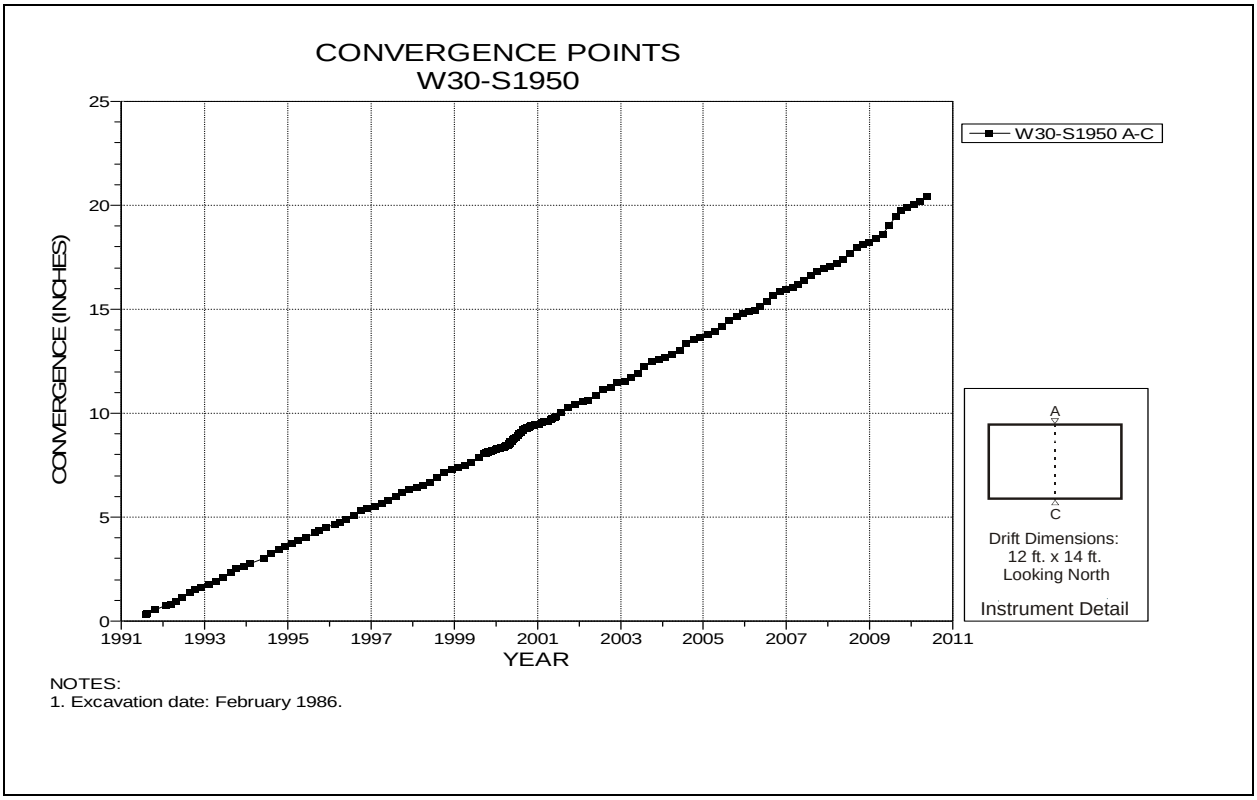


Figure 4-141 Convergence Point Array
W30 S1950 – Roof to Floor

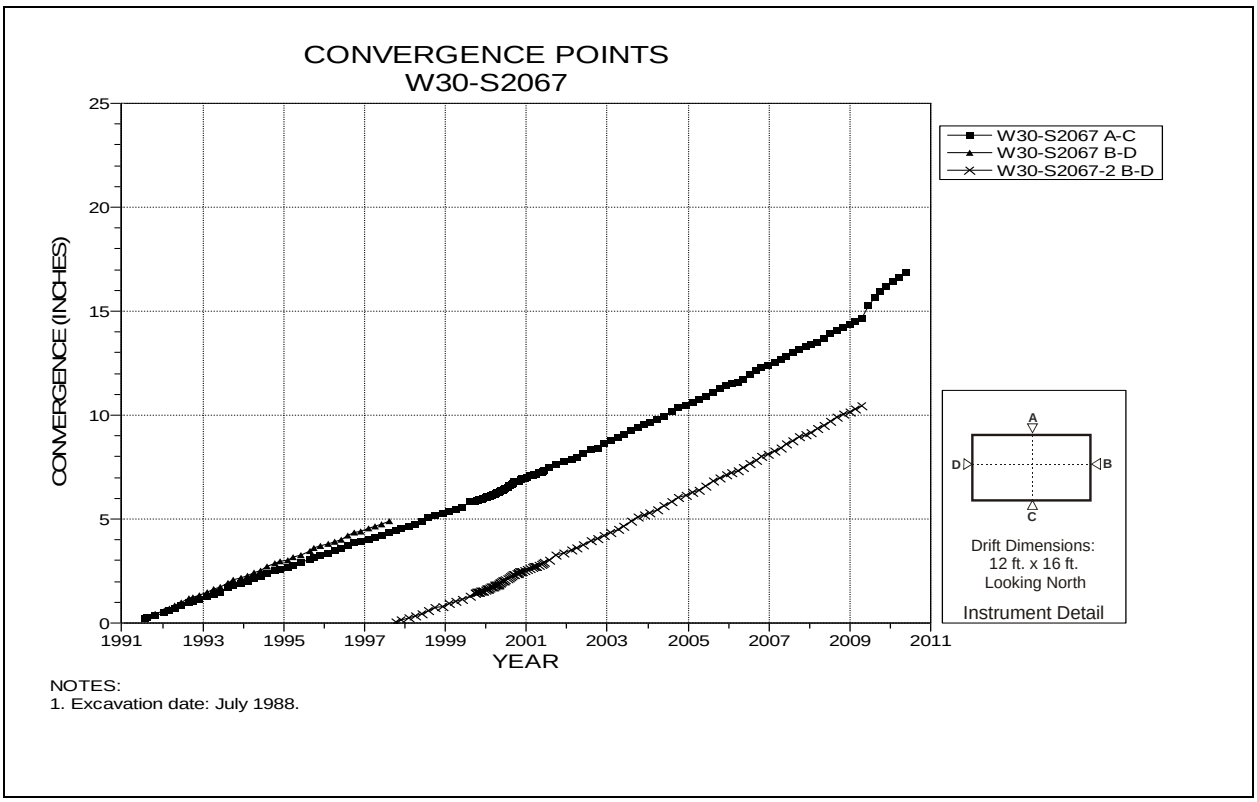


Figure 4-142 Convergence Point Array
W30 S2067 – All Chords

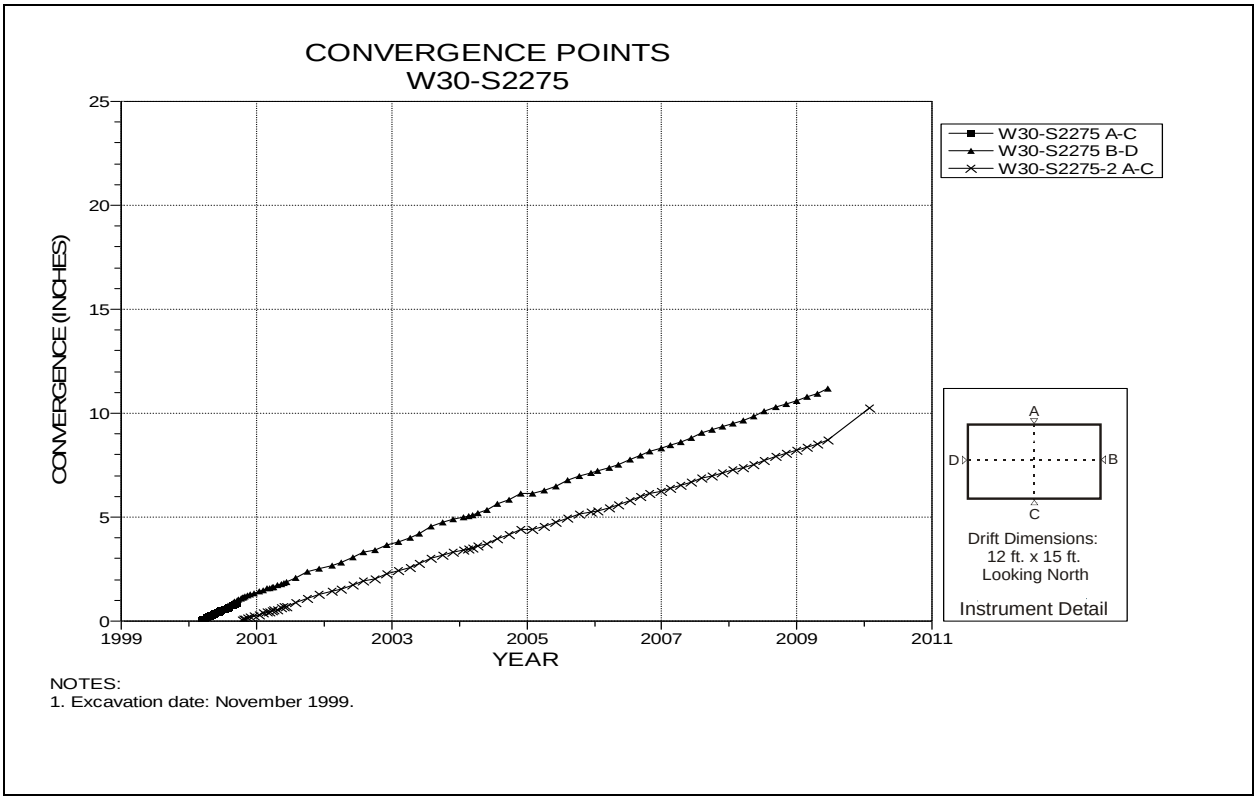


Figure 4-143 Convergence Point Array
W30 S2275 – All Chords

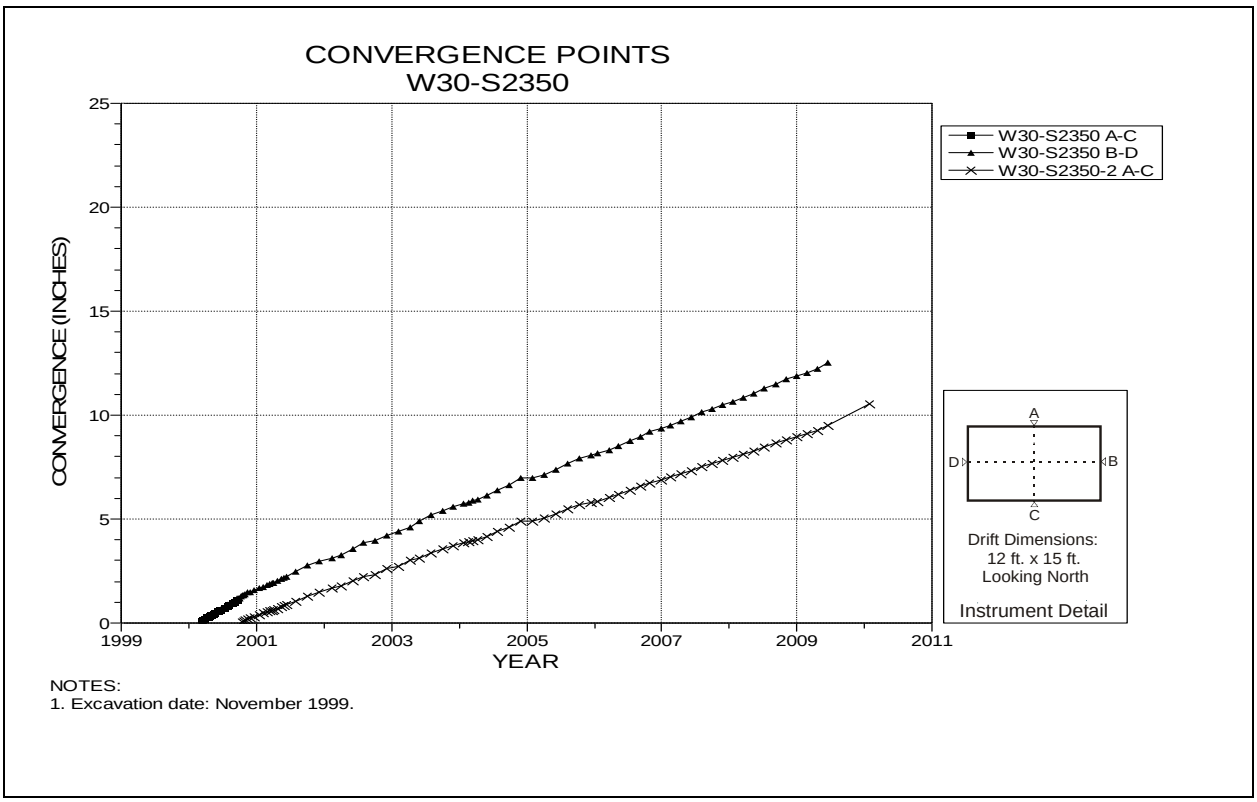


Figure 4-144 Convergence Point Array
W30 S2350 – All Chords

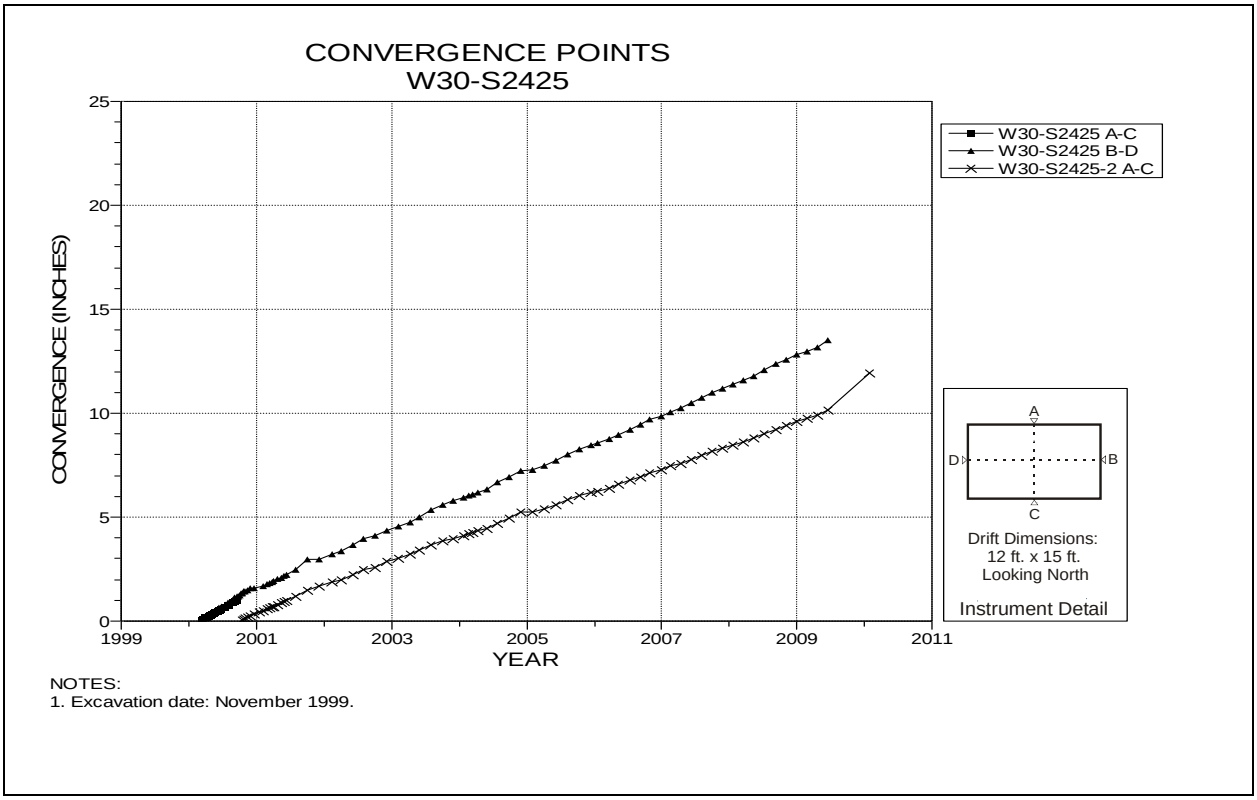


Figure 4-145 Convergence Point Array
W30 S2425 – All Chords

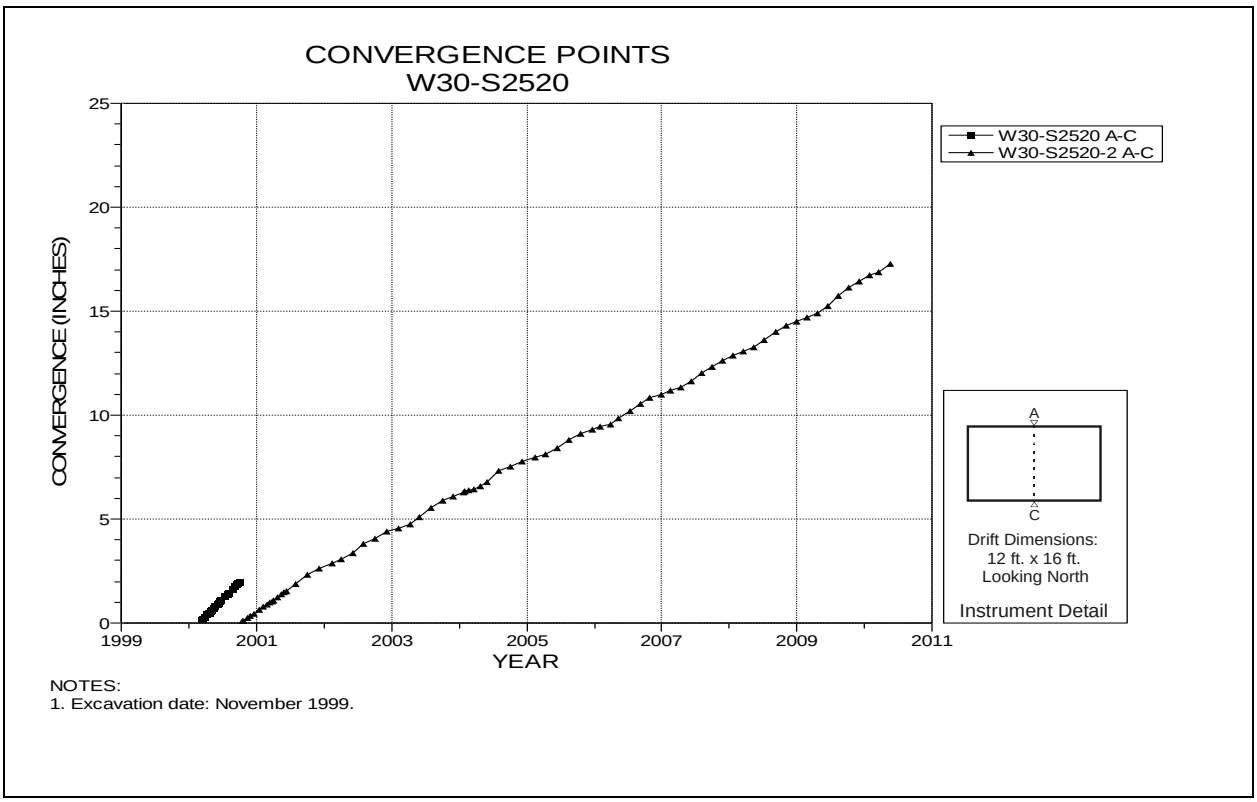


Figure 4-146 Convergence Point Array
W30 S2520 – Roof to Floor

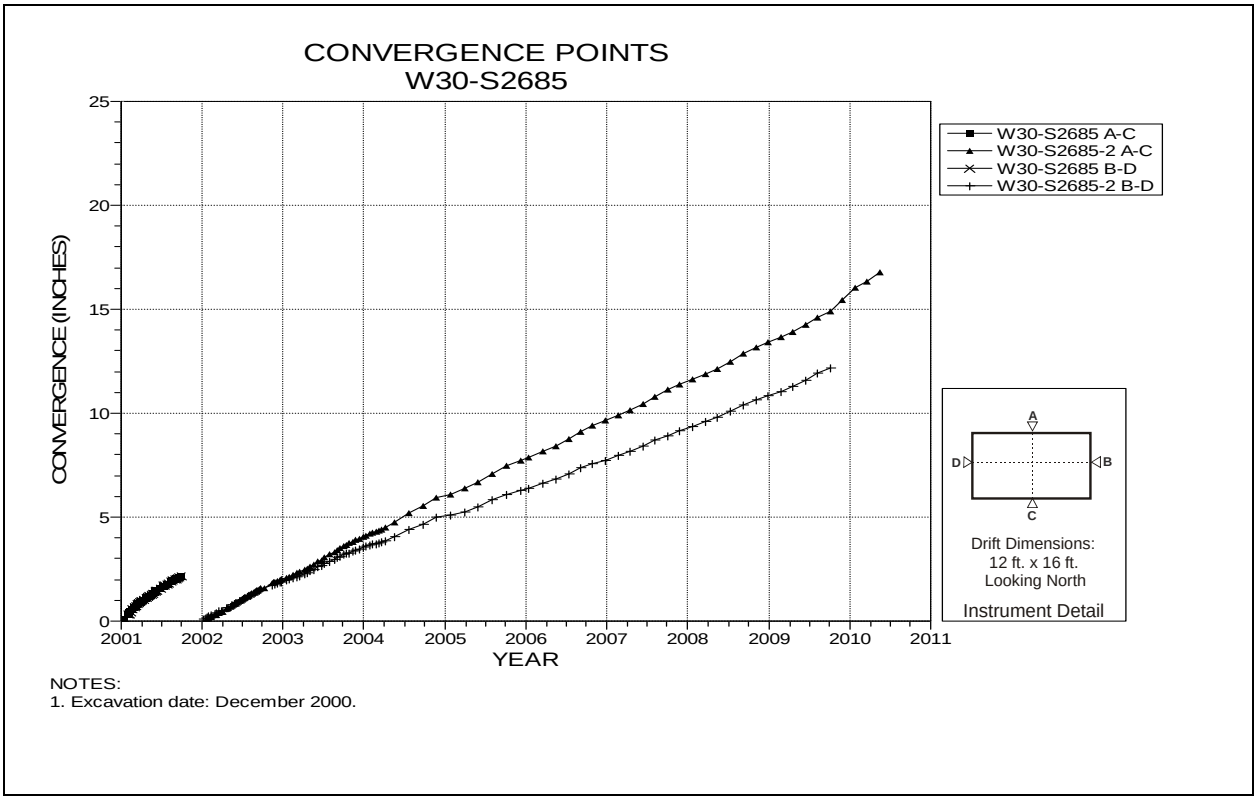


Figure 4-147 Convergence Point Array
W30 S2685 – All Chords

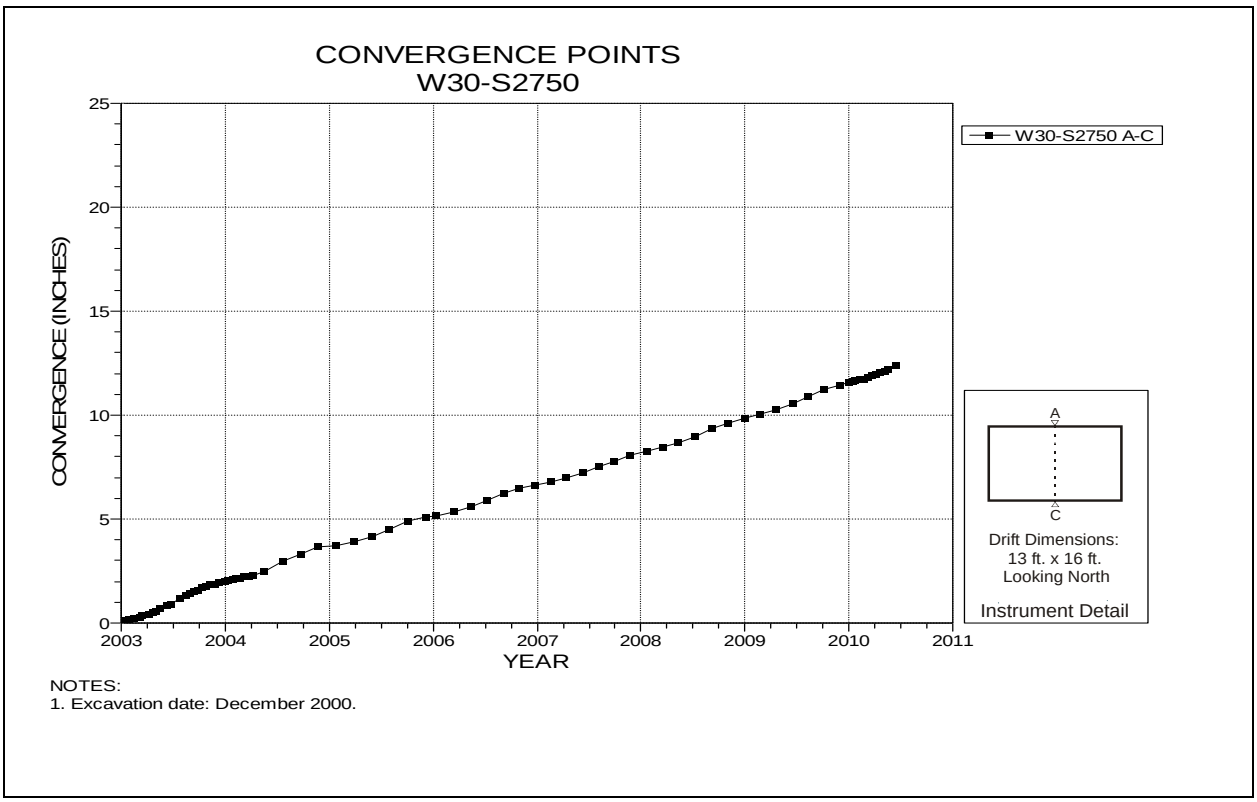


Figure 4-148 Convergence Point Array
W30 S2750 – Roof to Floor

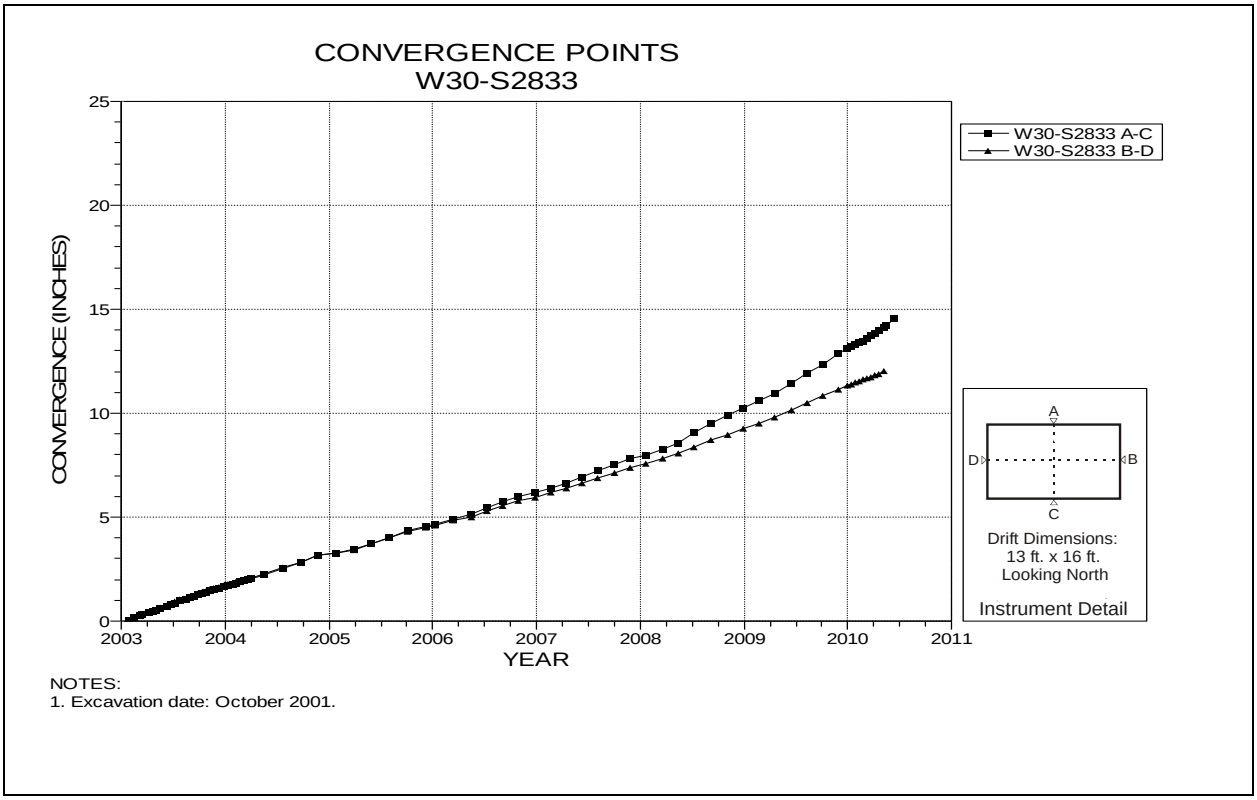


Figure 4-149 Convergence Point Array
W30 S2833 – All Chords

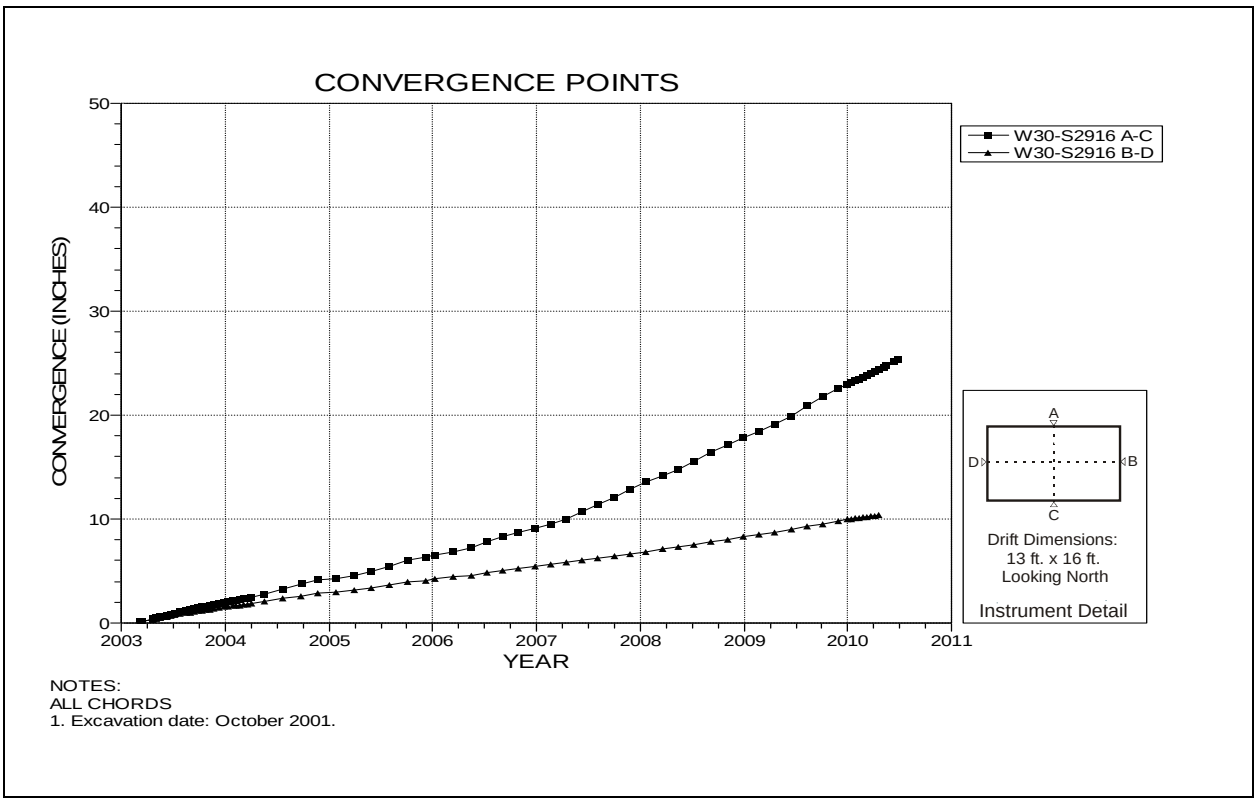


Figure 4-150 Convergence Point Array
W30 S2916 – All Chords

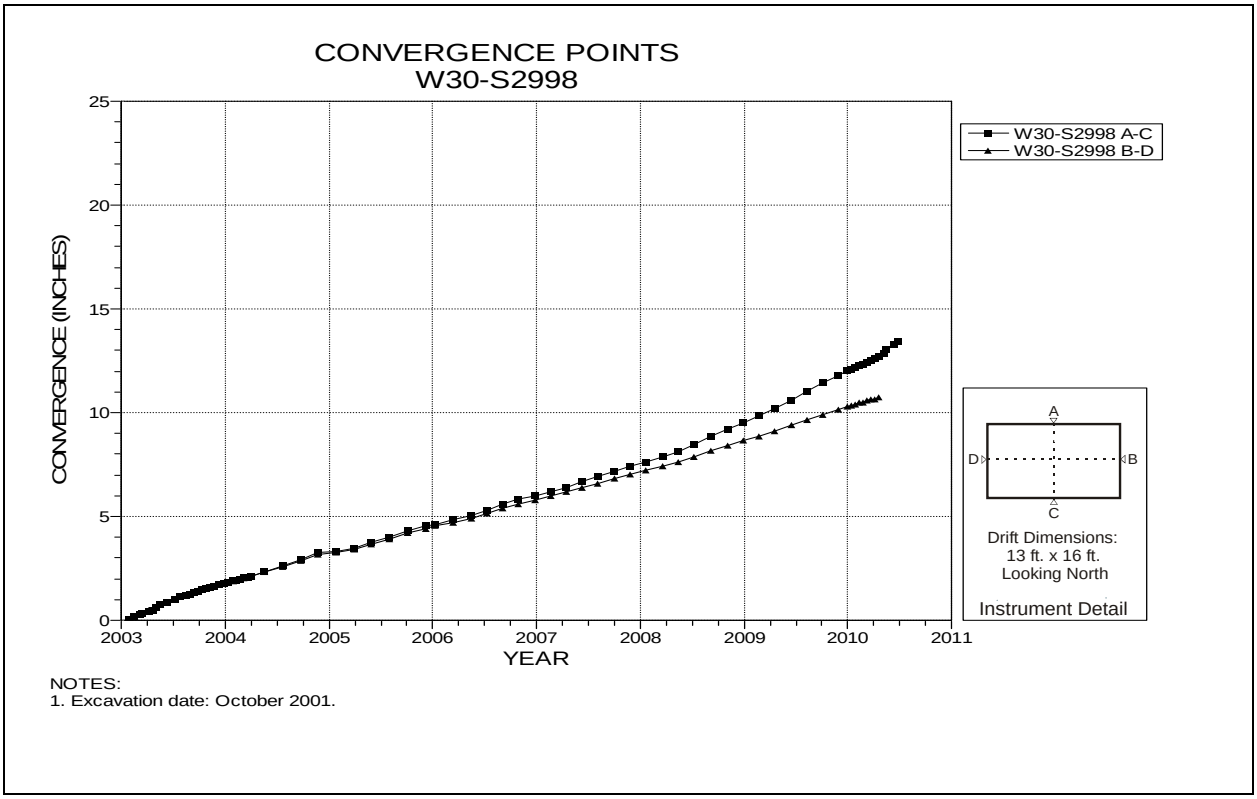


Figure 4-151 Convergence Point Array
W30 S2998 – All Chords

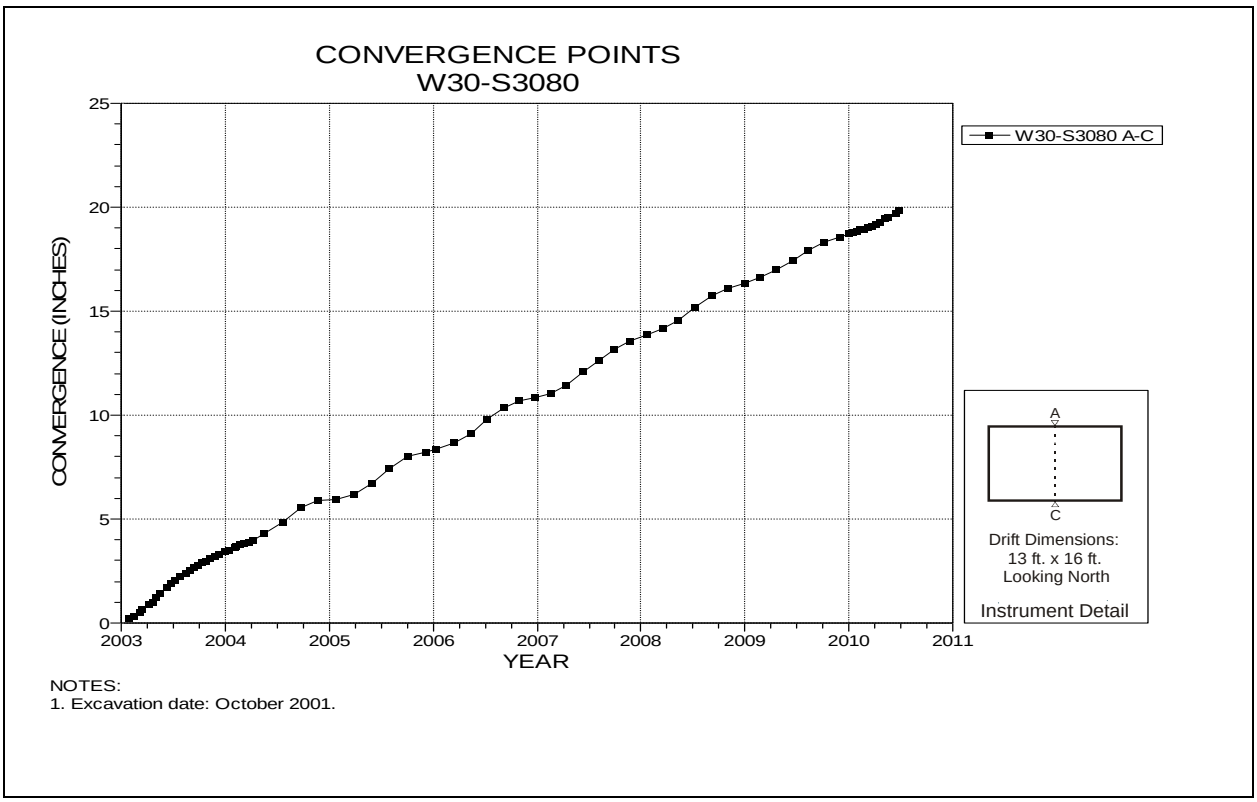


Figure 4-152 Convergence Point Array
W30 S3080 Drift – Roof to Floor

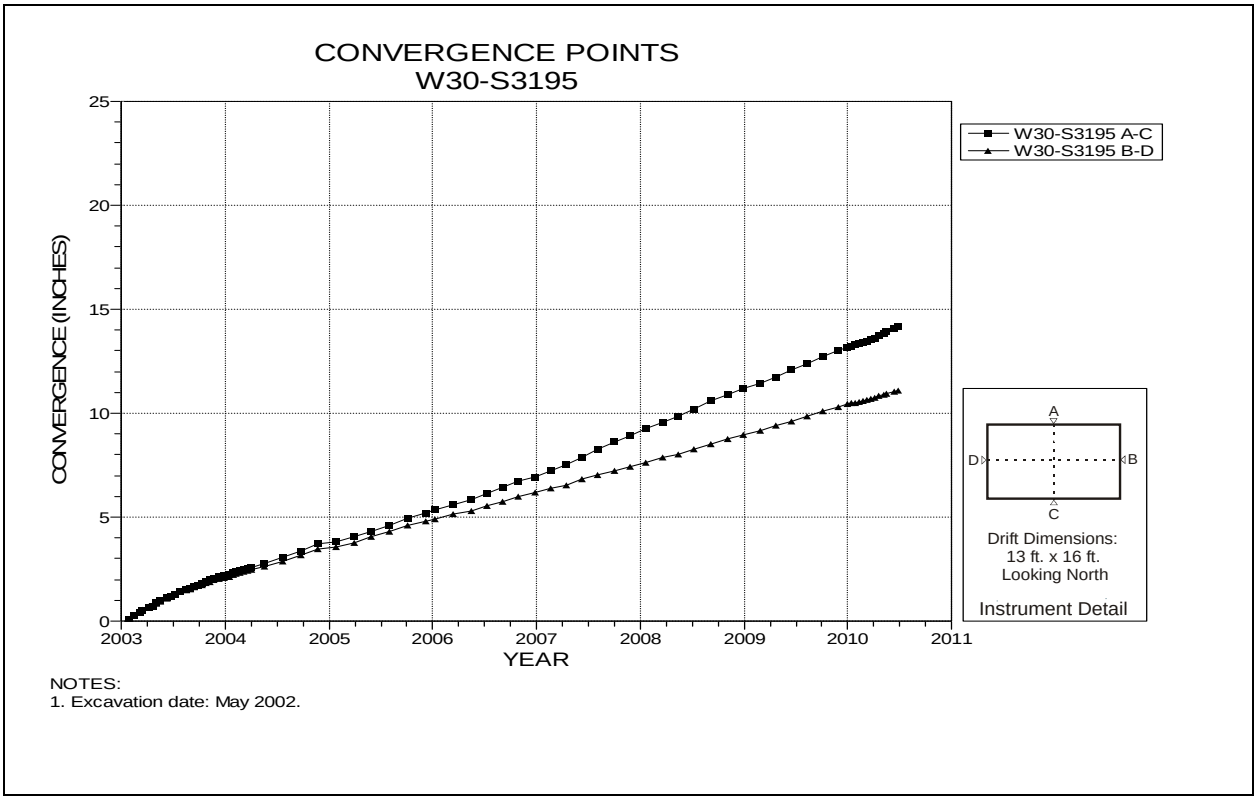


Figure 4-153 Convergence Point Array
W30 S3195 – All Chords

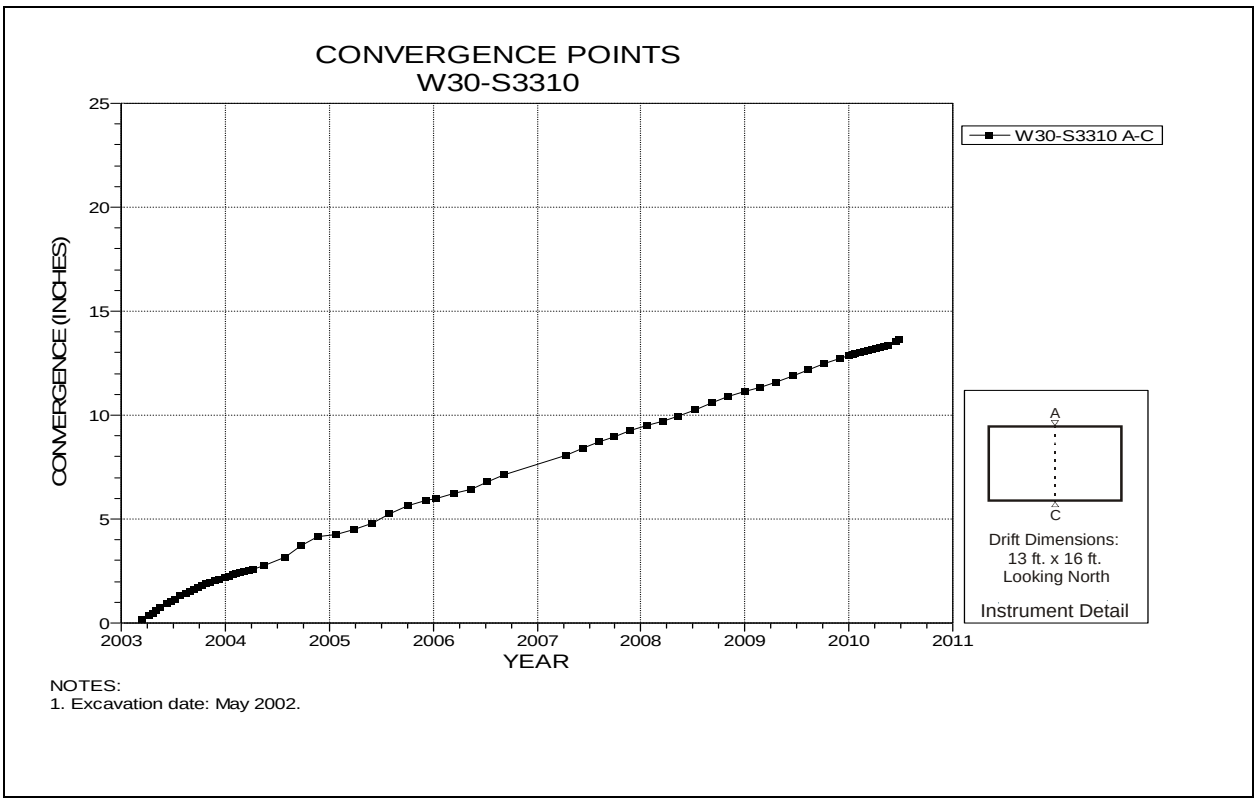


Figure 4-154 Convergence Point Array
W30 S3310 – Roof to Floor

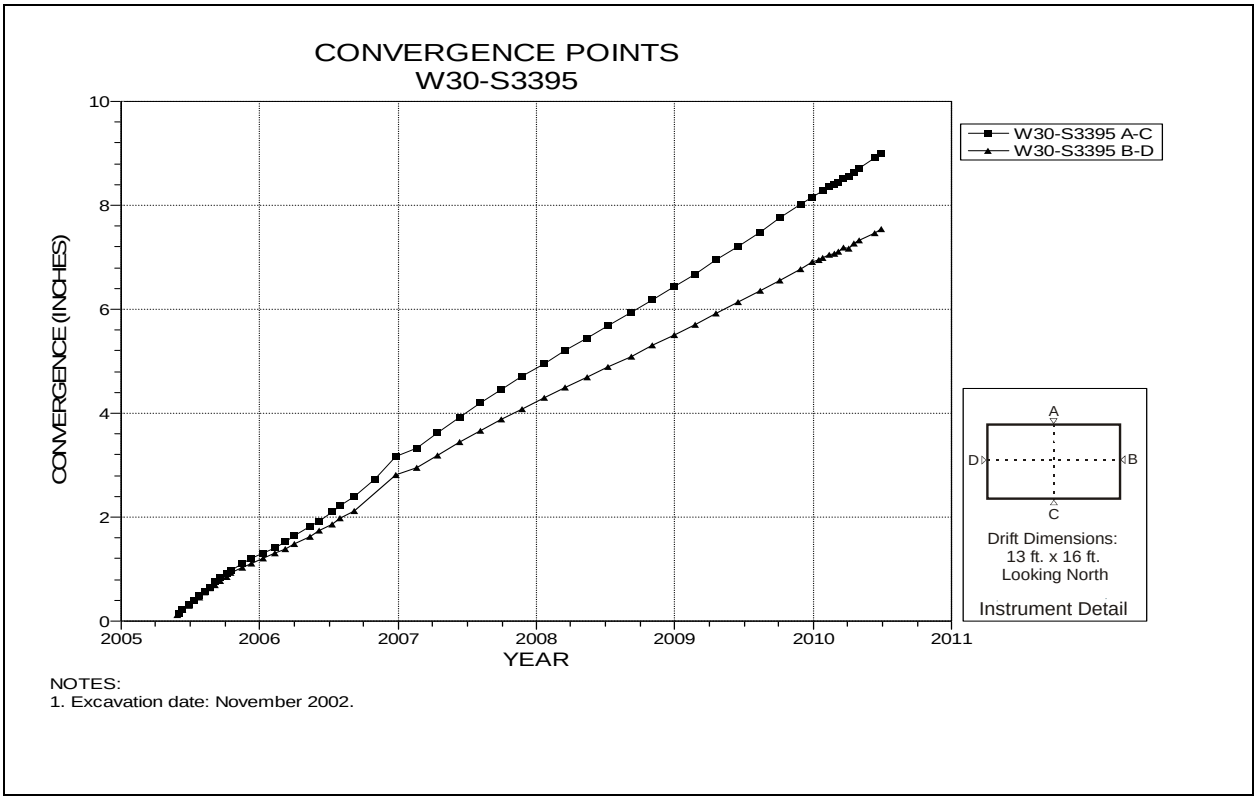


Figure 4-155 Convergence Point Array
W30 S3395 – All Chords

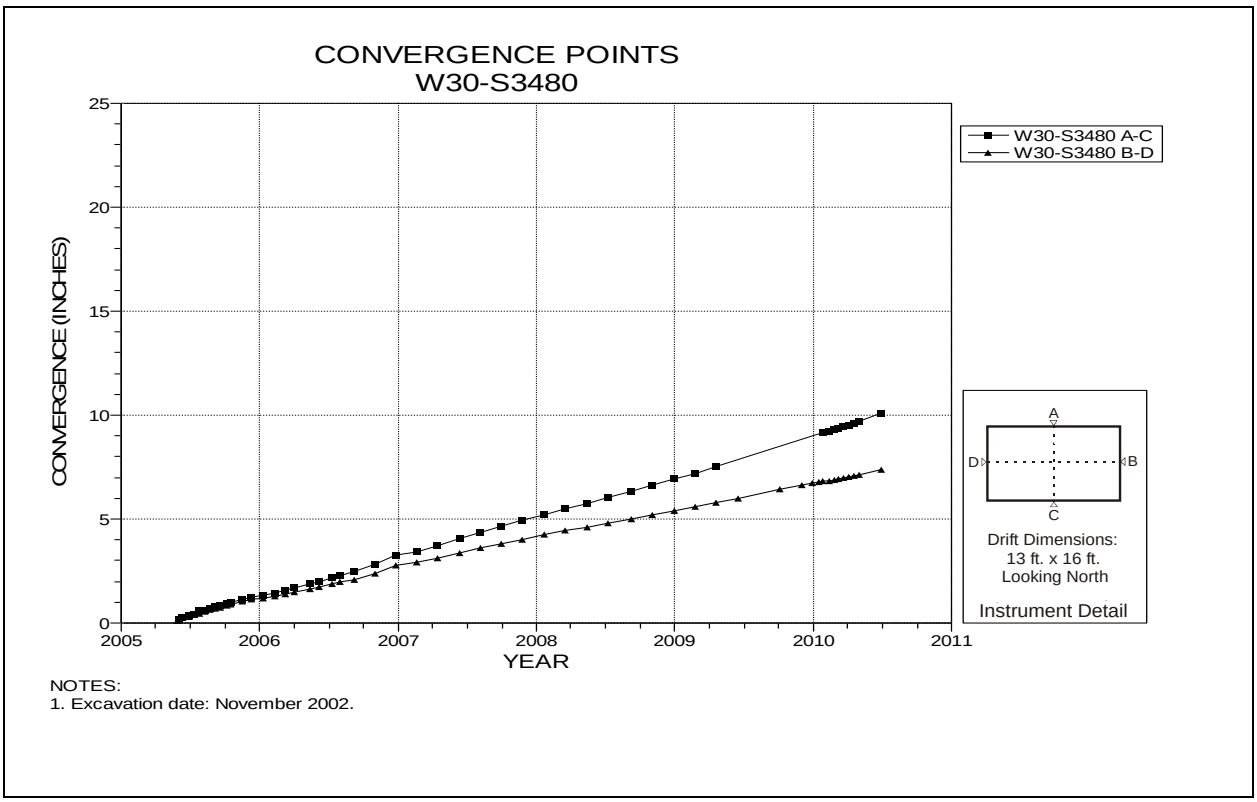


Figure 4-156 Convergence Point Array
W30 S3480 – All Chords

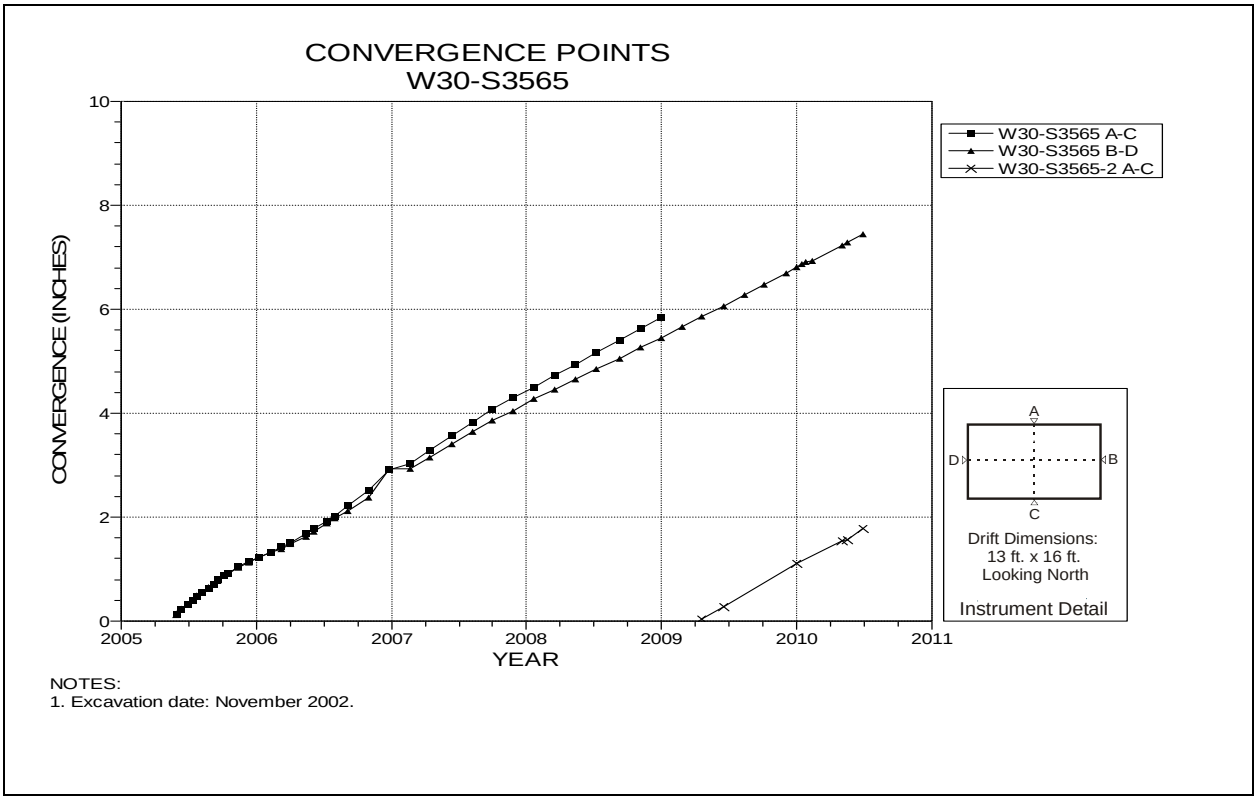


Figure 4-157 Convergence Point Array
W30 S3565 – All Chords

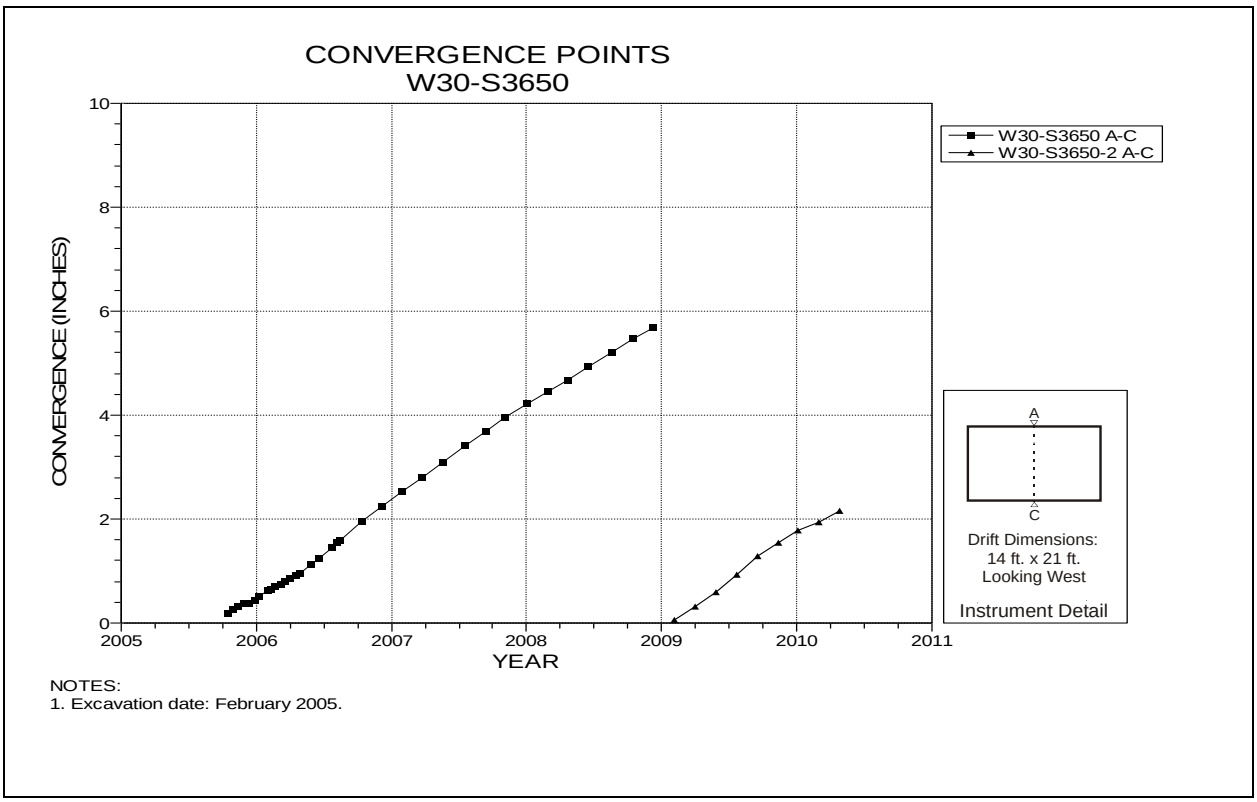


Figure 4-158 Convergence Point Array
W30 S3560 – Roof to Floor

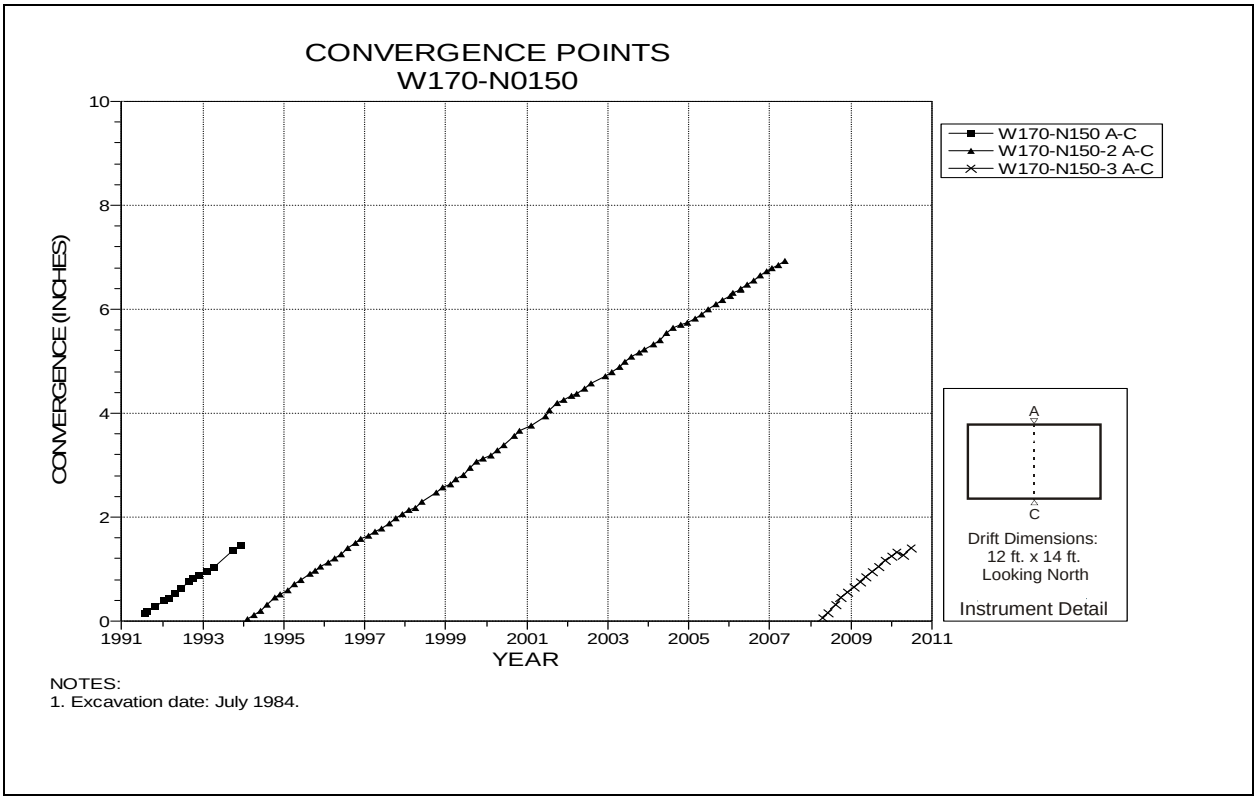


Figure 4-159 Convergence Point Array
W170 N150 – Roof to Floor

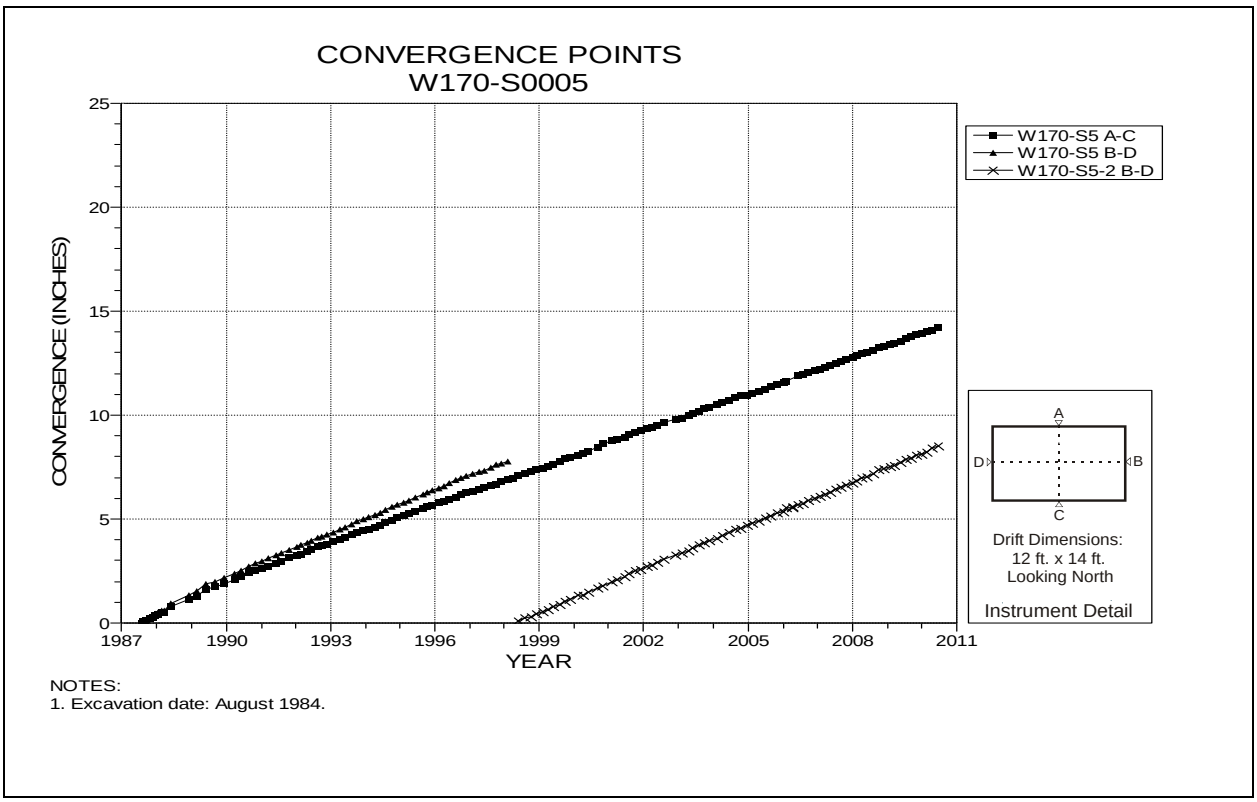


Figure 4-160 Convergence Point Array
W170 S5 – All Chords

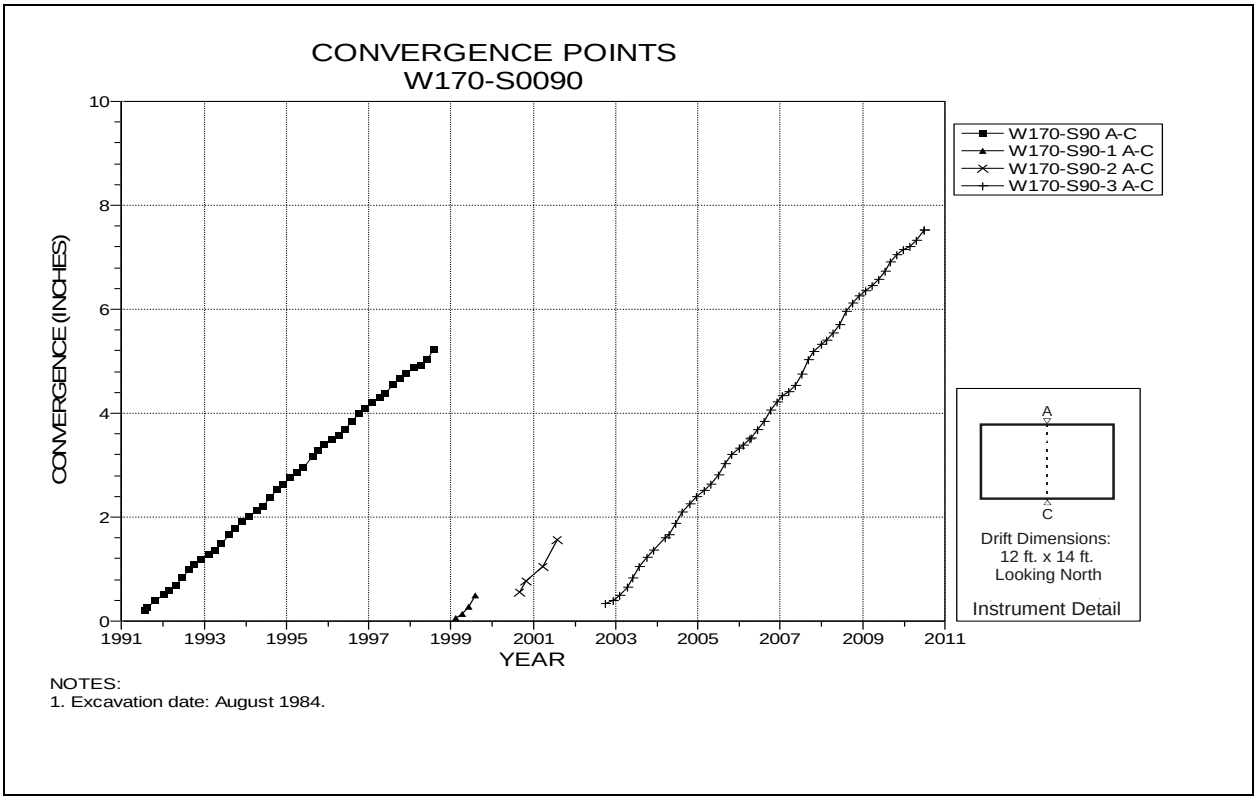


Figure 4-161 Convergence Point Array
W170 S90 – Roof to Floor

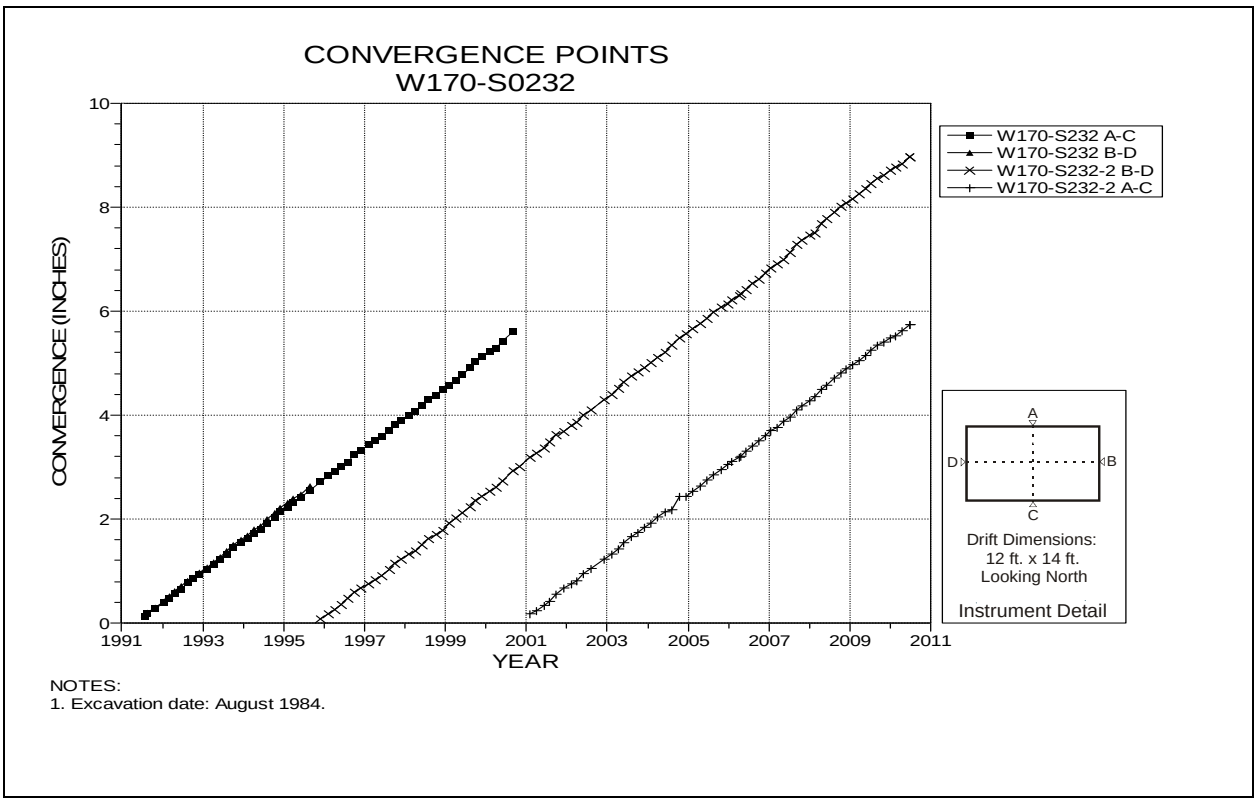


Figure 4-162 Convergence Point Array
W170 S232 – All Chords

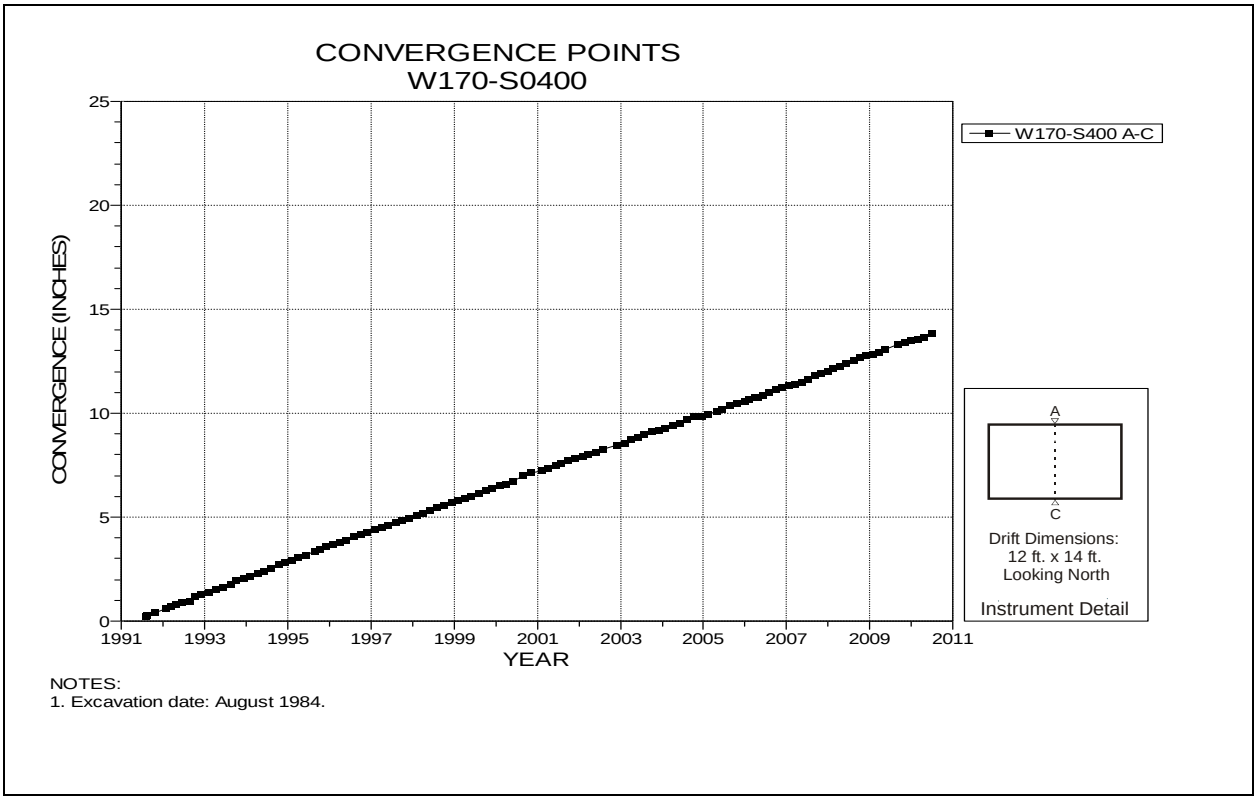


Figure 4-163 Convergence Point Array
W170 S400 – Roof to Floor

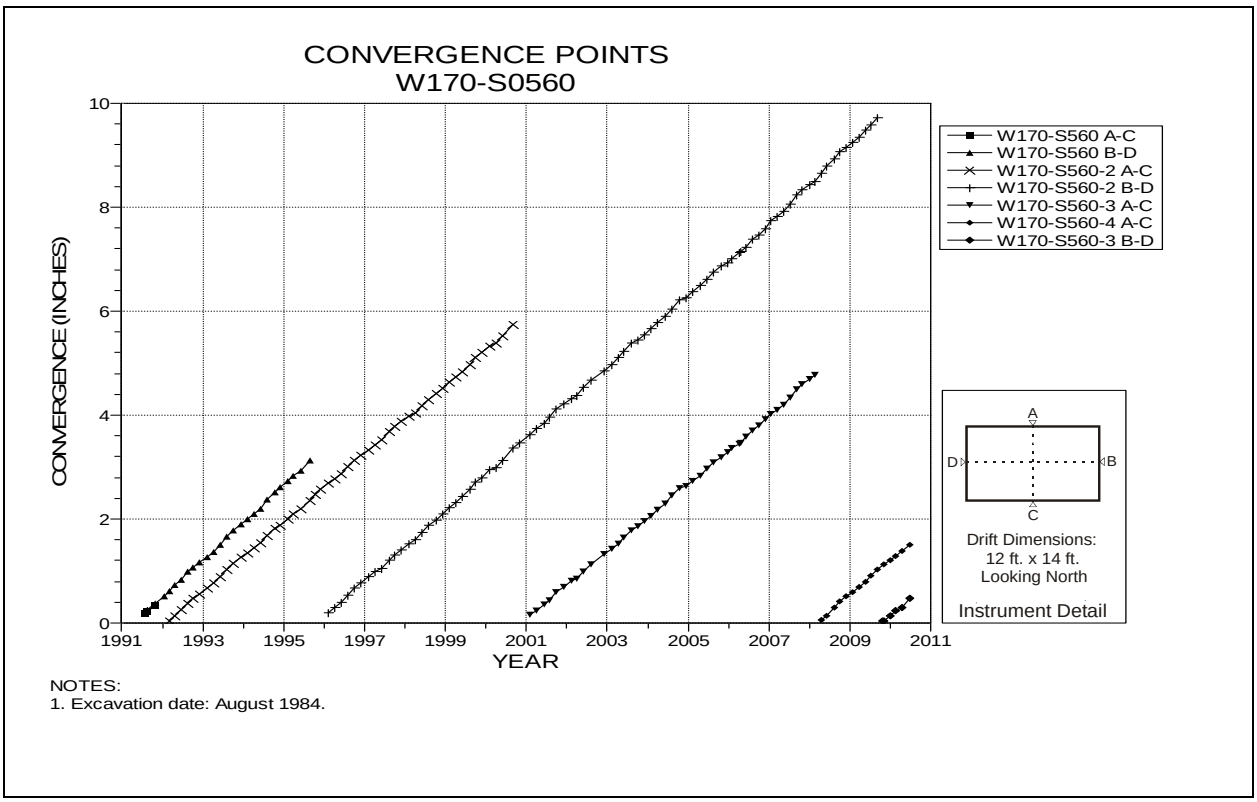


Figure 4-164 Convergence Point Array
W170 S560 – All Chords

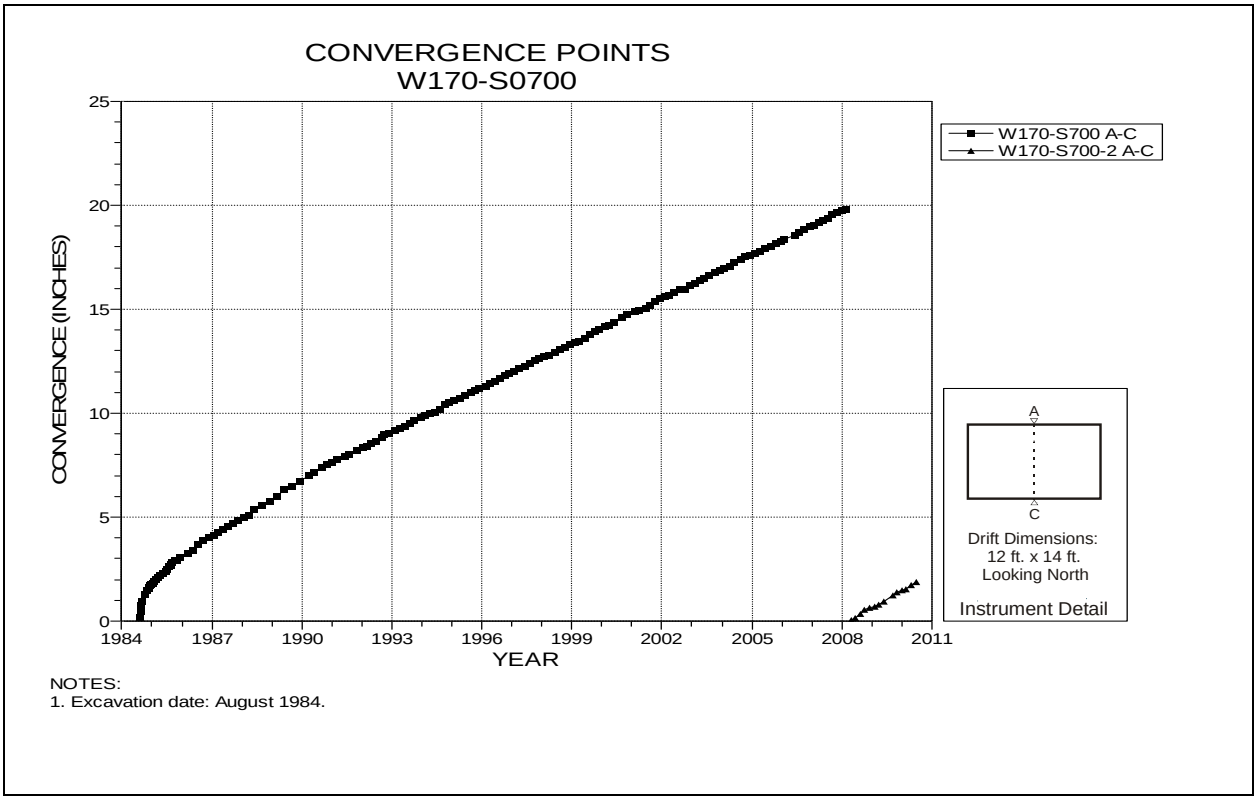


Figure 4-165 Convergence Point Array
W170 S700 – Roof to Floor

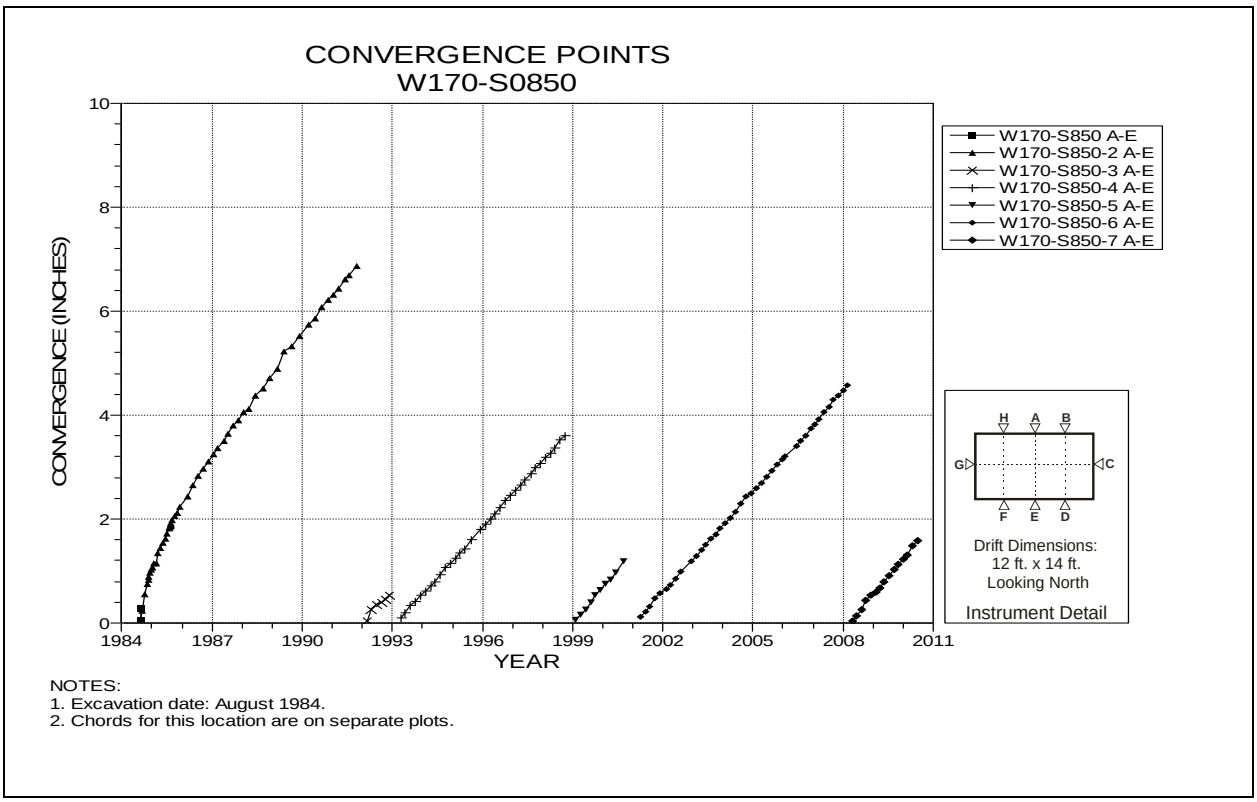


Figure 4-166 Convergence Point Array
W170 S850 – Roof to Floor – Centerline

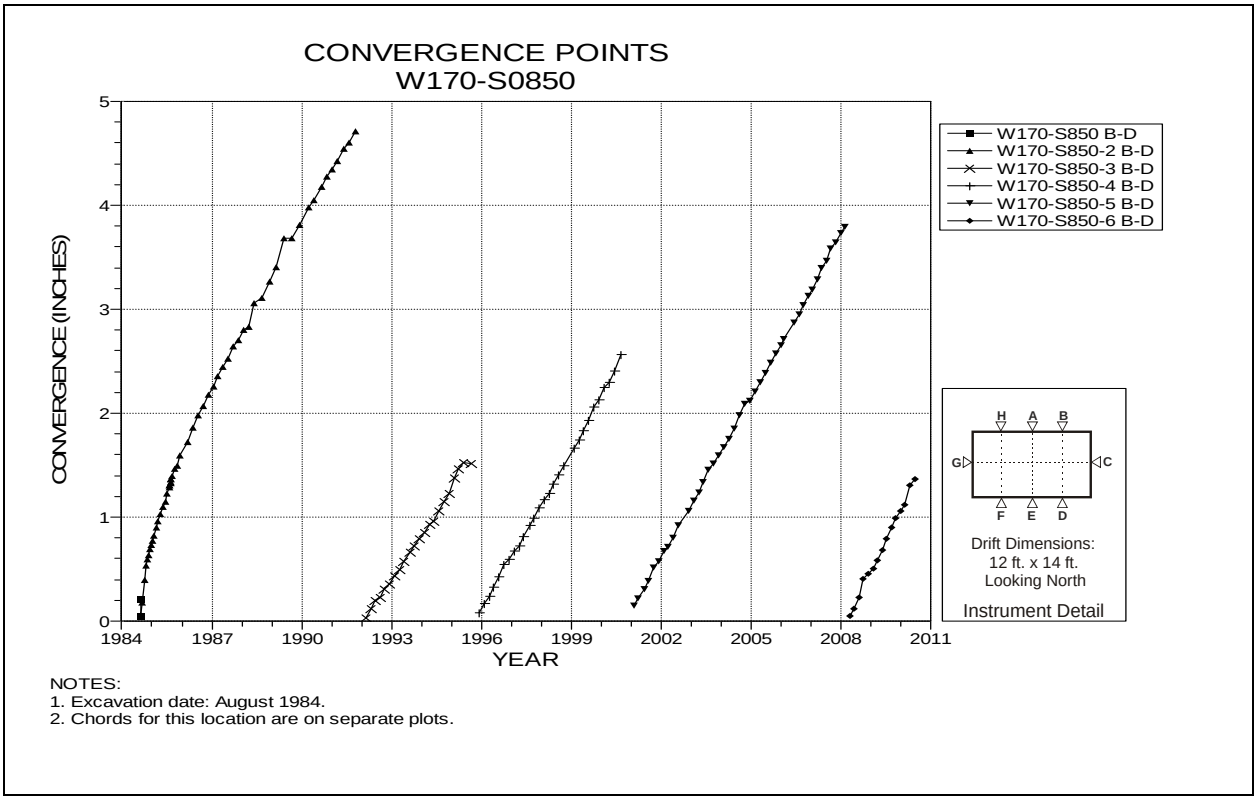


Figure 4-167 Convergence Point Array
W170 S850 – Roof to Floor – Quarterpoint

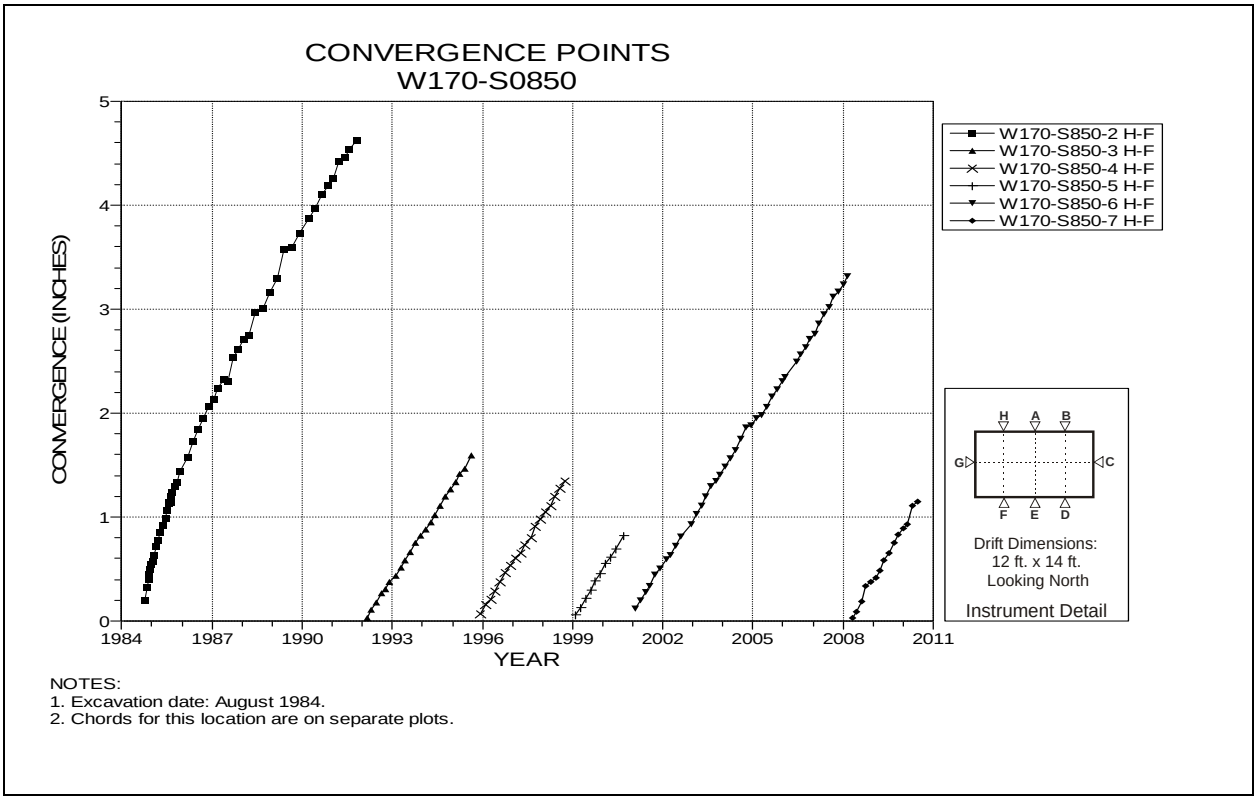


Figure 4-168 Convergence Point Array
W170 S850 – Roof to Floor - Quarterpoint

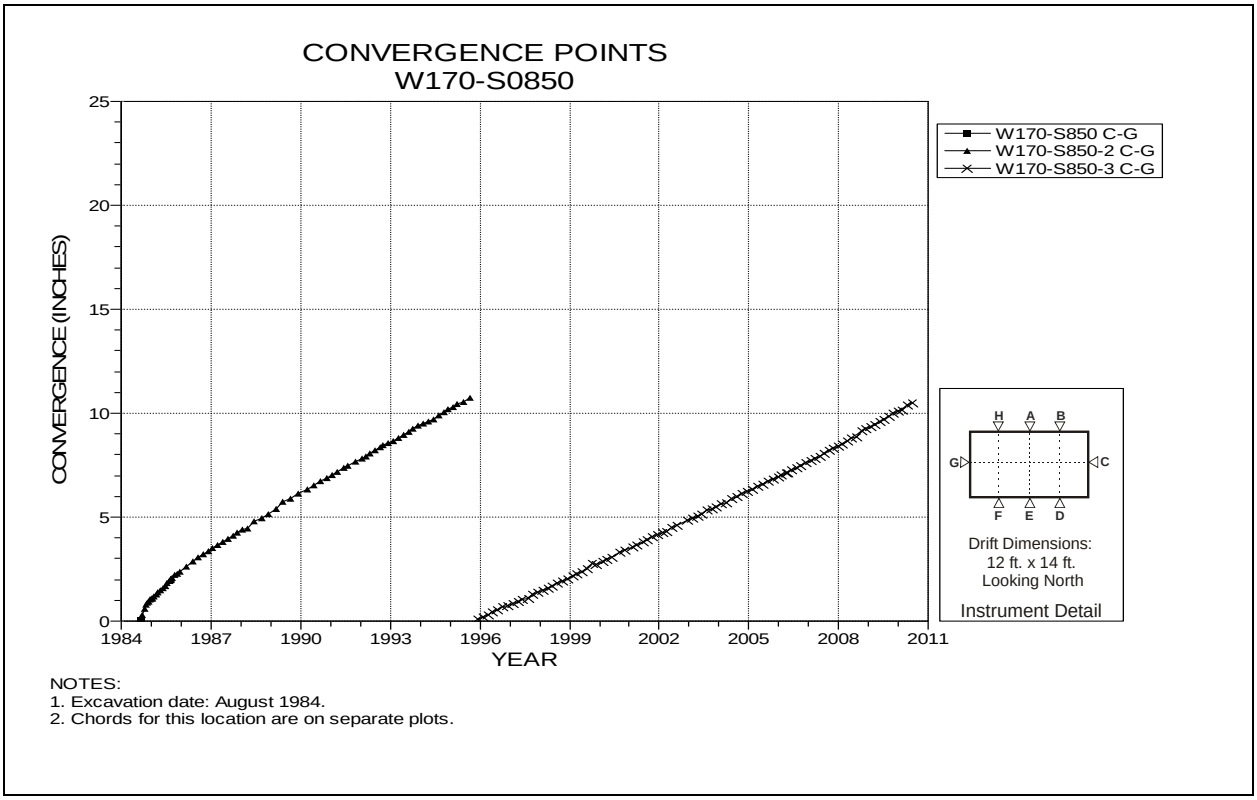


Figure 4-169 Convergence Point Array
W170 S850 – Rib to Rib

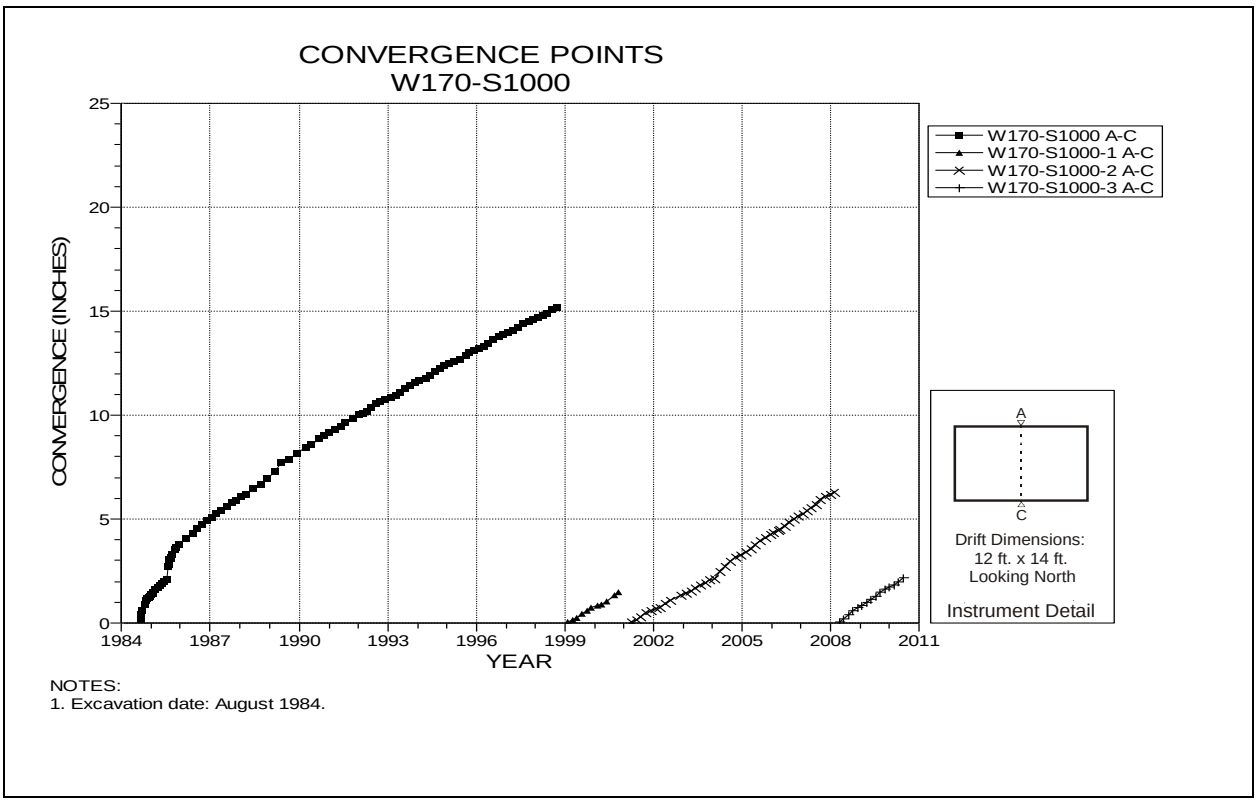


Figure 4-170 Convergence Point Array
W170 S1000 – Roof to Floor

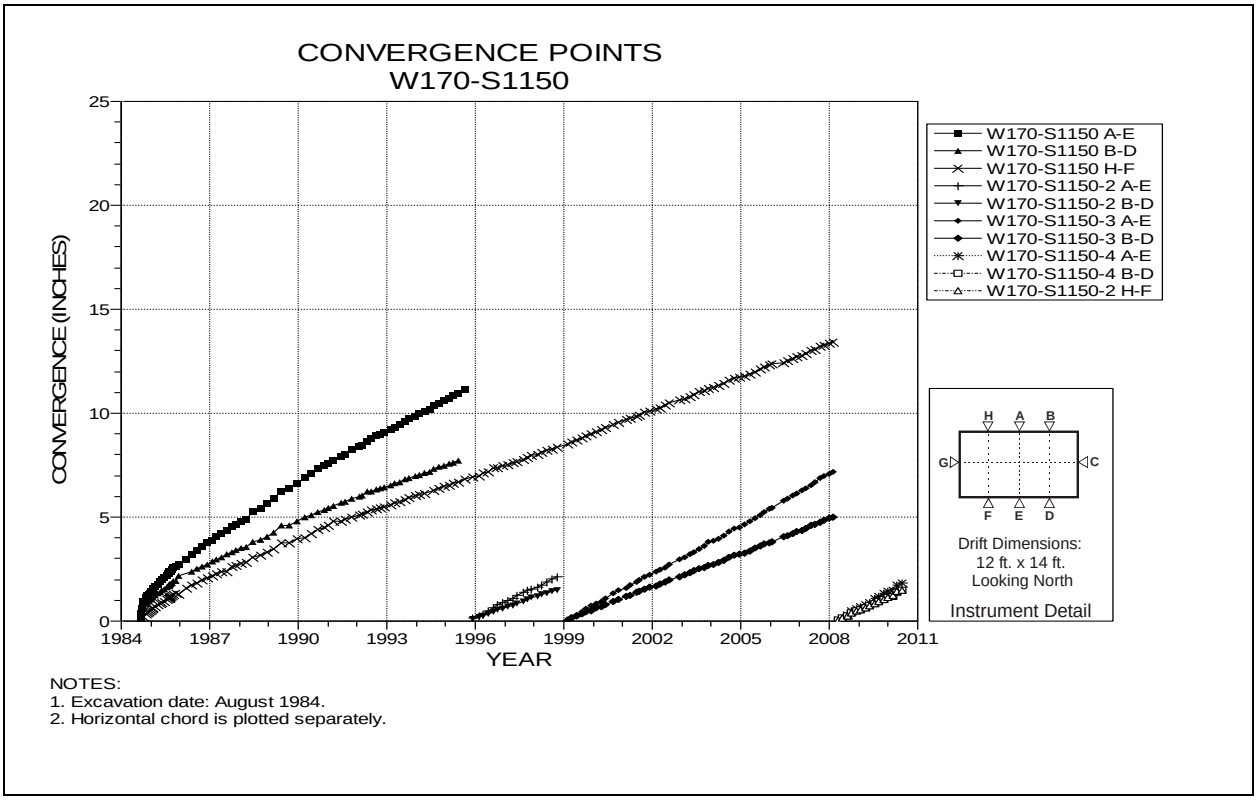


Figure 4-171 Convergence Point Array
W170 S1150 – Roof to Floor – Quarter Points

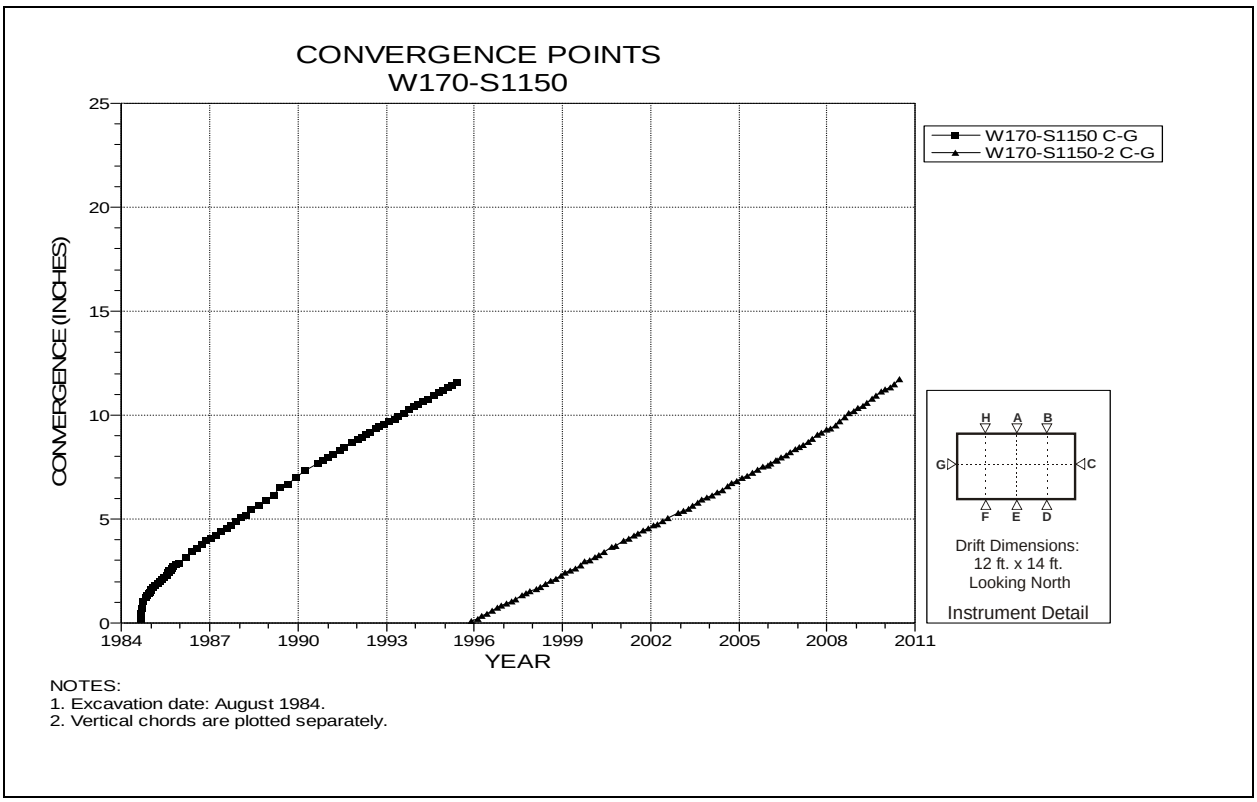


Figure 4-172 Convergence Point Array
W170 S1150 – Rib to Rib

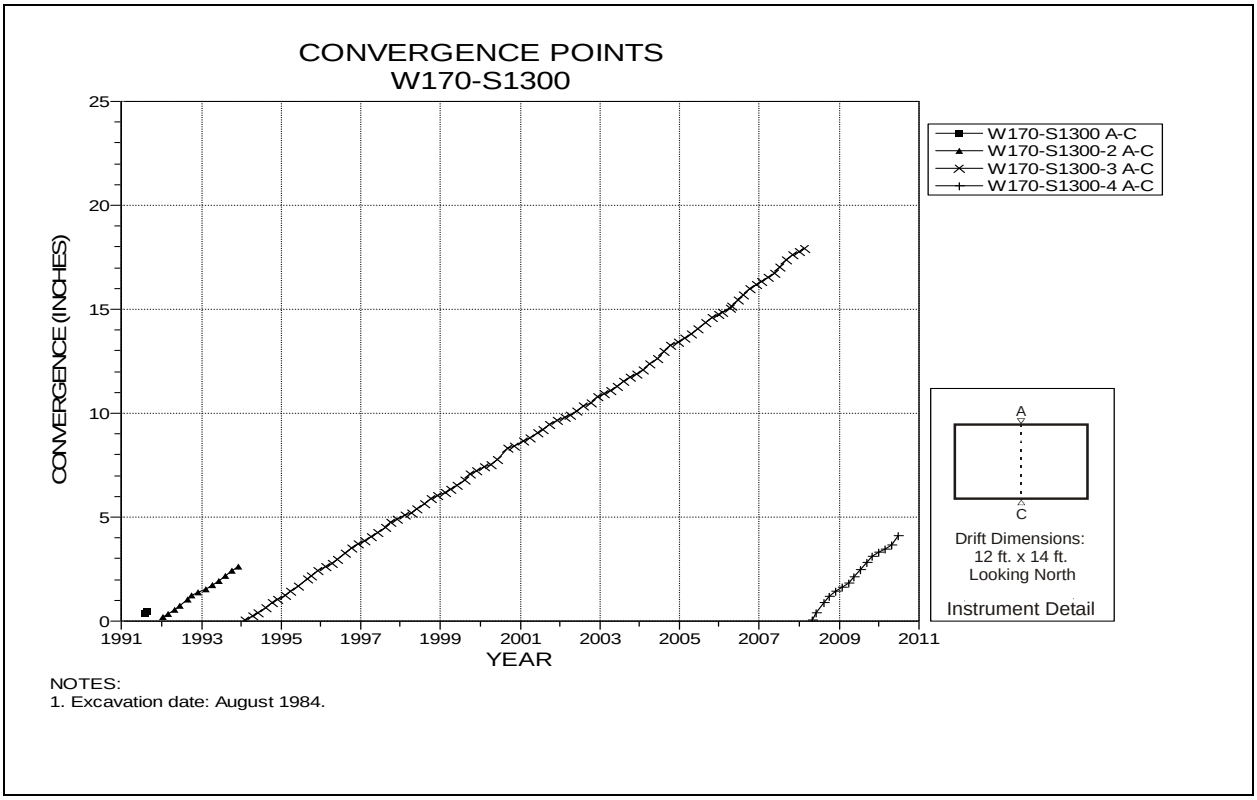


Figure 4-173 Convergence Point Array
W170 S1300 – Roof to Floor

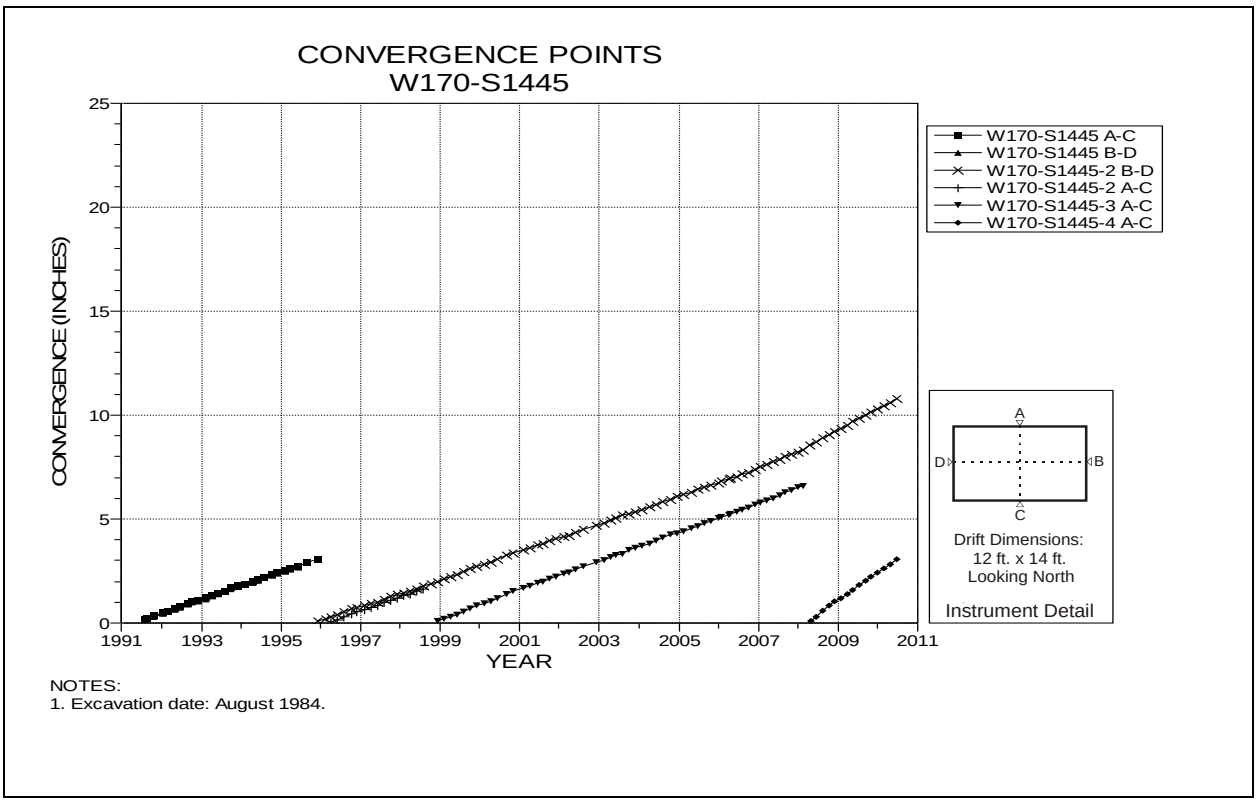


Figure 4-174 Convergence Point Array
W170 S1445 – All Chords

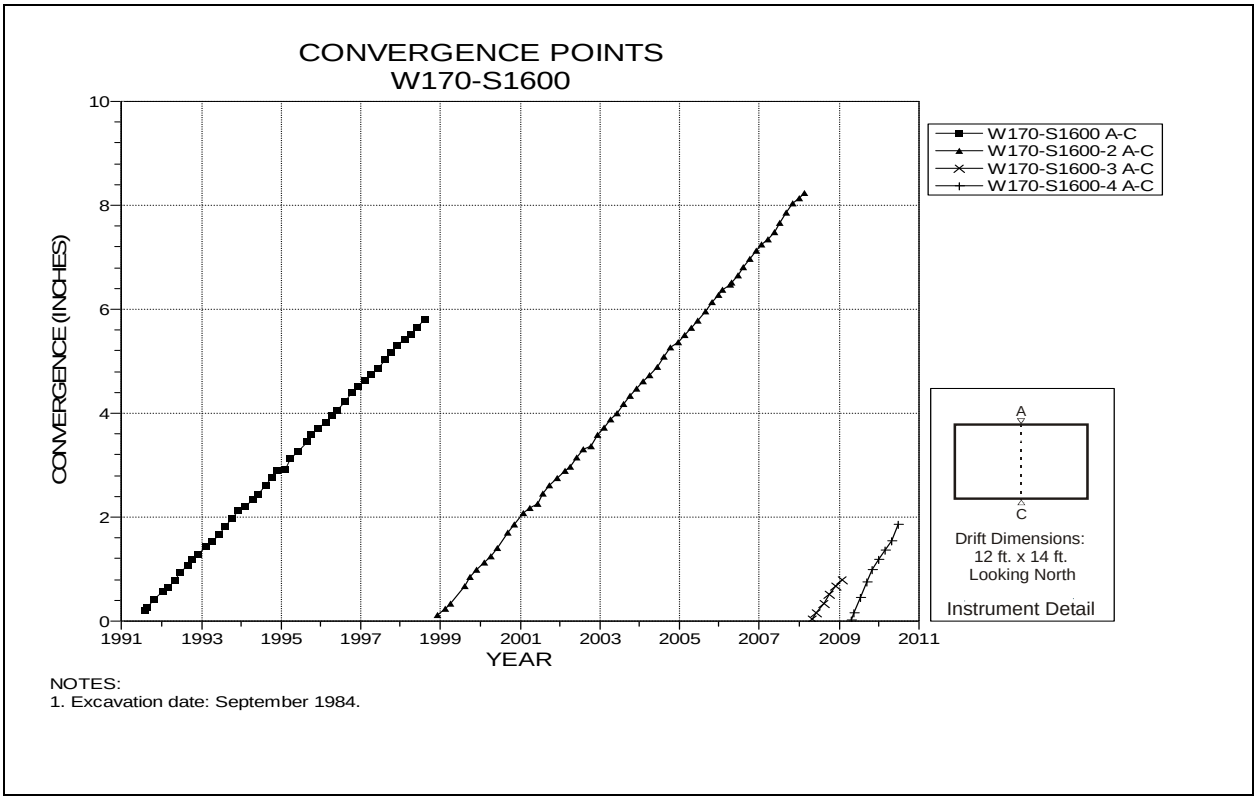


Figure 4-175 Convergence Point Array
W170 S1600 – Roof to Floor

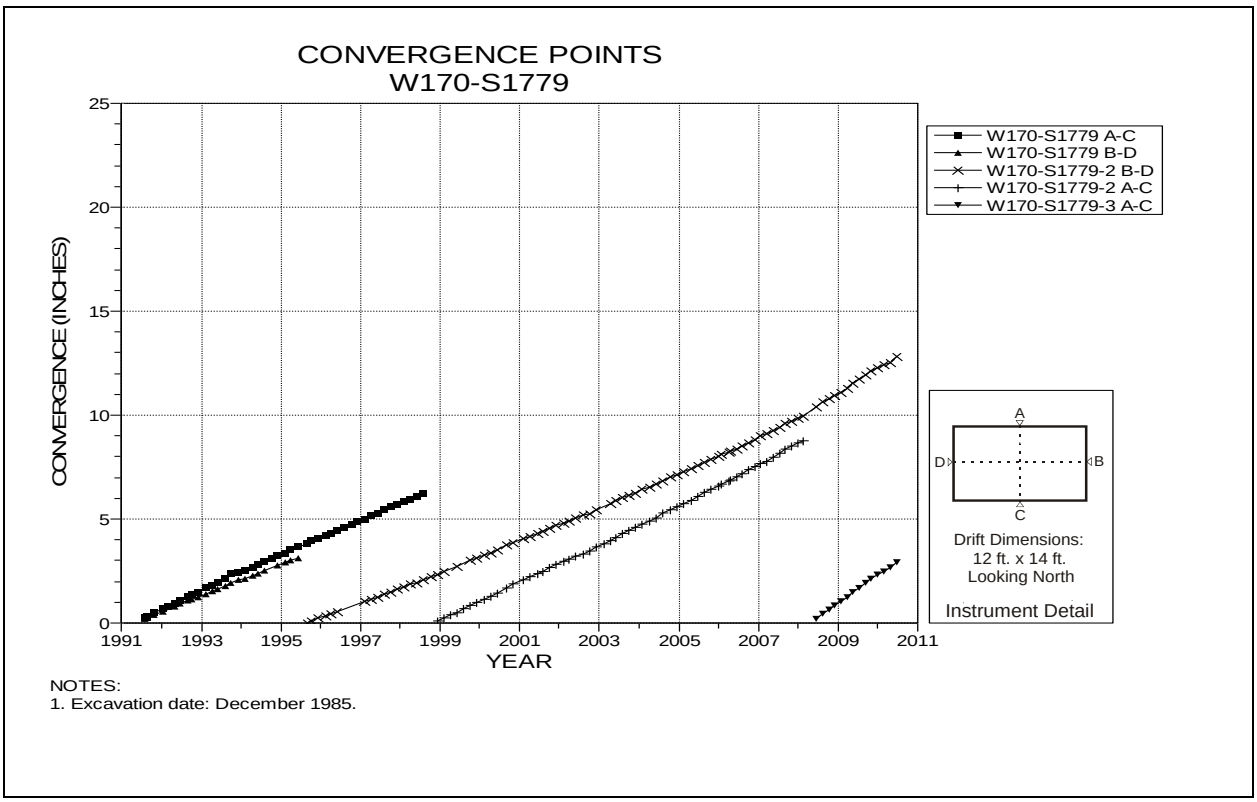


Figure 4-176 Convergence Point Array
W170 S1779 – All Chords

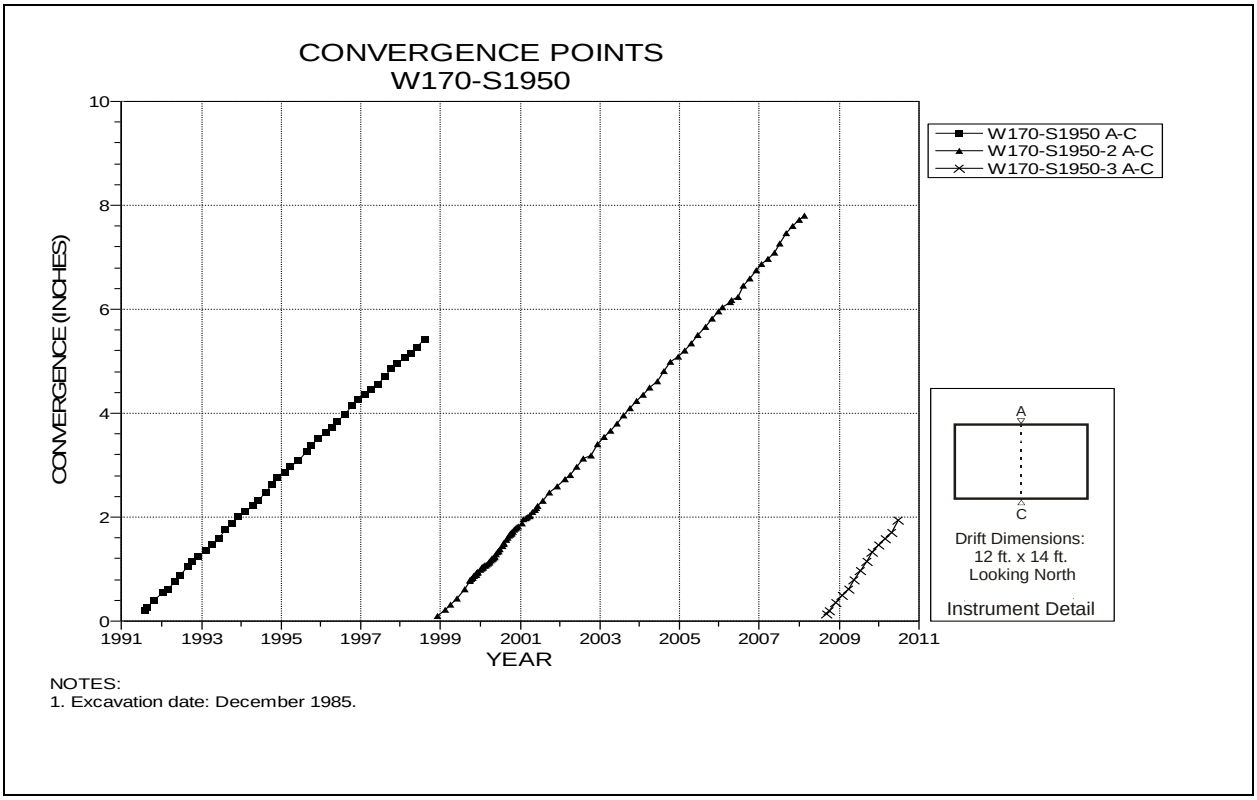


Figure 4-177 Convergence Point Array
W170 S1950 – Roof to Floor

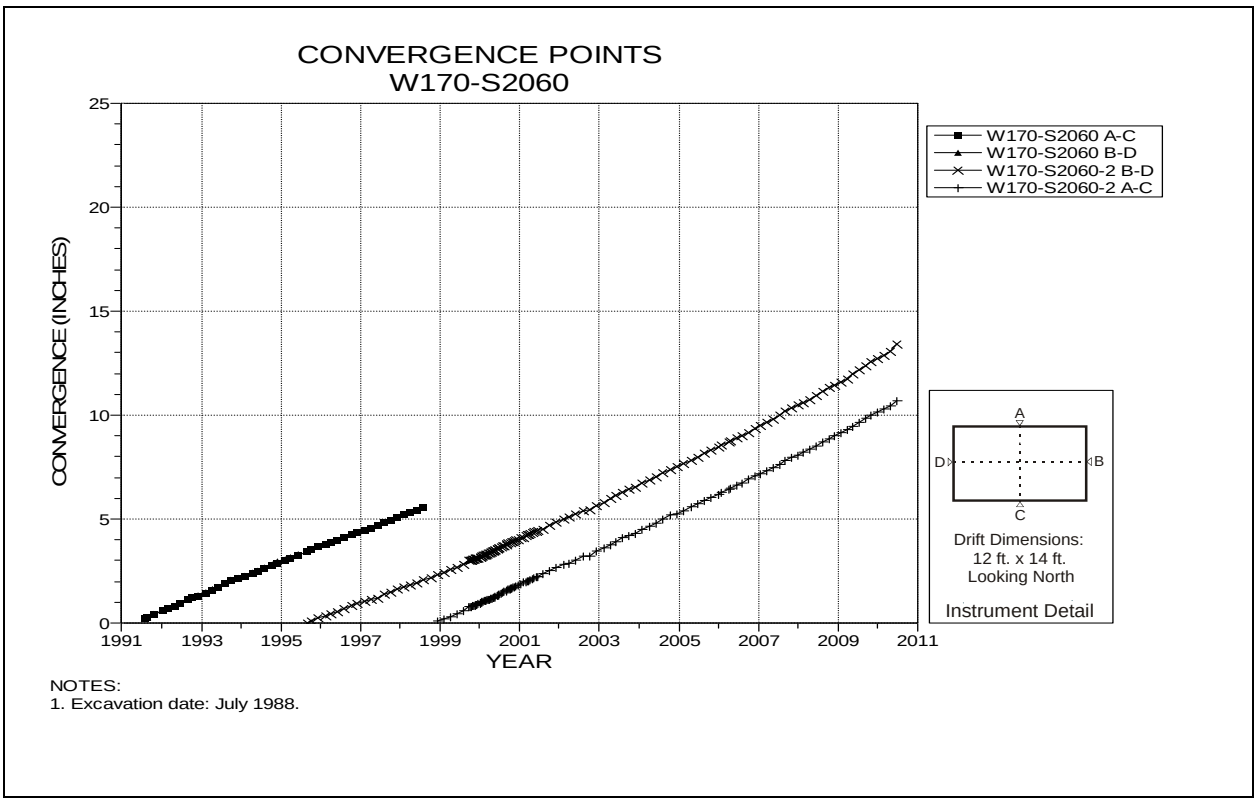


Figure 4-178 Convergence Point Array
W170 S2060 – All Chords

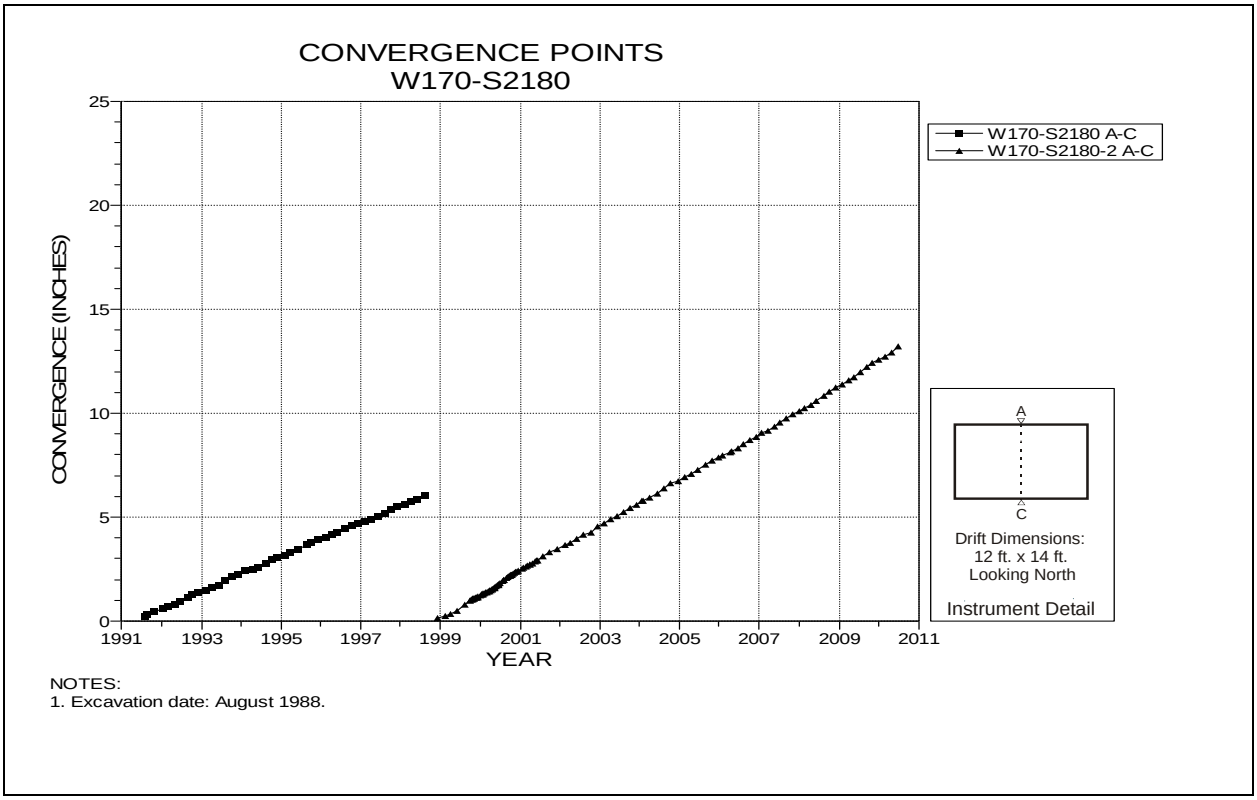


Figure 4-179 Convergence Point Array
W170 S2180 – Roof to Floor

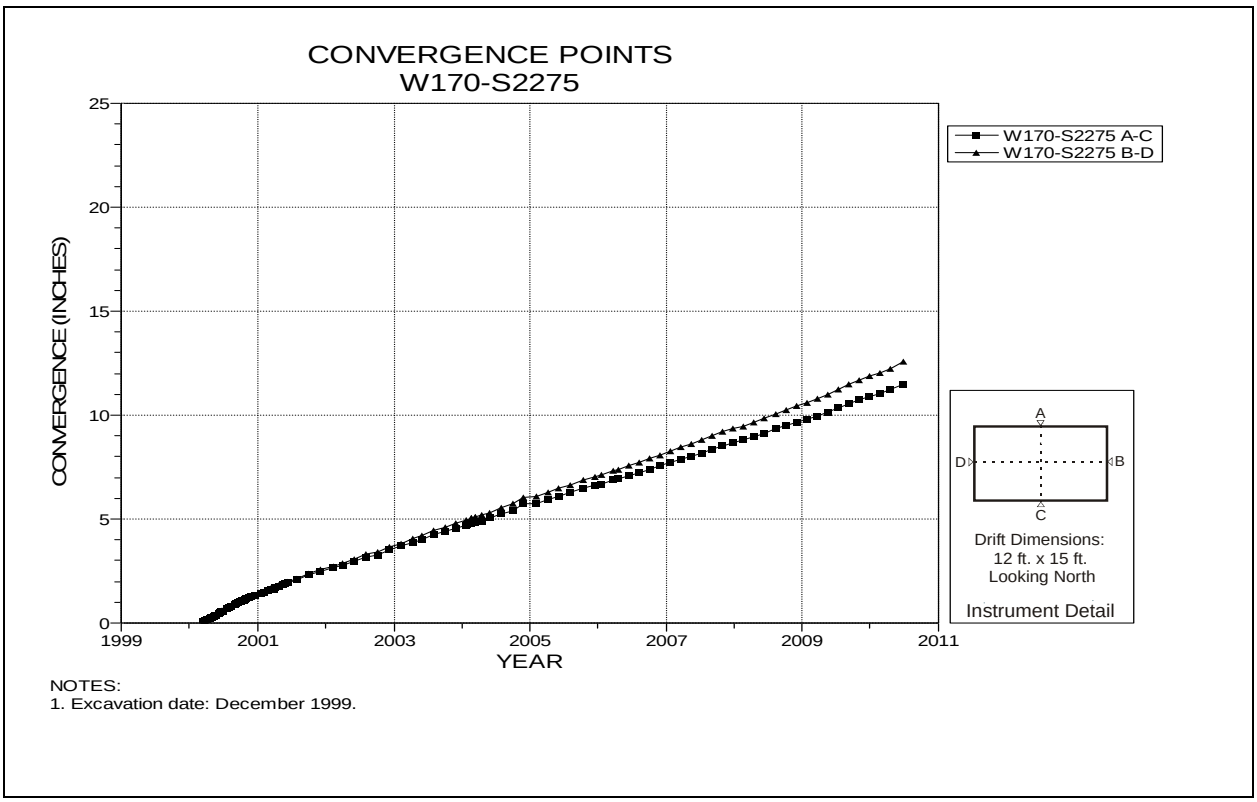


Figure 4-180 Convergence Point Array
W170 S2275 – All Chords

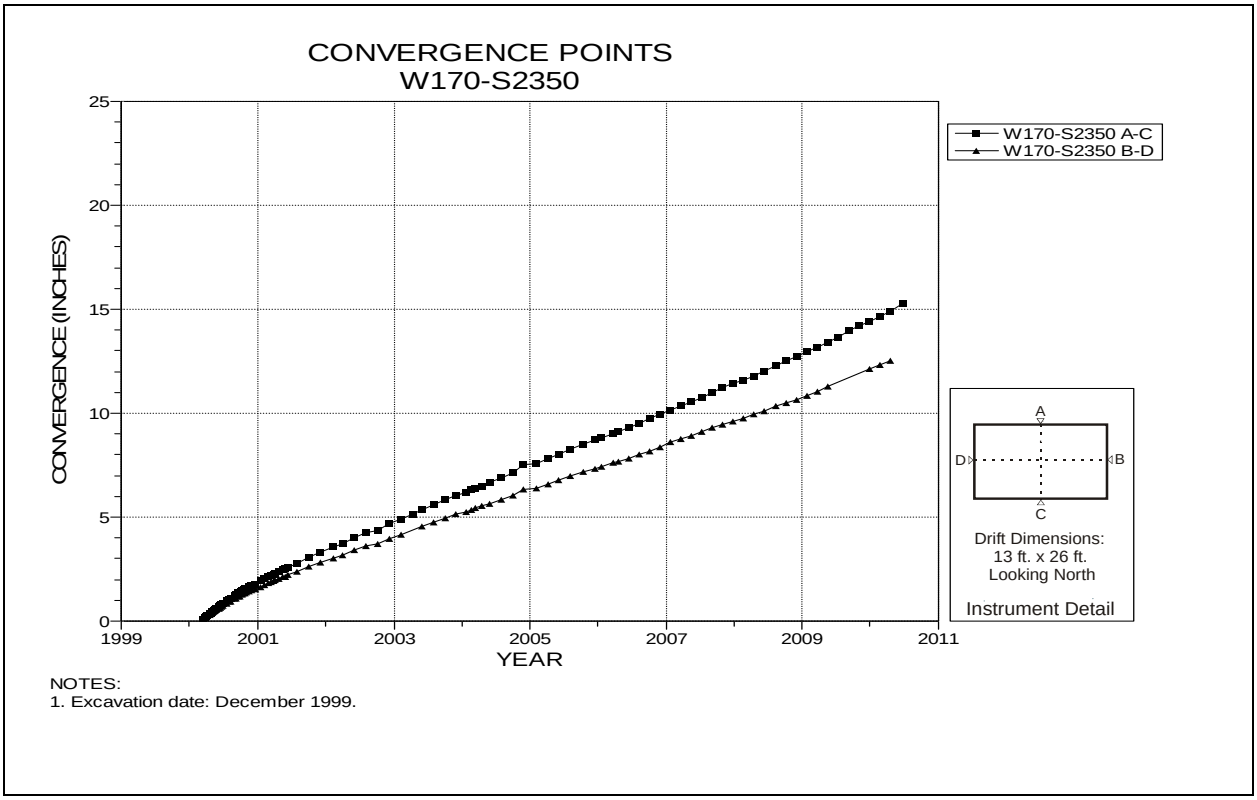


Figure 4-181 Convergence Point Array
W170 S2350 – All Chords

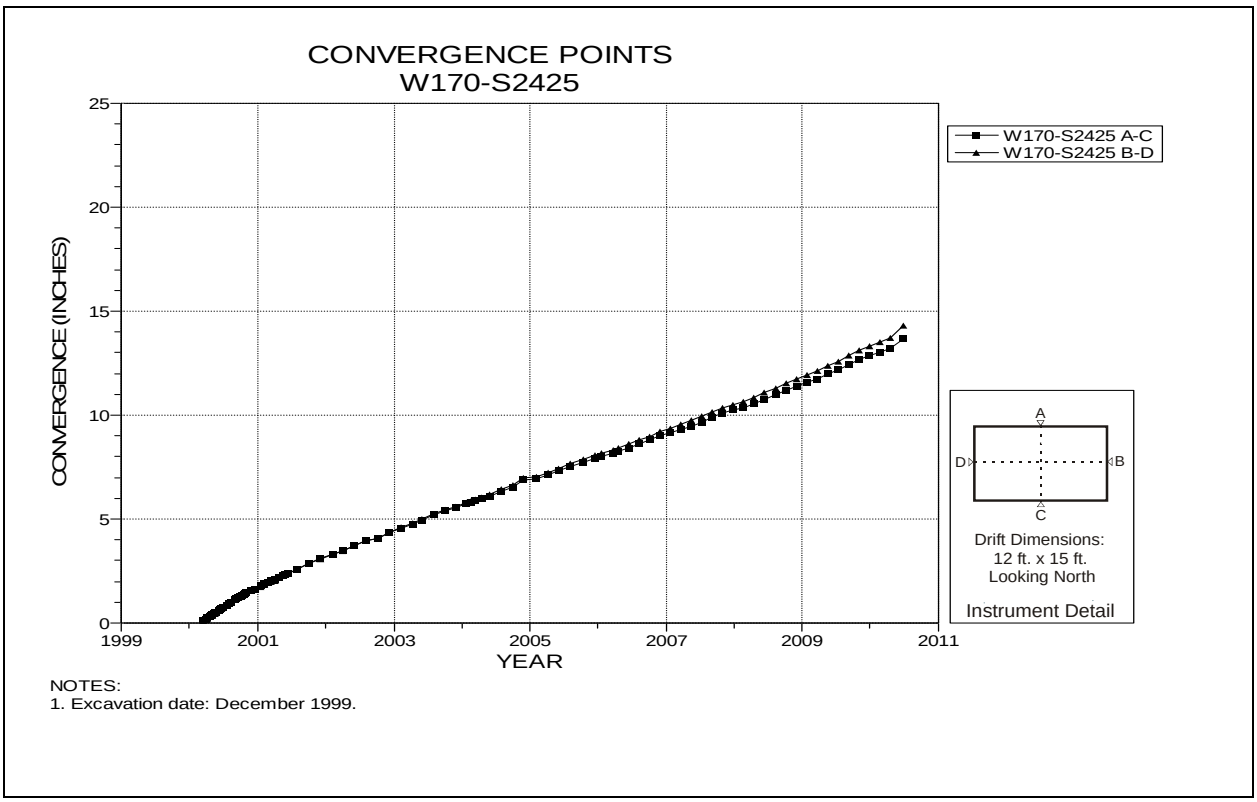


Figure 4-182 Convergence Point Array
W170 S2425 – All Chords

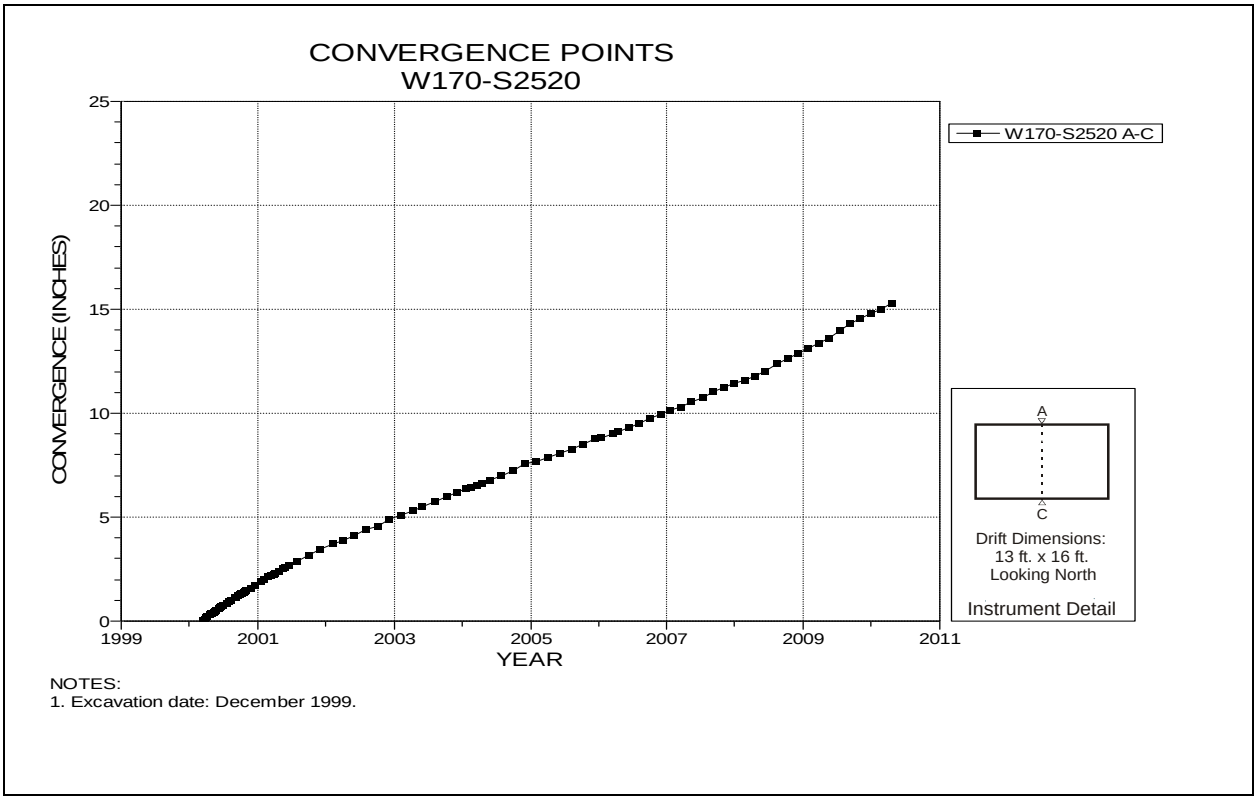


Figure 4-183 Convergence Point Array
W170 S2520 – Roof to Floor

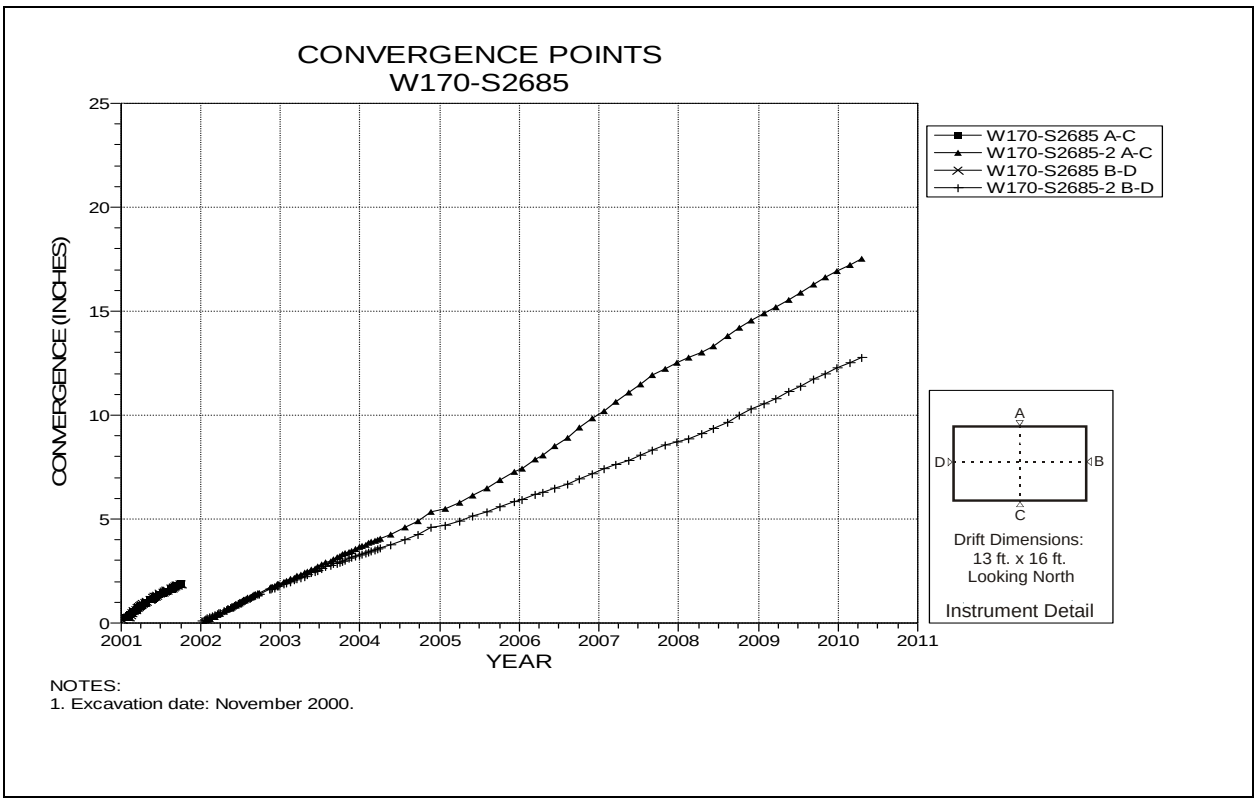


Figure 4-184 Convergence Point Array
W170 S2685 – All Chords

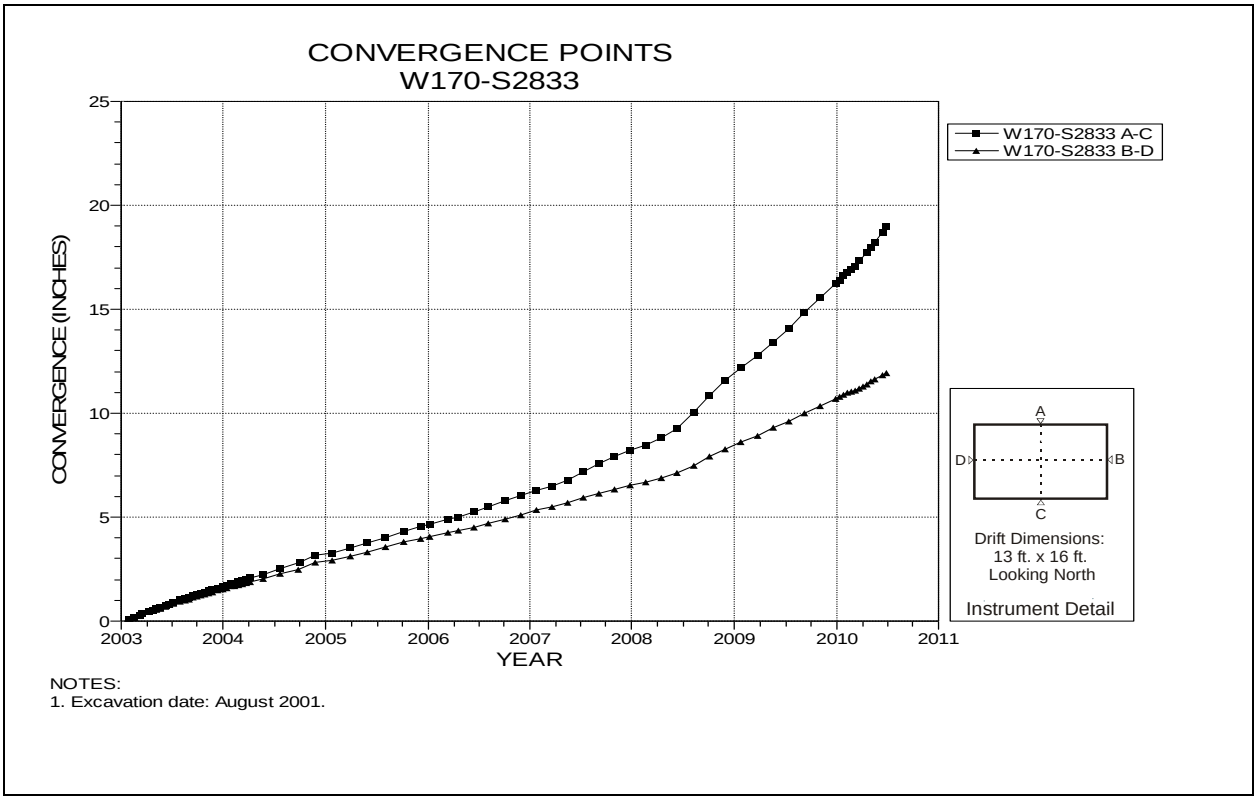


Figure 4-185 Convergence Point Array
W170 S2833 – All Chords

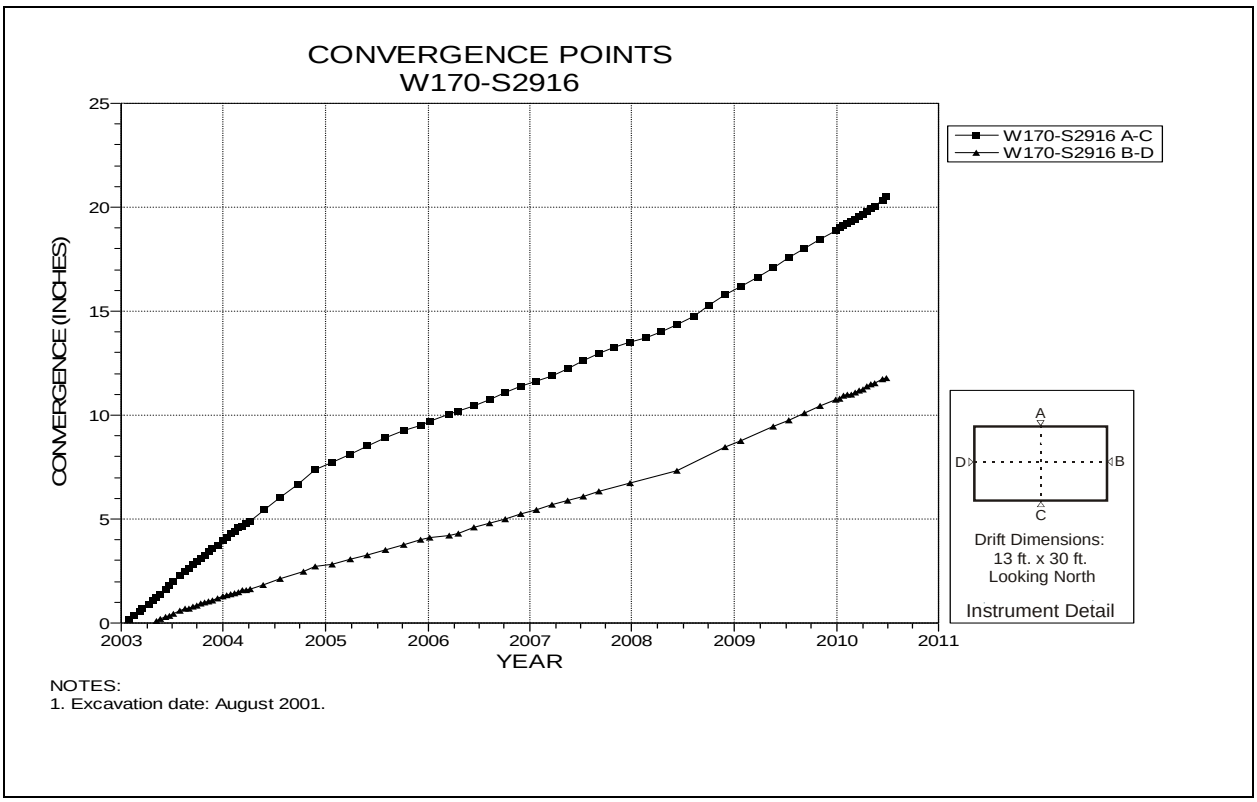


Figure 4-186 Convergence Point Array
W170 S2916 – All Chords

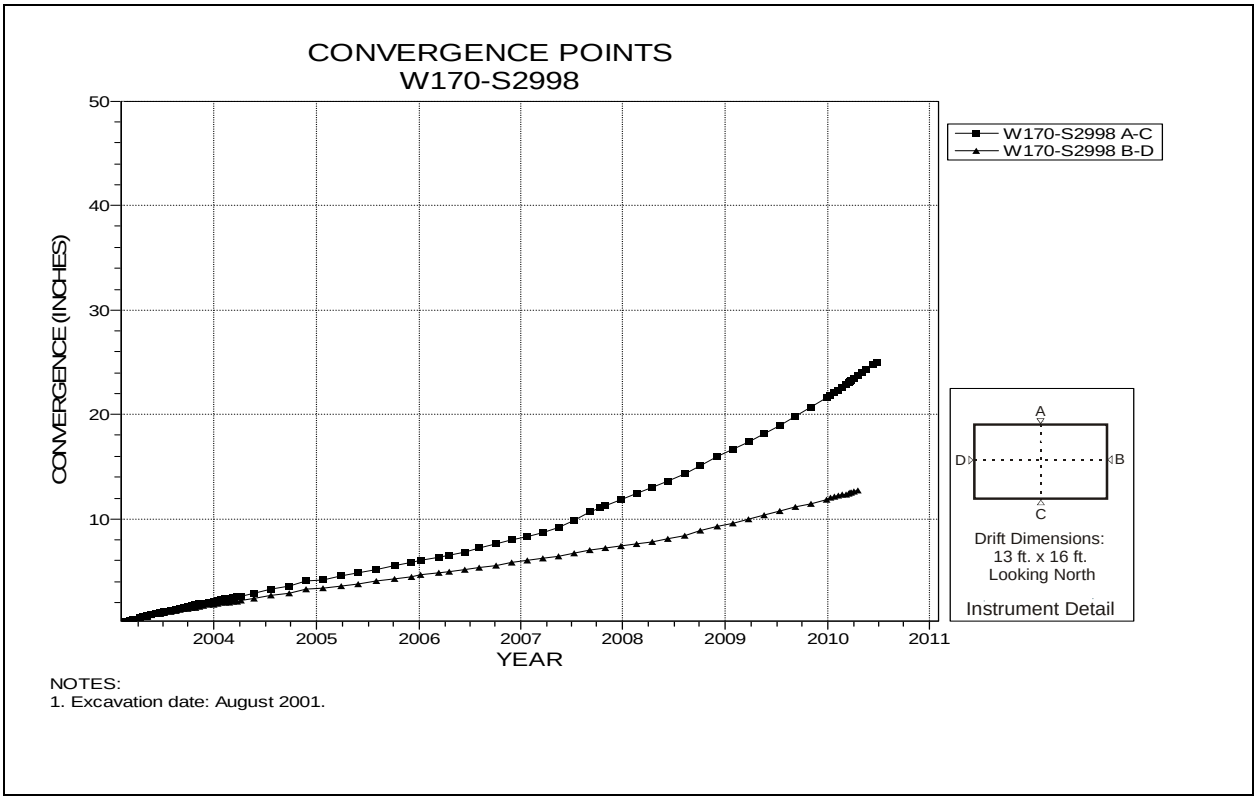


Figure 4-187 Convergence Point Array
W170 S2998 – All Chords

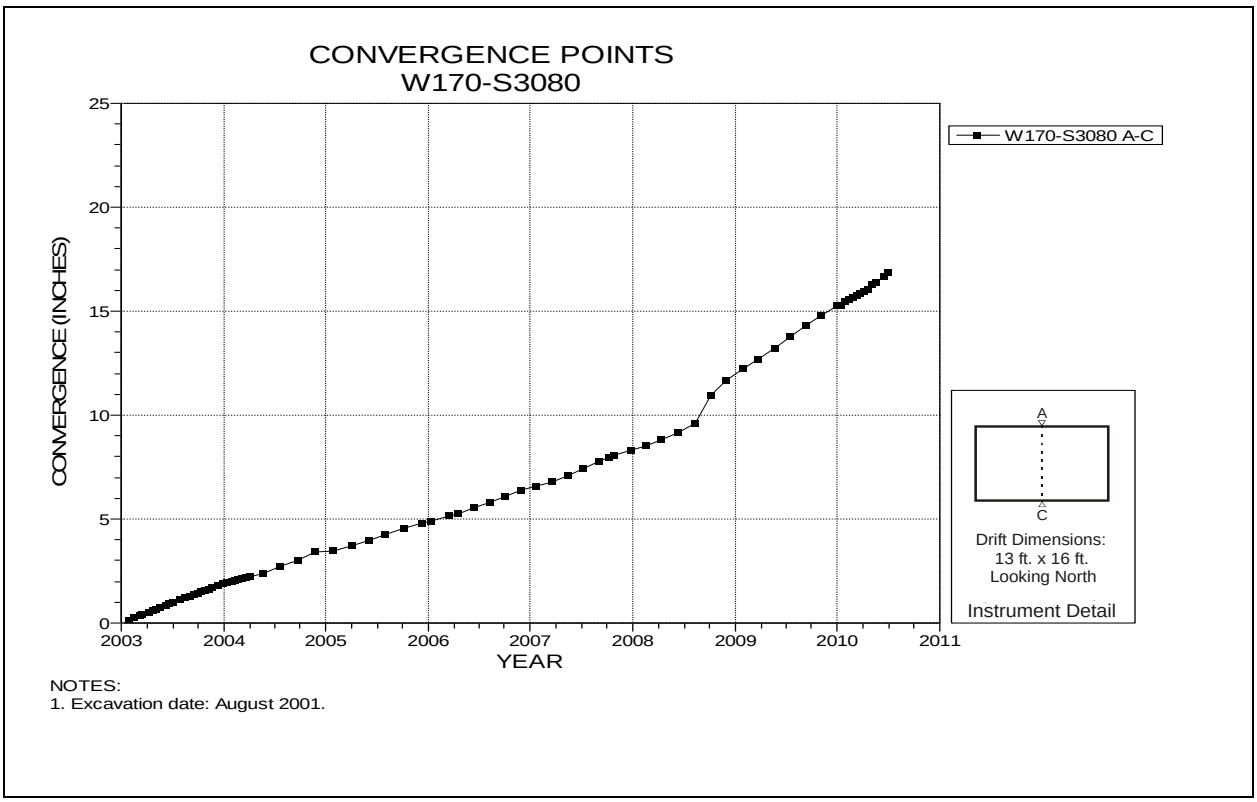


Figure 4-188 Convergence Point Array
W170 S3080 – Roof to Floor

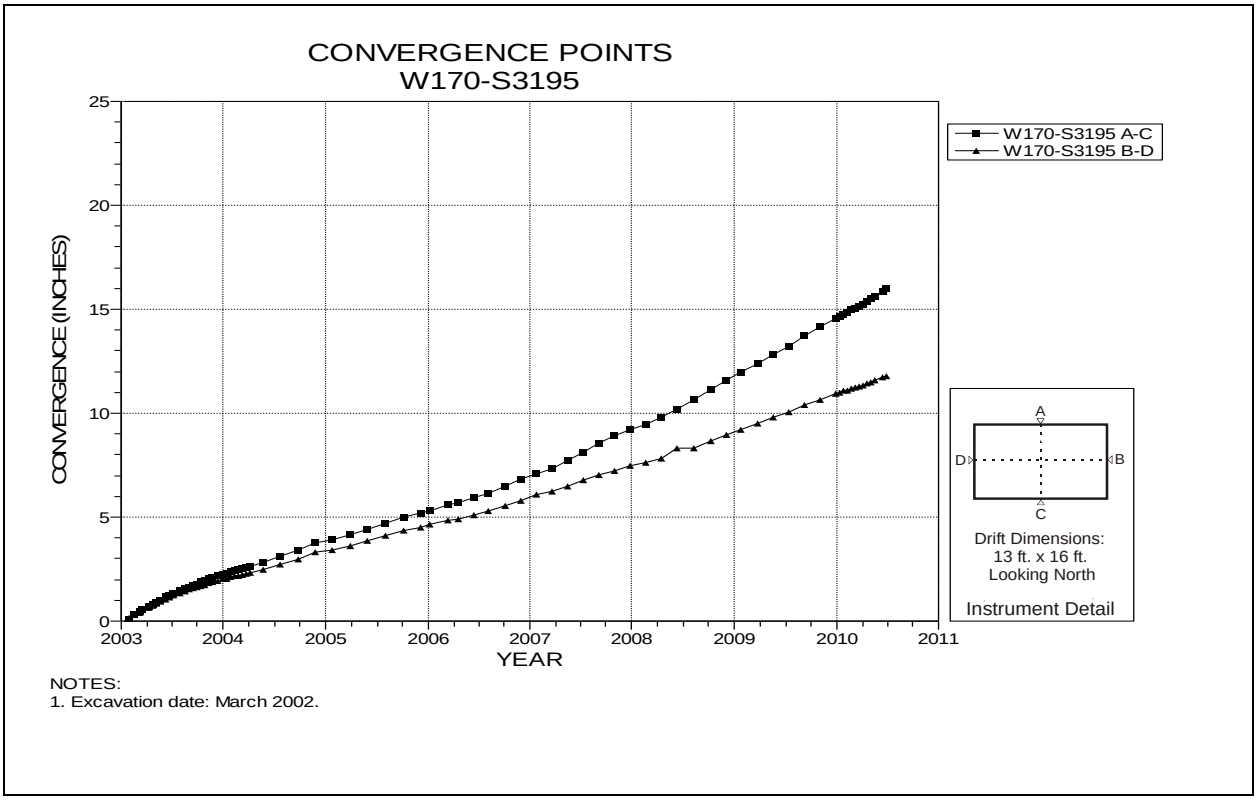


Figure 4-189 Convergence Point Array
W170 S3195 – All Chords

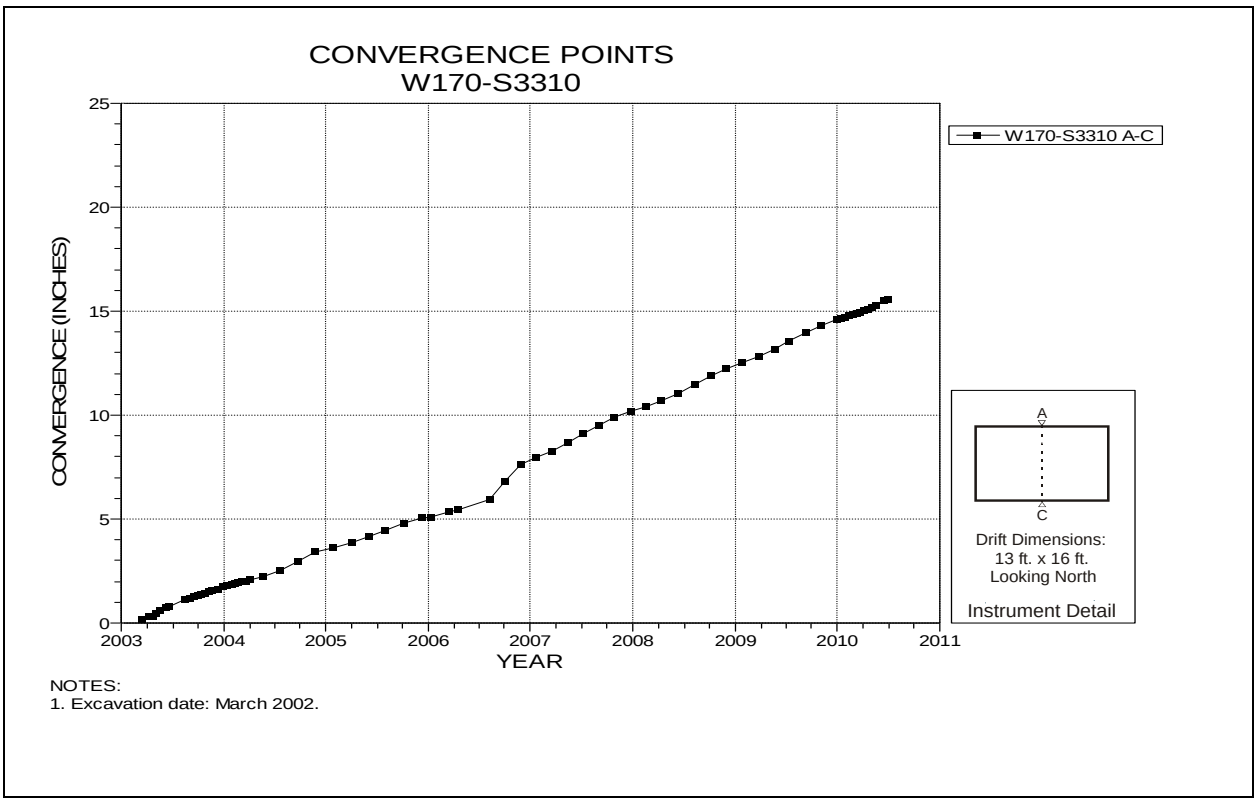


Figure 4-190 Convergence Point Array
W170 S3310 – Roof to Floor

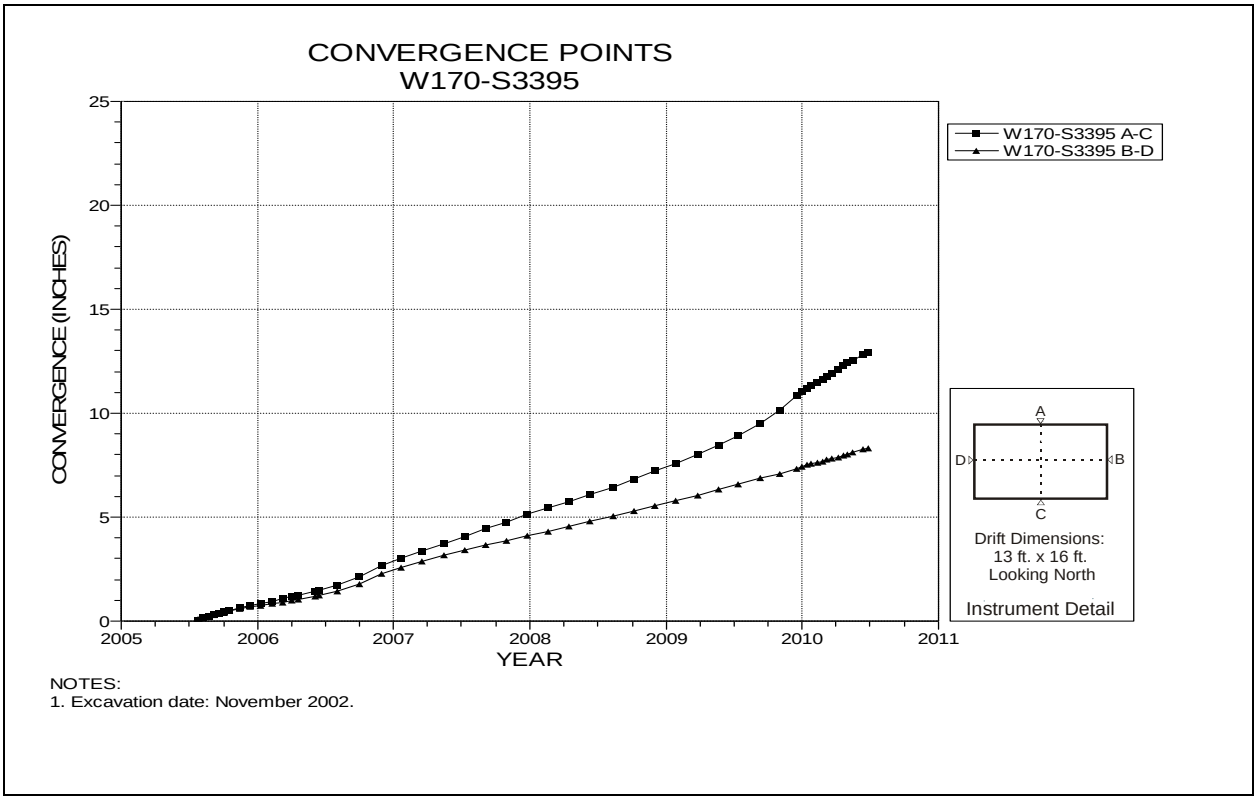


Figure 4-191 Convergence Point Array
W170 S3395 – All Chords

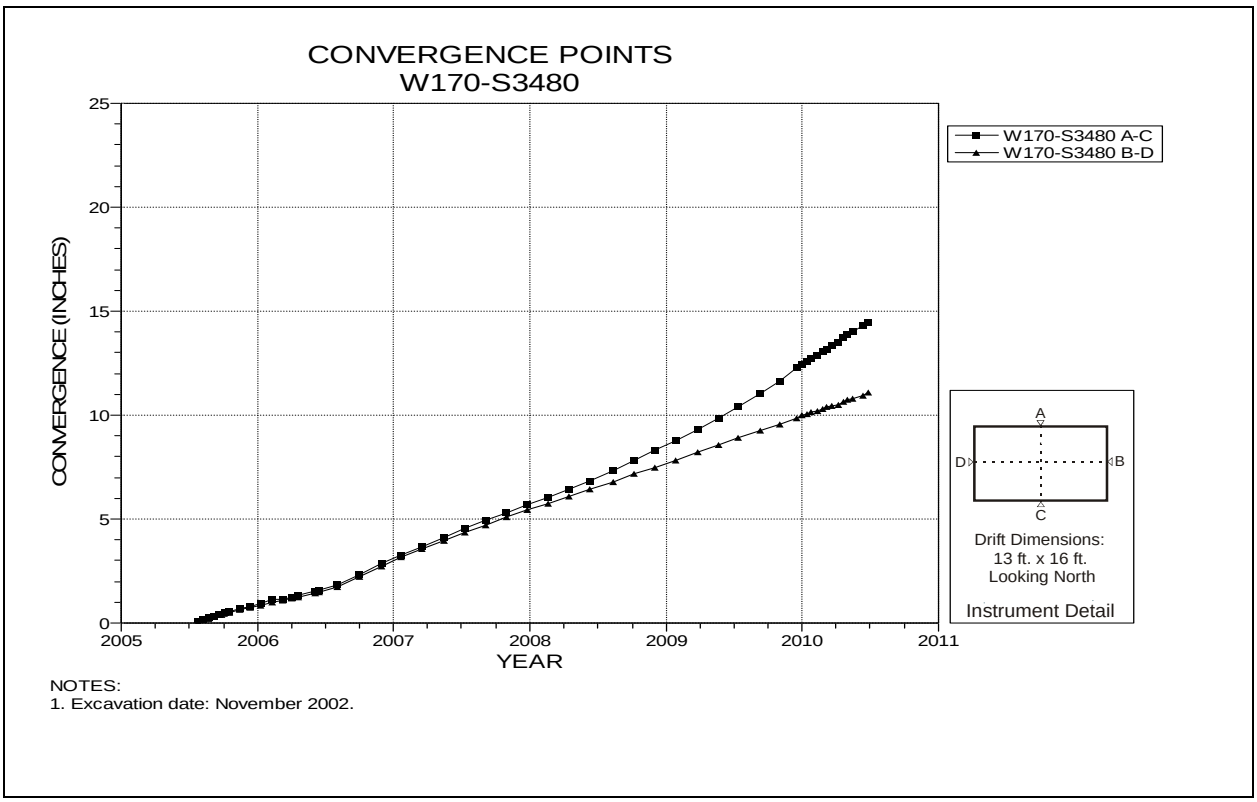


Figure 4-192 Convergence Point Array
W170 S3480 – All Chords

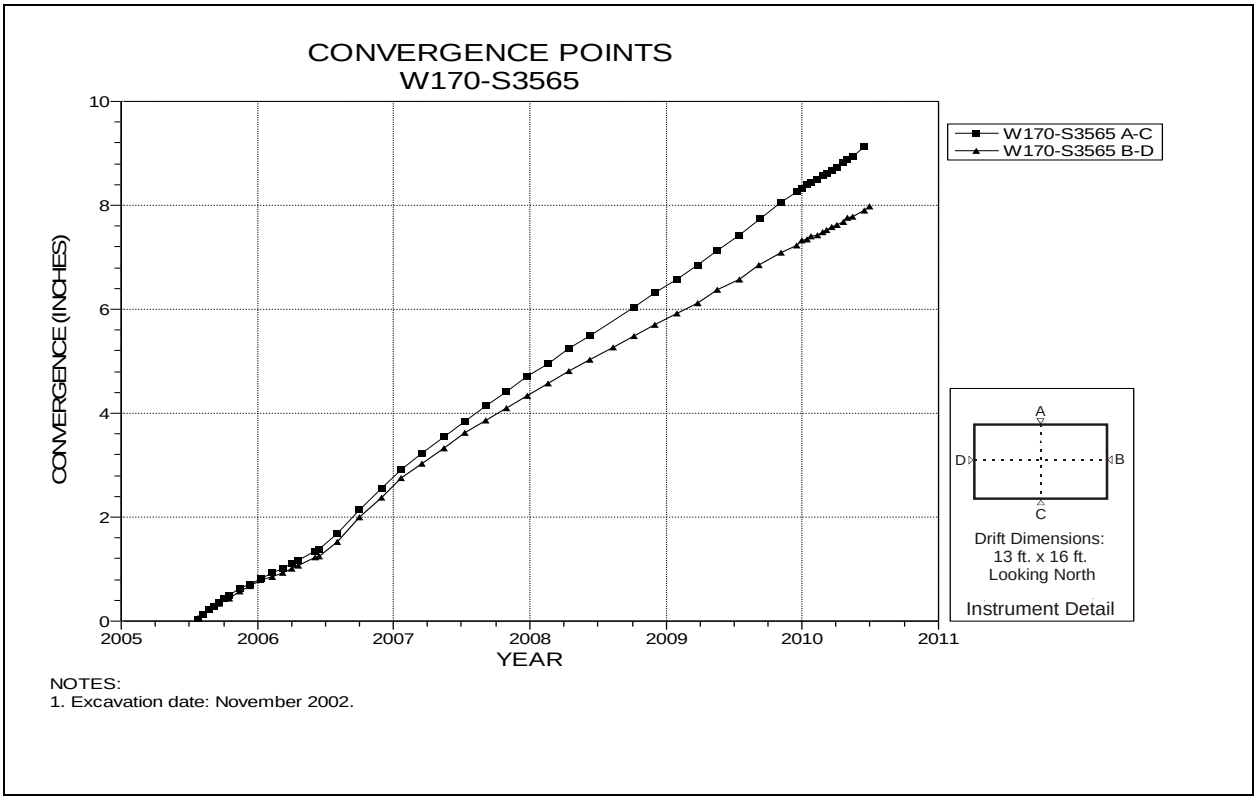


Figure 4-193 Convergence Point Array
W170 S3565 – All Chords

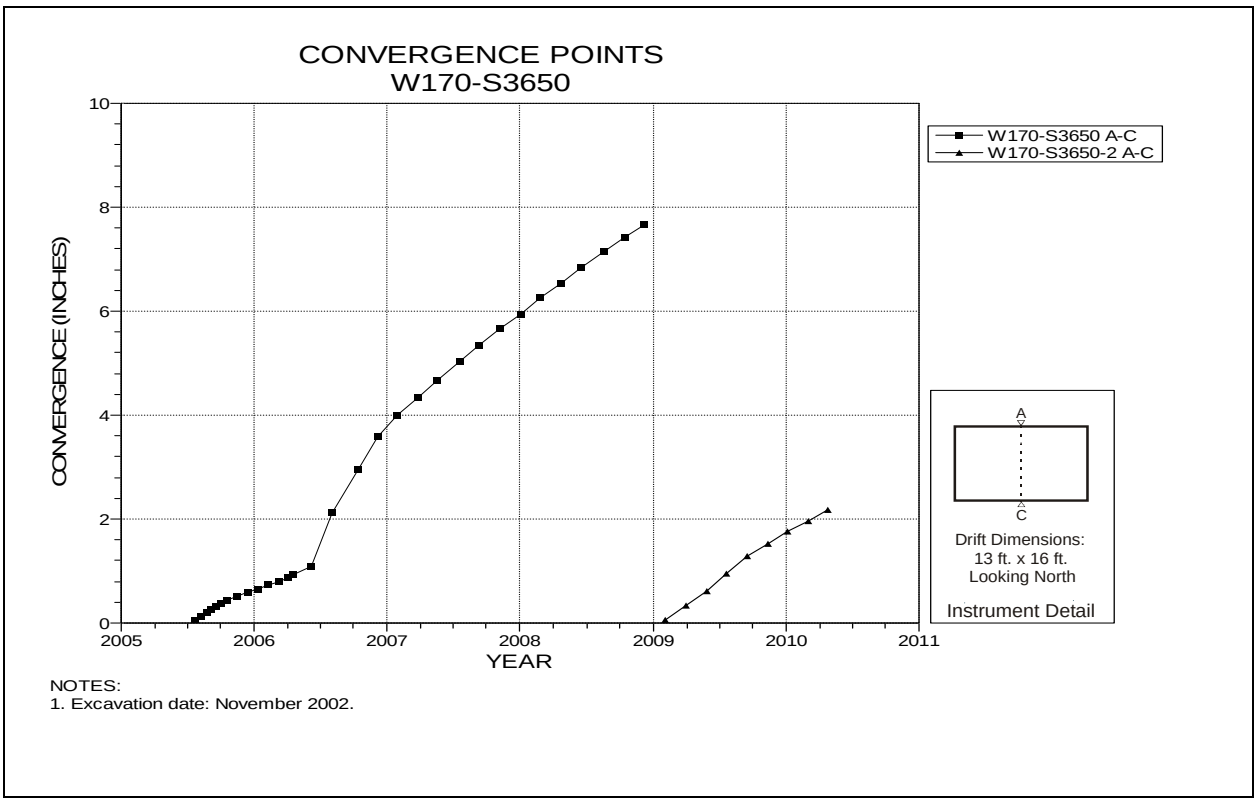


Figure 4-194 Convergence Point Array
W170 S3650 – Roof to Floor

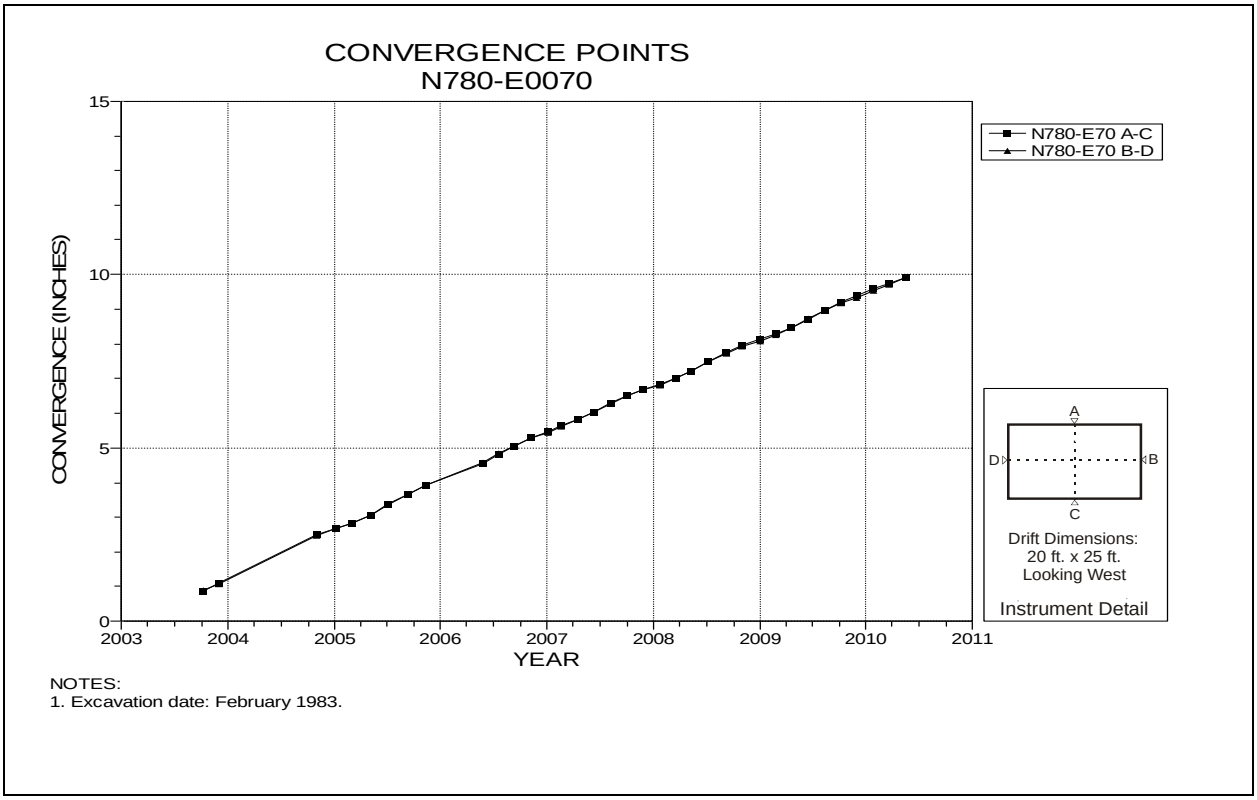


Figure 4-195 Convergence Point Array
N780 E70 – All Chords

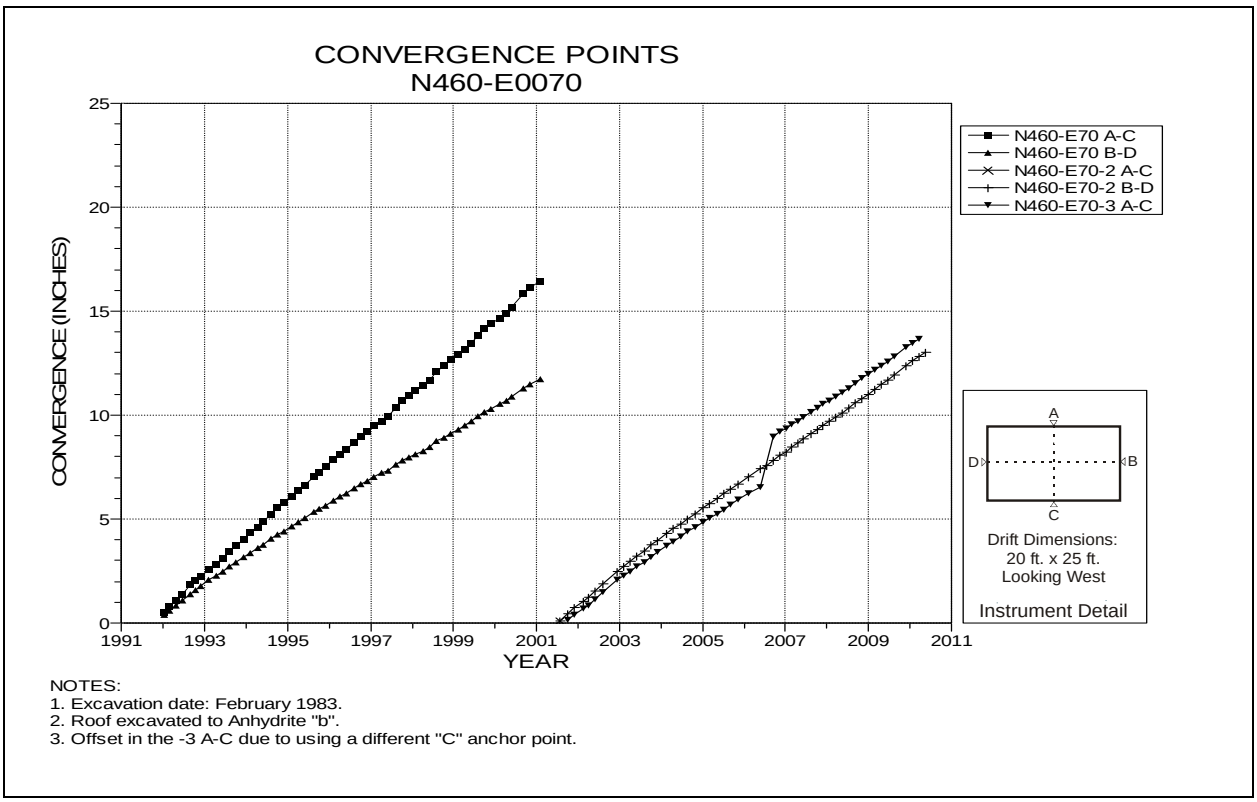


Figure 4-196 Convergence Point Array
N460 E70 – All Chords

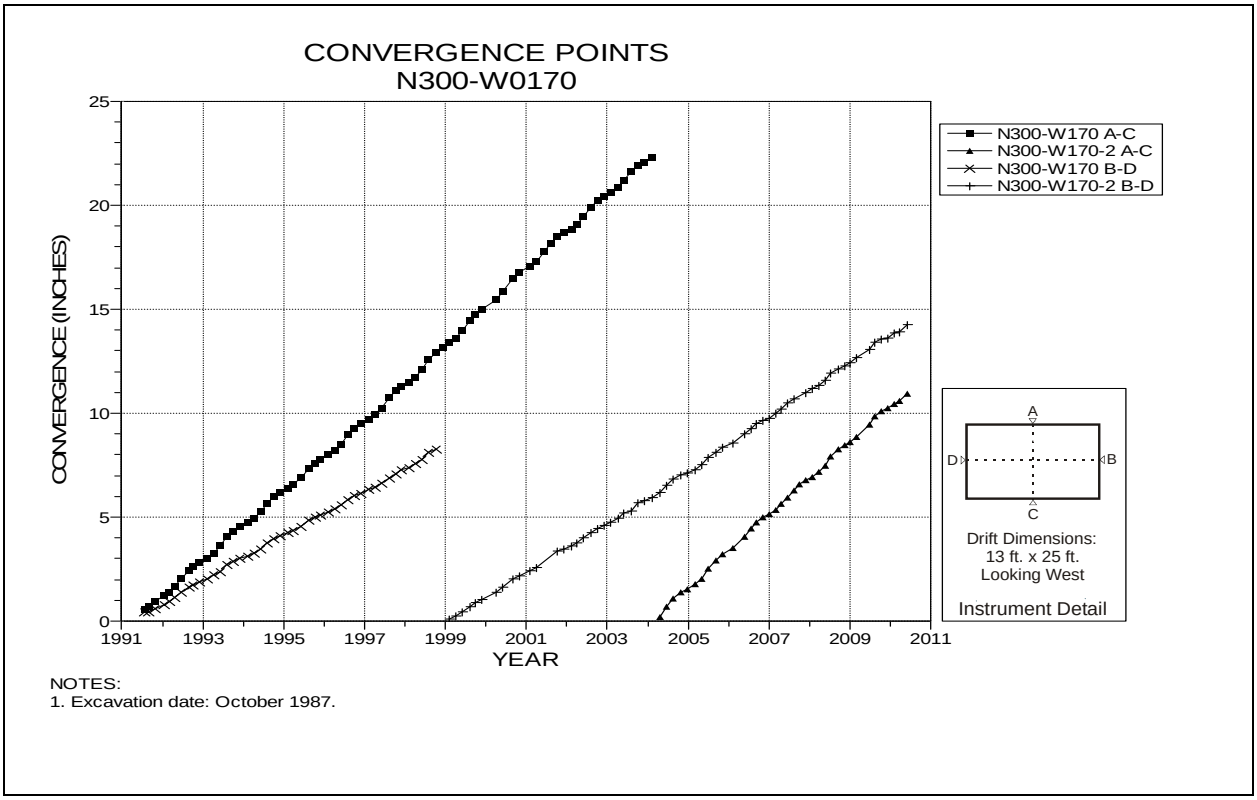


Figure 4-197 Convergence Point Array
N300 W170 – All Chords

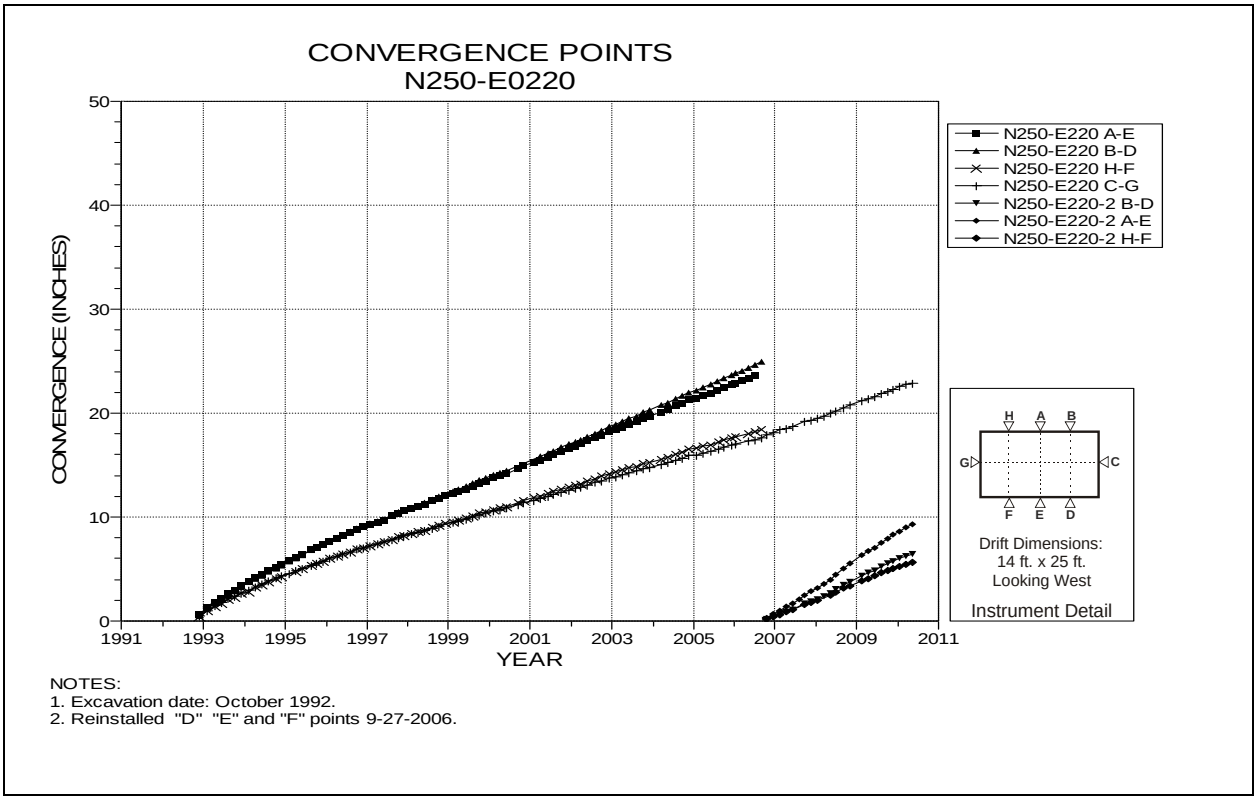


Figure 4-198 Convergence Point Array
N250 E220 – All Chords

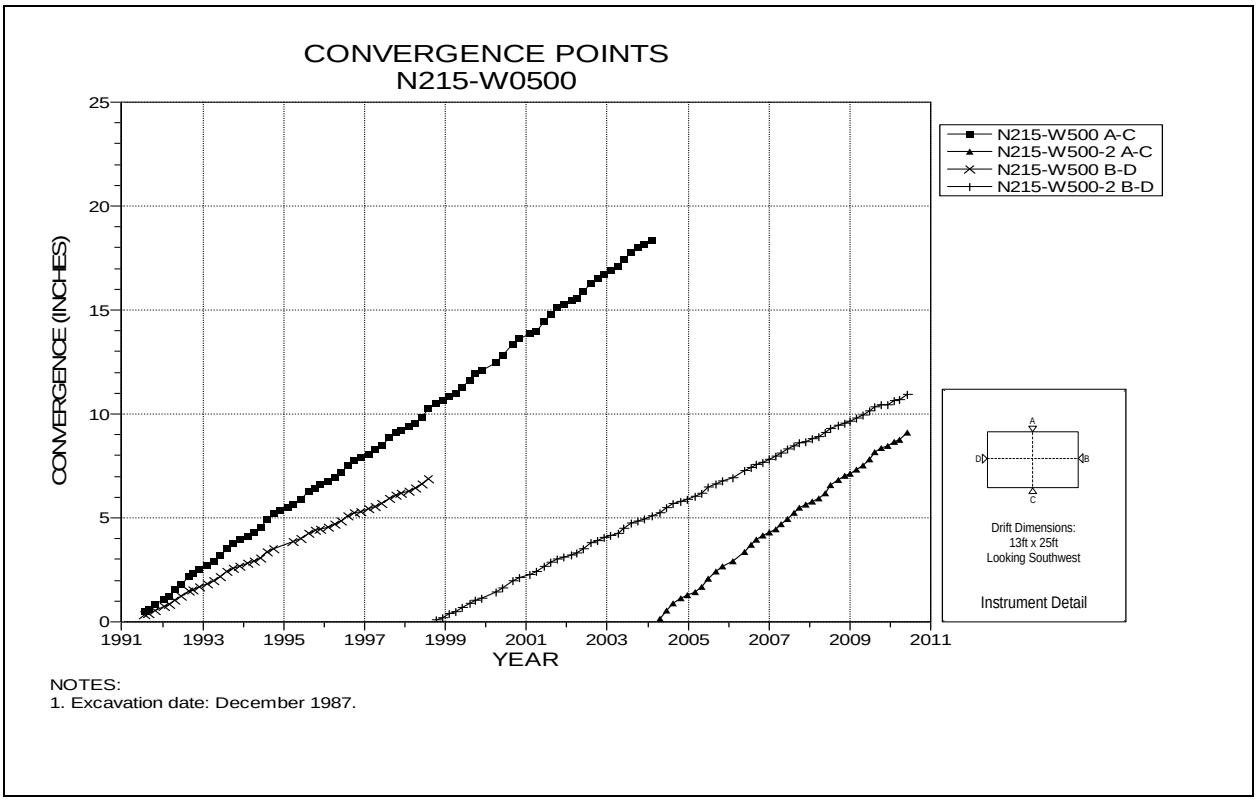


Figure 4-199 Convergence Point Array
N215 W500 – All Chords

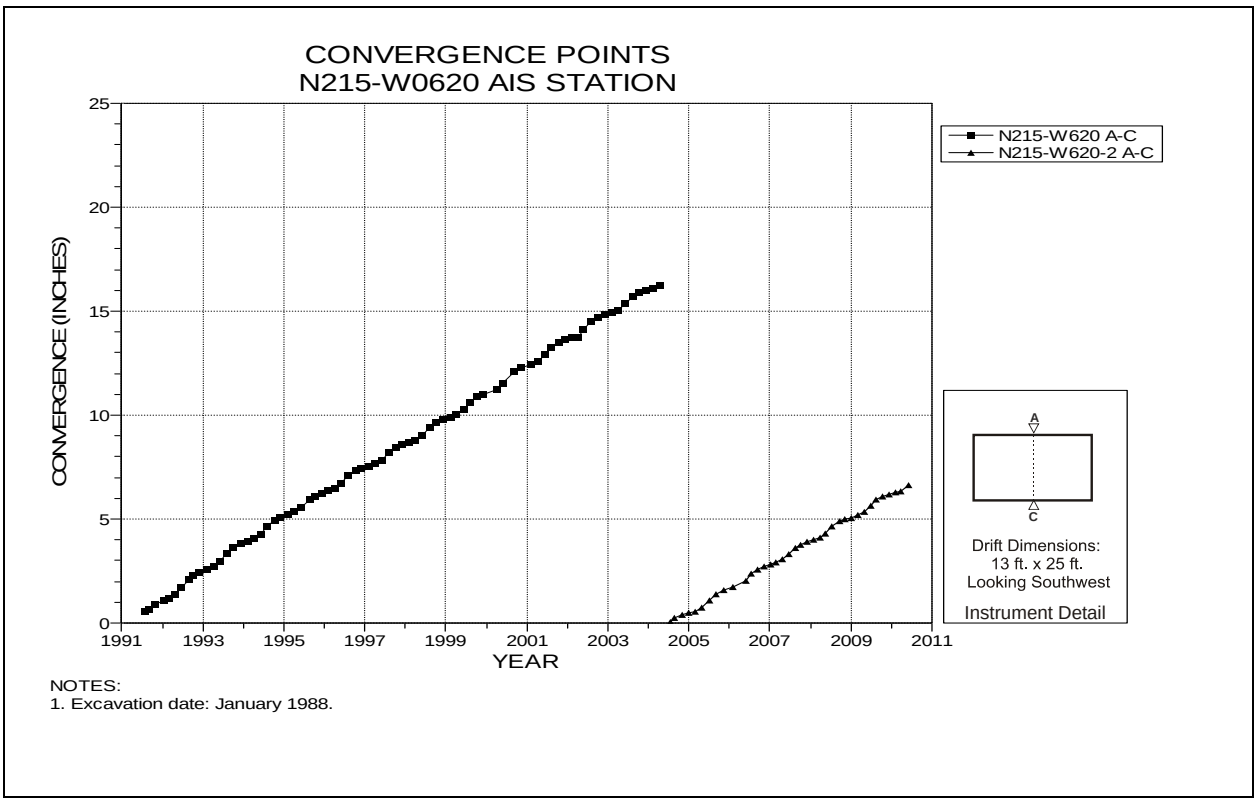


Figure 4-200 Convergence Point Array
N215 W620 at Air Intake Shaft – Roof to Floor

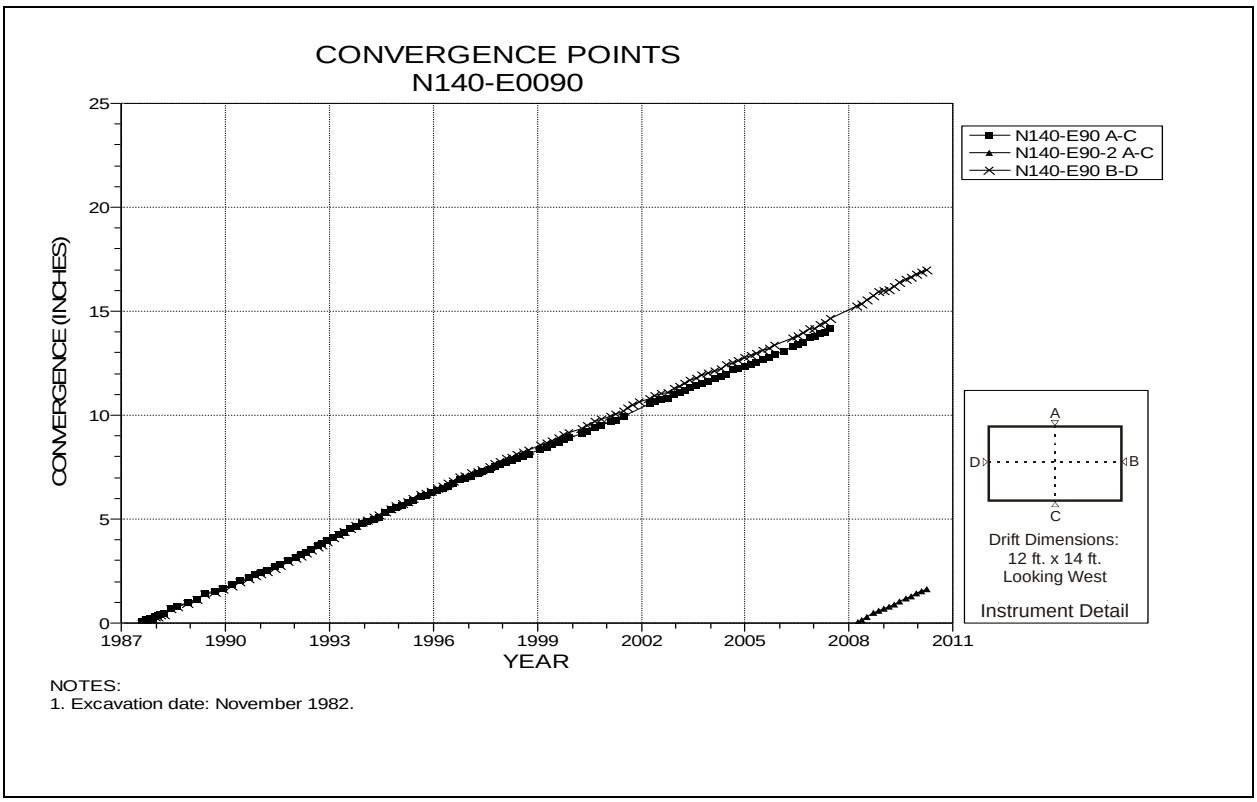


Figure 4-201 Convergence Point Array
N140 E90 – All Chords

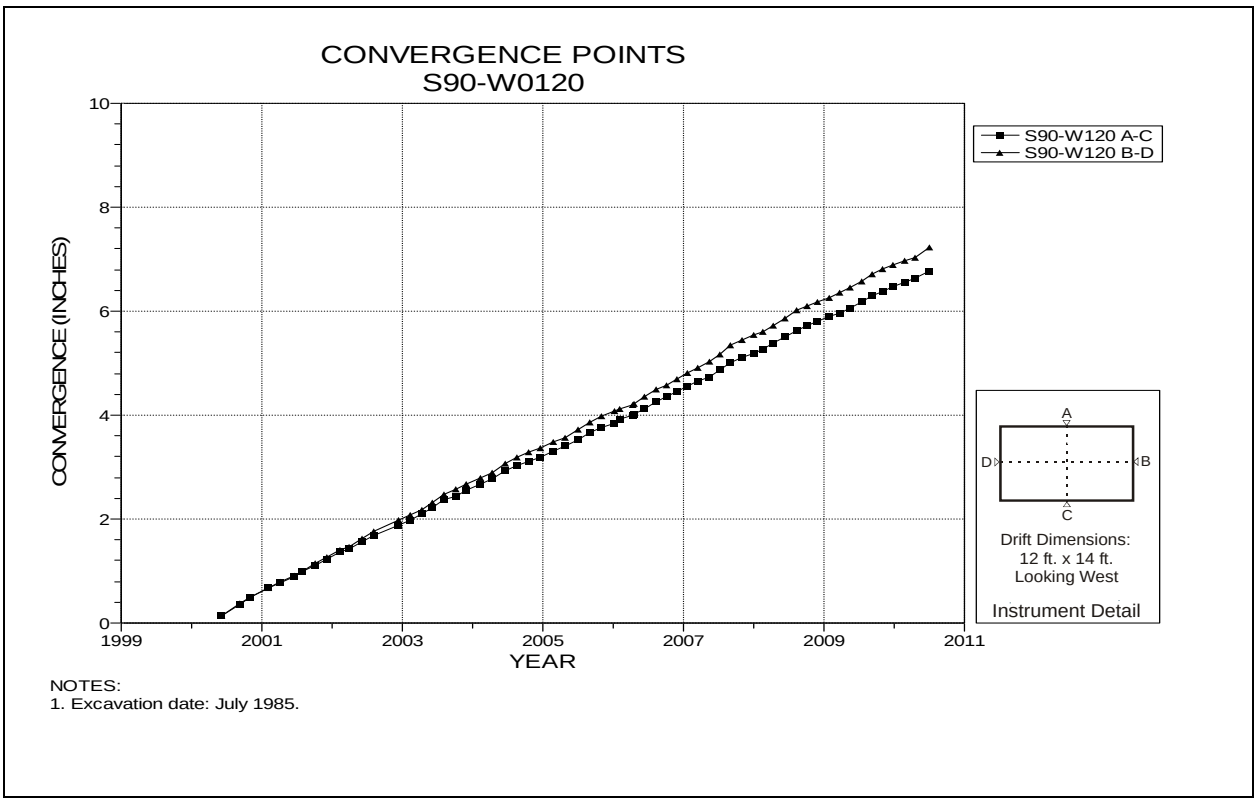


Figure 4-202 Convergence Point Array
S90 W120 – All Chords

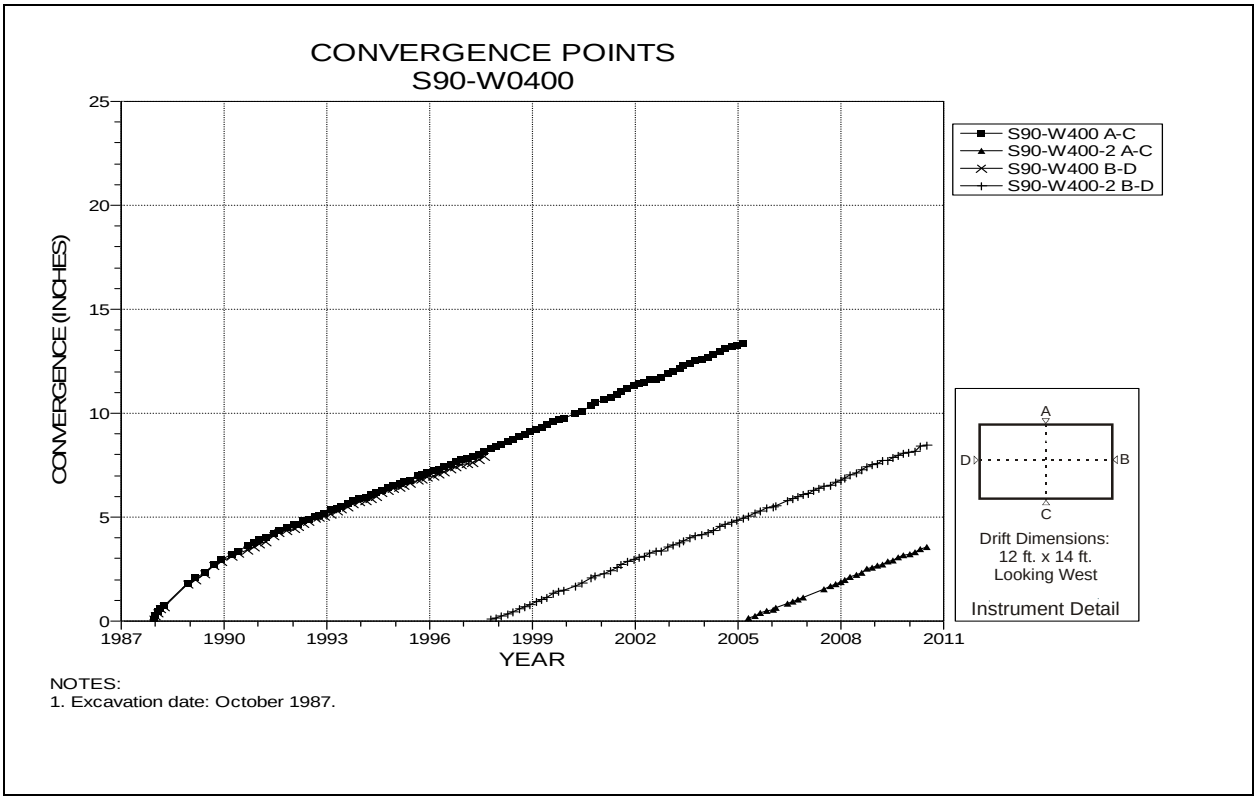


Figure 4-203 Convergence Point Array
S90 W400 – All Chords

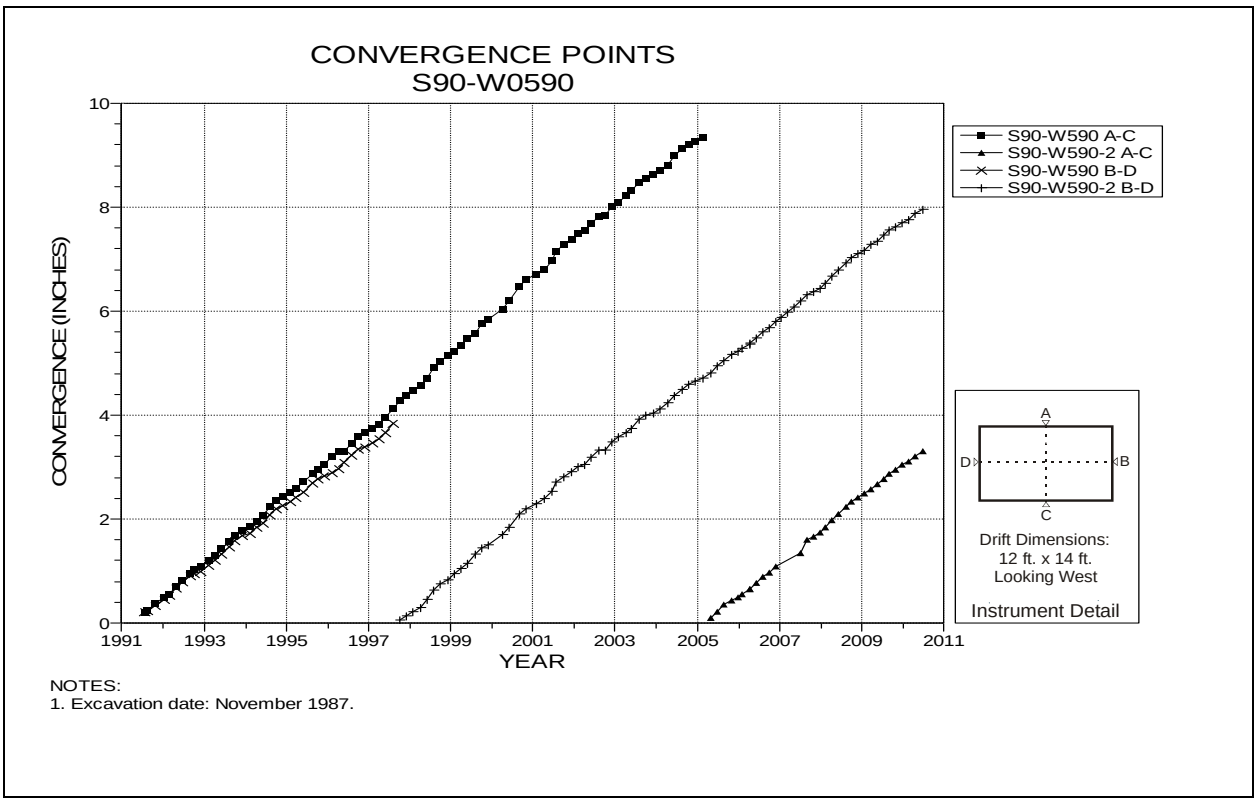


Figure 4-204 Convergence Point Array
S90 W590 – All Chords

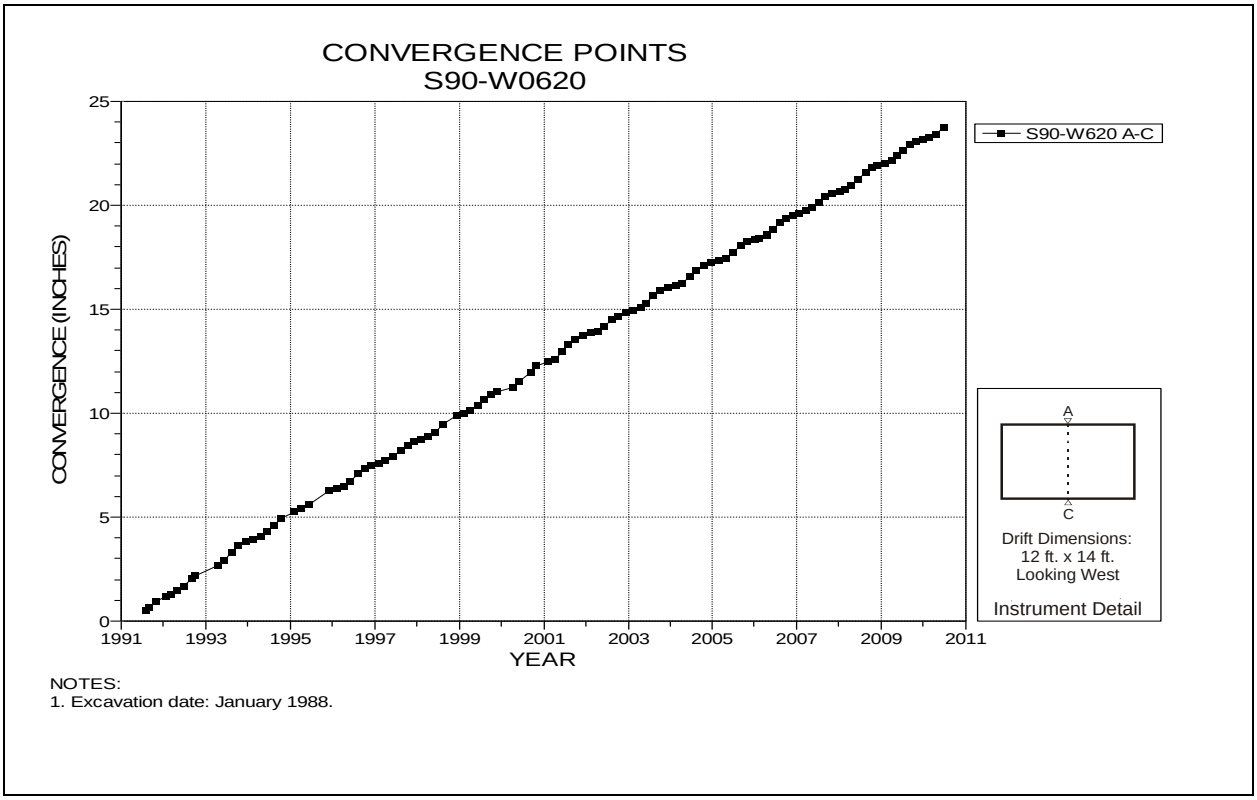


Figure 4-205 Convergence Point Array
S90 W620 – Roof to Floor

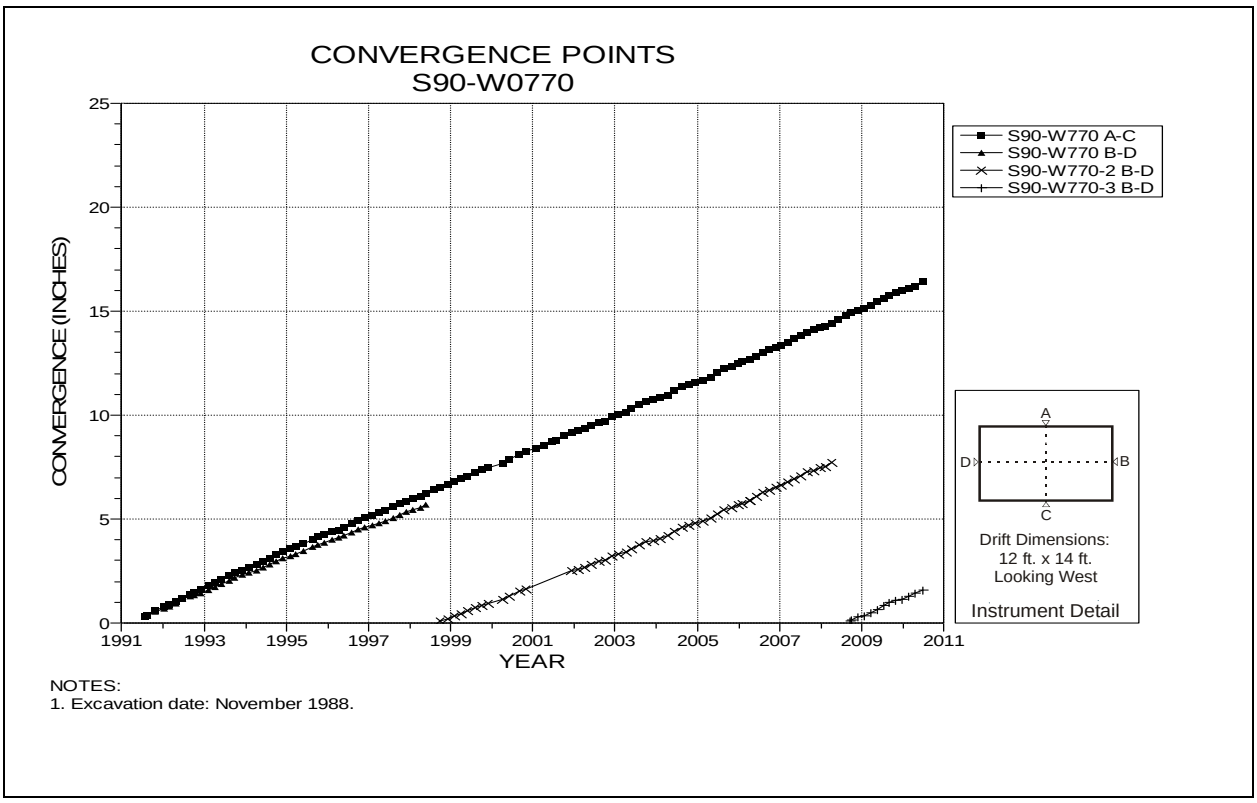


Figure 4-206 Convergence Point Array
S90 W770 – All Chords

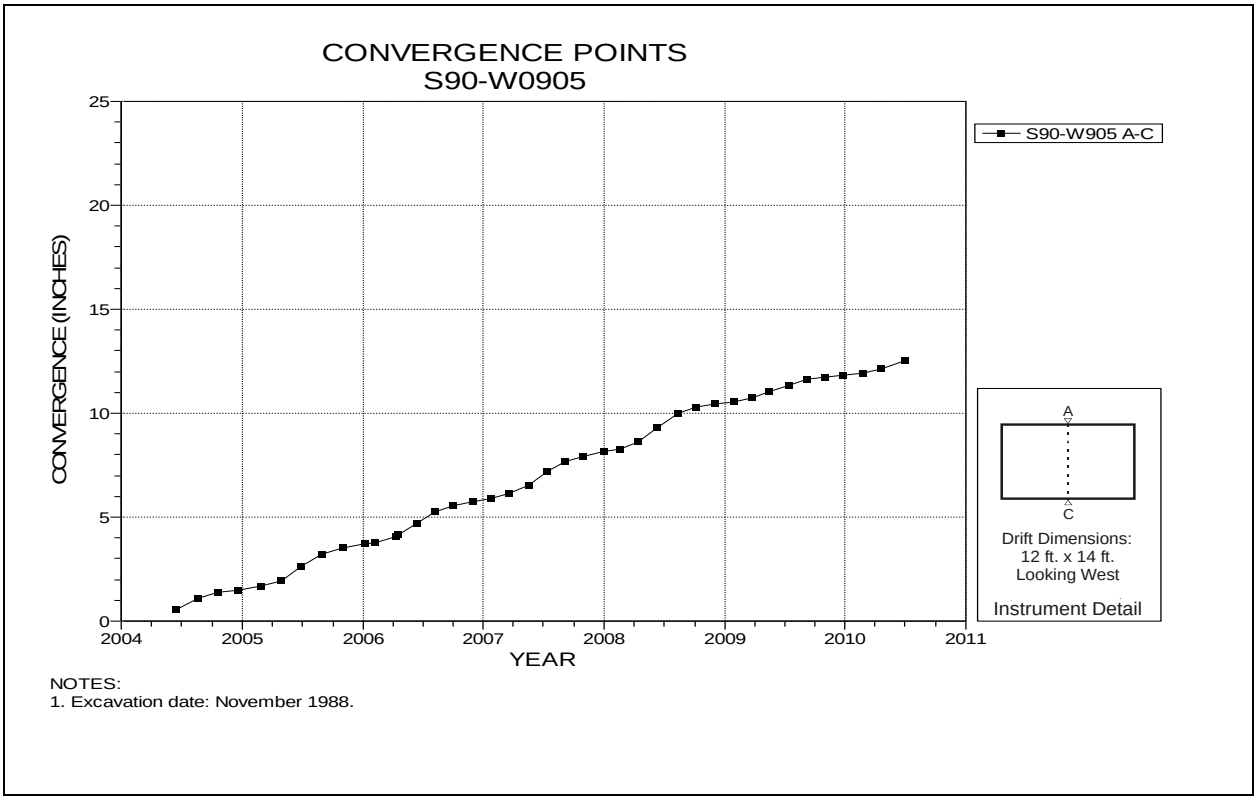


Figure 4-207 Convergence Point Array
S90 W905 – Roof to Floor

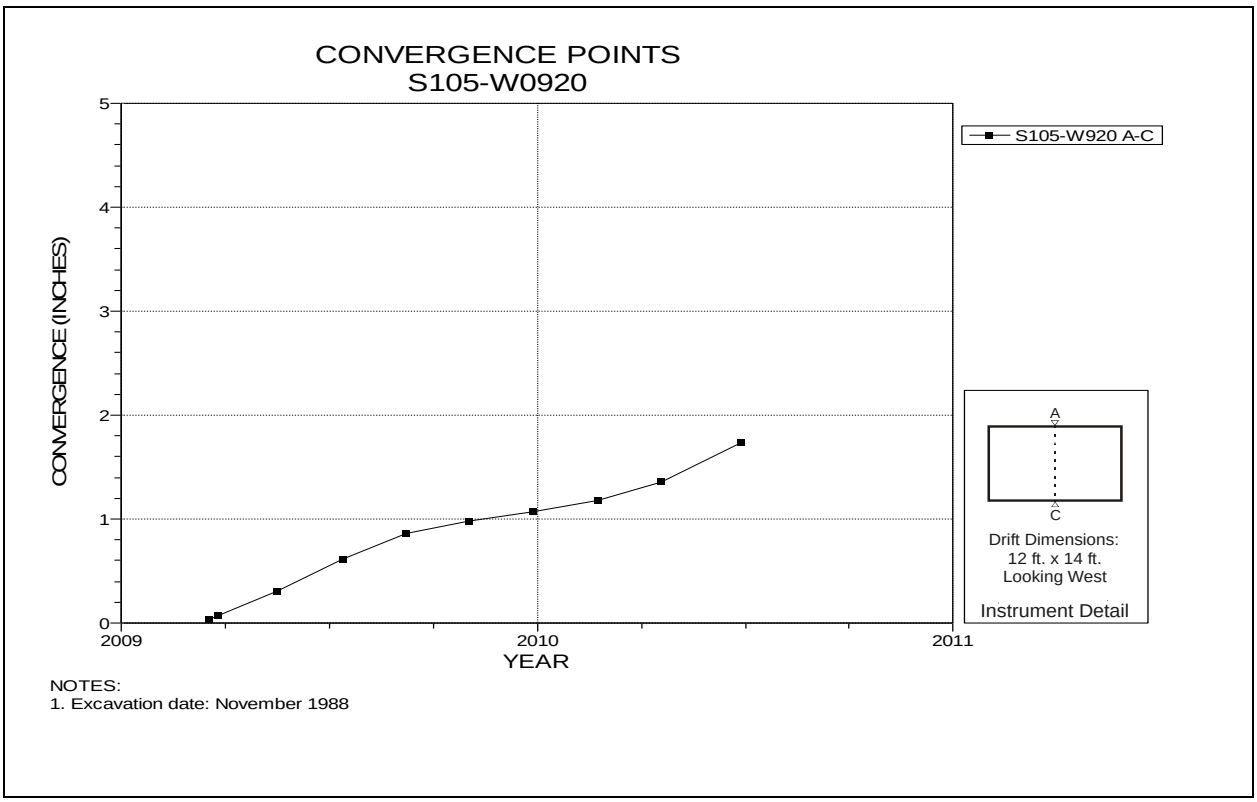


Figure 4-208 Convergence Point Array
S105 W920 – Roof to Floor

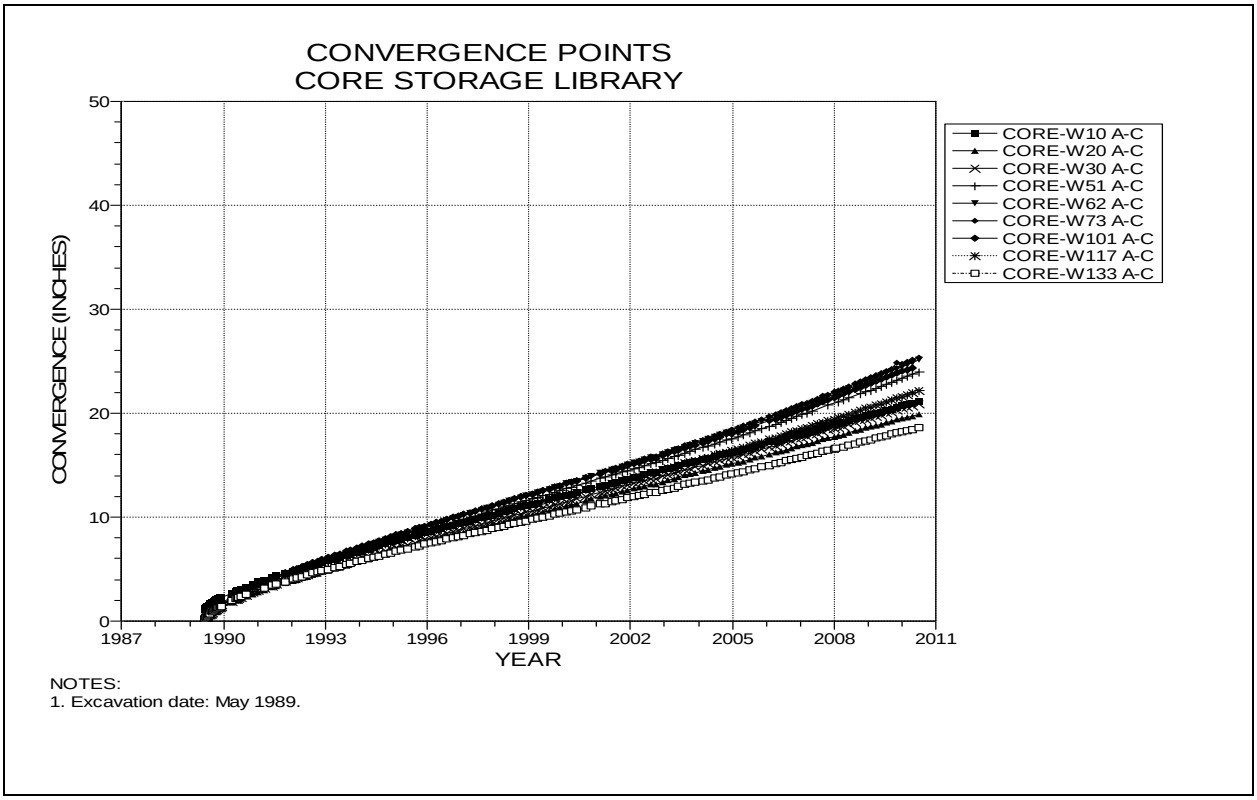


Figure 4-209 Convergence Point Array
S400 Core Storage Library – All Chords

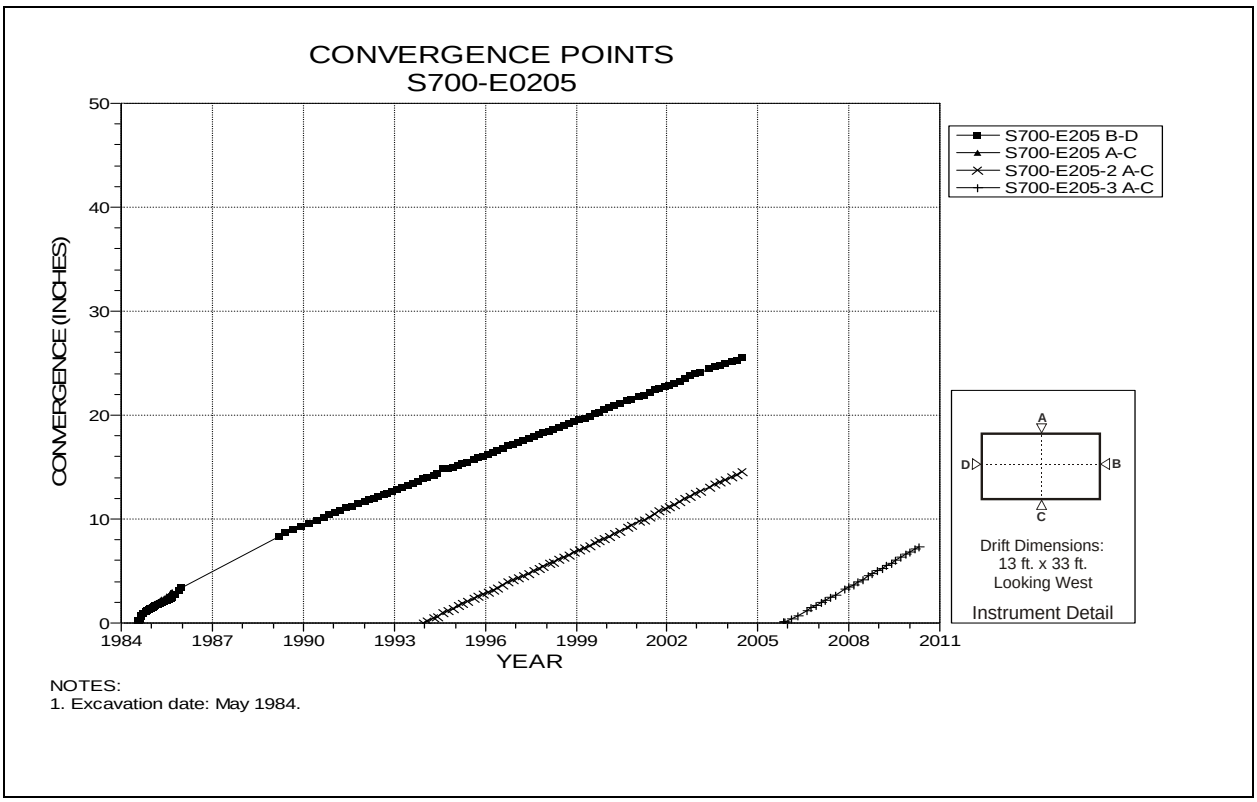


Figure 4-210 Convergence Point Array
S700 E205 – All Chords

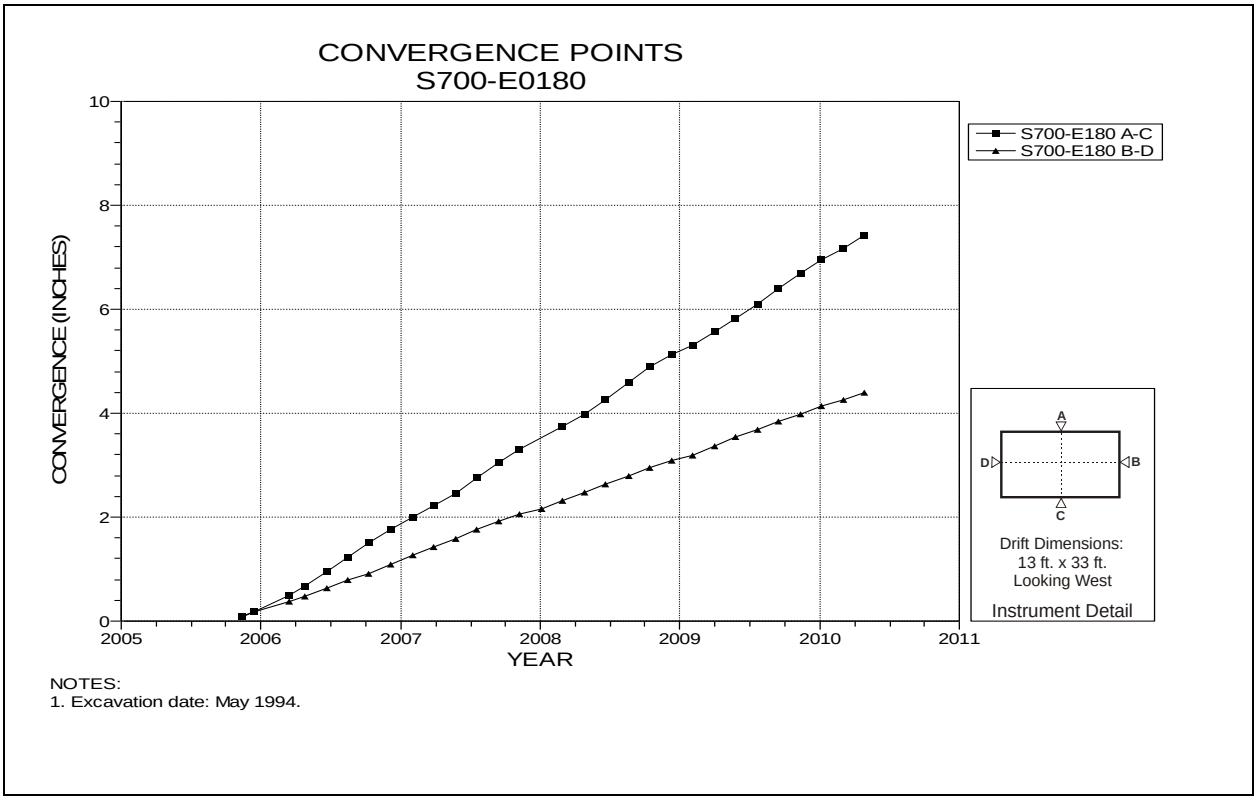


Figure 4-211 Convergence Point Array
S700 E180 – All Chords

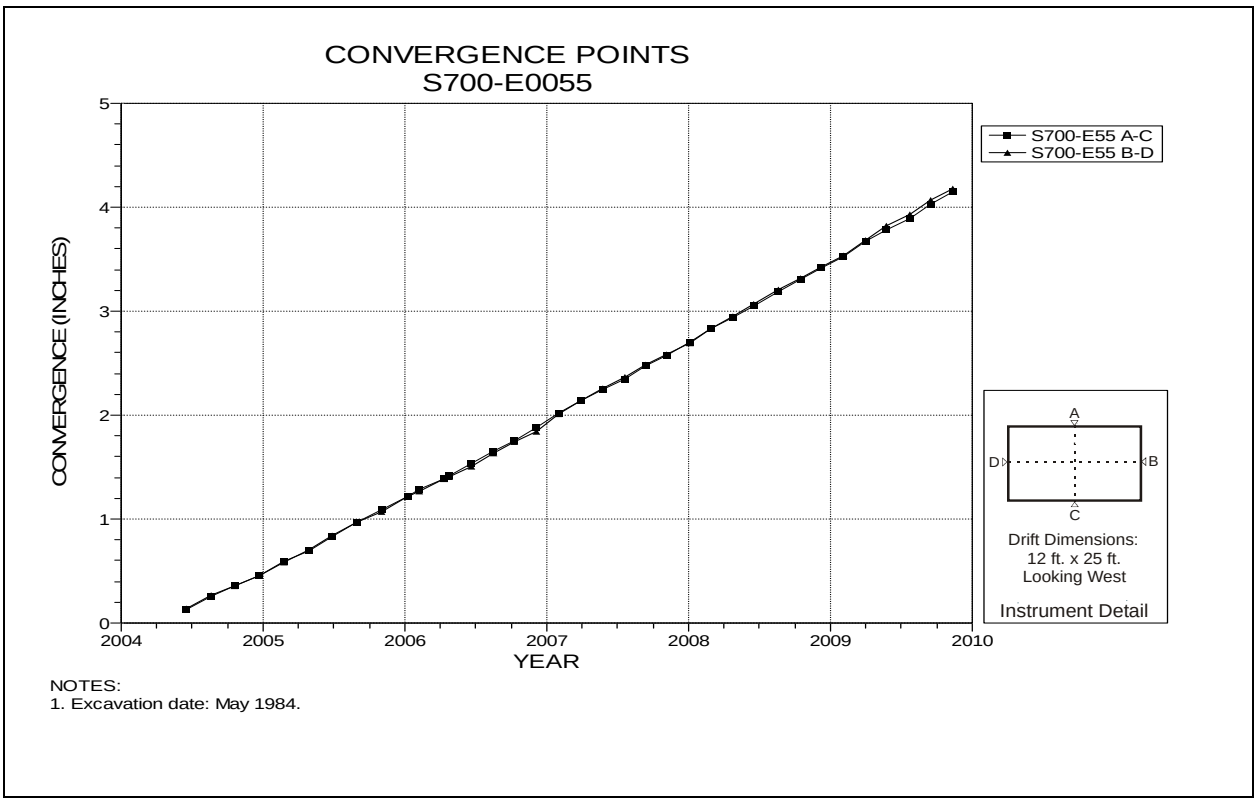


Figure 4-212 Convergence Point Array
S700 E55 – All Chords

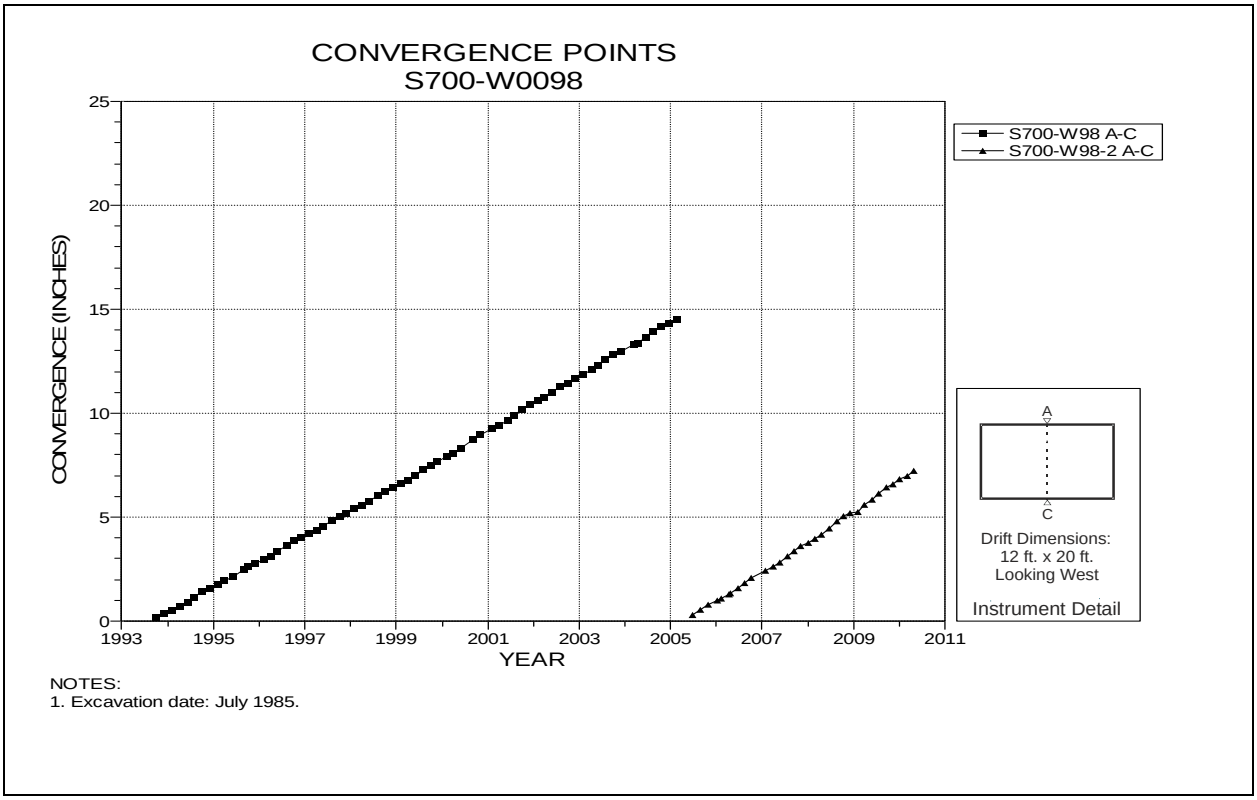


Figure 4-213 Convergence Point Array
S700 W98 – Roof to Floor

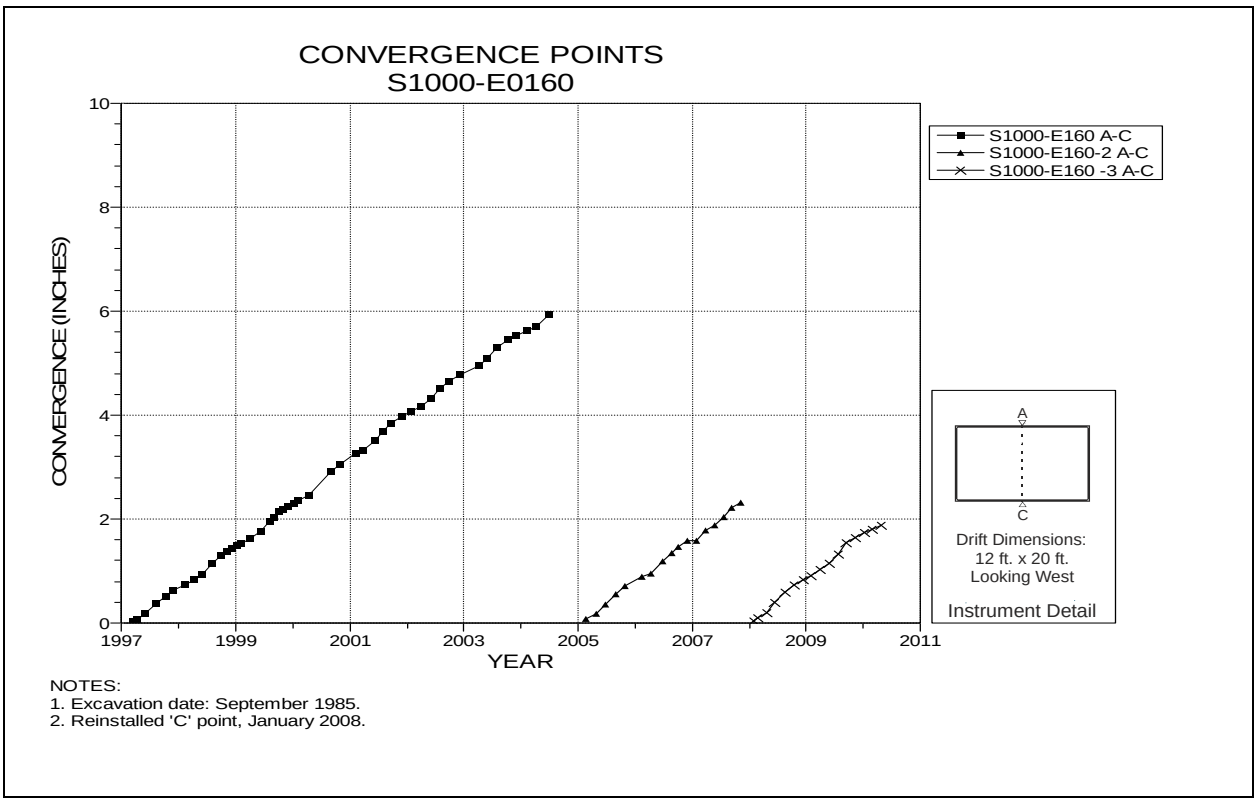


Figure 4-214 Convergence Point Array
S1000 E160 – Roof to Floor

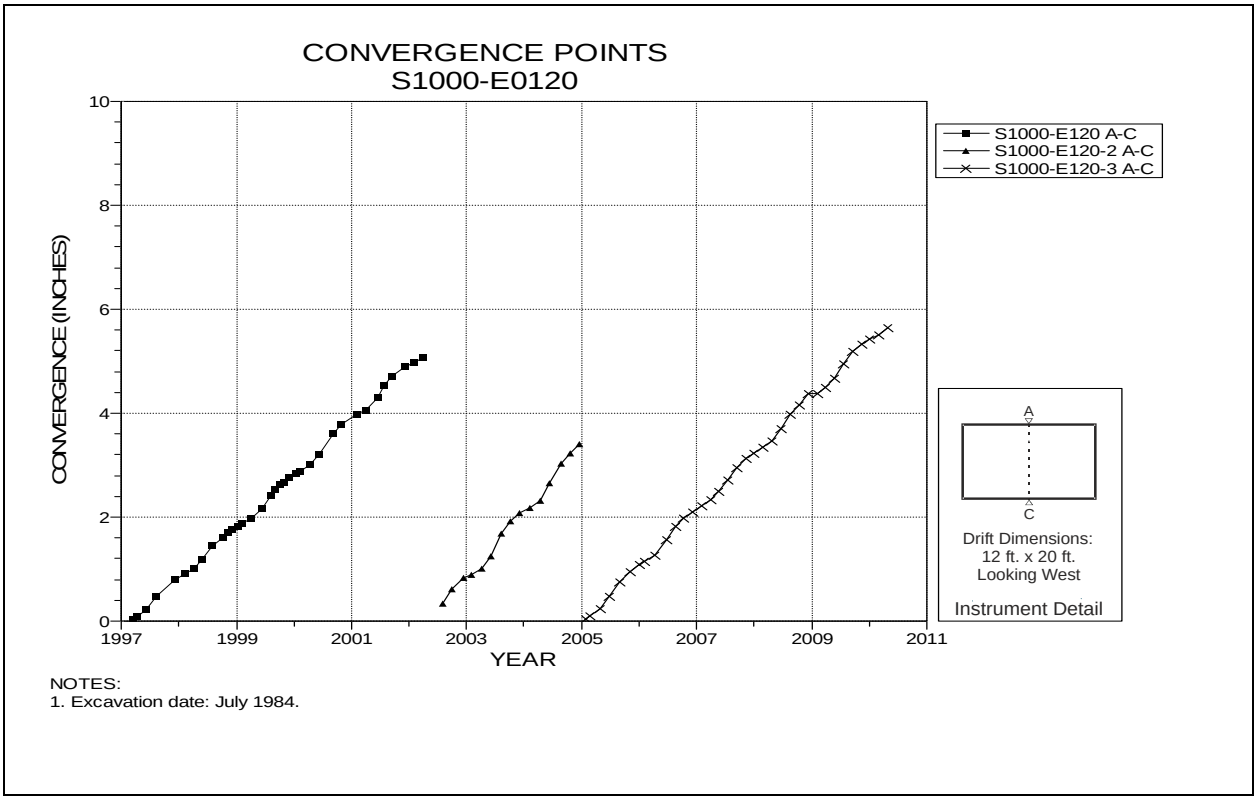


Figure 4-215 Convergence Point Array
S1000 E120 – Roof to Floor

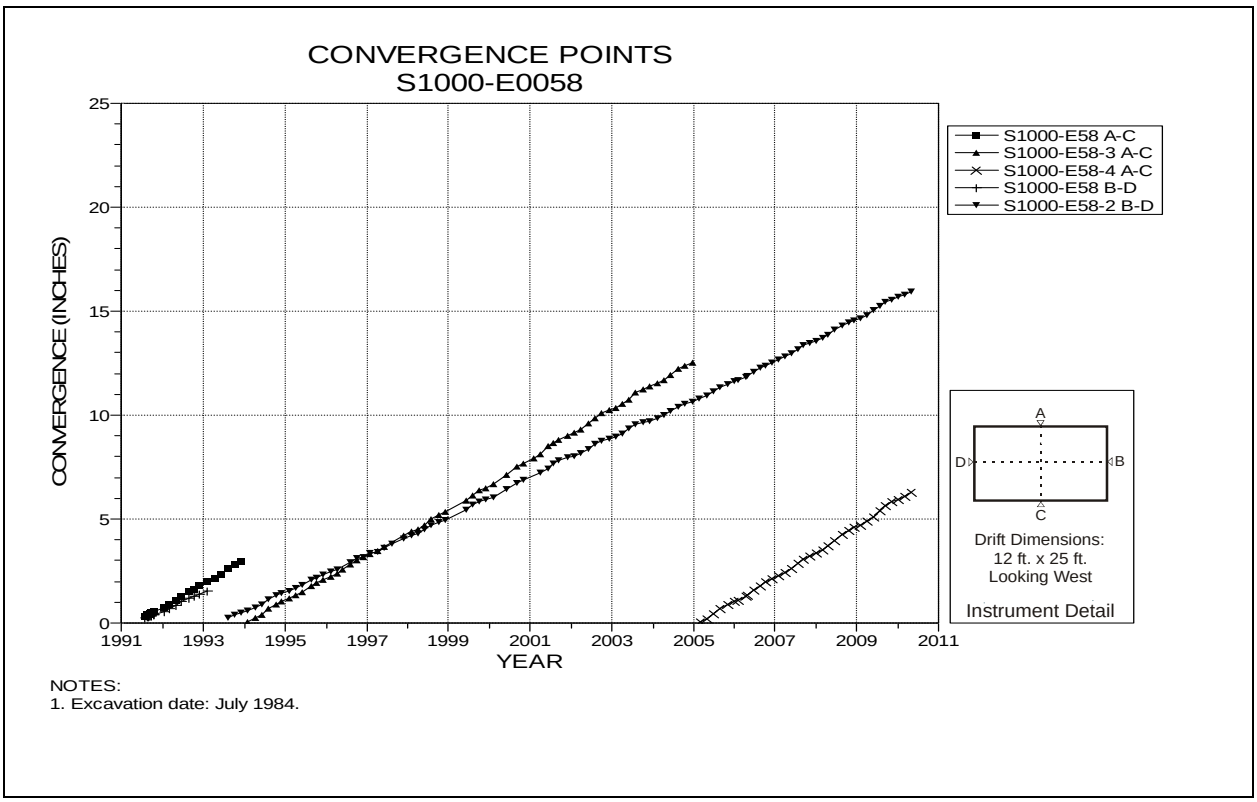


Figure 4-216 Convergence Point Array
S1000 E58 – All Chords

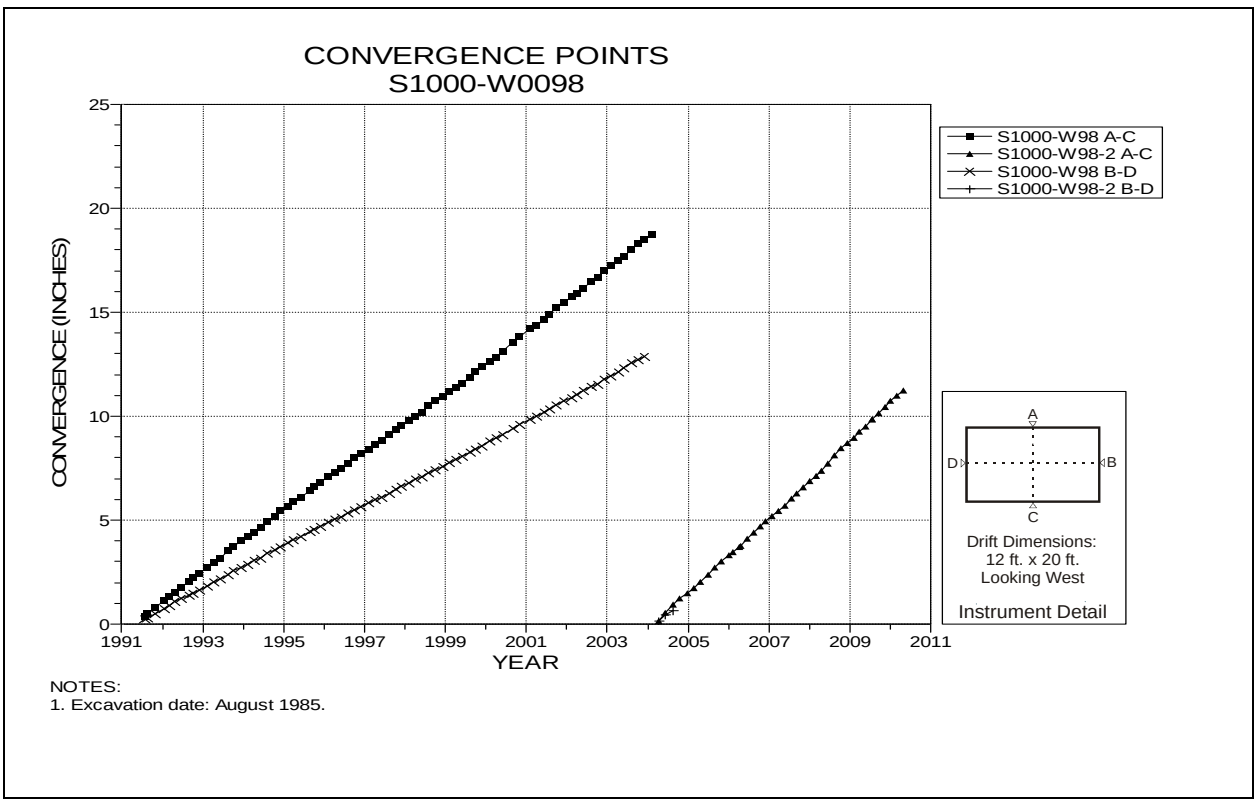


Figure 4-217 Convergence Point Array
S1000 W98 – All Chords

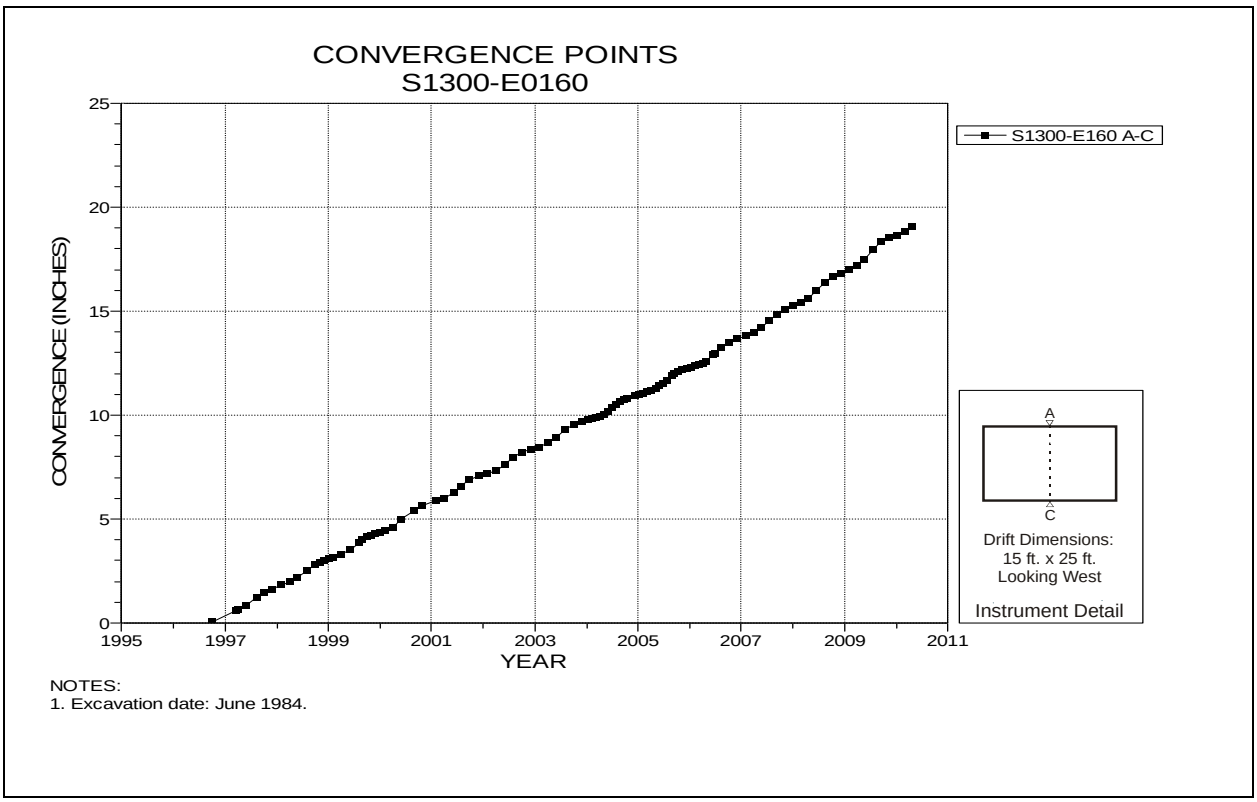


Figure 4-218 Convergence Point Array
S1300 E160 – Roof to Floor

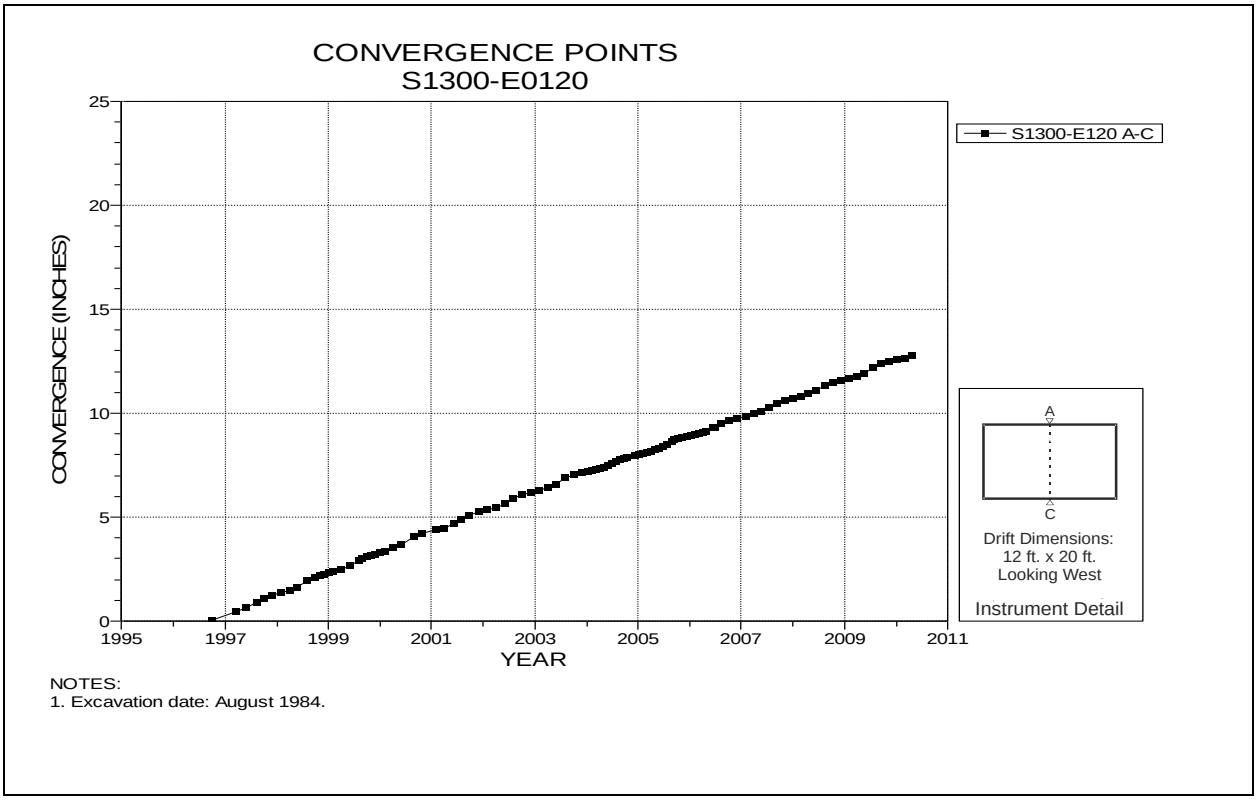


Figure 4-219 Convergence Point Array
S1300 E120 – Roof to Floor

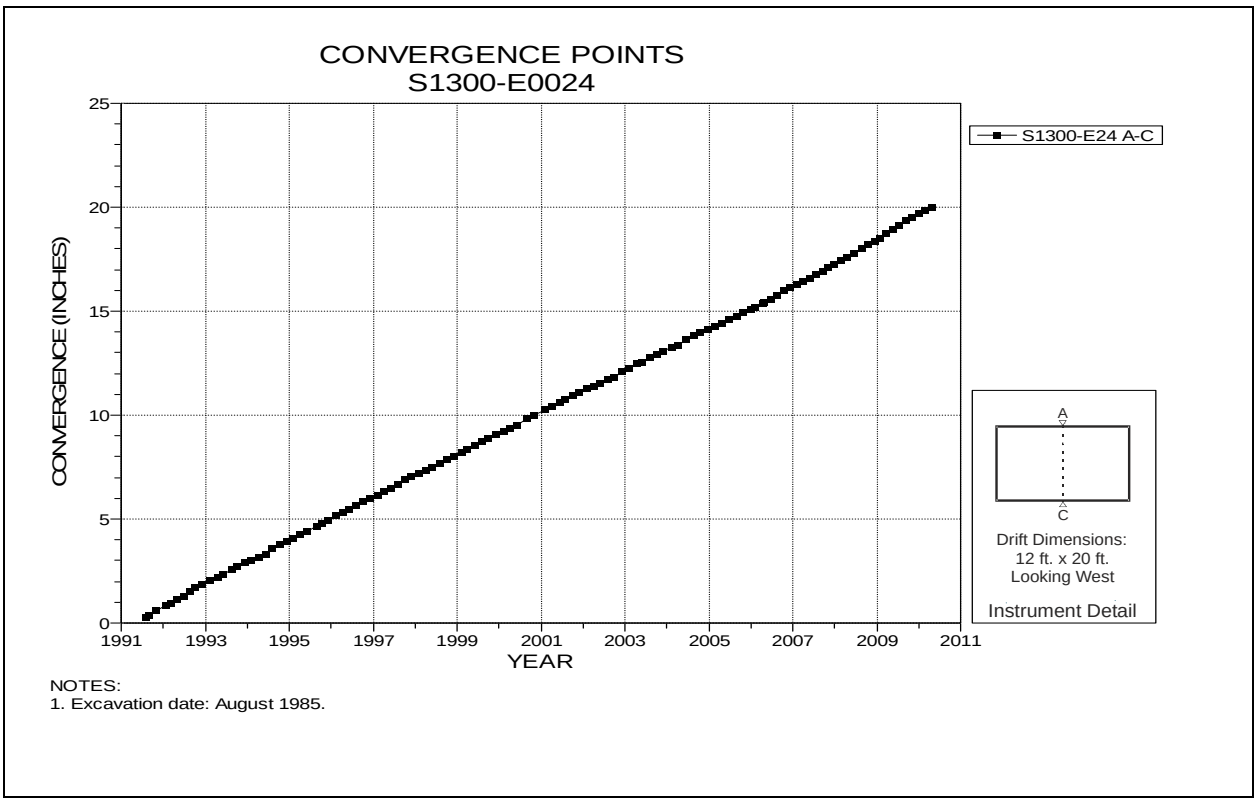


Figure 4-220 Convergence Point Array
S1300 E24 – Roof to Floor

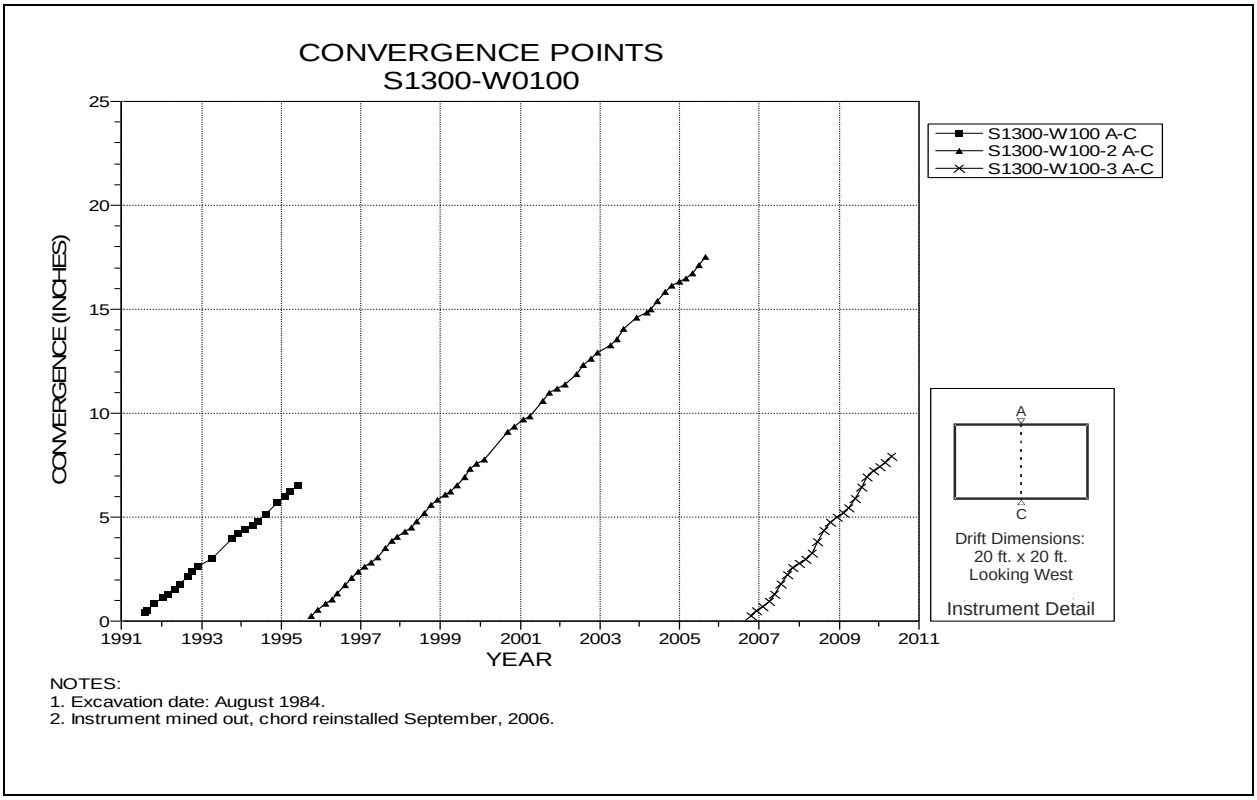


Figure 4-221 Convergence Point Array
S1300 W100 – Roof to Floor

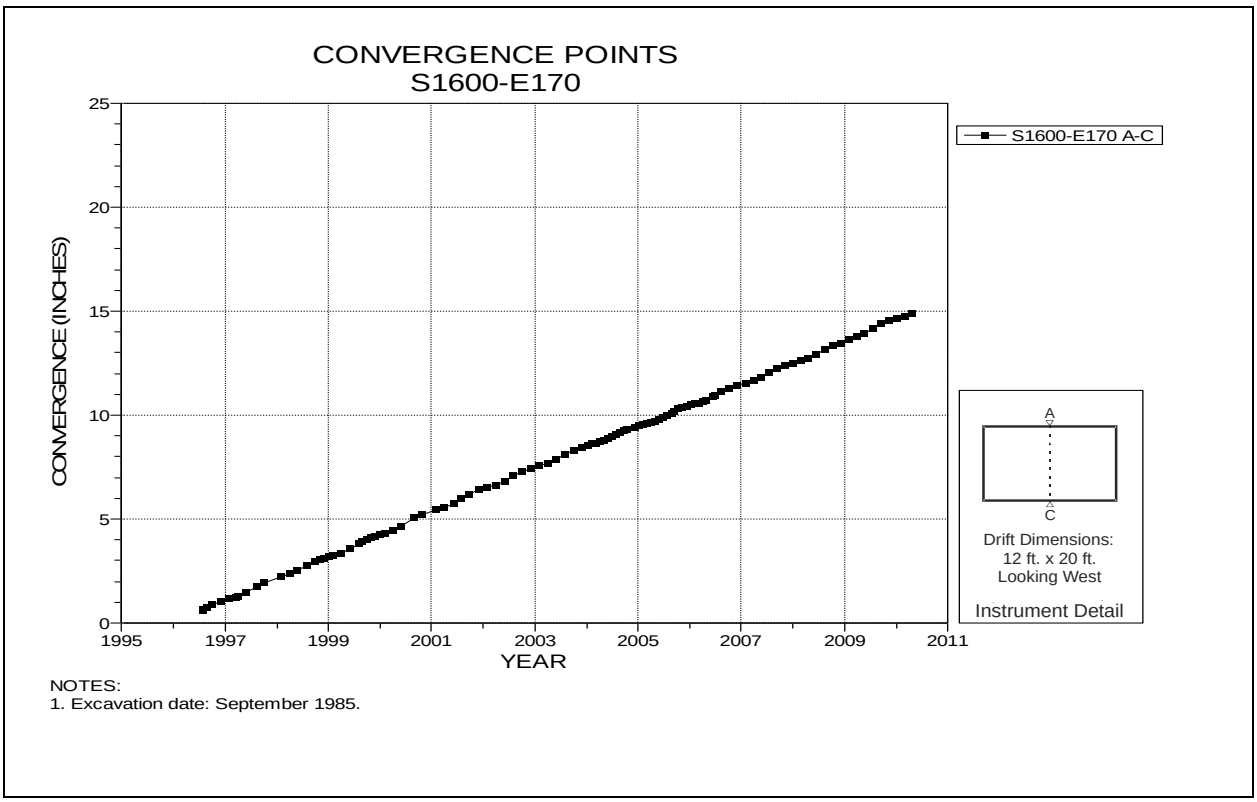


Figure 4-222 Convergence Point Array
S1600 E170 – Roof to Floor

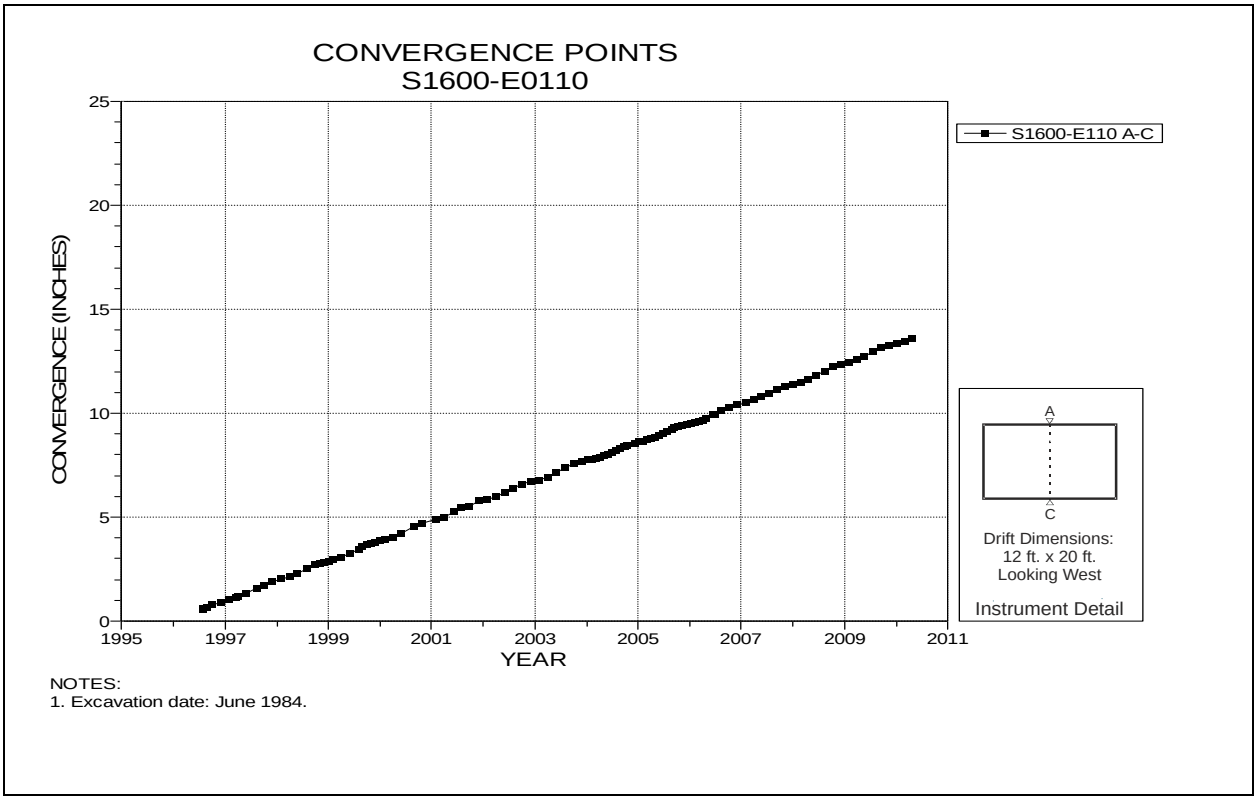


Figure 4-223 Convergence Point Array
S1600 E110 – Roof to Floor

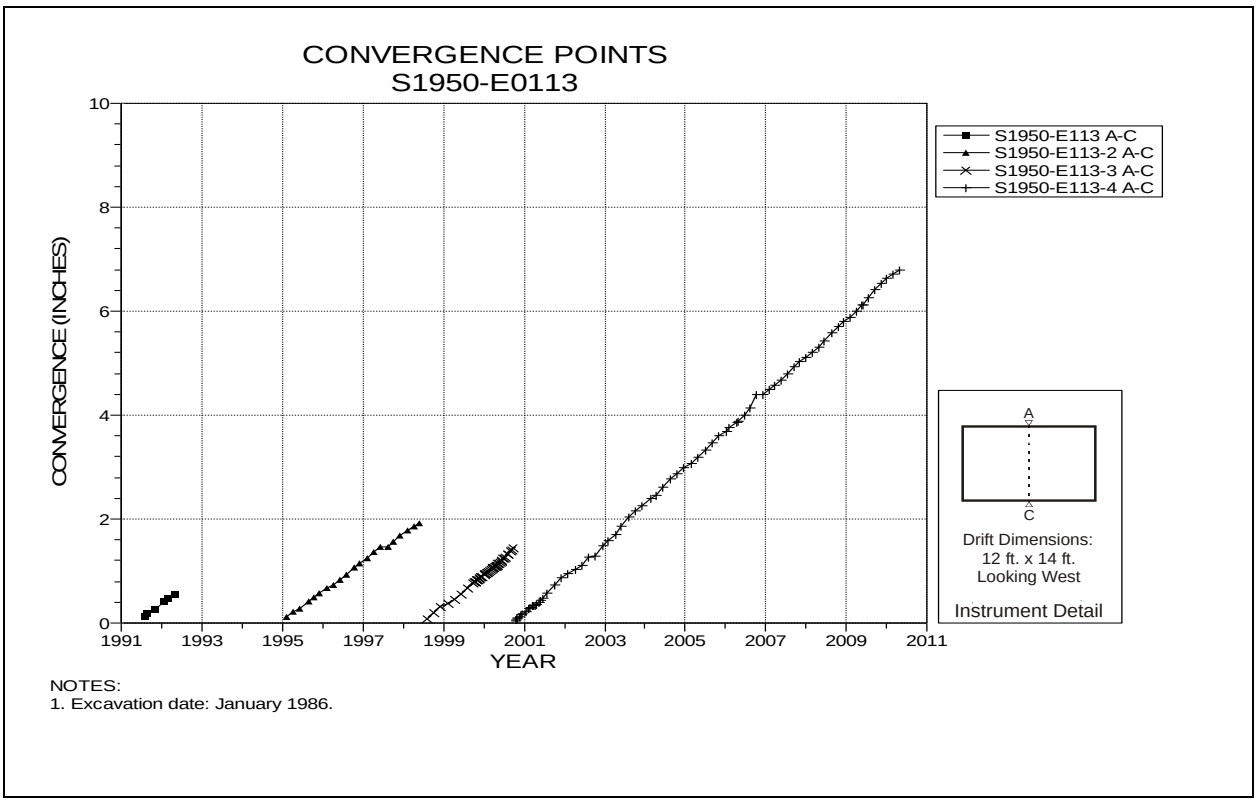


Figure 4-224 Convergence Point Array
S1950 E113 – Roof to Floor

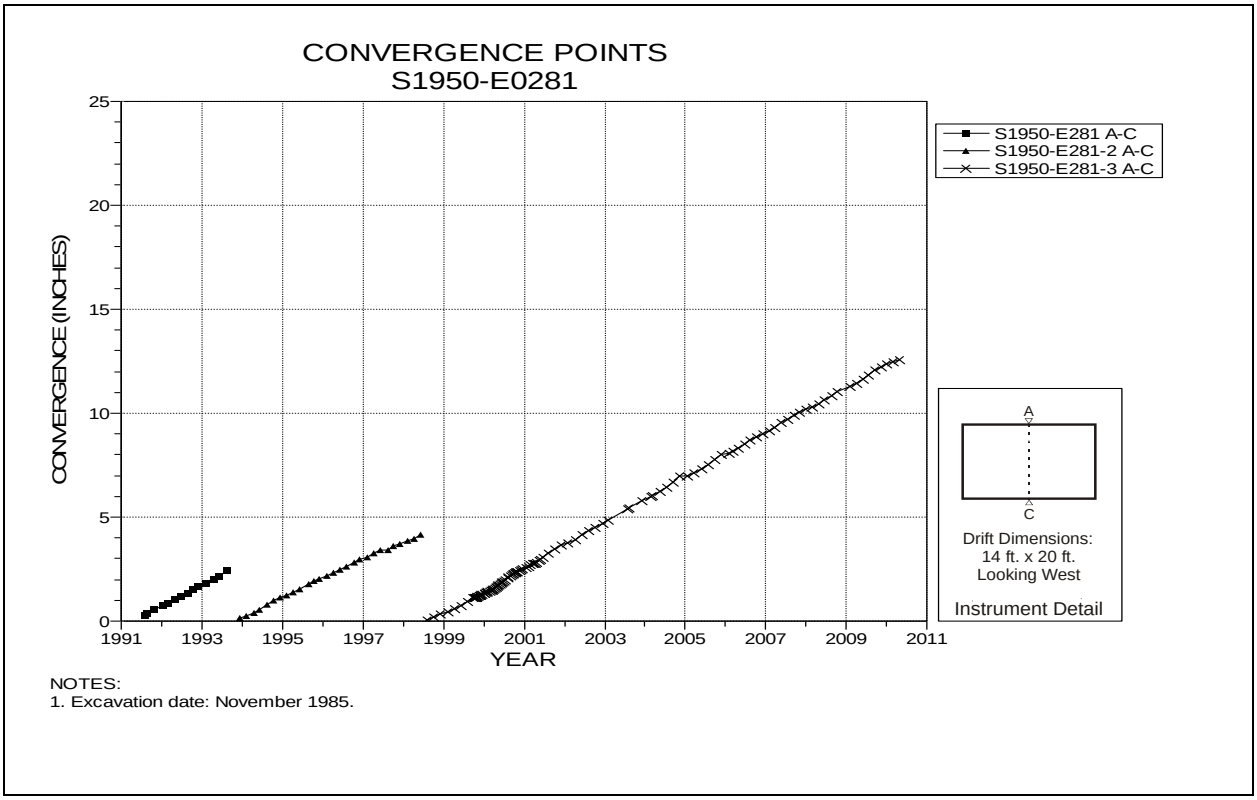


Figure 4-225 Convergence Point Array
S1950 E281 – Roof to Floor

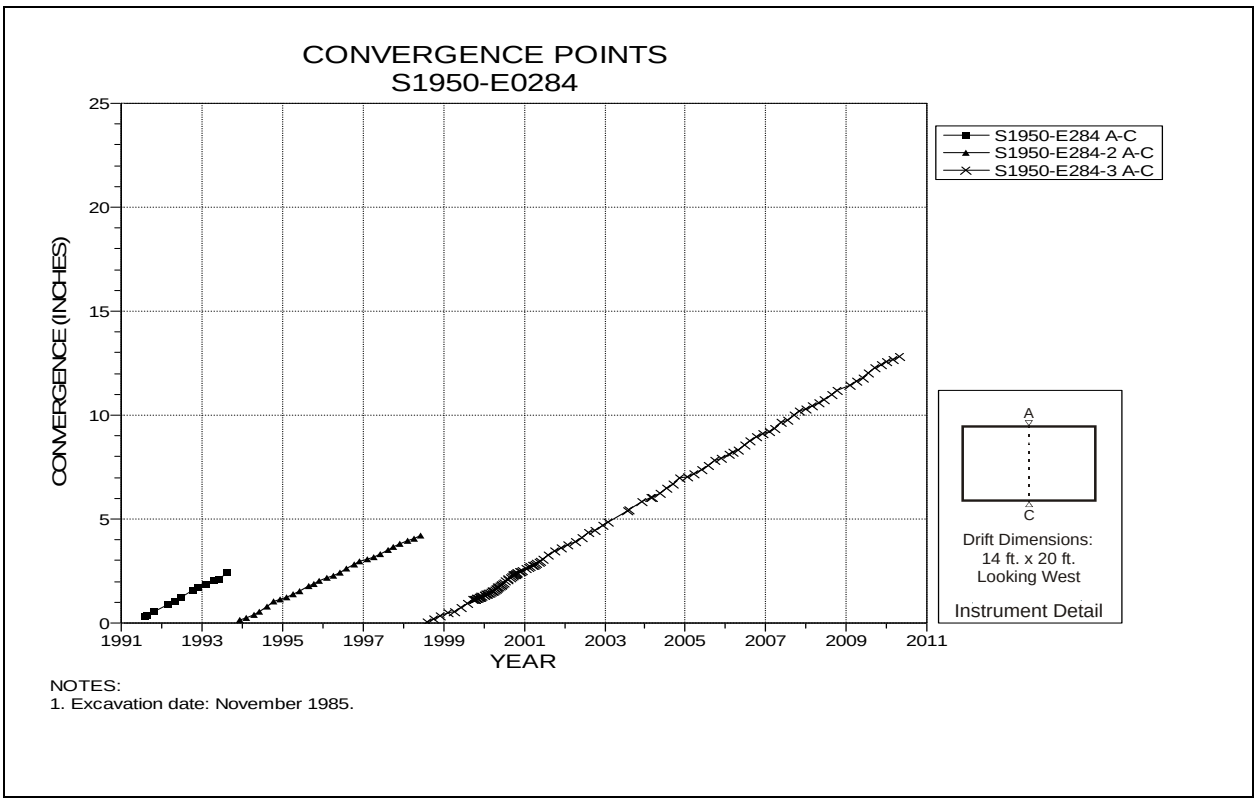


Figure 4-226 Convergence Point Array
S1950 E284 – Roof to Floor

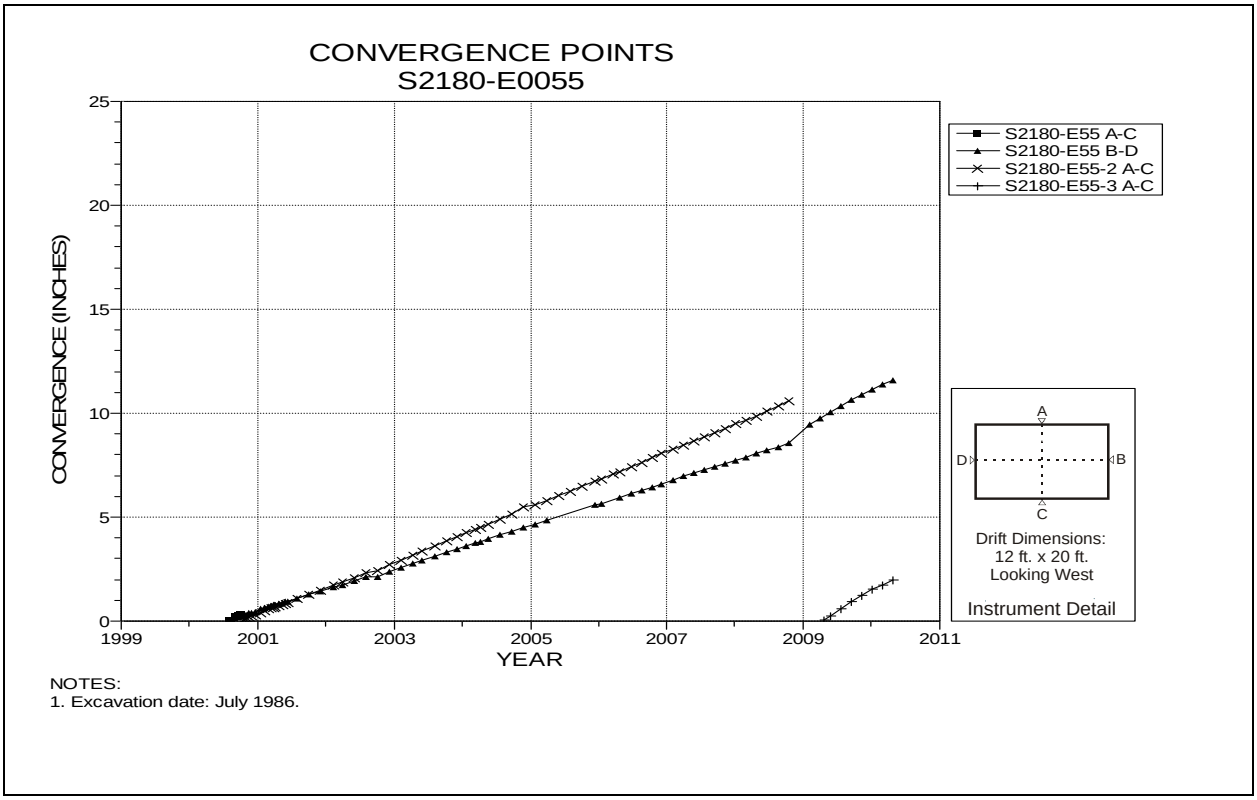


Figure 4-227 Convergence Point Array
S2180 E55 – All Chords

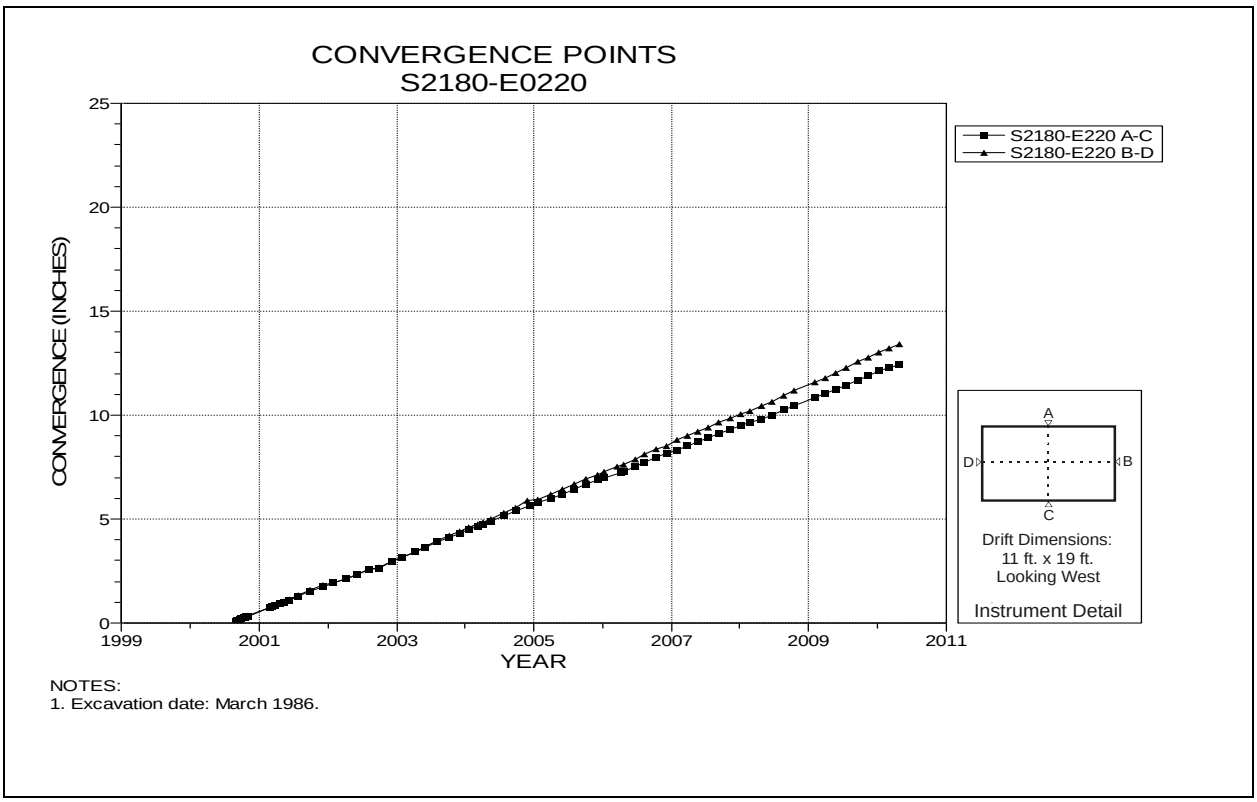


Figure 4-228 Convergence Point Array
S2180 E220 – All Chords

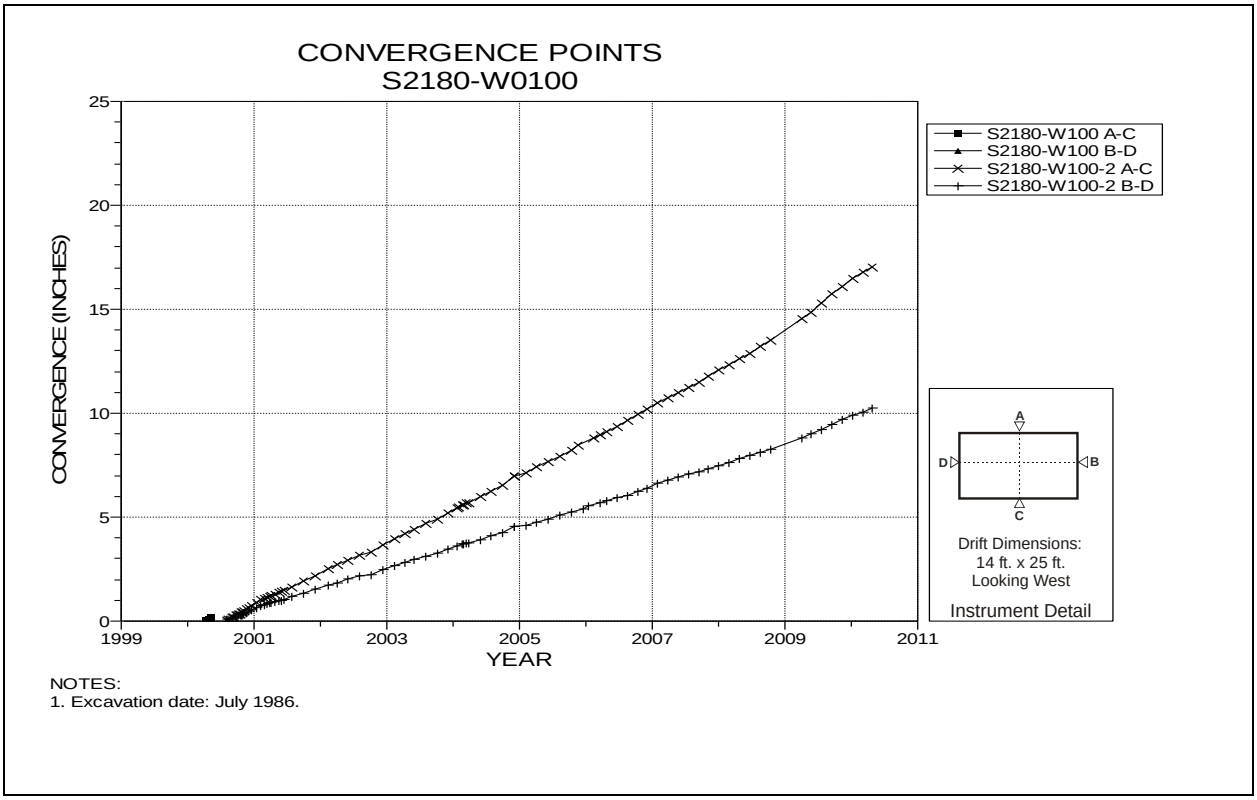


Figure 4-229 Convergence Point Array
S2180 W100 – All Chords

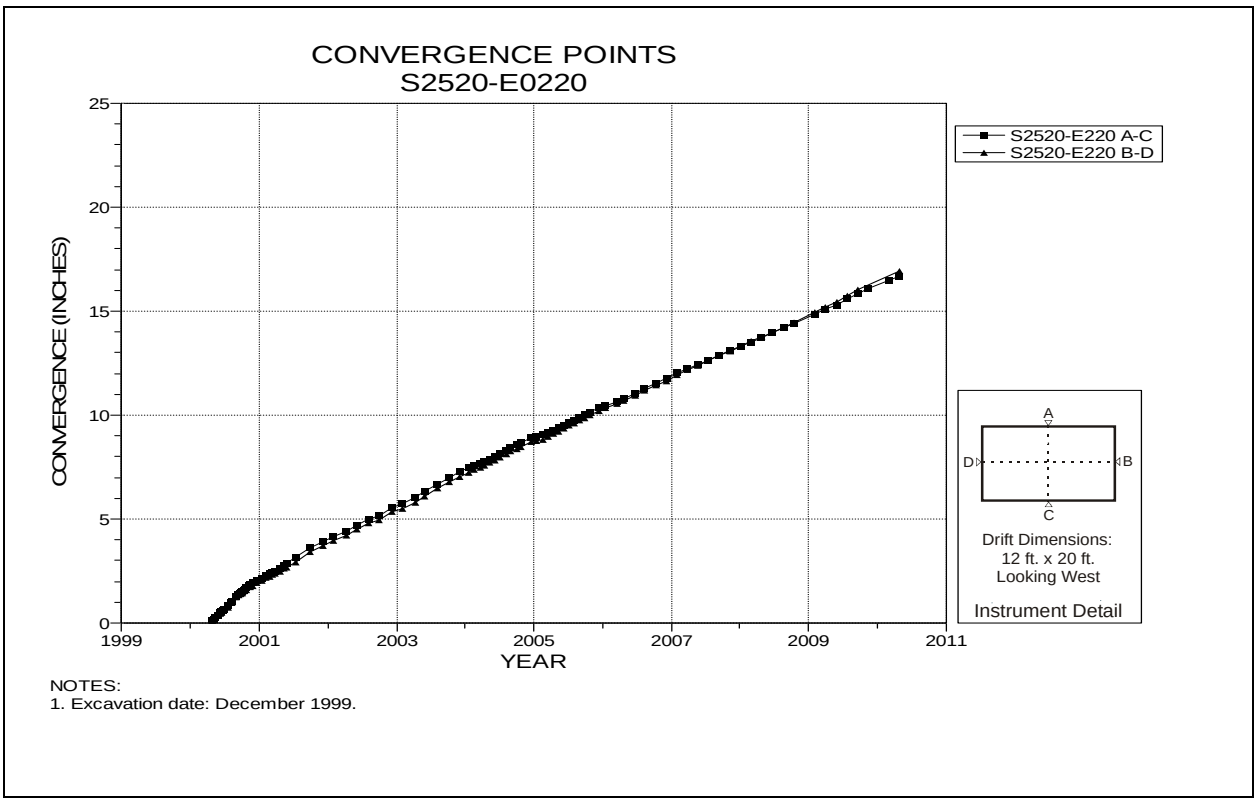


Figure 4-230 Convergence Point Array
S2520 E220 – All Chords

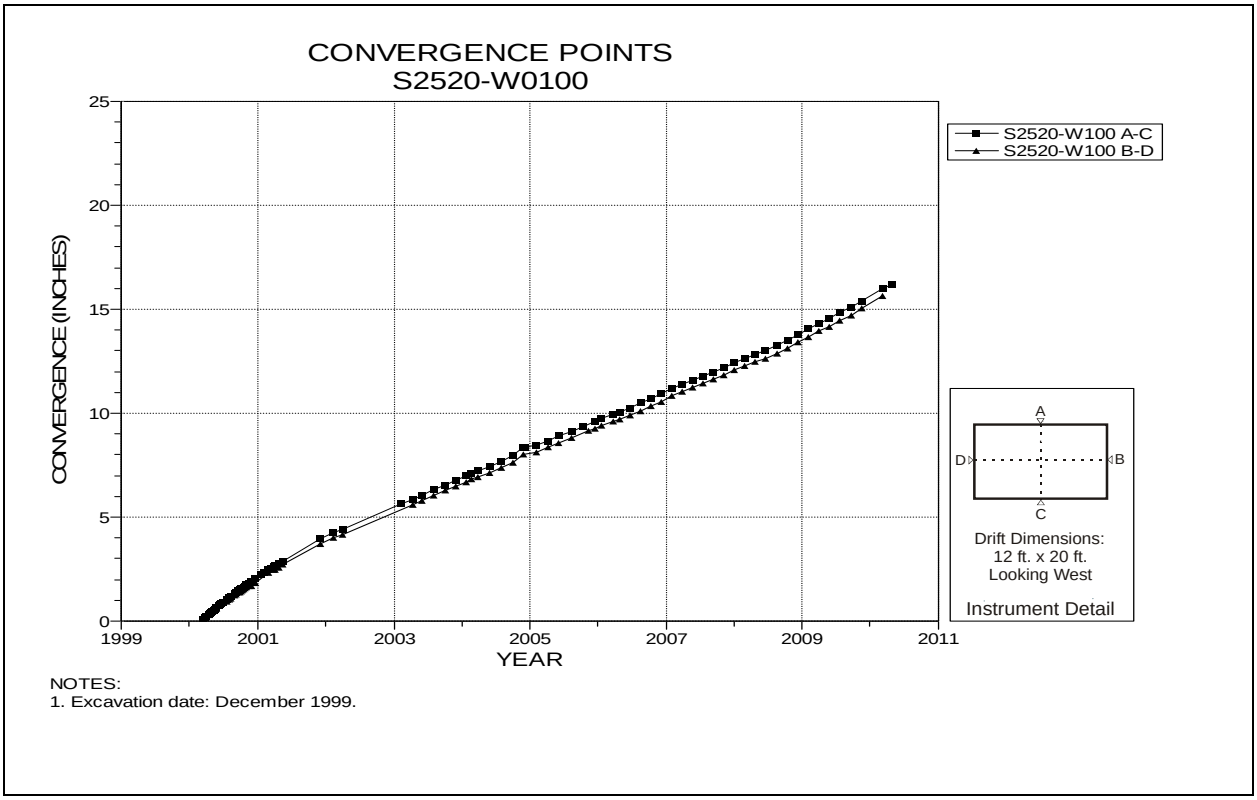


Figure 4-231 Convergence Point Array
S2520 W100 – All Chords

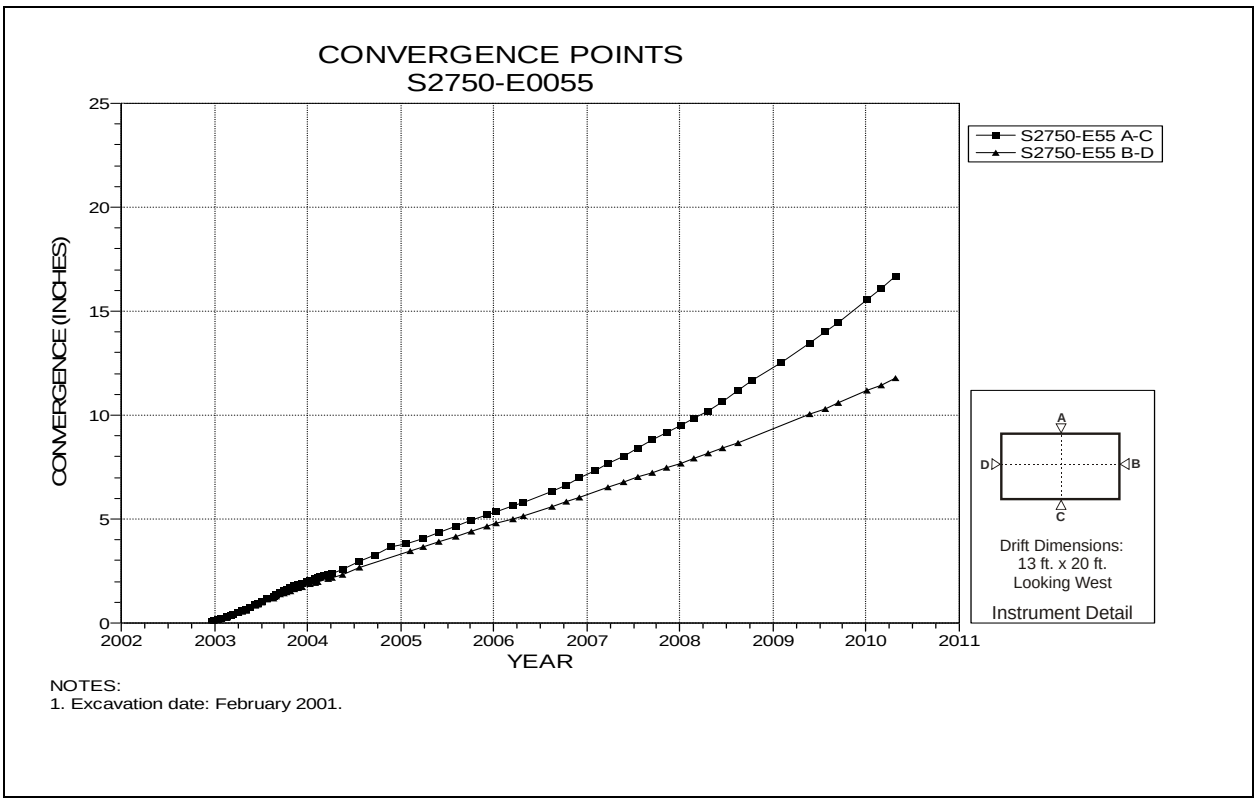


Figure 4-232 Convergence Point Array
S2750 E55 – All Chords

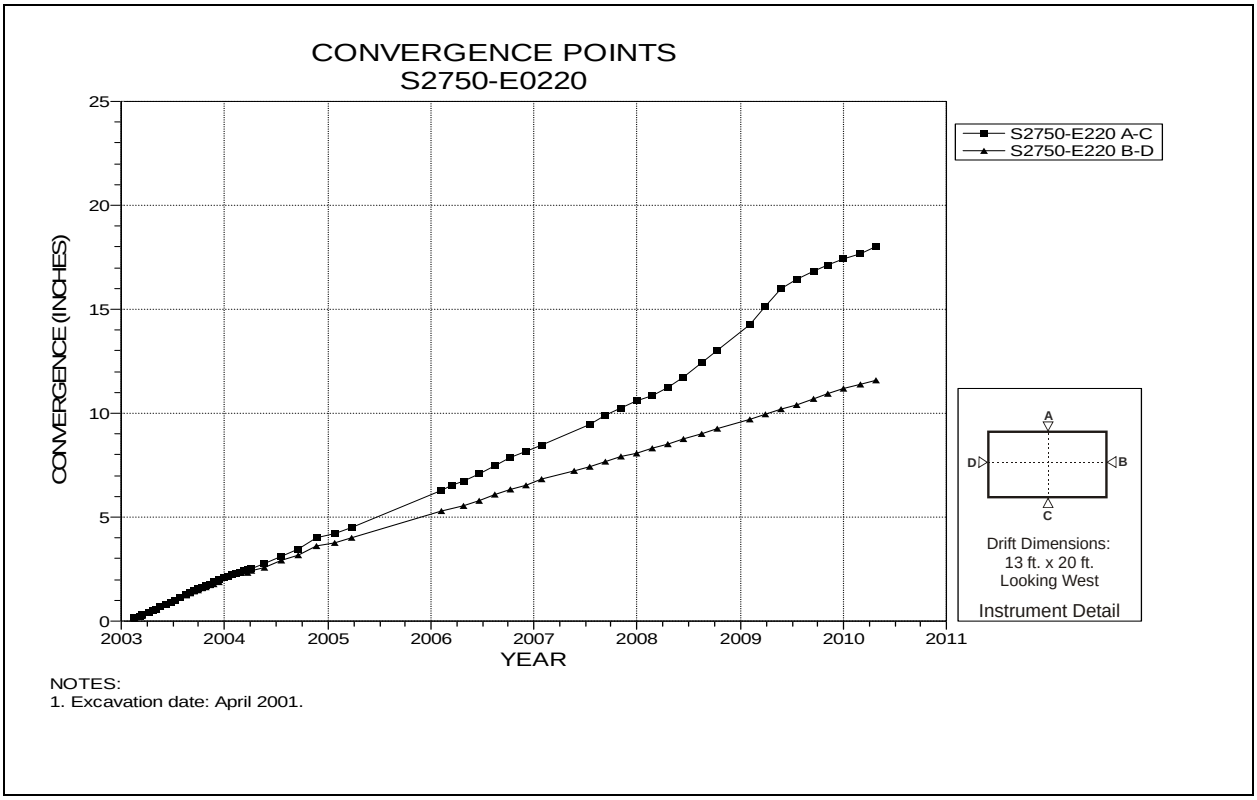


Figure 4-233 Convergence Point Array
S2750 E220 – All Chords

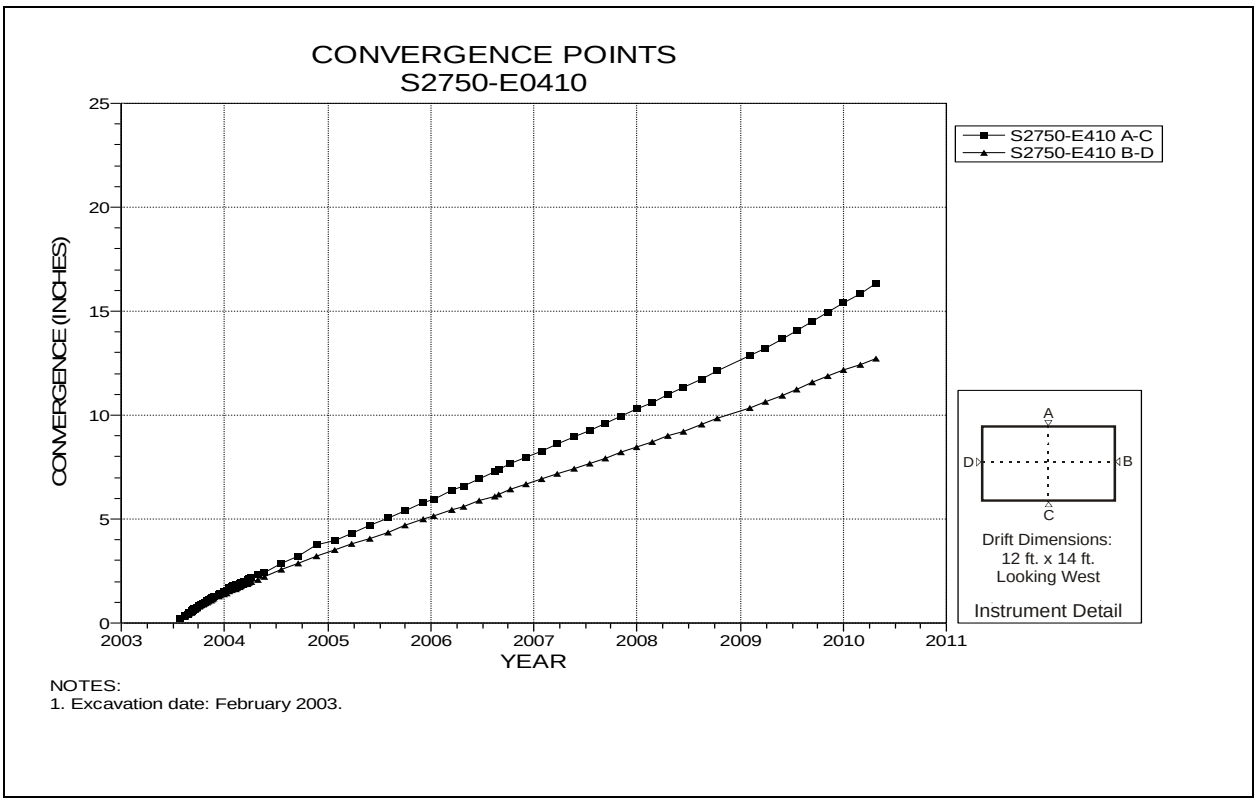


Figure 4-234 Convergence Point Array
S2750 E410 – All Chords

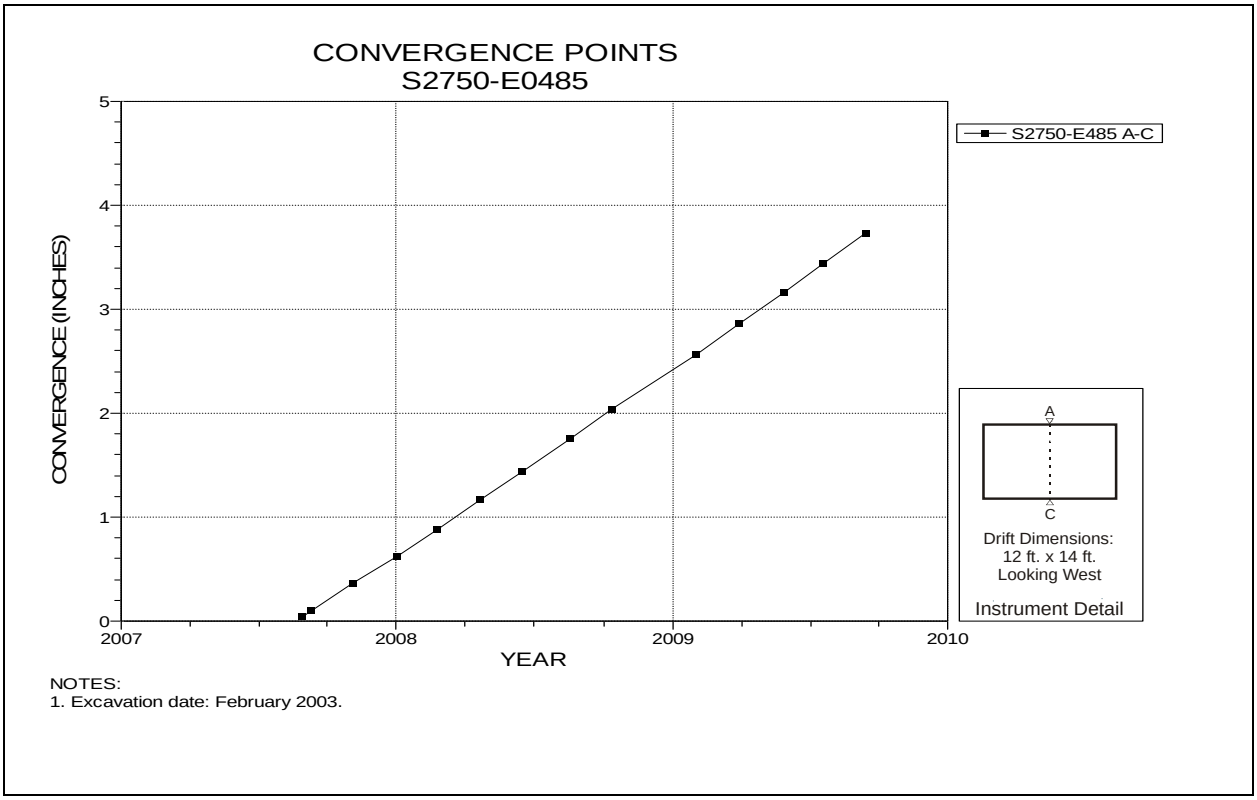


Figure 4-235 Convergence Point Array
S2750 E485 – Roof to Floor

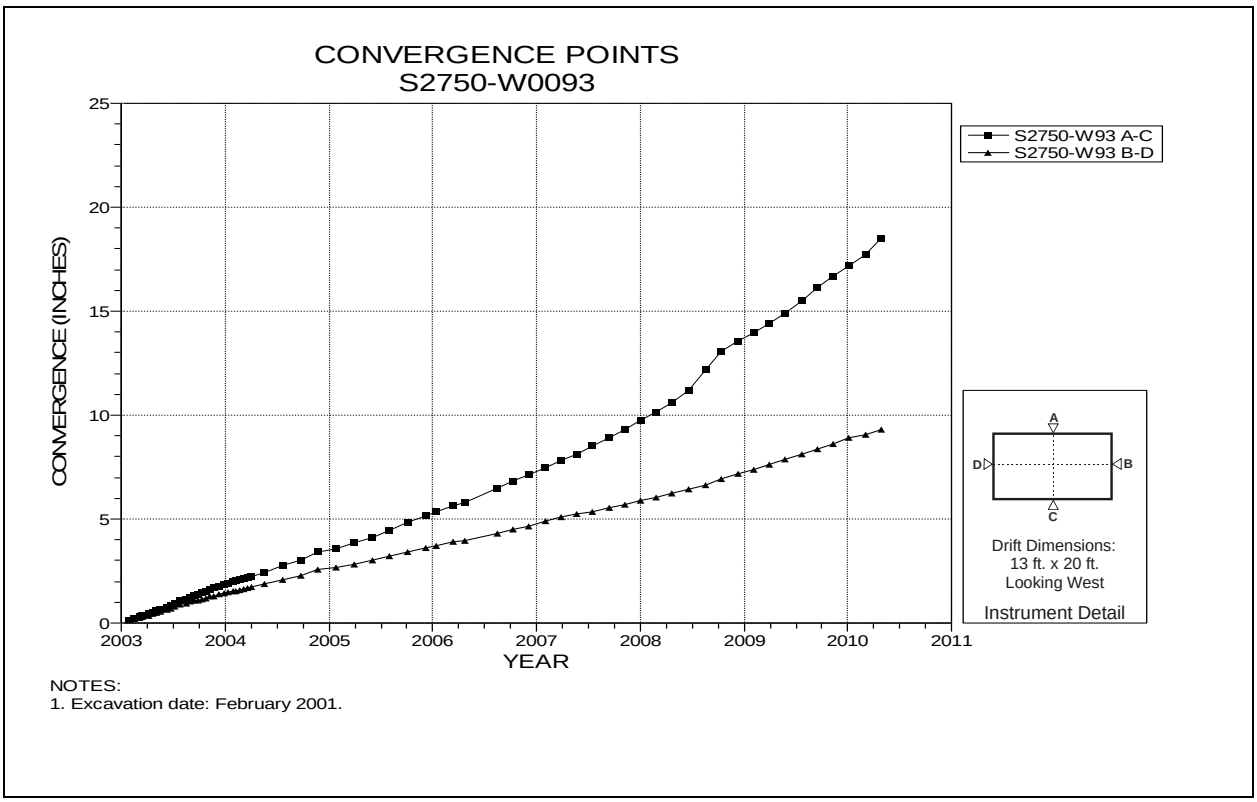


Figure 4-236 Convergence Point Array
S2750 W93 – All Chords

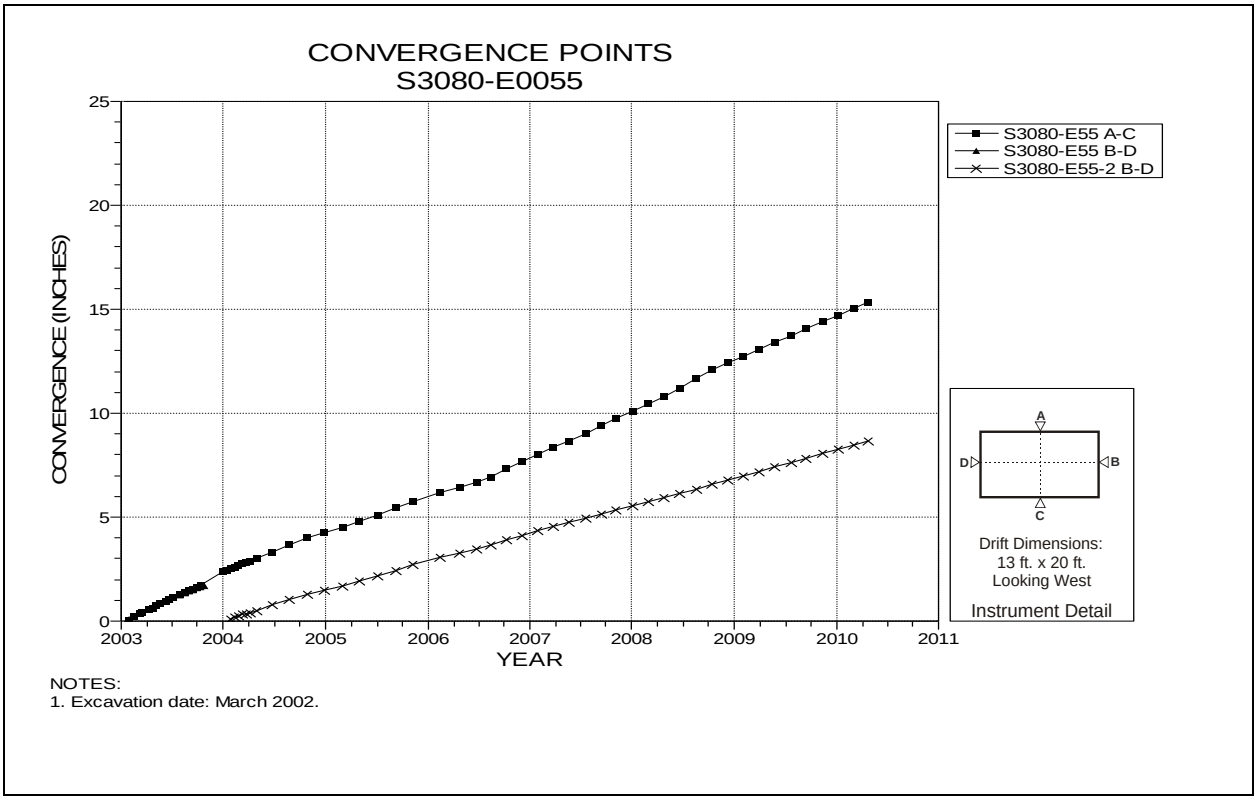


Figure 4-237 Convergence Point Array
S3080 E55 – All Chords

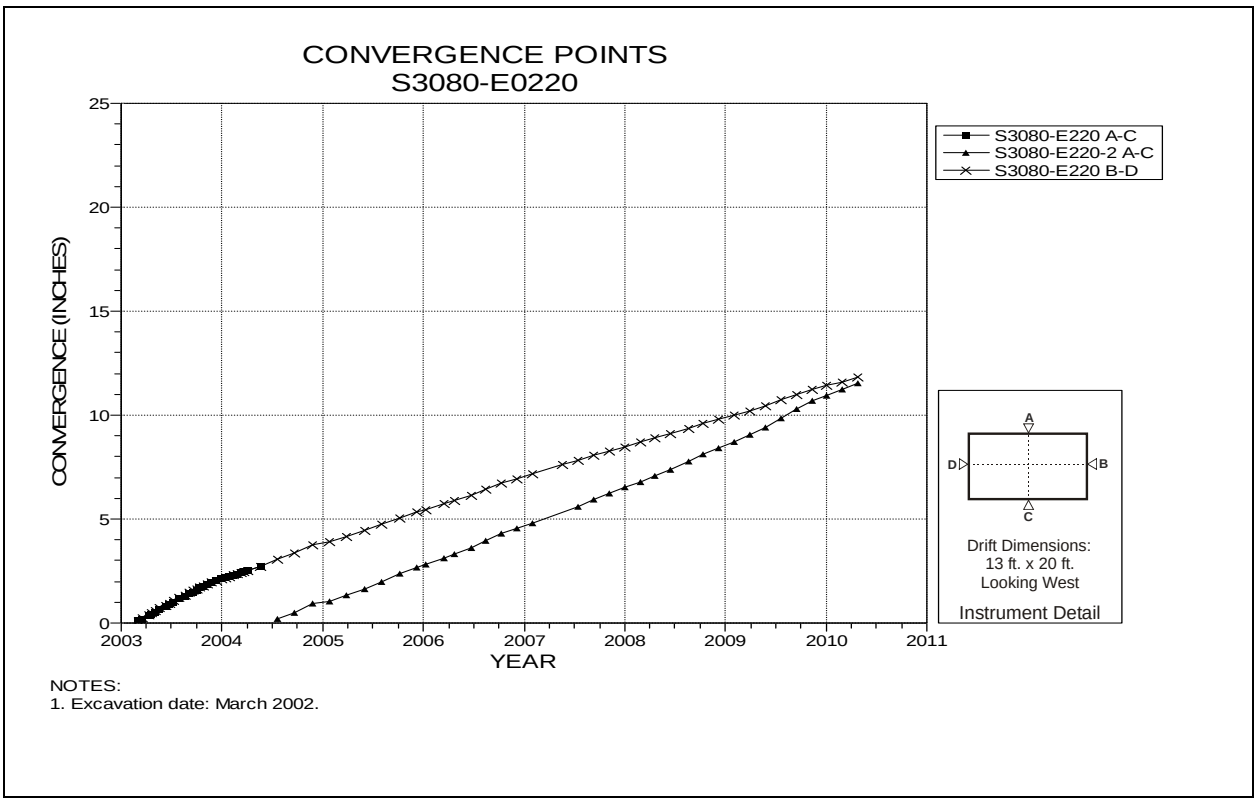


Figure 4-238 Convergence Point Array
S3080 E220 – All Chords

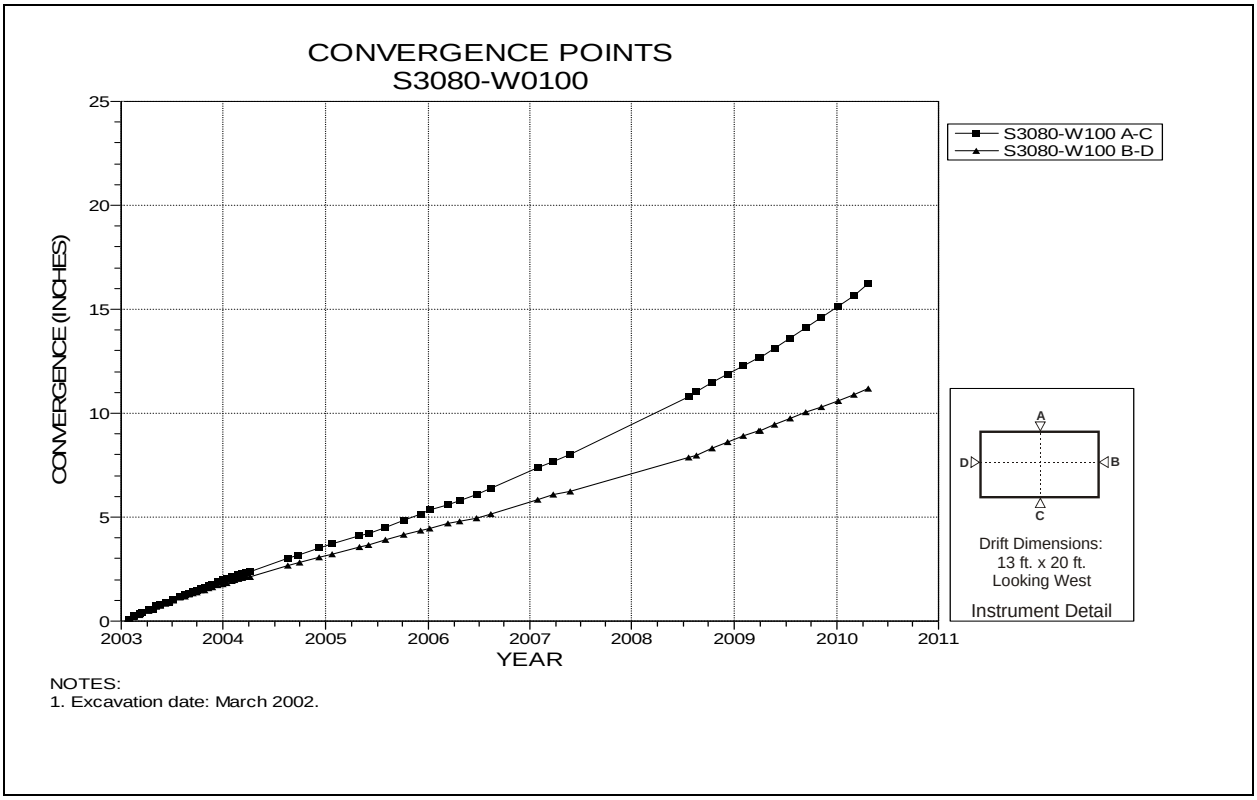


Figure 4-239 Convergence Point Array
S3080 W100 – All Chords

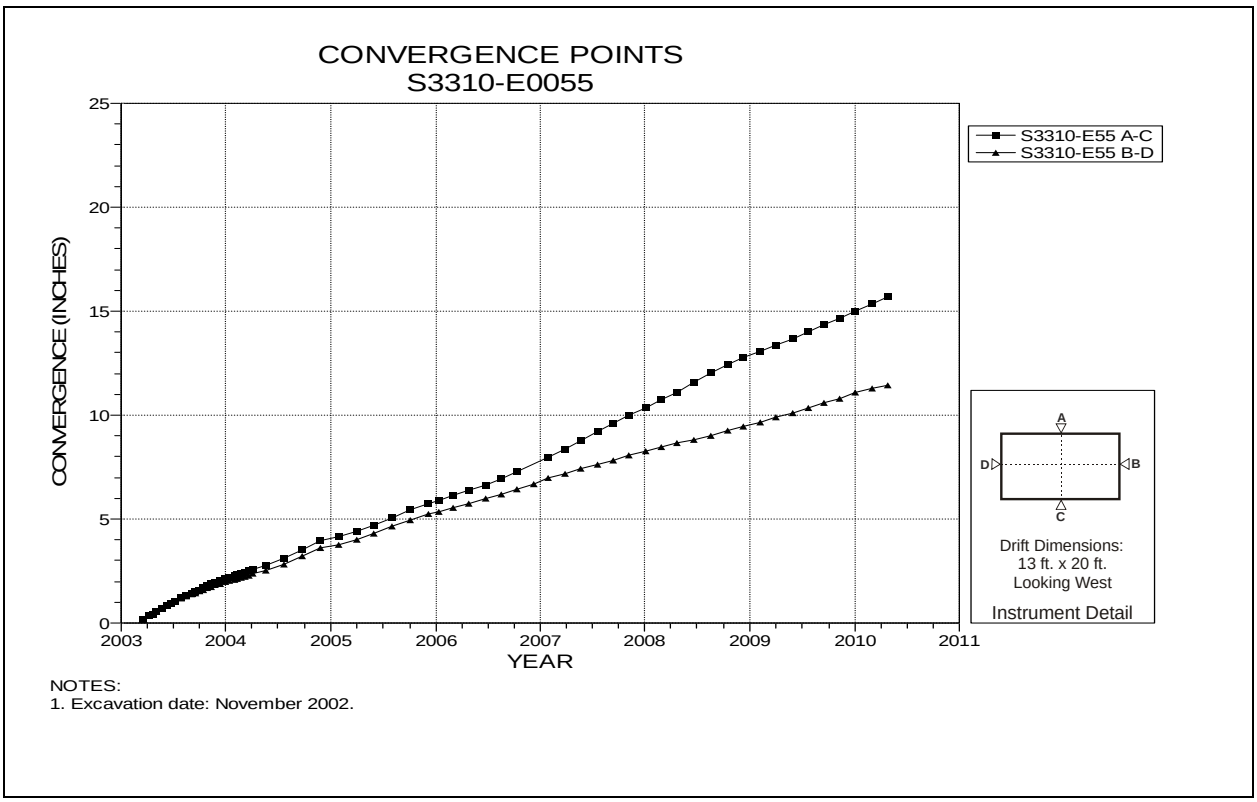


Figure 4-240 Convergence Point Array
S3310 E55 – All Chords

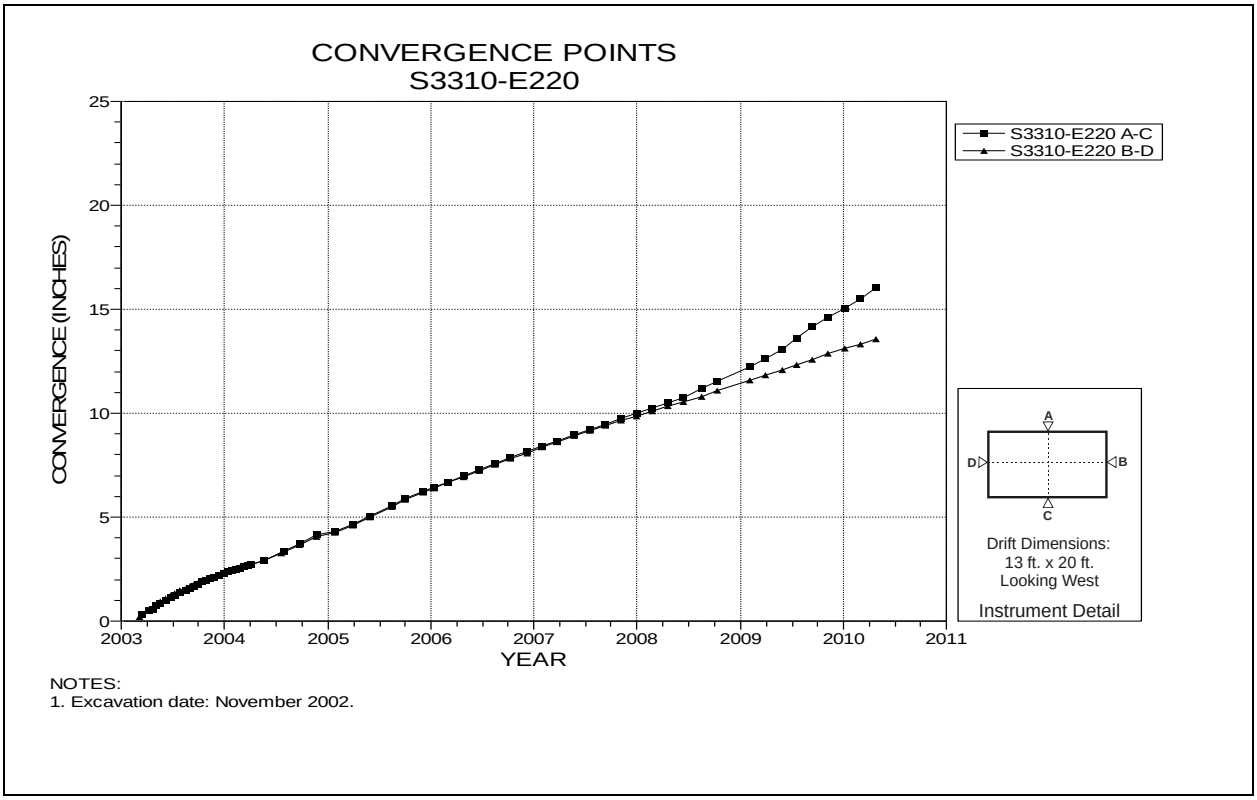


Figure 4-241 Convergence Point Array
S3310 E220 – All Chords

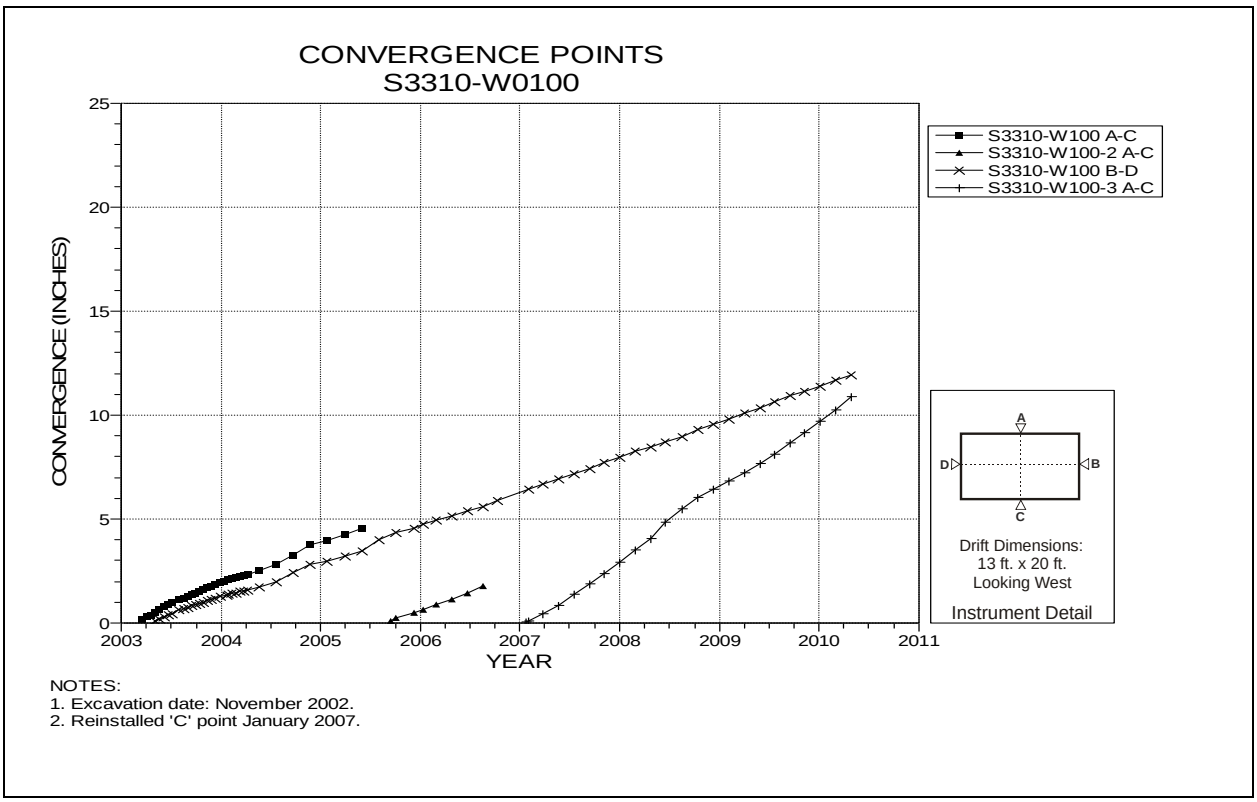


Figure 4-242 Convergence Point Array
S3310 W100 – All Chords

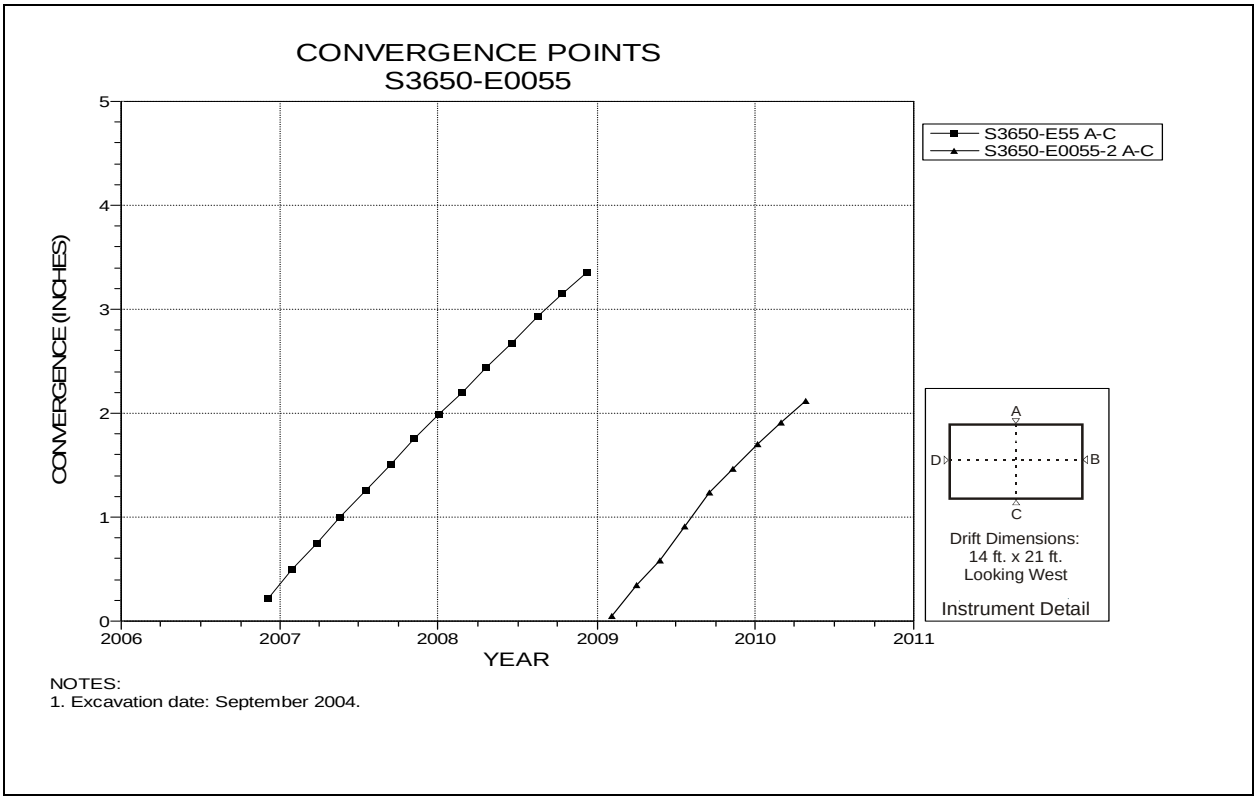


Figure 4-243 Convergence Point Array
S3650 E55 – Roof to Floor

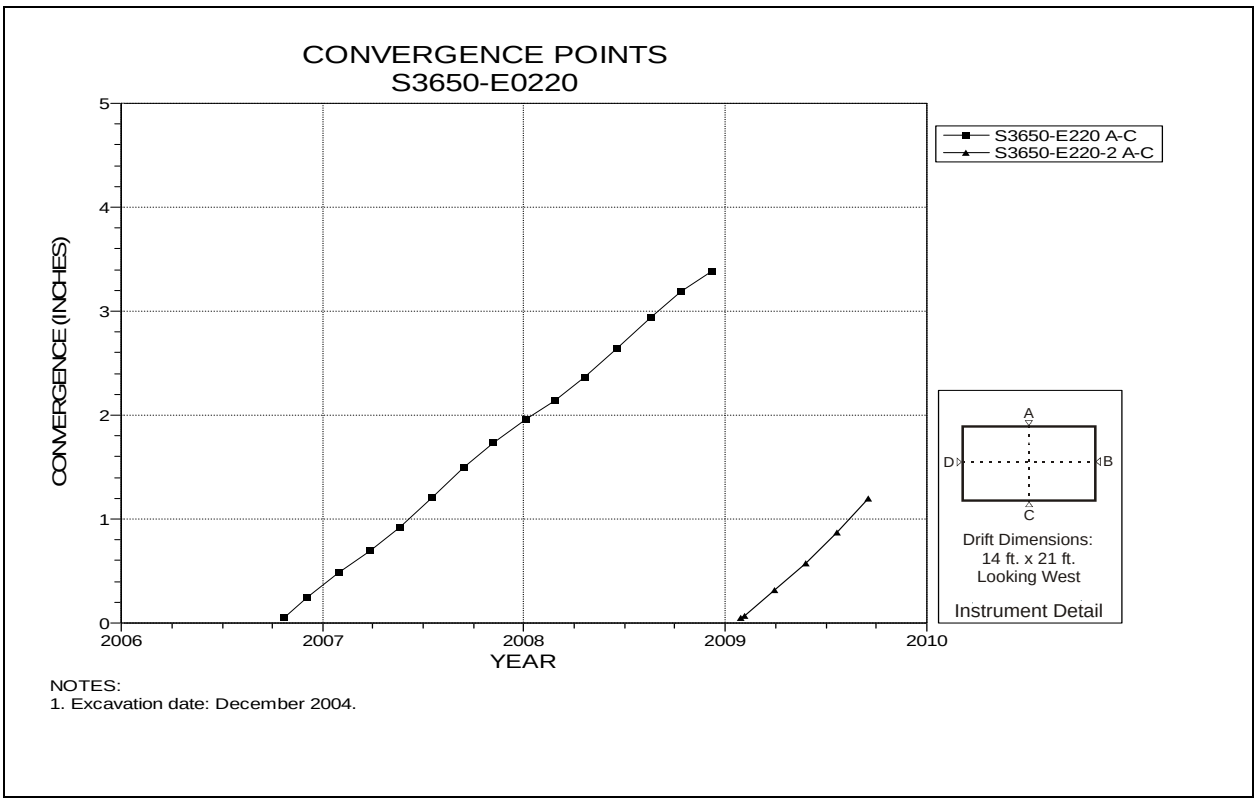


Figure 4-244 Convergence Point Array
S3650 E220 – Roof to Floor

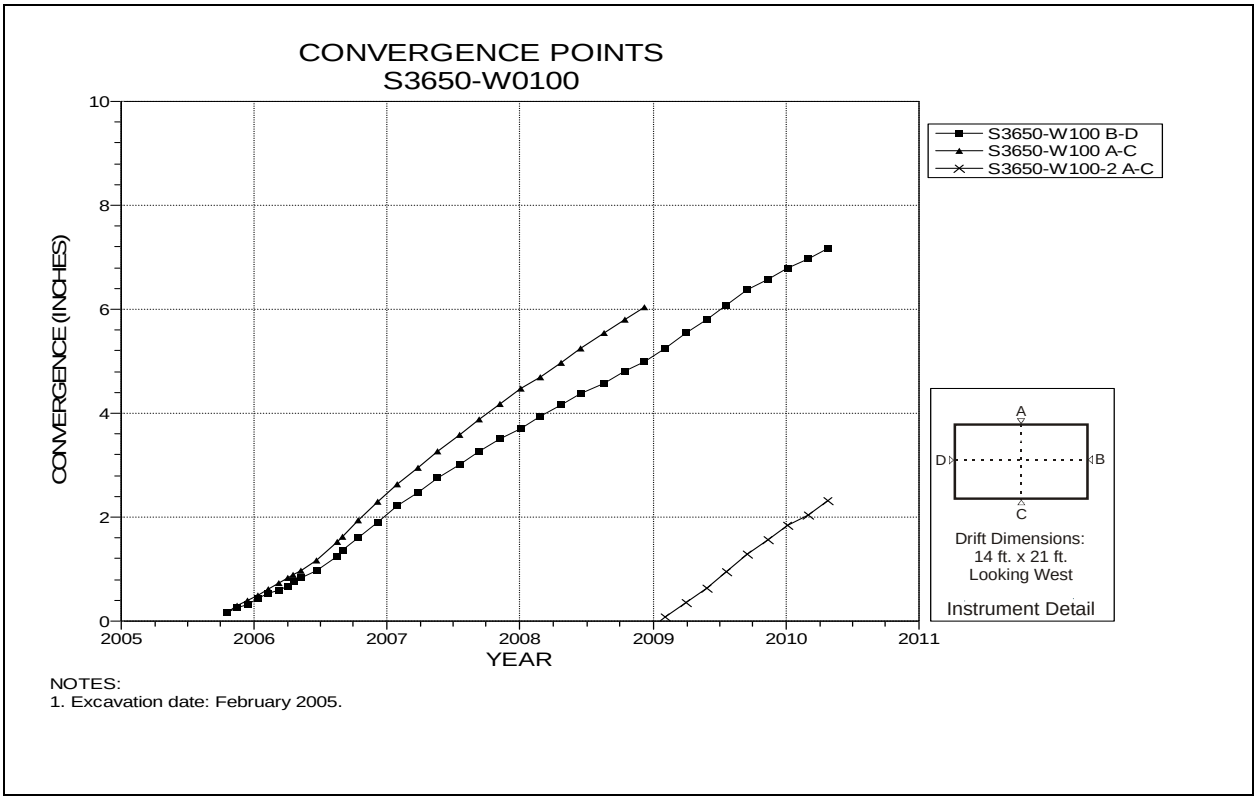


Figure 4-245 Convergence Point Array
S3650 W100 – All Chords

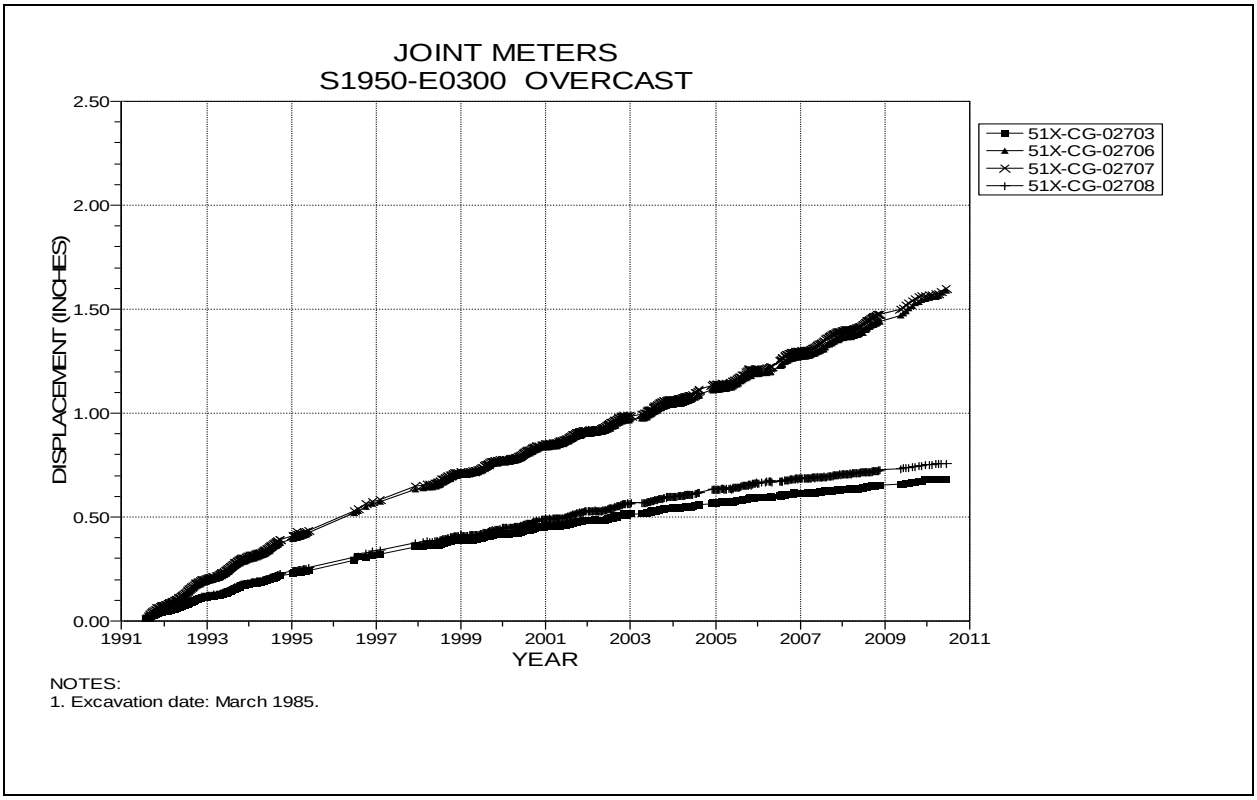


Figure 4-246 Joint Meters
S1950 E300 Overcast

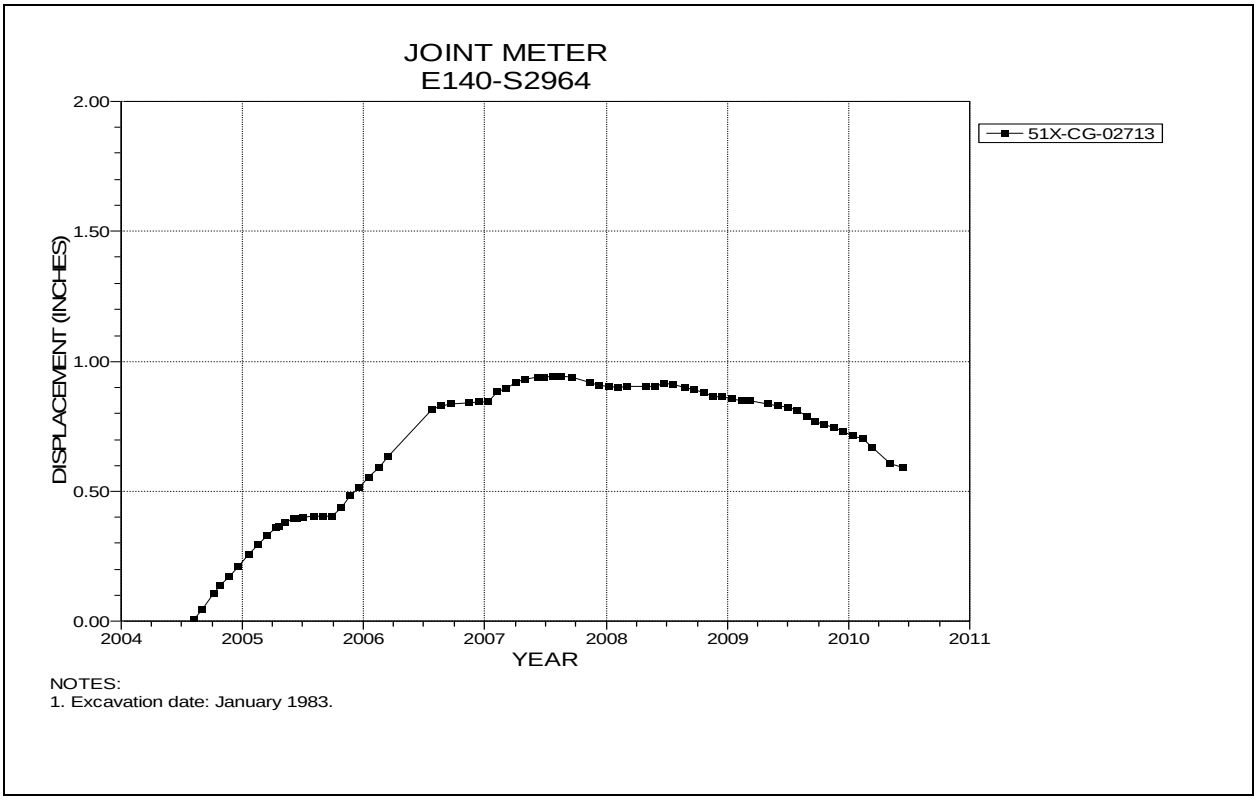


Figure 4-247 Joint Meter
E140 S2964

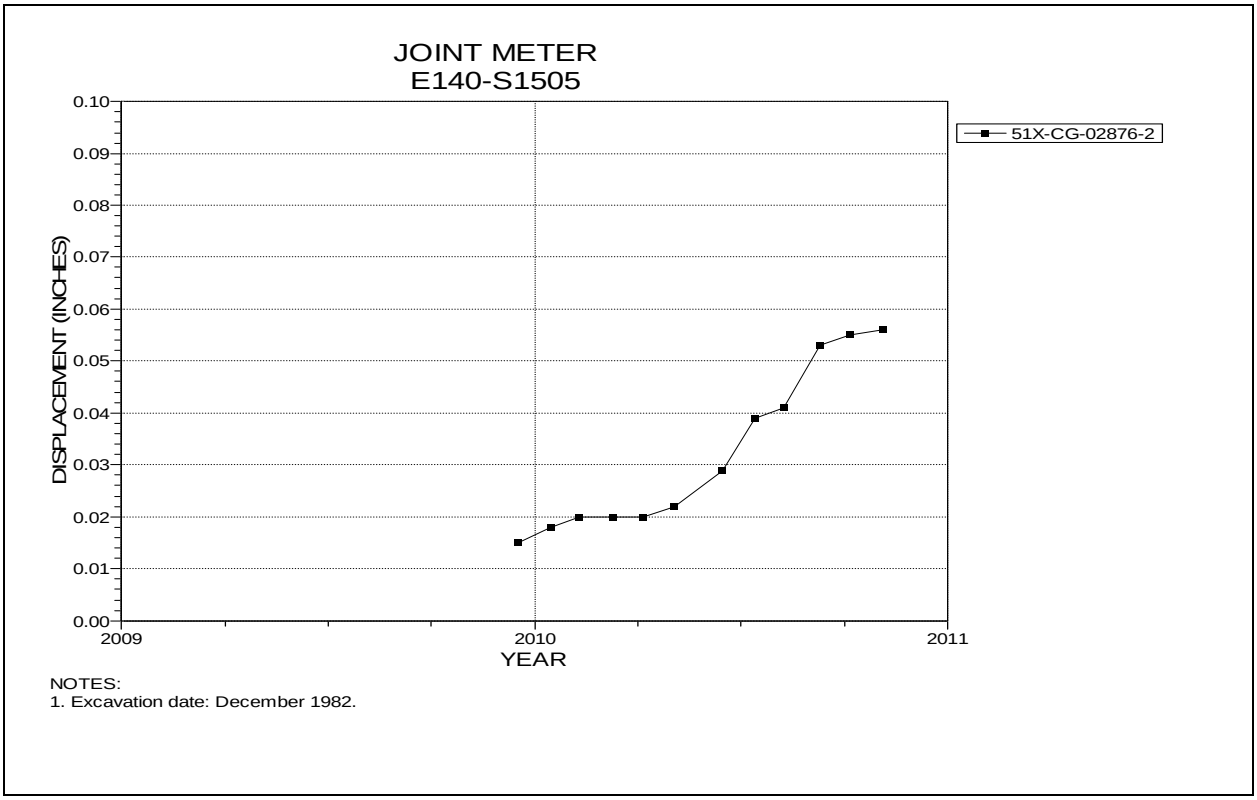


Figure 4-248 Joint Meter
E140 S1505

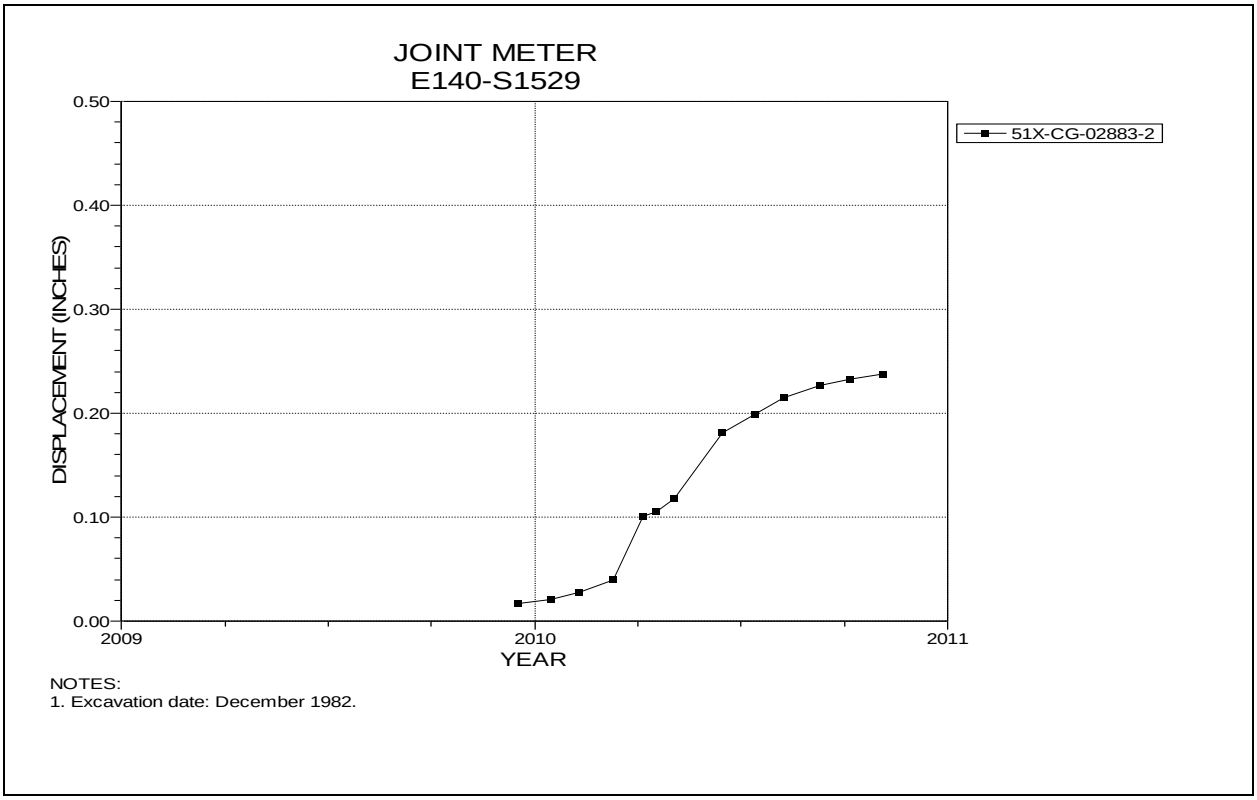


Figure 4-249 Joint Meter
E140 S1529

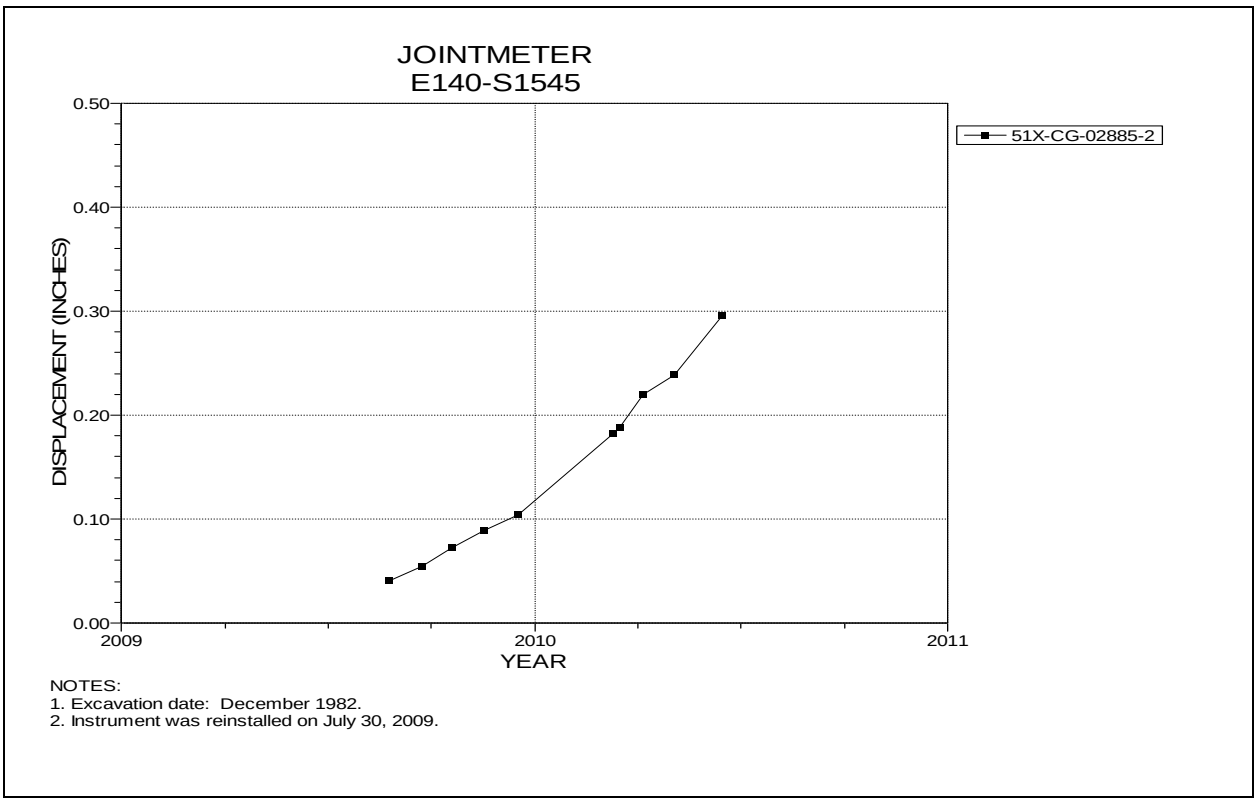


Figure 4-250 Joint Meter
E140 S1545

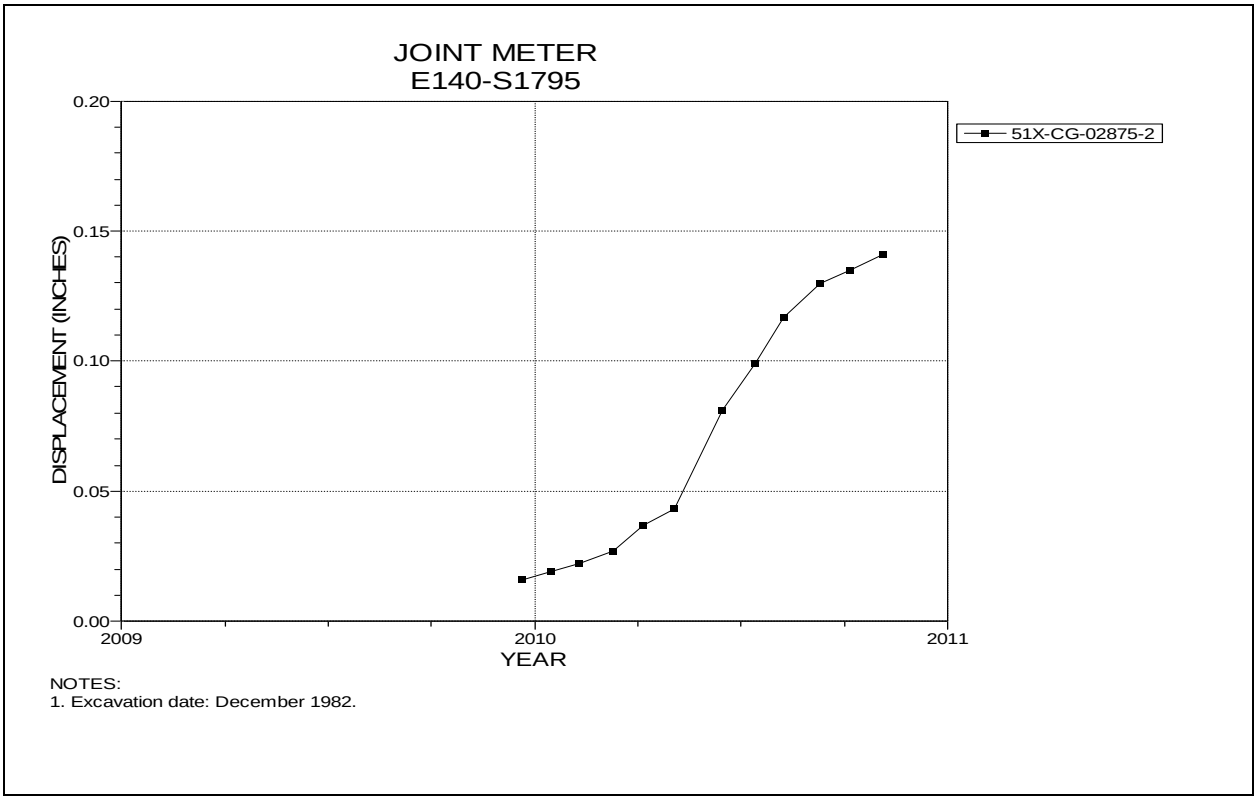


Figure 4-251 Joint Meter
E140 S1795

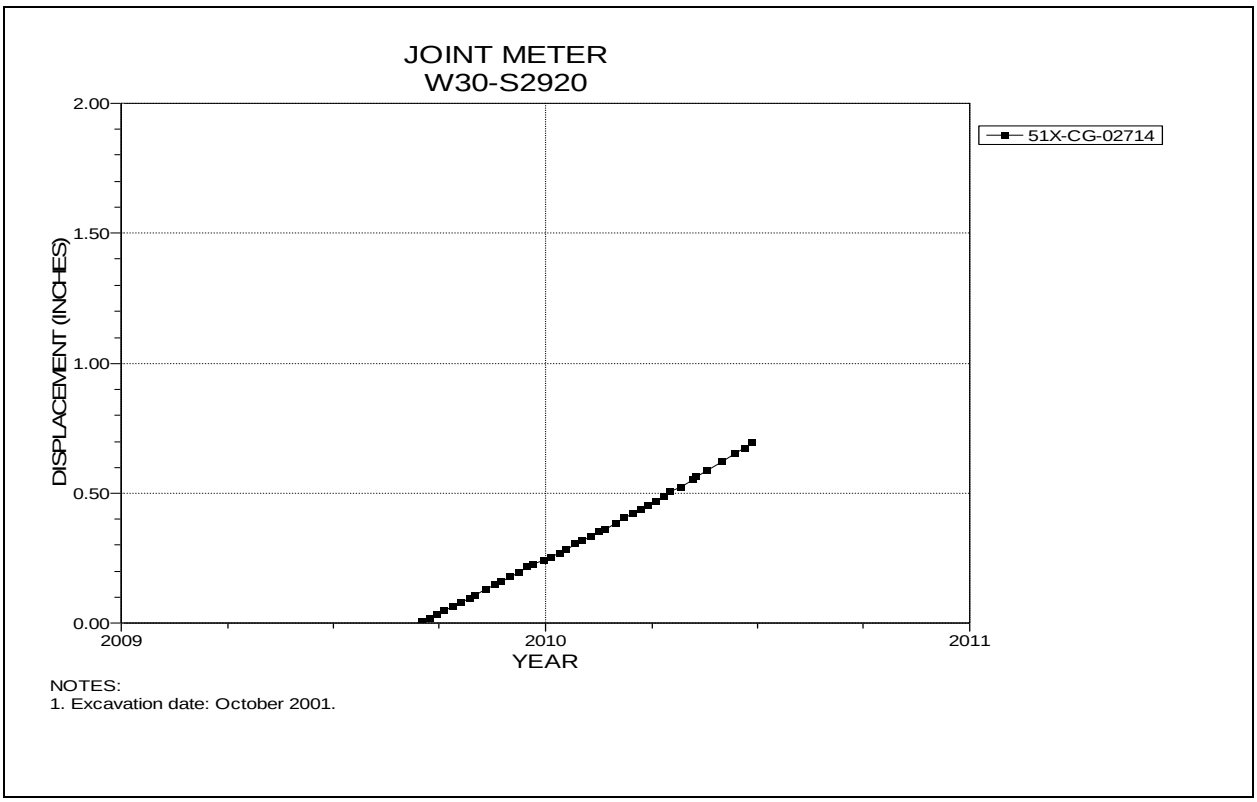


Figure 4-252 Joint Meter
W30 S2920

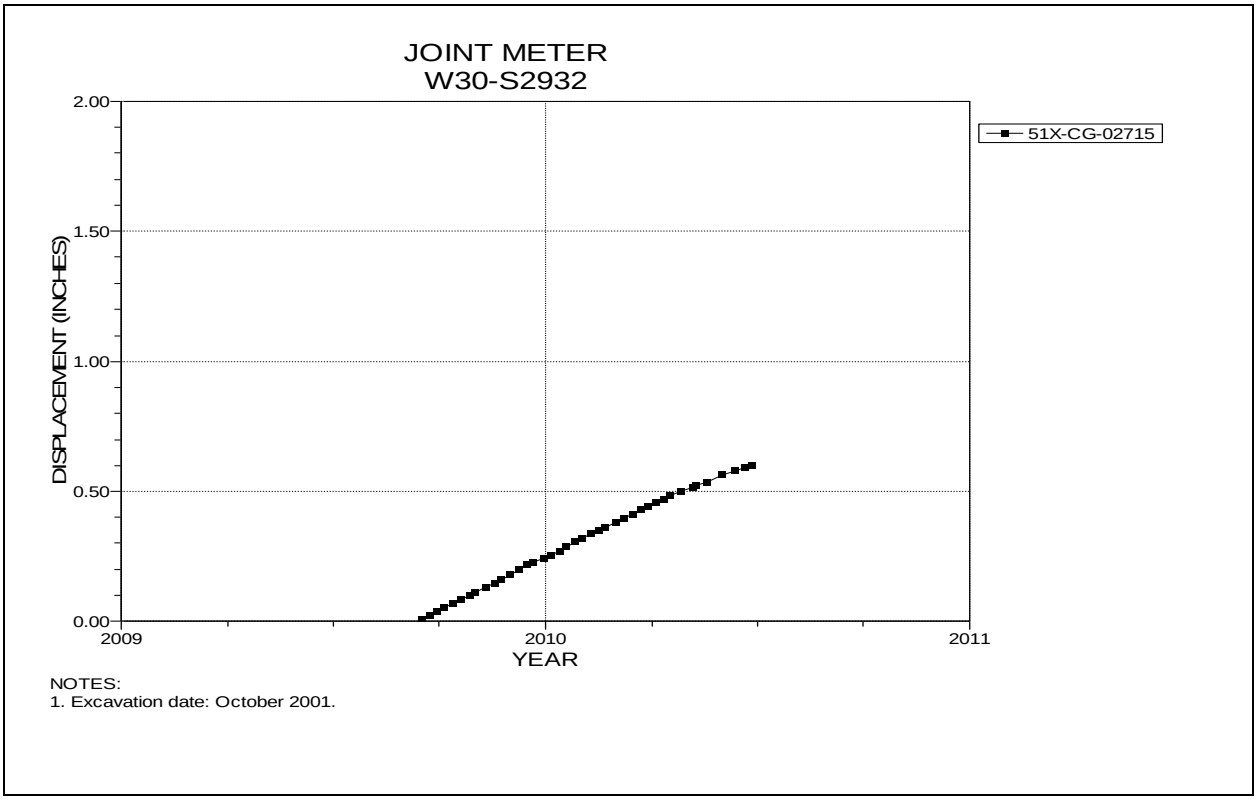


Figure 4-253 Joint Meter
W30 S2932

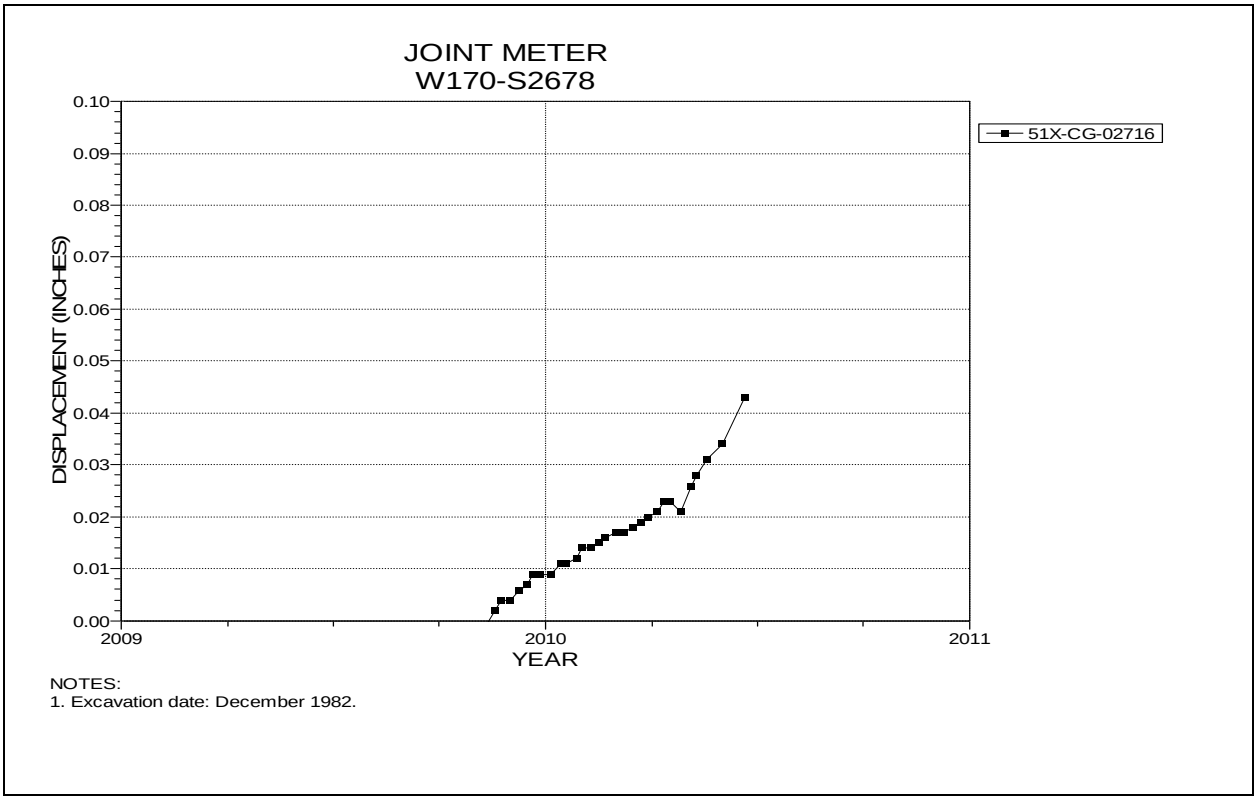


Figure 4-254 Joint Meter
W170 S2678

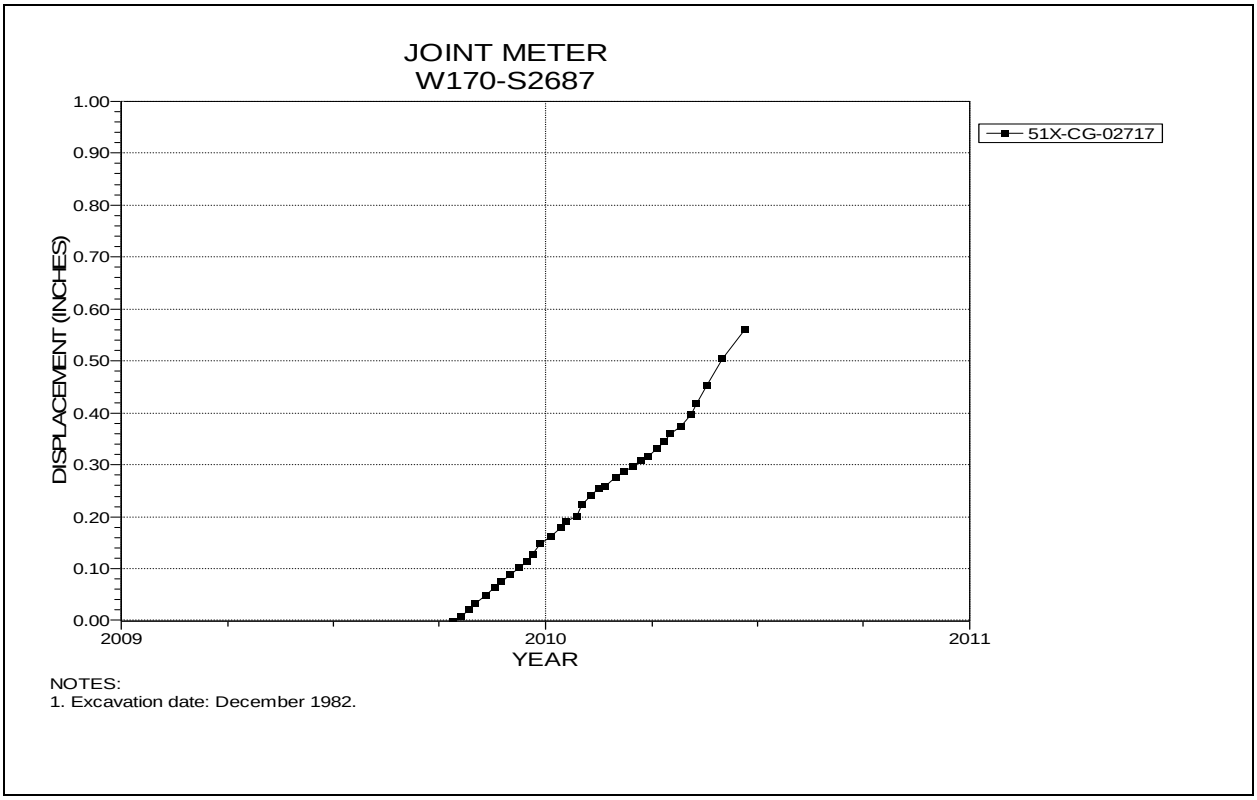


Figure 4-255 Joint Meter
W170 S2687

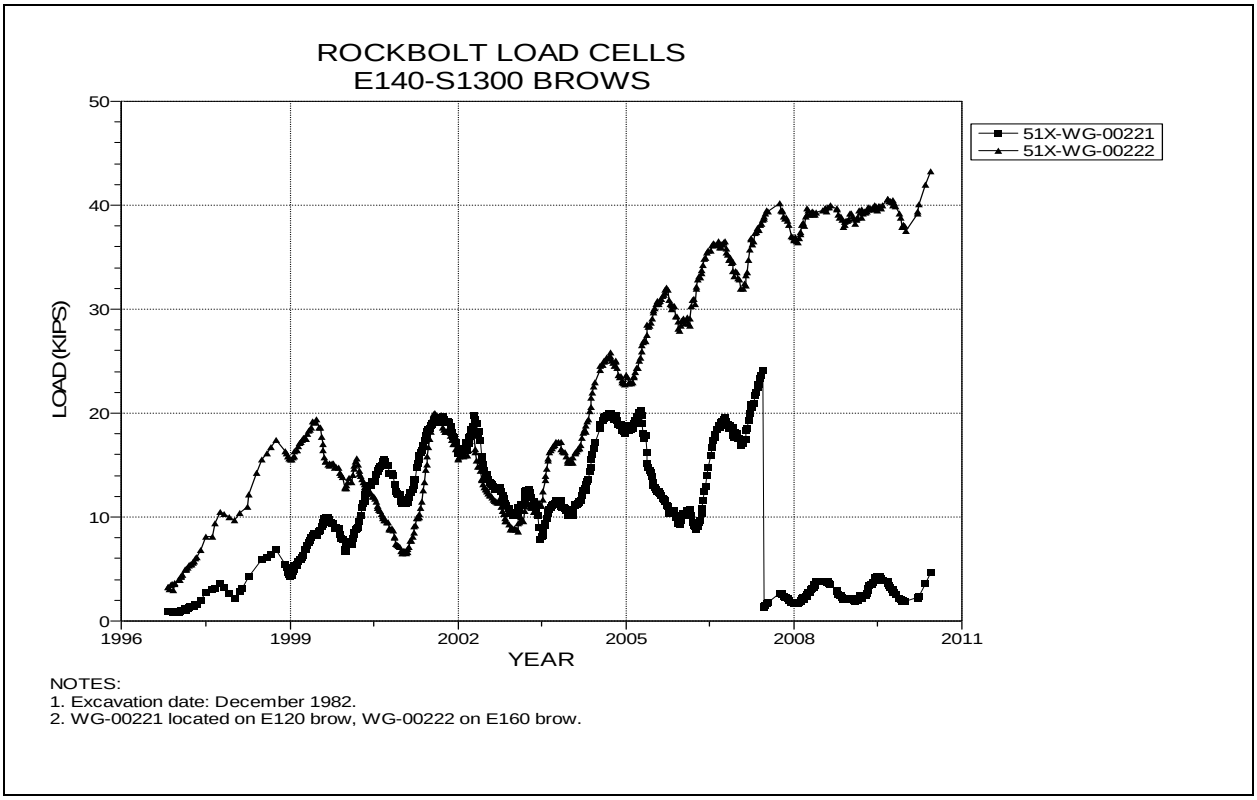


Figure 4-256 Rock Bolt Load Cells
E140 S1300 Brows

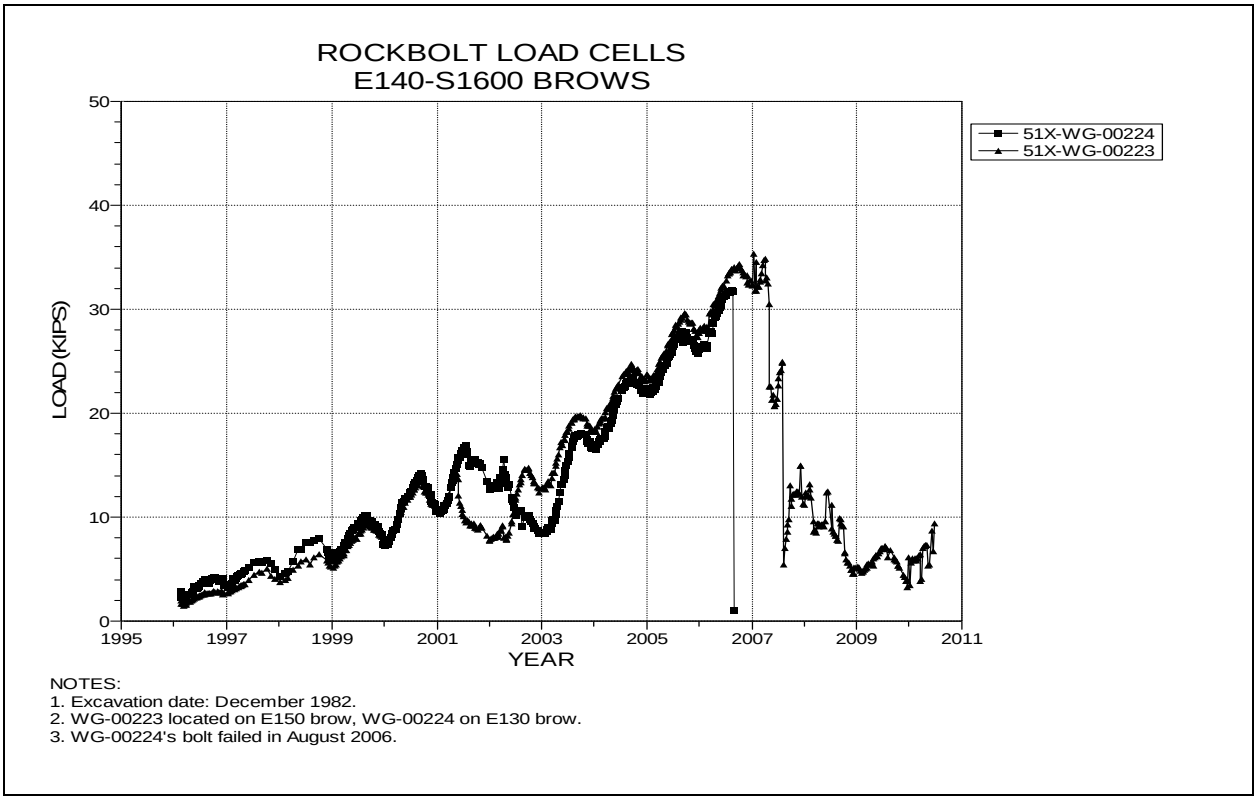
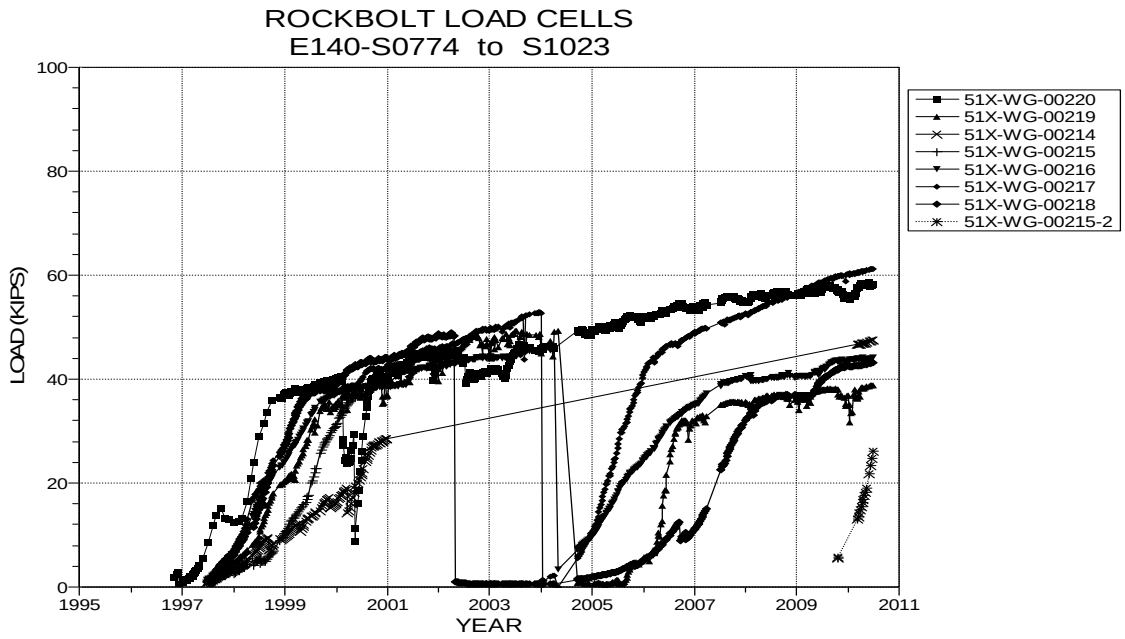
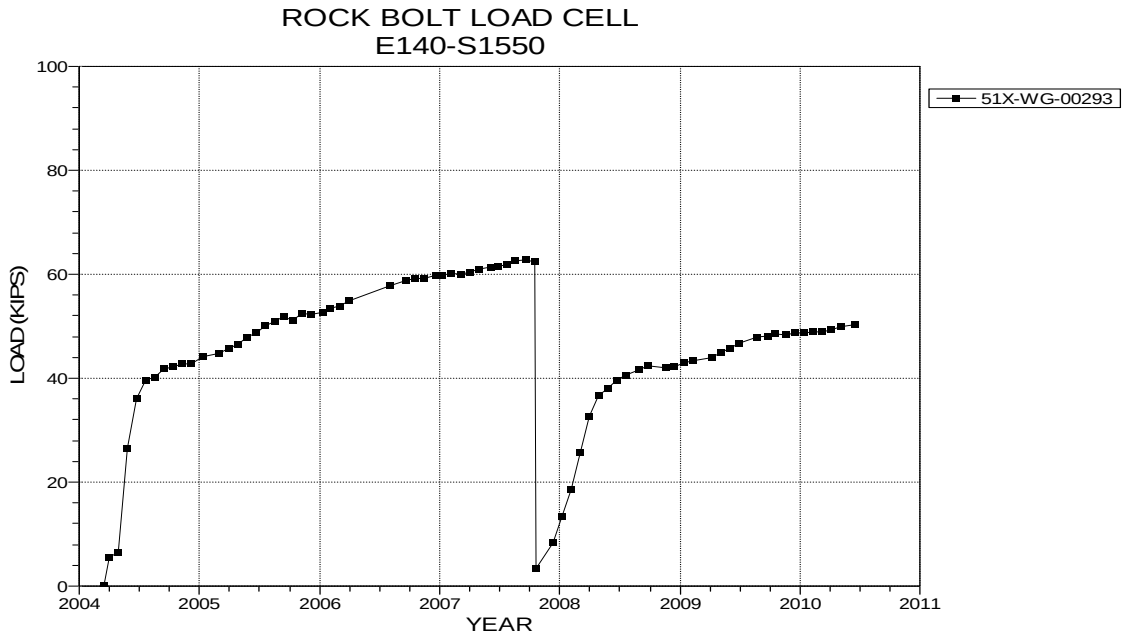


Figure 4-257 Rock Bolt Load Cells
E140 S1600 Brows



NOTES:
1. 51X-WG-00215-2 is WG-00215 installed on a replacement bolt.

Figure 4-258 Rock Bolt Load Cells
E140 S774 to S1023



NOTES:
1. Excavation date: December 1982.
2. Bolt broke in October 2007 and was reinstalled.

Figure 4-259 Rock Bolt Load Cell
E140 S1550

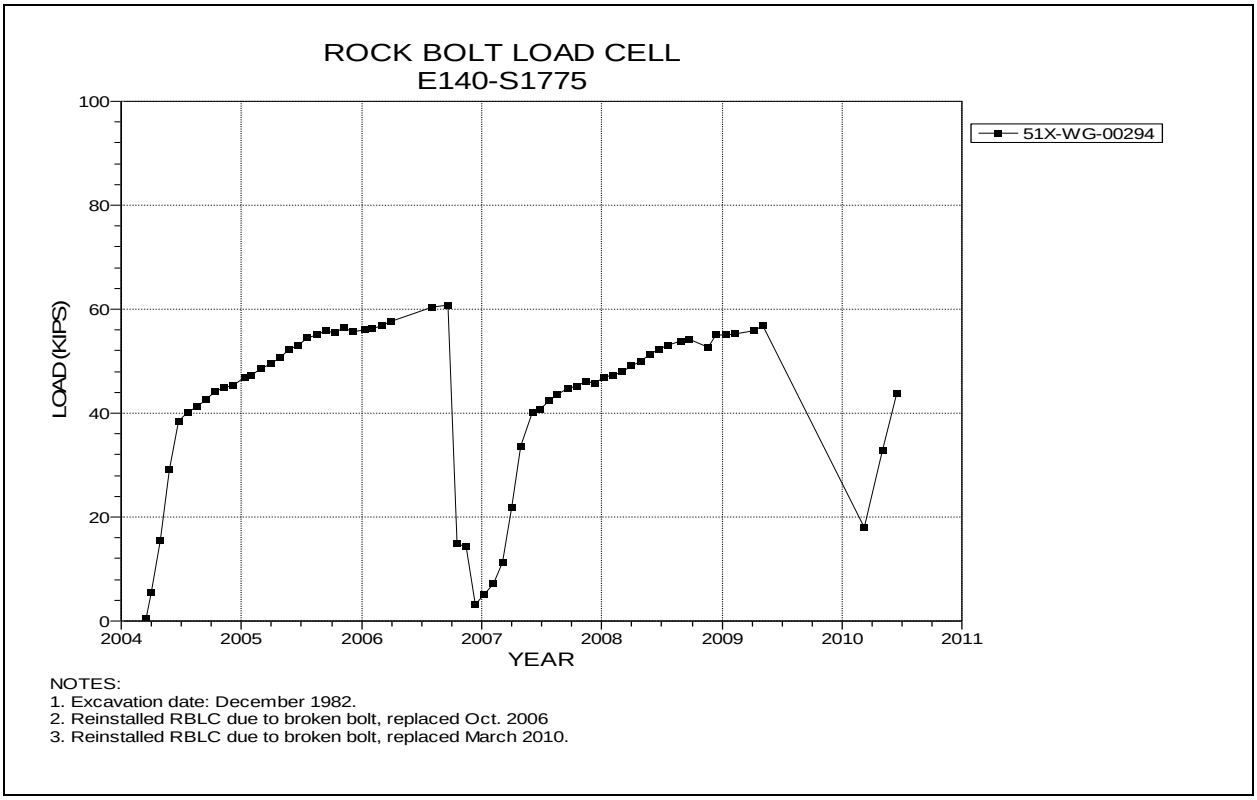


Figure 4-260 Rock Bolt Load Cell
E140 S1775

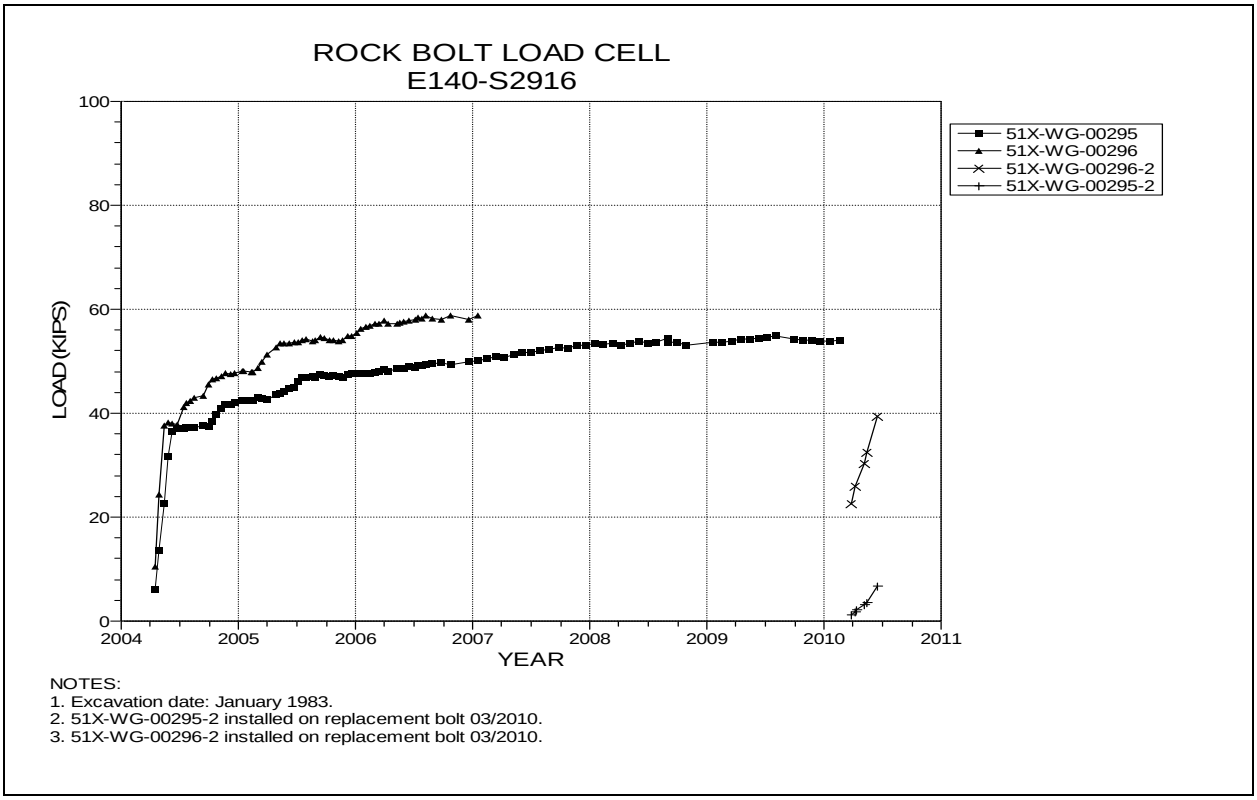


Figure 4-261 Rock Bolt Load Cell
E140 S2916

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5.0 Instrumentation Summary for the Waste Disposal Area

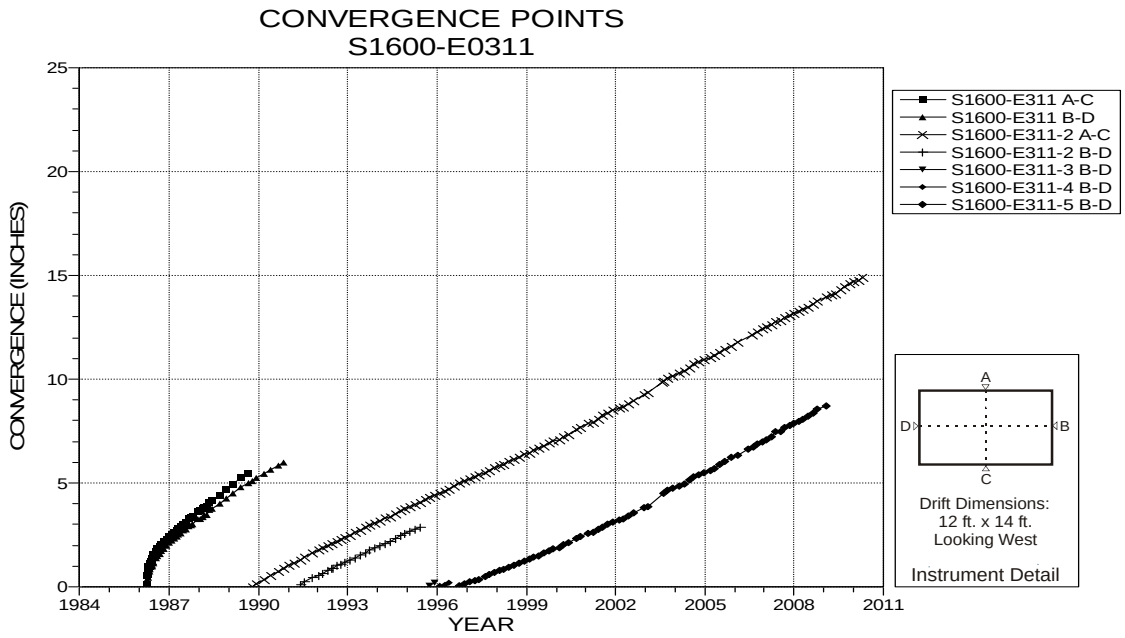
This chapter presents a summary of the data collected from instruments located in the Waste Disposal Area at the WIPP. Table 5-1 presents data and analysis of the access drifts associated with Panel 1. Plots of the instrument data are presented as Figures 5-1 through 5-16. Table 5-2 presents data and analysis of the access drifts associated with Panel 2. Plots of the instrument data are presented as Figures 5-17 and 5-18.

Panel 3 data and analysis are presented on Table 5-3. Plots of the instrument data are presented as Figures 5-19 through 5-22. Table 5-4 presents data and analysis of Panel 4. Plots of the instrument data are presented as Figures 5-23 through 5-30. Table 5-5 presents data and analysis of Panel 5. Plots of the instrument data are presented as Figures 5-31 through 5-95. Table 5-6 presents data and analysis of Panel 6. Plots of the instrument data are presented as Figures 5-96 through 5-155.

Table 5-1
Panel 1 Access Drifts Data Analysis

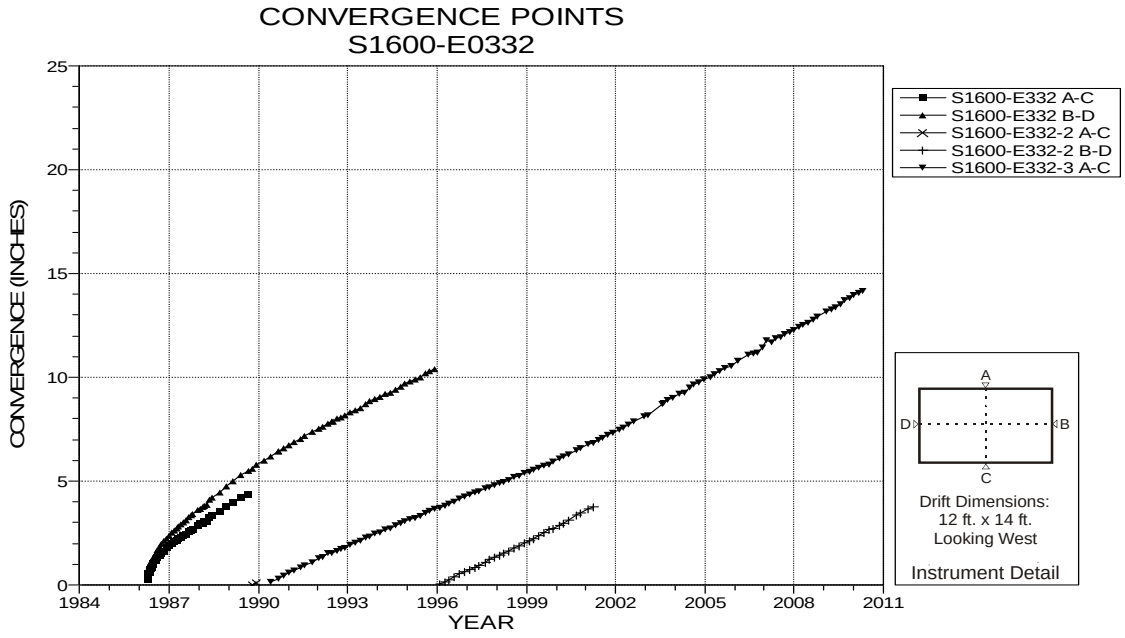
CONVERGENCE POINTS

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
S1600-E311-2 A-C	S1600-E311	5-1	04/26/10	14.86	20.311	0.74	0.67	10%	
S1600-E332-3 A-C	S1600-E332	5-2	04/26/10	14.16	18.584	0.85	0.78	9%	
S1600-E357-2 A-C	S1600-E357	5-3	04/26/10	16.49	21.883	0.77	1.24	-38%	
S1600-E382-2 A-C	S1600-E382	5-4	04/26/10	16.39	21.768	0.74	1.20	-38%	
S1600-E407-2 A-G	S1600-E407	5-5	04/26/10	18.02	23.462	0.92	1.38	-33%	
S1600-E407-2 B-F	S1600-E407	5-5	04/26/10	16.68	21.688	0.82	1.31	-37%	
S1600-E407-2 H-L	S1600-E407	5-5	04/26/10	17.55	22.611	0.87	1.34	-35%	
S1600-E432-2 A-C	S1600-E432	5-6	04/26/10	20.76	27.518	1.43	1.32	8%	
S1600-E453 A-C	S1600-E453	5-7	04/26/10	3.616	3.616	0.58	0.57	2%	
S1600-E453 B-D	S1600-E453	5-7	04/26/10	3.396	3.396	0.45	0.55	-18%	
S1950-E311-6 A-C	S1950-E311	5-8	04/26/10	7.54	29.391	1.16	1.16	0%	
S1950-E311-3 B-D	S1950-E311	5-8	04/26/10	14.49	27.488	1.32	1.35	-2%	
S1950-E332-4 A-C	S1950-E332	5-9	04/26/10	16.74	35.338	1.48	1.25	18%	
S1950-E332-4 B-D	S1950-E332	5-9	04/26/10	12.10	30.049	1.48	1.35	10%	
S1950-E357-7 A-C	S1950-E357	5-10	04/26/10	21.14	41.299	2.04	1.96	4%	
S1950-E357-4 B-D	S1950-E357	5-10	04/26/10	13.06	31.520	1.59	1.46	9%	
S1950-E382-5 A-C	S1950-E382	5-11	05/11/10	24.95	43.587	2.26	2.19	3%	
S1950-E382-3 B-D	S1950-E382	5-11	04/26/10	19.67	34.056	1.61	1.65	-2%	
S1950-E407-4 A-G	S1950-E407	5-12	04/26/10	24.71	46.536	2.27	2.22	2%	
S1950-E407-3 H-L	S1950-E407	5-12	04/26/10	24.58	45.308	2.03	1.98	3%	
S1950-E407-3 D-J	S1950-E407	5-13	04/26/10	20.67	34.851	1.69	1.70	-1%	
S1950-E432-3 A-C	S1950-E432	5-14	04/26/10	24.42	46.213	1.95	1.94	1%	
S1950-E432-3 B-D	S1950-E432	5-14	04/26/10	19.42	33.816	1.60	1.44	11%	
S1950-E457-5 A-C	S1950-E457	5-15	09/14/09	4.921	37.191	1.07	0.89	20%	
S1950-E457-4 B-D	S1950-E457	5-15	09/14/09	12.46	27.748	0.82	0.59	39%	



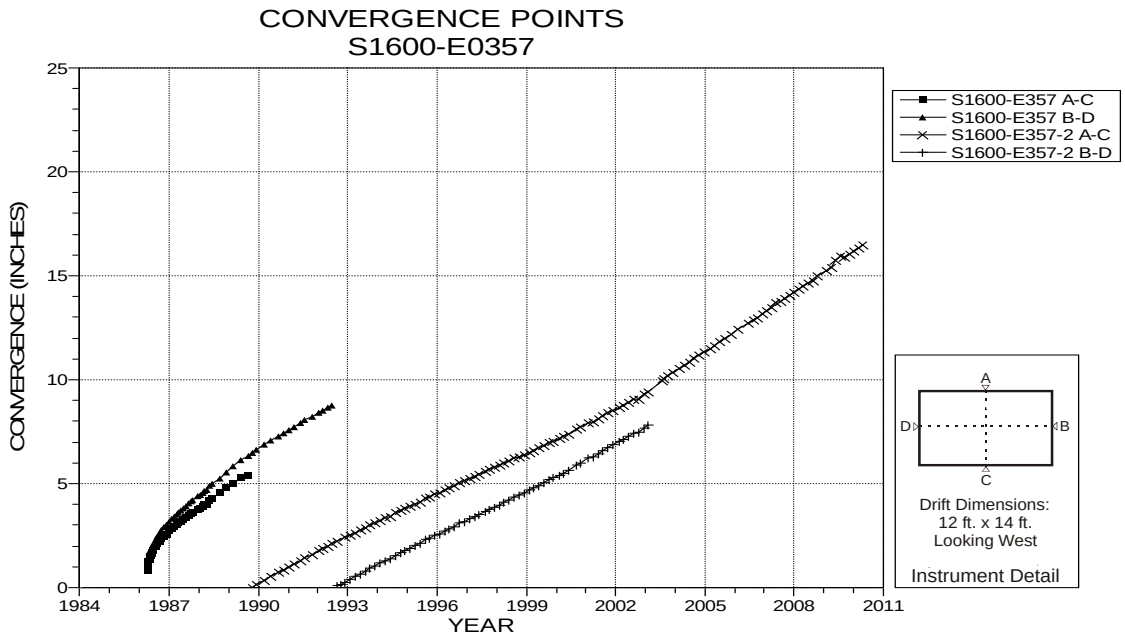
NOTES:
1. Excavation date: April 1986.

Figure 5-1 Convergence Point Array
S1600 E311 – All Chords



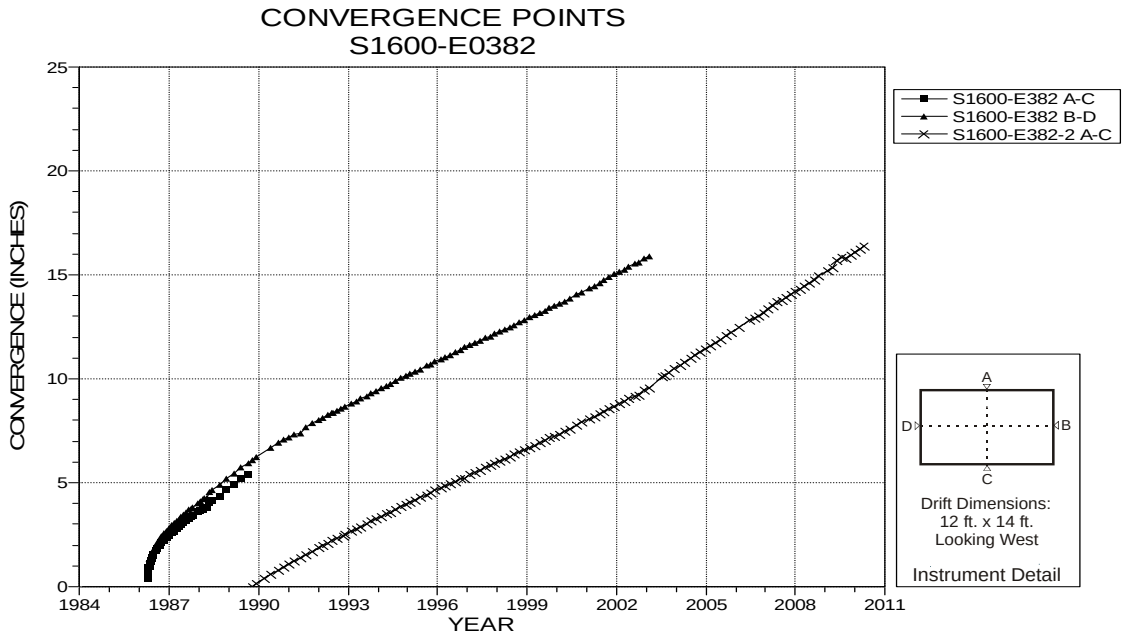
NOTES:
1. Excavation date: April 1986.

Figure 5-2 Convergence Point Array
S1600 E332 – All Chords



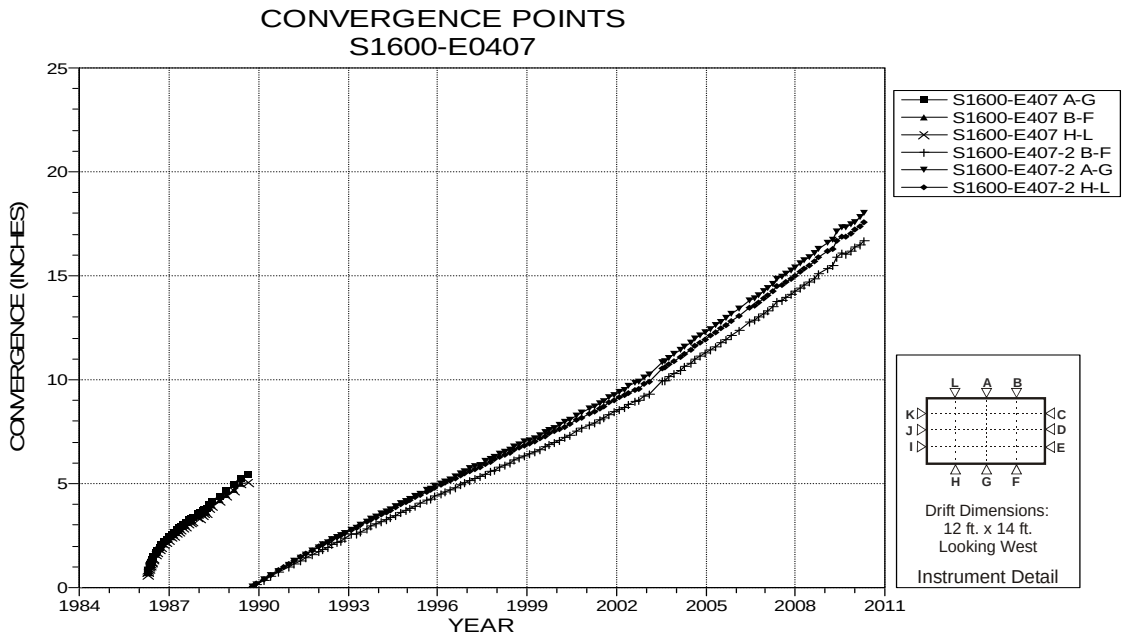
NOTES:
1. Excavation date: April 1986.

Figure 5-3 Convergence Point Array
S1600 E357 – All Chords



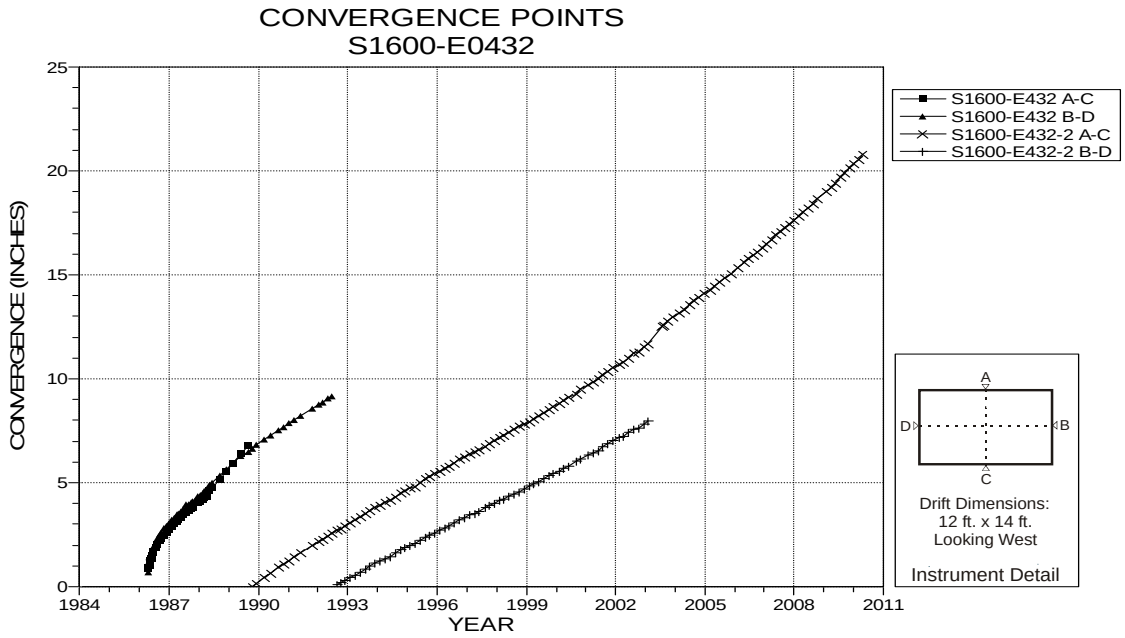
NOTES:
1. Excavation date: April 1986.

Figure 5-4 Convergence Point Array
S1600 E382 – All Chords



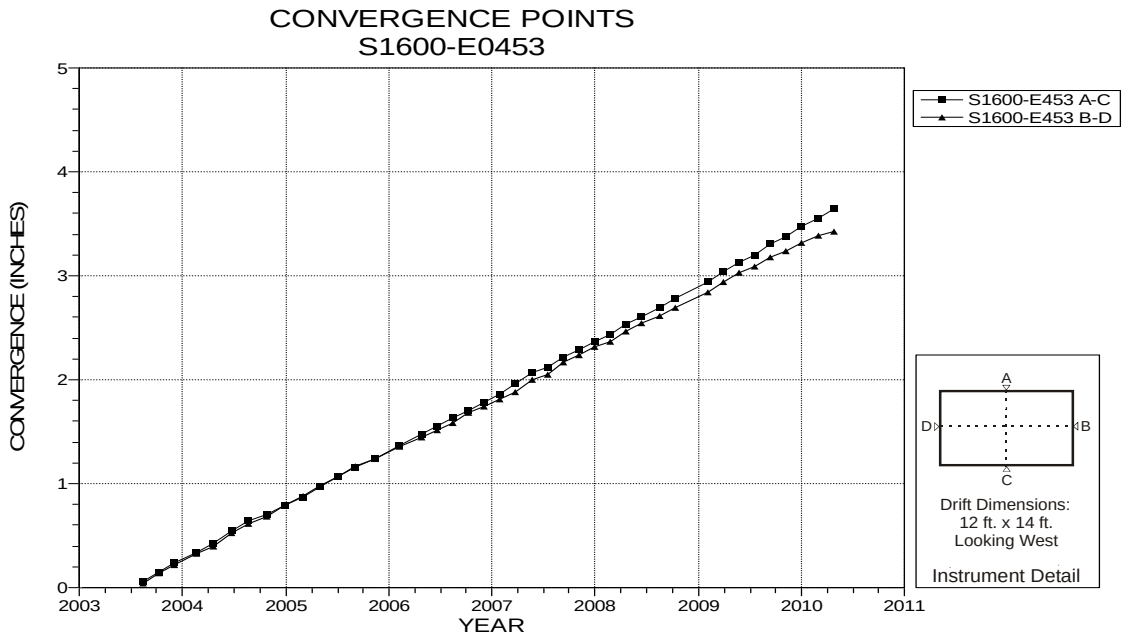
NOTES:
1. Excavation date: April 1986.

Figure 5-5 Convergence Point Array
S1600 E407 – All Chords



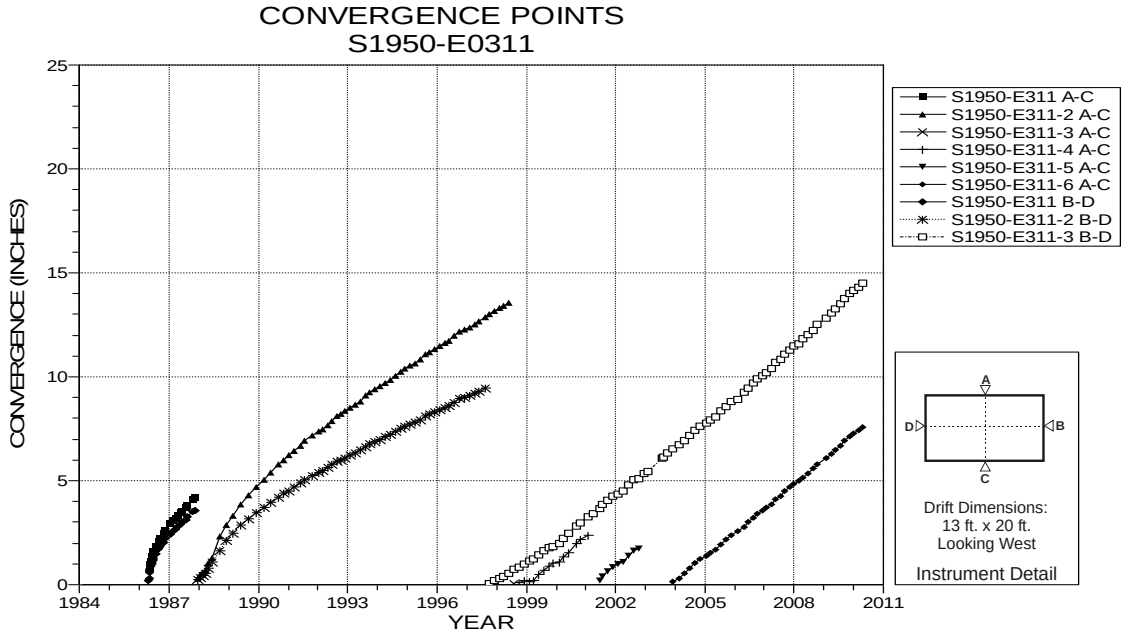
NOTES:
1. Excavation date: April 1986.

Figure 5-6 Convergence Point Array
S1600 E432 – Rib to Rib



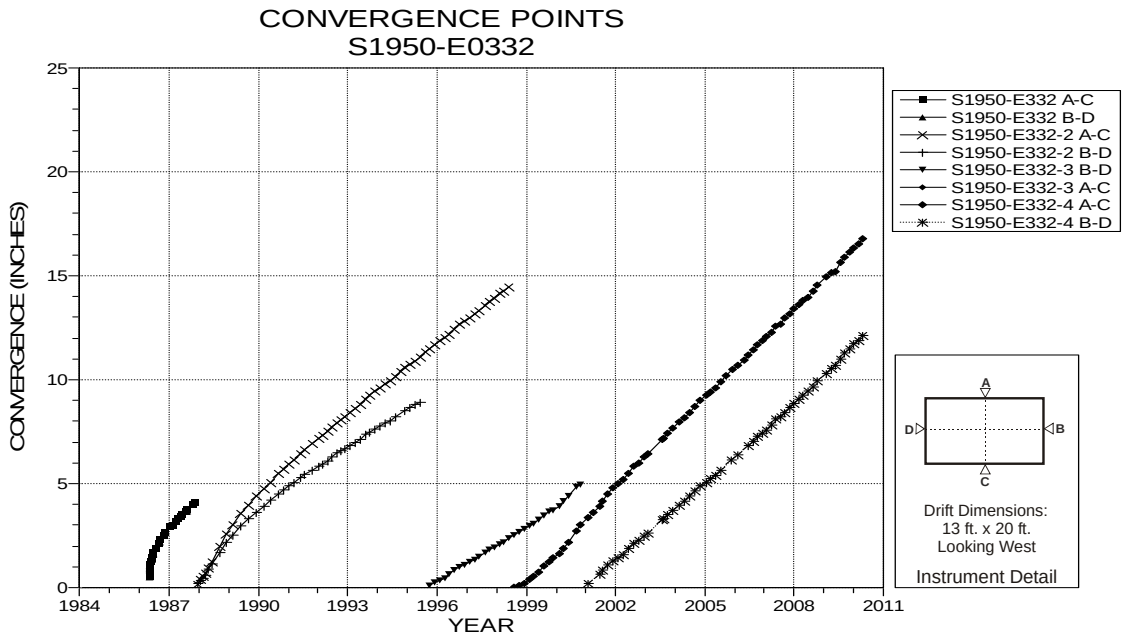
NOTES:
1. Excavation date: April 1986.

Figure 5-7 Convergence Point Array
S1600 E453 – All Chords



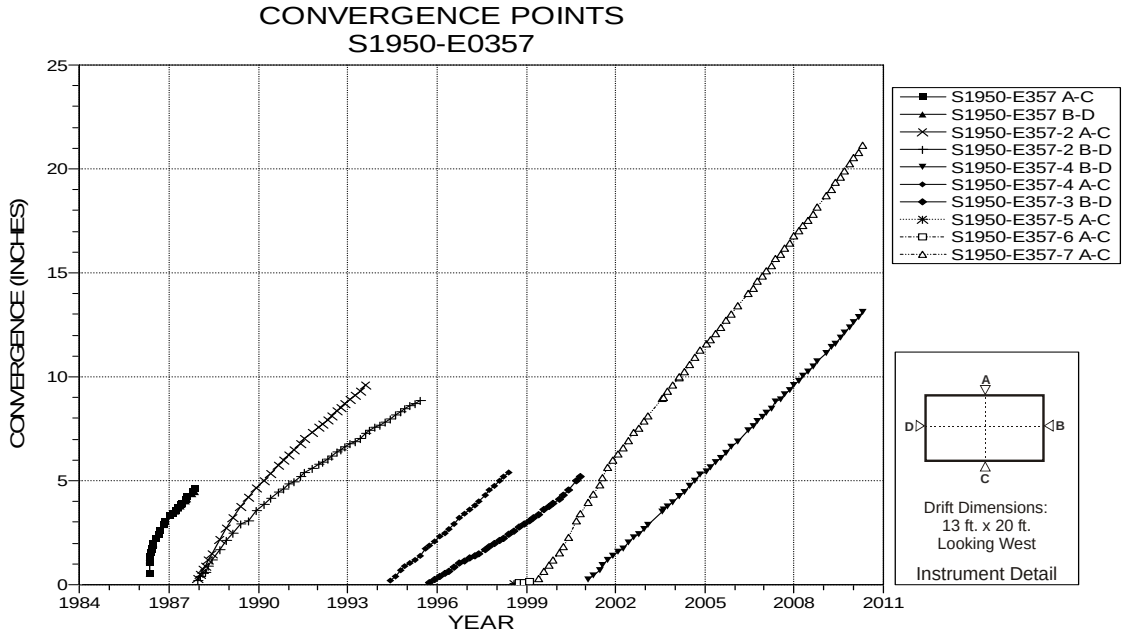
NOTES:
1. Excavation date: May 1986.

Figure 5-8 Convergence Point Array
S1950 E311 – All Chords



NOTES:
1. Excavation date: May 1986.

Figure 5-9 Convergence Point Array
S1950 E332 – All Chords



NOTES:
1. Excavation date: May 1986.

Figure 5-10 Convergence Point Array
S1950 E357 – All Chords

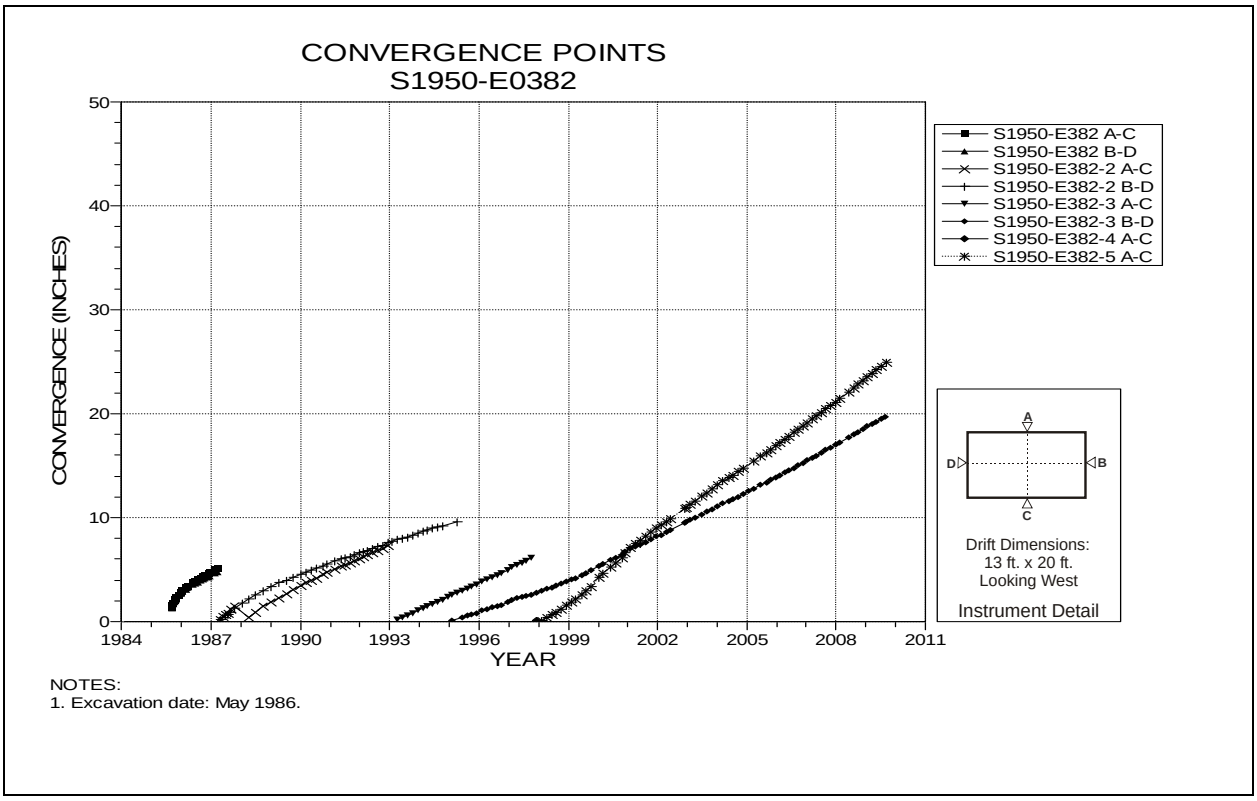


Figure 5-11 Convergence Point Array
S1950 E382 – All Chords

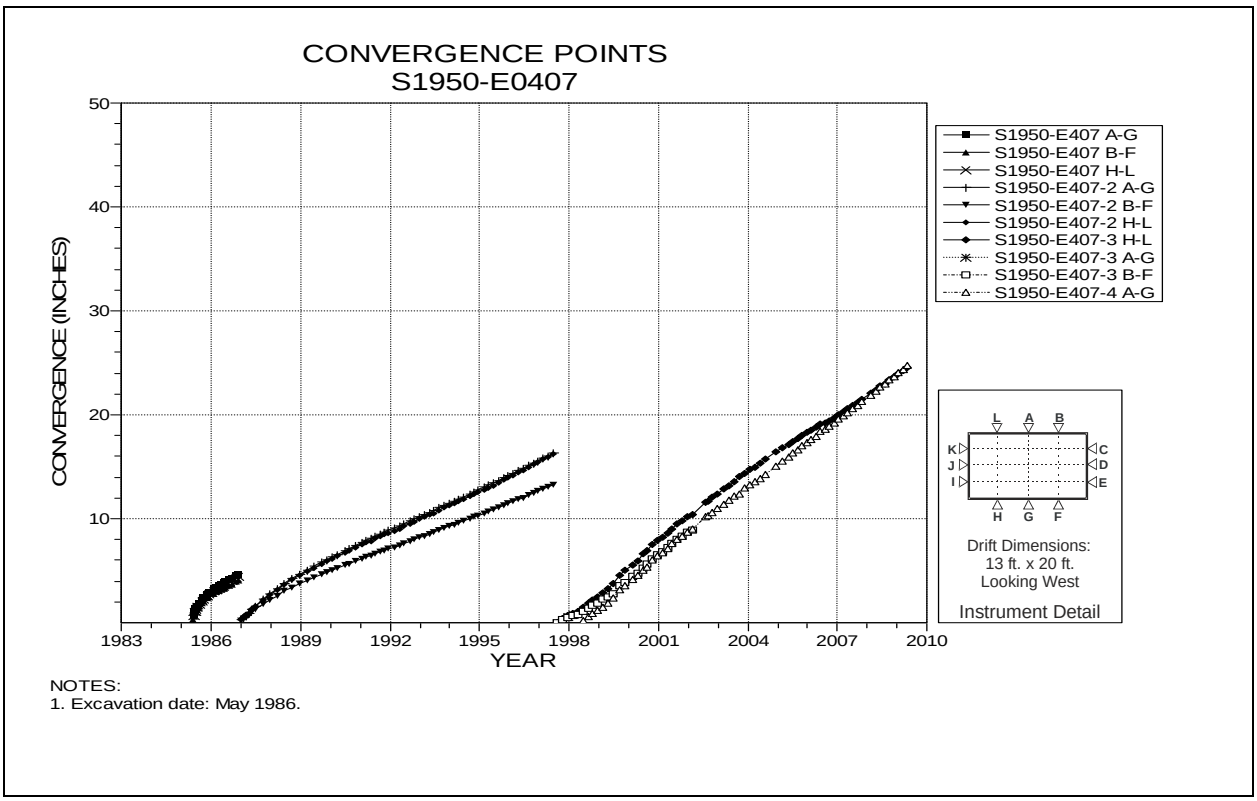


Figure 5-12 Convergence Point Array
S1950 E407 – Roof to Floor

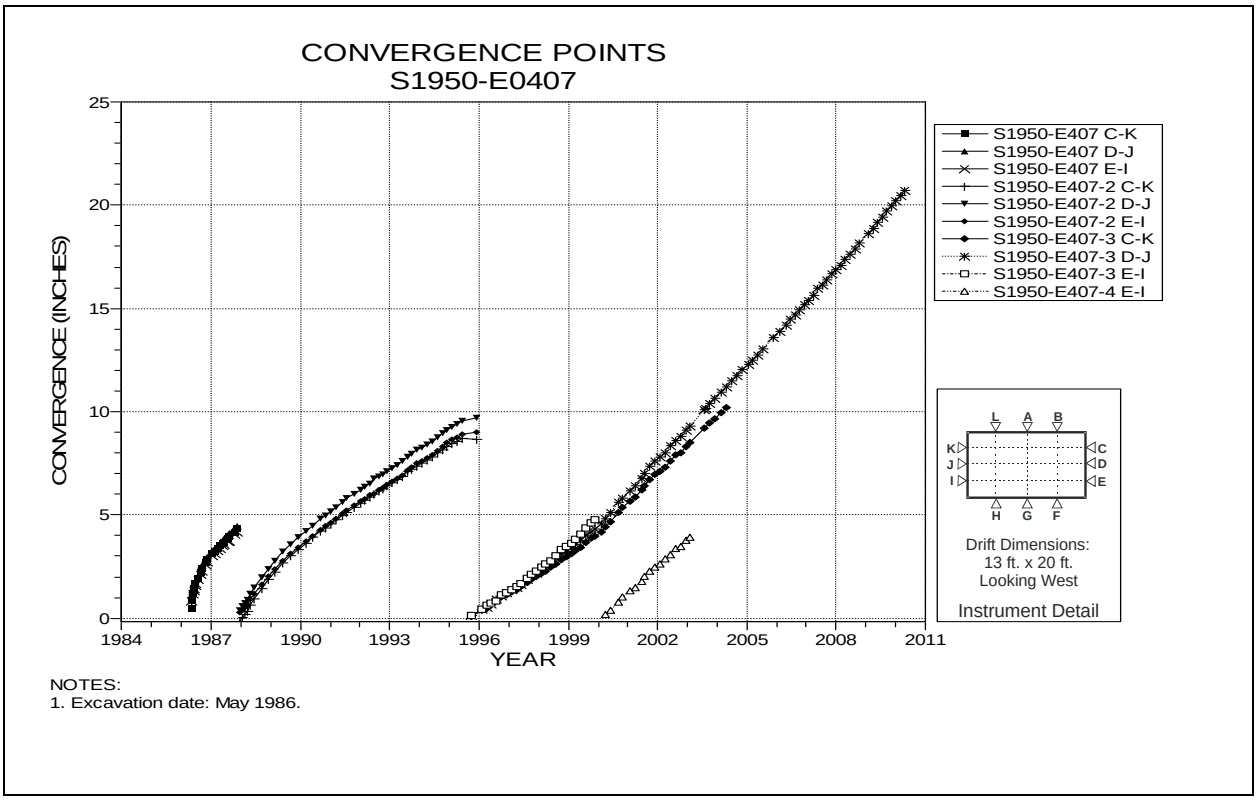


Figure 5-13 Convergence Point Array
S1950 E407 – Rib to Rib

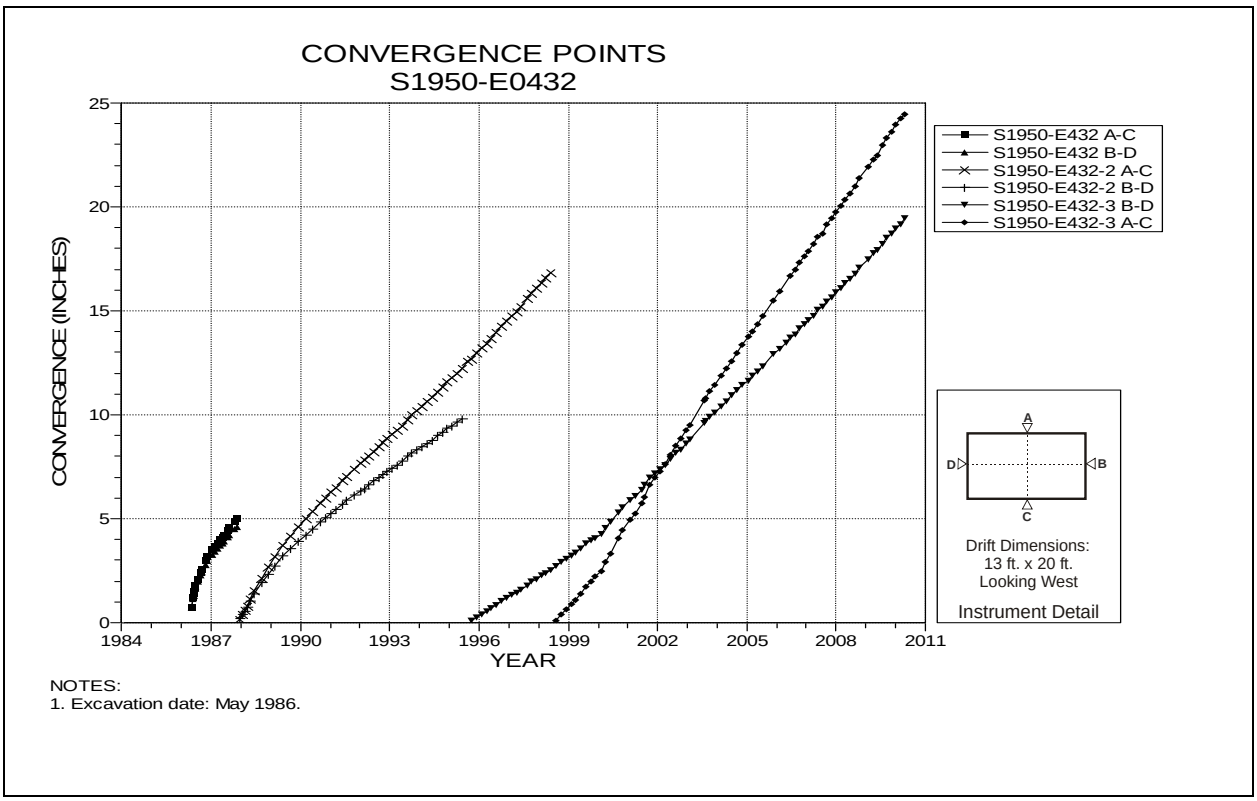


Figure 5-14 Convergence Point Array
S1950 E432 – All Chords

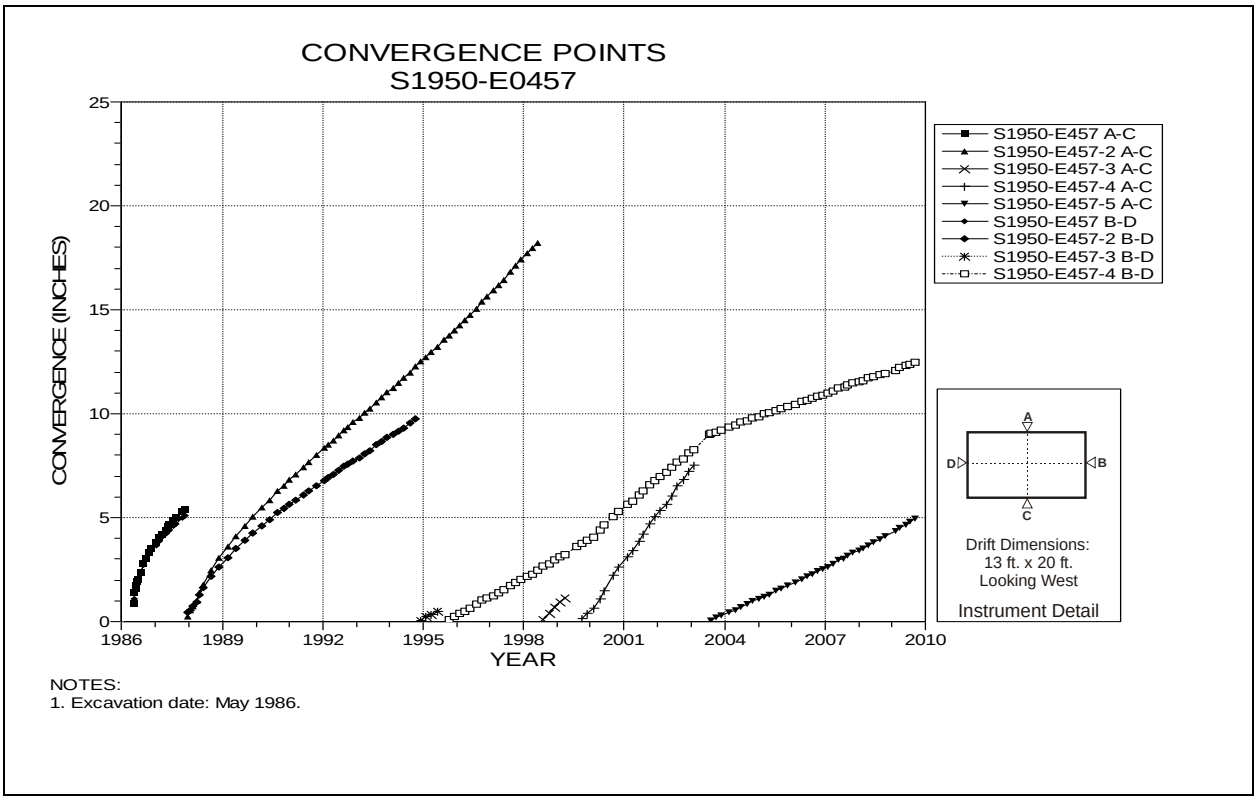
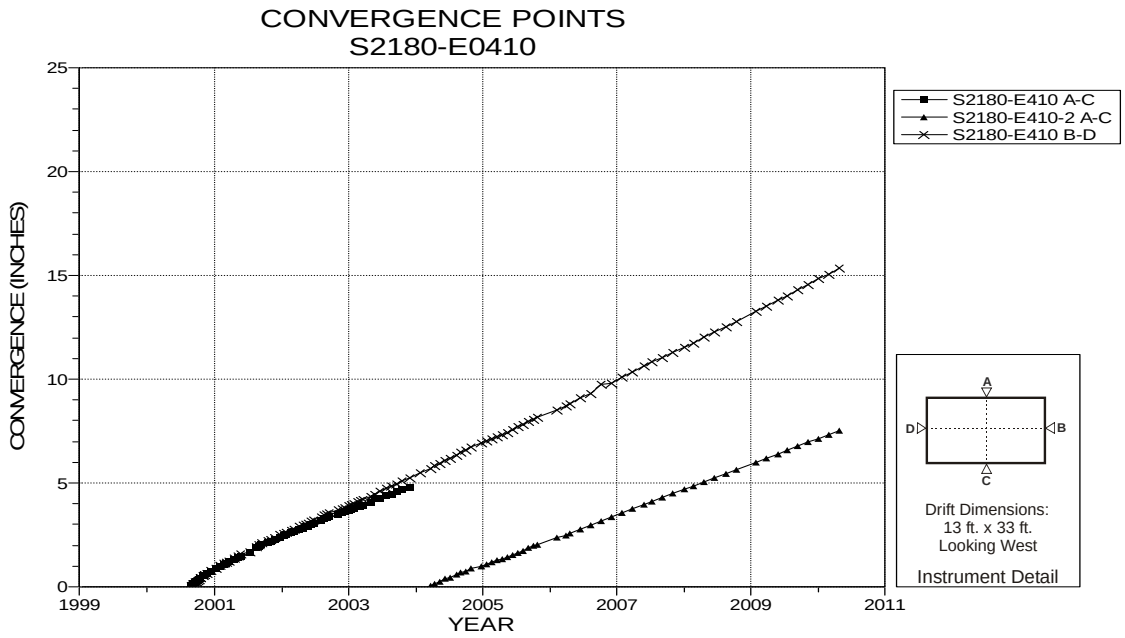


Figure 5-15 Convergence Point Array
S1950 E457 – All Chords

Table 5-2
Panel 2 Access Drifts Data Analysis

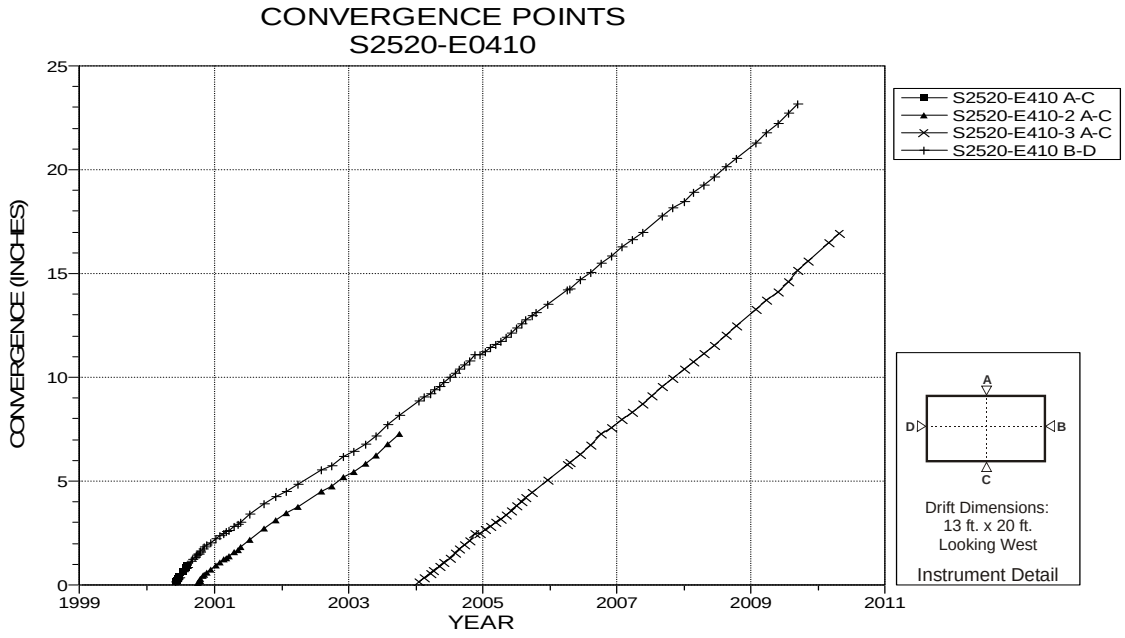
CONVERGENCE POINTS

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
S2180-E410-2 A-C	S2180-E410	5-16	04/26/10	7.491	12.288	1.23	1.21	2%	
S2180-E410 B-D	S2180-E410	5-16	04/26/10	15.32	15.316	1.71	1.63	5%	
S2520-E410-3 A-C	S2520-E410	5-17	04/26/10	16.9	25.033	3.04	2.73	11%	
S2520-E410 B-D	S2520-E410	5-17	09/15/09	23.15	23.154	3.1	2.7	15%	



NOTES:
1. Excavation date: October 1999.

Figure 5-16 Convergence Point Array
S2180 E410 – All Chords



NOTES:
1. Excavation date: December 1999.

Figure 5-17 Convergence Point Array
S2520 E410 – All Chords

Table 5-3
Panel 3 Data Analysis

CONVERGENCE POINTS

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
S2750-E410 A-C	S2750-E410	5-18	04/26/10	16.33	16.326	2.97	2.48	20%	
S2750-E410 B-D	S2750-E410	5-18	04/26/10	12.68	12.675	1.9	1.82	5%	
S2750-E485 A-C	S2750-E485	5-19	09/15/09	3.71	3.71	1.93	1.83	6%	
S3080-E410-2 A-C	S3080-E410	5-20	03/01/10	16.77	19.283	4.07	3.4	20%	
S3080-E410 B-D	S3080-E410	5-20	03/01/10	14.94	14.938	2.17	2.09	4%	
S3080-E485 A-C	S3080-E485	5-21	11/11/09	5.604	5.604	2.82	2.45	15%	

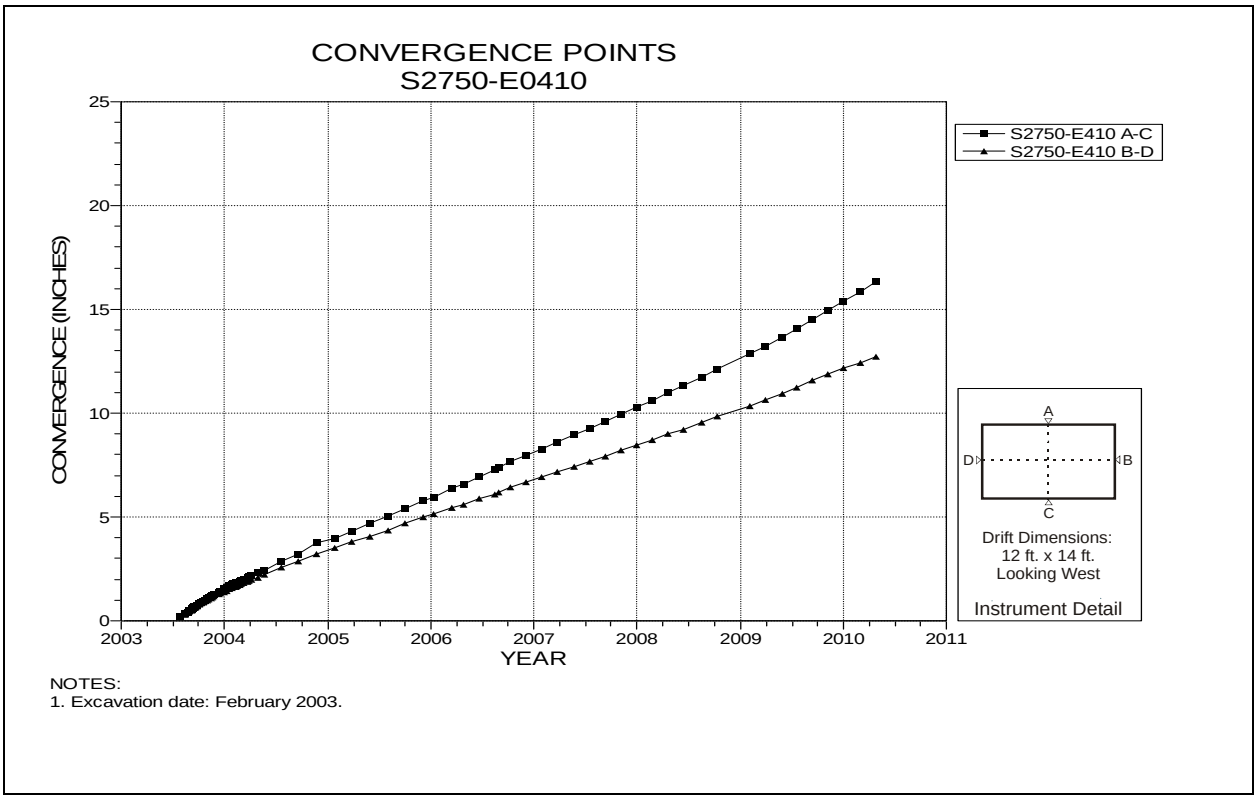


Figure 5-18 Convergence Point Array
S2750 E410 – All Chords

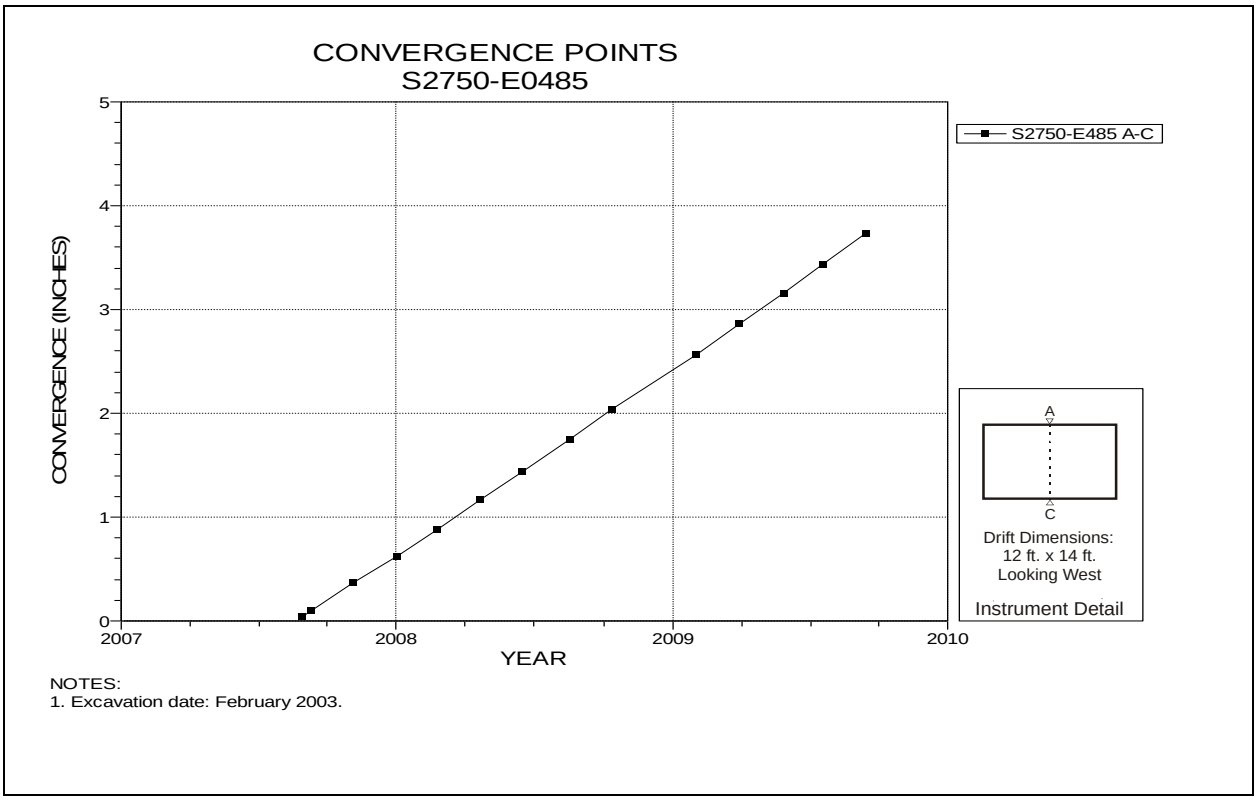


Figure 5-19 Convergence Point Array
S2750 E485 – Roof to Floor

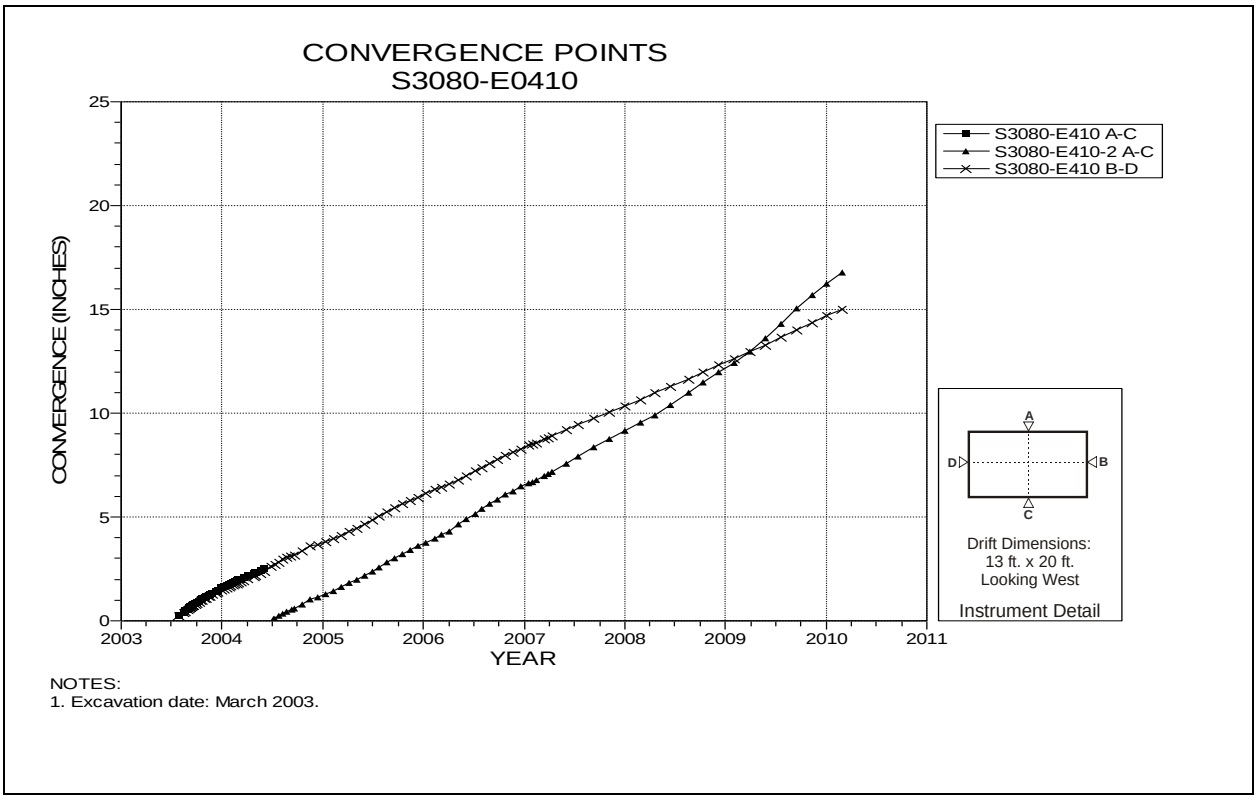


Figure 5-20 Convergence Point Array
S3080 E410 – All Chords

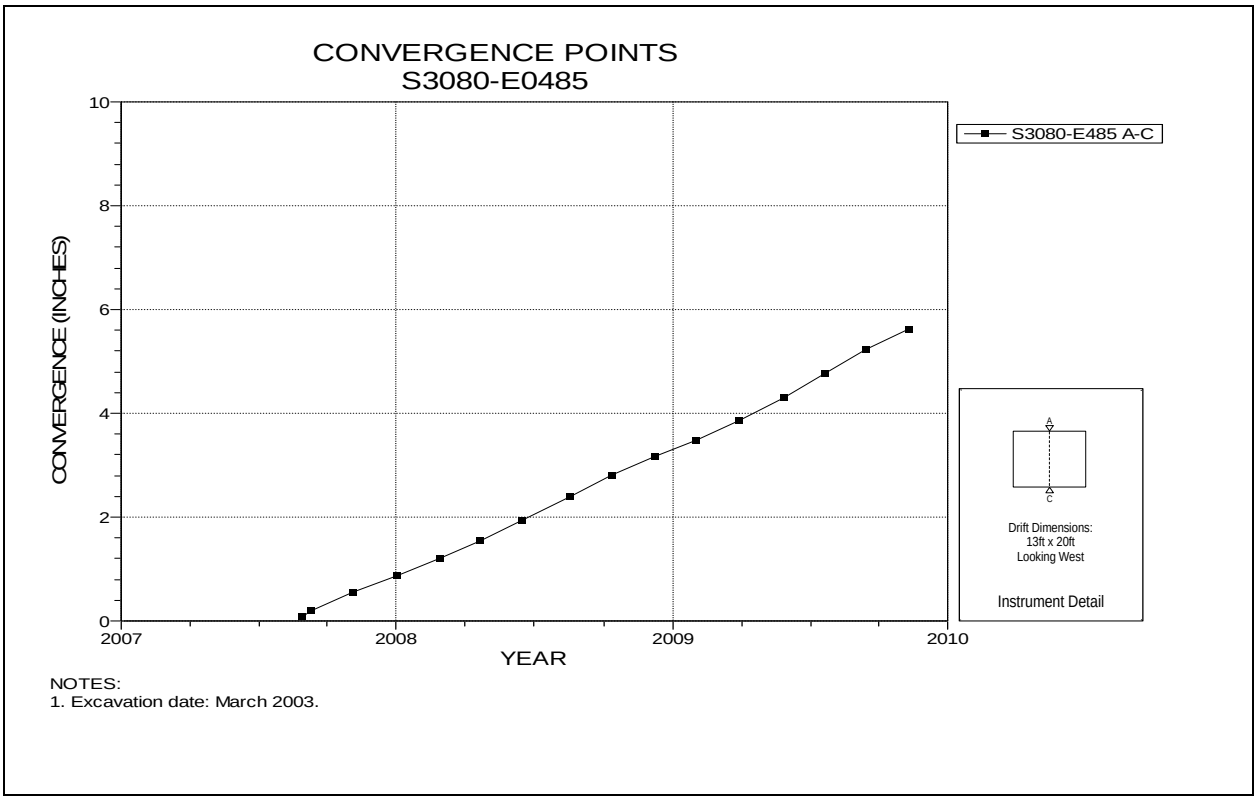


Figure 5-21 Convergence Point Array
S3080 E485 – Roof to Floor

Table 5-4
Panel 4 Data Analysis

EXTENSOMETERS

Field Tag	Location	Figure Number	Date of Last Reading	Collar Displacement Relative to Deepest Anchor (inches)	Displacement Rate 2009 to 2010 (in/year)	Displacement Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
51X-GE-00378	PANEL 4 ROOM 2	5-22	06/07/10	10.124	2.37	1.77	34%	
51X-GE-00380	PANEL 4 ROOM 4	5-23	06/07/10	12.448	3.99	2.71	47%	
51X-GE-00381	PANEL 4 ROOM 6	5-24	06/07/10	9.481	2.62	1.89	39%	
51X-GE-00382	PANEL 4 ROOM 7	5-25	06/07/10	7.324	1.85	1.57	18%	
51X-GE-00384	S3310 DRIFT-E1125	5-26	06/07/10	10.506	4.29	2.39	79%	
51X-GE-00386	S3650 DRIFT-E725	5-27	06/07/10	7.557	2.44	1.82	34%	
51X-GE-00385	S3650 DRIFT-E1125	5-28	06/07/10	8.906	2.87	2.23	29%	

CONVERGENCE POINTS

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
S3310-E410 A-C	S3310-E410	5-29	04/27/10	9.738	9.738	1.61	1.6	1%	

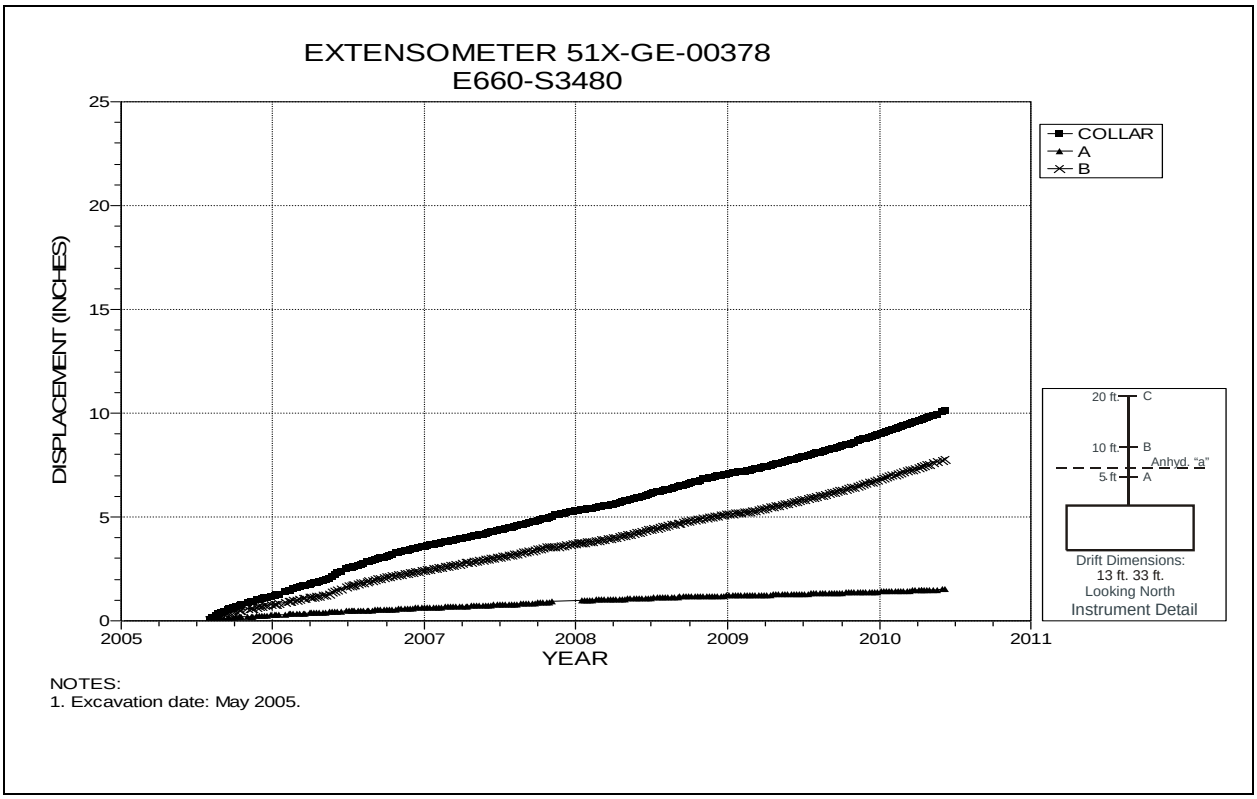


Figure 5-22 Extensometer 51X-GE-00378
Room 2, Panel 4 at E660 S3480 – Room Center – Roof

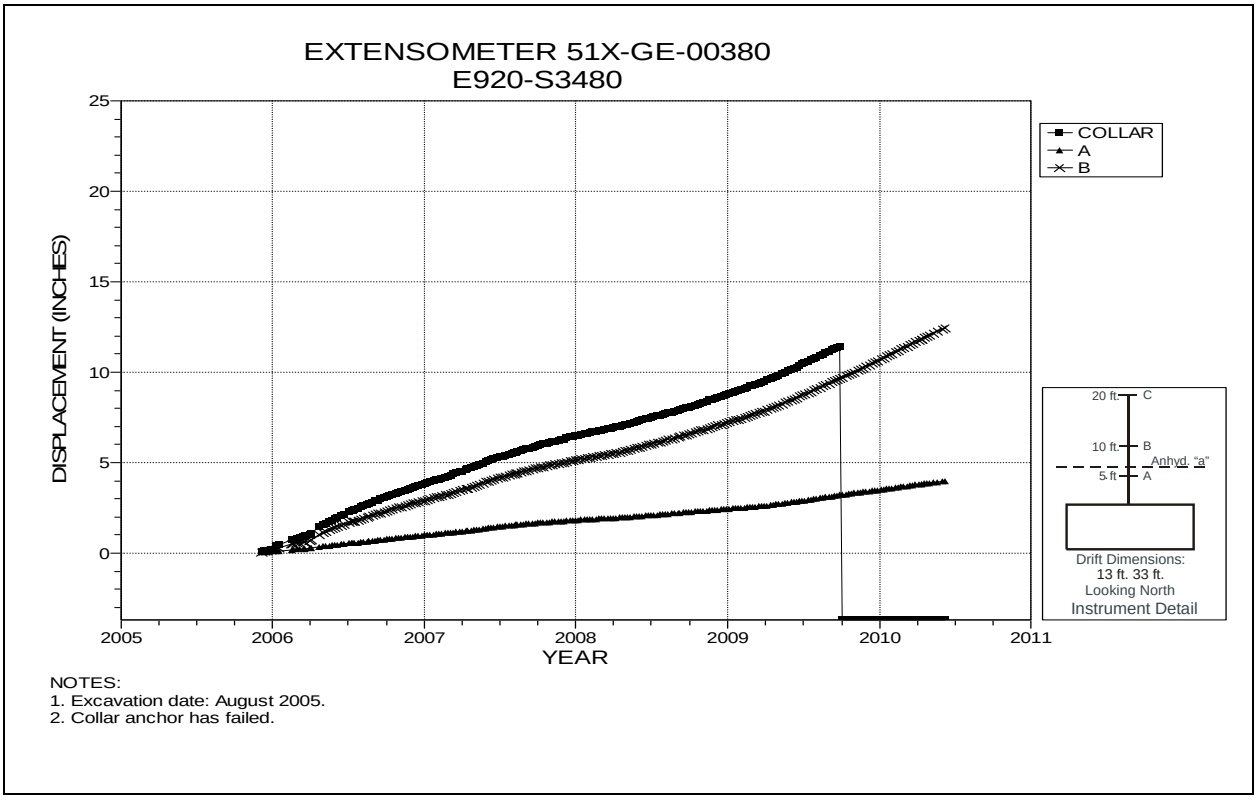


Figure 5-23 Extensometer 51X-GE-00380
Room 4, Panel 4 at E920 S3480 – Room Center – Roof

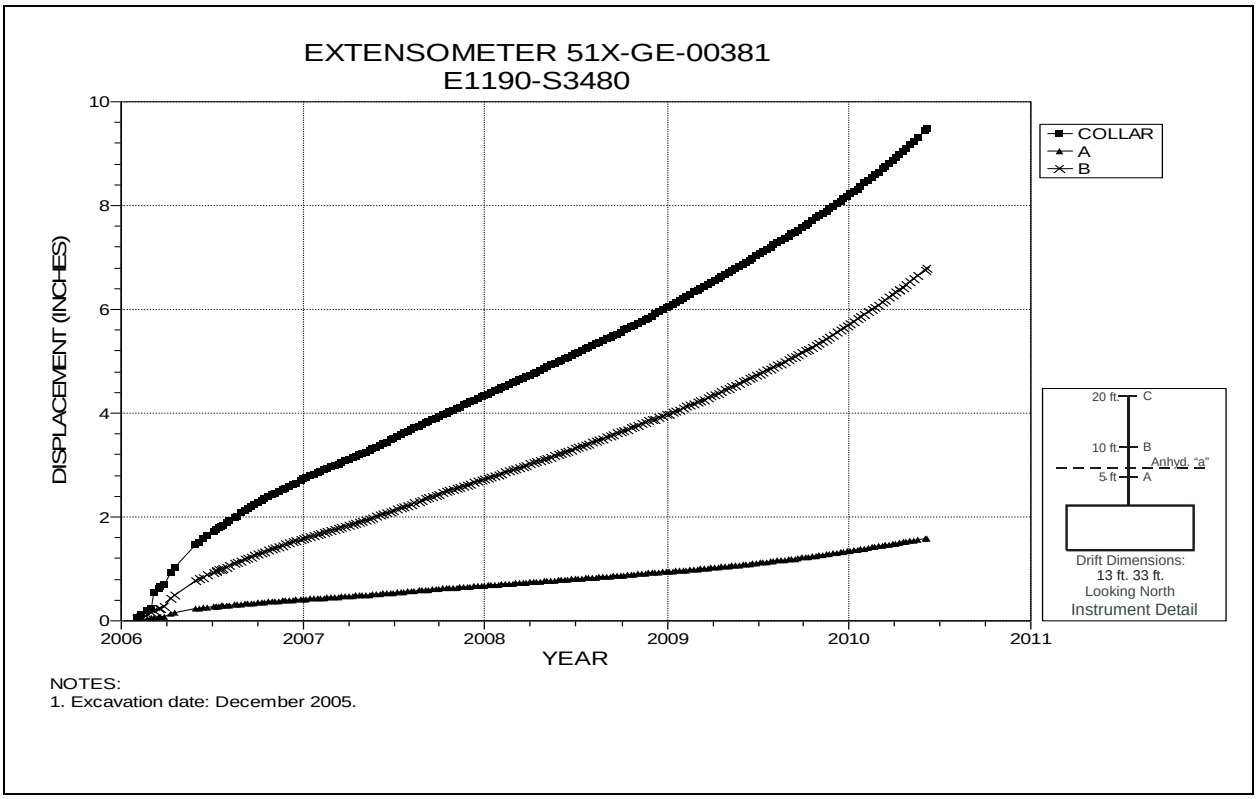


Figure 5-24 Extensometer 51X-GE-00381
Room 6, Panel 4 at E1190 S3480 – Room Center – Roof

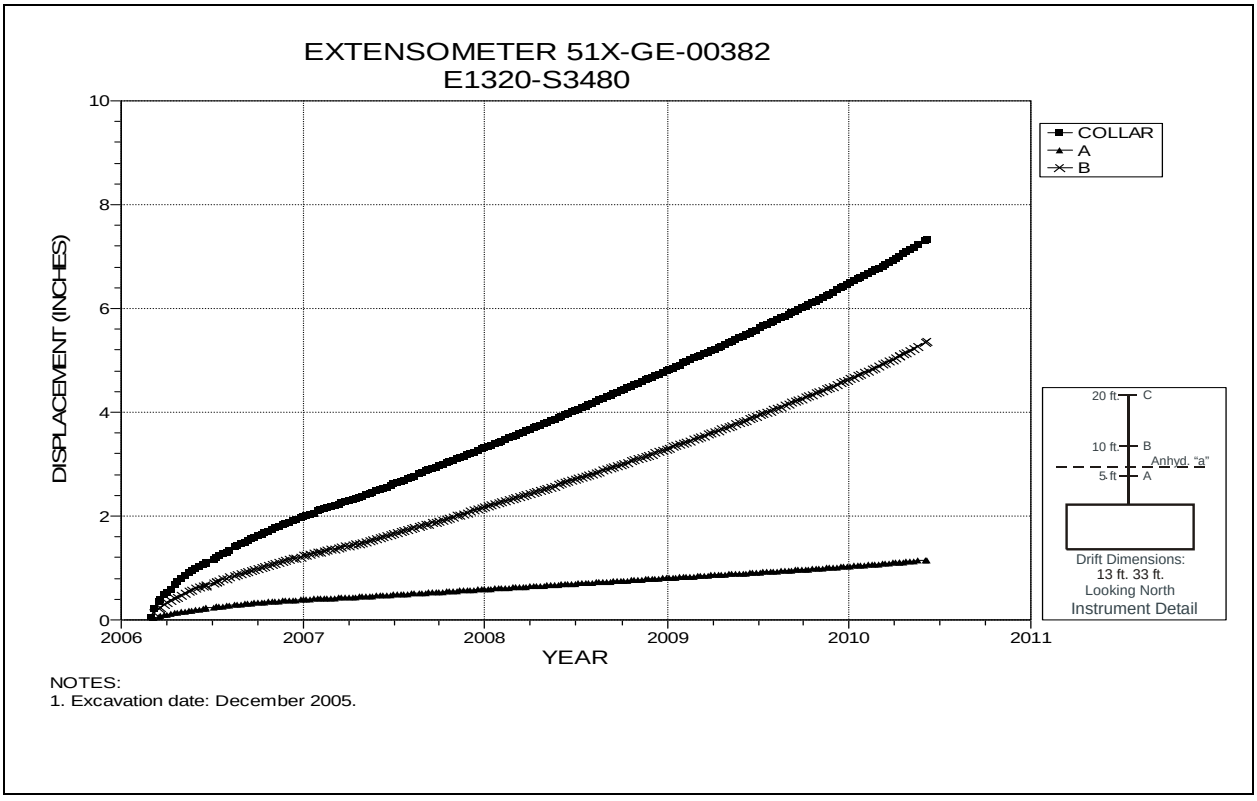


Figure 5-25 Extensometer 51X-GE-00382
Room 7, Panel 4 at E920 S3480 – Room Center – Roof

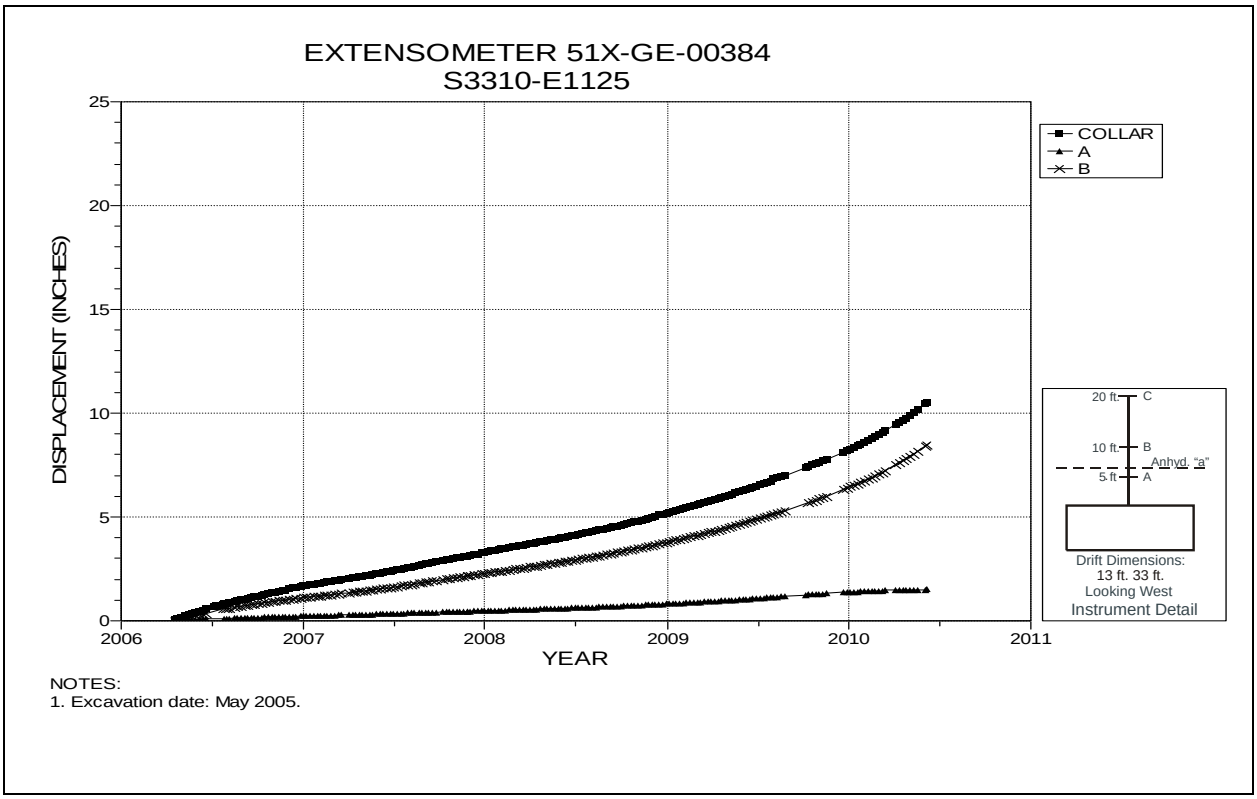


Figure 5-26 Extensometer 51X-GE-00384
S3310 E1125 – Roof

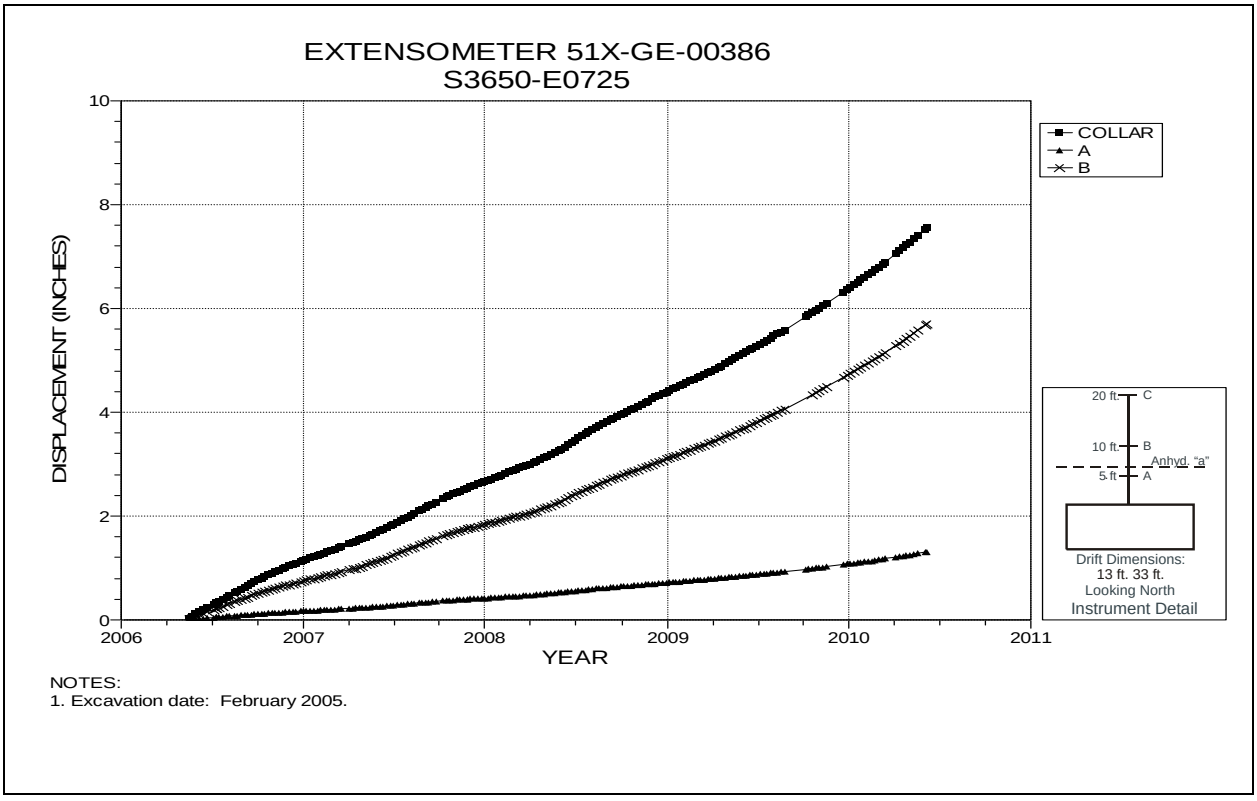


Figure 5-27 Extensometer 51X-GE-00386
S3650 E725 – Roof

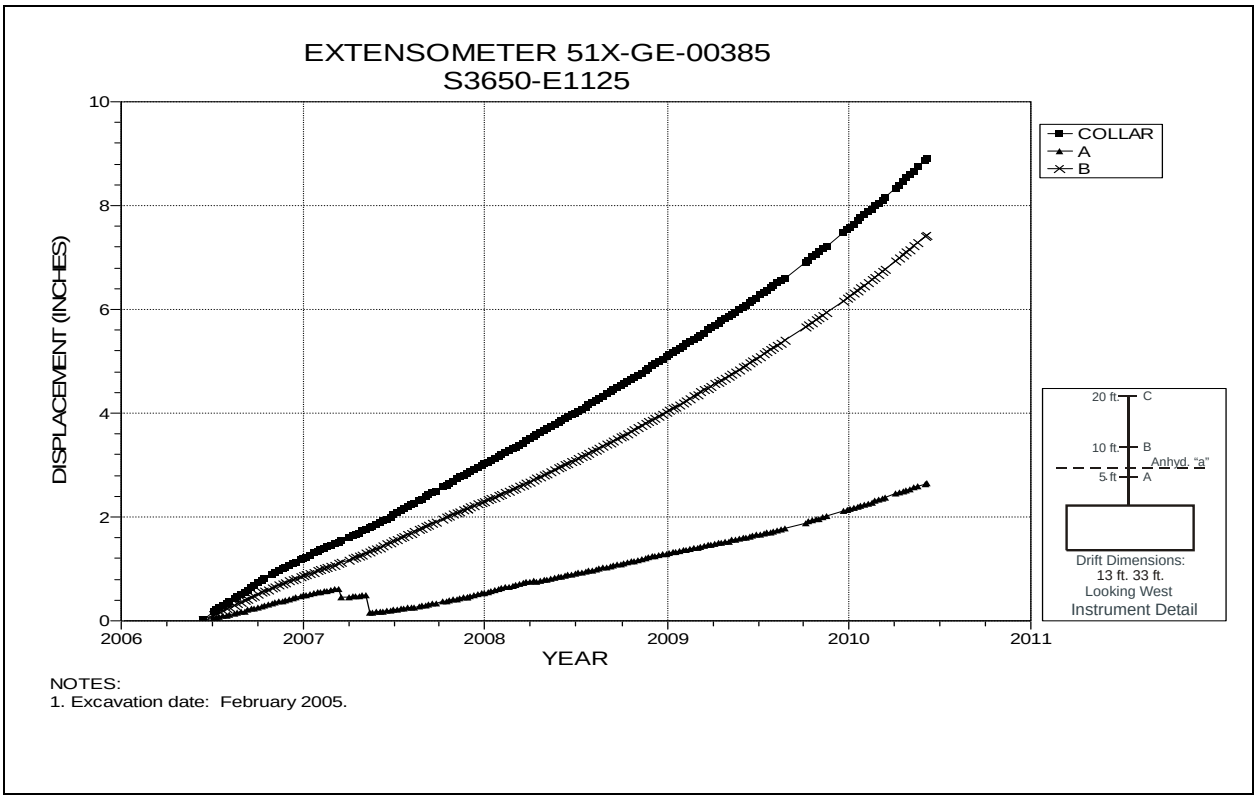


Figure 5-28 Extensometer 51X-GE-00385
S3650 E1125 – Roof

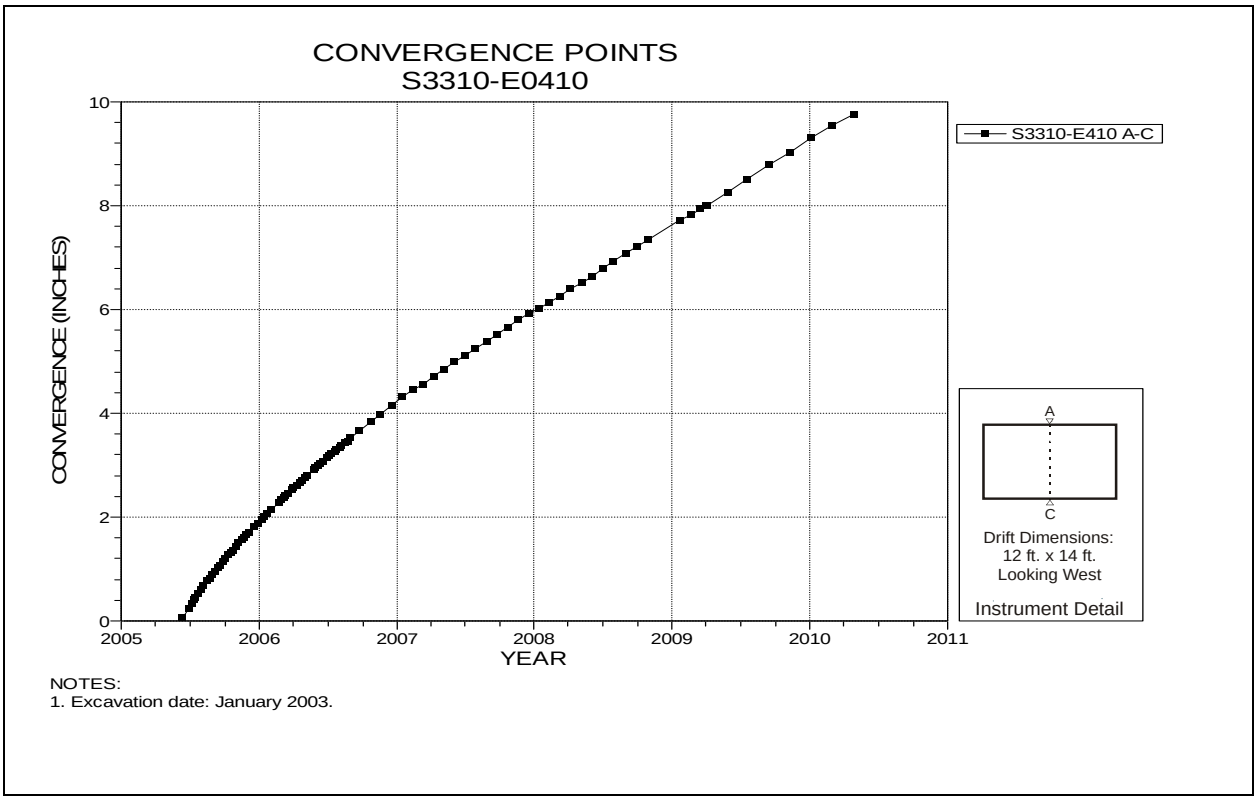


Figure 5-29 Convergence Point Array
S3310 E410 – Roof to Floor

Table 5-5 Panel 5 Data Analysis

EXTENSOMETERS

Field Tag	Location	Figure Number	Date of Last Reading	Collar Displacement Relative to Deepest Anchor (inches)	Displacement Rate 2009 to 2010 (in/year)	Displacement Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
51X-GE-00400	S3310-W585	5-30	06/28/10	4.787	2.65	1.89	40%	
51X-GE-00397	S3310-W985	5-31	06/28/10	3.474	1.88	1.23	53%	
51X-GE-00389	W390-S3480	5-32	06/28/10	7.348	2.67	1.87	43%	
51X-GE-00390	W520-S3480	5-33	06/28/10	7.434	2.12	1.86	14%	
51X-GE-00391-2	W660-S3480	5-34	06/28/10	2.007	2.07	1.66	25%	
51X-GE-00392	W790-S3480	5-35	06/28/10	3.736	1.77	1.47	20%	
51X-GE-00393	W920-S3480	5-36	06/28/10	2.414	0.97	1.03	-6%	
51X-GE-00394	W1050-S3480	5-37	06/28/10	2.365	0.94	0.96	-2%	
51X-GE-00395	W1190-S3480	5-38	06/28/10	2.470	0.98	1.04	-6%	
51X-GE-00398-1	S3650-W585	5-39	08/24/09	1.690	1.50	1.10	36%	
51X-GE-00399	S3650-W985	5-40	06/28/10	2.285	0.96	0.95	1%	

ROCKBOLT LOAD CELLS

Field Tag	Location	Figure Number	Date of Initial Reading	Date of Last Reading	Load (kips)	Comments
51X-WG-00323	S3310-W590	5-41	02/13/08	06/02/10	29.448	
51X-WG-00316	S3310-W985	5-42	10/17/07	07/22/09	17.486	
51X-WG-00321	W390-S3480	5-43	01/22/08	06/02/10	1.743	
51X-WG-00322	W520-S3480	5-44	01/22/08	06/02/10	46.616	
51X-WG-00320	W660-S3480	5-45	12/05/07	06/02/10	26.613	
51X-WG-00317	W790-S3480	5-46	10/18/07	03/02/10	28.555	
51X-WG-00318	W920-S3480	5-47	10/18/07	02/01/10	37.595	
51X-WG-00314	W1050-S3480	5-48	10/17/07	09/16/09	36.132	
51X-WG-00319	S3650-W585	5-49	10/18/07	06/02/10	28.665	
51X-WG-00315	S3650-W985	5-50	10/17/07	10/12/09	27.144	

Table 5-5 (Continued) Panel 5 Data Analysis

CONVERGENCE POINTS

Field Tag	Location	Figure Number	Last Reading 2008 to 2009		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)[1]	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent[1]	Comments
			Date	Inches					
S3310-W285 A-C	S3310-W285	5-51	06/02/10	5.705	5.705	1.73	1.87	-7%	
S3310-W390-2 A-C	S3310-W390	5-52	06/02/10	8.834	11.296	3.24	3.61	-10%	
S3310-W460 A-C	S3310-W460	5-53	06/02/10	10.481	10.481	3.84	4.05	-5%	
S3310-W520-2 A-C	S3310-W520	5-54	06/02/10	13.199	17.499	5.17	5.24	-1%	
S3310-W590-2 A-C	S3310-W590	5-55	06/02/10	12.653	15.731	5.40	4.93	10%	
S3310-W660-2 A-C	S3310-W660	5-56	06/02/10	12.369	16.098	4.80	4.91	-2%	
S3310-W725-2 A-C	S3310-W725	5-57	03/31/10	13.848	17.874	6.22	5.45	14%	
S3310-W790-2 A-C	S3310-W790	5-58	03/31/10	12.304	16.857	4.84	4.79	1%	
S3310-W855-2 A-C	S3310-W855	5-59	10/12/09	10.034	15.112	6.13	4.50	36%	
S3310-W920-2 A-C	S3310-W920	5-60	10/12/09	9.736	16.194	6.25	4.21	48%	
S3310-W985-2 A-C	S3310-W985	5-61	07/22/09	6.984	12.794	N/A	3.73	N/A	Insufficient data, waste emplacement
S3310-W1050-2 A-C	S3310-W1050	5-62	07/22/09	7.475	12.832	N/A	3.85	N/A	Insufficient data, waste emplacement
W390-S3395-2 A-C	W390-S3395	5-63	06/02/10	21.133	22.759	5.74	5.36	7%	
W390-S3480-2 A-C	W390-S3480	5-64	06/02/10	18.279	19.47	4.88	4.22	16%	
W390-S3565-2 A-C	W390-S3565	5-65	06/02/10	14.525	15.434	3.14	3.15	0%	
W520-S3395-2 A-C	W520-S3395	5-66	06/02/10	10.905	15.216	4.11	3.85	7%	
W520-S3480-2 A-C	W520-S3480	5-67	06/02/10	11.549	16.041	4.24	3.98	7%	
W520-S3565-2 A-C	W520-S3565	5-68	06/02/10	8.894	13.171	3.02	2.99	1%	
W660-S3395-2 A-C	W660-S3395	5-69	06/02/10	8.015	12.553	3.27	3.26	0%	
W660-S3480-2 A-C	W660-S3480	5-70	06/02/10	9.874	14.71	4.24	3.80	12%	
W660-S3565-2 A-C	W660-S3565	5-71	03/02/10	6.964	11.639	3.23	2.96	9%	
W790-S3395-2 A-C	W790-S3395	5-72	02/01/10	7.85	11.698	3.88	3.54	10%	
W790-S3480-2 A-C	W790-S3480	5-73	03/02/10	8.536	12.326	3.93	3.64	8%	
W790-S3565-2 A-C	W790-S3565	5-74	03/02/10	7.657	11.45	3.48	3.21	8%	
W920-S3395-2 A-C	W920-S3395	5-75	01/05/10	7.206	10.057	3.62	3.25	11%	
W920-S3480-2 A-C	W920-S3480	5-76	02/01/10	7.503	10.637	3.34	3.25	3%	
W920-S3565-2 A-C	W920-S3565	5-77	02/01/10	7.116	10.238	3.04	3.05	0%	
W1050-S3395-2 A-C	W1050-S3395	5-78	09/16/09	5.782	7.61	3.77	3.15	20%	

[1]N/A-insufficient data available to perform calculation.

Table 5-5 (Continued) Panel 5 Data Analysis

CONVERGENCE POINTS

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)[1]	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent[1]	Comments
			Date	Inches					
W1050-S3480-2 A-C	W1050-S3480	5-79	09/16/09	5.701	7.388	3.38	3.12	8%	
W1050-S3565-2 A-C	W1050-S3565	5-80	09/16/09	5.235	6.907	2.96	2.80	6%	
S3650-W285-2 A-C	S3650-W285	5-81	06/02/10	2.510	4.951	1.81	1.90	-5%	
S3650-W390-2 A-C	S3650-W390	5-82	06/02/10	13.417	14.990	2.98	3.07	-3%	
S3650-W456-3 A-C	S3650-W456	5-83	06/02/10	9.403	14.160	3.31	3.31	0%	
S3650-W520-2 A-C	S3650-W520	5-84	06/02/10	8.557	16.311	3.43	3.67	-7%	
S3650-W585-2 A-C	S3650-W585	5-85	06/02/10	7.843	15.521	3.19	3.29	-3%	
S3650-W660-2 A-C	S3650-W660	5-86	03/30/10	7.640	13.354	3.12	3.46	-10%	
S3650-W725-2 A-C	S3650-W725	5-87	03/30/10	8.079	13.758	3.58	3.58	0%	
S3650-W790-2 A-C	S3650-W790	5-88	03/30/10	8.636	14.552	3.61	3.86	-6%	
S3650-W855-2 A-C	S3650-W855	5-89	03/02/10	8.209	14.801	3.91	3.62	8%	
S3650-W920 A-C	S3650-W920	5-90	02/01/10	7.257	7.257	3.19	3.36	-5%	
S3650-W985 A-C	S3650-W985	5-91	10/12/09	5.969	5.969	3.32	3.10	7%	
S3650-W1050 A-C	S3650-W1050	5-92	09/16/09	5.697	5.697	3.51	3.22	9%	
S3650-W1120 A-C	S3650-W1120	5-93	07/22/09	4.407	4.407	N/A	2.68	N/A	Insufficient data, waste emplacement
S3650-W1190 A-C	S3650-W1190	5-94	07/22/09	3.514	3.514	N/A	2.16	N/A	Insufficient data, waste emplacement

[1]N/A-insufficient data available to perform calculation.

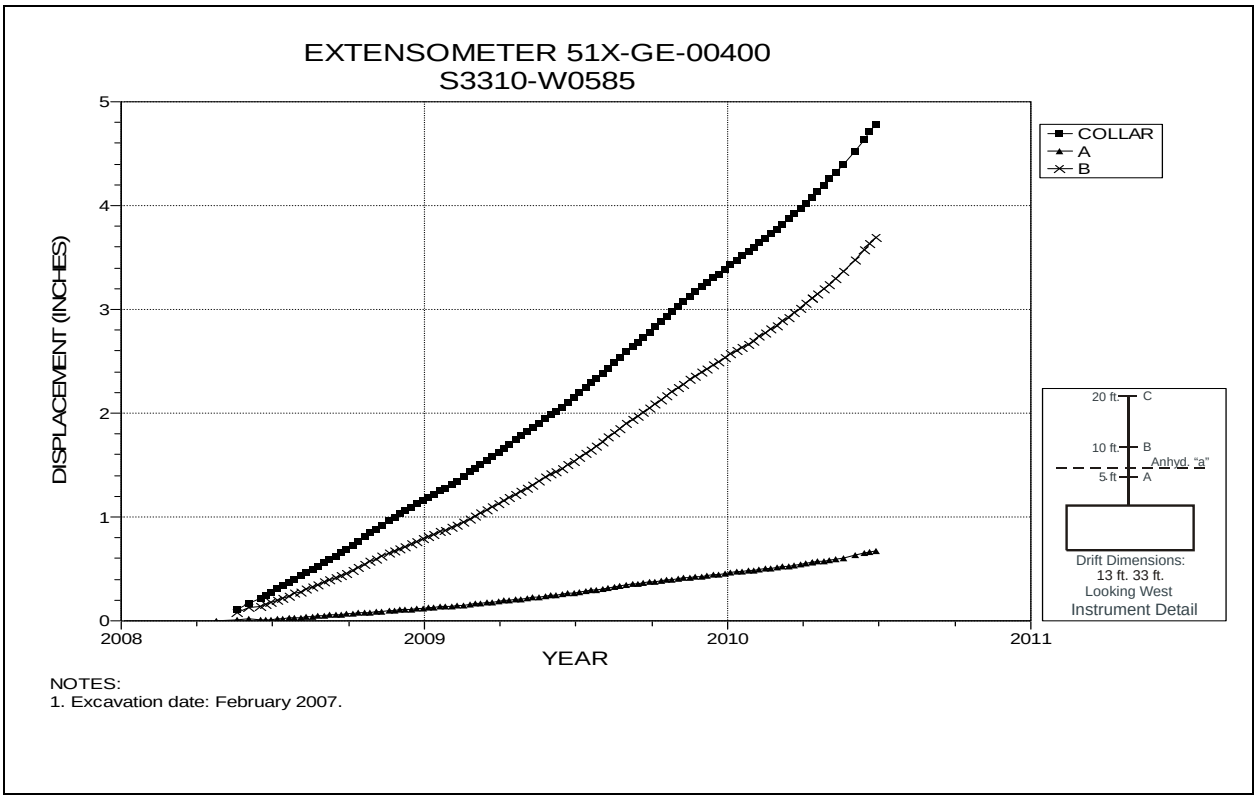


Figure 5-30 Extensometer 51X-GE-00400
S3310 W585 – Roof

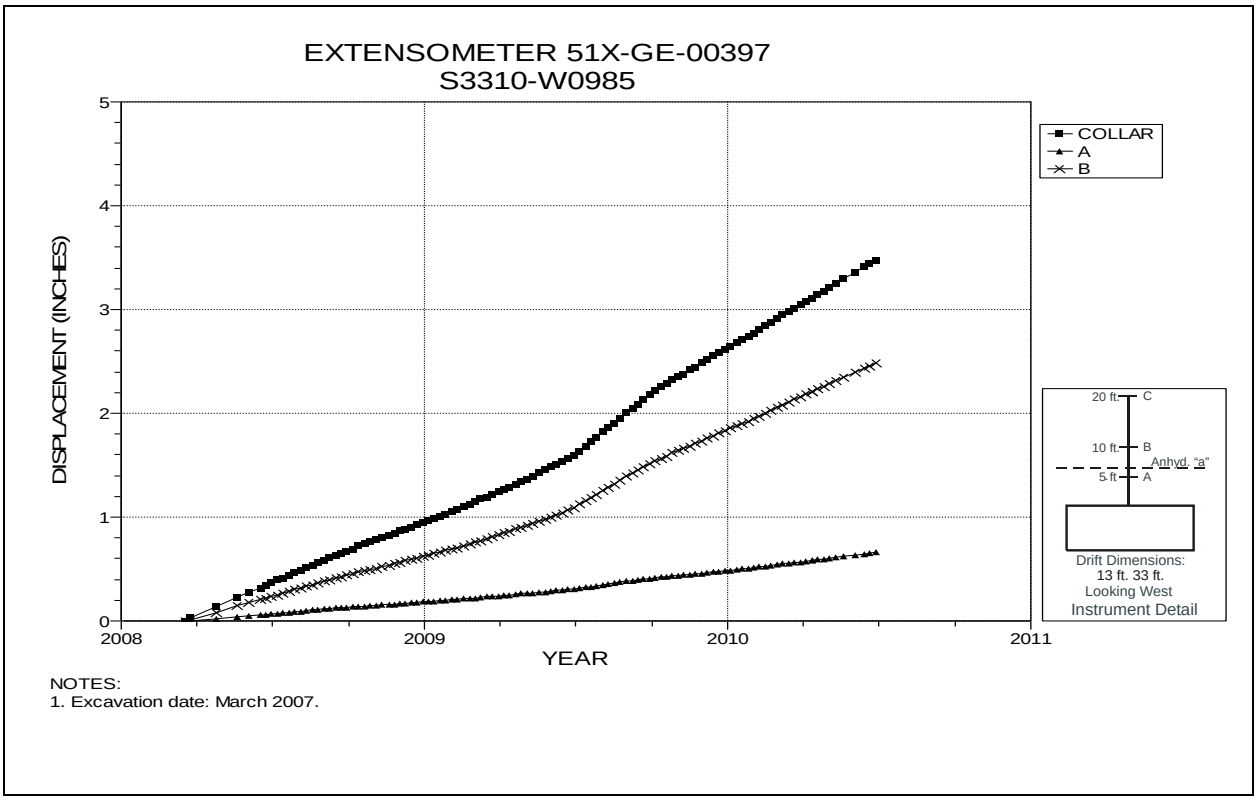


Figure 5-31 Extensometer 51X-GE-00397
S3310 W985 – Roof

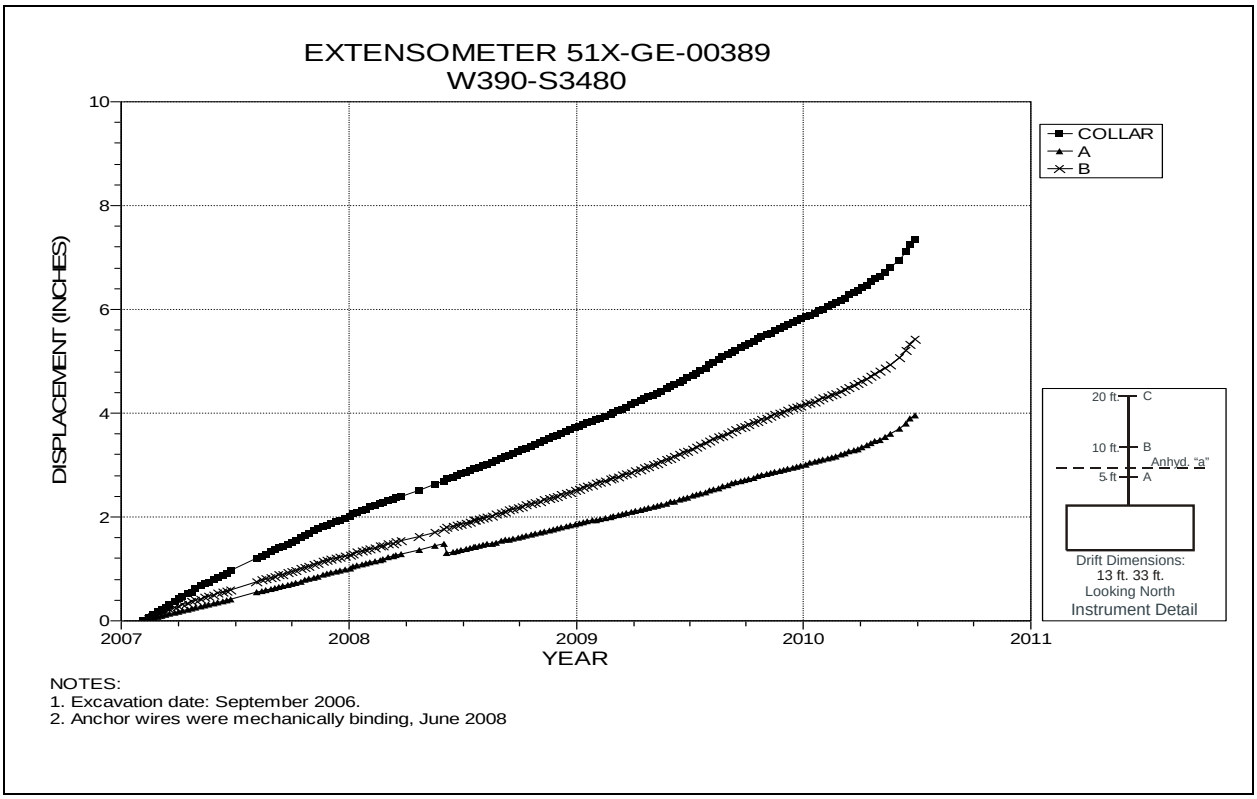


Figure 5-32 Extensometer 51X-GE-00389
Room 1, Panel 5 at W390 S3480 – Room Center – Roof

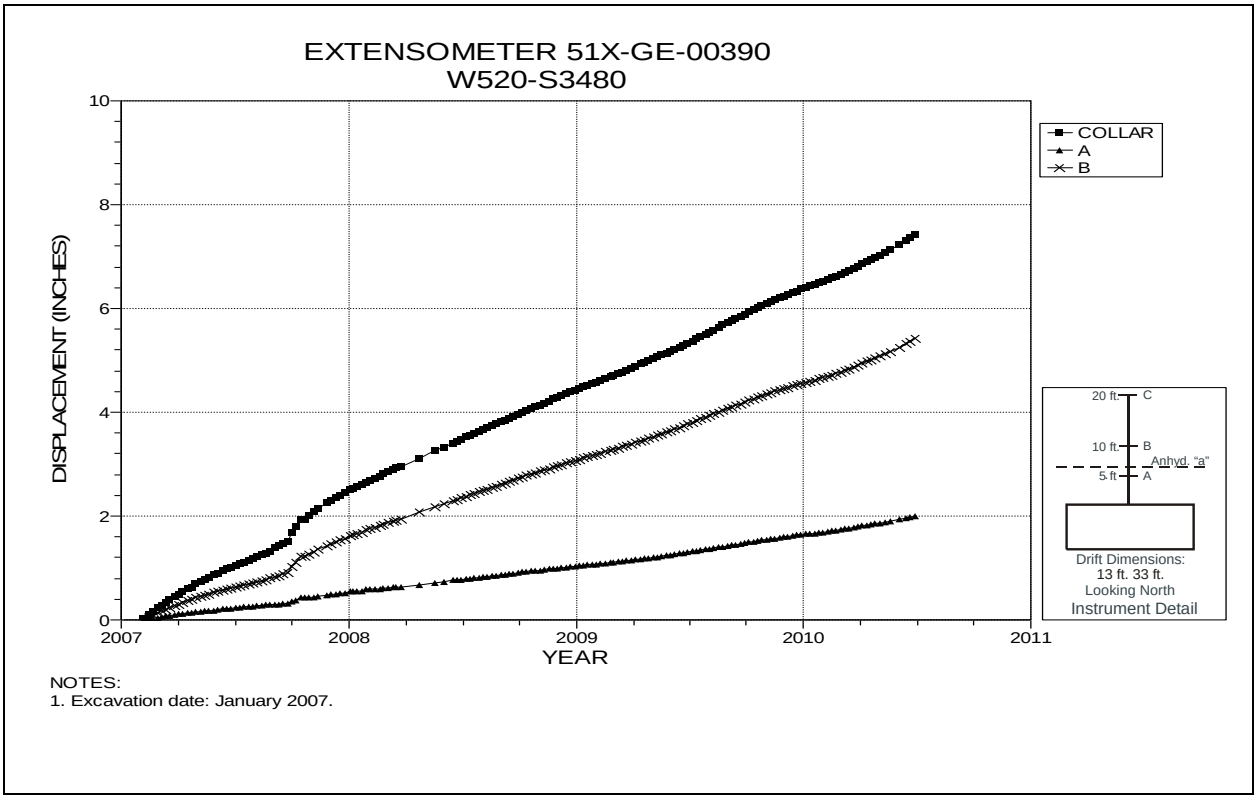
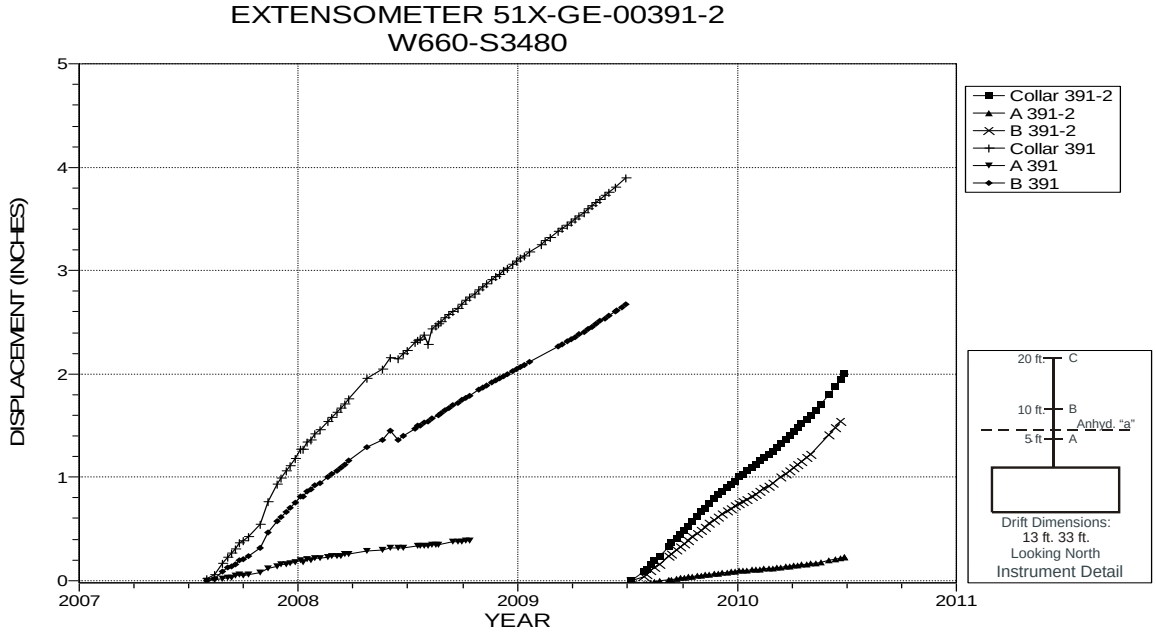
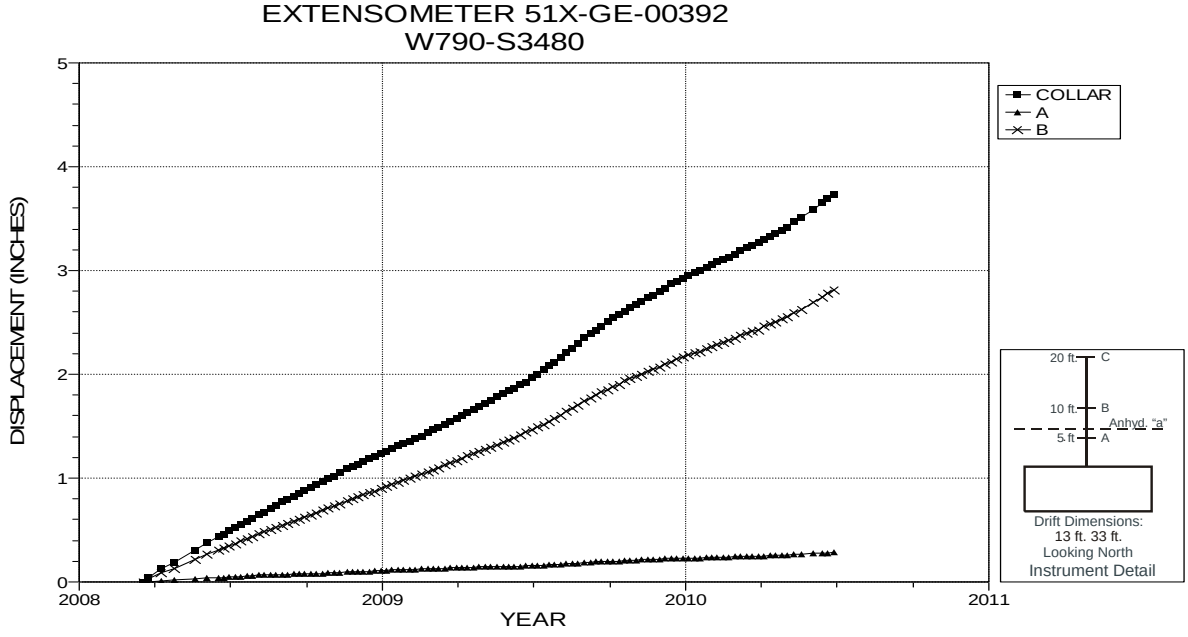


Figure 5-33 Extensometer 51X-GE-00390
Room 2, Panel 5 at W520 S3480 – Room Center – Roof



NOTES:
1. Excavation date: February 2007.
2. 51-GE-00391 was replaced in July, 2009 due to the earlier failure of anchor A.

Figure 5-34 Extensometer 51X-GE-00391
Room 3, Panel 5 at W660 S3480 – Room Center – Roof



NOTES:
1. Excavation date: April 2007

Figure 5-35 Extensometer 51X-GE-00392
Room 4, Panel 5 at W790 S3480 – Room Center – Roof

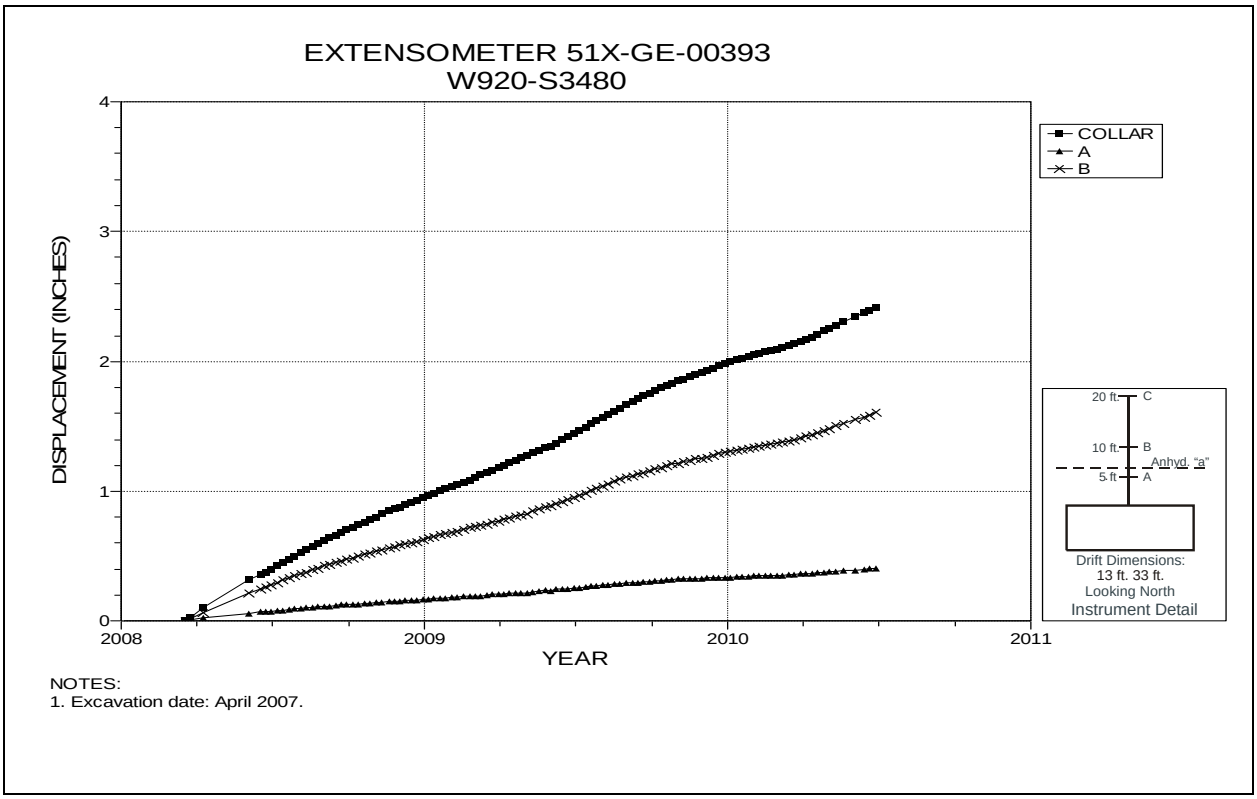


Figure 5-36 Extensometer 51X-GE-00393
Room 5, Panel 5 at W920 S3480 – Room Center – Roof

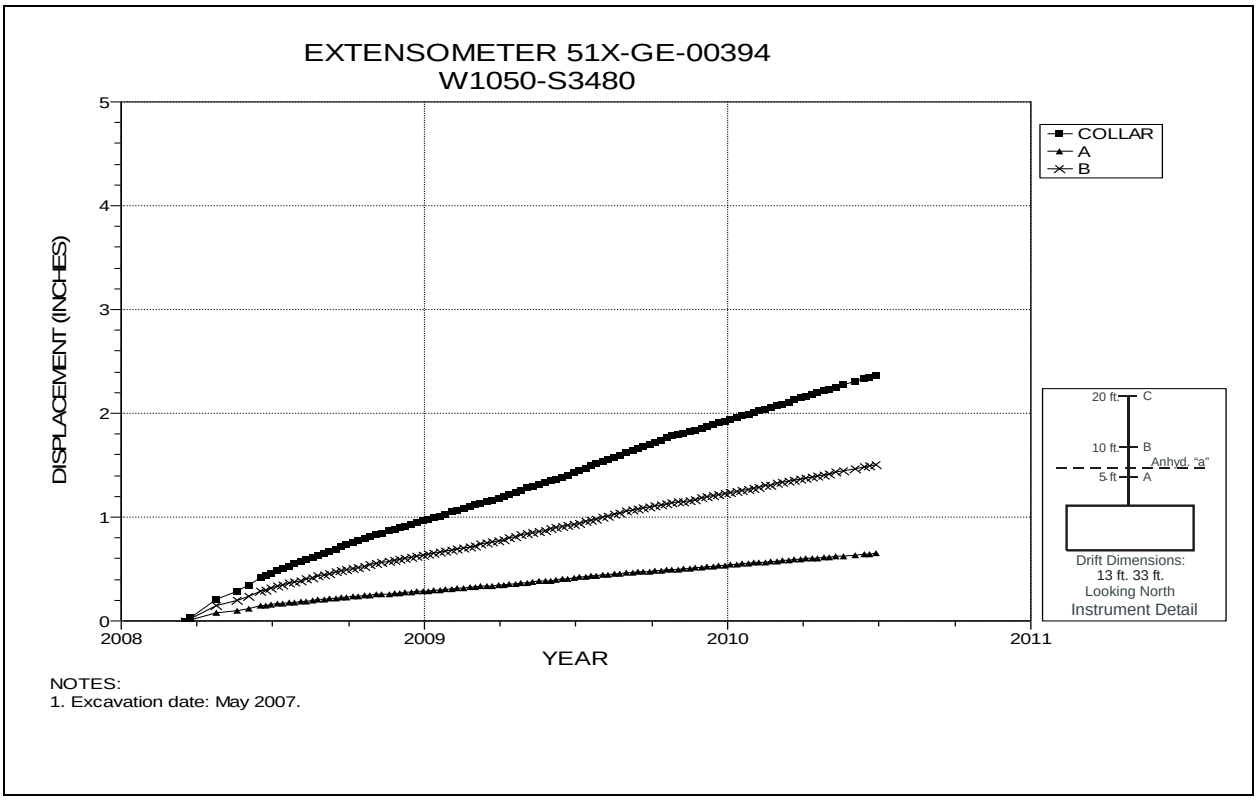


Figure 5-37 Extensometer 51X-GE-00394
Room 6, Panel 5 at W1050 S3480 – Room Center – Roof

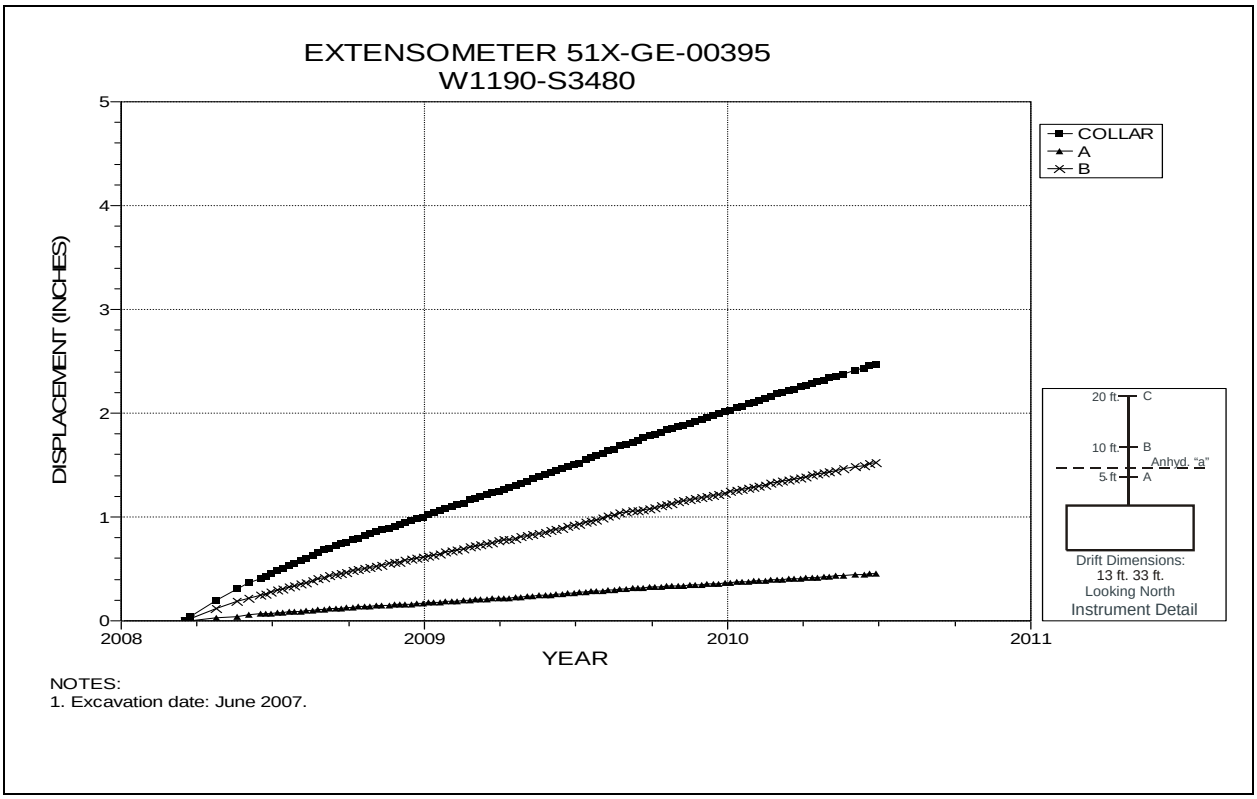


Figure 5-38 Extensometer 51X-GE-00395
Room 7, Panel 5 at W1190 S3480 – Room Center – Roof

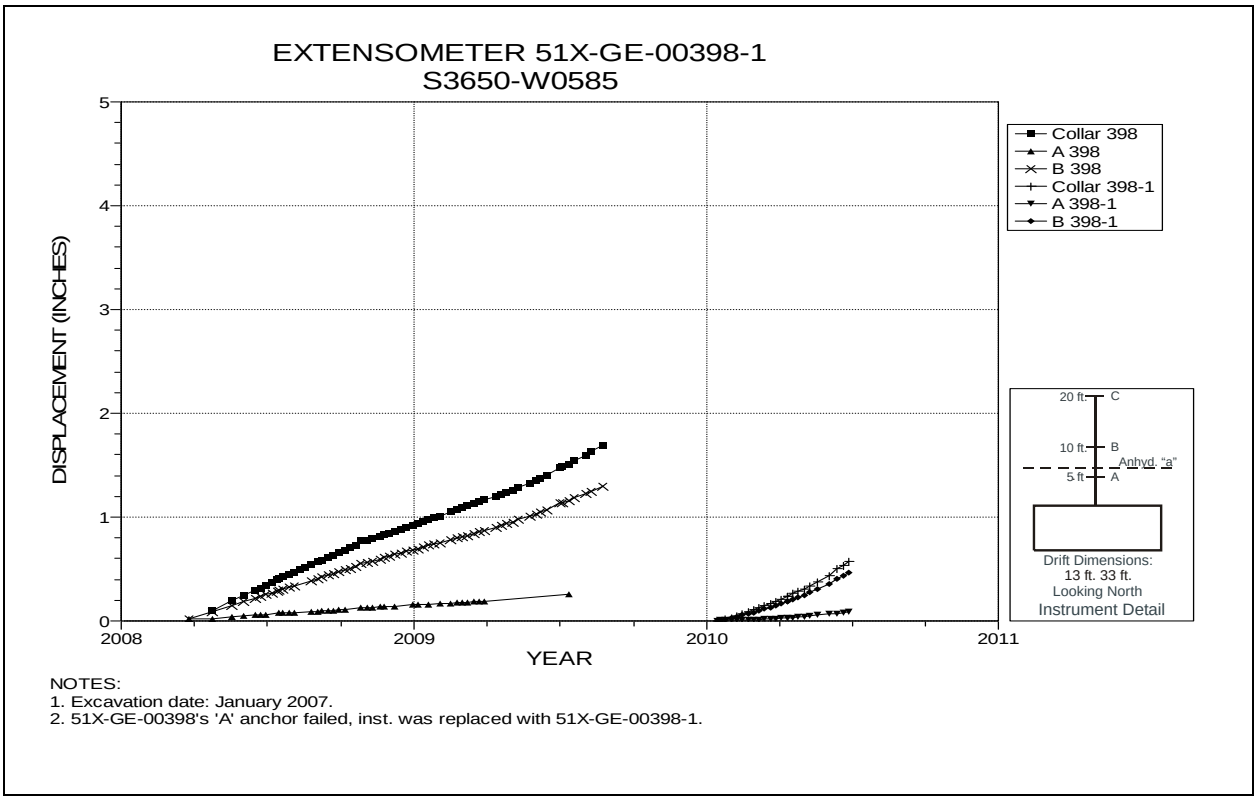


Figure 5-39 Extensometer 51X-GE-00398
S3650 W585 – Roof

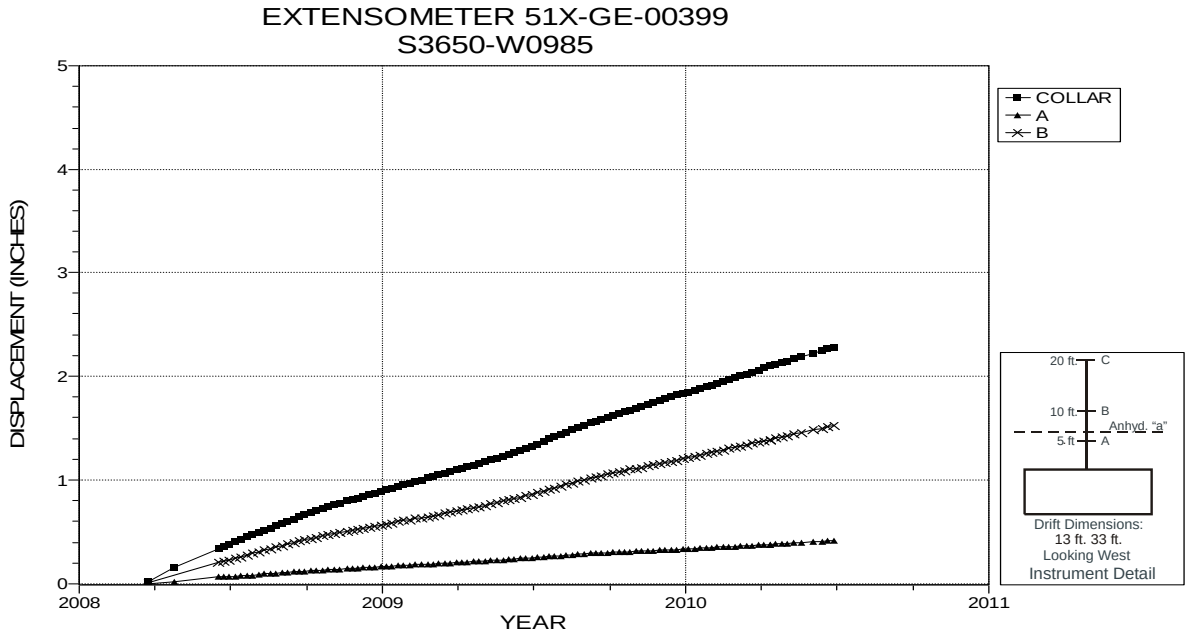


Figure 5-40 Extensometer 51X-GE-00399
S3650 W985 – Roof

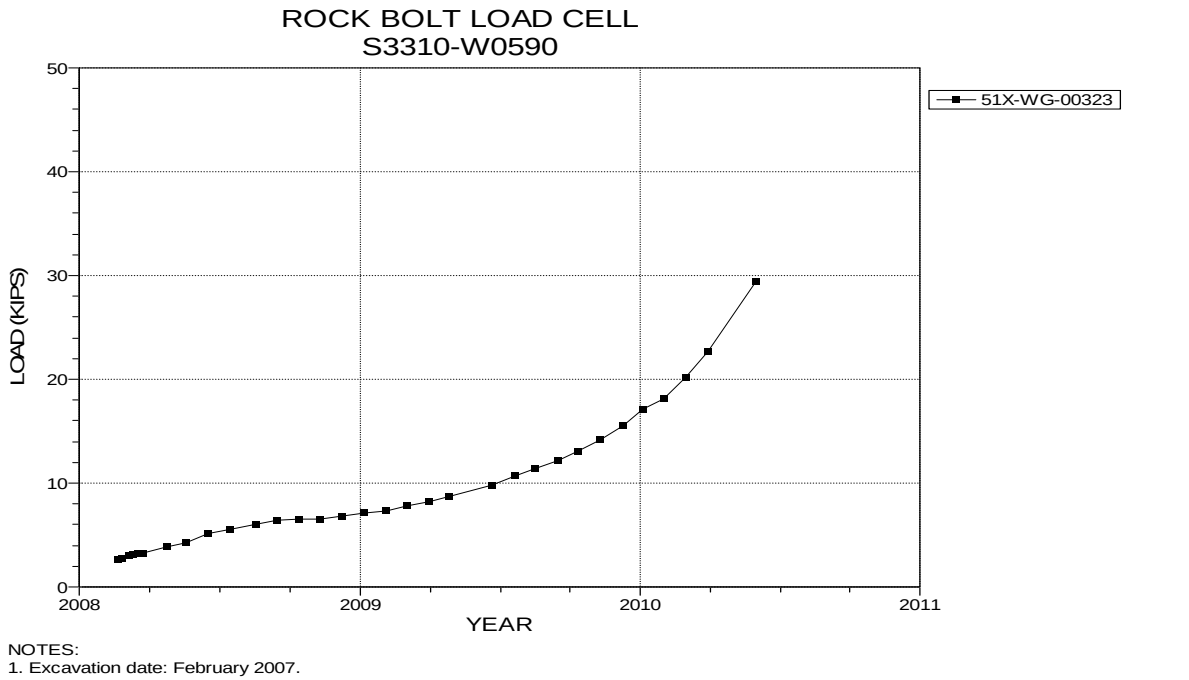


Figure 5-41 Rock Bolt Load Cell
S3310 W590

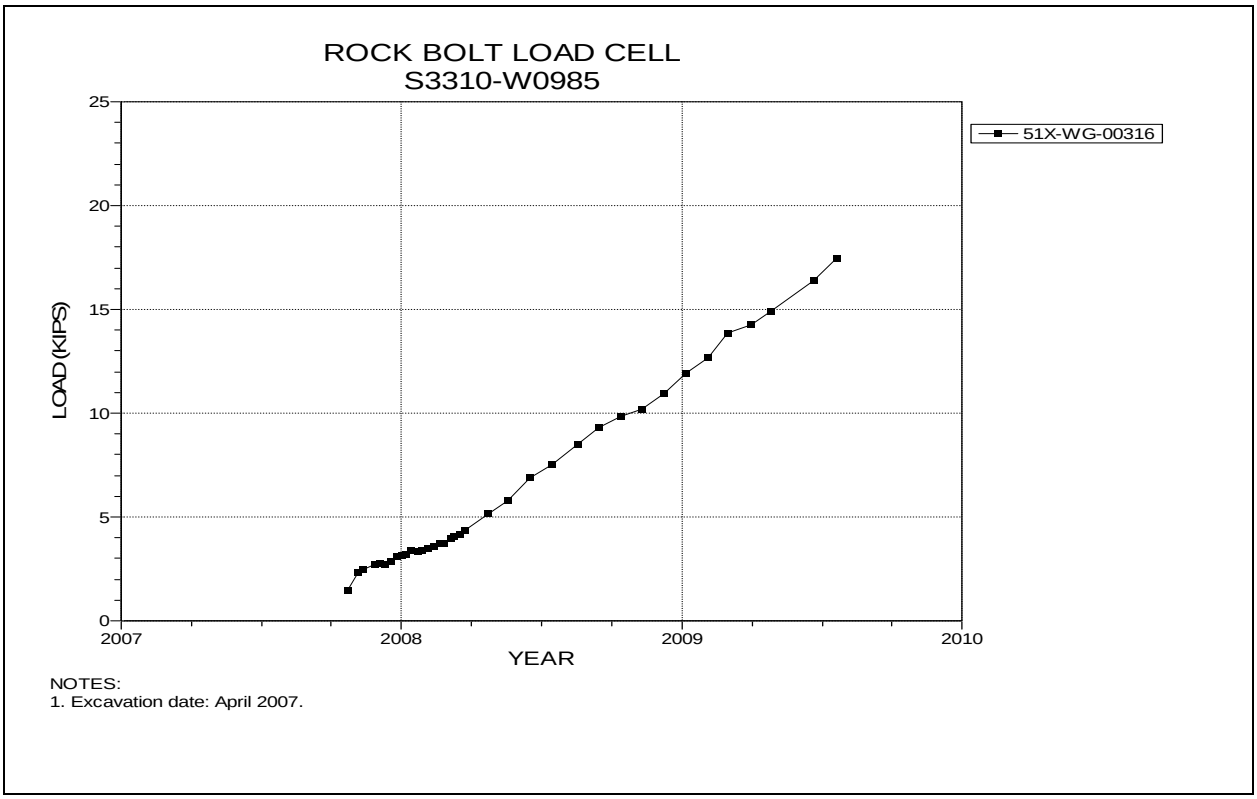


Figure 5-42 Rock Bolt Load Cell
S3310 W985

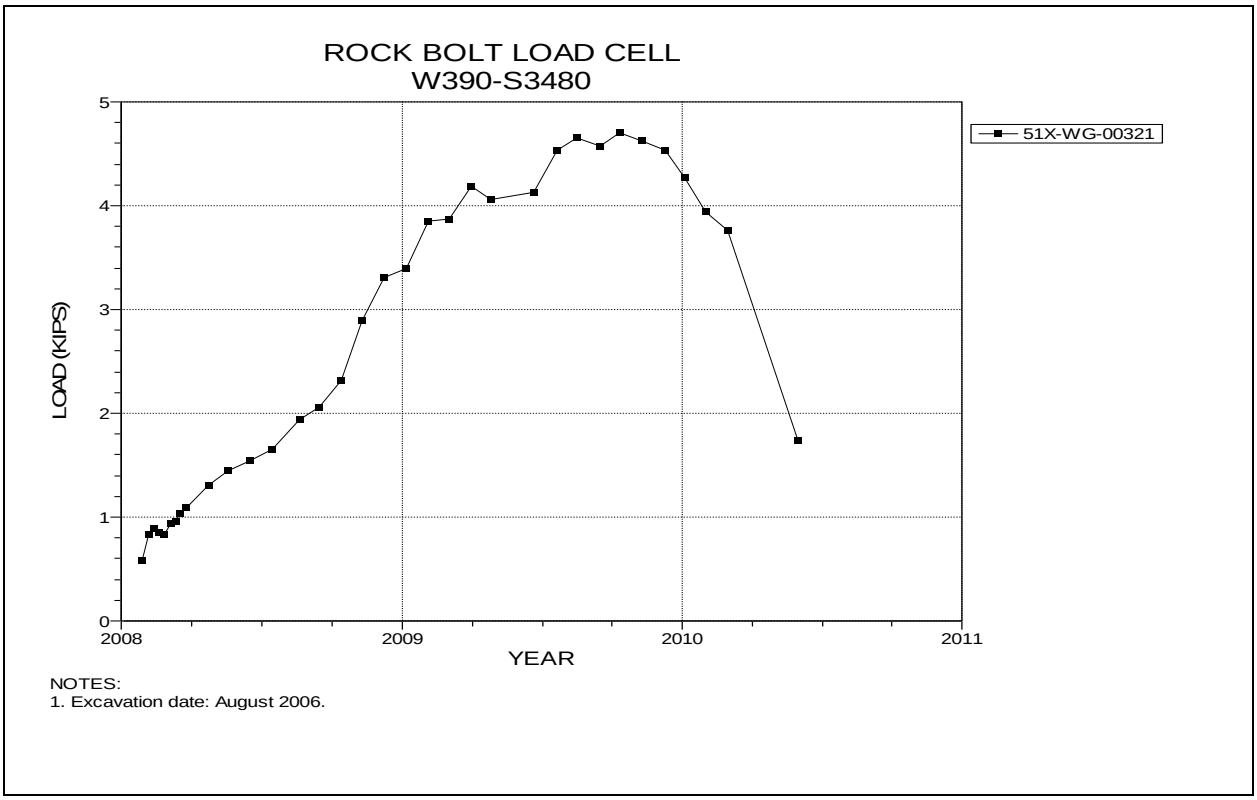


Figure 5-43 Rock Bolt Load Cell
Room 1, Panel 5 at W390 S3480

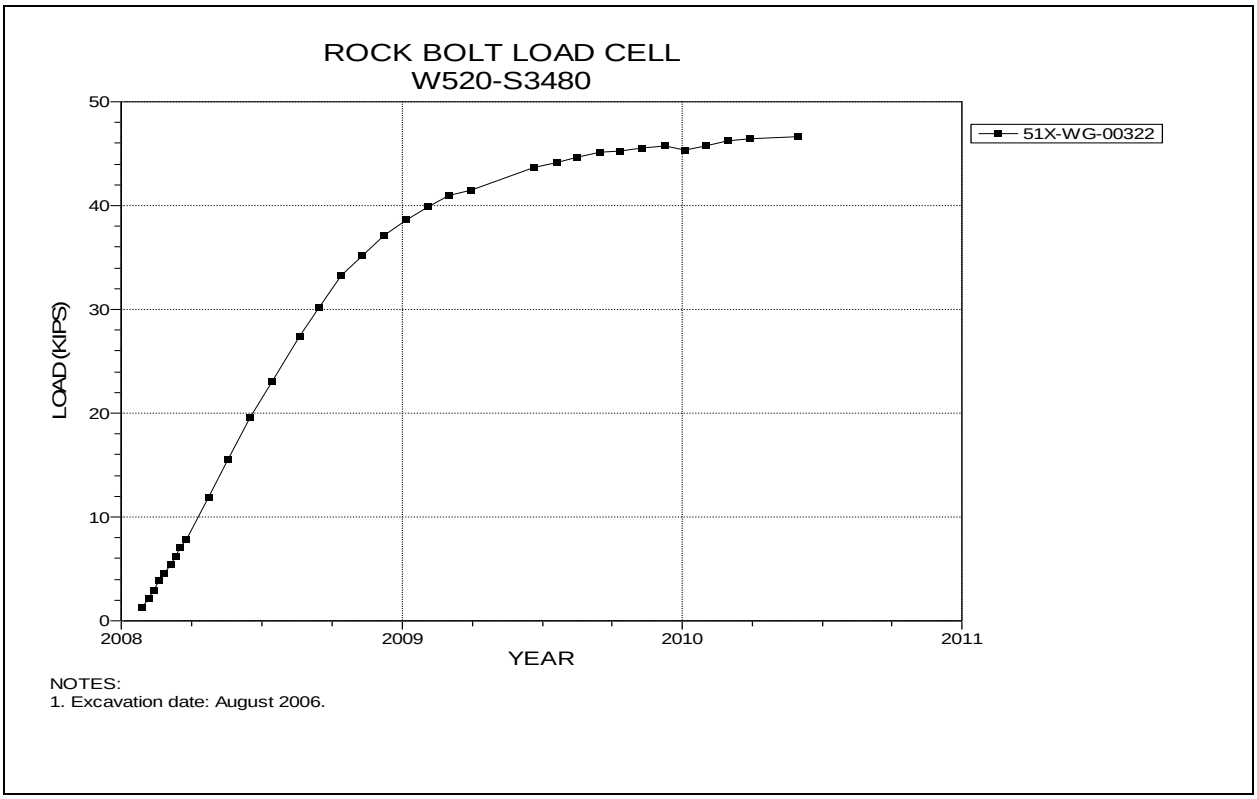


Figure 5-44 Rock Bolt Load Cell
Room 2, Panel 5 at W520 S3480

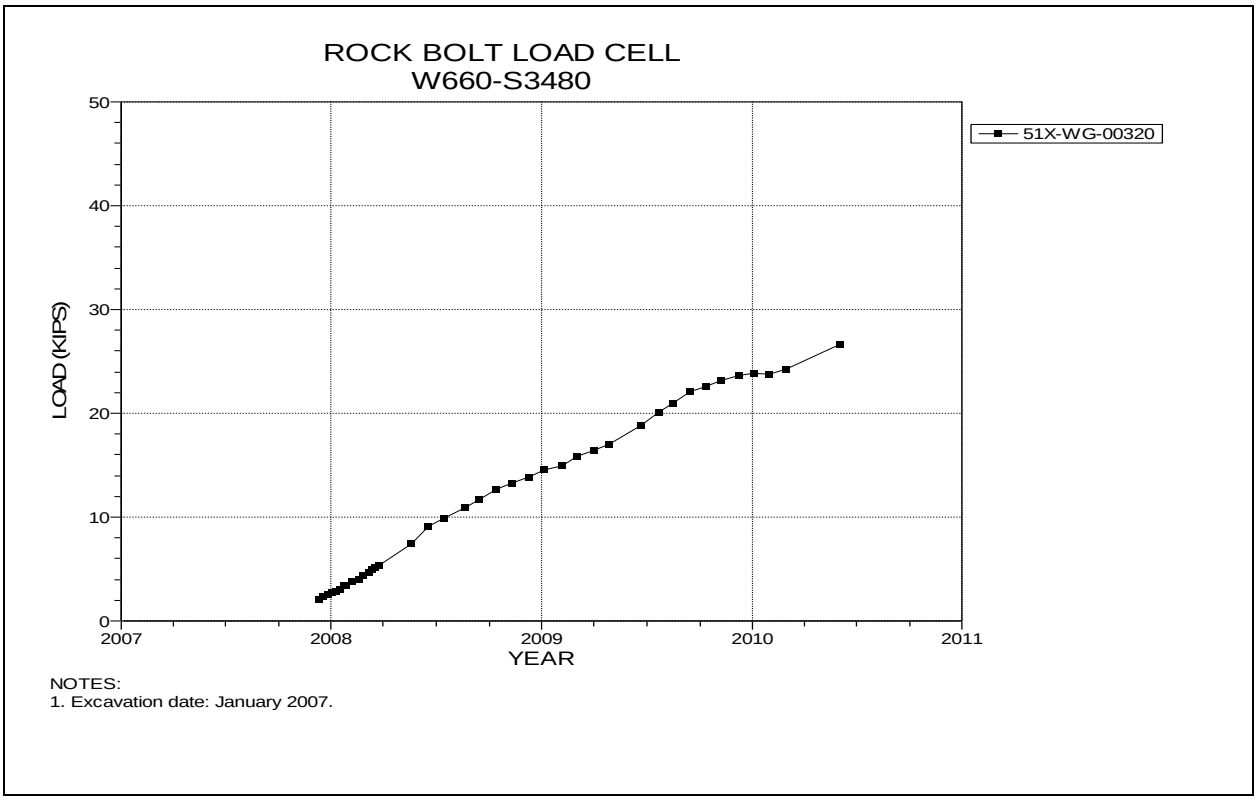


Figure 5-45 Rock Bolt Load Cell
Room 3, Panel 5 at W660 S3480

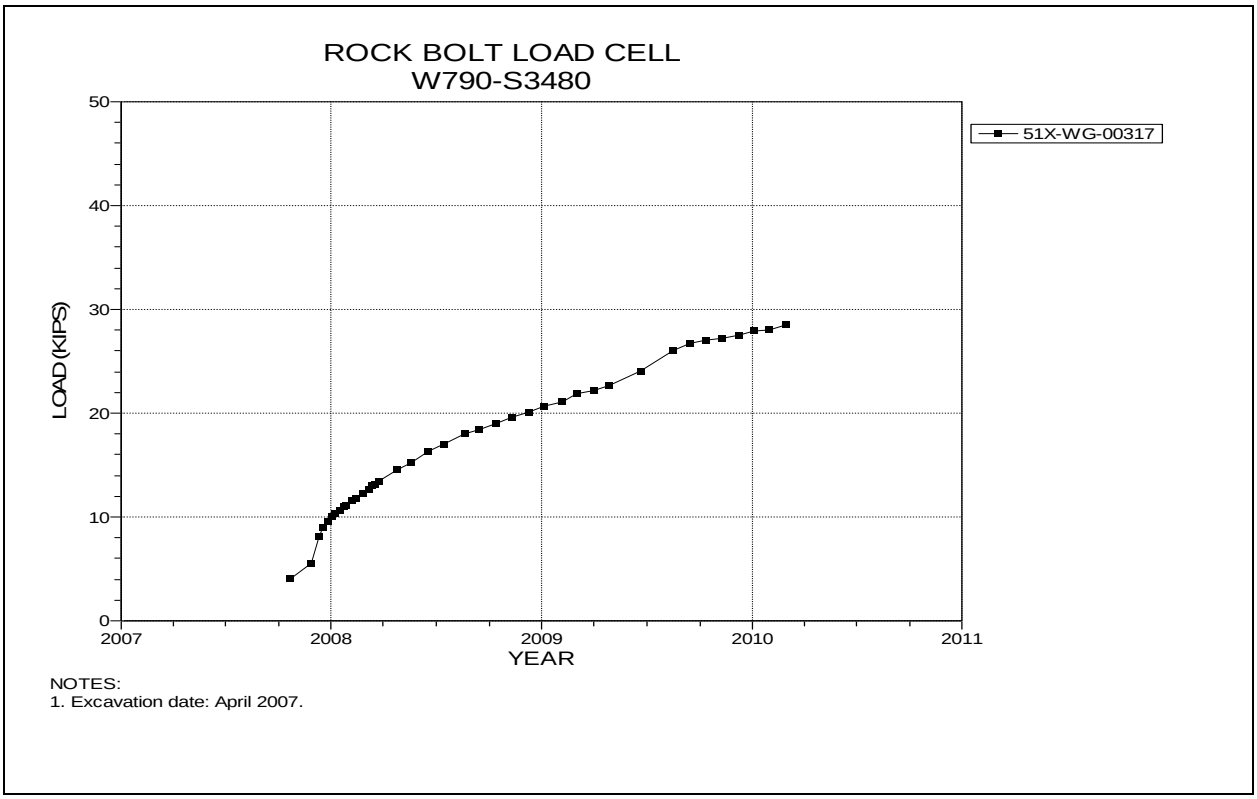


Figure 5-46 Rock Bolt Load Cell
Room 4, Panel 5 at W790 S3480

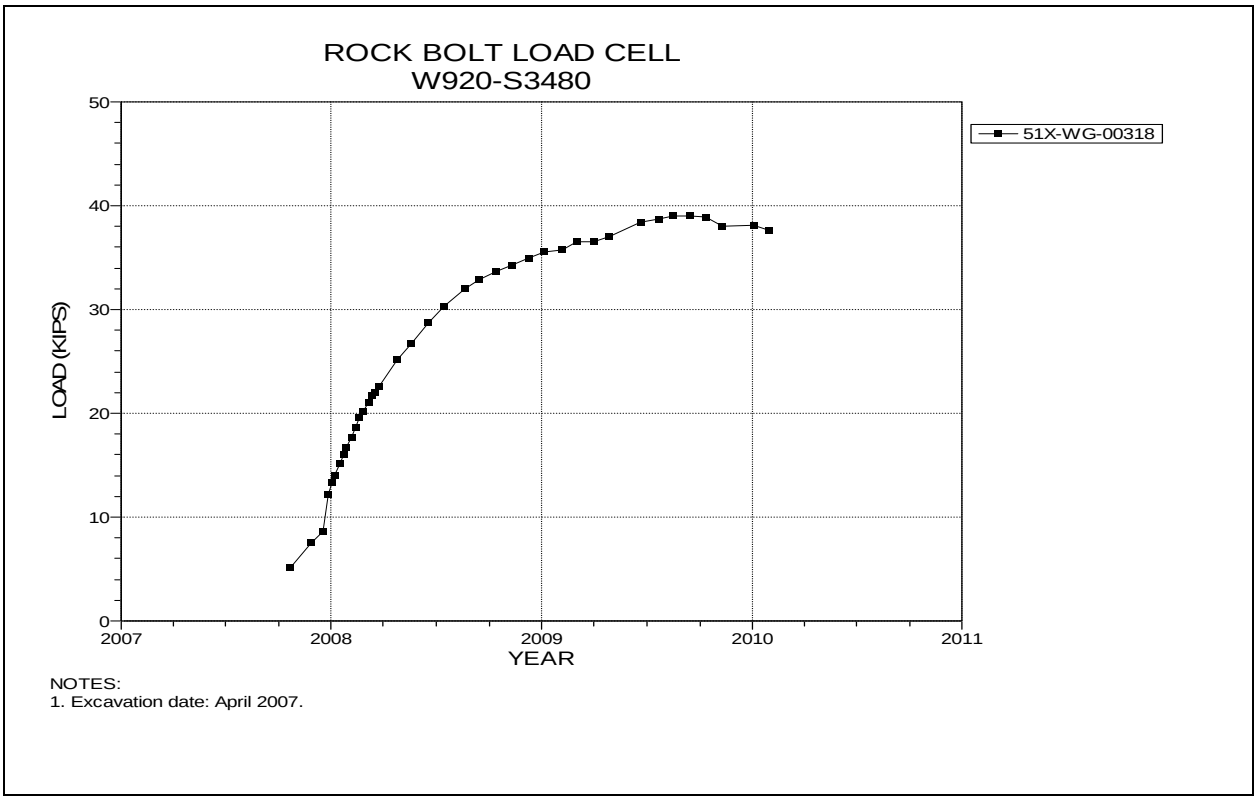


Figure 5-47 Rock Bolt Load Cell
Room 5, Panel 5 at W920 S3480

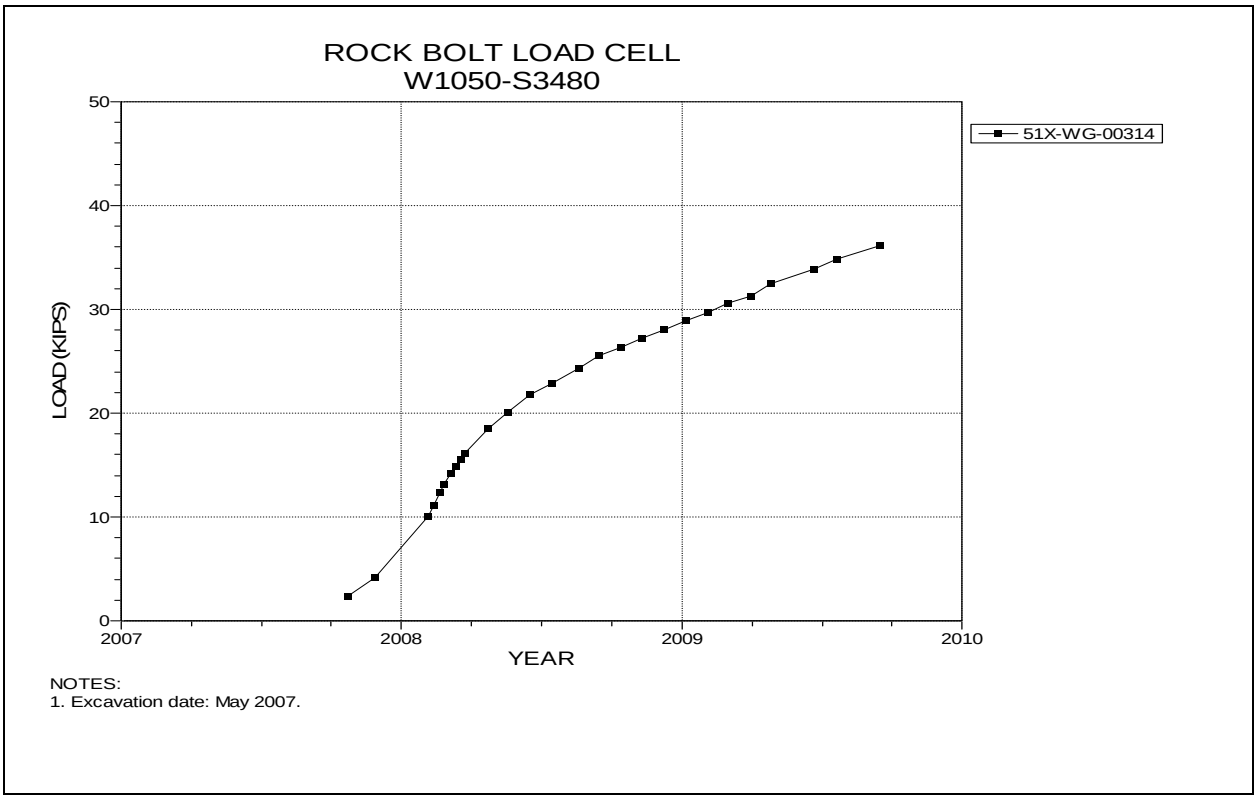


Figure 5-48 Rock Bolt Load Cell
Room 6, Panel 5 at W1050 S3480

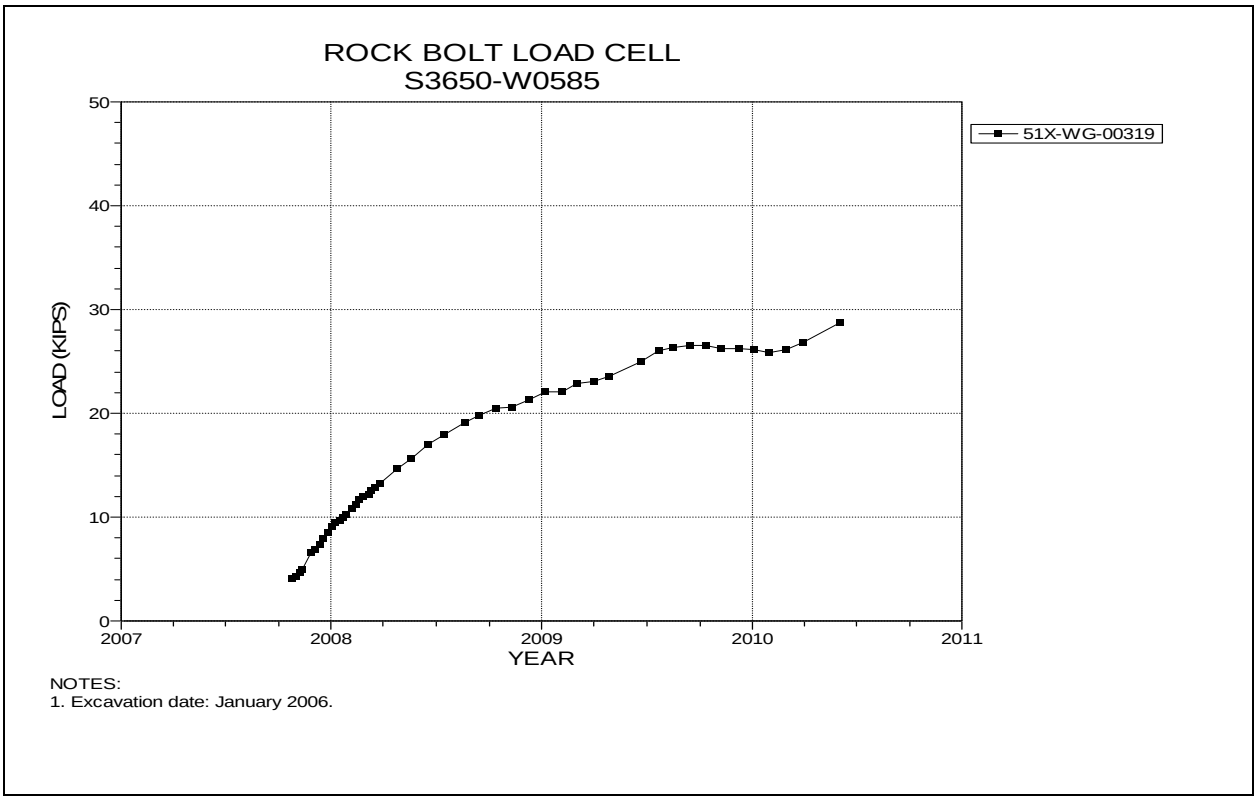


Figure 5-49 Rock Bolt Load Cell
S3650 W585

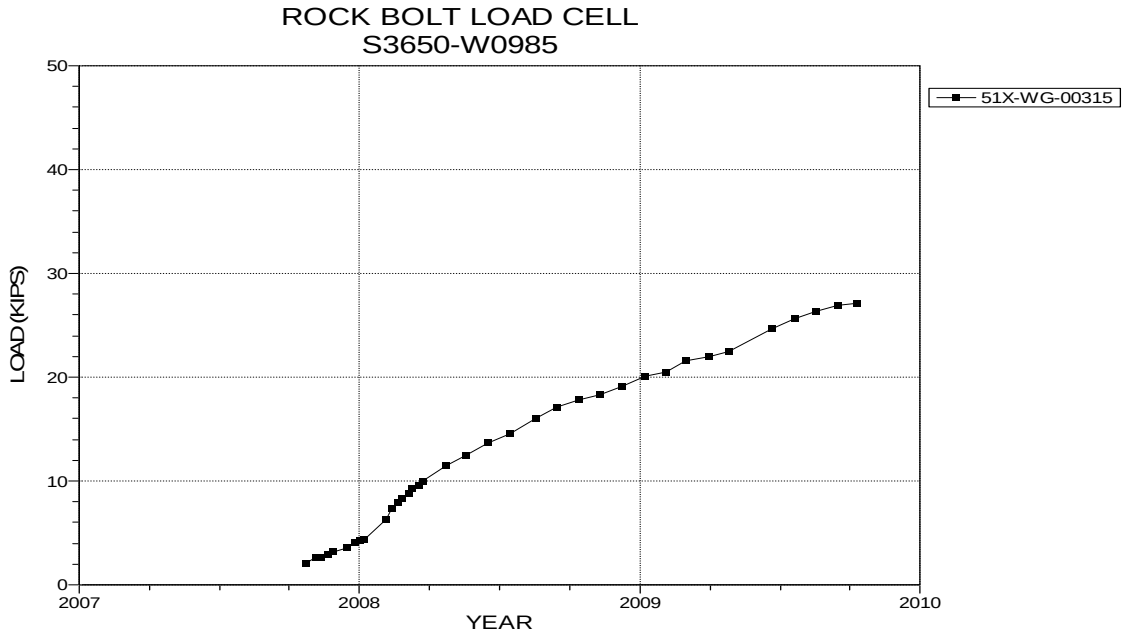


Figure 5-50 Rock Bolt Load Cell
S3650 W985

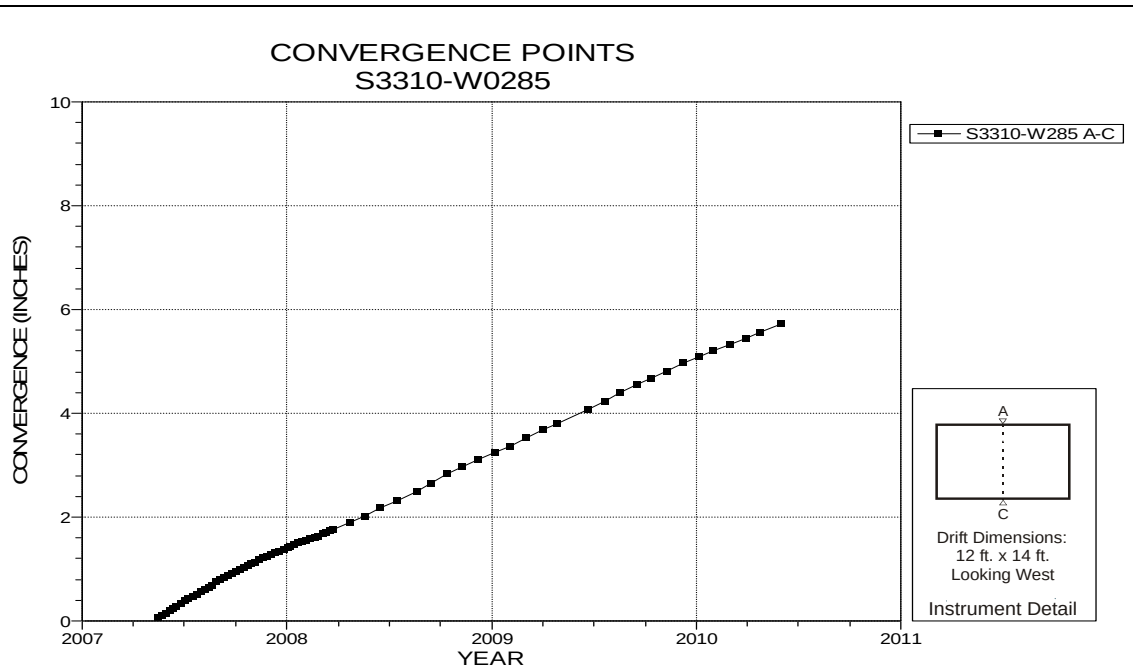


Figure 5-51 Convergence Point Array
S3310 W285 – Roof to Floor

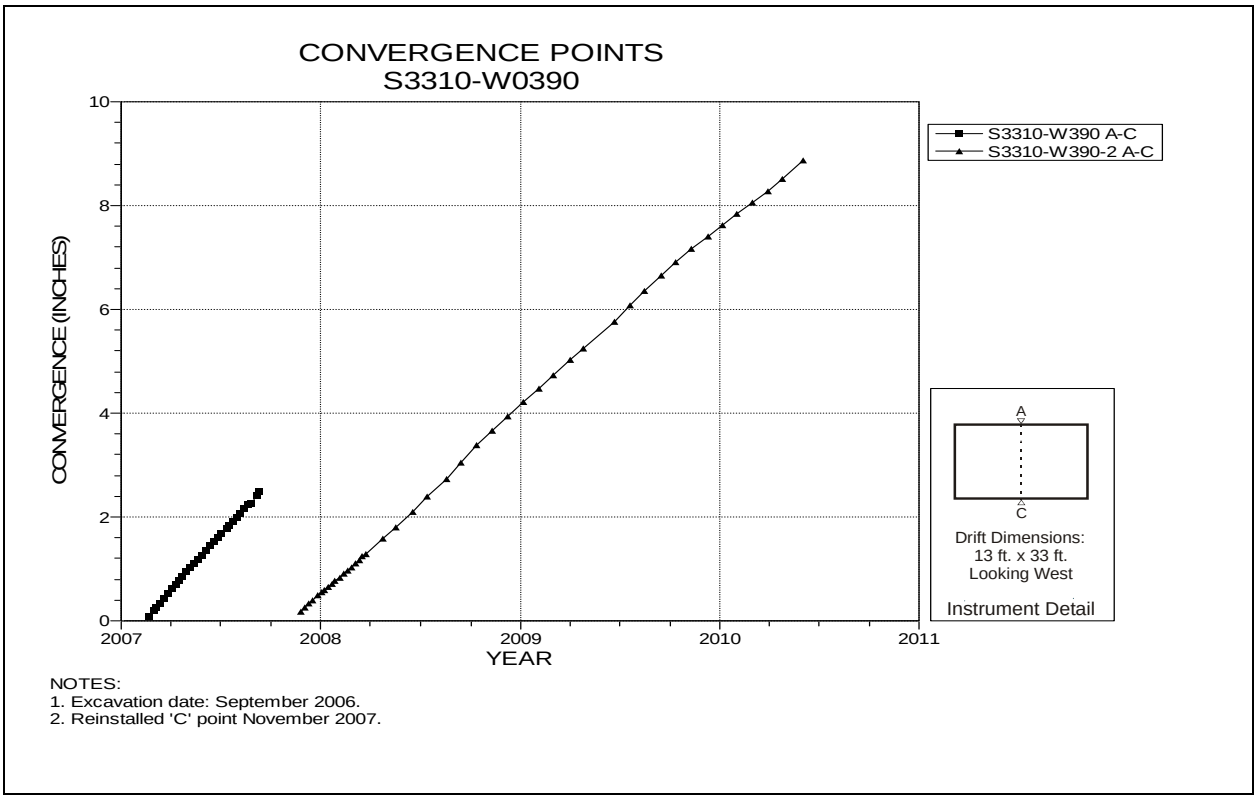


Figure 5-52 Convergence Point Array
S3310 W390 Intersection (Room 1, Panel 5) – Roof to Floor

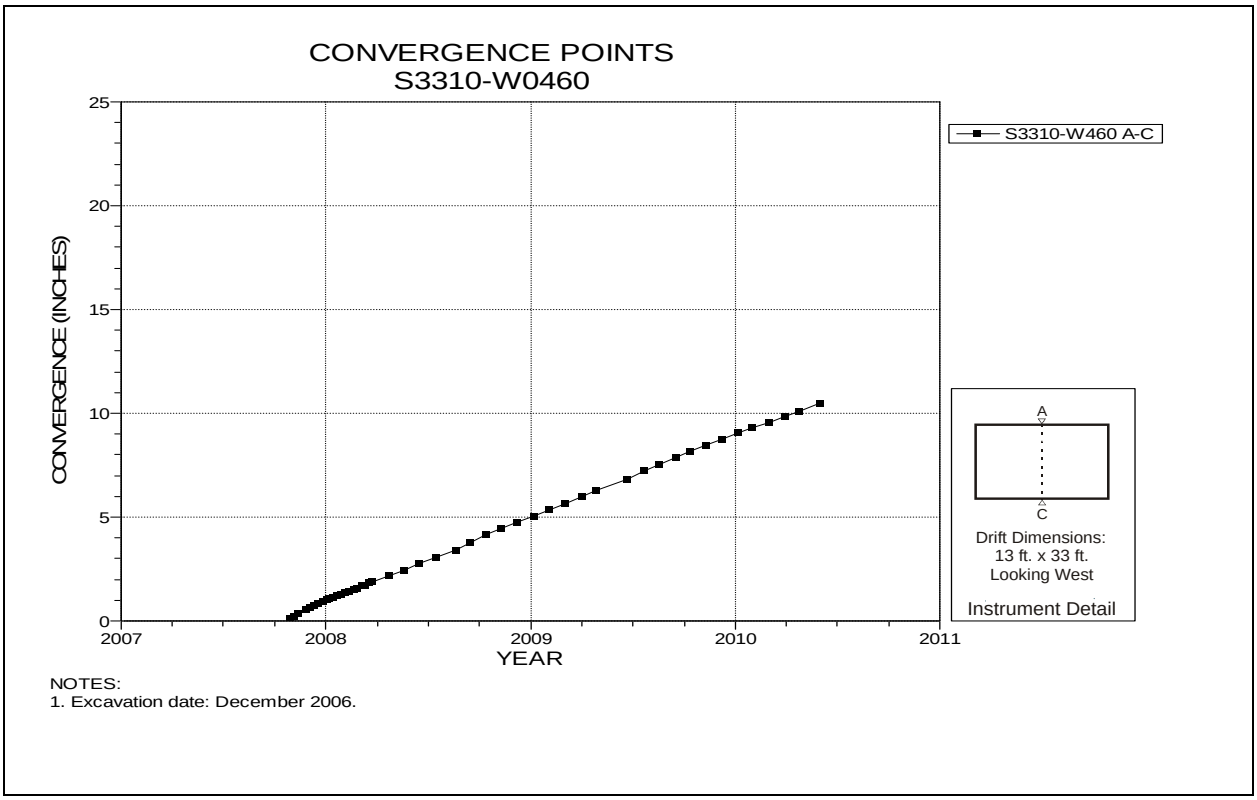


Figure 5-53 Convergence Point Array
S3310 W460 – Roof to Floor

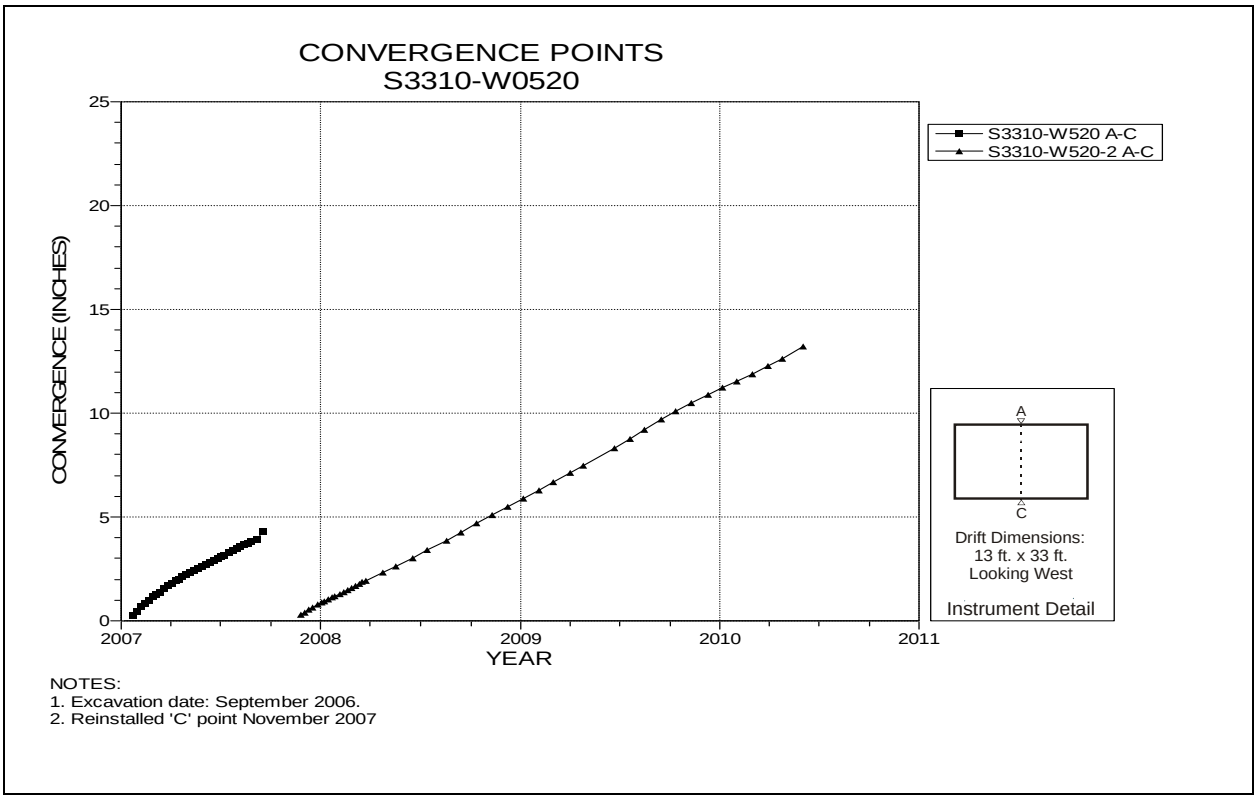


Figure 5-54 Convergence Point Array
S3310 W520 Intersection (Room 2, Panel 5) – Roof to Floor

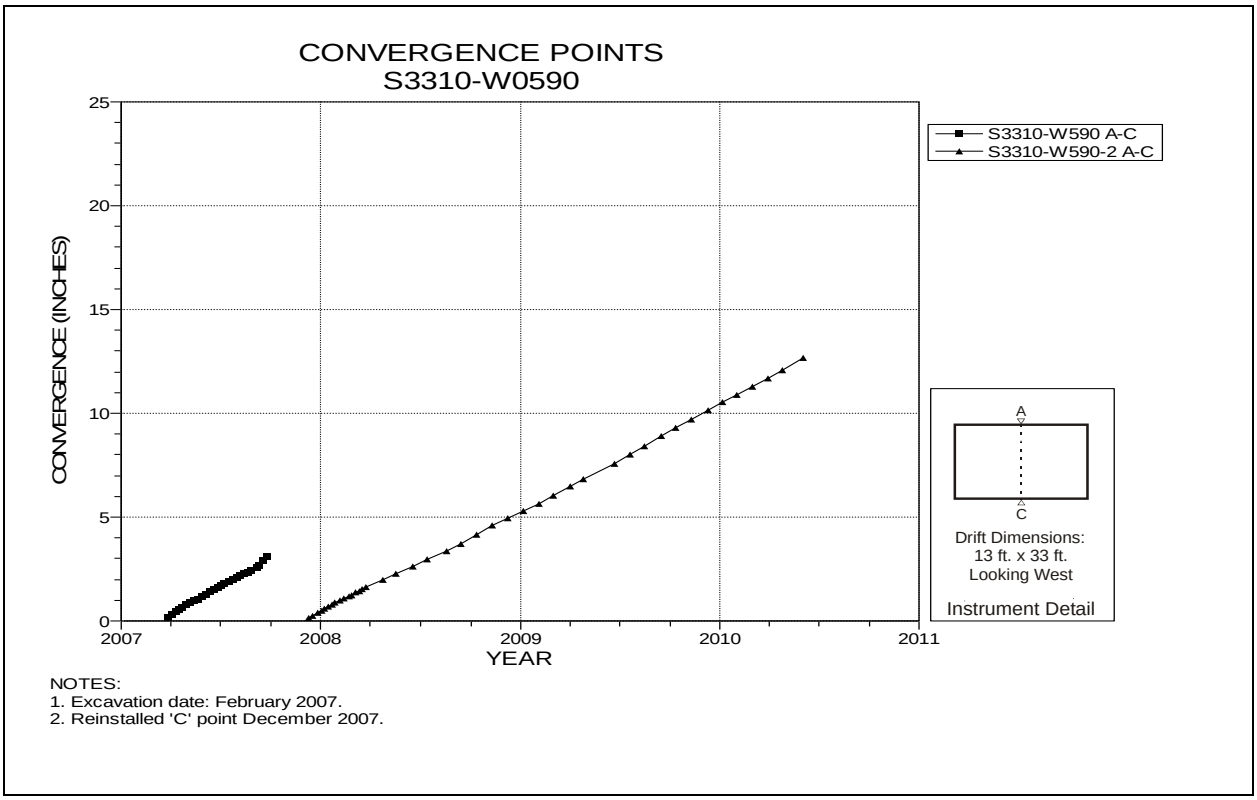


Figure 5-55 Convergence Point Array
S3310 W590 – Roof to Floor

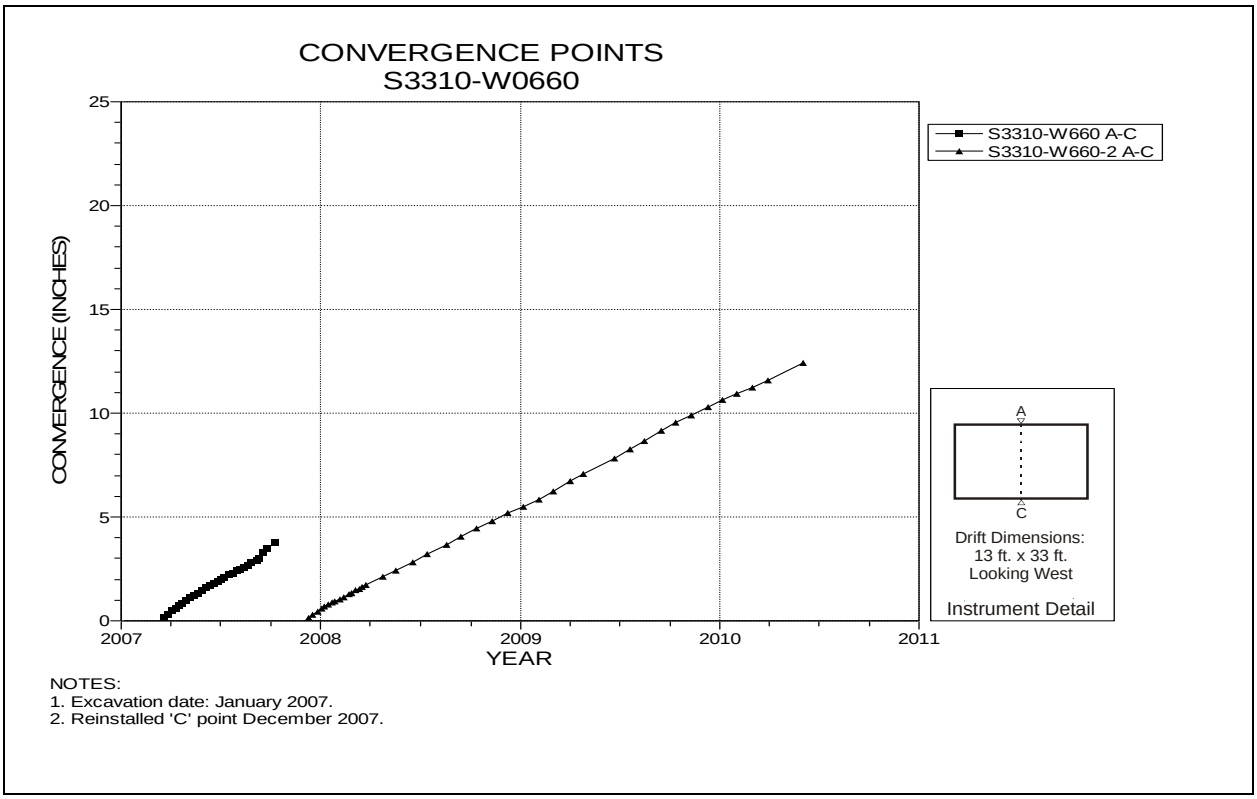


Figure 5-56 Convergence Point Array
S3310 W660 Intersection (Room 3, Panel 5) – Roof to Floor

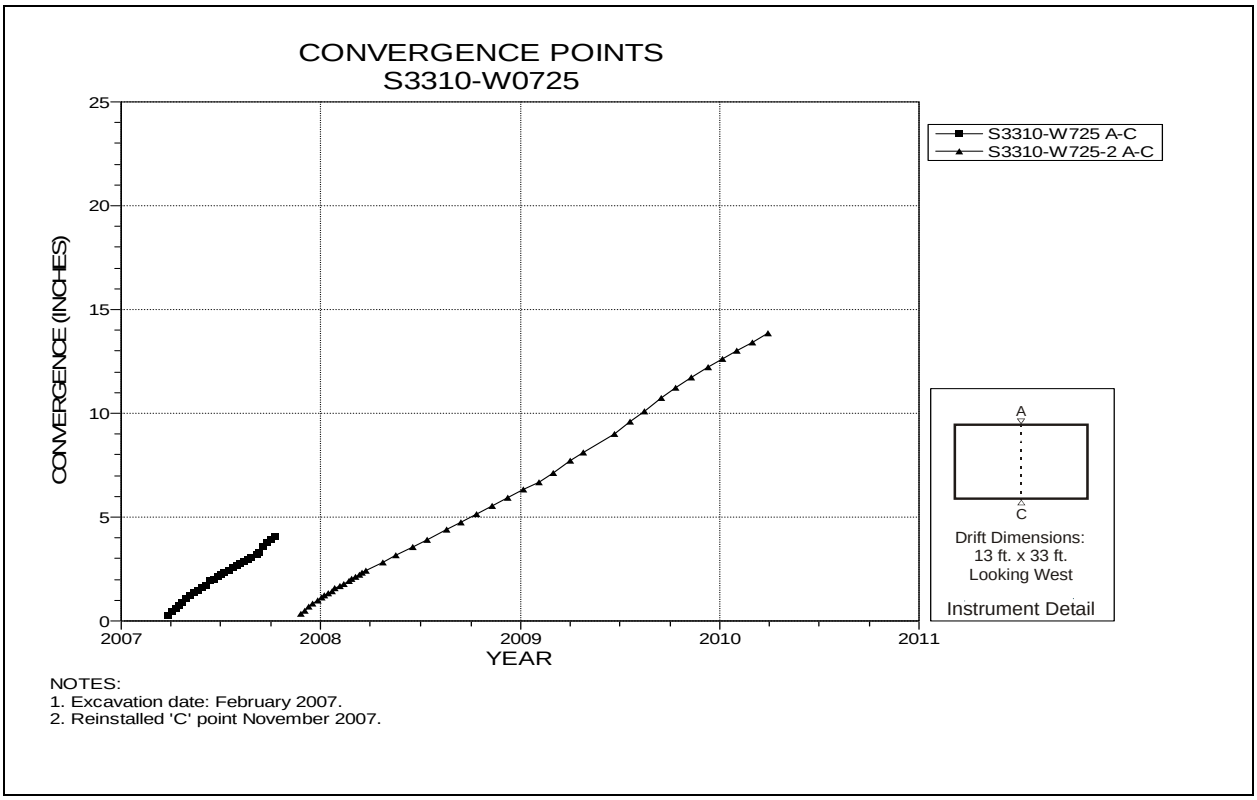


Figure 5-57 Convergence Point Array
S3310 W725 – Roof to Floor

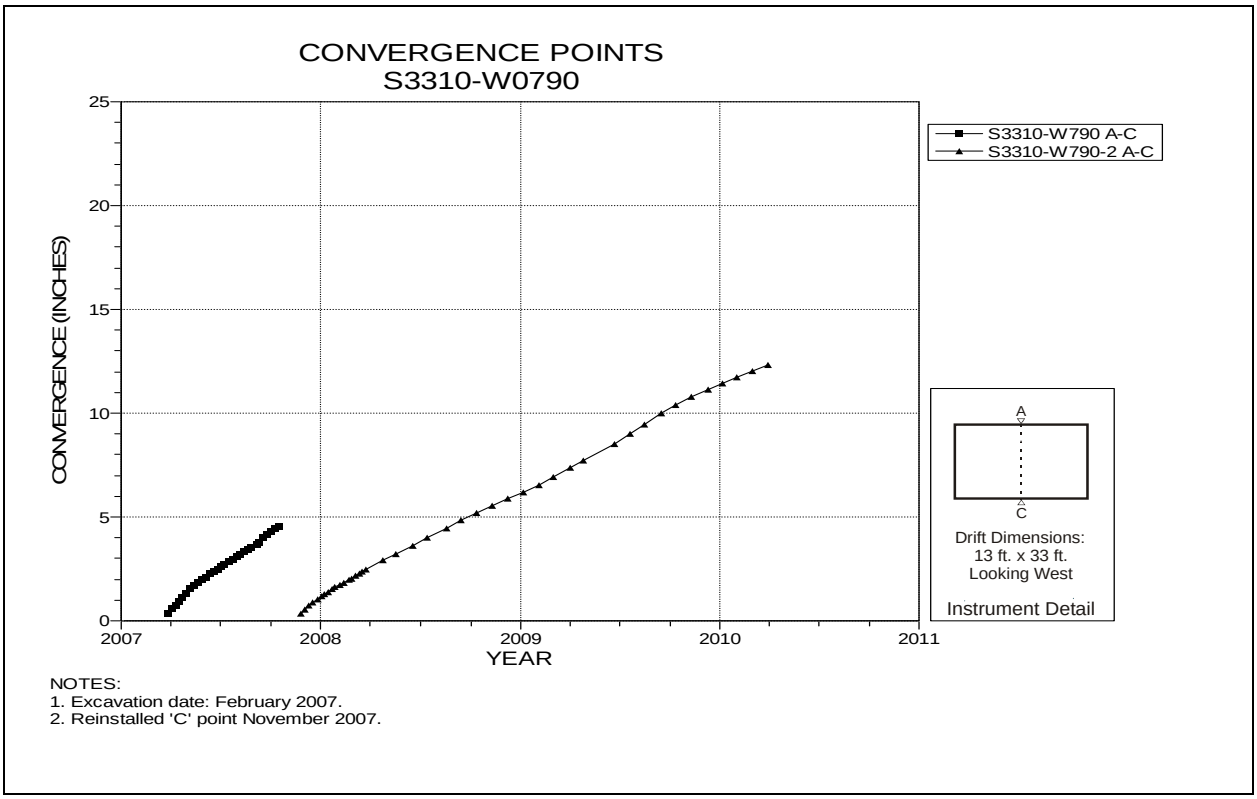


Figure 5-58 Convergence Point Array
S3310 W790 Intersection (Room 4, Panel 5) – Roof to Floor

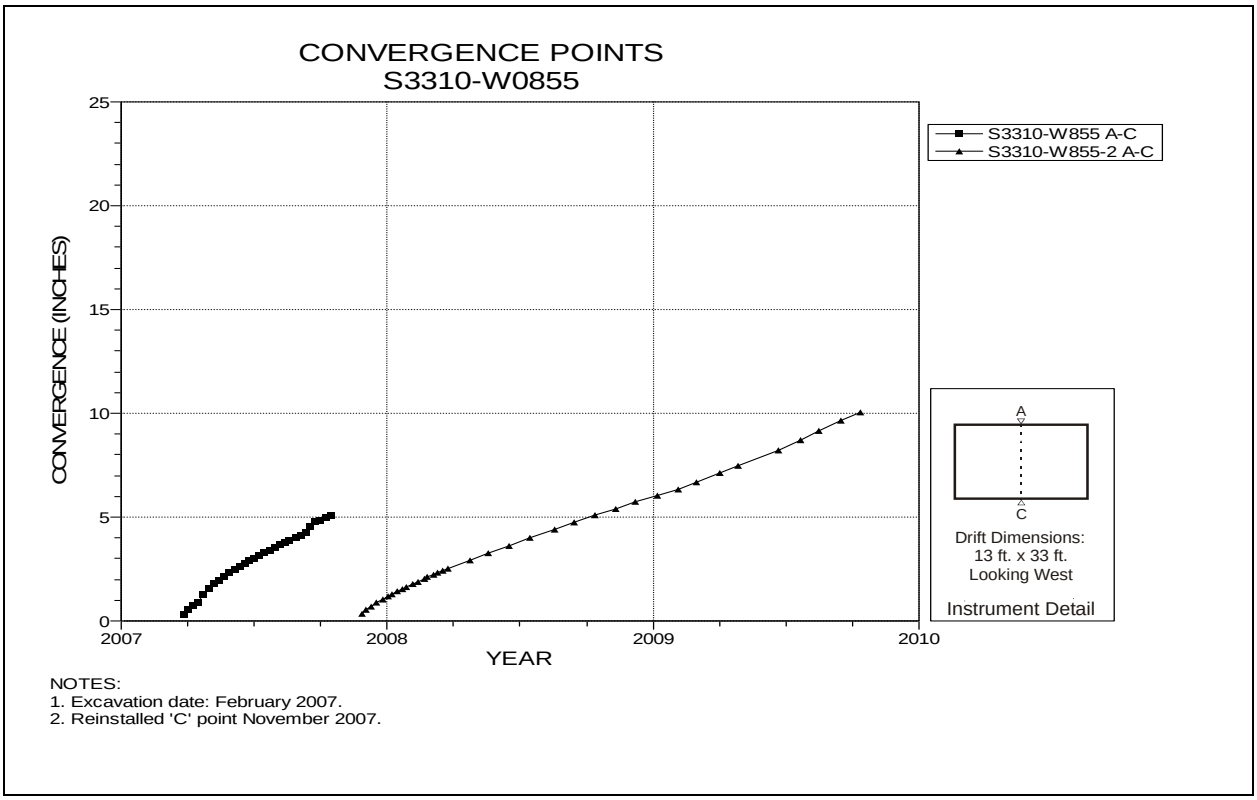


Figure 5-59 Convergence Point Array
S3310 W855 – Roof to Floor

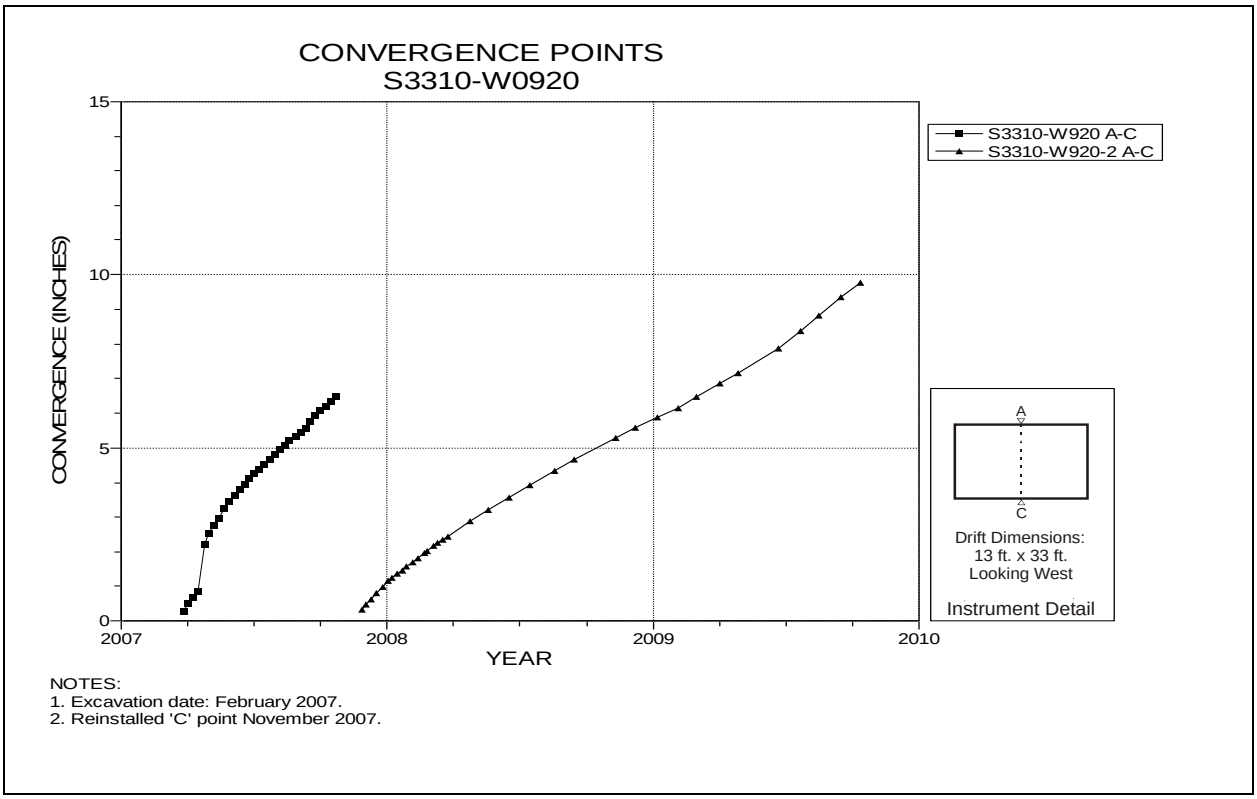


Figure 5-60 Convergence Point Array
S3310 W920 Intersection (Room 5, Panel 5) – Roof to Floor

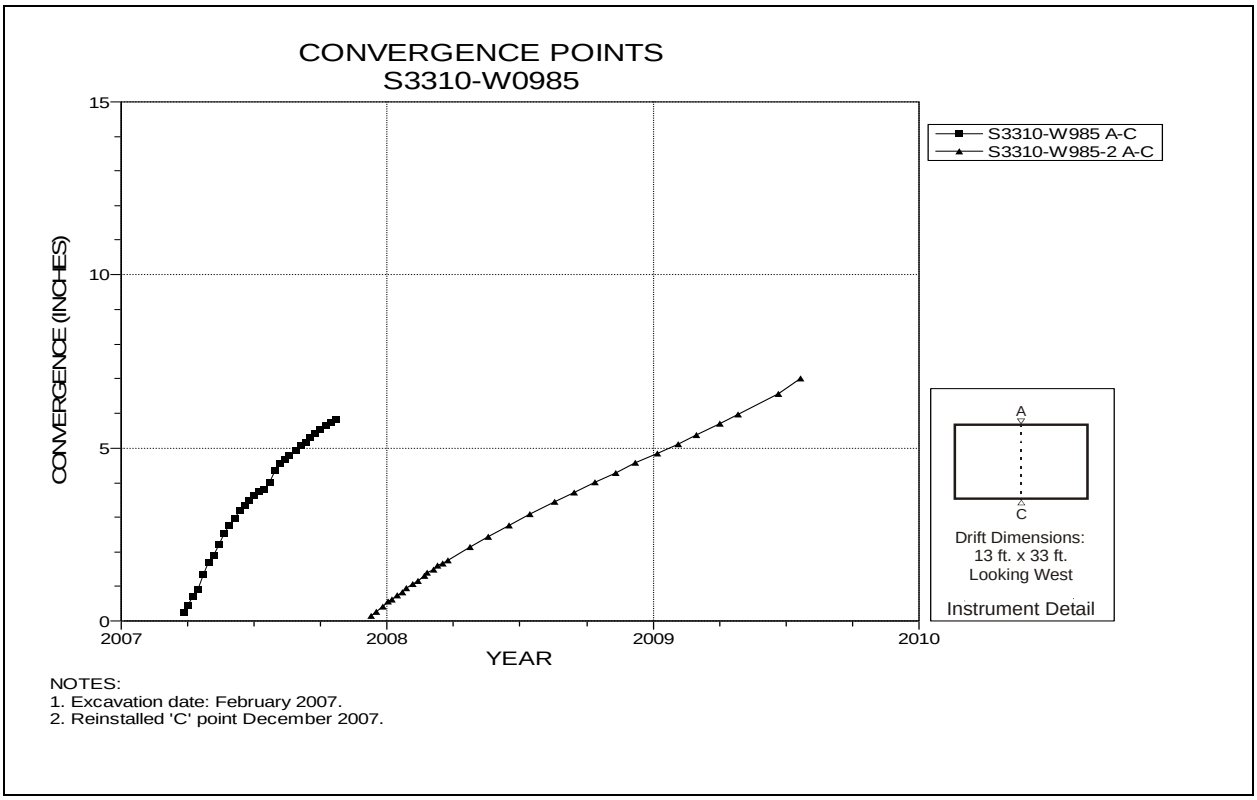


Figure 5-61 Convergence Point Array
S3310 W985 – Roof to Floor

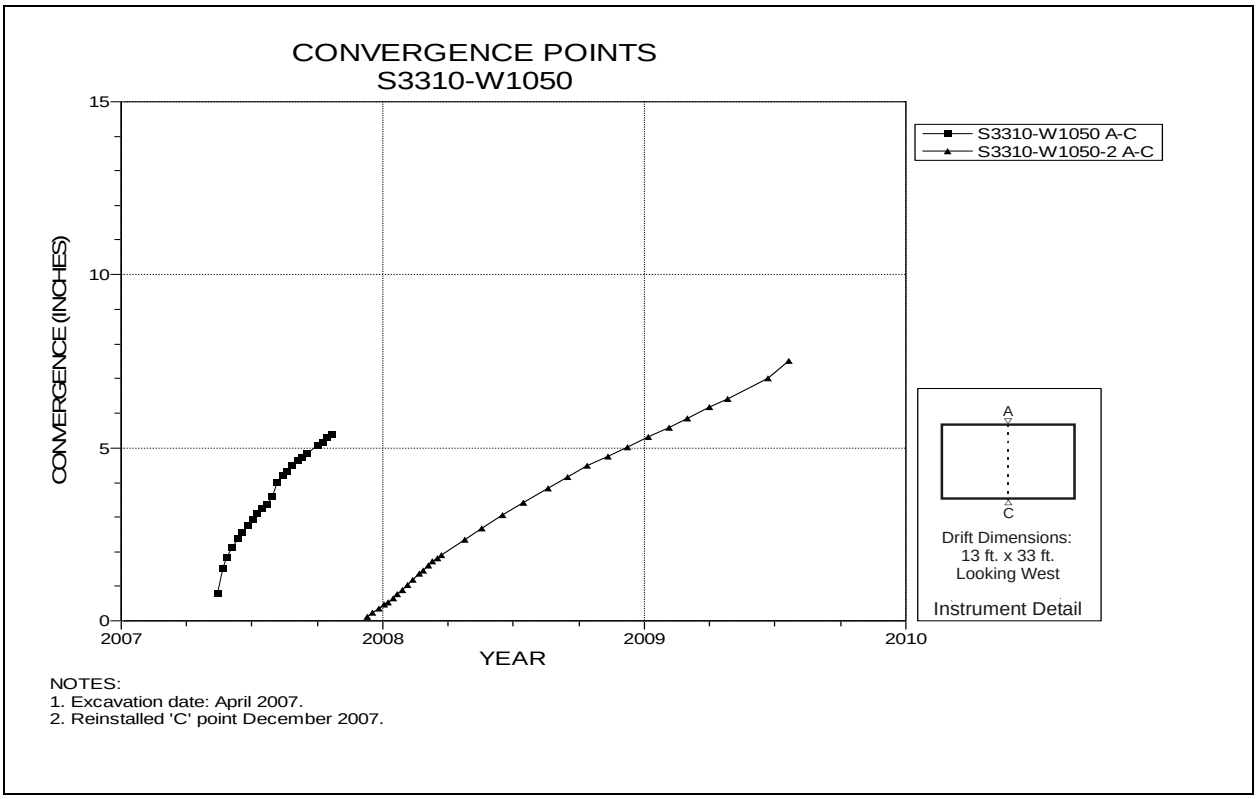


Figure 5-62 Convergence Point Array
S3310 W1050 Intersection (Room 6, Panel 5) – Roof to Floor

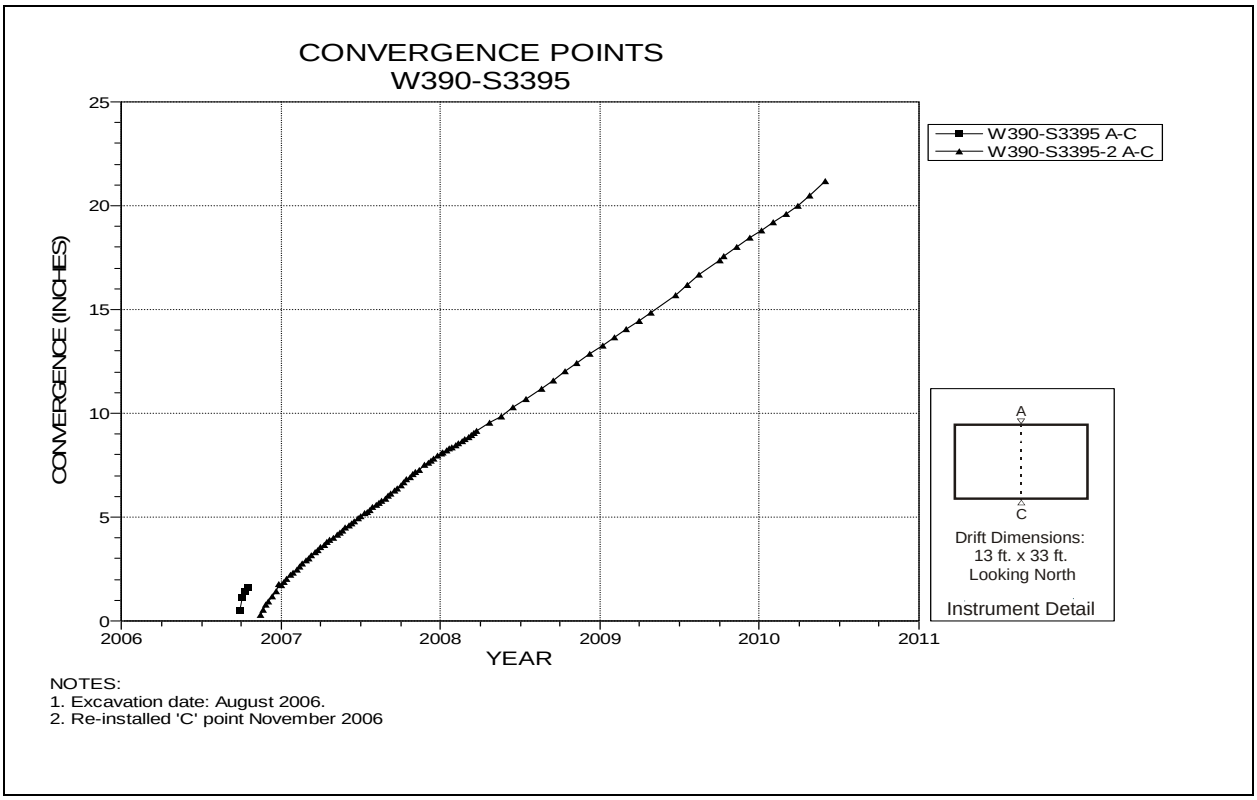


Figure 5-63 Convergence Point Array
Room 1, Panel 5 at W390 S3395 – Roof to Floor

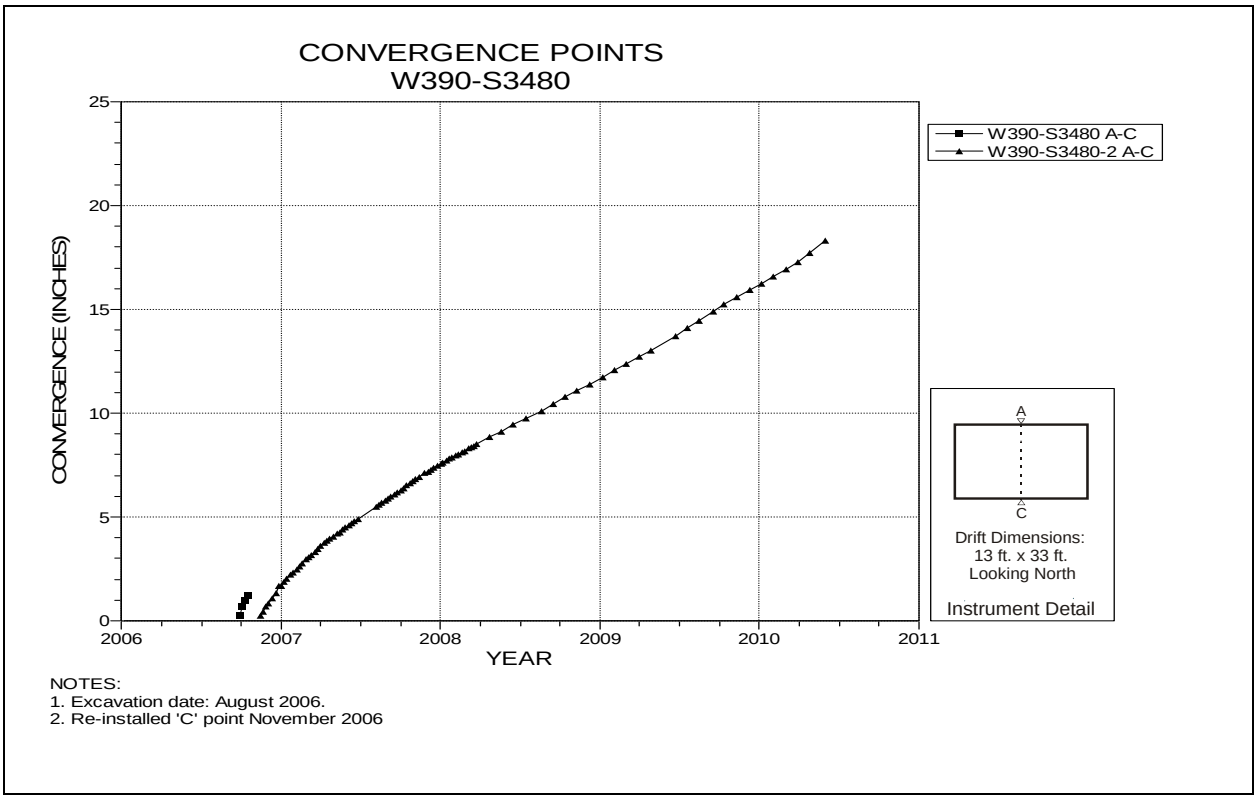


Figure 5-64 Convergence Point Array
Room 1, Panel 5 at W390 S3480 – Room Center – Roof to Floor

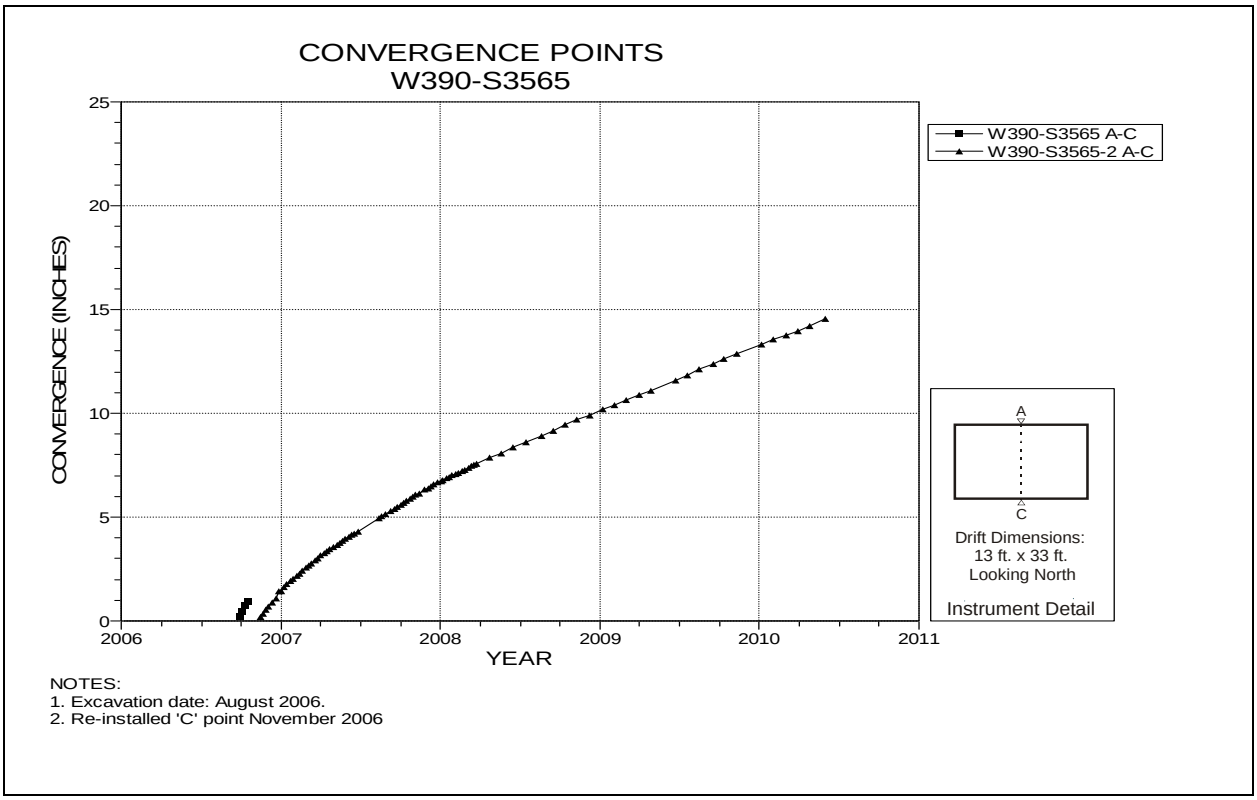


Figure 5-65 Convergence Point Array
Room 1, Panel 5 at W390 S3565 – Roof to Floor

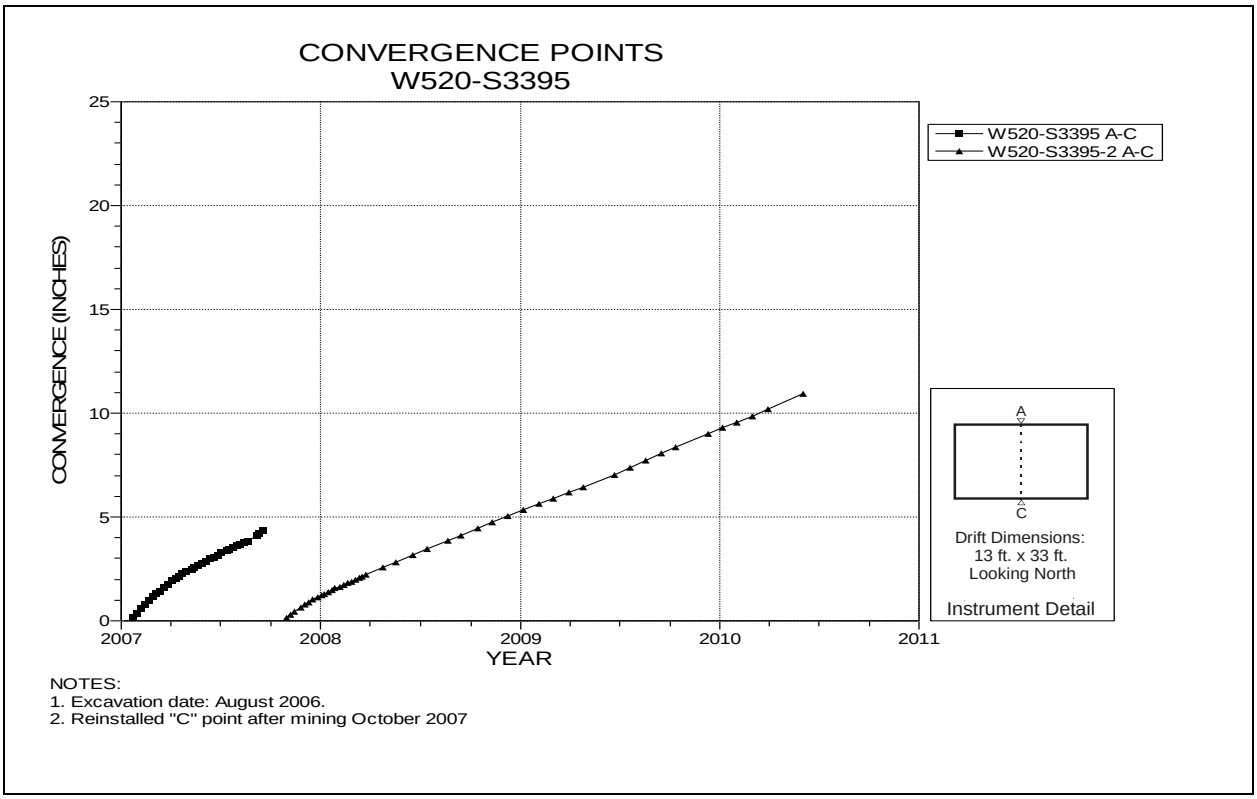


Figure 5-66 Convergence Point Array
Room 2, Panel 5 at W520 S3395 – Roof to Floor

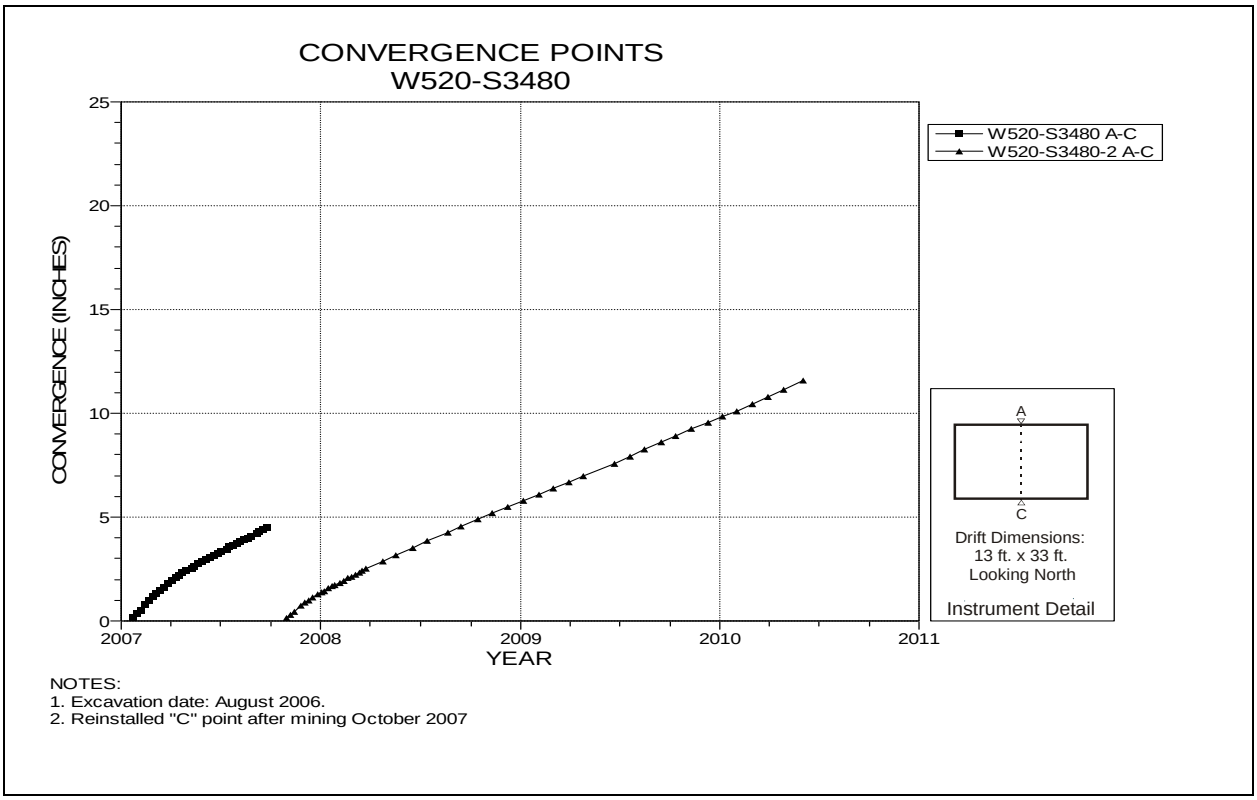


Figure 5-67 Convergence Point Array
Room 2, Panel 5 at W520 S3480 – Room Center – Roof to Floor

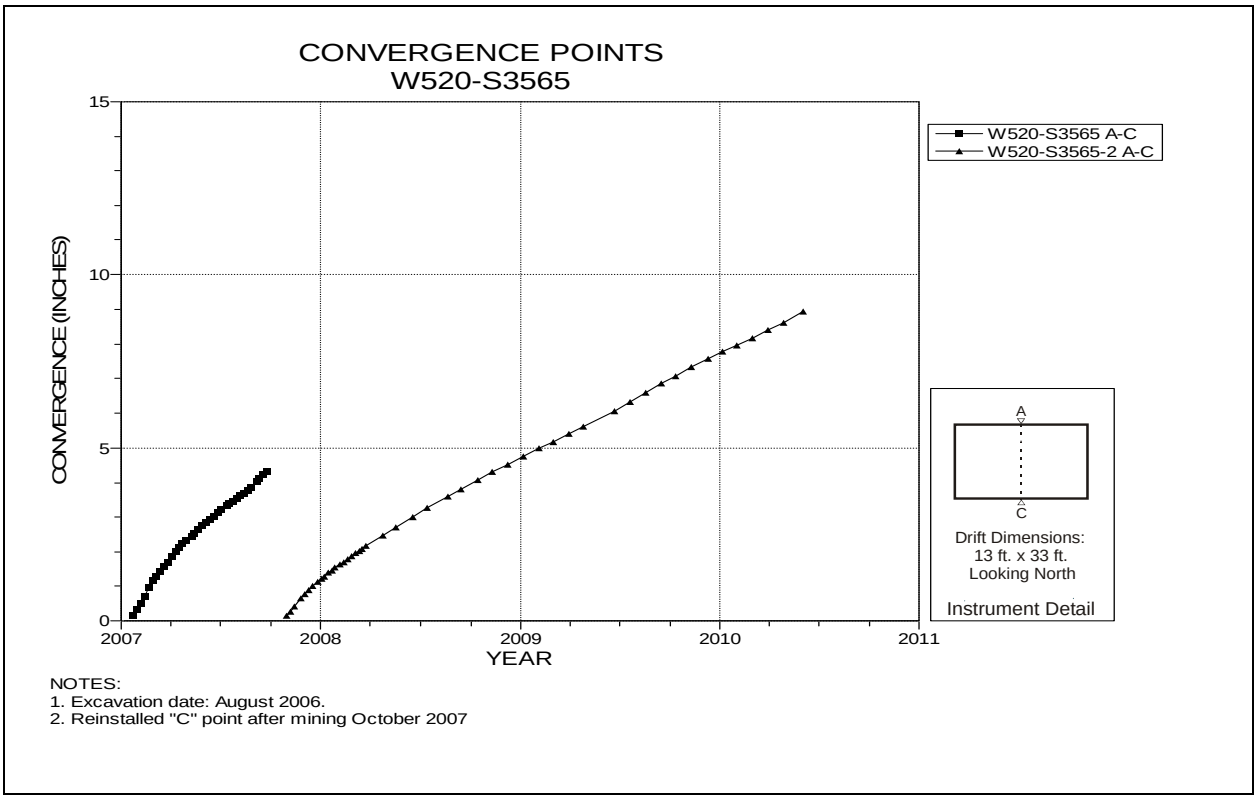


Figure 5-68 Convergence Point Array
Room 2, Panel 5 at W520 S3565 – Roof to Floor

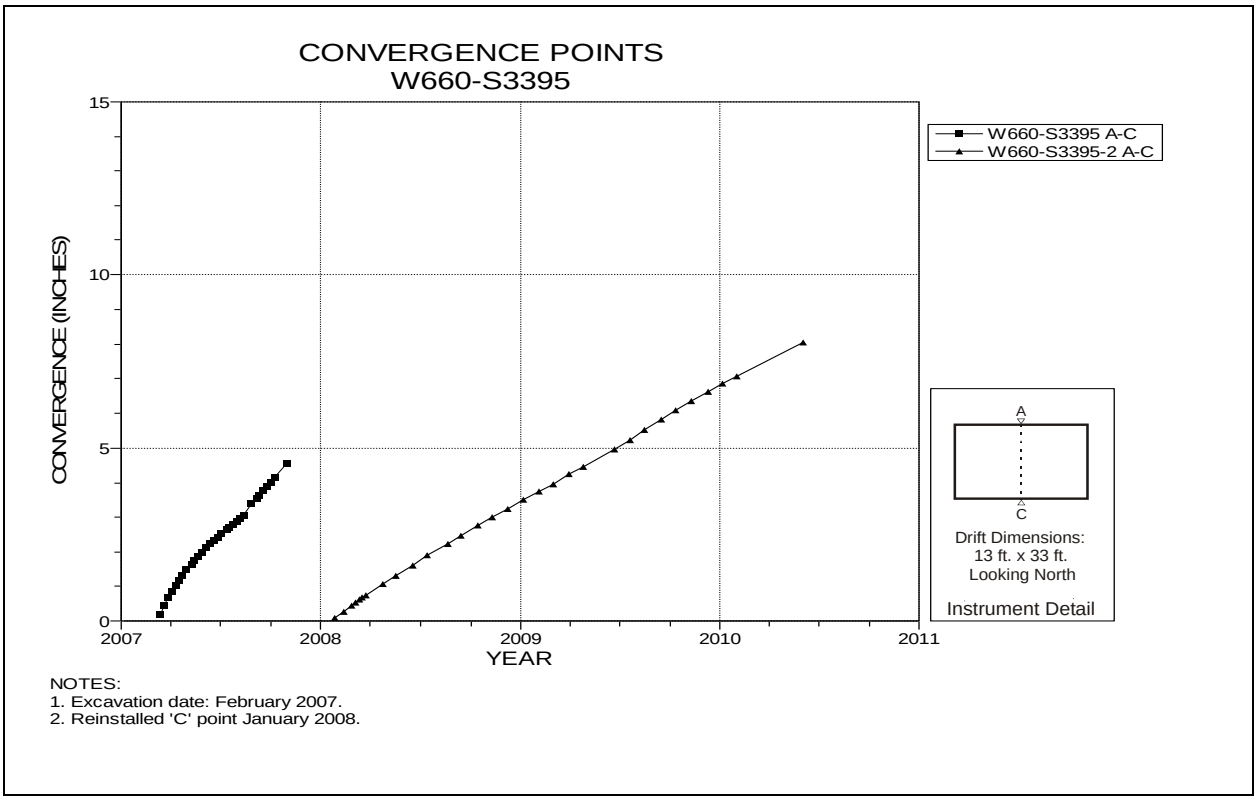


Figure 5-69 Convergence Point Array
Room 3, Panel 5 at W660 S3395 – Roof to Floor

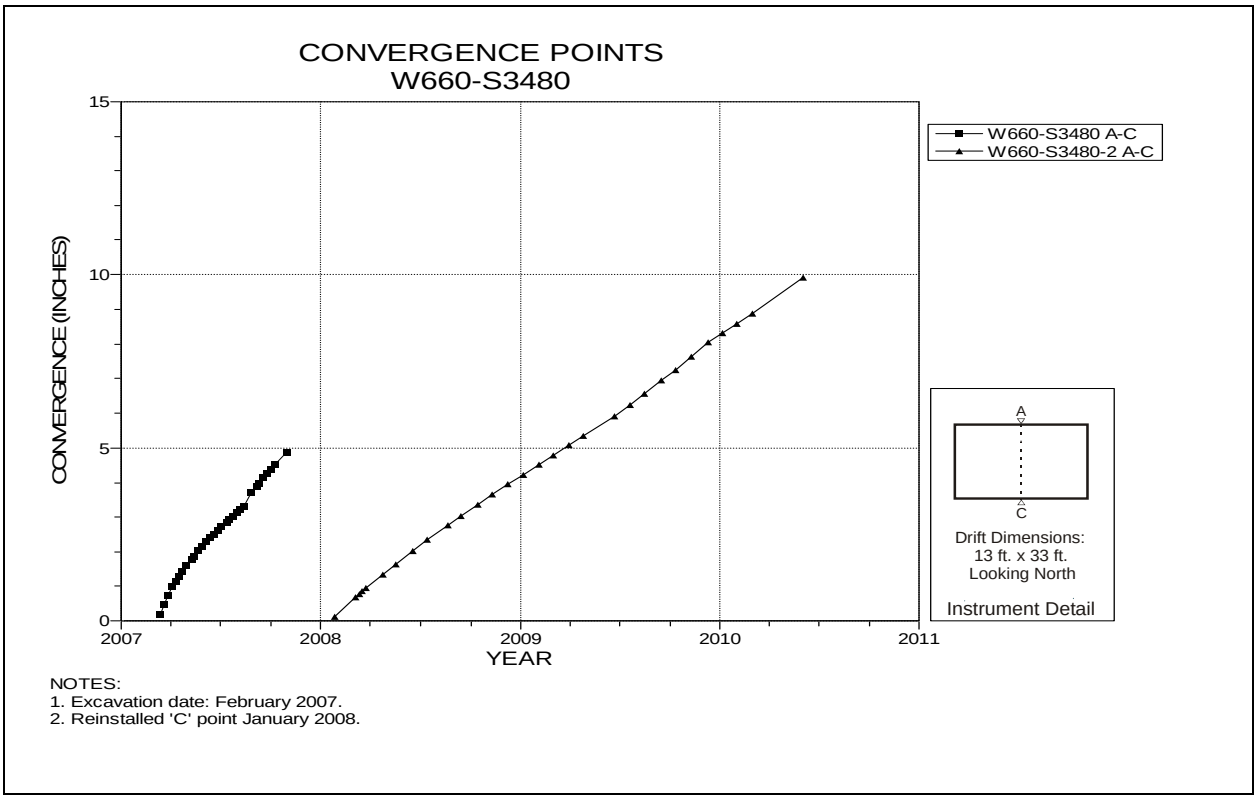


Figure 5-70 Convergence Point Array
Room 3, Panel 5 at W660 S3480 – Room Center – Roof to Floor

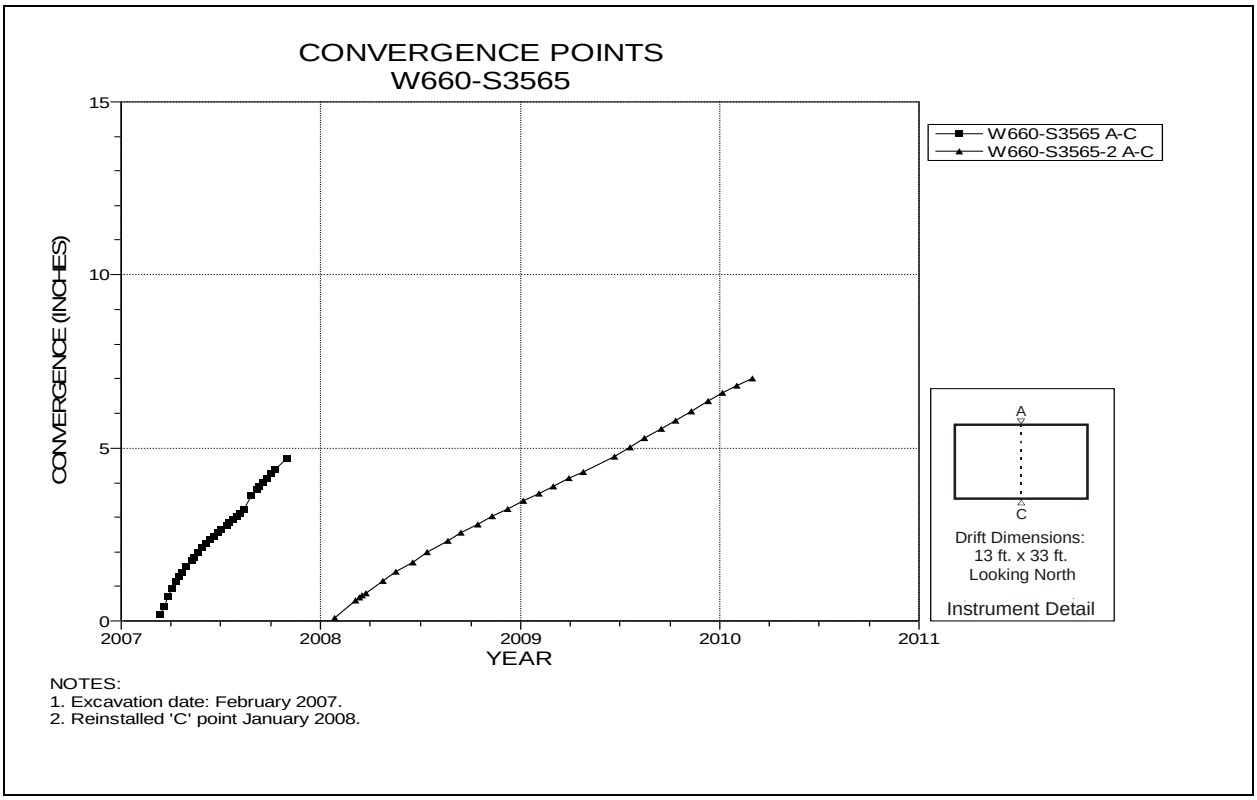


Figure 5-71 Convergence Point Array
Room 3, Panel 5 at W660 S3565 – Roof to Floor

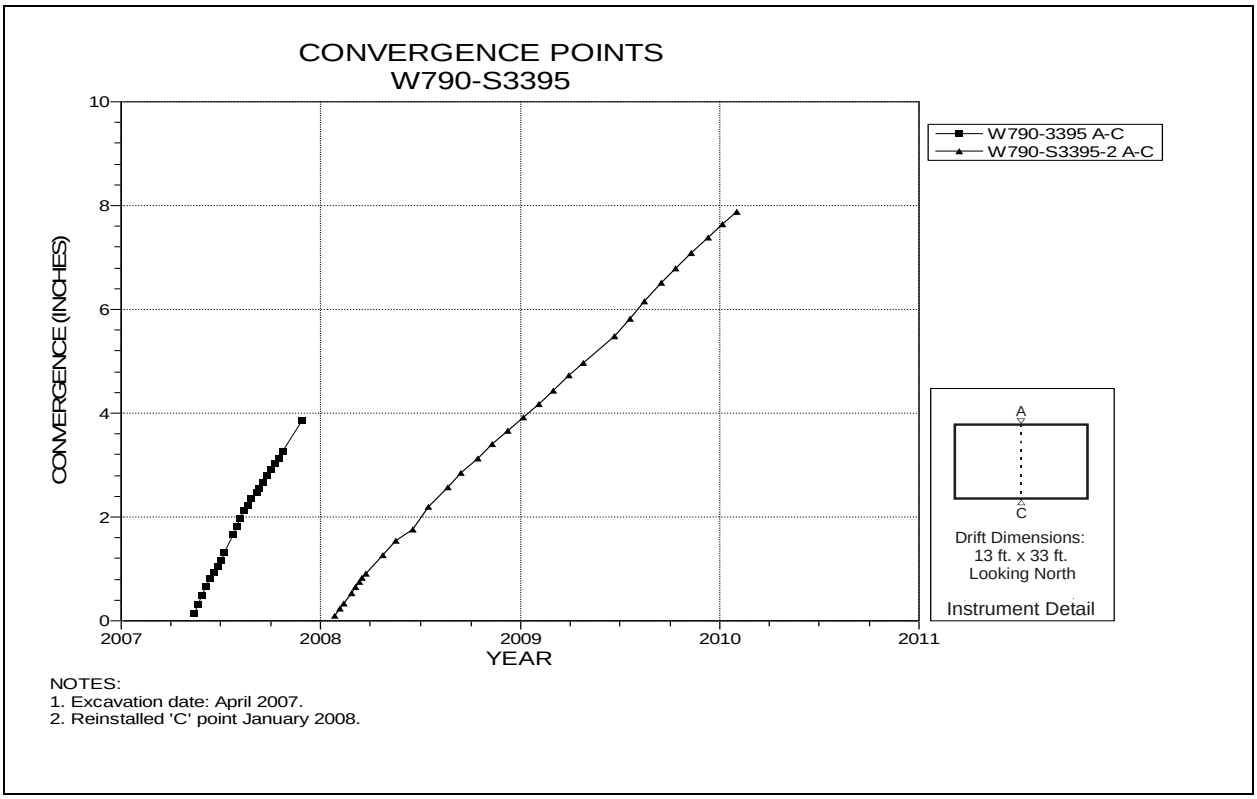


Figure 5-72 Convergence Point Array
Room 4, Panel 5 at W790 S3395 – Roof to Floor

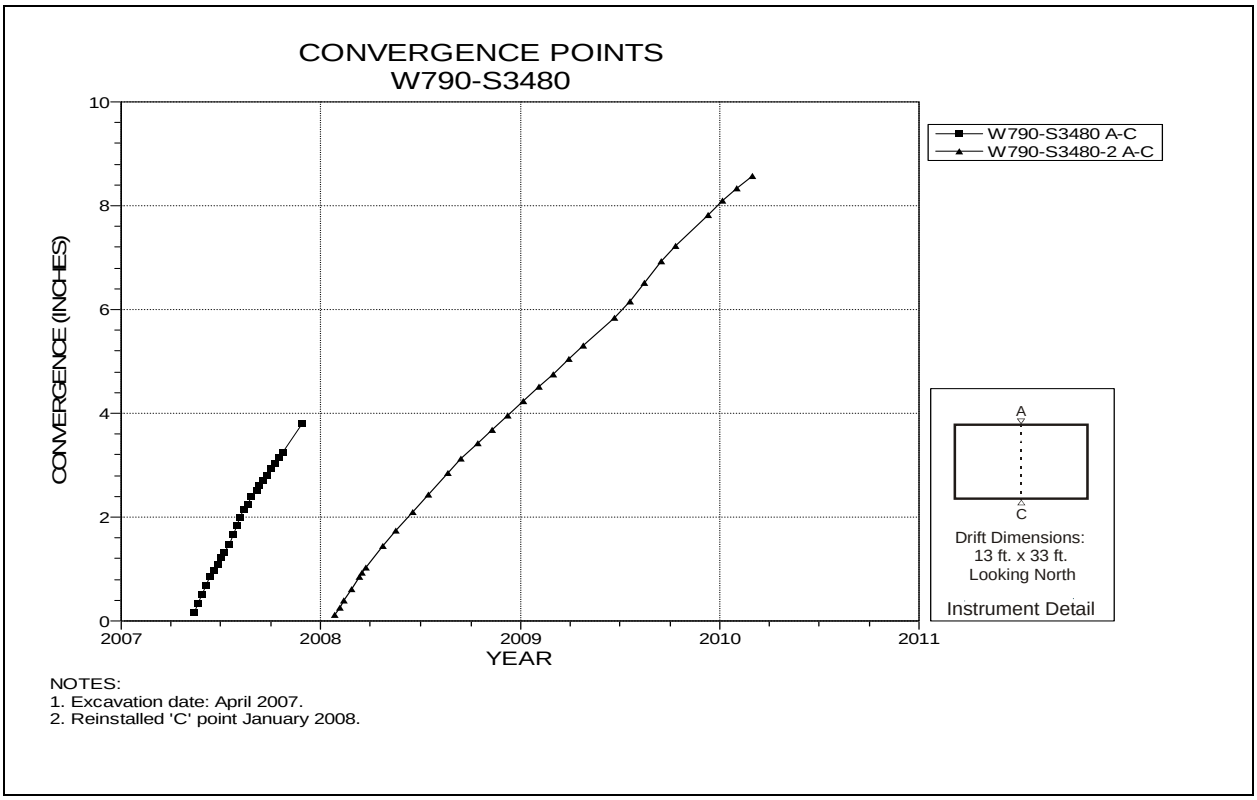


Figure 5-73 Convergence Point Array
Room 4, Panel 5 at W790 S3480 – Room Center – Roof to Floor

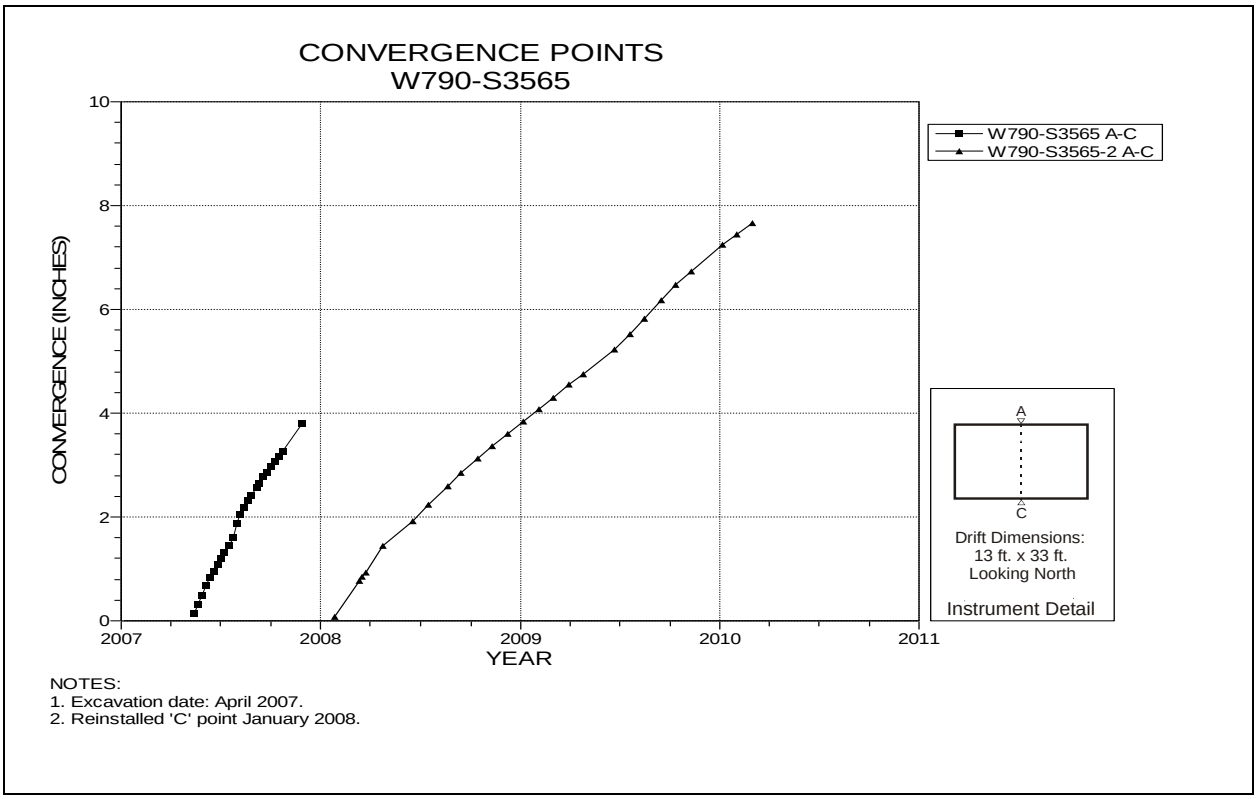


Figure 5-74 Convergence Point Array
Room 4, Panel 5 at W790 S3565 – Roof to Floor

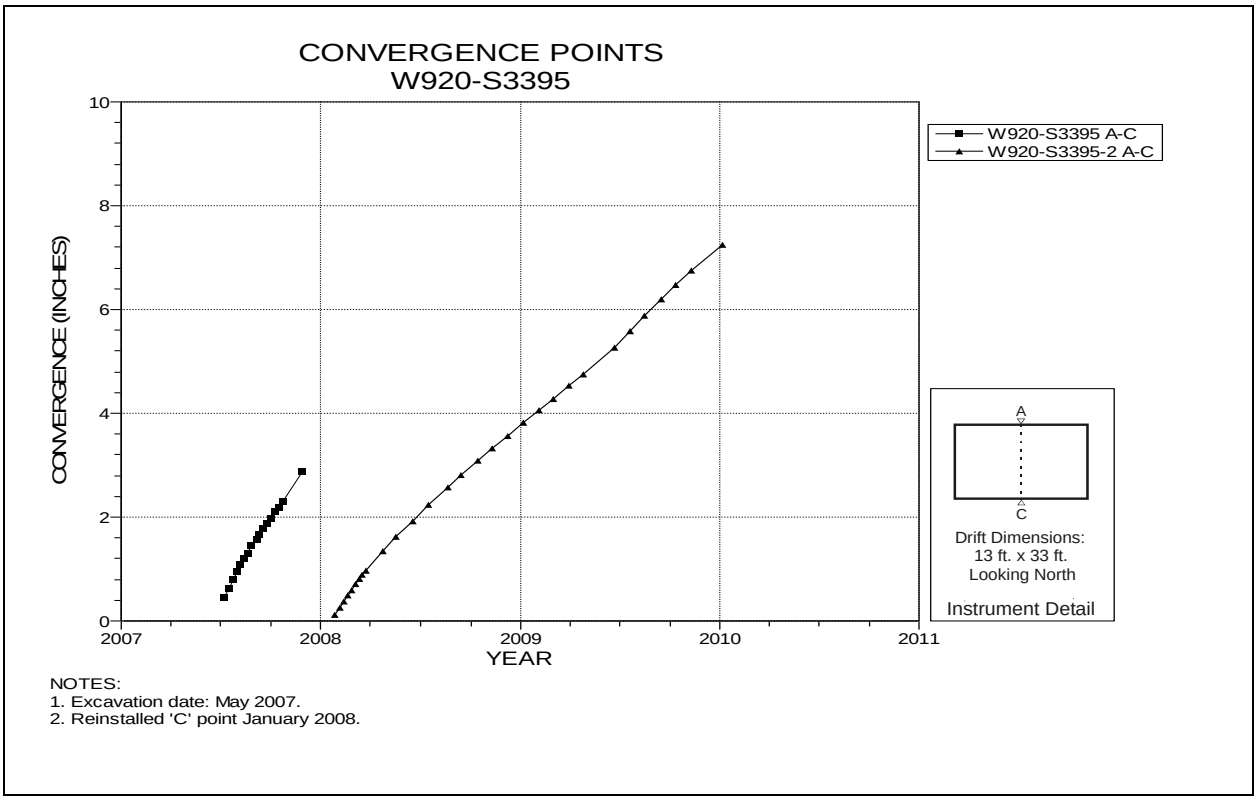


Figure 5-75 Convergence Point Array
Room 5, Panel 5 at W920 S3395 – Roof to Floor

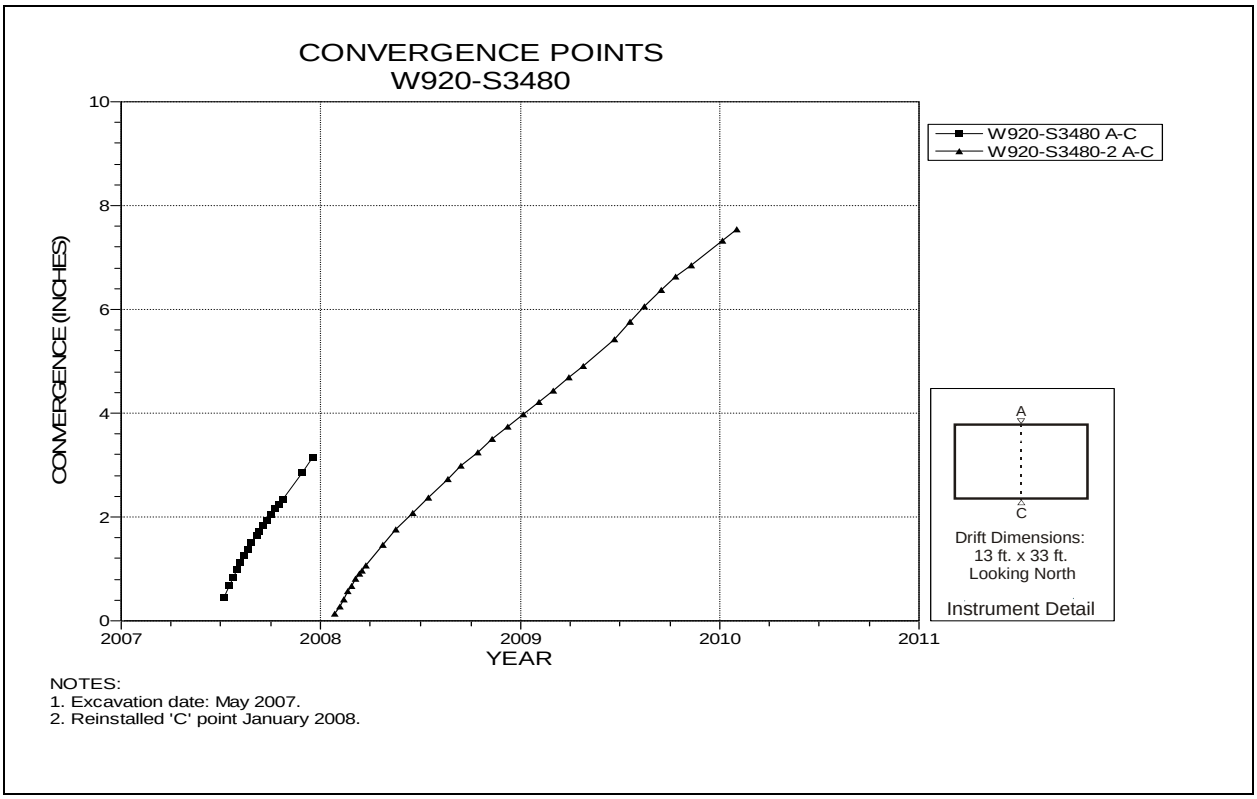


Figure 5-76 Convergence Point Array
Room 5, Panel 5 at W920 S3480 – Room Center – Roof to Floor

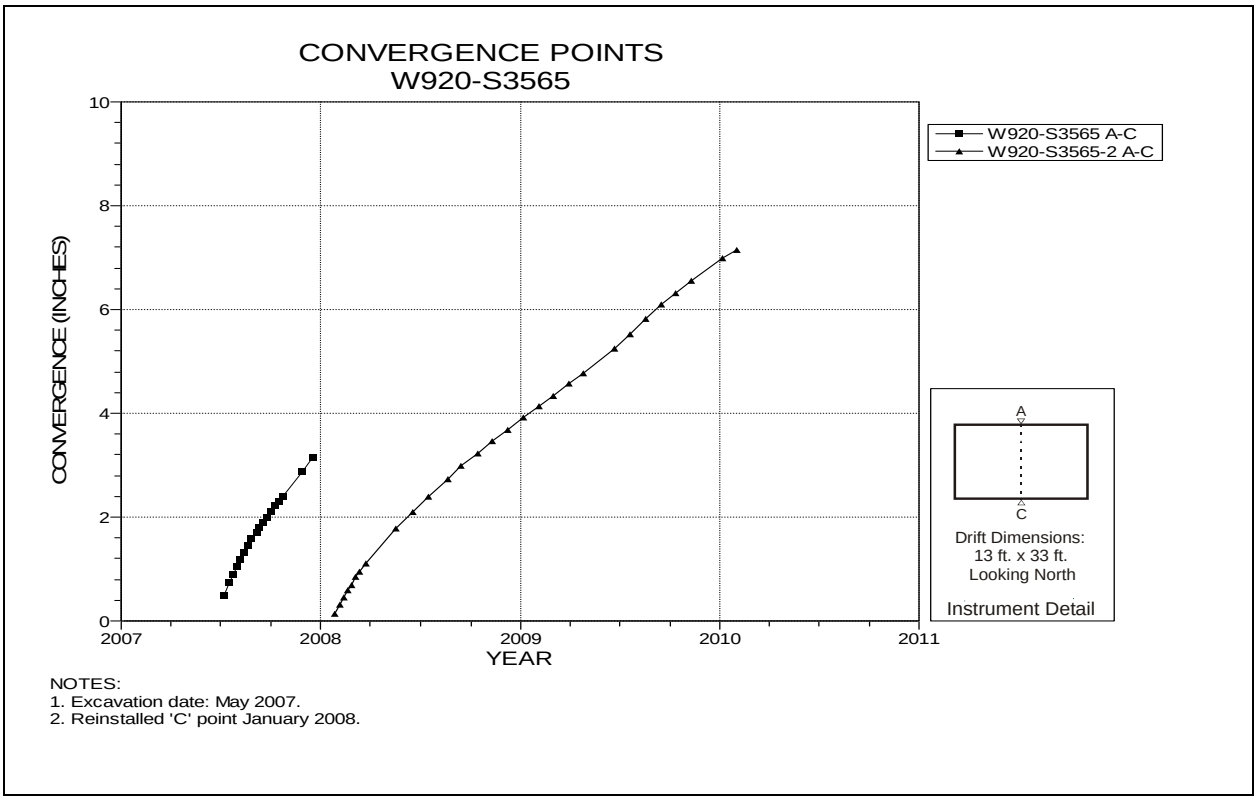


Figure 5-77 Convergence Point Array
Room 5, Panel 5 at W920 S3565 – Roof to Floor

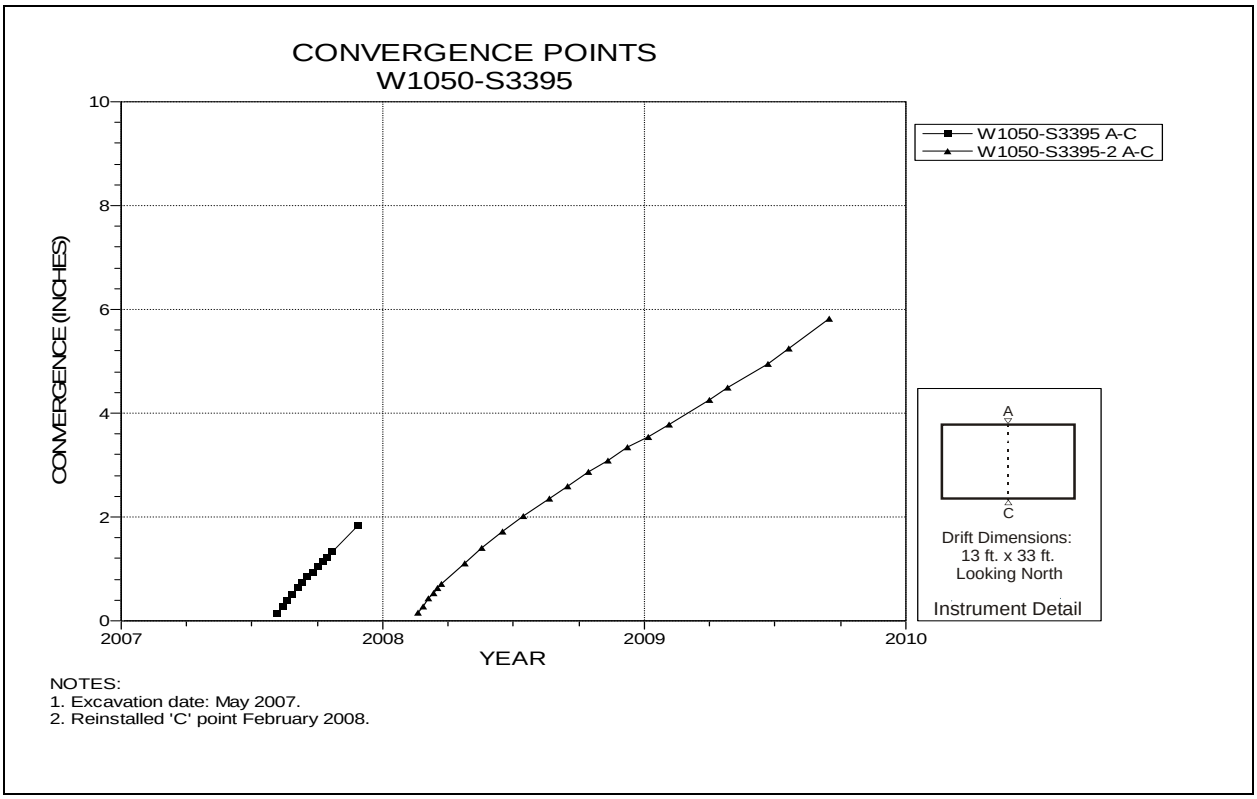


Figure 5-78 Convergence Point Array
Room 6, Panel 5 at W1050 S3395 – Roof to Floor

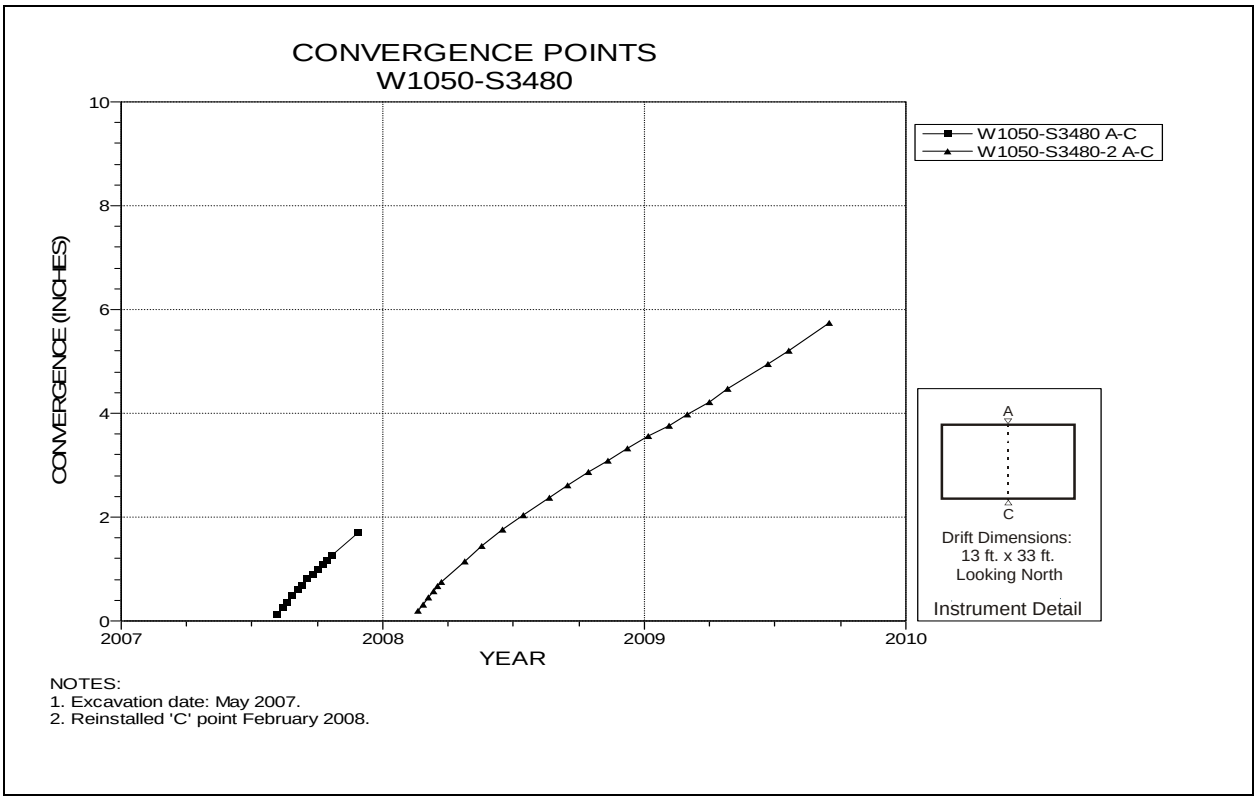


Figure 5-79 Convergence Point Array
Room 6, Panel 5 at W1050 S3480 – Room Center – Roof to Floor

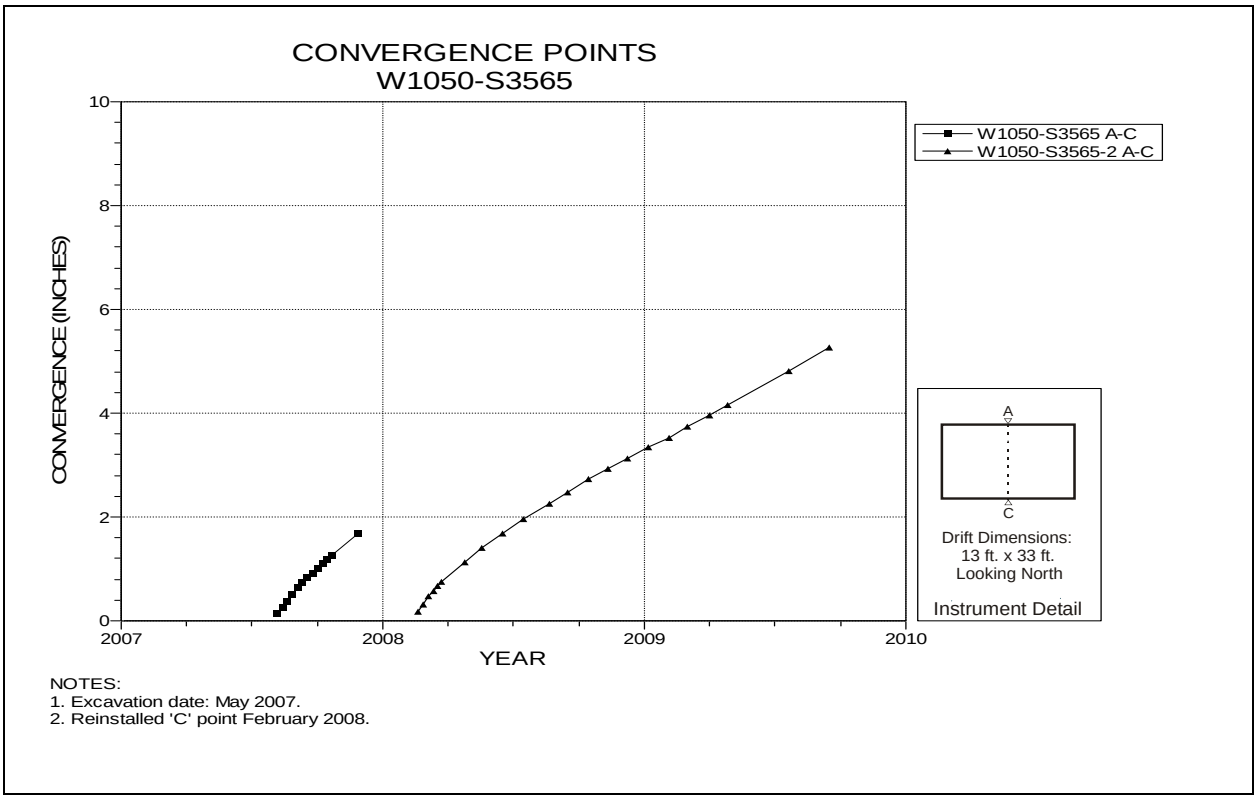


Figure 5-80 Convergence Point Array
Room 6, Panel 5 at W1050 S3565 – Roof to Floor

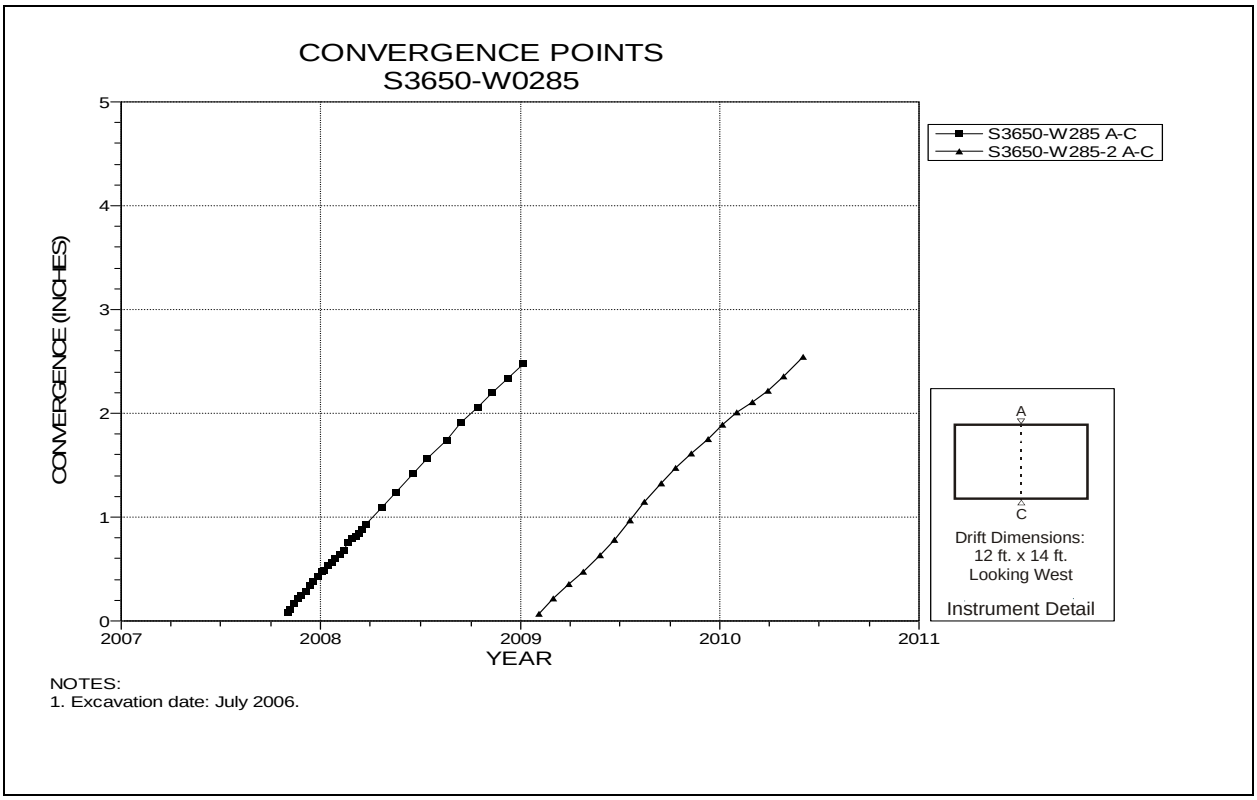


Figure 5-81 Convergence Point Array
S3650 W285 – Roof to Floor

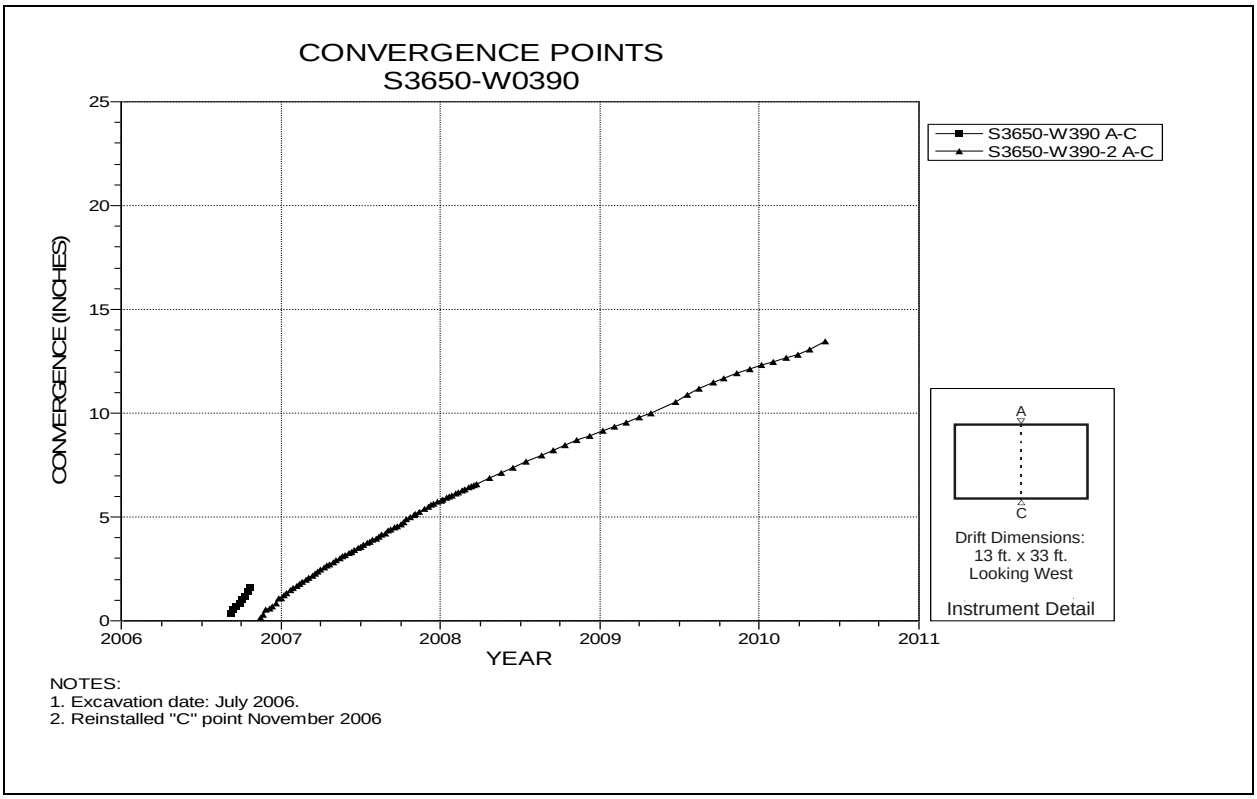


Figure 5-82 Convergence Point Array
S3650 W390 Intersection (Room 1, Panel 5) – Roof to Floor

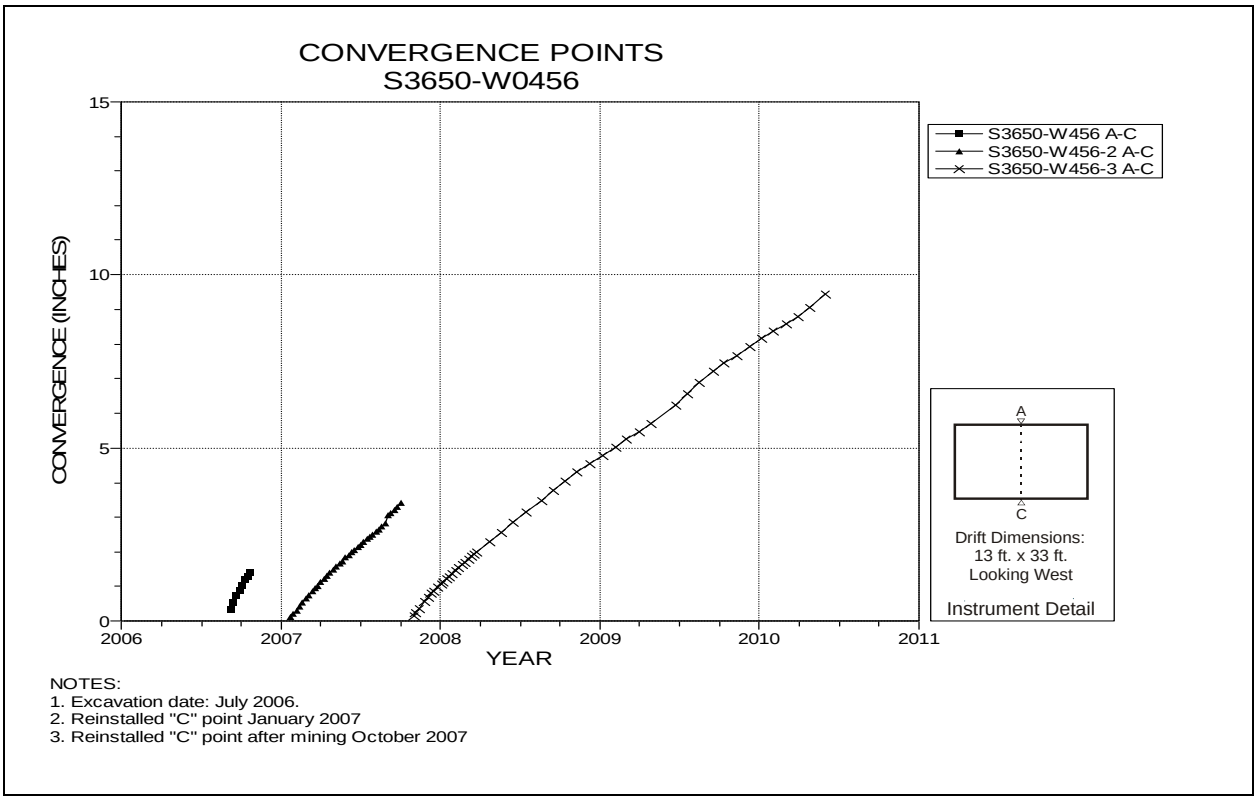


Figure 5-83 Convergence Point Array
S3650 W456 – Roof to Floor

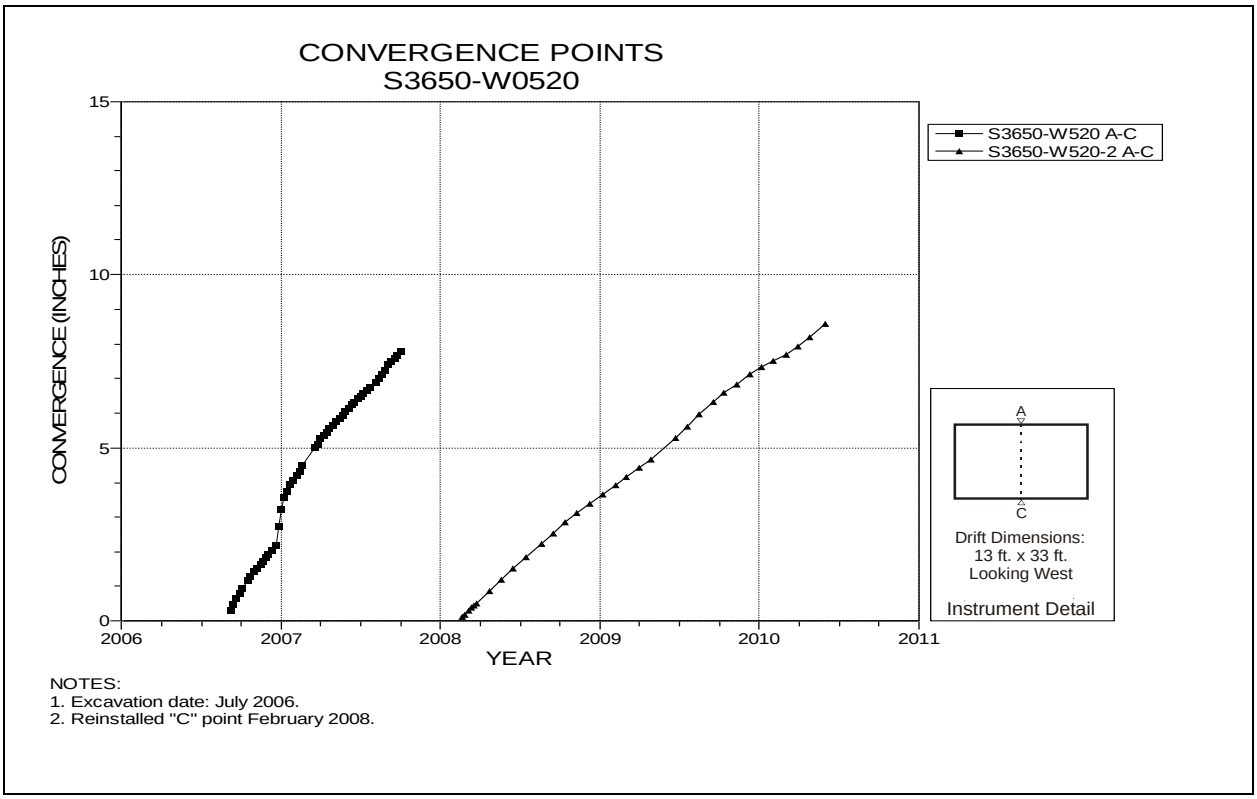


Figure 5-84 Convergence Point Array
S3650 W520 Intersection (Room 2, Panel 5) – Roof to Floor

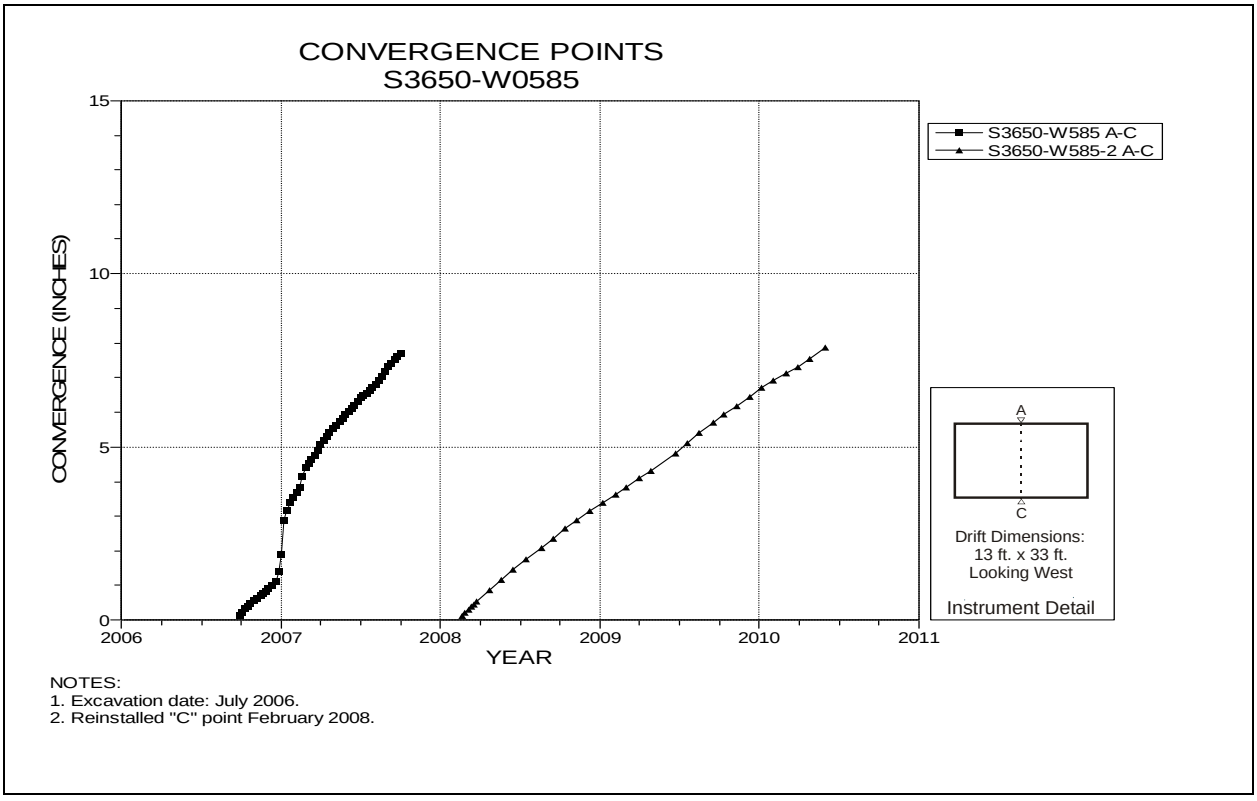


Figure 5-85 Convergence Point Array
S3650 W585 – Roof to Floor

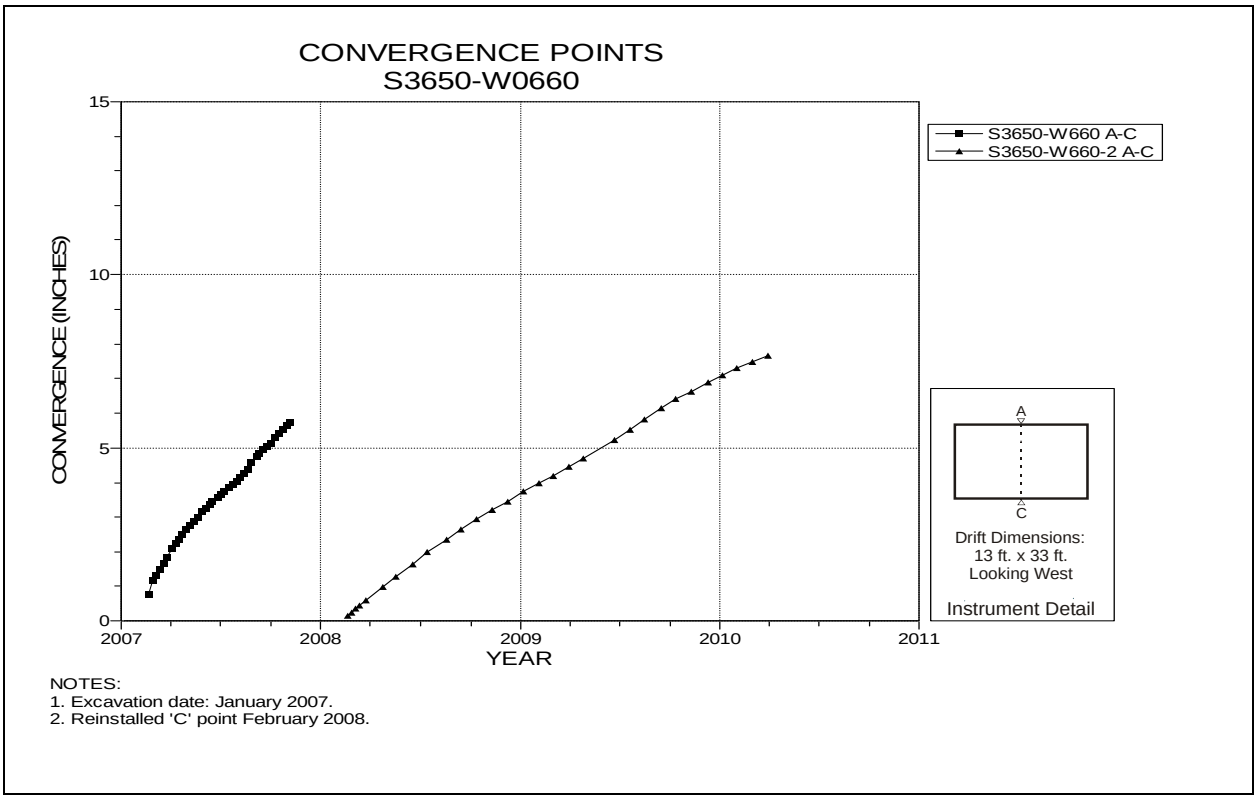


Figure 5-86 Convergence Point Array
S3650 W660 Intersection (Room 3, Panel 5) – Roof to Floor

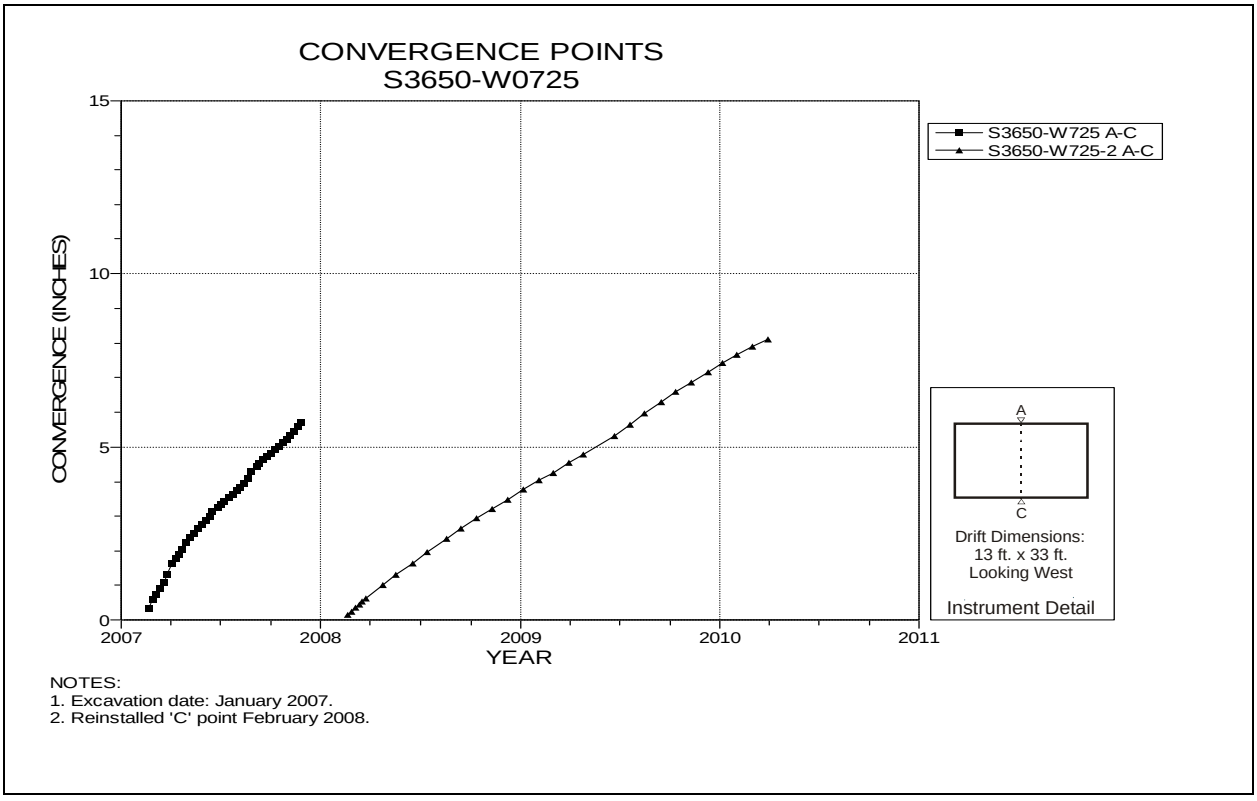


Figure 5-87 Convergence Point Array
S3650 W725 – Roof to Floor

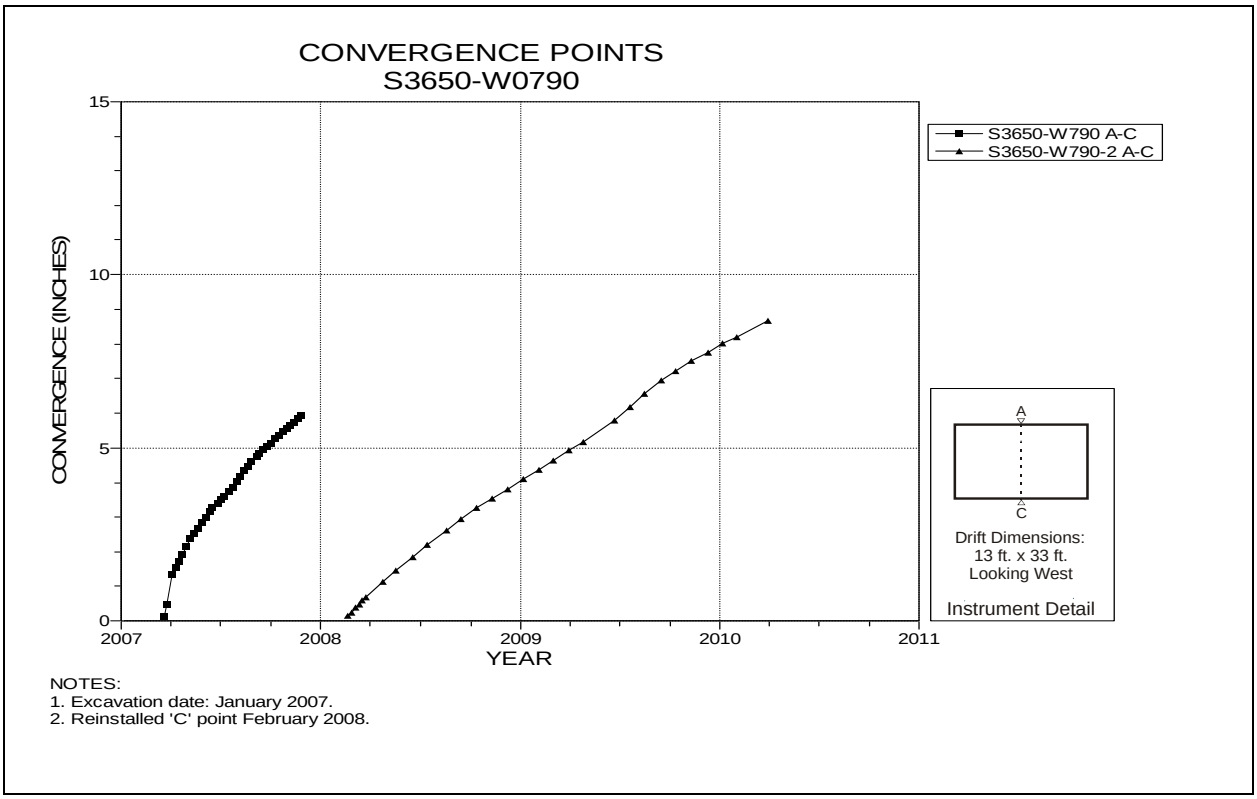


Figure 5-88 Convergence Point Array
S3650 W790 Intersection (Room 4, Panel 5) – Roof to Floor

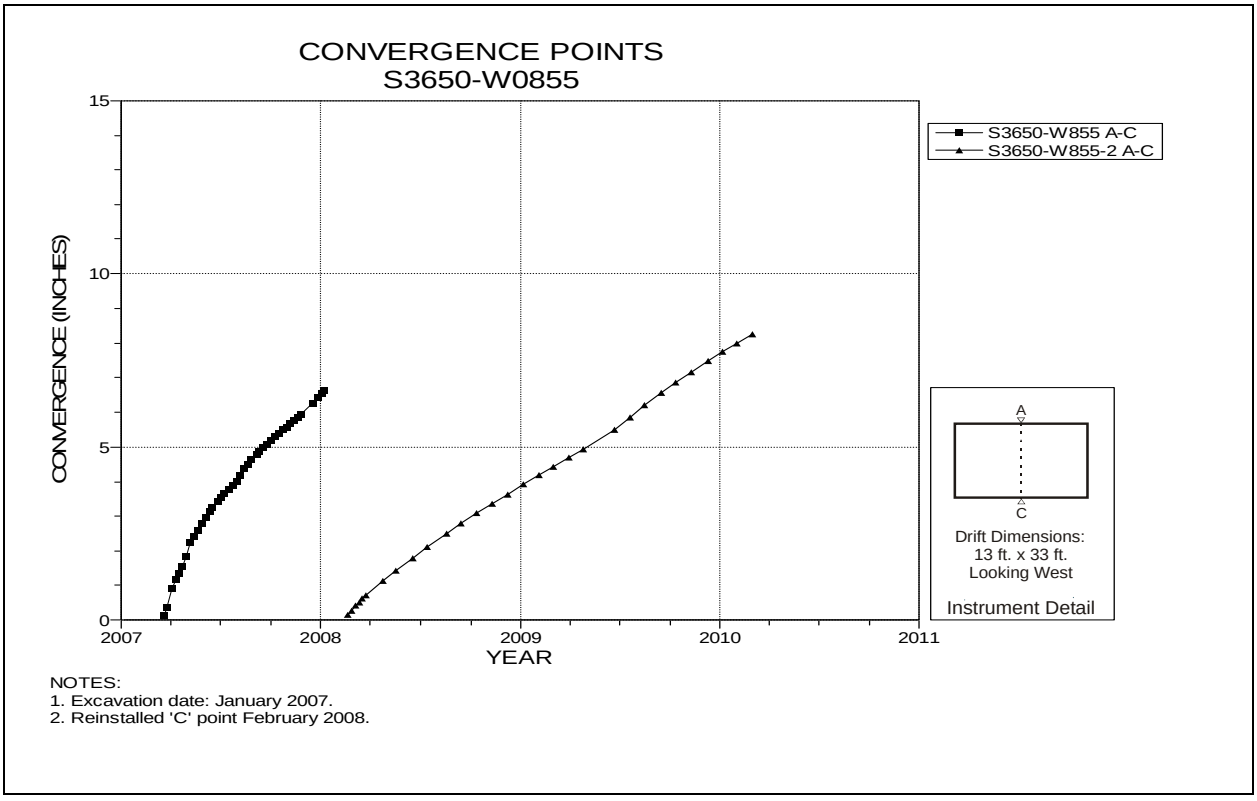


Figure 5-89 Convergence Point Array
S3650 W855 – Roof to Floor

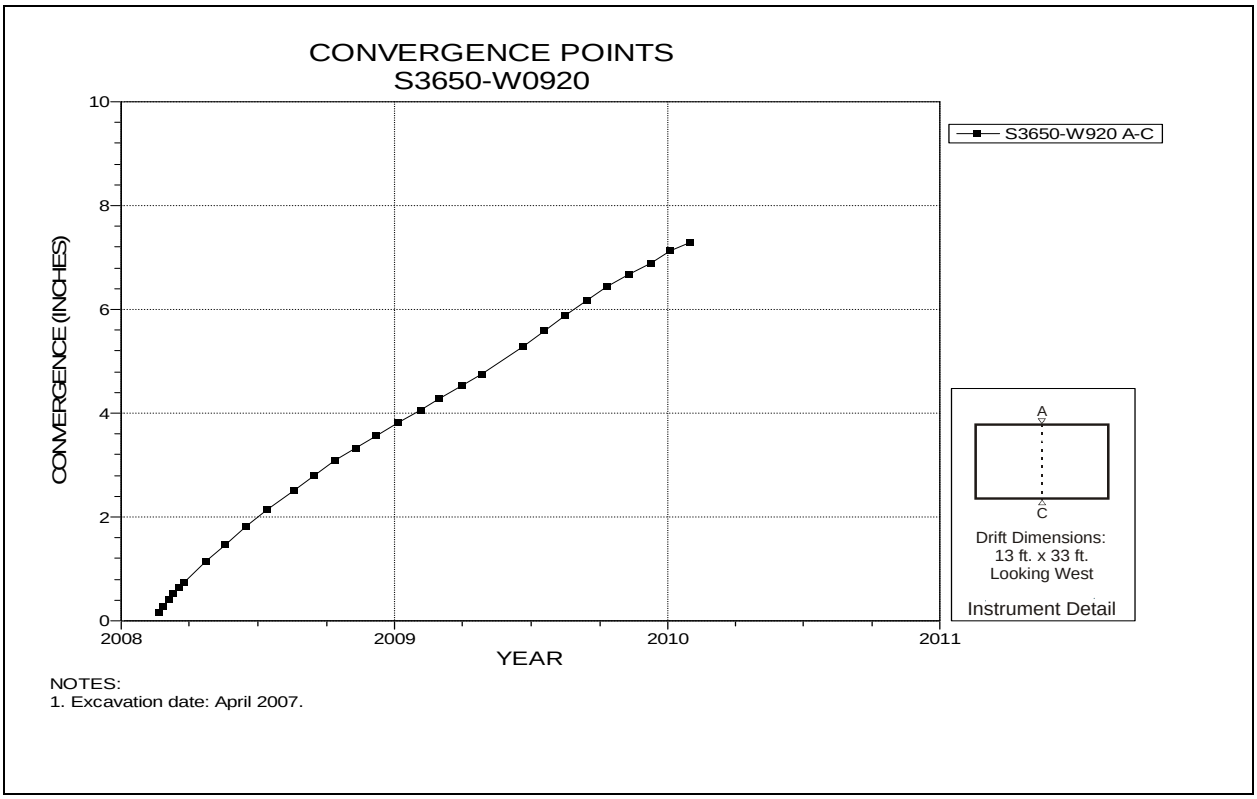


Figure 5-90 Convergence Point Array
S3650 W920 Intersection (Room 5, Panel 5) – Roof to Floor

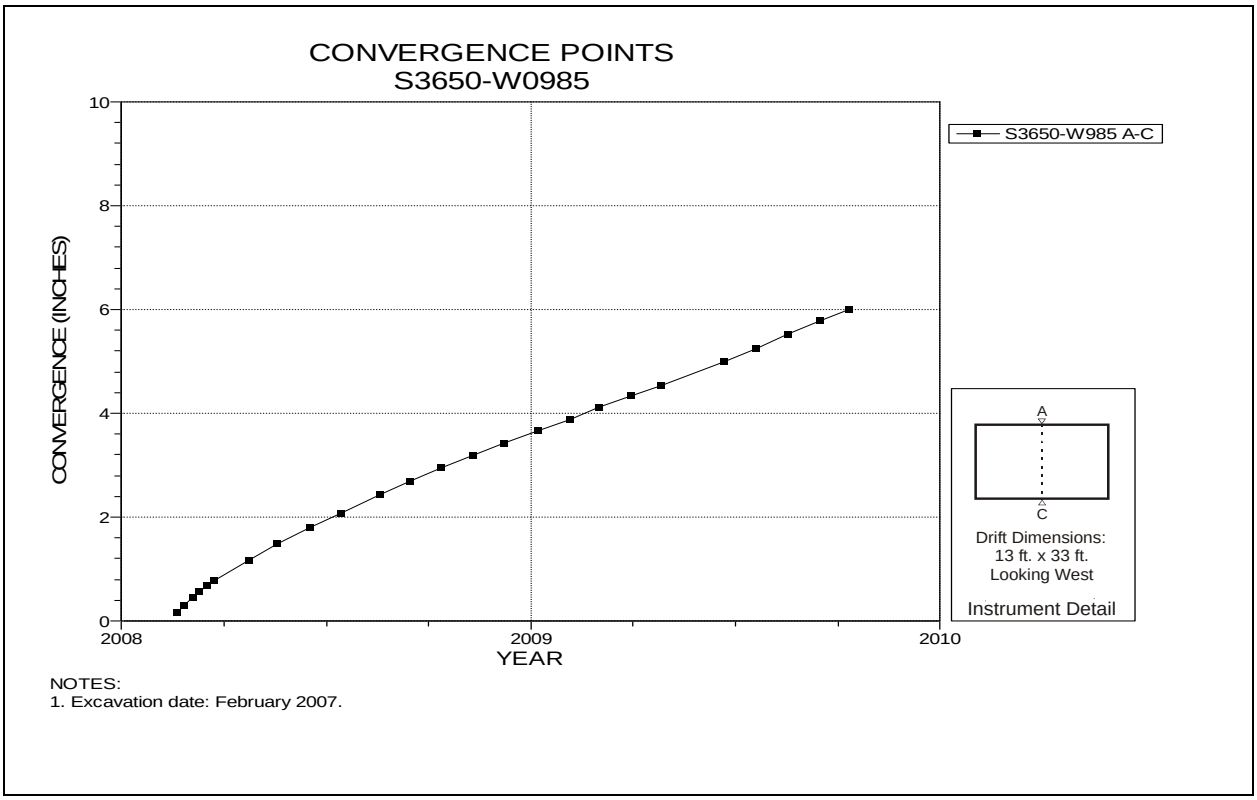


Figure 5-91 Convergence Point Array
S3650 W985 – Roof to Floor

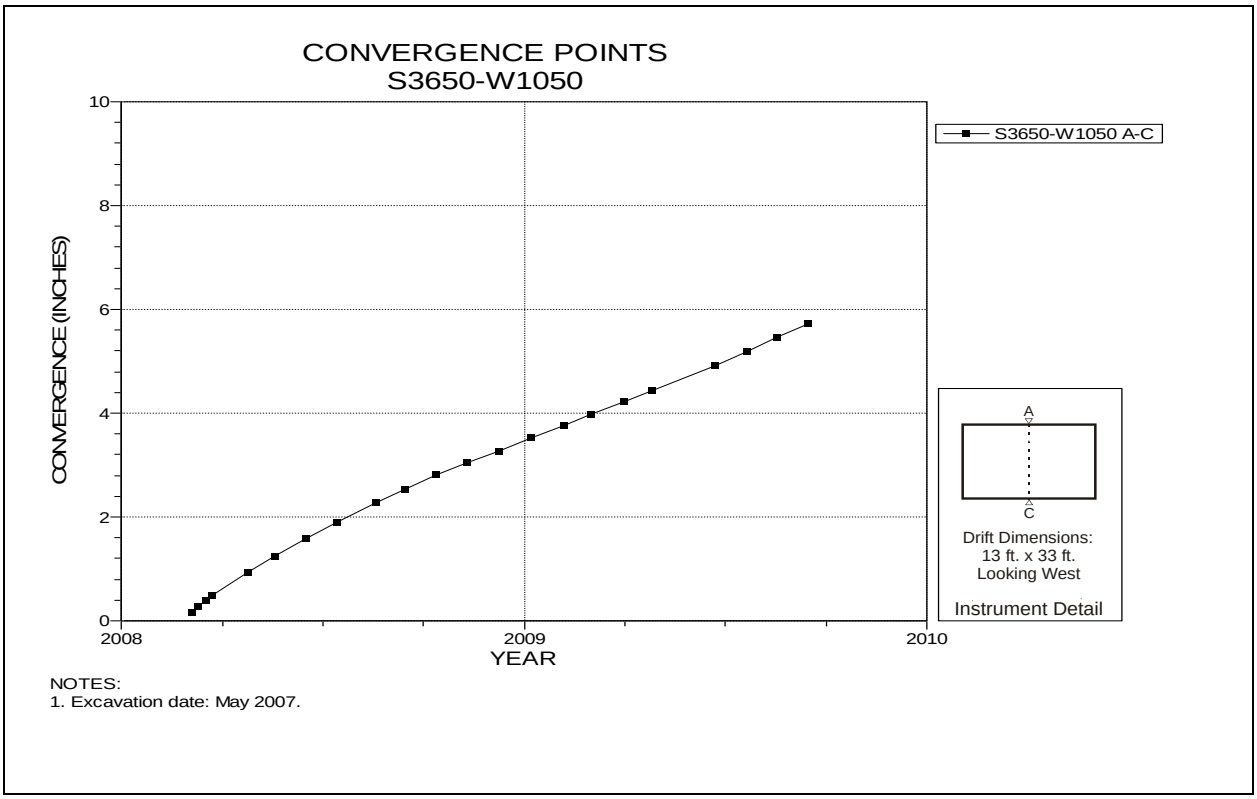


Figure 5-92 Convergence Point Array
S3650 W1050 Intersection (Room 6, Panel 5) – Roof to Floor

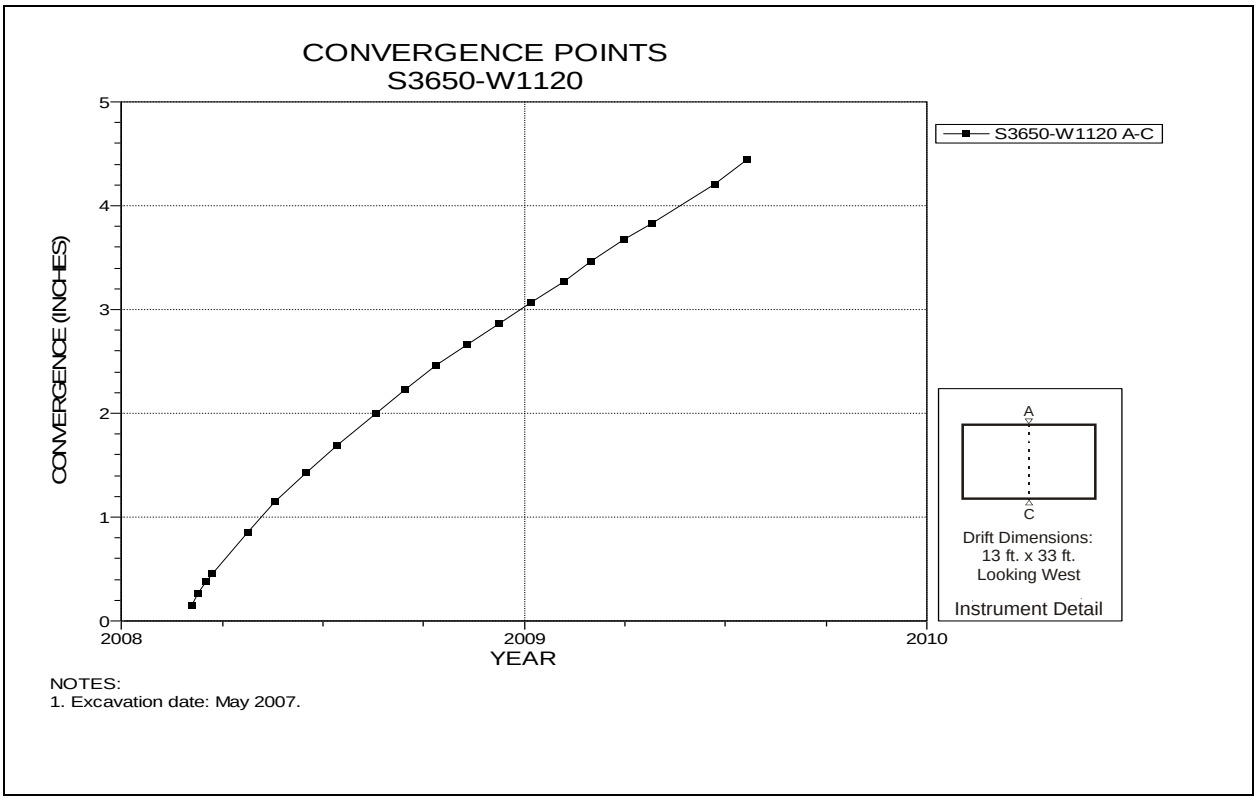


Figure 5-93 Convergence Point Array
S3650 W1120 – Roof to Floor

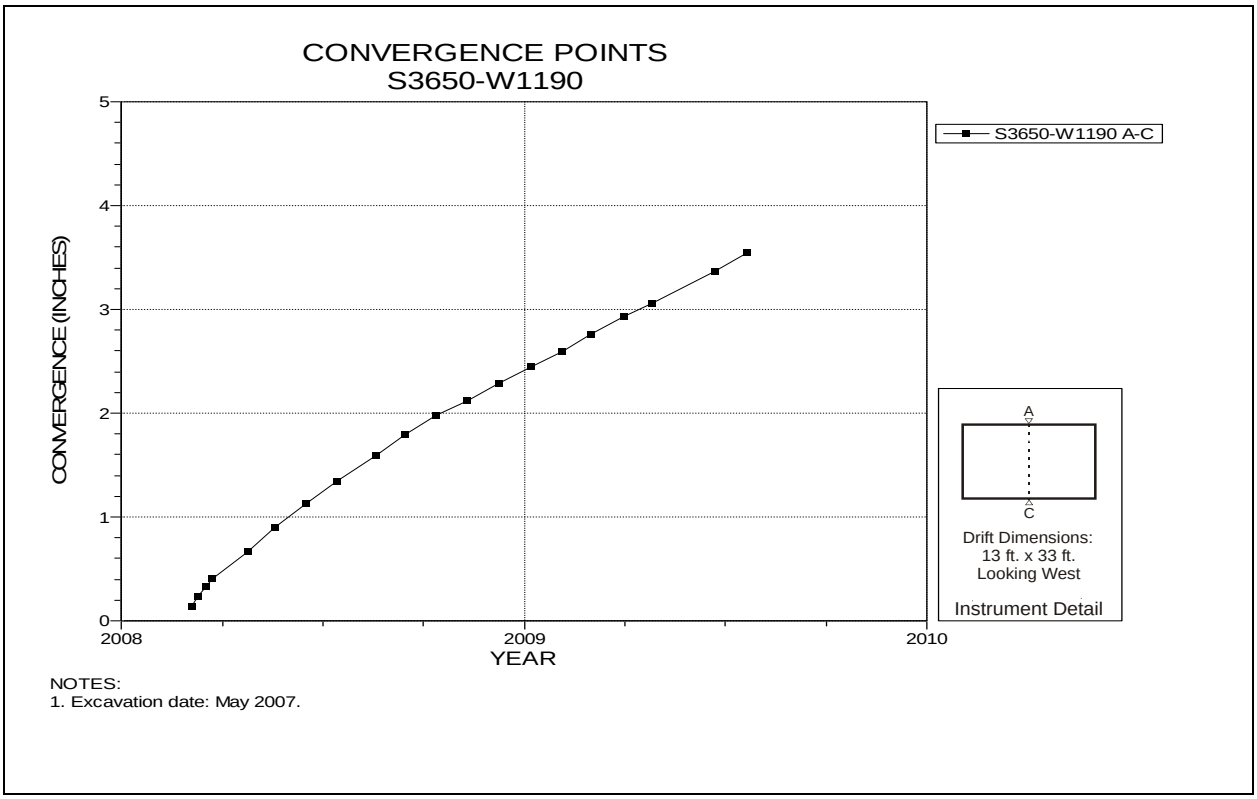


Figure 5-94 Convergence Point Array
S3650 W1190 Intersection (Room 7, Panel 5) – Roof to Floor

Table 5-6 Panel 6 Data Analysis

EXTENSOMETERS

Field Tag	Location	Figure Number	Date of Last Reading	Collar Displacement Relative to Deepest Anchor (inches)	Displacement Rate 2009 to 2010 (in/year)	Displacement Rate 2008 to 2009 (in/year)[1]	Rate Change Percent[1]	Comments
51X-GE-00413	S2750-W585	5-95	06/28/10	0.739	4.06	N/A	N/A	Installed this reporting period.
51X-GE-00414	S2750-W985	5-96	06/28/10	0.163	1.23	N/A	N/A	Installed this reporting period.
51X-GE-00403	W390-S2916	5-97	06/28/10	5.346	3.87	2.41	61%	
51X-GE-00405	W520-S2916	5-98	06/28/10	3.129	3.10	N/A	N/A	Installed this reporting period.
51X-GE-00406	W660-S2916	5-99	06/28/10	2.099	2.81	N/A	N/A	Installed this reporting period.
51X-GE-00407	W790-S2916	5-100	06/28/10	1.970	2.70	N/A	N/A	Installed this reporting period.
51X-GE-00408	W920-S2916	5-101	06/28/10	1.134	1.79	N/A	N/A	Installed this reporting period.
51X-GE-00409	W1050-S2916	5-102	06/28/10	1.249	3.11	N/A	N/A	Installed this reporting period.
51X-GE-00410	W1190-S2916	5-103	06/28/10	0.609	2.16	N/A	N/A	Installed this reporting period.
51X-GE-00411	S3080-W585	5-104	06/28/10	0.930	4.59	N/A	N/A	Installed this reporting period.
51X-GE-00412	S3080-W985	5-105	06/28/10	0.472	0.96	N/A	N/A	Installed this reporting period.

[1] N/A-Insufficient data available to perform calculation.

CONVERGENCE POINTS

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year)	Closure Rate 2008 to 2009 (in/year)	Rate Change Percent	Comments
			Date	Inches					
S2750-W285-2 A-C	S2750-W285	5-106	06/30/10	0.326	5.007	7.14	4.24	68%	
S2750-W390-2 A-C	S2750-W390	5-107	06/30/10	0.451	7.577	7.95	6.71	18%	
S2750-W460-2 A-C	S2750-W460	5-108	06/30/10	0.408	6.434	9.62	6.89	40%	
S2750-W520-2 A-C	S2750-W520	5-109	06/30/10	0.346	7.062	7.63	8.37	-9%	
S2750-W590-2 A-C	S2750-W590	5-110	06/30/10	0.361	4.063	8.08	7.93	2%	

Table 5-6 (continued) Panel 6 Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year) [1]	Closure Rate 2008 to 2009 (in/year) [1]	Rate Change Percent [1]	Comments
			Date	Inches					
S2750-W660-2 A-C	S2750-W660	5-111	06/30/10	0.337	4.427	7.83	10.33	-24%	
S2750-W725-2 A-C	S2750-W725	5-112	06/30/10	0.332	4.612	7.91	N/A	N/A	Installed this reporting period.
S2750-W790-2 A-C	S2750-W790	5-113	06/30/10	0.269	4.722	7.06	N/A	N/A	Installed this reporting period.
S2750-W855-2 A-C	S2750-W855	5-114	06/30/10	0.218	1.903	5.32	N/A	N/A	Installed this reporting period.
S2750-W920-2 A-C	S2750-W920	5-115	06/30/10	0.226	2.15	5.97	N/A	N/A	Installed this reporting period.
S2750-W985-2 A-C	S2750-W985	5-116	06/30/10	0.167	2.077	4.79	N/A	N/A	Installed this reporting period.
S2750-W1050-2 A-C	S2750-W1050	5-117	06/30/10	0.186	2.169	5.48	N/A	N/A	Installed this reporting period.
S2750-W1120-2 A-C	S2750-W1120	5-118	06/30/10	0.325	0.941	3.65	N/A	N/A	Installed this reporting period.
S2750-W1190-2 A-C	S2750-W1190	5-119	06/21/10	1.361	2.384	3.74	N/A	N/A	Installed this reporting period.
W390-S2833-2 A-C	W390-S2833	5-120	06/30/10	0.653	8.182	12.13	6.53	86%	
W390-S2916-2 A-C	W390-S2916	5-121	06/30/10	0.592	9.805	11	7.03	56%	
W390-S2998-2 A-C	W390-S2998	5-122	06/30/10	0.505	9.558	9.78	6.84	43%	
W520-S2833-2 A-C	W520-S2833	5-123	06/30/10	0.372	6.38	6.94	8.43	-18%	
W520-S2916-2 A-C	W520-S2916	5-124	06/30/10	0.432	6.535	8.12	8.27	-2%	
W520-S2998-2 A-C	W520-S2998	5-125	06/30/10	0.345	6.055	6.78	7.57	-10%	
W660-S2833-2 A-C	W660-S2833	5-126	06/30/10	0.238	4.532	6.70	10.54	-36%	
W660-S2916-2 A-C	W660-S2916	5-127	06/30/10	0.237	5.299	7.51	11.58	-35%	
W660-S2998-2 A-C	W660-S2998	5-128	06/30/10	0.211	5.001	6.29	11.53	-45%	
W790-S2833-2 A-C	W790-S2833	5-129	06/30/10	0.223	5.531	6.62	N/A	N/A	Installed this reporting period.
W790-S2916-2 A-C	W790-S2916	5-130	06/30/10	0.217	5.481	6.57	N/A	N/A	Installed this reporting period.
W790-S2998-2 A-C	W790-S2998	5-131	06/30/10	0.223	5.329	6.57	N/A	N/A	Installed this reporting period.
W920-S2833-2 A-C	W920-S2833	5-132	06/21/10	0.052	3.738	7.85	N/A	N/A	Installed this reporting period.
W920-S2916-2 A-C	W920-S2916	5-133	06/30/10	0.182	3.959	5.40	N/A	N/A	Installed this reporting period.
W920-S2998-2 A-C	W920-S2998	5-134	06/30/10	0.180	3.765	5.36	N/A	N/A	Installed this reporting period.

[1] Insufficient data available to perform calculation.

Table 5-6 (continued) Panel 6 Data Analysis

CONVERGENCE POINTS (Continued)

Field Tag	Location	Figure Number	Last Reading 2009 to 2010		Cumulative Displacement (inches)	Closure Rate 2009 to 2010 (in/year) [1]	Closure Rate 2008 to 2009 (in/year) [1]	Rate Change Percent [1]	Comments
			Date	Inches					
W1050-S2833-2 A-C	W1050-S2833	5-135	06/30/10	0.158	1.100	5.03	N/A	N/A	Installed this reporting period.
W1050-S2916-2 A-C	W1050-S2916	5-136	06/30/10	0.167	1.209	N/A	N/A	N/A	Installed this reporting period.
W1050-S2998-2 A-C	W1050-S2998	5-137	06/30/10	0.159	1.105	4.67	N/A	N/A	Installed this reporting period.
W1190-S2833-2 A-C	W1190-S2833	5-138	06/30/10	1.892	3.320	4.96	N/A	N/A	Installed this reporting period.
W1190-S2916-2 A-C	W1190-S2916	5-139	06/30/10	0.203	1.733	5.84	N/A	N/A	Installed this reporting period.
W1190-S2998-2 A-C	W1190-S2998	5-140	06/30/10	0.177	1.702	5.03	N/A	N/A	Installed this reporting period.
S3080-W285-2 A-C	S3080-W285	5-141	06/30/10	0.163	4.130	2.92	3.10	-6	
S3080-W390-2 A-C	S3080-W390	5-142	06/30/10	0.363	8.561	6.66	7.63	-13	
S3080-W460-2 A-C	S3080-W460	5-143	06/30/10	0.19	8.224	N/A	7.65	N/A	Installed this reporting period.
S3080-W520-2 A-C	S3080-W520	5-144	06/30/10	0.455	8.926	8.20	10.33	-21	
S3080-W585-2 A-C	S3080-W585	5-145	06/30/10	0.475	9.653	8.64	10.27	-16	
S3080-W660-2 A-C	S3080-W660	5-146	06/30/10	0.424	7.548	6.82	8.97	-24	
S3080-W725-2 A-C	S3080-W725	5-147	06/30/10	0.384	0.384	6.33	N/A	N/A	Installed this reporting period.
S3080-W790-2 A-C	S3080-W790	5-148	06/30/10	0.412	6.149	6.98	N/A	N/A	Installed this reporting period.
S3080-W855 A-C	S3080-W855	5-149	02/09/10	3.260	3.260	7.29	N/A	N/A	Installed this reporting period.
S3080-W920 A-C	S3080-W920	5-150	02/09/10	3.779	3.779	8.37	N/A	N/A	Installed this reporting period.
S3080-W985 A-C	S3080-W985	5-151	02/09/10	2.018	2.018	7.07	N/A	N/A	Installed this reporting period.
S3080-W1050-2 A-C	S3080-W1050	5-152	06/30/10	0.269	1.867	5.32	N/A	N/A	Installed this reporting period.
S3080-W1120-2 A-C	S3080-W1120	5-153	06/30/10	0.153	1.496	4.55	N/A	N/A	Installed this reporting period.
S3080-W1190-2 A-C	S3080-W1190	5-154	06/21/10	0.029	1.257	N/A	N/A	N/A	Installed this reporting period.

[1] N/A-insufficient data available to perform calculation.

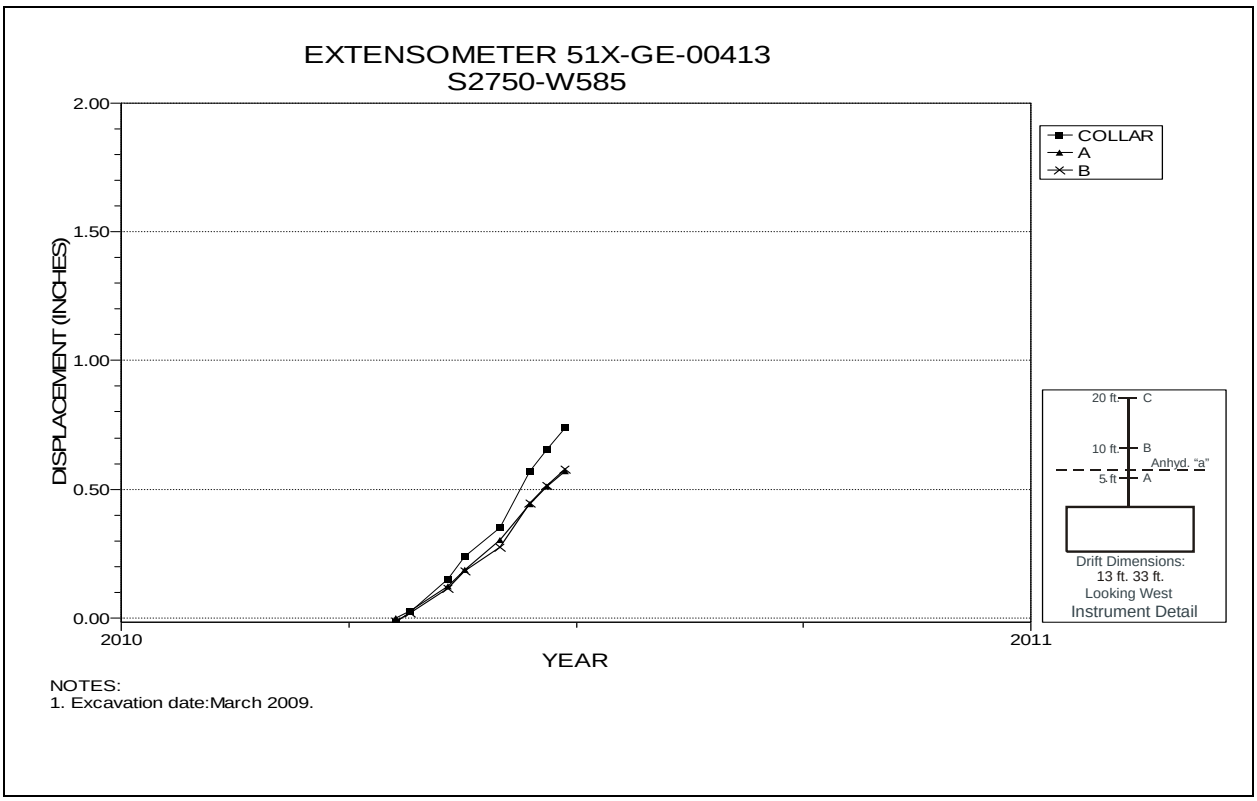


Figure 5-95 Extensometer 51X-GE-00413
S2750 W585 – Roof

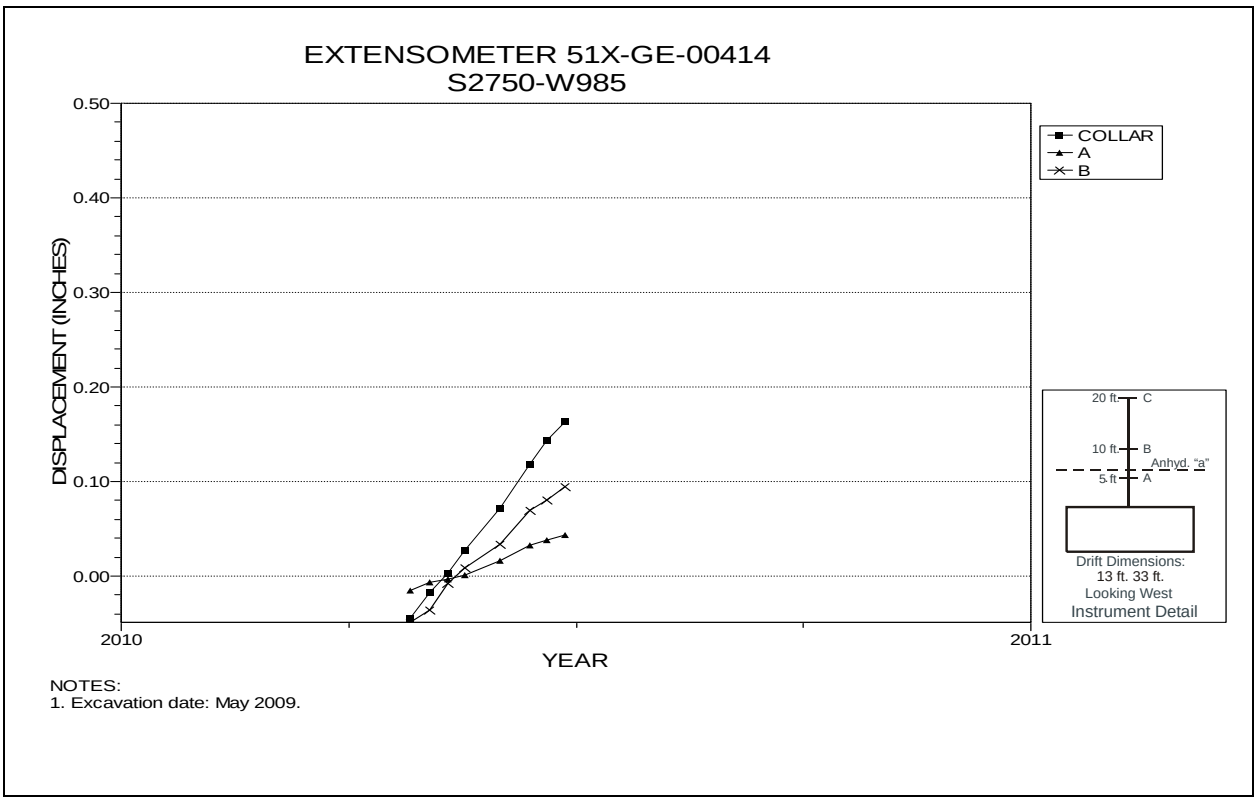


Figure 5-96 Extensometer 51X-GE-00414
S2750 W985 – Roof

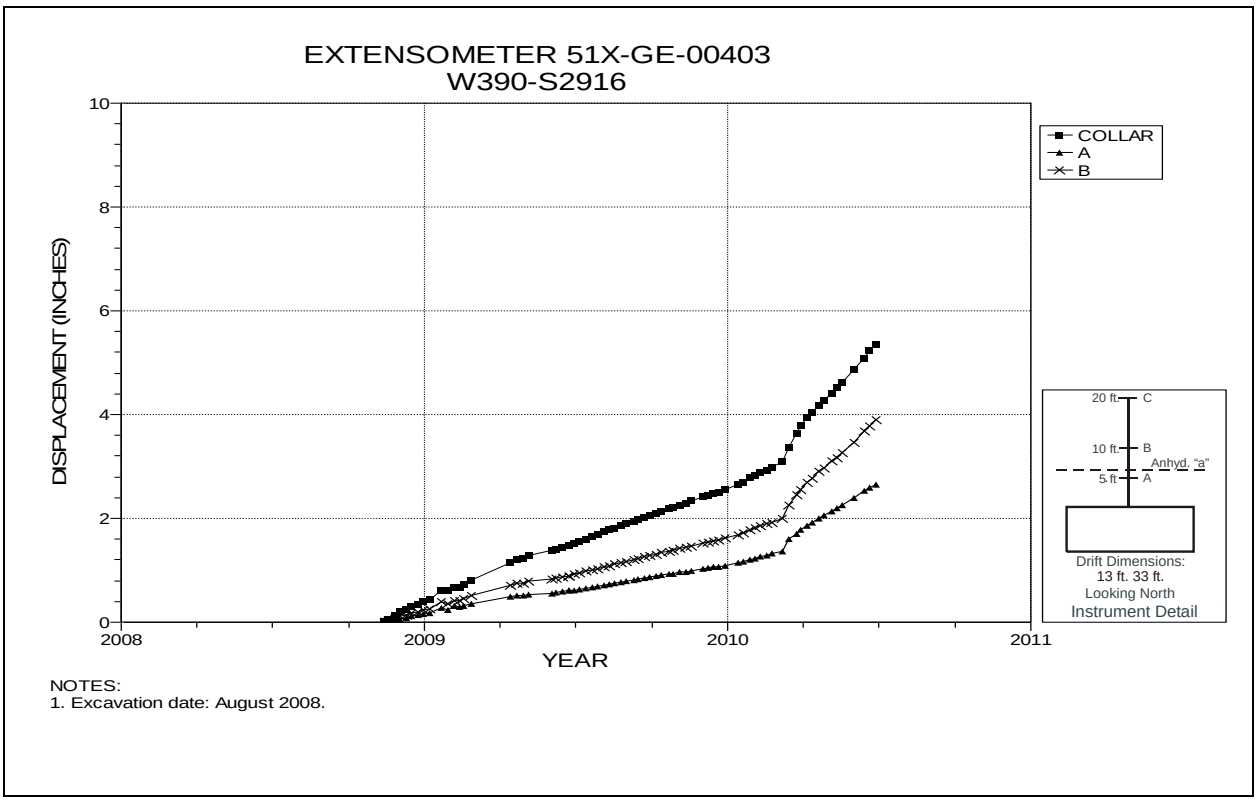


Figure 5-97 Extensometer 51X-GE-00403
Room 1, Panel 6 at W390 S2916– Room Center – Roof

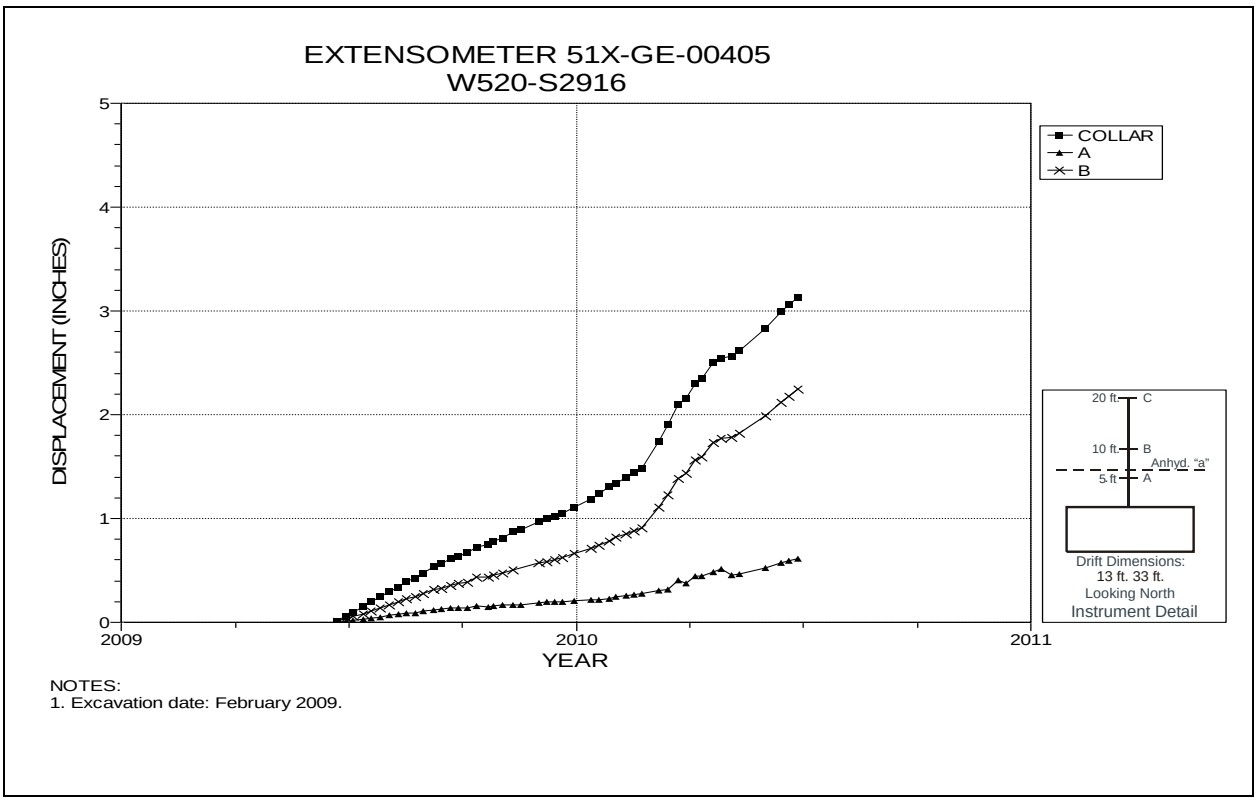


Figure 5-98 Extensometer 51X-GE-00405
Room 2, Panel 6 at W520 S2916 – Room Center – Roof

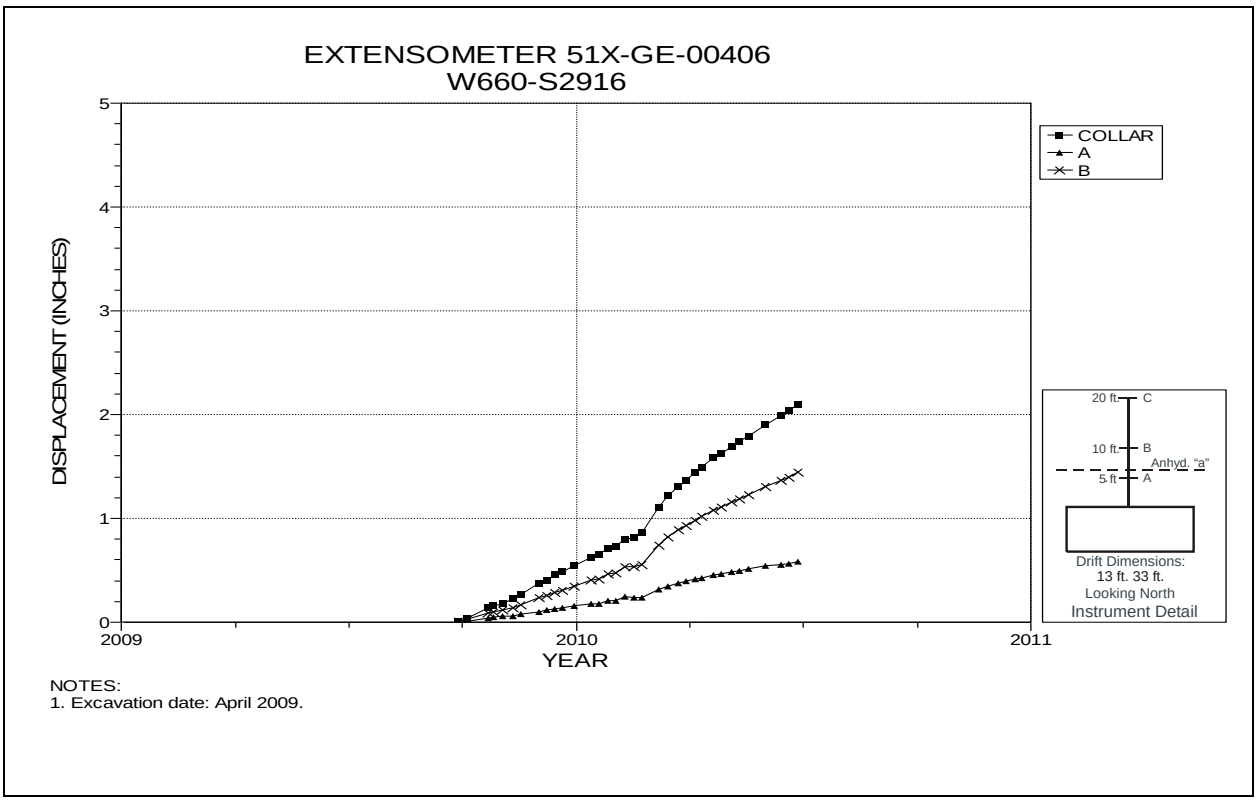


Figure 5-99 Extensometer 51X-GE-00406
Room 3, Panel 6 at W660 S2916– Room Center – Roof

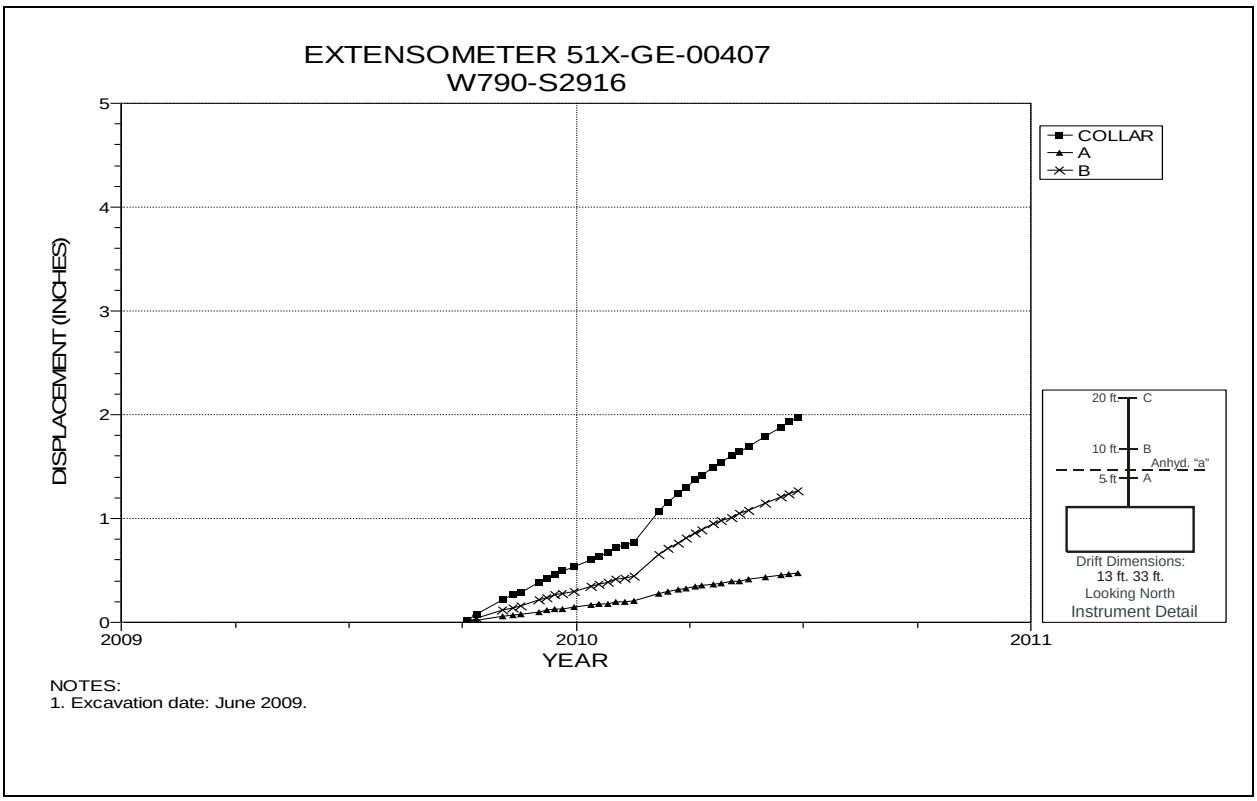


Figure 5-100 Extensometer 51X-GE-00407
Room 4, Panel 6 W790 S2916 – Room Center – Roof

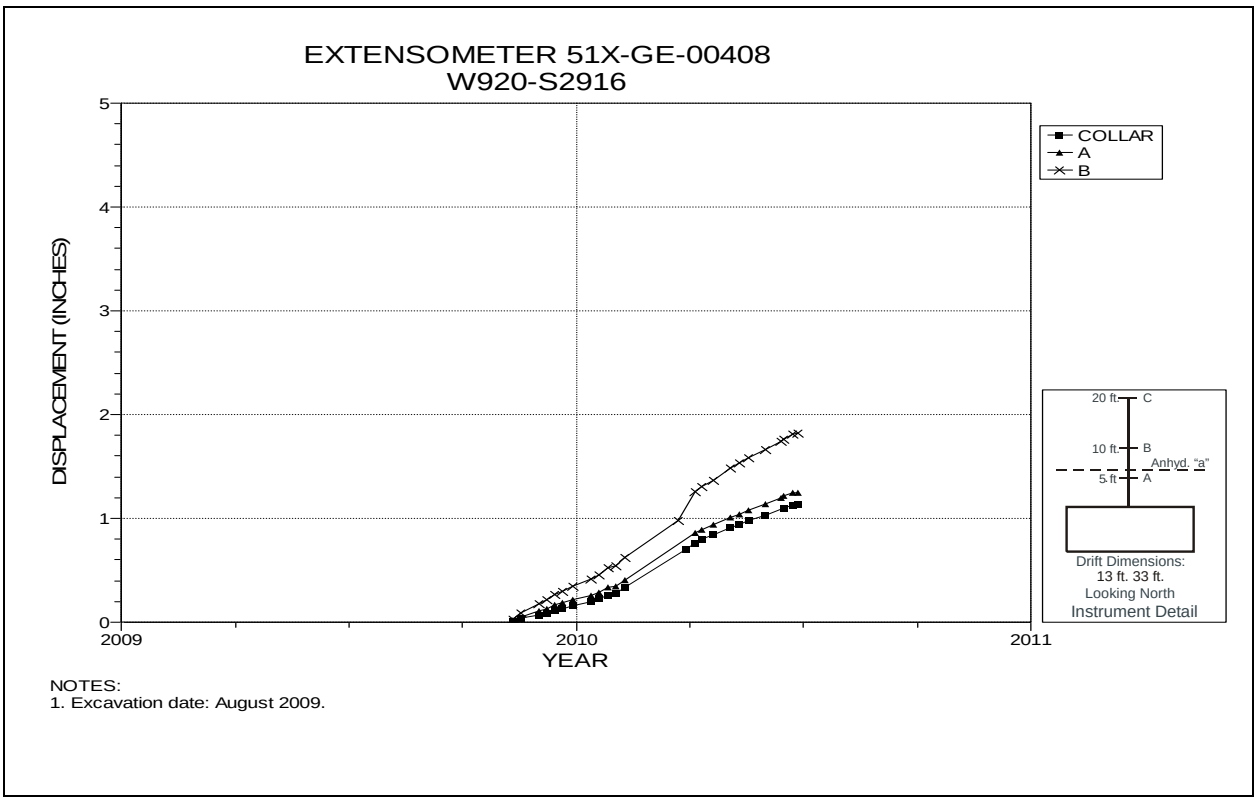


Figure 5-101 Extensometer 51X-GE-00408
Room 5, Panel 6 at W920 S2916– Room Center – Roof

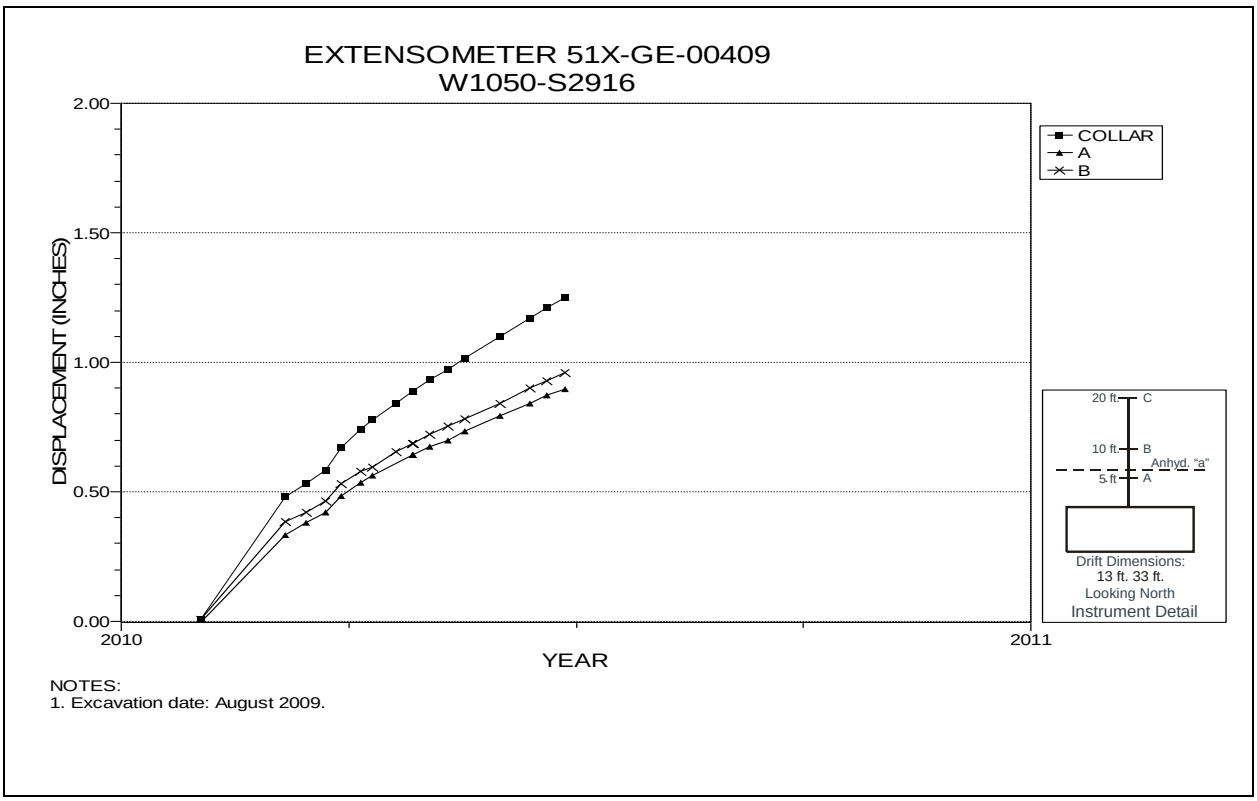


Figure 5-102 Extensometer 51X-GE-00409
Room 6, Panel 6 at W1050 S2916– Room Center – Roof

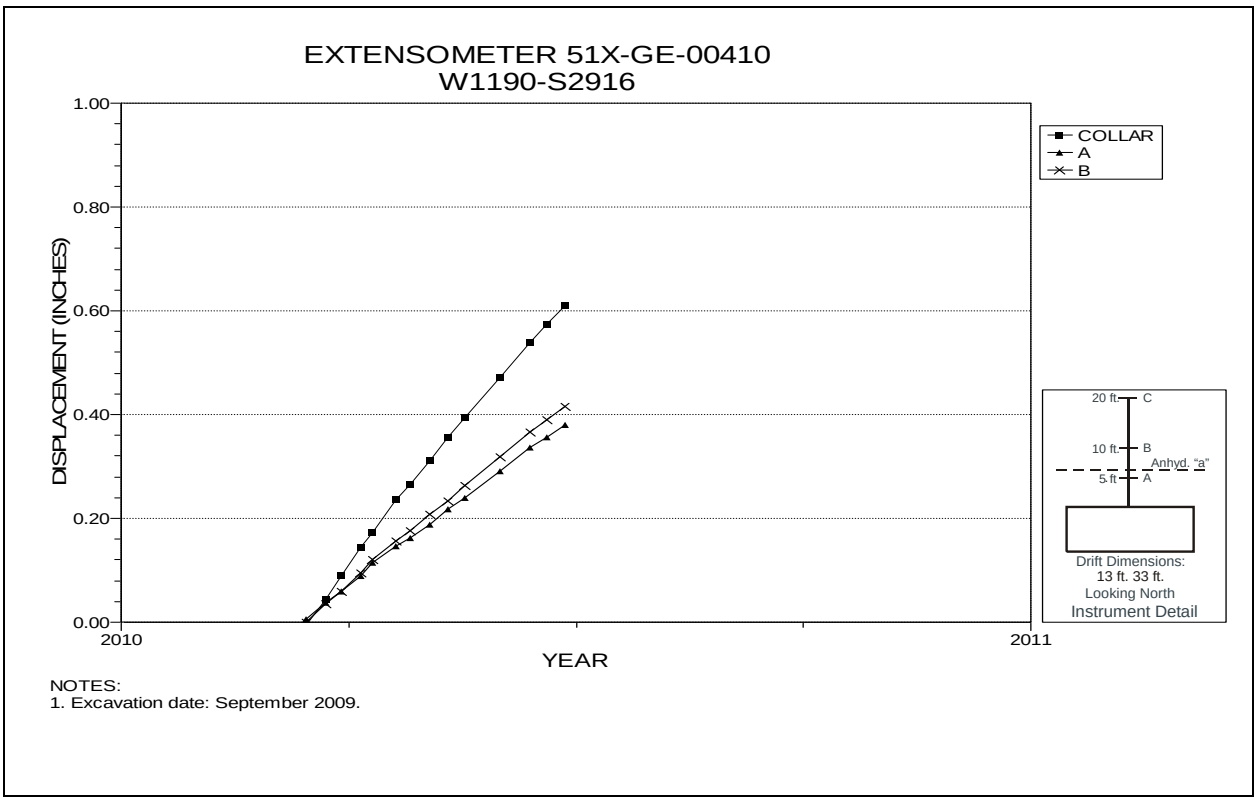


Figure 5-103 Extensometer 51X-GE-00410
Room 7, Panel 6 at W1190 S2916– Room Center – Roof

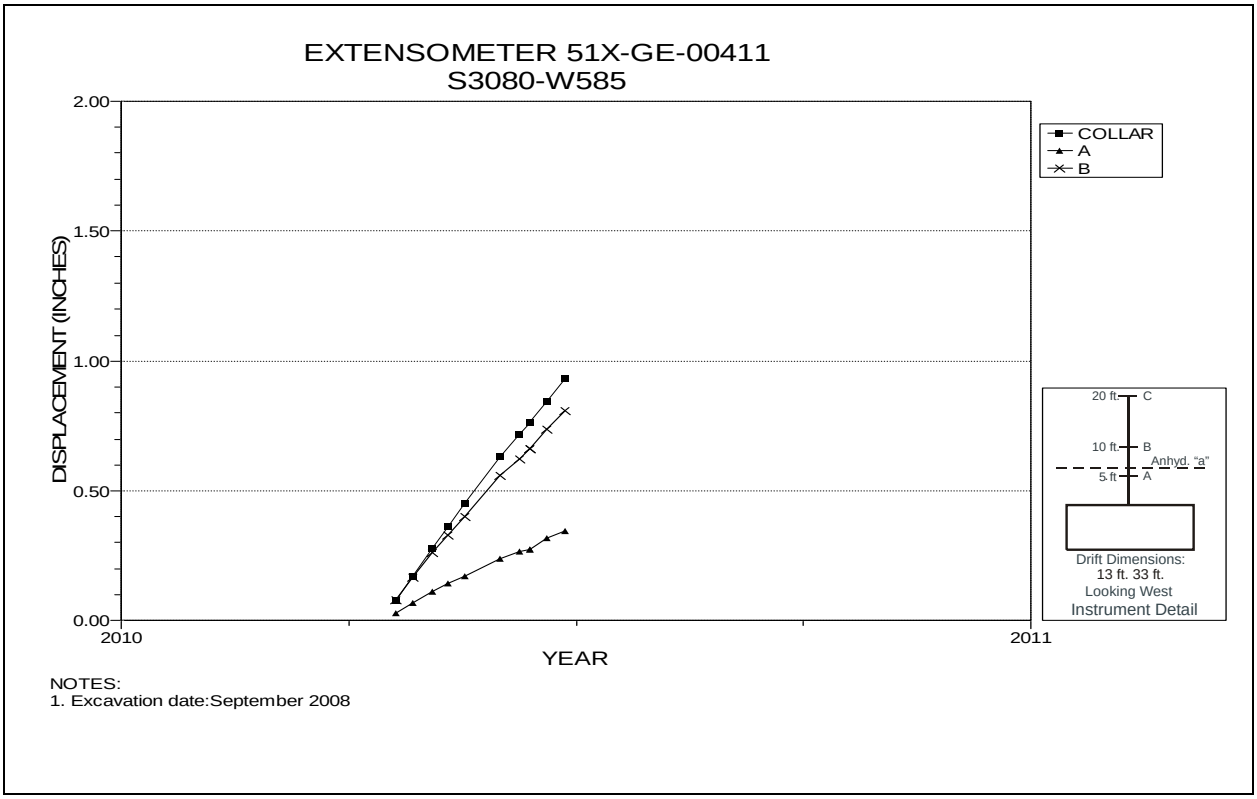


Figure 5-104 Extensometer 51X-GE-00411
S3080 W585 – Roof

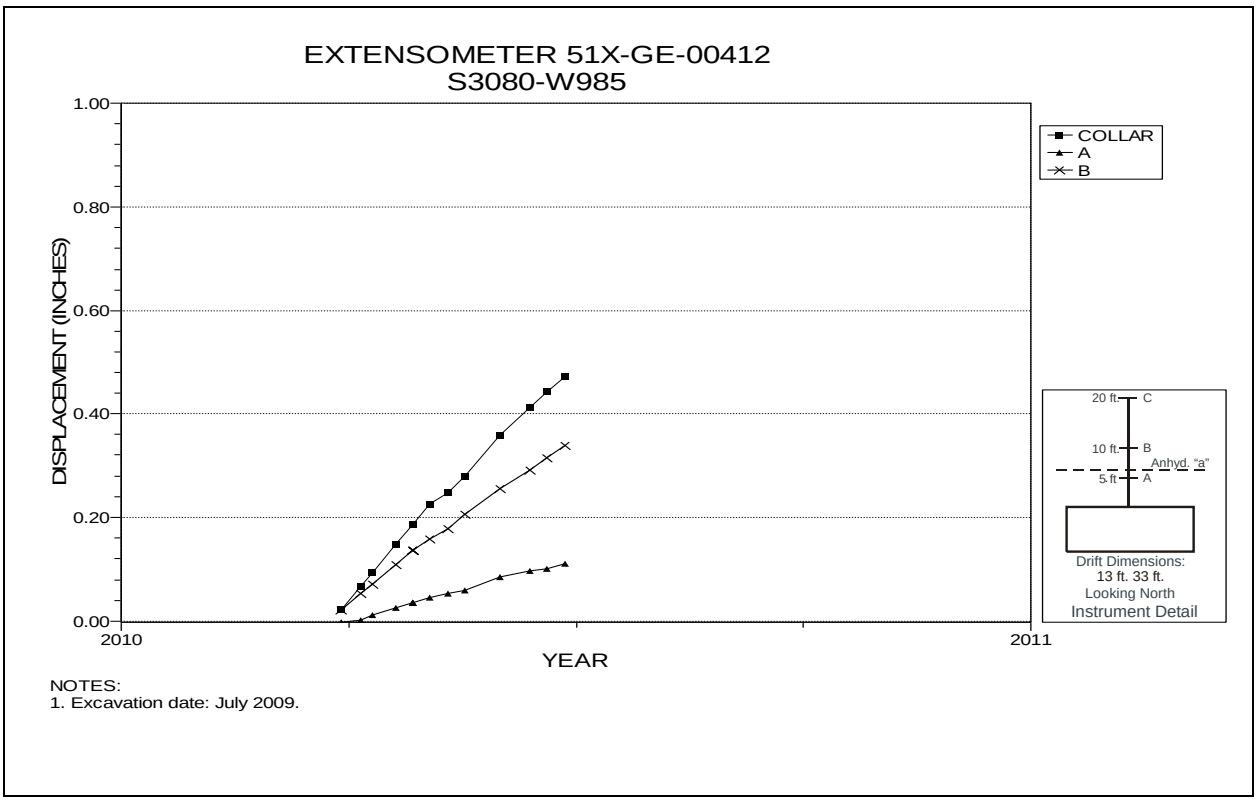


Figure 5-105 Extensometer 51X-GE-00412
S3080 W985 – Roof

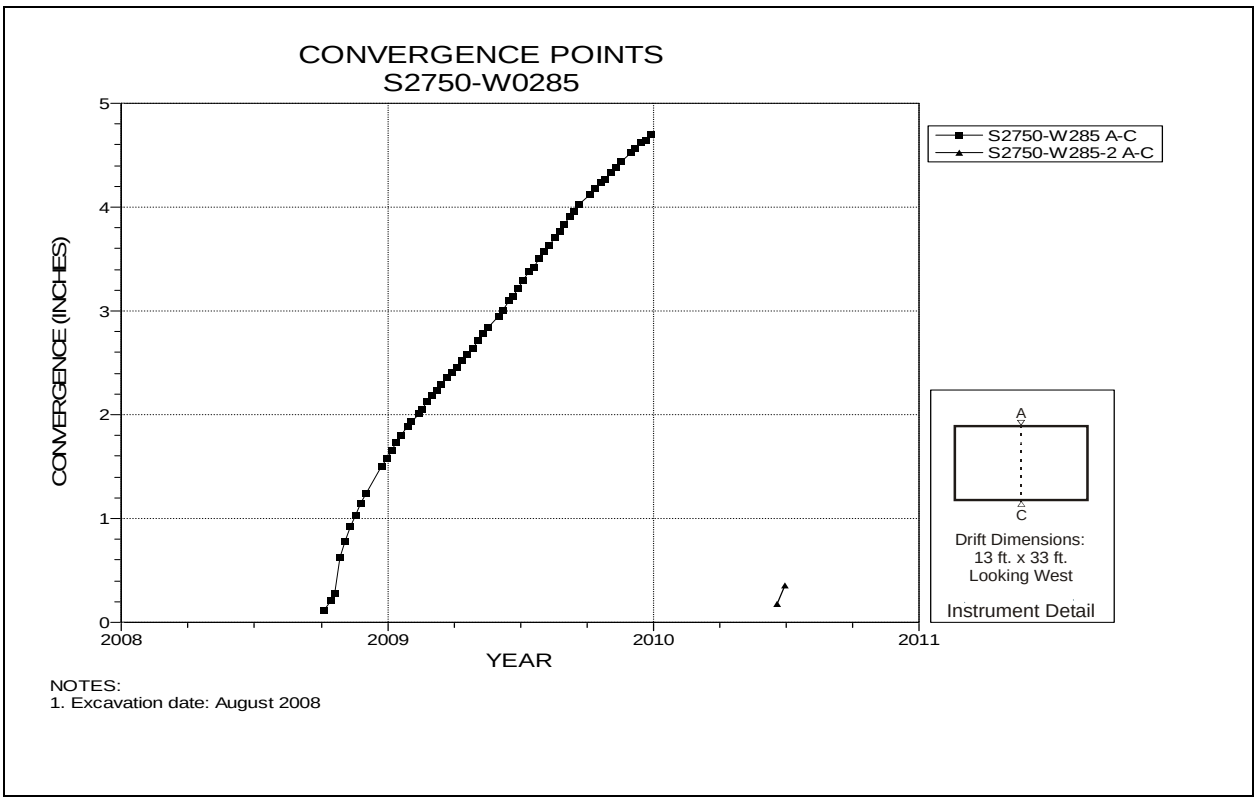


Figure 5-106 Convergence Point Array
S2750 W285 – Roof to Floor

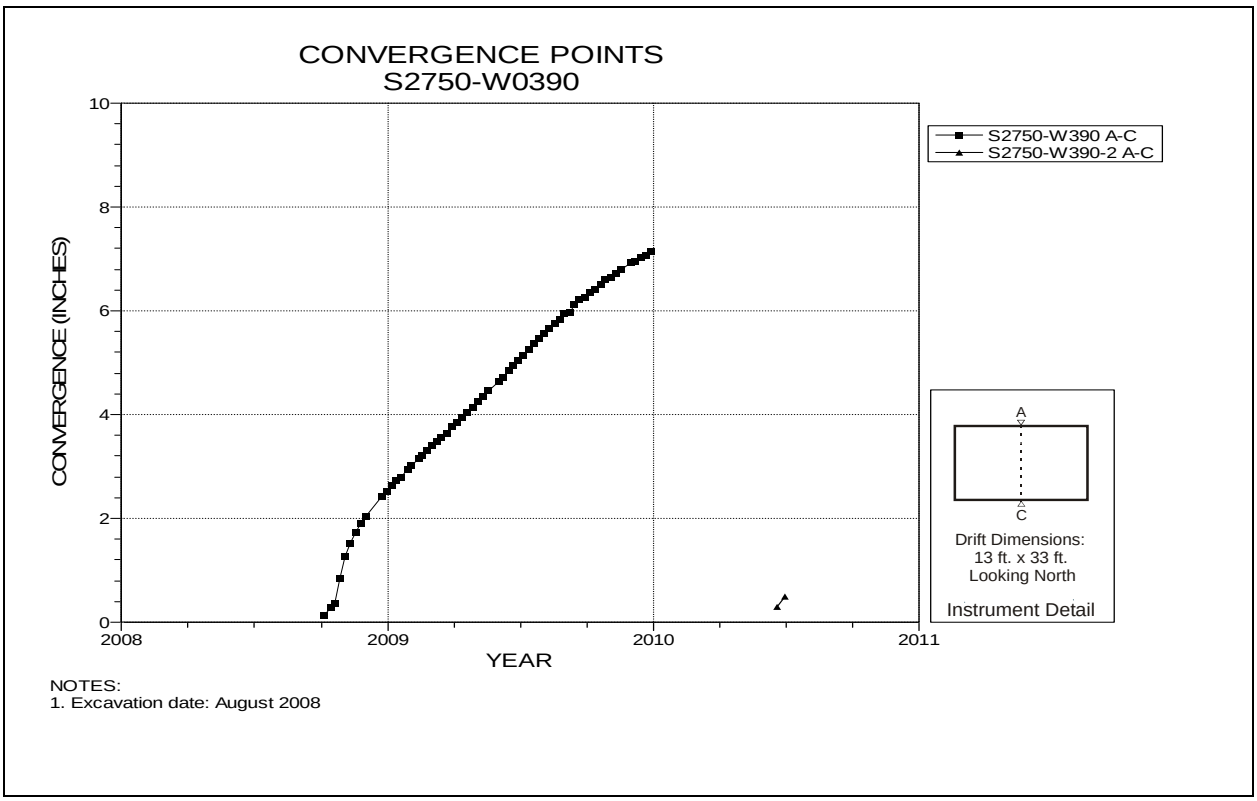


Figure 5-107 Convergence Point Array
S2750 W390 Intersection (Room 1, Panel 6) – Roof to Floor

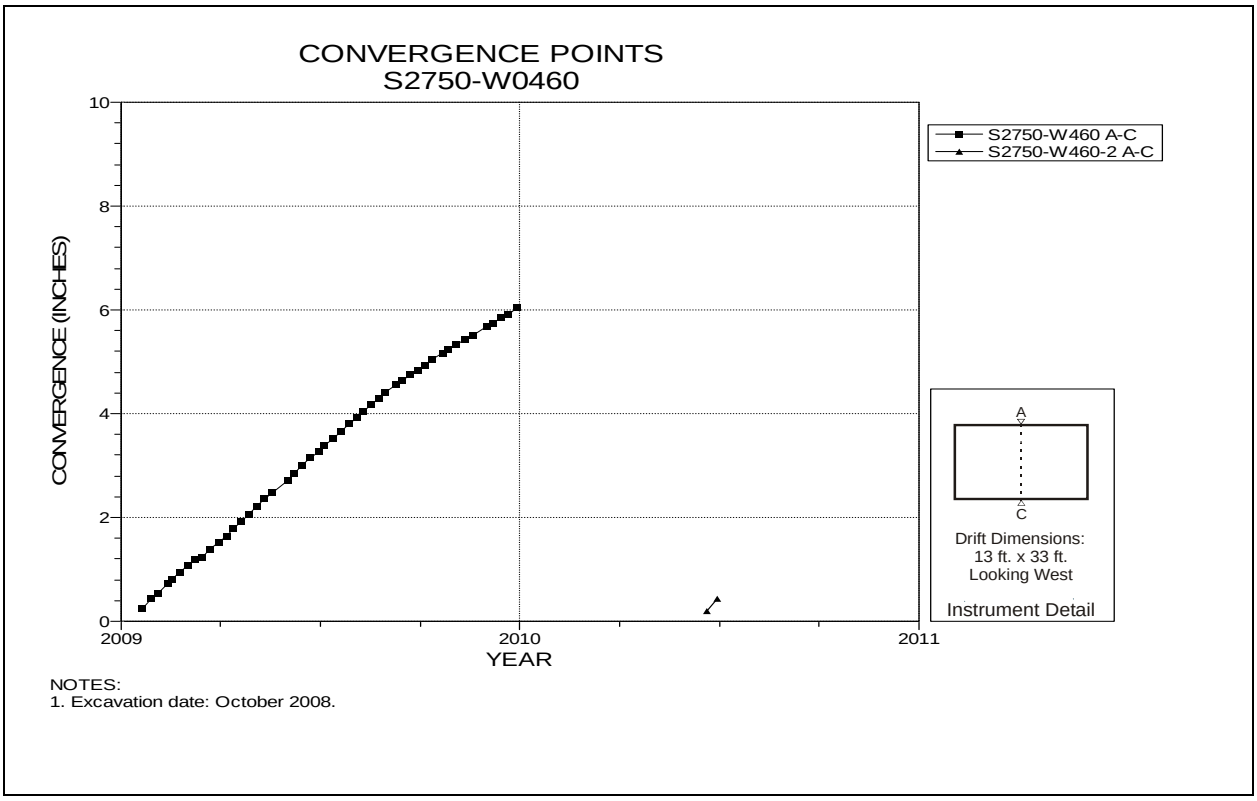


Figure 5-108 Convergence Point Array
S2750 W460 – Roof to Floor

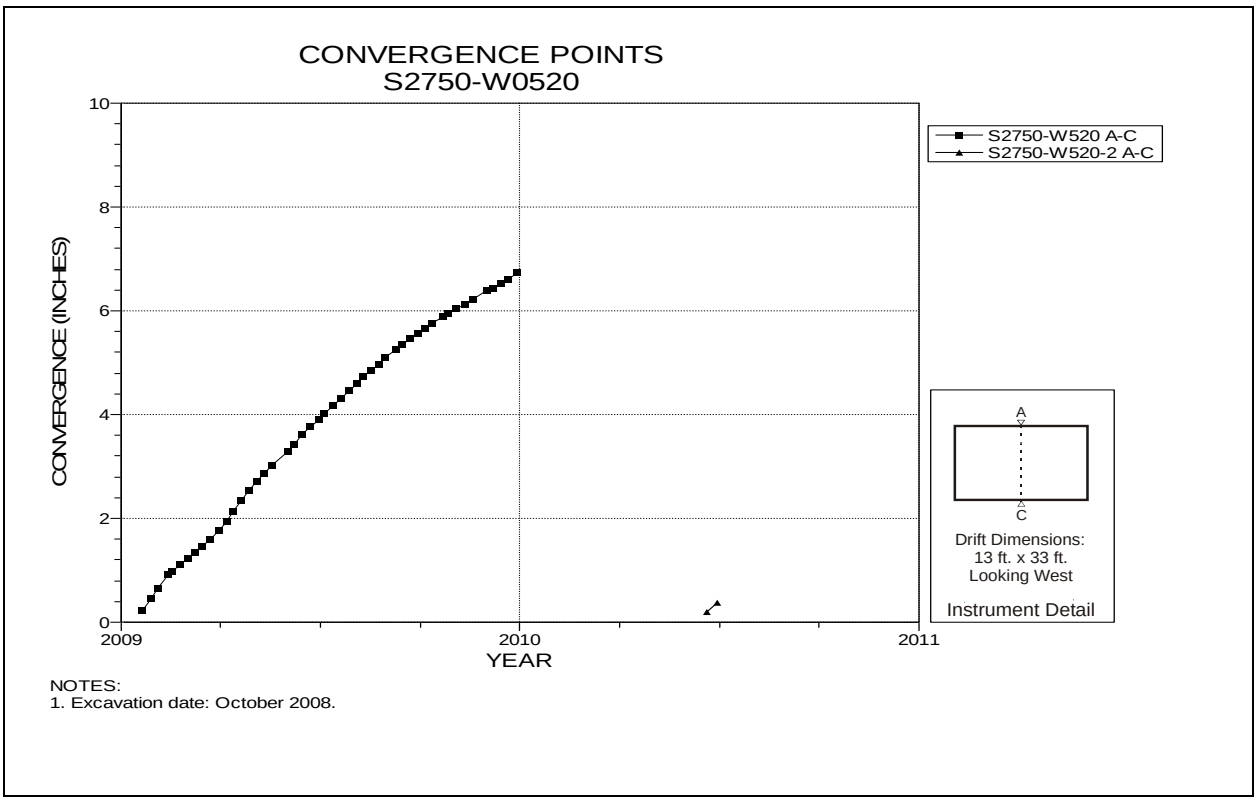


Figure 5-109 Convergence Point Array
S2750 W520 Intersection (Room 2, Panel 6) – Roof to Floor

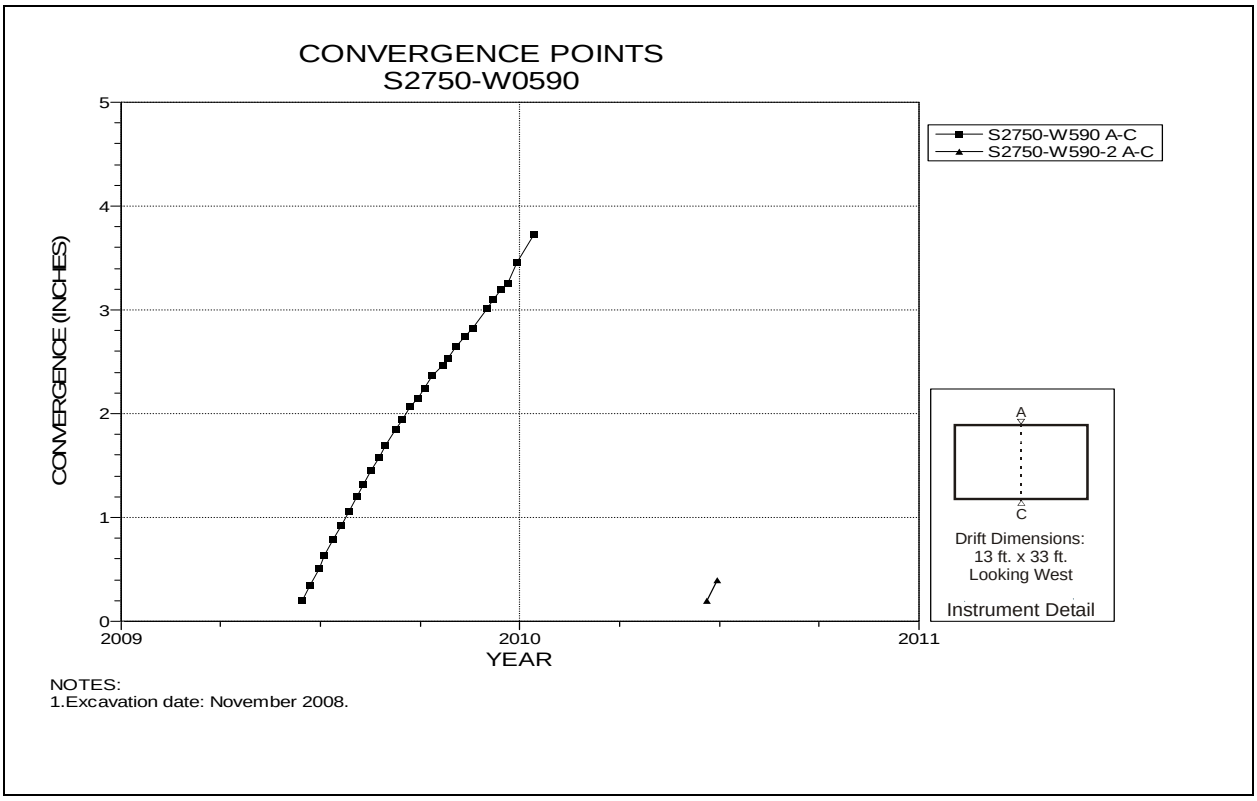


Figure 5-110 Convergence Point Array
S2750 W590 – Roof to Floor

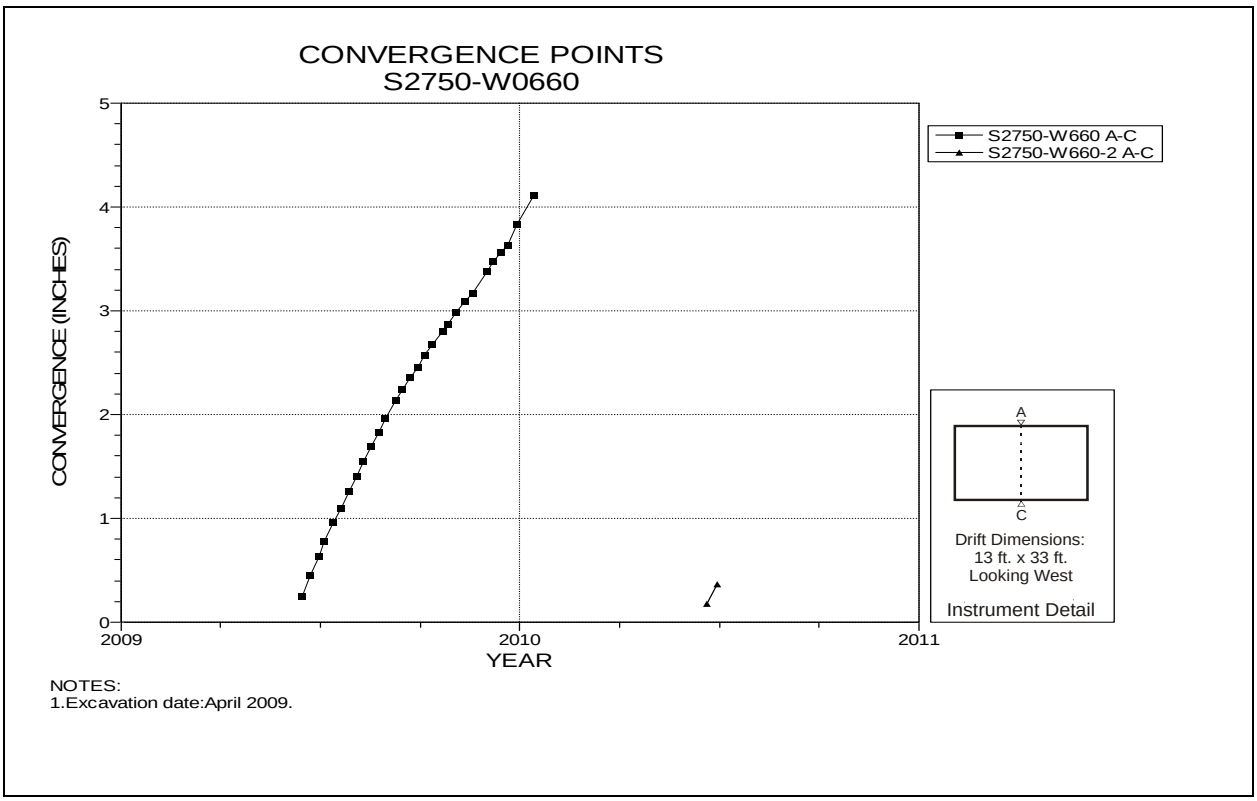


Figure 5-111 Convergence Point Array
S2750 W660 Intersection (Room 3 Panel 6) – Roof to Floor

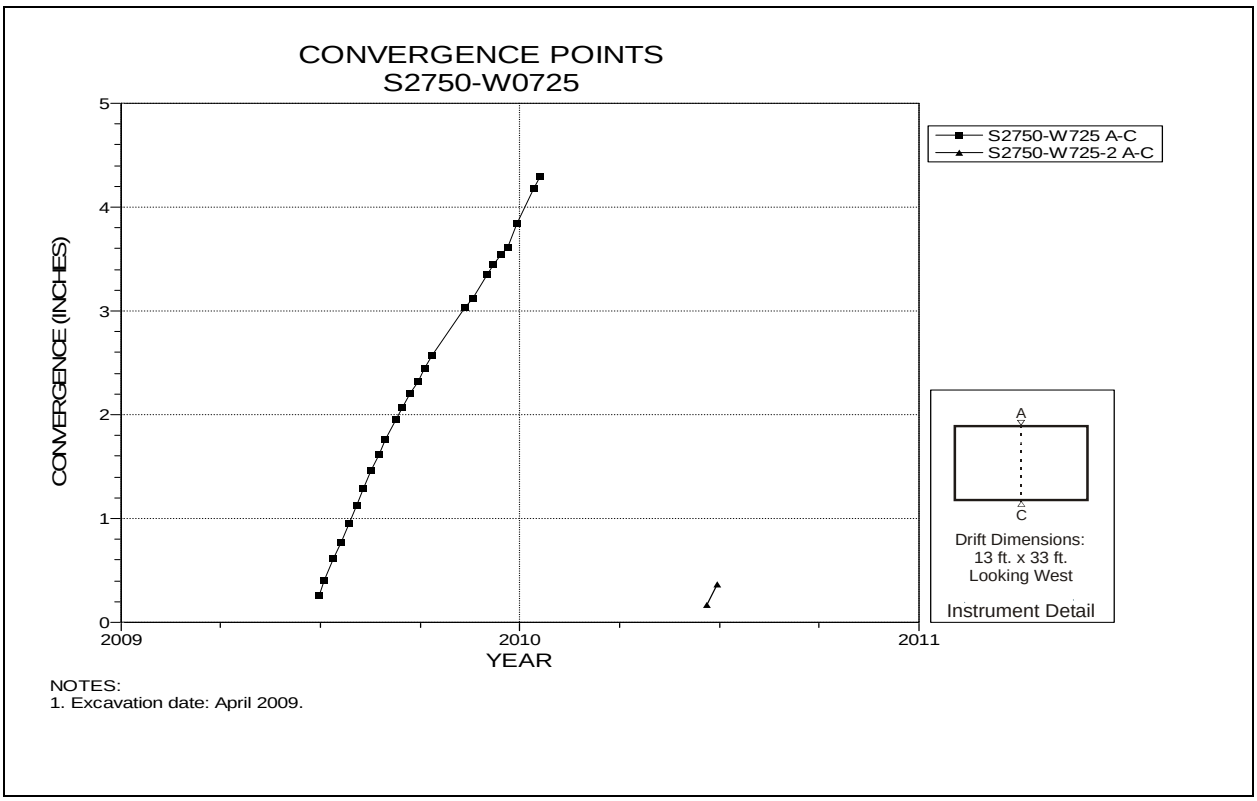


Figure 5-112 Convergence Point Array
S2750 W725 – Roof to Floor

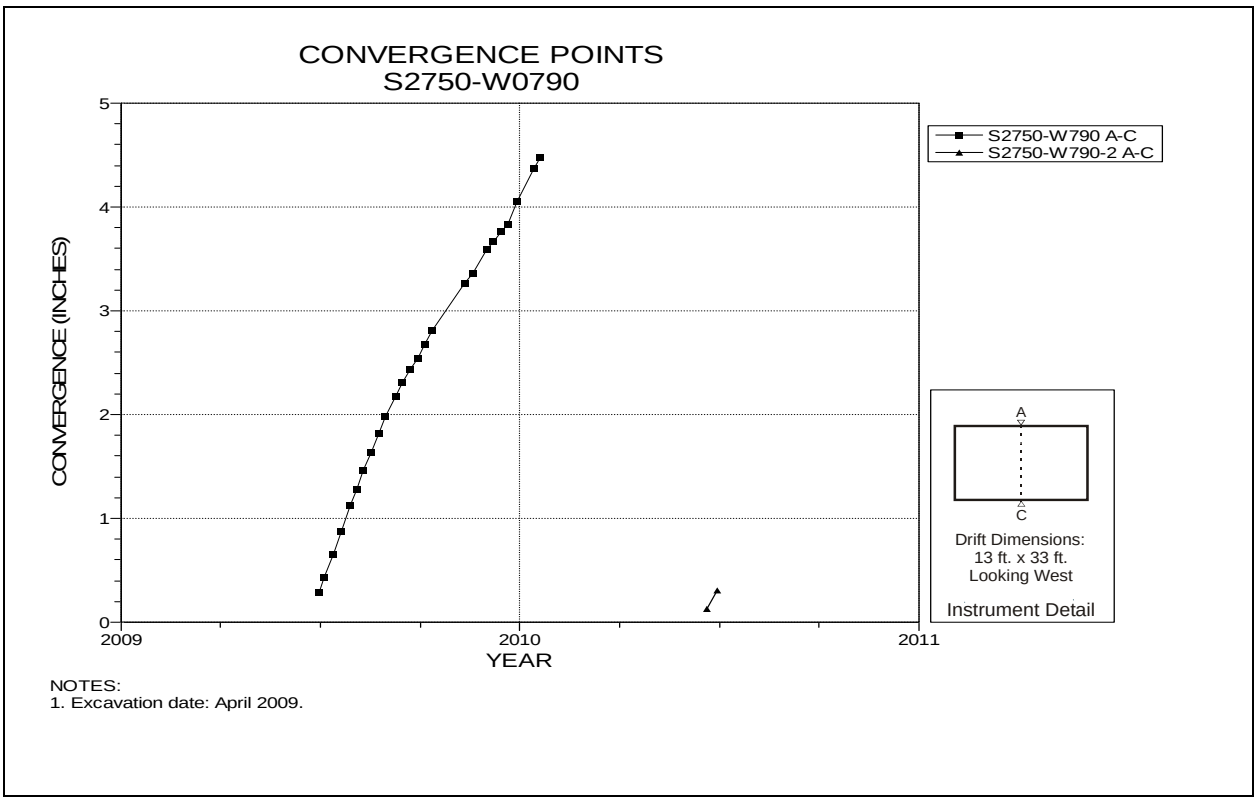


Figure 5-113 Convergence Point Array
S2750 W790 Intersection (Room 4, Panel 6) – Roof to Floor

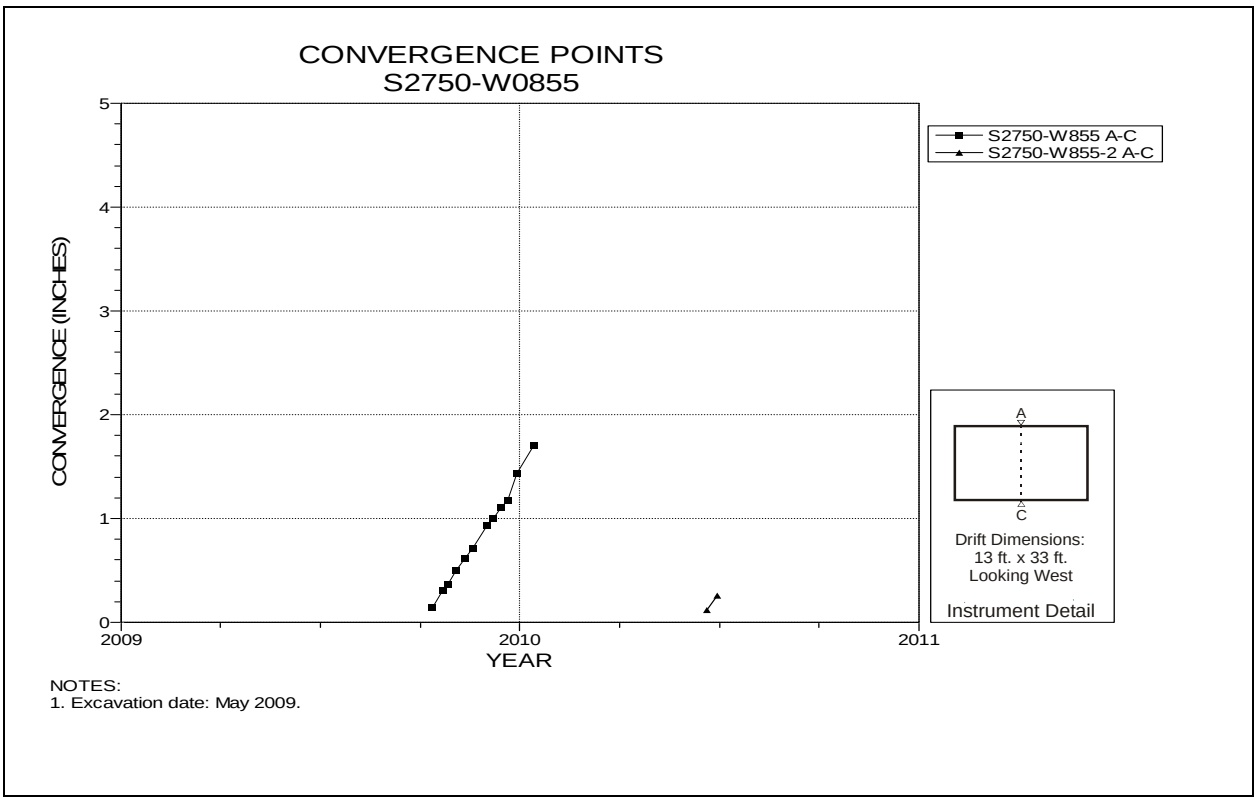


Figure 5-114 Convergence Point Array
S2750 W885 – Roof to Floor

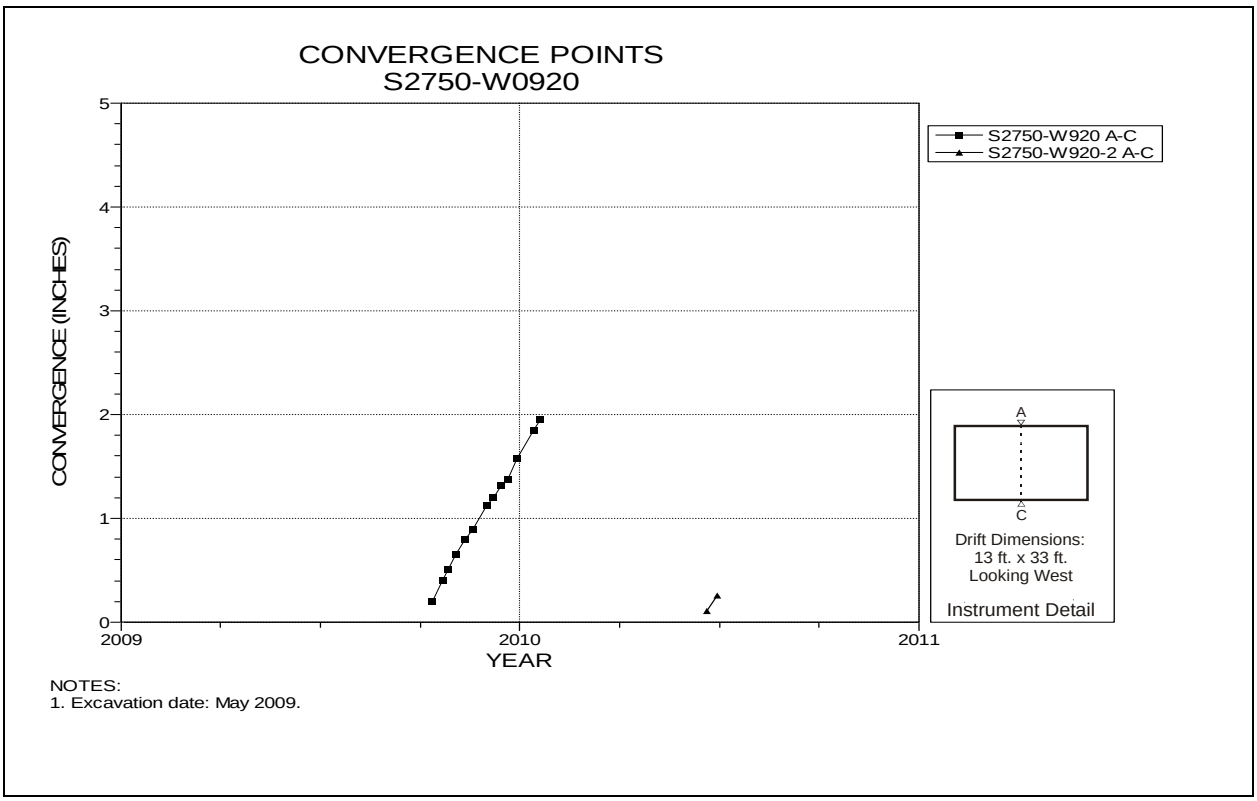


Figure 5-115 Convergence Point Array
S2750 W920 Intersection (Room 5, Panel 6) – Roof to Floor

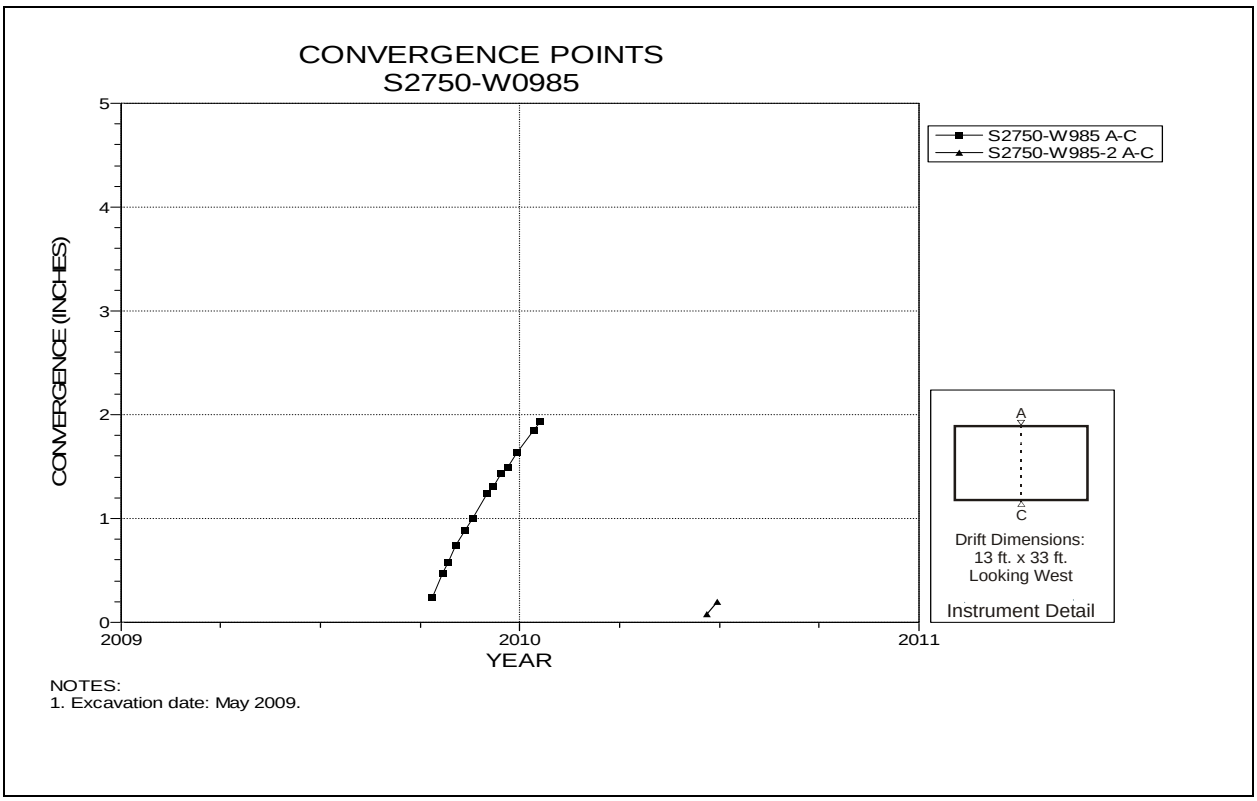


Figure 5-116 Convergence Point Array
S2750 W985 – Roof to Floor

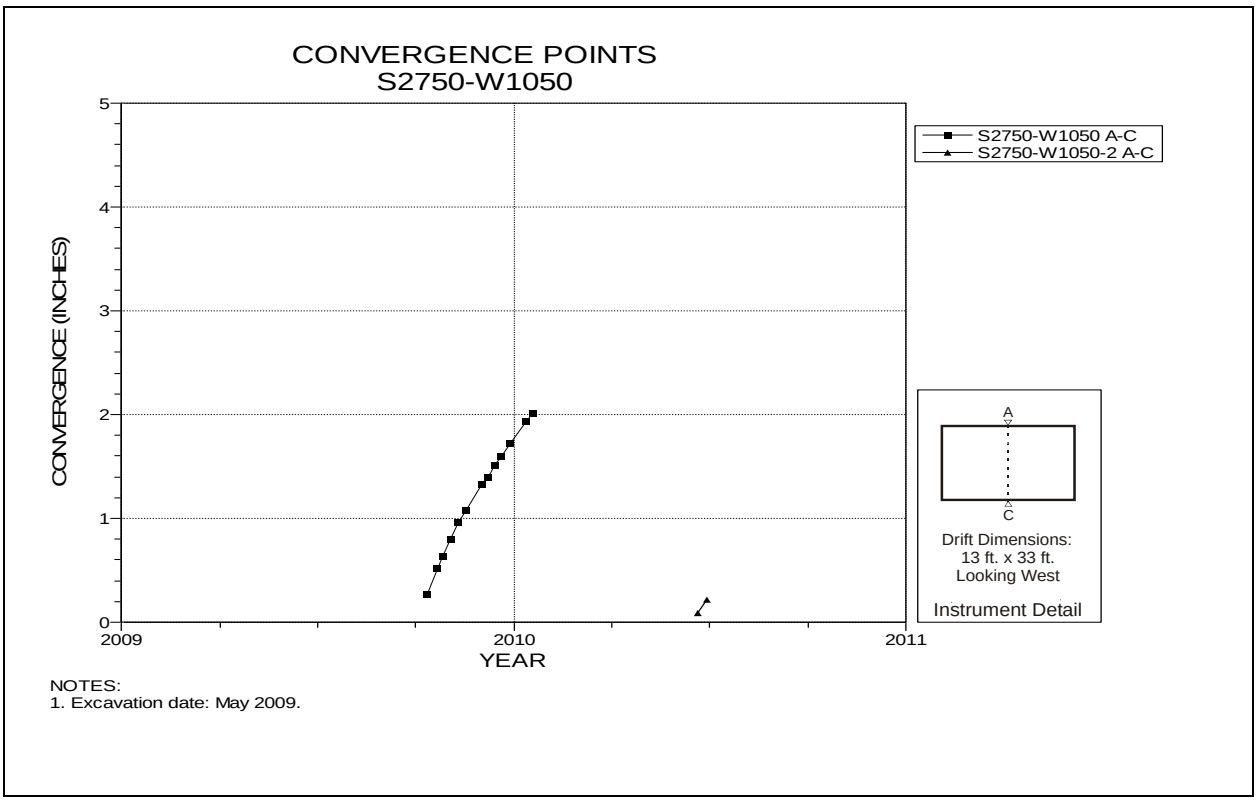


Figure 5-117 Convergence Point Array
S2750 W1050 Intersection (Room 6, Panel 6) – Roof to Floor

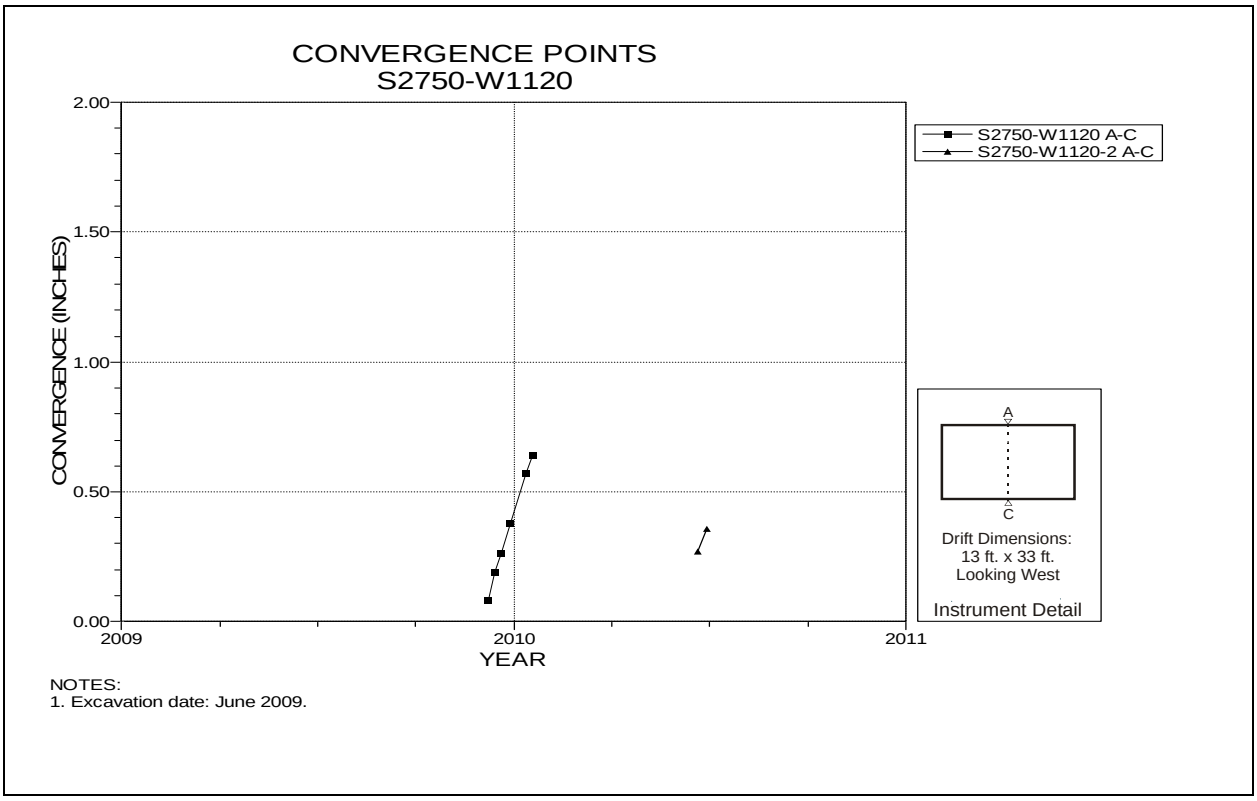


Figure 5-118 Convergence Point Array
S2750 W1120 – Roof to Floor

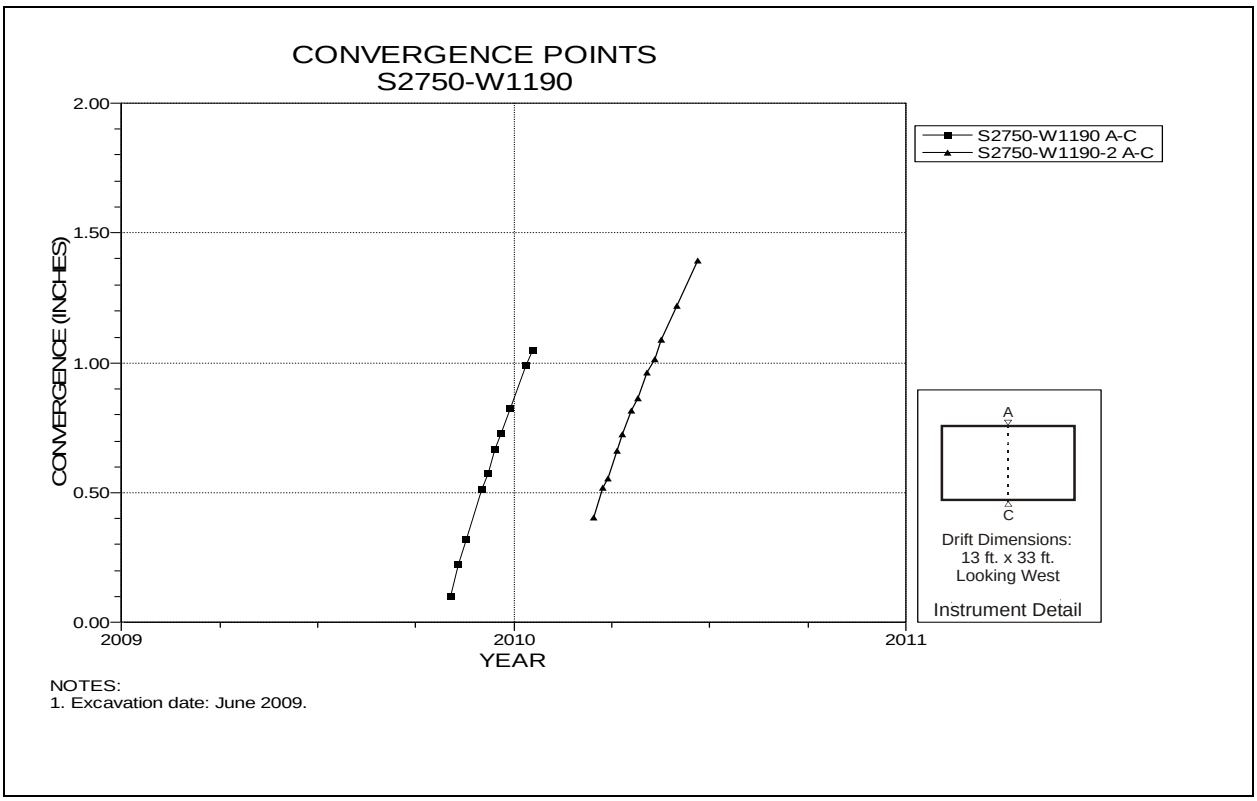


Figure 5-119 Convergence Point Array
S2750 W1190 Intersection (Room 7, Panel 6) – Roof to Floor

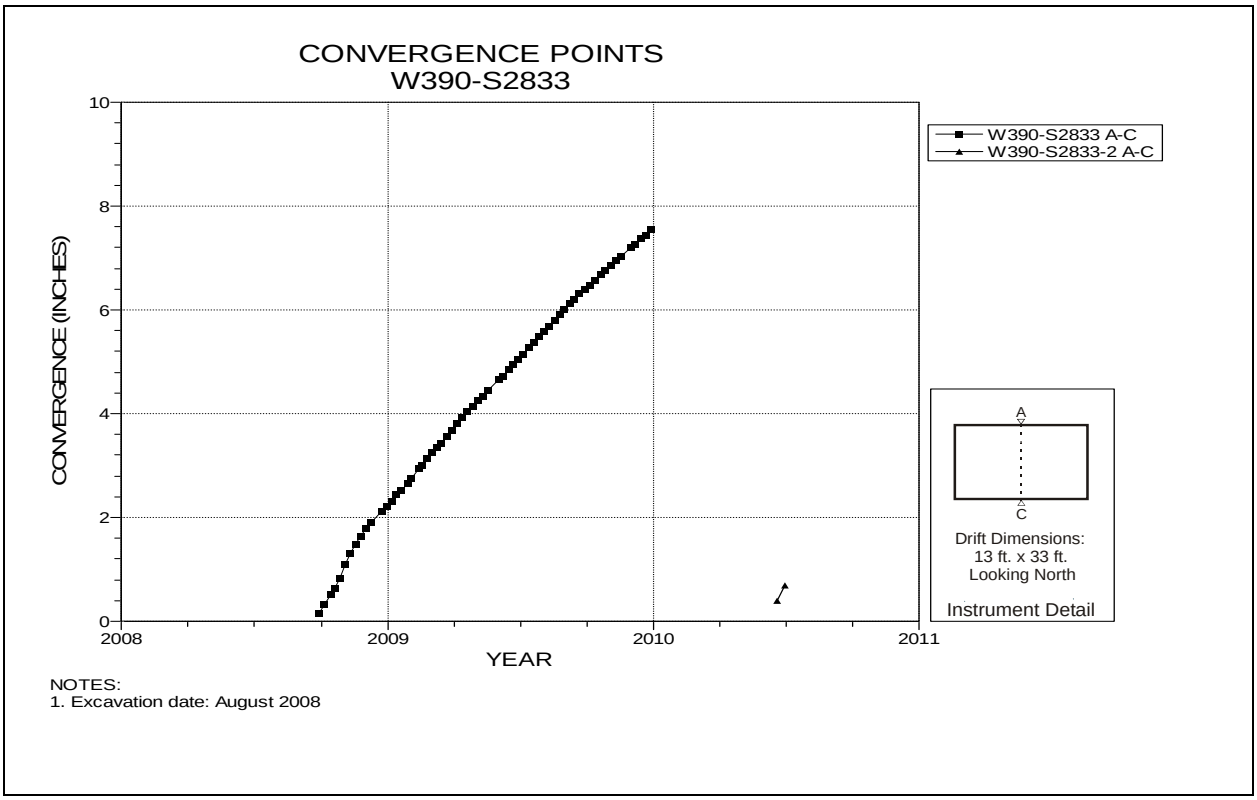


Figure 5-120 Convergence Point Array
Room 1, Panel 6 at W390 W2833 – Roof to Floor

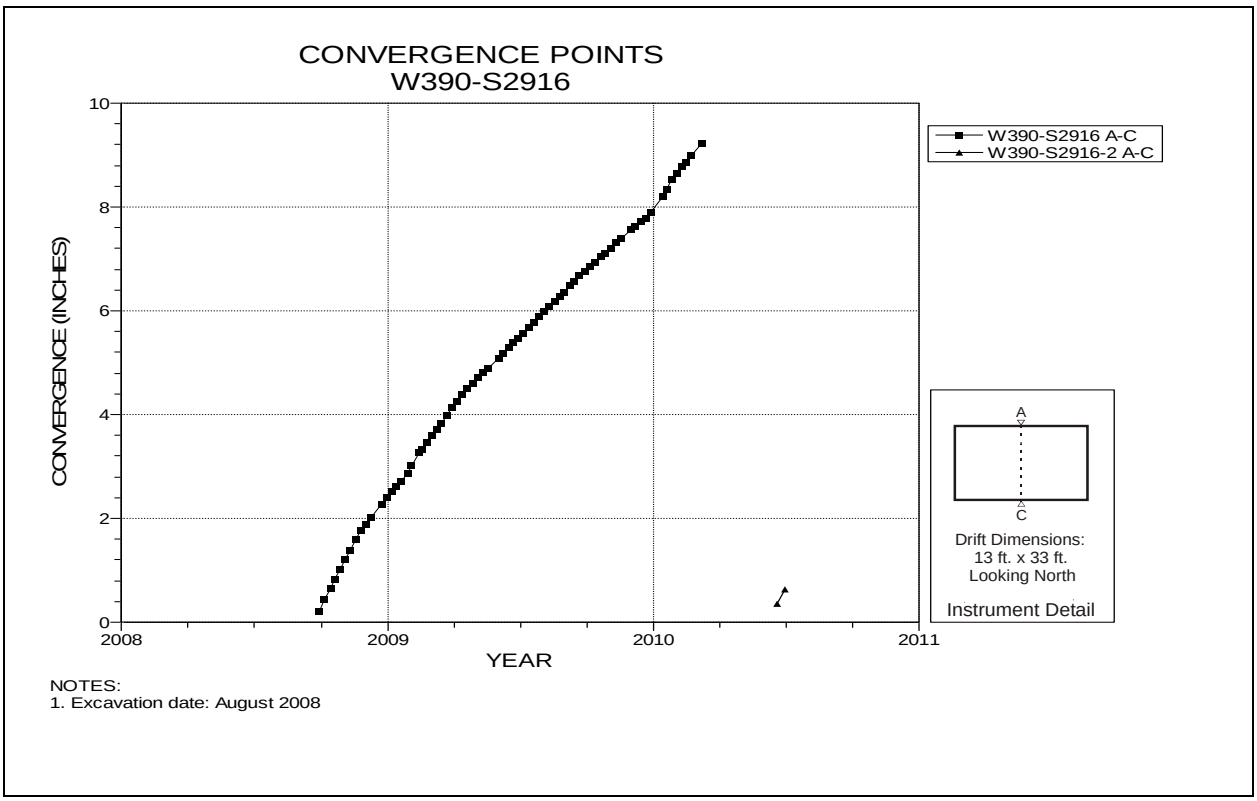


Figure 5-121 Convergence Point Array
Room 1, Panel 6 at W390 S2916– Room Center – Roof to Floor

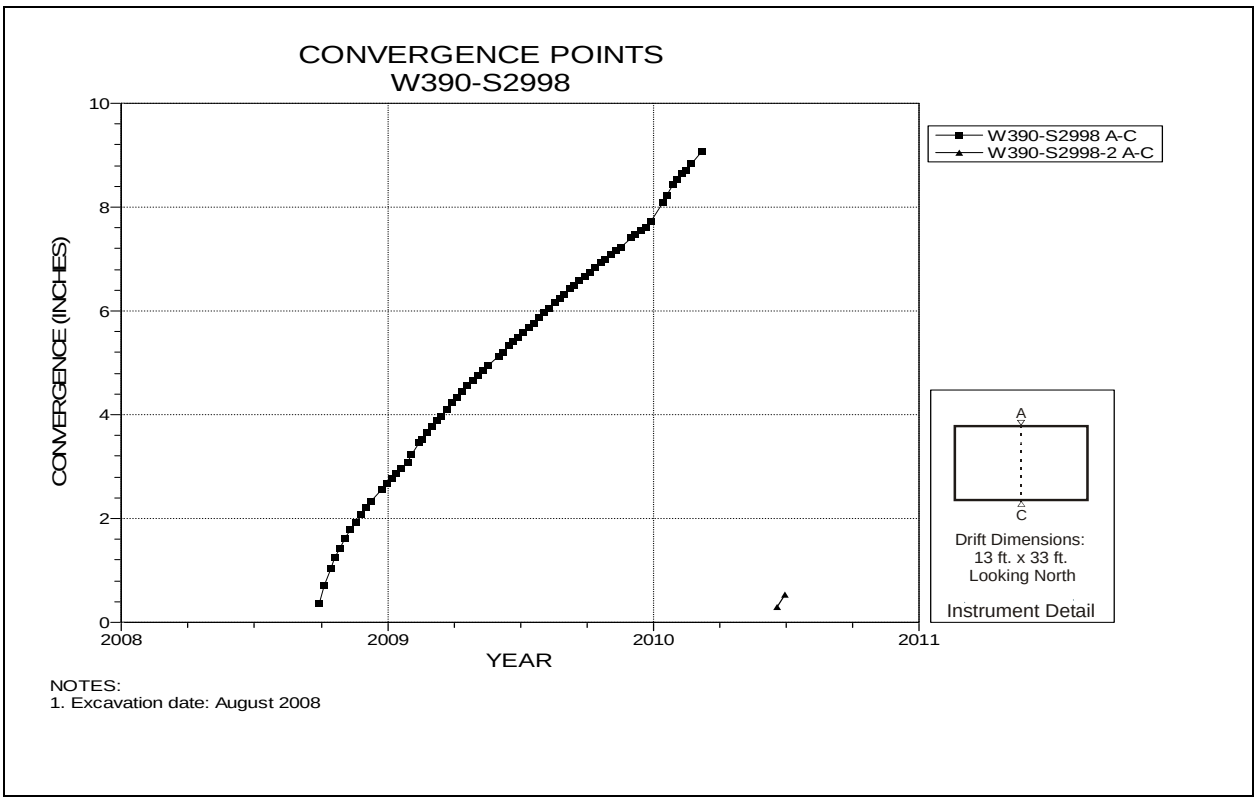


Figure 5-122 Convergence Point Array
Room 1, Panel 6 at W390 S2998 – Roof to Floor

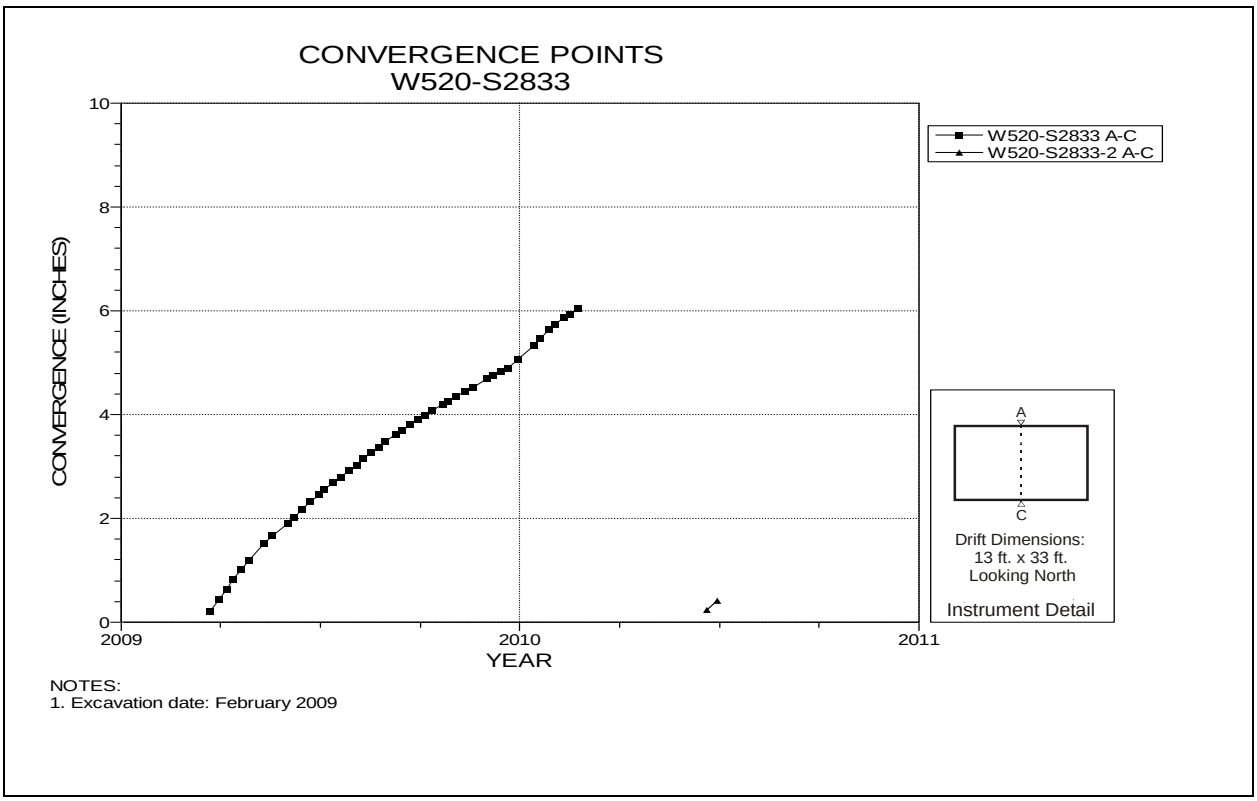


Figure 5-123 Convergence Point Array
Room 2, Panel 6 at W520 S2833 – Roof to Floor

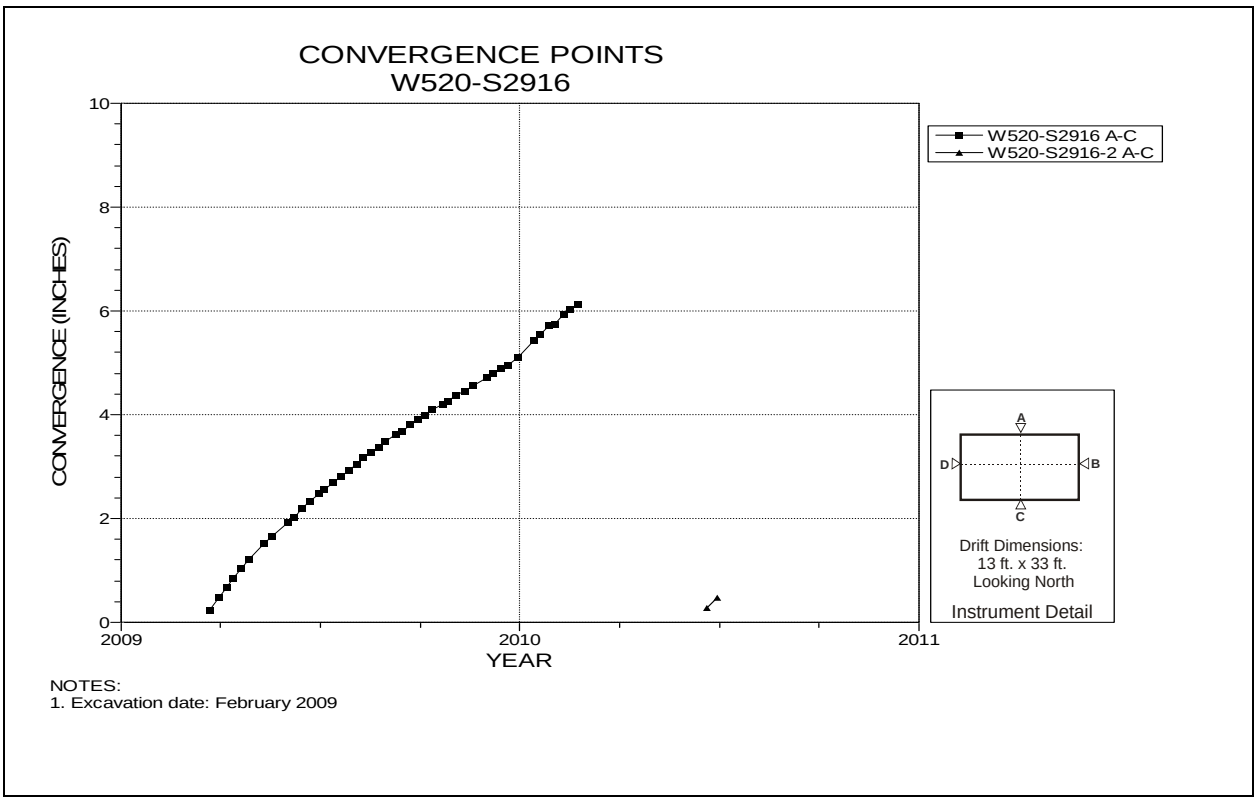


Figure 5-124 Convergence Point Array
Room 2, Panel 6 at W520 S2916– Room Center – Roof to Floor

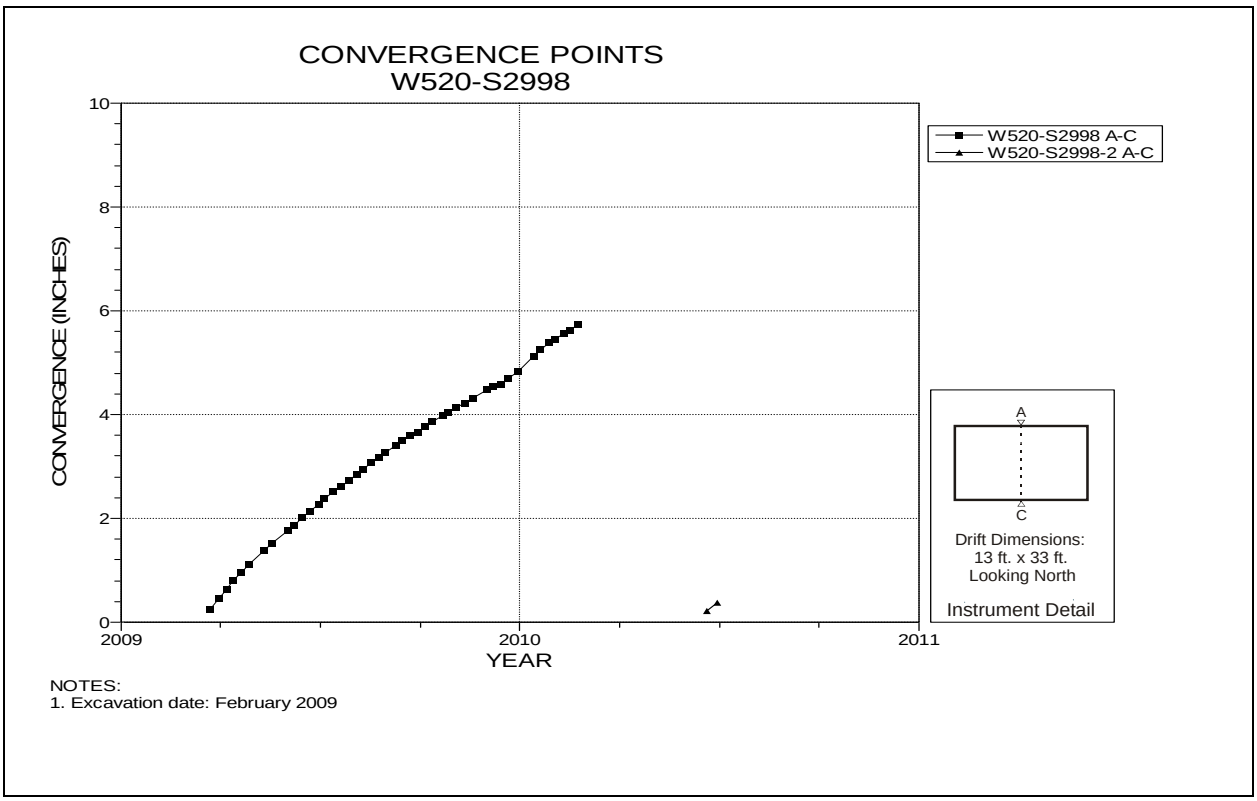


Figure 5-125 Convergence Point Array
Room 2, Panel 6 at W520 S2998 – Roof to Floor

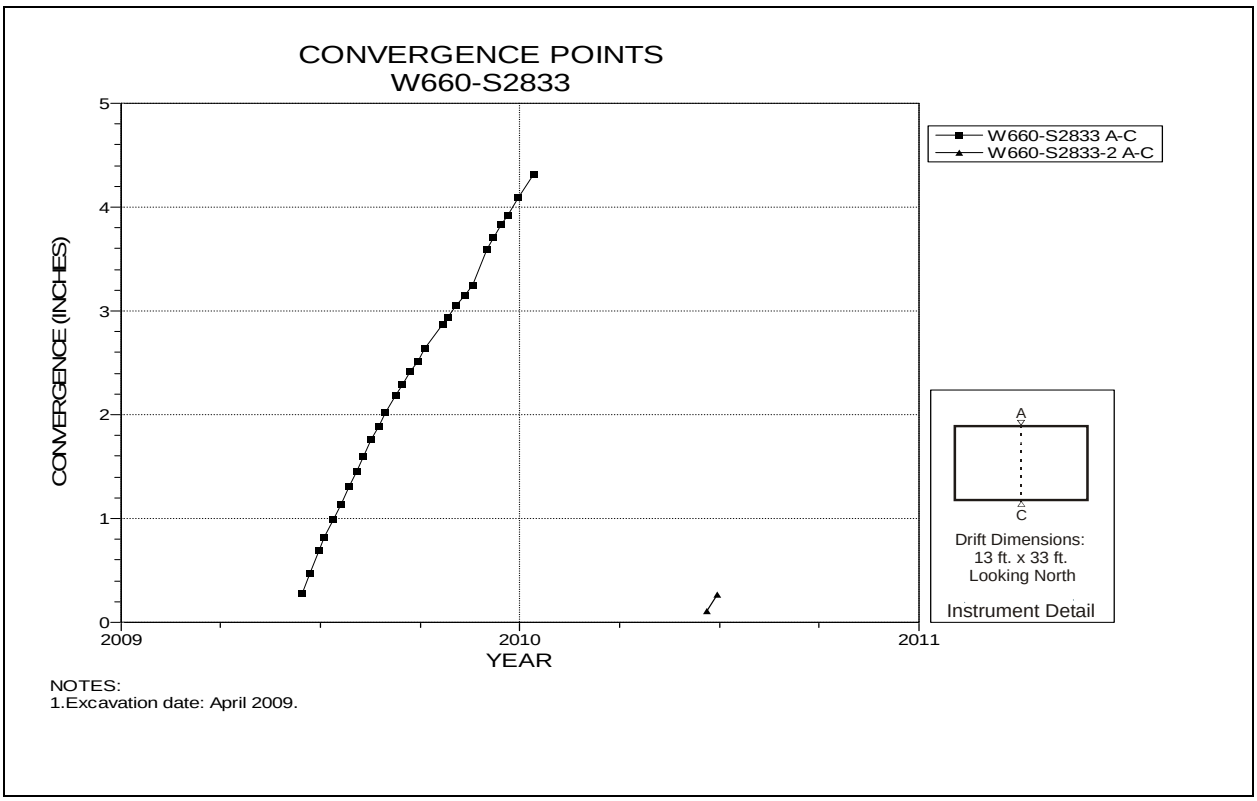


Figure 5-126 Convergence Point Array
Room 3, Panel 6 at W660 S2833 – Roof to Floor

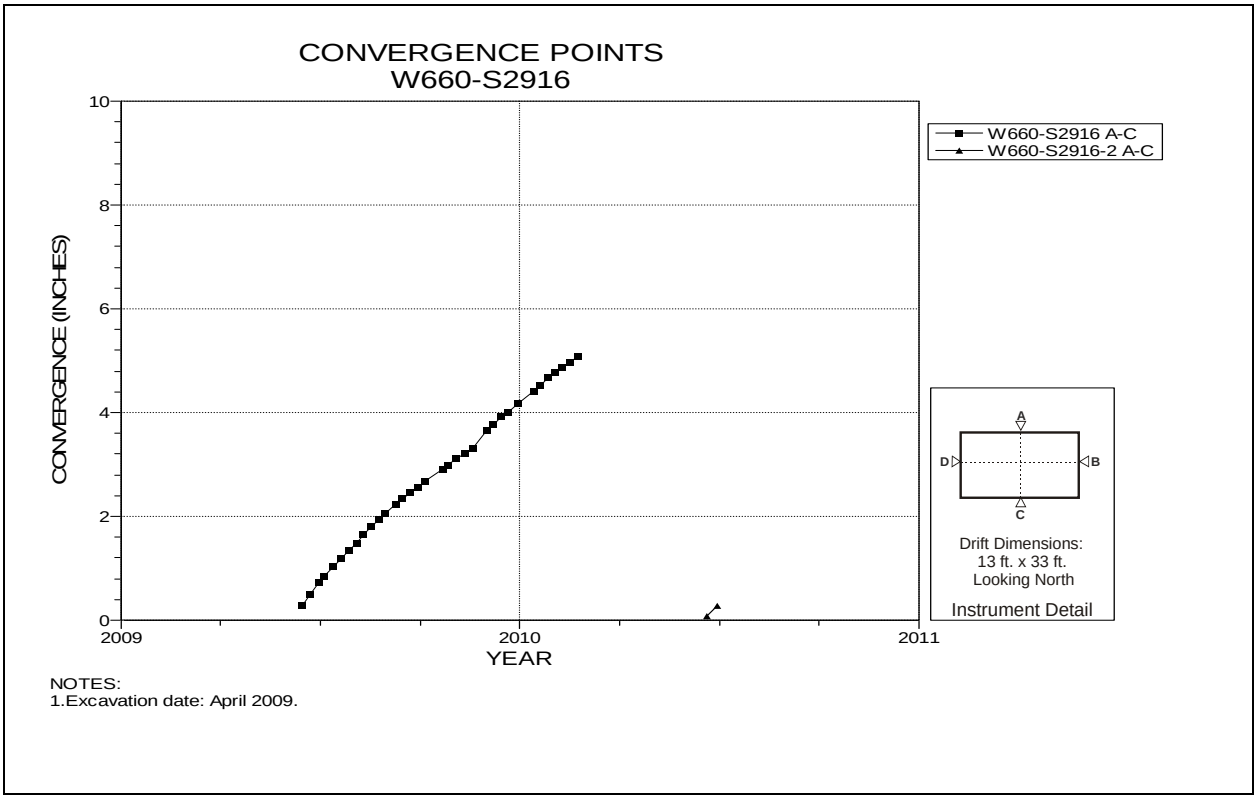


Figure 5-127 Convergence Point Array
Room 3, Panel 6 at W660 S2916– Room Center – Roof to Floor

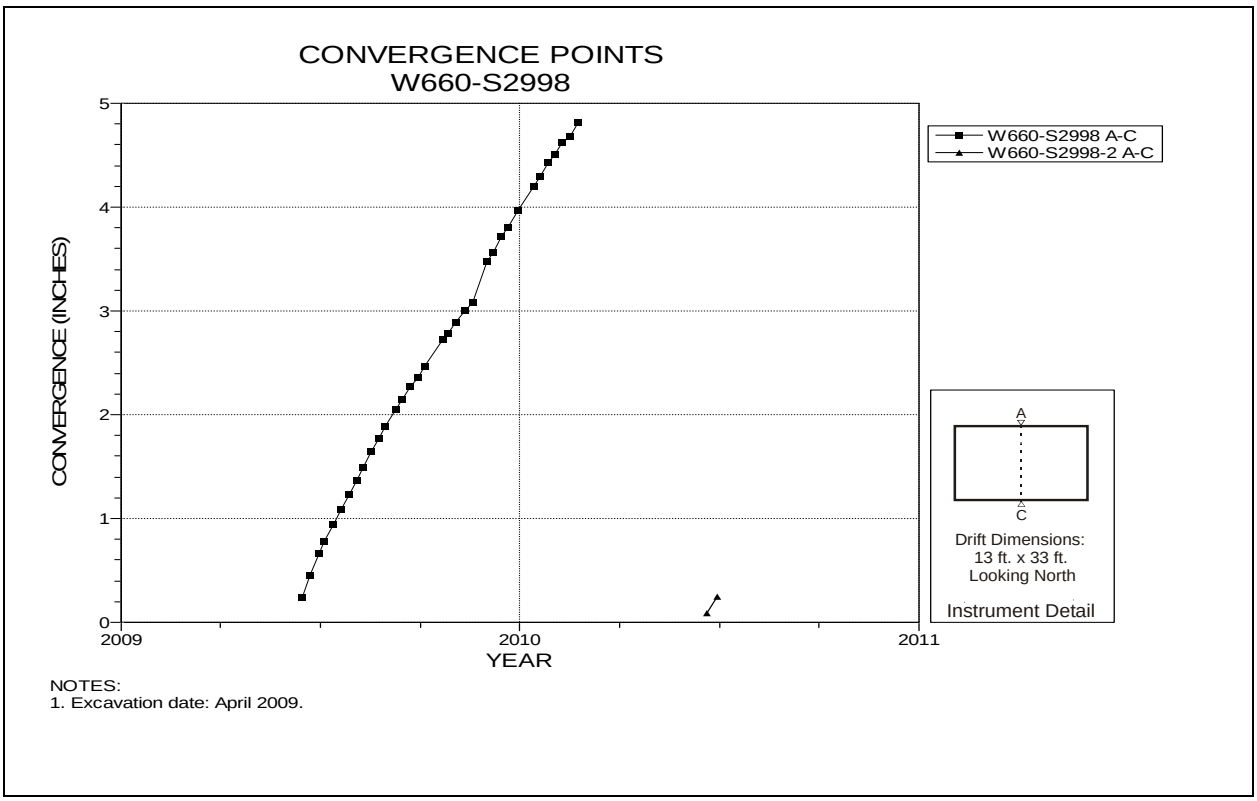


Figure 5-128 Convergence Point Array
Room 3, Panel 6 at W660 S2998 – Roof to Floor

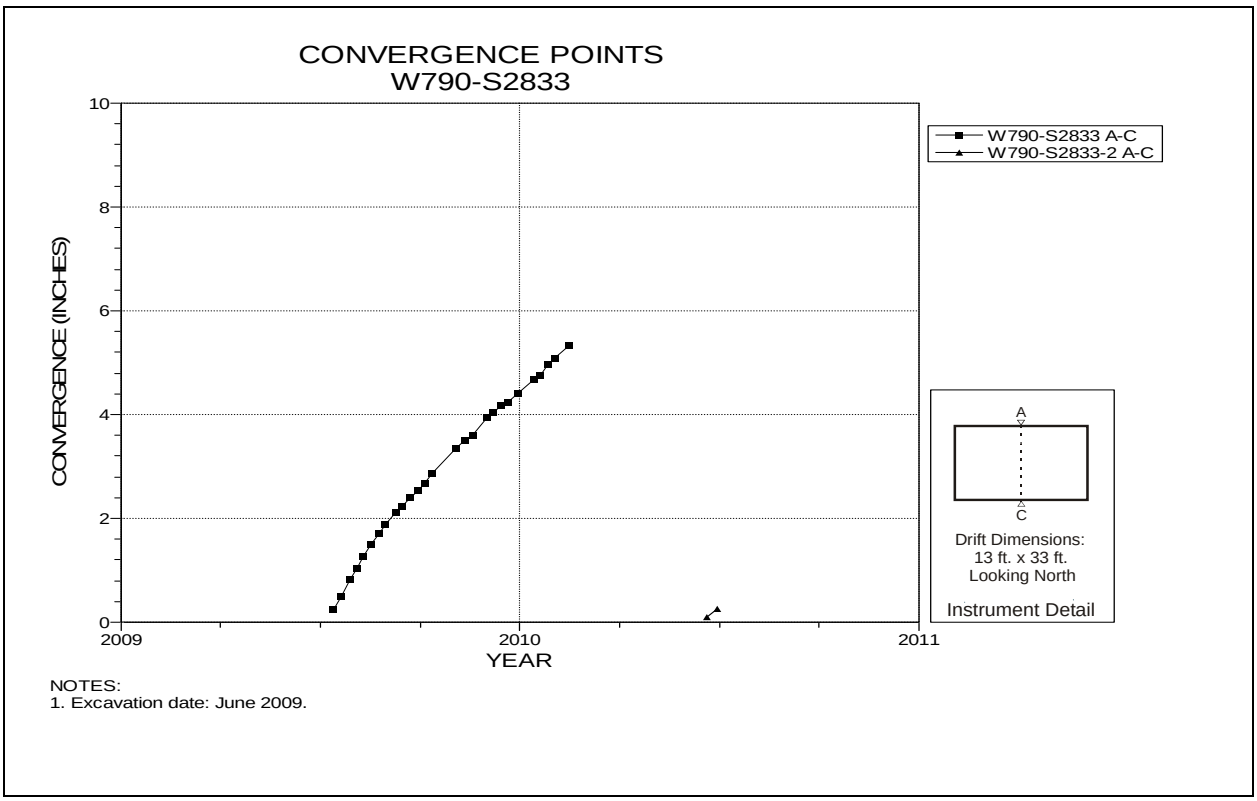


Figure 5-129 Convergence Point Array
Room 4, Panel 6 at W790 S2833 – Roof to Floor

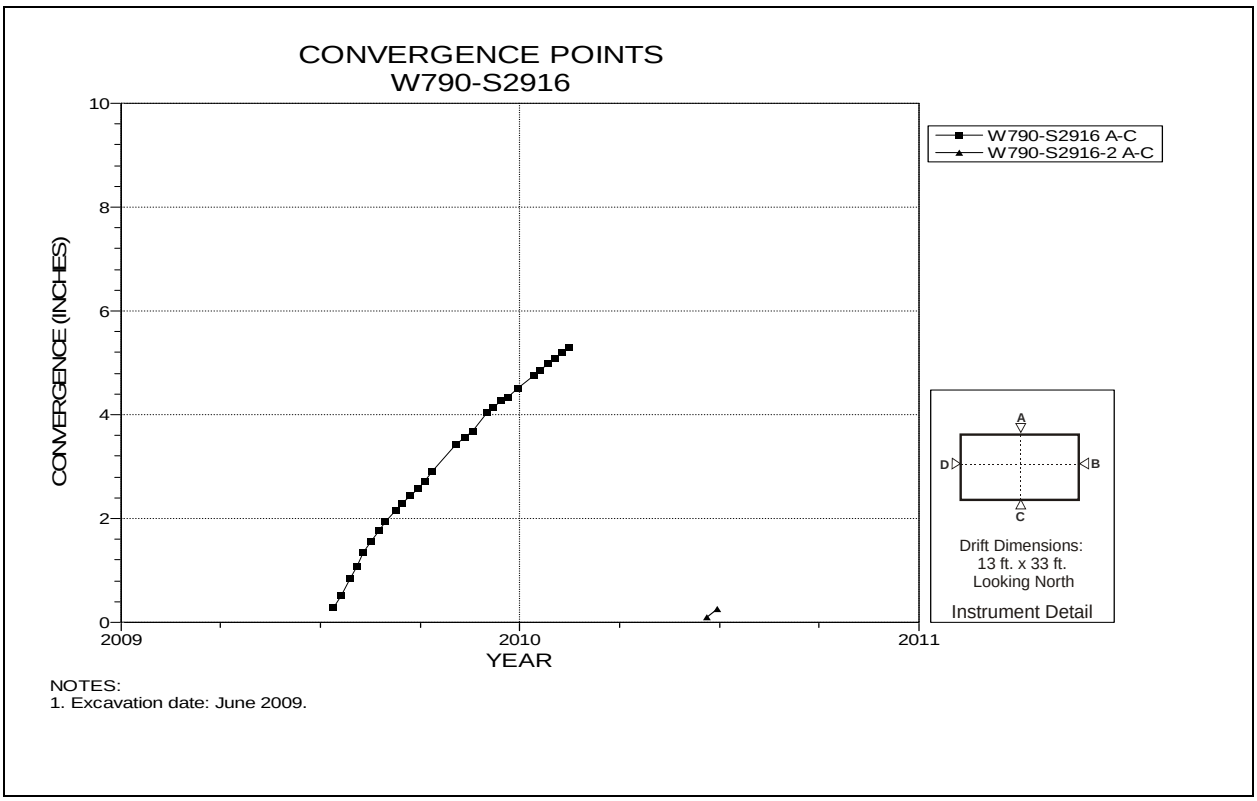


Figure 5-130 Convergence Point Array
Room 4, Panel 6 at W790 S2916– Room Center – Roof to Floor

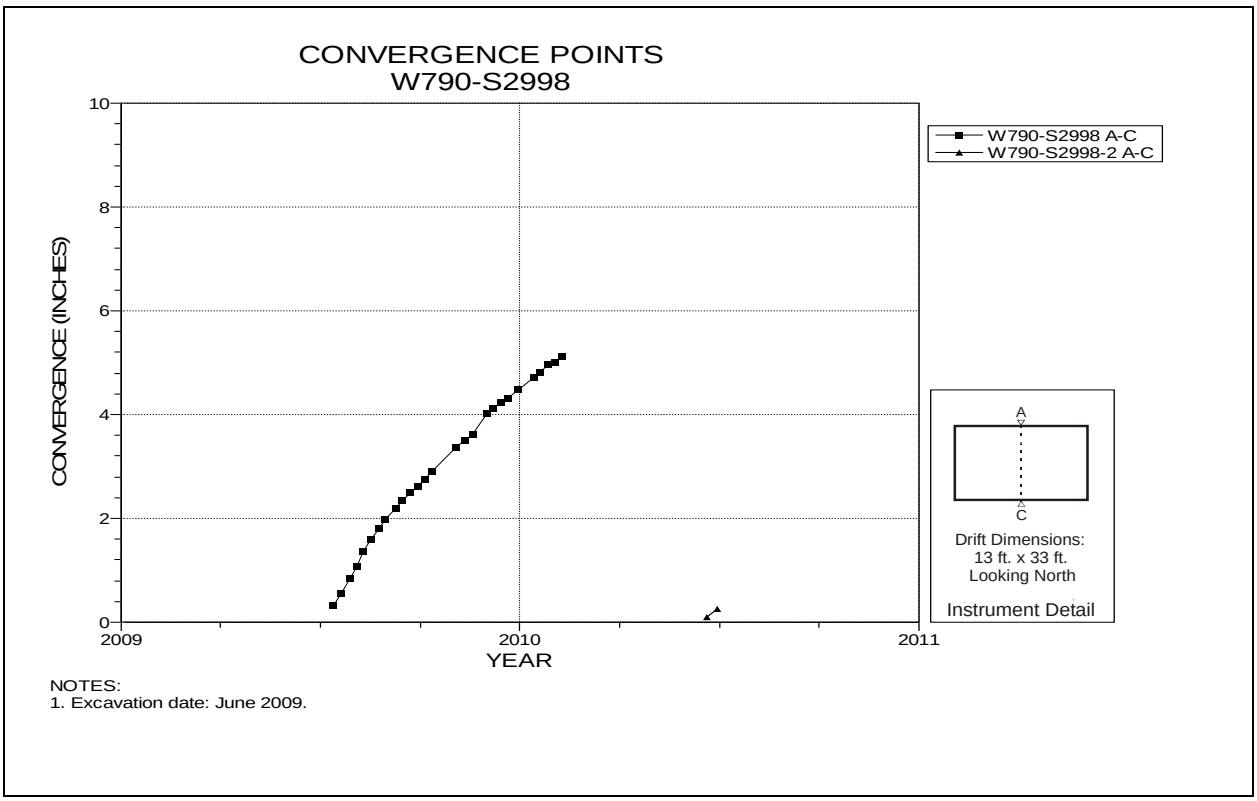


Figure 5-131 Convergence Point Array
Room 4, Panel 6 at W790 S2998 – Roof to Floor

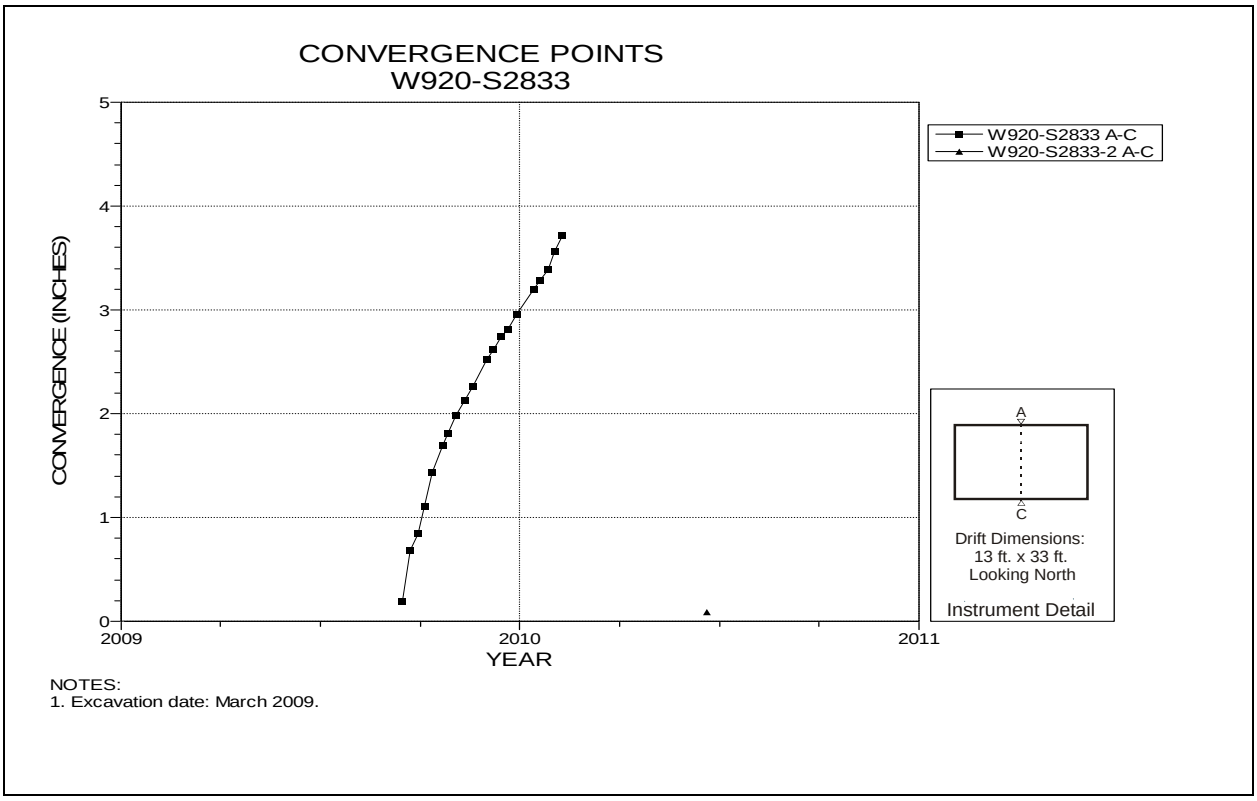


Figure 5-132 Convergence Point Array
Room 5, Panel 6 at W920 S2833 – Roof to Floor

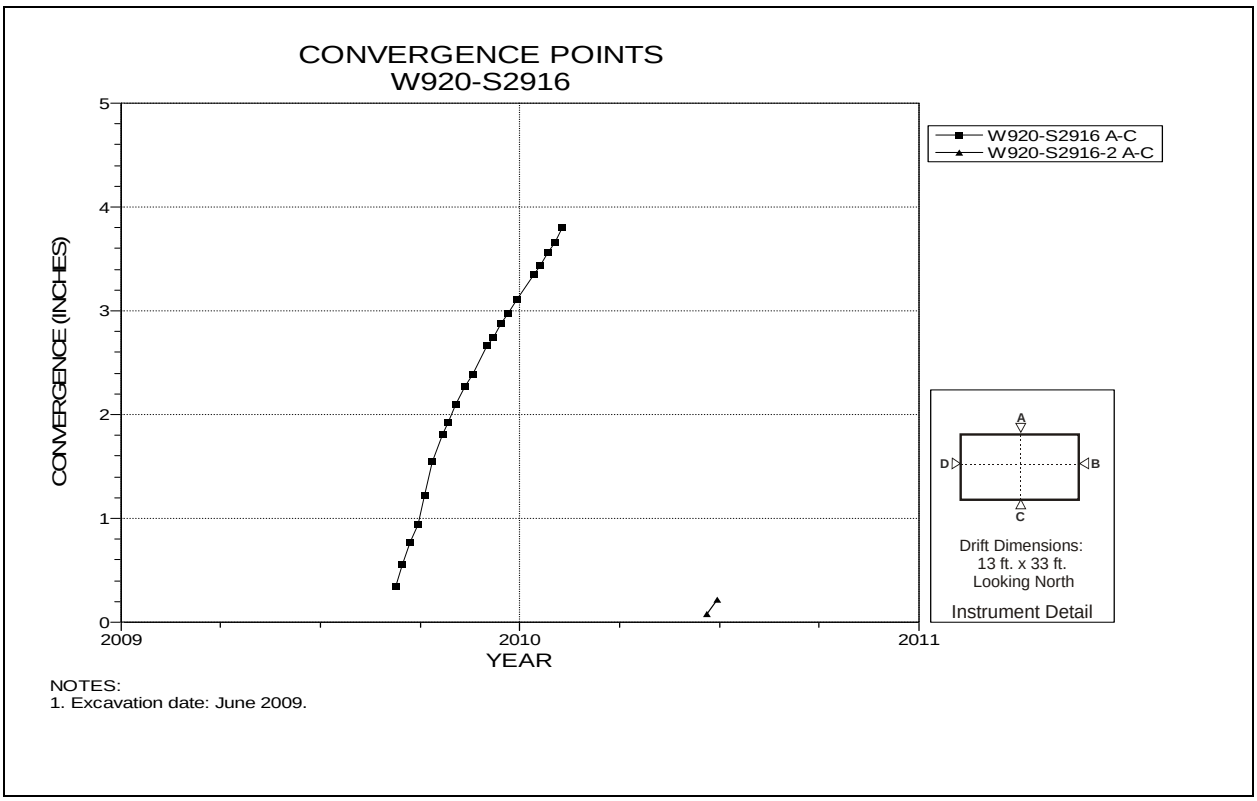


Figure 5-133 Convergence Point Array
Room 5, Panel 6 at W920 S2916– Room Center – Roof to Floor

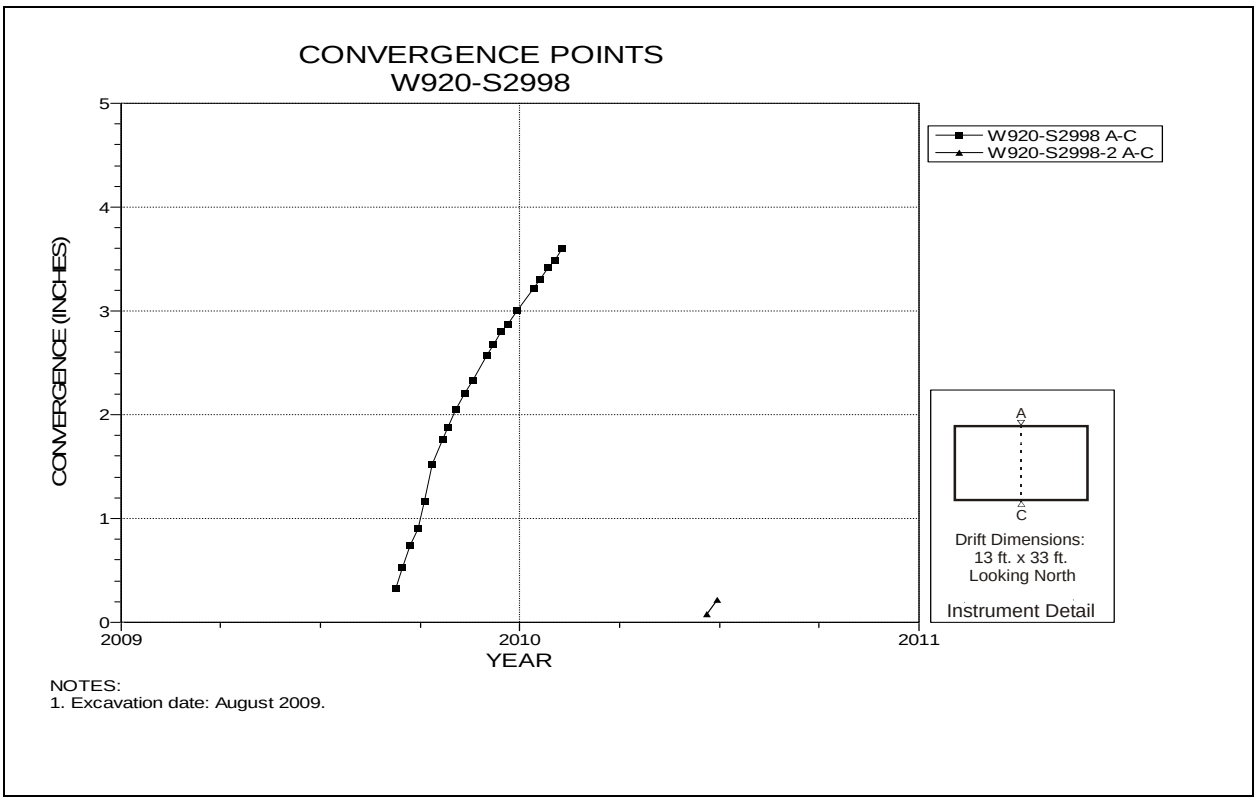


Figure 5-134 Convergence Point Array
Room 5, Panel 6 at W920 S2998 – Roof to Floor

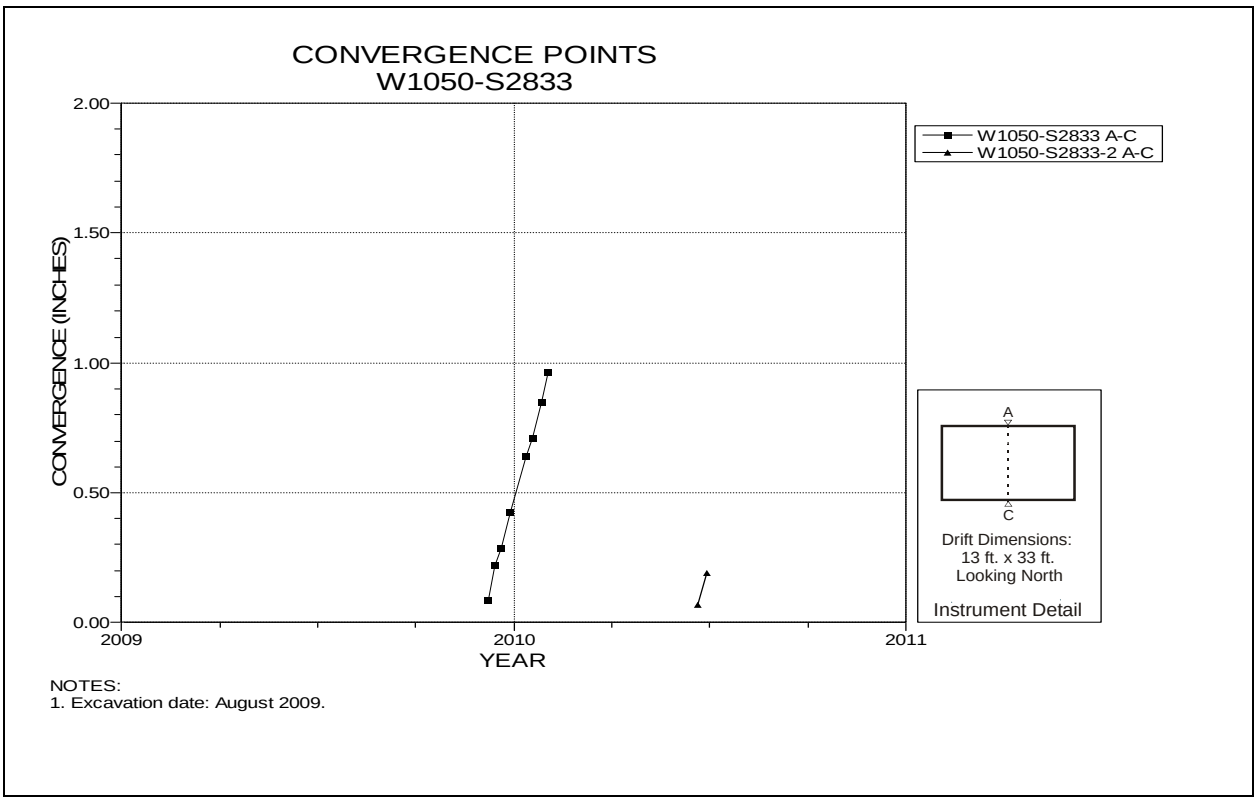


Figure 5-135 Convergence Point Array
Room 6, Panel 6 at W1050 S2833 – Roof to Floor

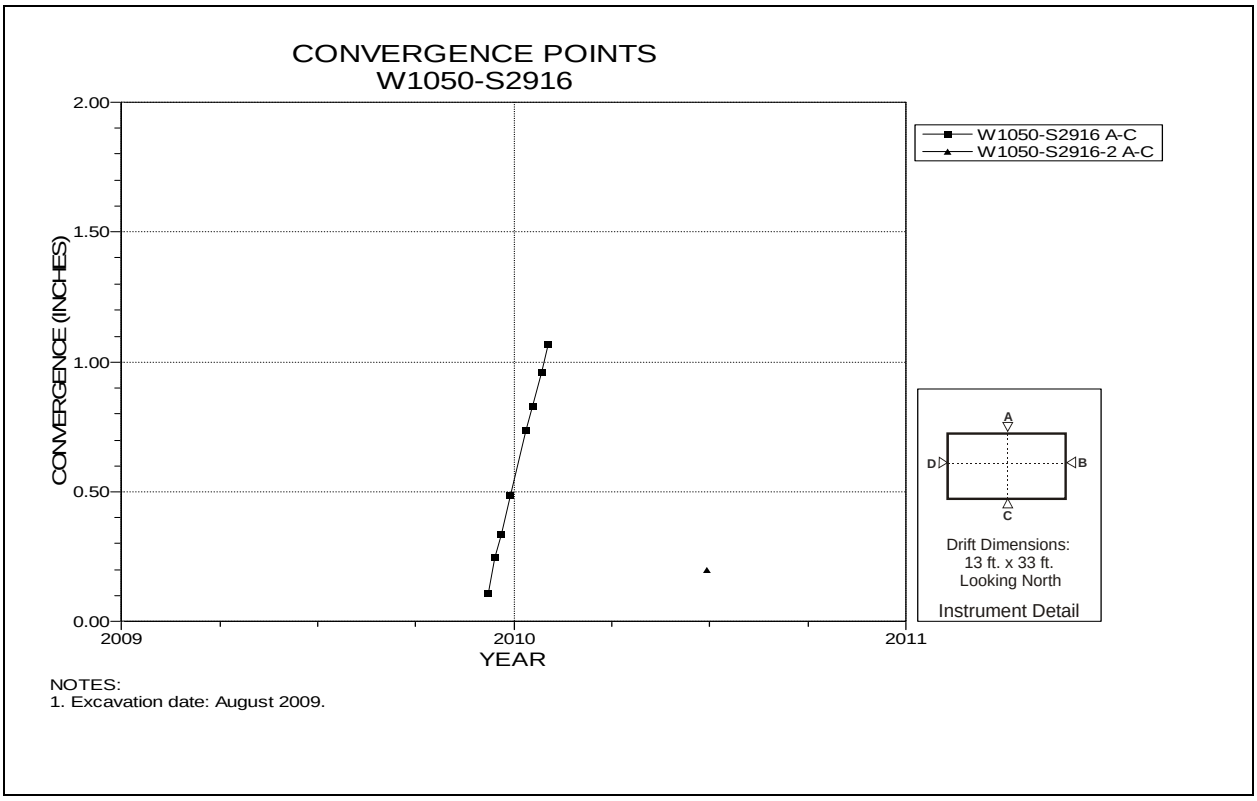


Figure 5-136 Convergence Point Array
Room 6, Panel 6 at W1050 S2916– Room Center – Roof to Floor

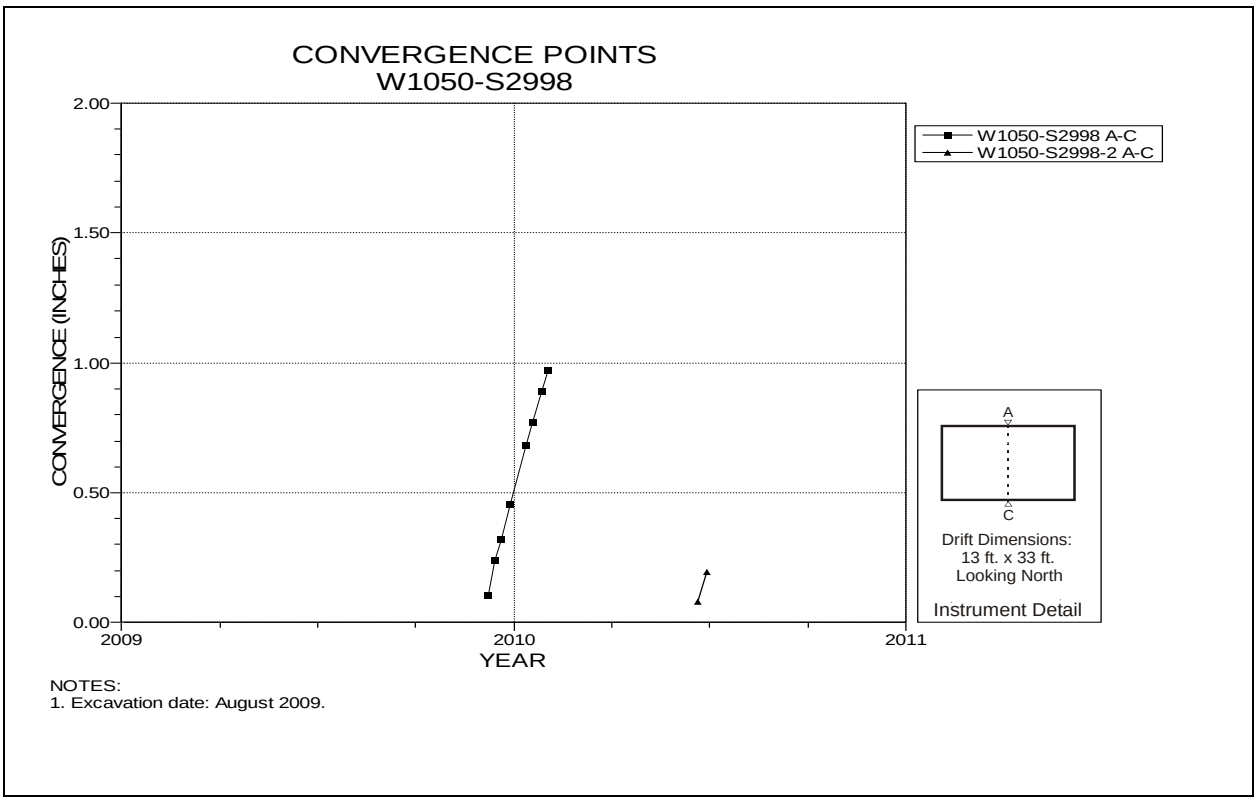


Figure 5-137 Convergence Point Array
Room 6, Panel 6 at W1050 S2998 – Roof to Floor

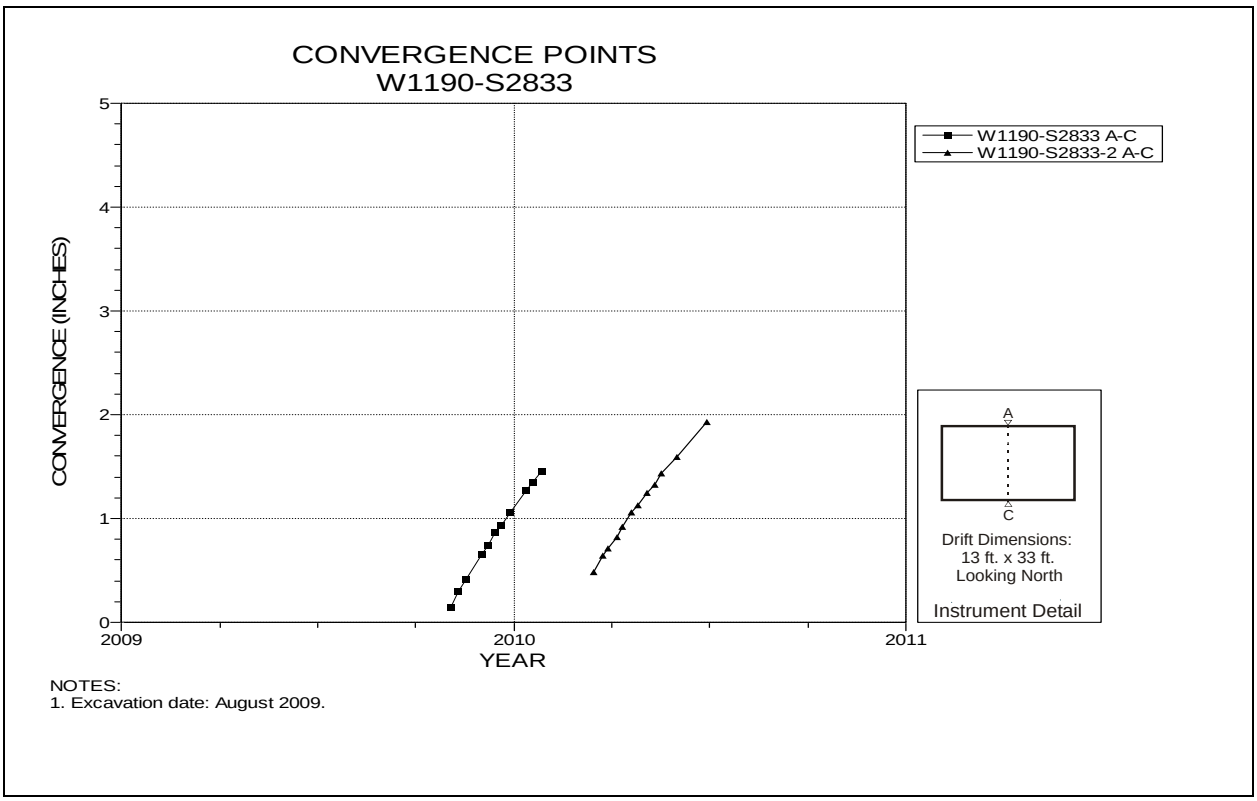


Figure 5-138 Convergence Point Array
Room 7, Panel 6 at W1190 S2833 – Roof to Floor

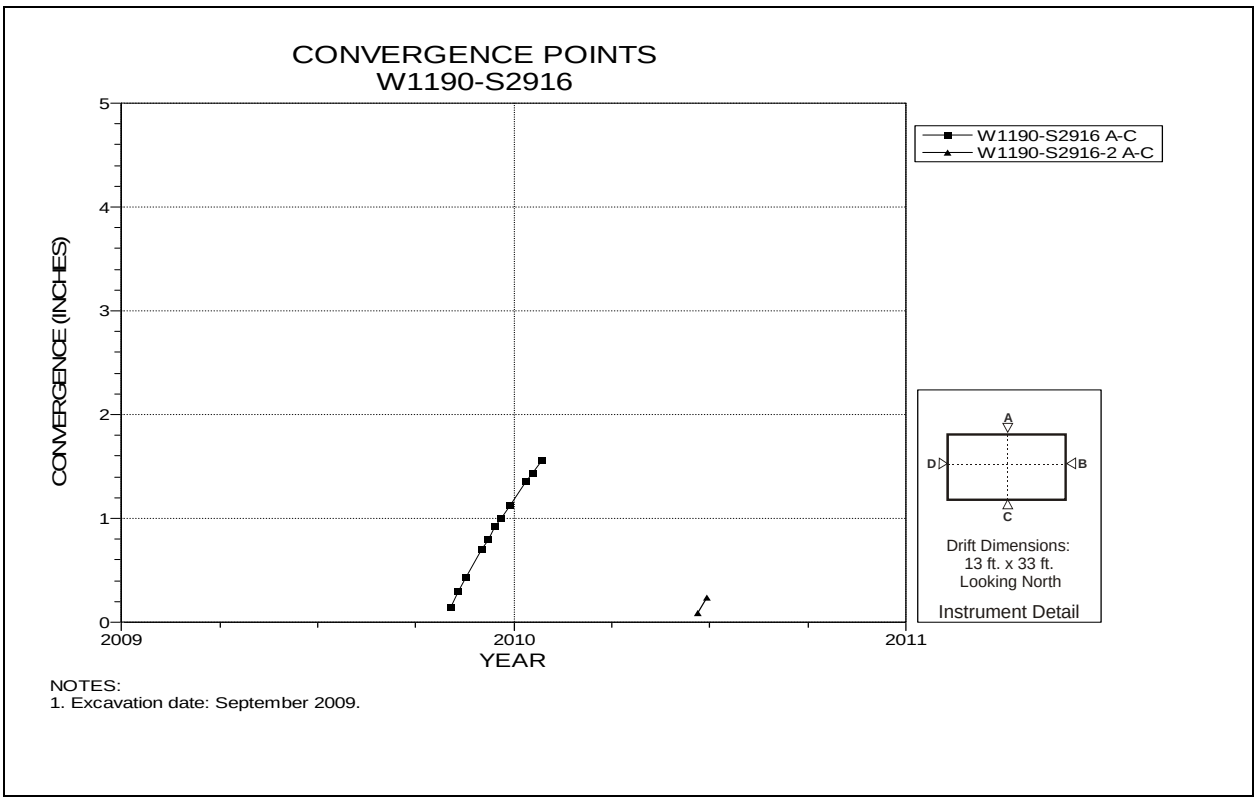


Figure 5-139 Convergence Point Array
Room 7, Panel 6 at W1190 S2916– Room Center – Roof to Floor

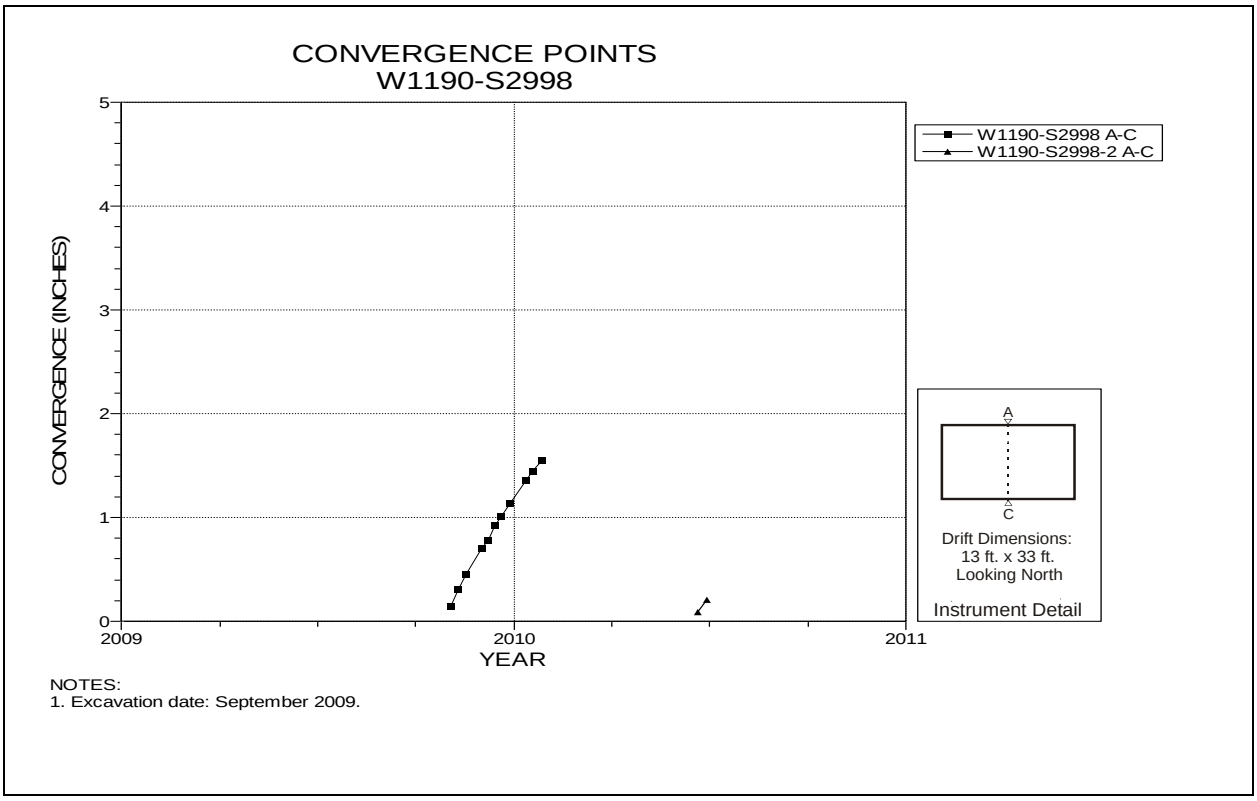


Figure 5-140 Convergence Point Array
Room 7, Panel 6 at W1190 S2998 – Roof to Floor

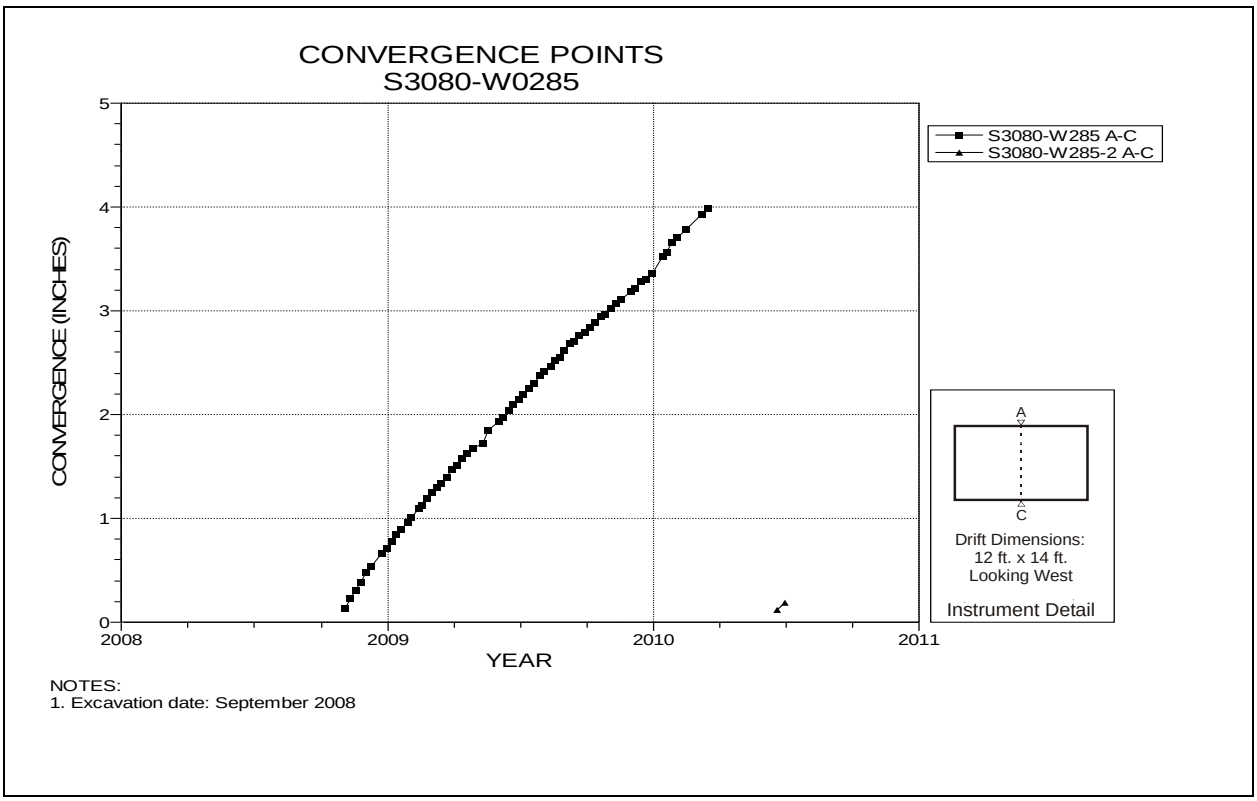


Figure 5-141 Convergence Point Array
S3080 W285 – Roof to Floor

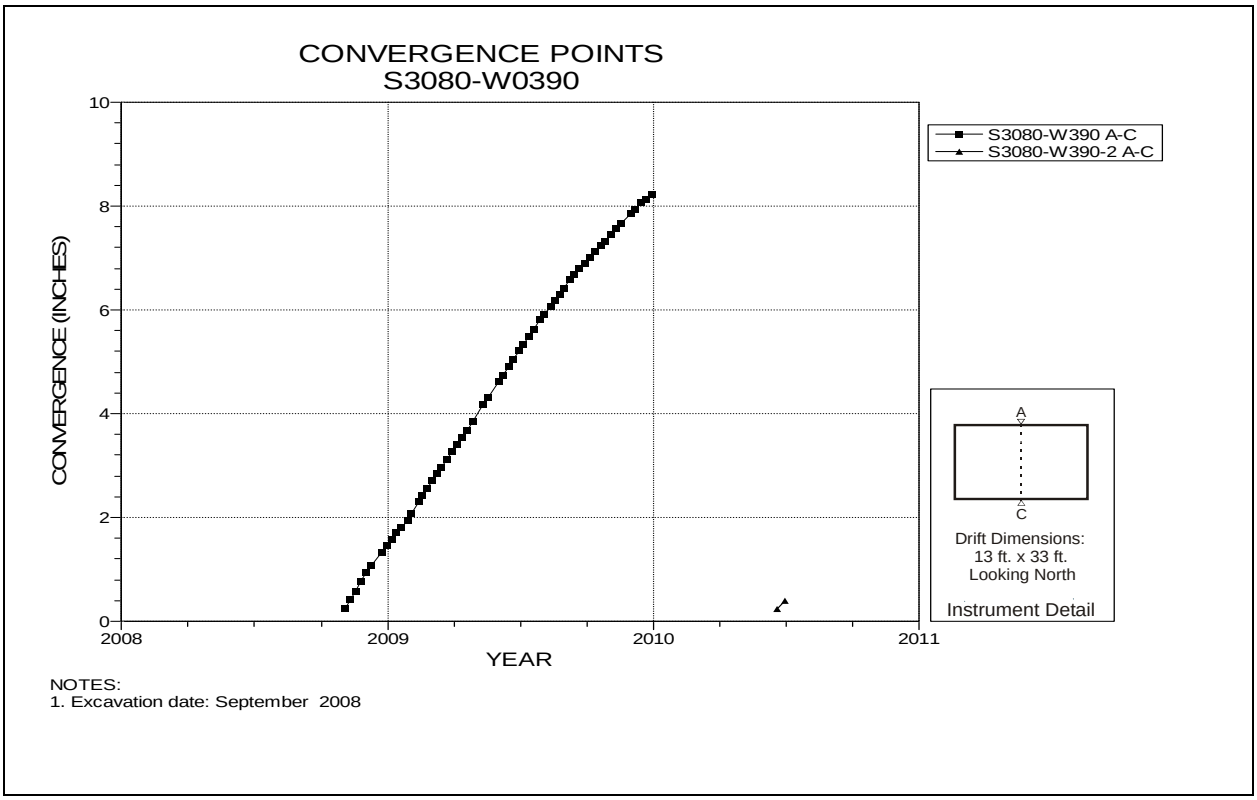


Figure 5-142 Convergence Point Array
S3080 W390 Intersection (Room 1, Panel 6) – Roof to Floor

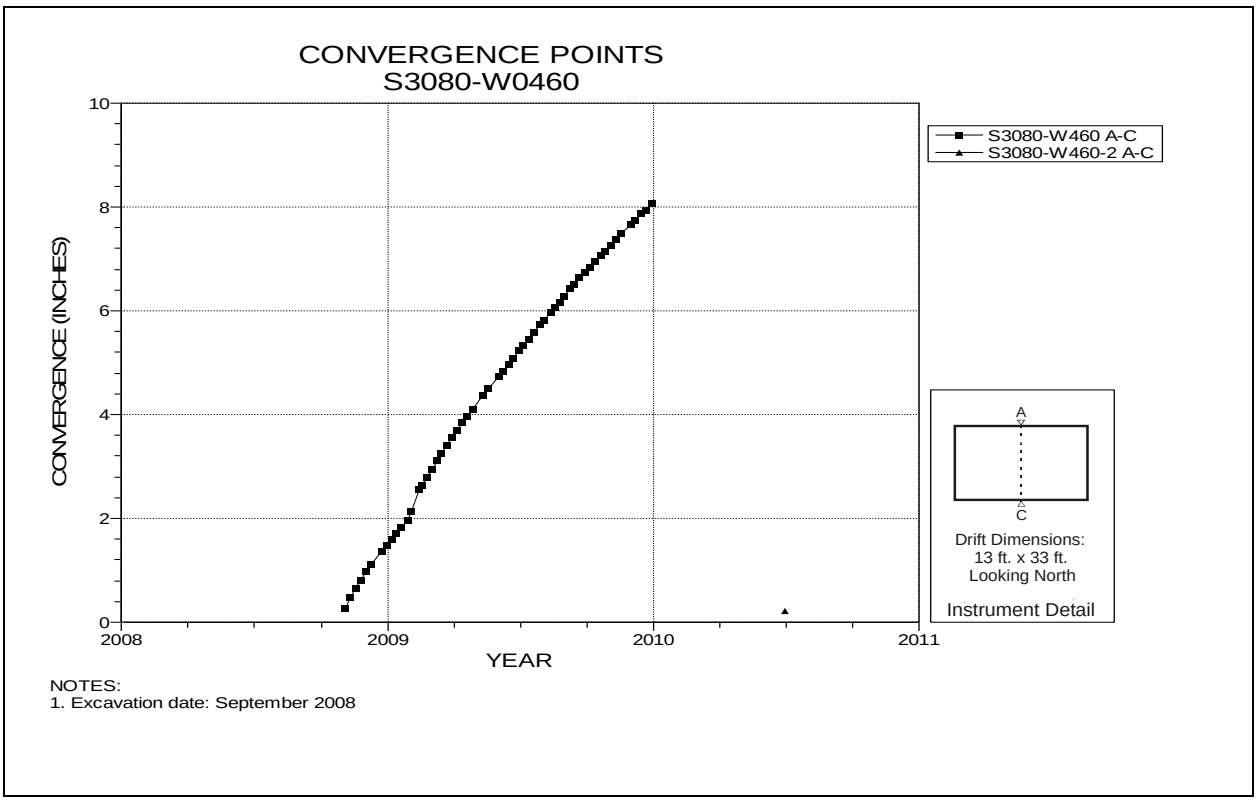


Figure 5-143 Convergence Point Array
S3080 W460 – Roof to Floor

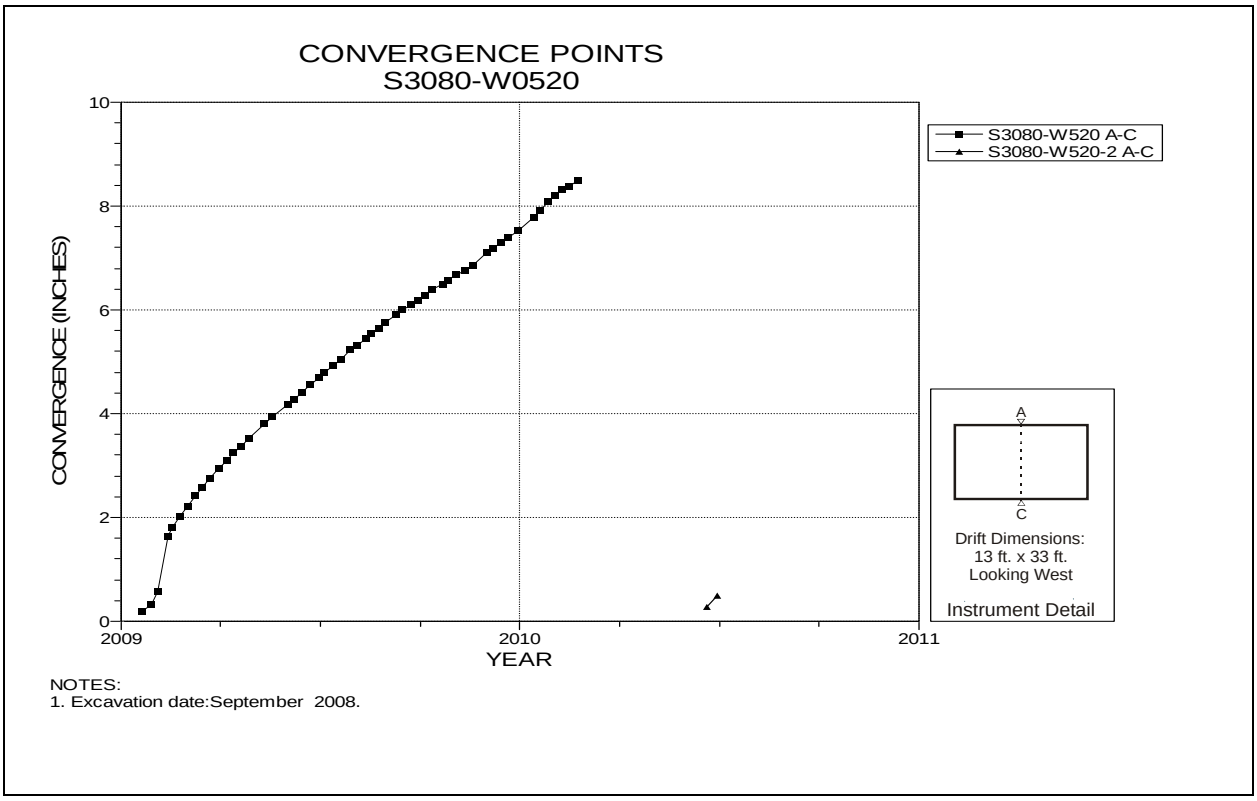


Figure 5-144 Convergence Point Array
S3080 W520 Intersection (Room 2, Panel 6)– Roof to Floor

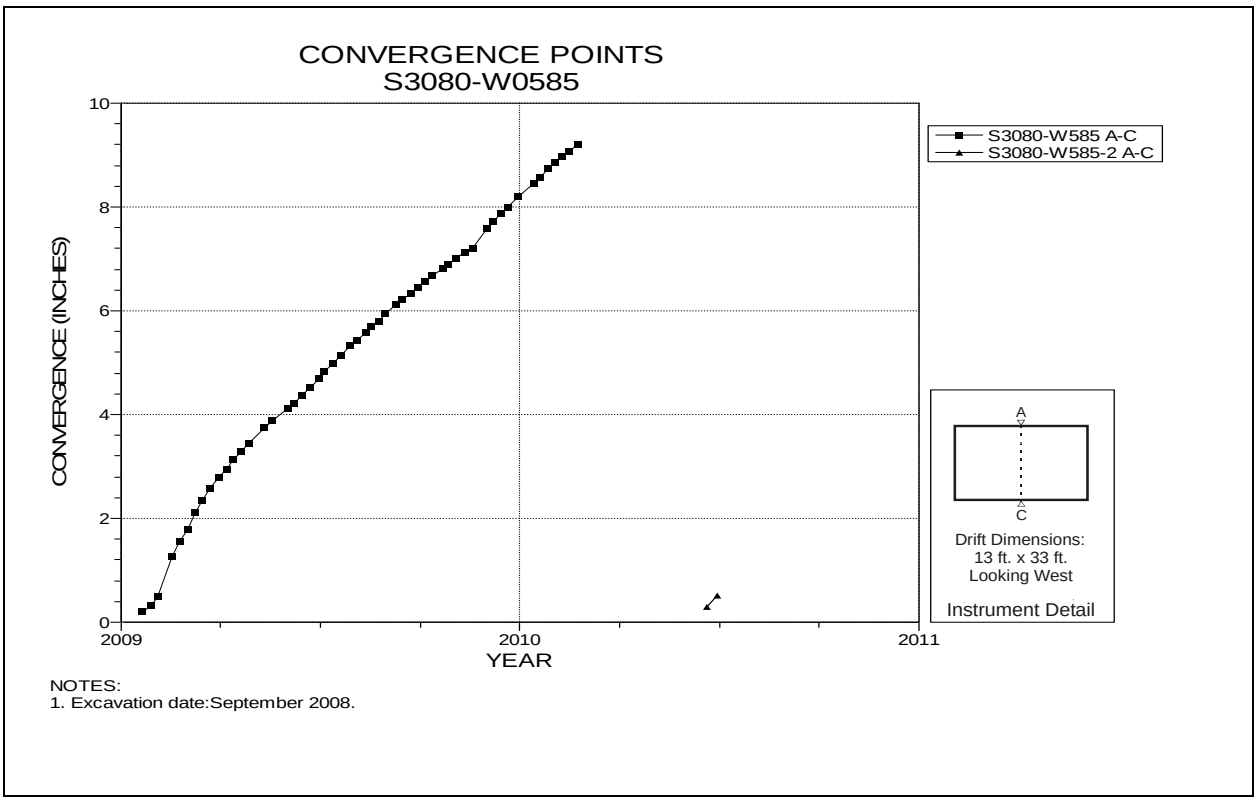


Figure 5-145 Convergence Point Array
S3080 W585 – Roof to Floor

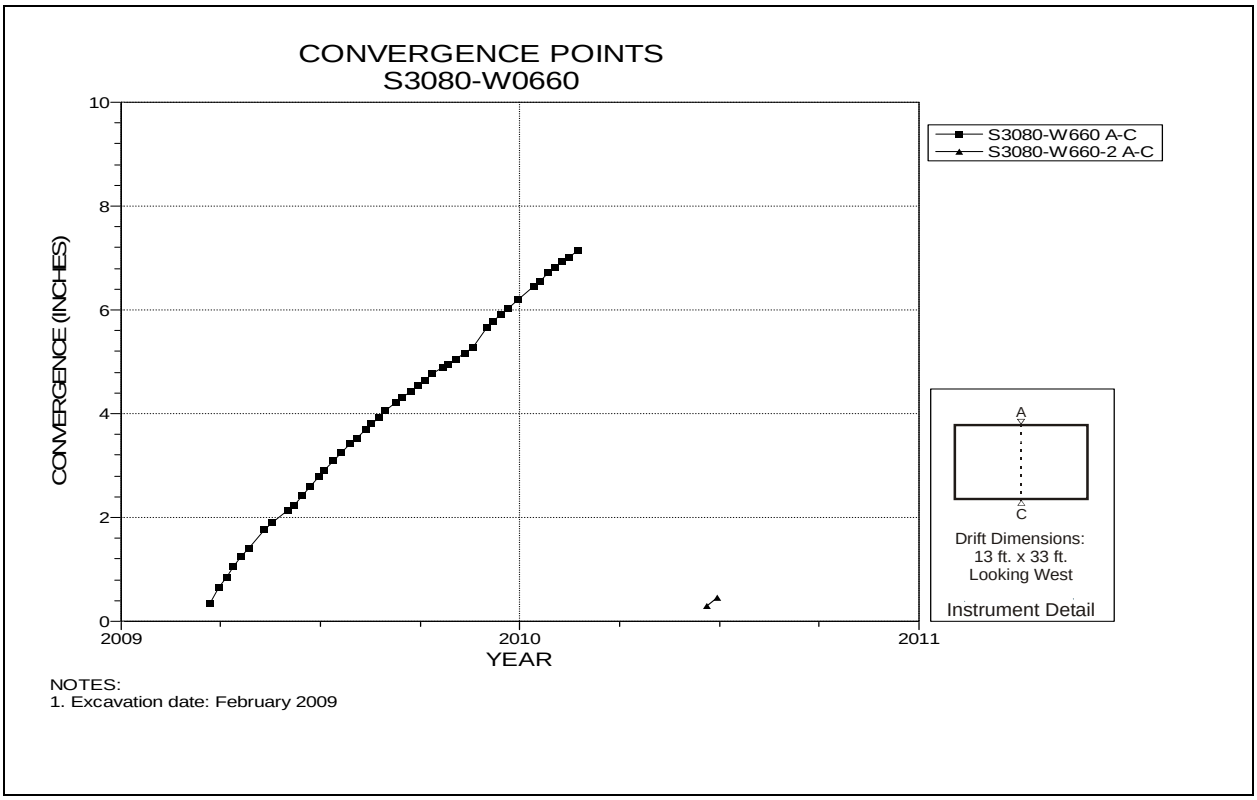


Figure 5-146 Convergence Point Array
S3080 W660 Intersection (Room 3, Panel 6) – Roof to Floor

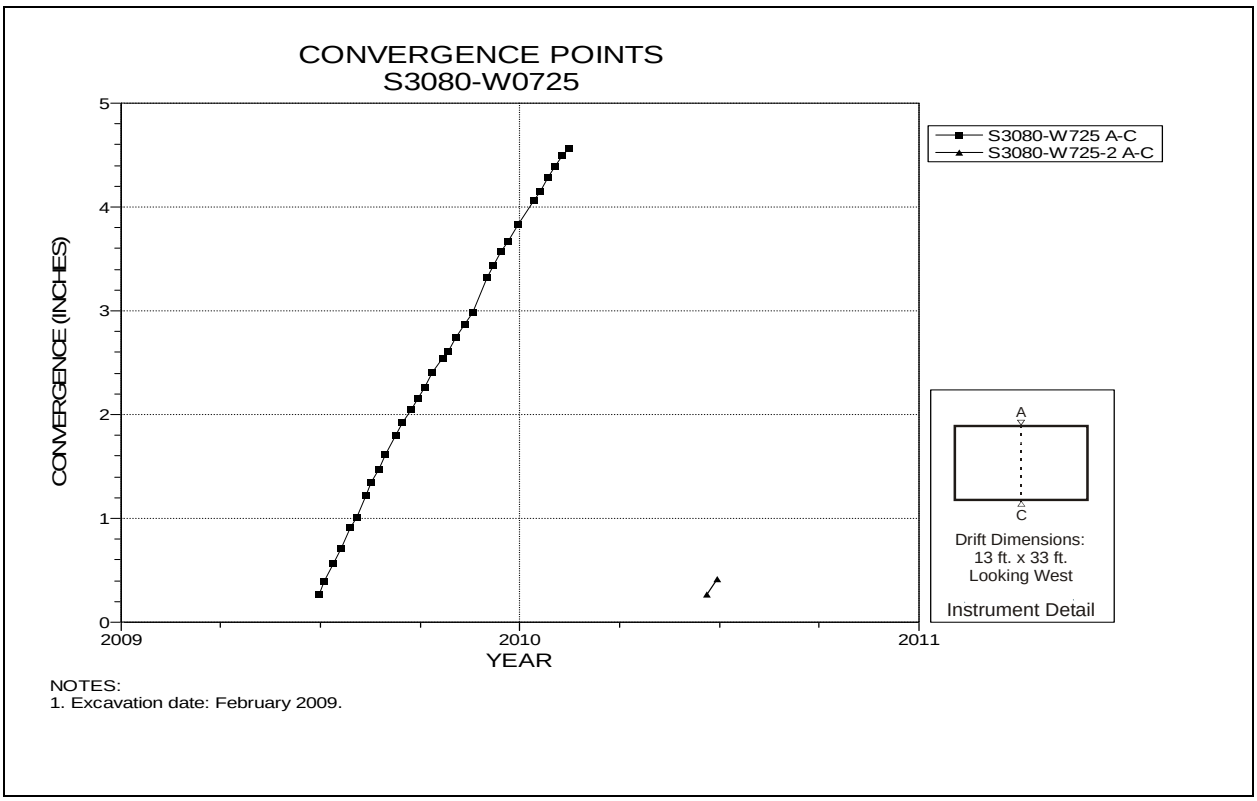


Figure 5-147 Convergence Point Array
S3080 W725 – Roof to Floor

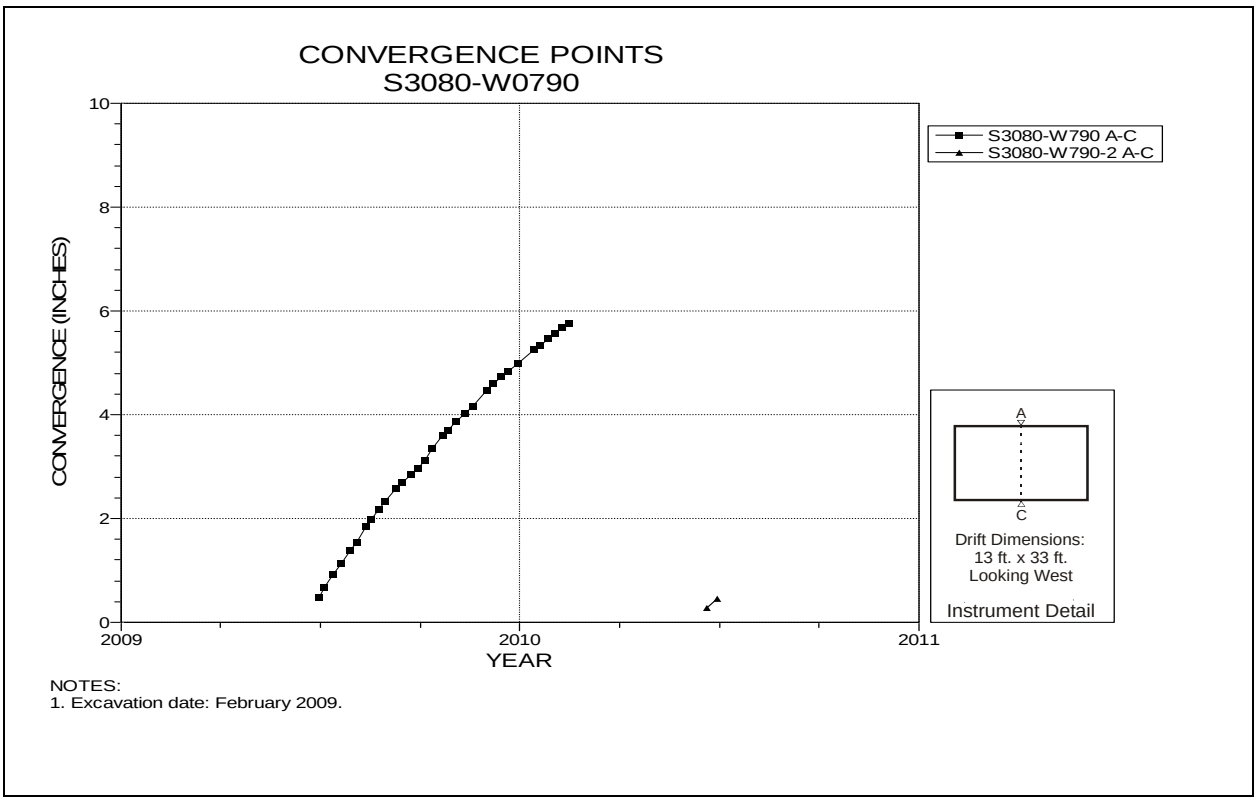


Figure 5-148 Convergence Point Array
S3080 W790 Intersection (Room 4, Panel 6) – Roof to Floor

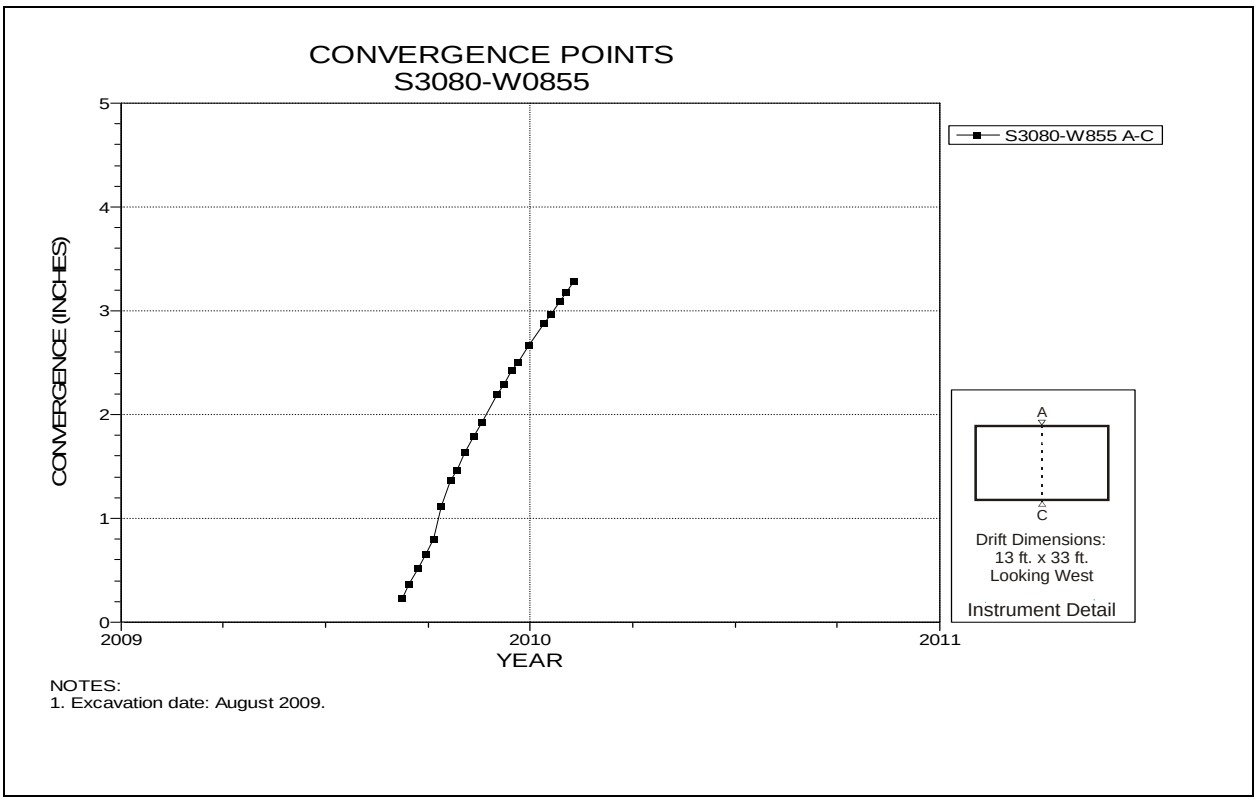


Figure 5-149 Convergence Point Array
S3080 W855 – Roof to Floor

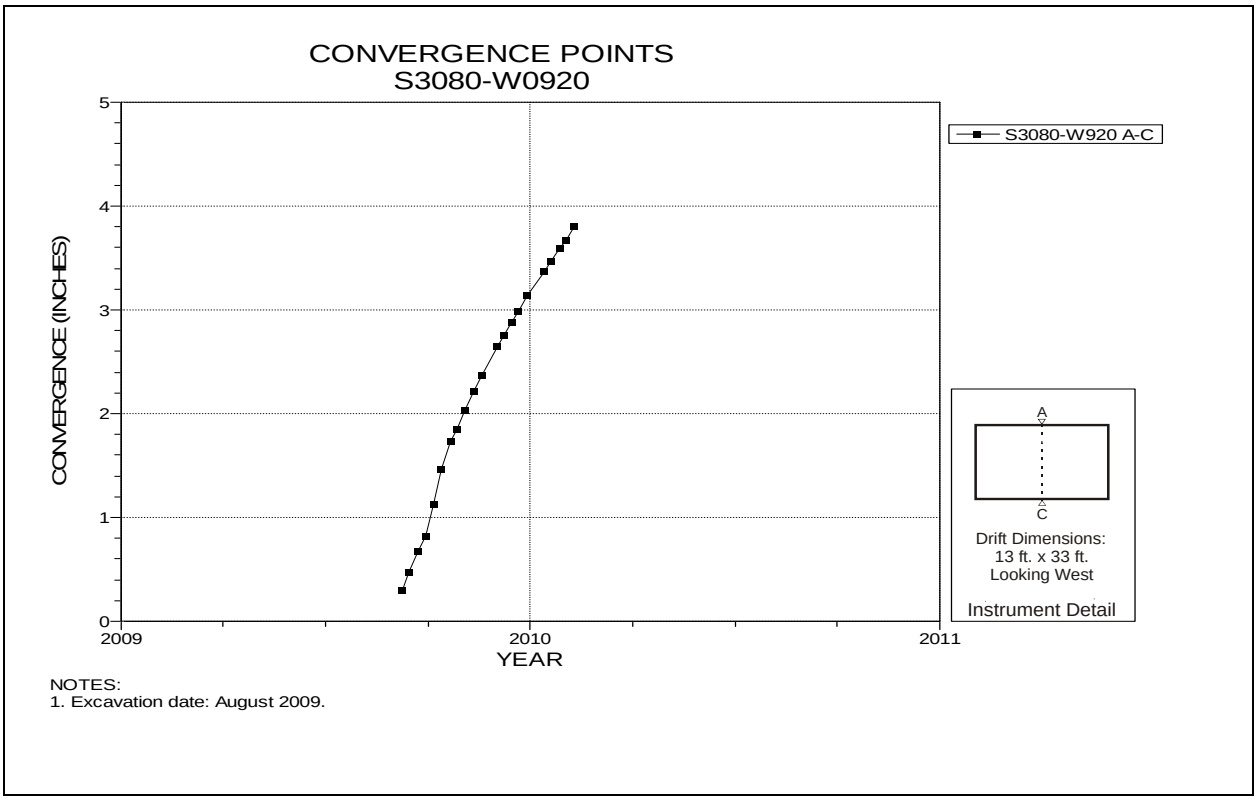


Figure 5-150 Convergence Point Array
S3080 W920 Intersection (Room 5, Panel 6) – Roof to Floor

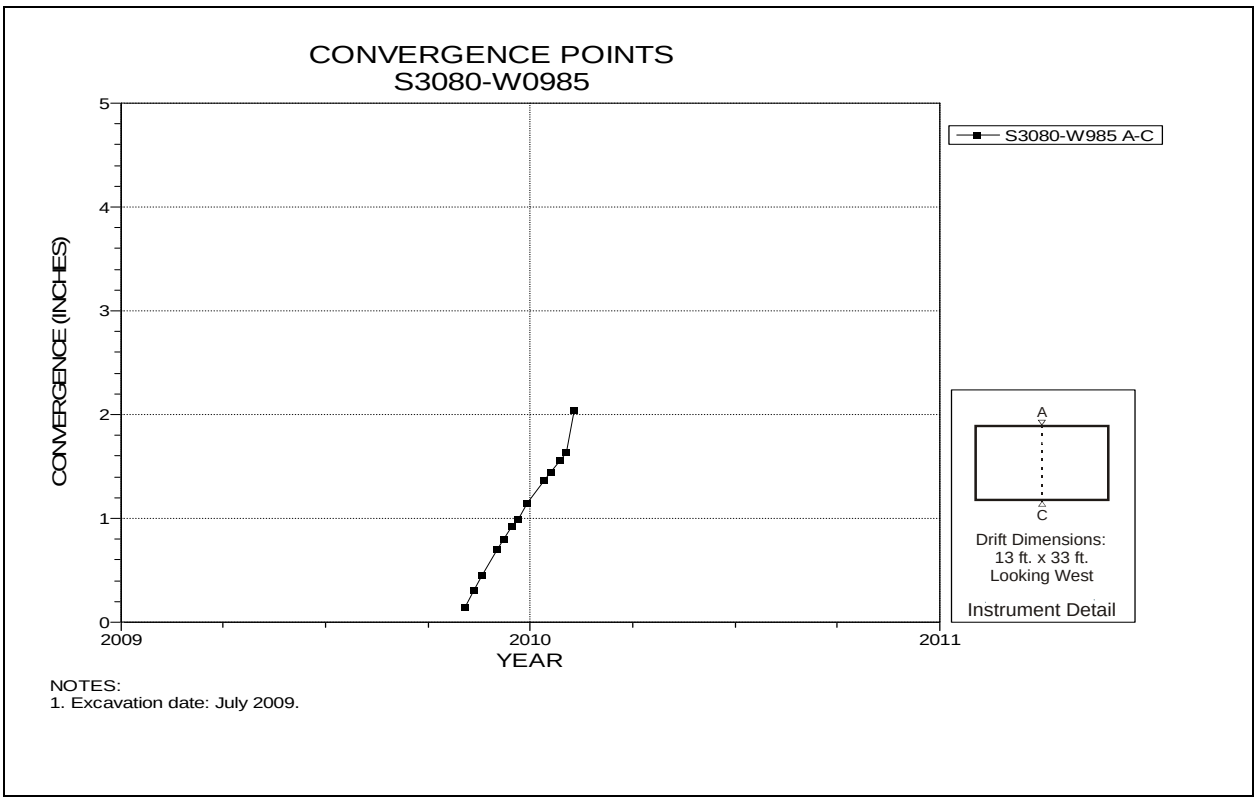


Figure 5-151 Convergence Point Array
S3080 W985 – Roof to Floor

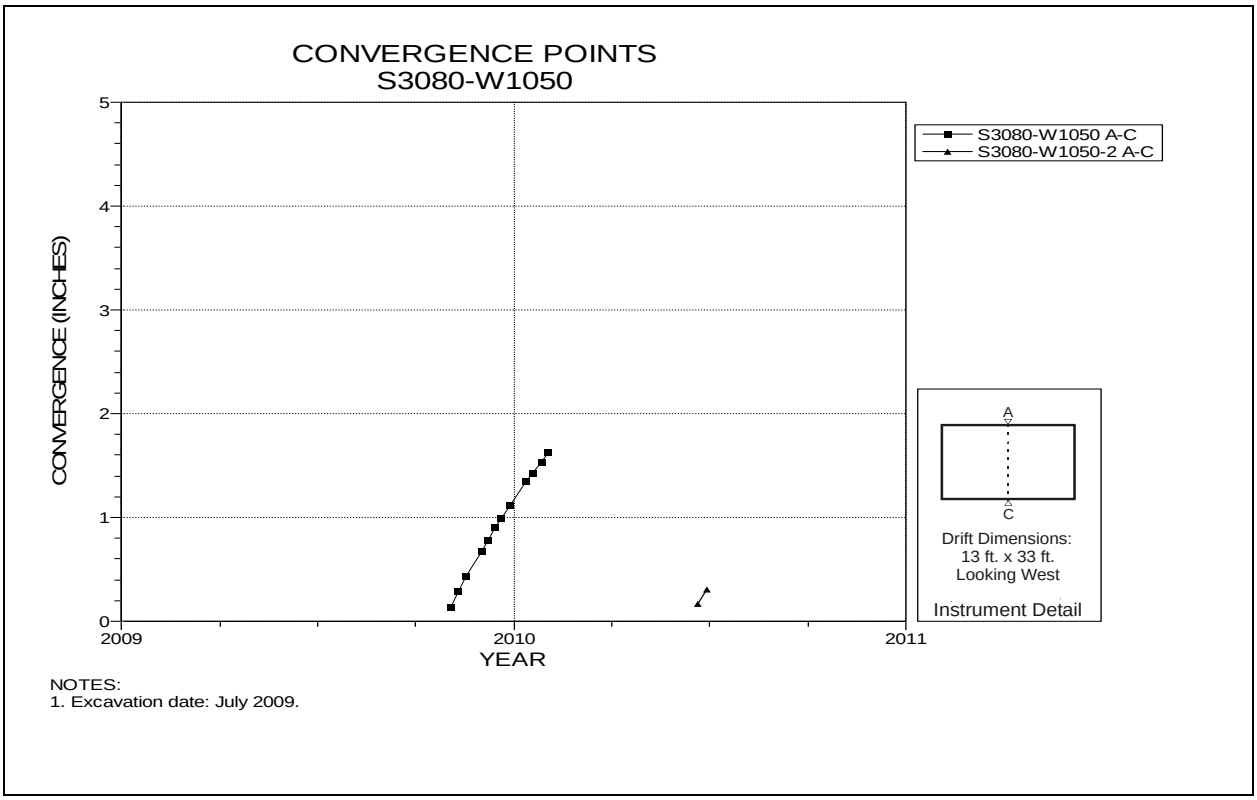


Figure 5-152 Convergence Point Array
S3080 W1050 Intersection (Room 6, Panel 6) – Roof to Floor

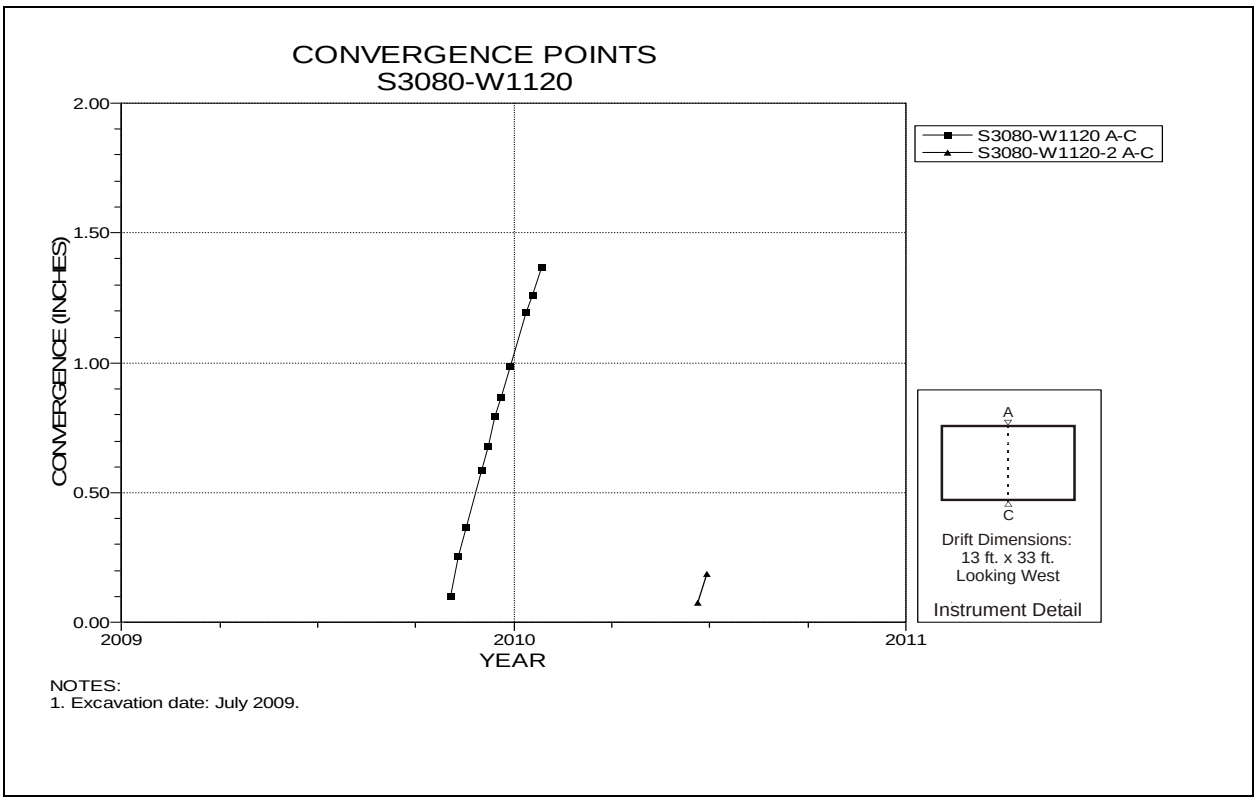


Figure 5-153 Convergence Point Array
S3080 W1120 – Roof to Floor

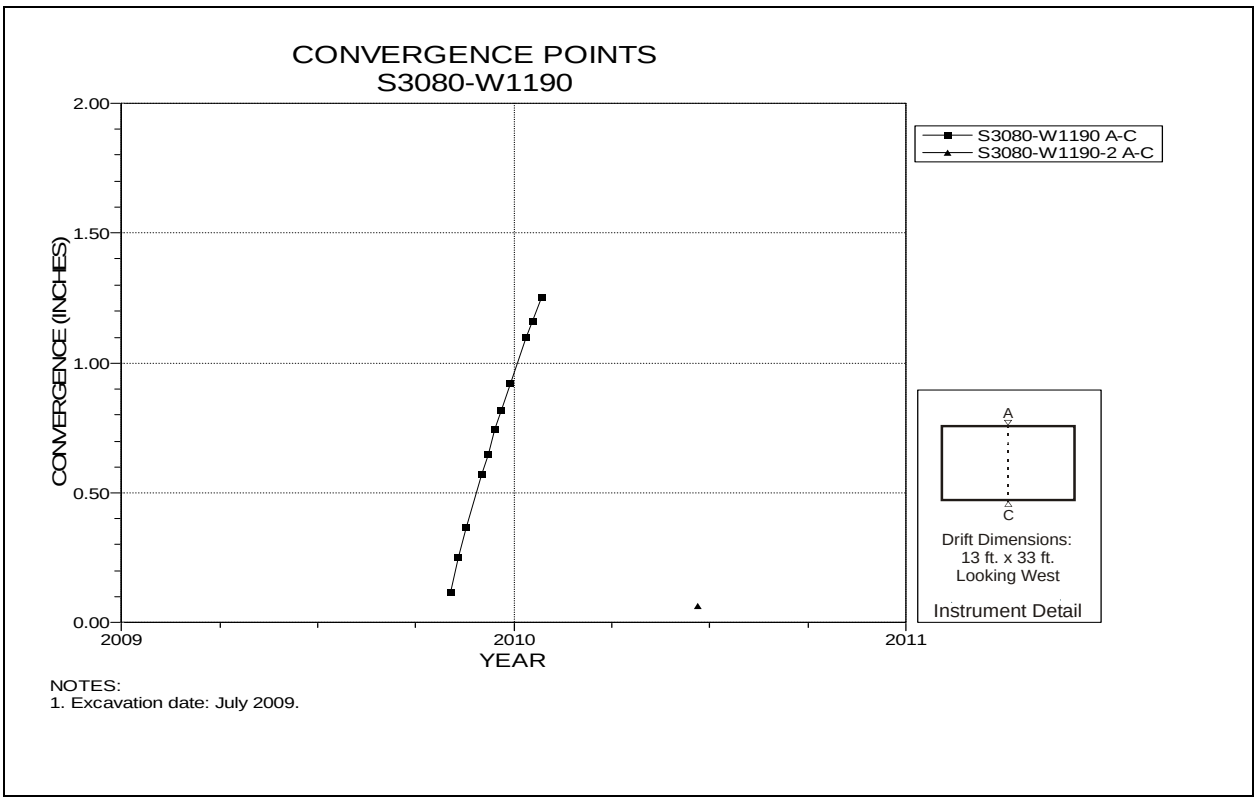


Figure 5-154 Convergence Point Array
S3080 W1190 Intersection (Room 7, Panel 6) – Roof to Floor

6.0 Geoscience Program Supporting Data

This chapter presents supporting data acquired as part of the Geoscience Program. It includes observations of clay seam displacements and other features in vertical observation holes, and fracture maps of excavation surfaces.

6.1 Borehole Inspections

This section presents a summary of the clay seam displacements (offsets) and fracture densities measured in observation boreholes located through the WIPP underground facility. Relative lateral displacement of rock strata above and below a clay layer is measured as offset within a borehole. Fracture density is a calculated parameter based on the number of fractures (separations) and fracture zones observed in an observation borehole. Fracture density is calculated to be the number of fractures plus twice the number of fracture zones in a roof beam divided by the thickness of the beam (in feet). Table 6-1 presents the observed offset data for boreholes, the observed fractures and fracture zones, and the calculated fracture densities. Table 6-2 is a summary of new boreholes drilled during this reporting period.

6.2 Fracture Mapping

This section presents graphical results of the fracture mapping done in Panels 5 and 6 of the Waste Disposal Area. Figures 6-1 through 6-61 are plan view fracture maps for the roof in these panels.

6.3 Stratigraphic Mapping

This section presents graphical results of stratigraphic mapping performed in Panel 6 of the Waste Disposal Area. Figures 6-62 through 6-70 are plan view stratigraphic maps for the North rib in S2750, the west rib in Rooms 1-7 and the south rib in S3080.

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH485	E140-N1400	1/7/2004	6/8/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH485		1/7/2004	6/8/2010	0		6.5	Separation	N/A	6.5	0.25	1.25	S	41.7	0.19
OH484	E140-N1265	1/7/2004	6/8/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH484		1/7/2004	6/8/2010	1		6.4	Separation	6.40	6.4	0.50	0.25	W	8.3	0.04
OH484		1/7/2004	6/8/2010				Separation		1.5	1.00	0.25	W	8.3	0.04
OH483	E140-N940	1/7/2004	6/8/2010				BOH		20.5	0.00	0.00		N/A	N/A
OH483		1/7/2004	6/8/2010	6		6.7	Separation	1.12	6.7	0.75	0.75	W	25.0	0.12
OH483		1/7/2004	6/8/2010				Separation		6.5	0.38	0.00		N/A	N/A
OH483		1/7/2004	6/8/2010				Separation		6.0	0.38	0.00		N/A	N/A
OH483		1/7/2004	6/8/2010				Separation		5.4	0.13	0.00		N/A	N/A
OH483		1/7/2004	6/8/2010				Separation		3.3	0.38	0.00		N/A	N/A
OH483		1/7/2004	6/8/2010				Separation		1.8	0.50	0.00		N/A	N/A
OH483		1/7/2004	6/8/2010				Separation		1.4	0.75	0.75	W	25.0	0.12
OH492	E140-N790	1/9/2004	6/8/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH492		1/9/2004	6/8/2010	0		6.6	Separation	N/A	6.6	0.50	0.00		N/A	N/A
OH521	E140-N90	6/5/2009	6/8/2010				BOH		20.2	0.00	0.00		N/A	N/A
OH521		6/5/2009	6/8/2010				Separation		8.4	0.38	0.00		N/A	N/A
OH521		6/5/2009	6/8/2010				Separation		8.0	0.25	0.00		N/A	N/A
OH521		6/5/2009	6/8/2010				Separation		7.4	0.25	0.00		N/A	N/A
OH521		6/5/2009	6/8/2010	0		7.1	Separation	N/A	7.1	0.25	0.00		N/A	N/A
OH523	E140-S164	11/22/2004	6/8/2010				Separation		20.3	0.00	0.00		N/A	N/A
OH523		11/22/2004	6/8/2010				Hangup		9.4	0.00	0.00		N/A	N/A
OH523		11/22/2004	6/8/2010				Hangup		8.4	0.00	0.00		N/A	N/A
OH523		11/22/2004	6/8/2010	0		7.4	Separation	N/A	7.4	2.00	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH498-1	E140-S415	3/2/2009	6/8/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH498-1		3/2/2009	6/8/2010	4		5.8	Separation	1.45	5.8	1.00	0.00		N/A	N/A
OH498-1		3/2/2009	6/8/2010				Separation		3.8	1.50	0.75	E	25.0	0.59
OH498-1		3/2/2009	6/8/2010				Separation		2.8	1.50	0.00		N/A	N/A
OH498-1		3/2/2009	6/8/2010				Separation		2.0	0.13	0.00		N/A	N/A
OH498-1		3/2/2009	6/8/2010				Separation		1.7	0.25	0.00		N/A	N/A
OH499-1	E140-S520	3/2/2009	6/8/2010				BOH		20.2	0.00	0.00		N/A	N/A
OH499-1		3/2/2009	6/8/2010	2		6.2	Separation	3.10	6.2	1.00	0.00		N/A	N/A
OH499-1		3/2/2009	6/8/2010				Separation		5.5	0.13	0.00		N/A	N/A
OH499-1		3/2/2009	6/8/2010				Separation		4.4	0.25	0.00		N/A	N/A
OH620	E140-S700	11/17/2005	6/7/2010				BOH		16.6	0.00	0.00		N/A	N/A
OH620		11/17/2005	6/7/2010	2		8.0	Separation	4.00	5.8	0.13	0.00		N/A	N/A
OH620		11/17/2005	6/7/2010				Separation		5.7	0.13	0.00		N/A	N/A
OH620		11/17/2005	6/7/2010				Rough Spot		4.3	0.00	0.00		N/A	N/A
OH874	E140-S850	3/2/2009	6/7/2010				BOH		20.1	0.00	0.00		N/A	N/A
OH874		3/2/2009	6/7/2010	3		7.2	Separation	2.40	7.2	0.13	0.00		N/A	N/A
OH874		3/2/2009	6/7/2010				Separation		4.8	0.13	0.00		N/A	N/A
OH874		3/2/2009	6/7/2010				Separation		4.0	0.13	0.75	W	25.0	0.59
OH874		3/2/2009	6/7/2010				Separation		3.7	0.13	0.00		N/A	N/A
OH575	E140-S1000	6/16/2005	6/7/2010				BOH		4.3	0.00	3.00		N/A	N/A
OH575		6/16/2005	6/7/2010				Separation		4.1	1.25	0.00		N/A	N/A
OH575		6/16/2005	6/7/2010				Separation		3.5	0.13	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH873	E140-S1145	3/2/2009	6/7/2010				BOH		21.1	0.00	0.00		N/A	N/A
OH873		3/2/2009	6/7/2010				Separation		6.4	0.25	0.75	E	25.0	0.59
OH873		3/2/2009	6/7/2010				Separation		6.0	0.13	0.25	E	8.3	0.20
OH873		3/2/2009	6/7/2010	6		5.2	Separation	0.87	5.2	0.50	0.00		N/A	N/A
OH873		3/2/2009	6/7/2010				Separation		5.0	0.13	0.00		N/A	N/A
OH873		3/2/2009	6/7/2010				Separation		3.7	2.00	0.00		N/A	N/A
OH873		3/2/2009	6/7/2010				Separation		3.0	0.25	0.00		N/A	N/A
OH873		3/2/2009	6/7/2010				Separation		2.5	1.00	0.00		N/A	N/A
OH873		3/2/2009	6/7/2010				Separation		1.6	0.19	0.00		N/A	N/A
OH873		3/2/2009	6/7/2010				Separation		1.1	0.13	0.00		N/A	N/A
OH578	E140-S1300	6/16/2005	6/7/2010				BOH		20.2	0.00	0.00		N/A	N/A
OH578		6/16/2005	6/7/2010	0		6.6	Separation	N/A	6.6	0.13	0.00		N/A	N/A
OH578		6/16/2005	6/7/2010				Rough Spot		0.5	0.00	0.00		N/A	N/A
OH872	E140-S1390	3/2/2009	6/7/2010				BOH		21.0	0.00	0.00		N/A	N/A
OH872		3/2/2009	6/7/2010	2		6.8	Separation	3.40	6.8	0.13	0.19	W	6.3	0.15
OH872		3/2/2009	6/7/2010				Separation		3.0	0.13	0.07	W	2.3	0.05
OH872		3/2/2009	6/7/2010				Separation		1.4	0.25	0.13	W	4.2	0.10
OH580-1	E140-S1463	3/2/2009	6/7/2010				BOH		20.1	0.00	0.00		N/A	N/A
OH580-1		3/2/2009	6/7/2010				Separation		6.9	0.13	0.25	W	8.3	0.20
OH580-1		3/2/2009	6/7/2010				Separation		6.2	1.00	0.13	W	4.2	0.10
OH580-1		3/2/2009	6/7/2010	5		4.7	Separation	0.94	4.7	4.00	0.00		N/A	N/A
OH580-1		3/2/2009	6/7/2010				Separation		4.3	2.00	0.00		N/A	N/A
OH580-1		3/2/2009	6/7/2010				Separation		2.5	2.00	0.13	W	4.2	0.10
OH580-1		3/2/2009	6/7/2010				Separation		1.6	0.50	0.00		N/A	N/A
OH580-1		3/2/2009	6/7/2010				Separation		1.0	0.13	0.00		N/A	N/A
OH580-1		3/2/2009	6/7/2010				Separation		0.8	0.50	0.13	W	4.2	0.10

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH582	E140-S1600	6/16/2005	6/7/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH582		6/16/2005	6/7/2010	0		6.2	Separation	N/A	6.2	0.25	0.25	S	8.3	0.05
OH871	E140-S1680	3/2/2009	6/7/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH871		3/2/2009	6/7/2010				Separation		6.4	0.13	0.00		N/A	N/A
OH871		3/2/2009	6/7/2010				Separation		6.3	0.13	1.25	W	41.7	0.99
OH871		3/2/2009	6/7/2010				Separation		6.2	0.13	1.00	W	33.3	0.79
OH871		3/2/2009	6/7/2010	3		5.3	Separation	1.77	5.3	2.50	0.00		N/A	N/A
OH871		3/2/2009	6/7/2010				Separation		2.7	0.75	0.00		N/A	N/A
OH871		3/2/2009	6/7/2010				Separation		1.7	0.13	0.00		N/A	N/A
OH871		3/2/2009	6/7/2010				Separation		1.1	0.13	0.00		N/A	N/A
OH143-3	E140-S1782	3/2/2009	6/7/2010				BOH		20.6	0.00	0.00		N/A	N/A
OH143-3		3/2/2009	6/7/2010				Separation		7.1	1.00	1.50	W	50.0	1.19
OH143-3		3/2/2009	6/7/2010	6		6.4	Separation	1.07	6.4	6.00	0.00		N/A	N/A
OH143-3		3/2/2009	6/7/2010				Separation		6.1	0.25	0.00		N/A	N/A
OH143-3		3/2/2009	6/7/2010				Separation		5.2	2.00	0.00		N/A	N/A
OH143-3		3/2/2009	6/7/2010				Separation		4.0	3.00	0.00		N/A	N/A
OH143-3		3/2/2009	6/7/2010				Separation		2.6	3.00	0.07	W	2.3	0.05
OH143-3		3/2/2009	6/7/2010				Separation		1.6	0.50	0.07	W	2.3	0.05
OH143-3		3/2/2009	6/7/2010				Separation		1.1	0.13	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH146-3	E140-S1832	3/2/2009	6/7/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH146-3		3/2/2009	6/7/2010				Separation		8.0	0.13	0.00		N/A	N/A
OH146-3		3/2/2009	6/7/2010	8		6.6	Separation	0.83	6.6	5.00	2.00	W	66.7	1.58
OH146-3		3/2/2009	6/7/2010				Separation		6.3	0.13	0.00		N/A	N/A
OH146-3		3/2/2009	6/7/2010				Separation		6.1	0.13	0.00		N/A	N/A
OH146-3		3/2/2009	6/7/2010				Separation		4.8	6.00	0.00		N/A	N/A
OH146-3		3/2/2009	6/7/2010				Separation		4.2	0.25	0.00		N/A	N/A
OH146-3		3/2/2009	6/7/2010				Separation		3.8	2.50	0.13	W	4.2	0.10
OH146-3		3/2/2009	6/7/2010				Separation		2.3	4.00	0.19	W	6.3	0.15
OH146-3		3/2/2009	6/7/2010				Separation		1.4	0.50	0.19	W	6.3	0.15
OH146-3		3/2/2009	6/7/2010				Separation		0.7	0.13	0.00		N/A	N/A
OH583	E140-S1950	6/16/2005	6/7/2010				BOH		20.6	0.00	0.00		N/A	N/A
OH583		6/16/2005	6/7/2010				Separation		6.8	0.13	0.00		N/A	N/A
OH583		6/16/2005	6/7/2010	2		6.0	Separation	3.00	6.0	2.00	0.75	E	25.0	0.15
OH583		6/16/2005	6/7/2010				Separation		5.7	0.13	0.13	E	4.2	0.03
OH583		6/16/2005	6/7/2010				Separation		2.0	0.25	0.25	E	8.3	0.05
OH474-1	E140-S2000	3/24/2009	6/7/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH474-1		3/24/2009	6/7/2010				Separation		6.8	0.38	0.00		N/A	N/A
OH474-1		3/24/2009	6/7/2010	5		6.4	Separation	1.28	6.4	0.25	1.75	E	58.3	1.45
OH474-1		3/24/2009	6/7/2010				Separation		5.6	0.13	0.00		N/A	N/A
OH474-1		3/24/2009	6/7/2010				Separation		5.4	0.13	0.00		N/A	N/A
OH474-1		3/24/2009	6/7/2010				Separation		3.2	1.00	0.00		N/A	N/A
OH474-1		3/24/2009	6/7/2010				Separation		2.8	1.00	0.25	E	8.3	0.21
OH474-1		3/24/2009	6/7/2010				Separation		1.5	1.25	0.38	E	12.5	0.31

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH472-1	E140-S2167	6/1/2009	6/7/2010				BOH		20.1	0.00	0.00		N/A	N/A
OH472-1		6/1/2009	6/7/2010				Separation		6.5	0.13	0.00		N/A	N/A
OH472-1		6/1/2009	6/7/2010				Separation		6.2	0.25	0.00		N/A	N/A
OH472-1		6/1/2009	6/7/2010	0		5.8	Separation	N/A	5.8	1.00	0.00		N/A	N/A
OH471-1	E140-S2333	3/24/2009	6/7/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH471-1		3/24/2009	6/7/2010	10		6.1	Separation	0.61	6.1	5.00	0.75	E	25.0	0.62
OH471-1		3/24/2009	6/7/2010				Separation		5.9	0.25	0.00		N/A	N/A
OH471-1		3/24/2009	6/7/2010				Separation		5.8	1.00	0.50	W	16.7	0.41
OH471-1		3/24/2009	6/7/2010				Separation		5.5	1.00	0.25	W	8.3	0.21
OH471-1		3/24/2009	6/7/2010				Separation		5.3	0.25	0.00		N/A	N/A
OH471-1		3/24/2009	6/7/2010				Separation		5.2	0.50	0.13	E	4.2	0.10
OH471-1		3/24/2009	6/7/2010				Separation		4.5	2.00	0.13	E	4.2	0.10
OH471-1		3/24/2009	6/7/2010				Separation		3.5	3.00	0.38	E	12.5	0.31
OH471-1		3/24/2009	6/7/2010				Separation		2.6	0.13	0.00		N/A	N/A
OH471-1		3/24/2009	6/7/2010				Separation		2.4	2.50	0.25	E	8.3	0.21
OH471-1		3/24/2009	6/7/2010				Separation		1.3	0.25	0.25	E	8.3	0.21

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH586-1	E140-S2358	3/2/2009	6/7/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH586-1		3/2/2009	6/7/2010				Hangup		7.0	0.00	0.00		N/A	N/A
OH586-1		3/2/2009	6/7/2010				Separation		6.6	1.00	0.00		N/A	N/A
OH586-1		3/2/2009	6/7/2010				Separation		6.5	1.00	0.00		N/A	N/A
OH586-1		3/2/2009	6/7/2010				Separation		6.0	4.00	0.00		N/A	N/A
OH586-1		3/2/2009	6/7/2010	6		5.5	Separation	0.92	5.5	4.00	1.75	W	58.3	1.38
OH586-1		3/2/2009	6/7/2010				Separation		4.8	0.50	0.00		N/A	N/A
OH586-1		3/2/2009	6/7/2010				Separation		4.6	0.50	0.00		N/A	N/A
OH586-1		3/2/2009	6/7/2010				Separation		3.6	4.00	0.25	E	8.3	0.20
OH586-1		3/2/2009	6/7/2010				Separation		3.4	0.25	0.00		N/A	N/A
OH586-1		3/2/2009	6/7/2010				Separation		2.4	1.00	0.25	E	8.3	0.20
OH586-1		3/2/2009	6/7/2010				Separation		1.4	0.25	0.07	NM	2.3	0.05
OH870	E140-S2456	6/1/2009	6/7/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH870		6/1/2009	6/7/2010				Separation		7.6	0.25	0.00		N/A	N/A
OH870		6/1/2009	6/7/2010				Separation		6.9	2.00	1.50	W	50.0	1.48
OH870		6/1/2009	6/7/2010				Separation		6.4	0.50	0.00		N/A	N/A
OH870		6/1/2009	6/7/2010	3		5.8	Separation	1.93	5.8	6.00	0.00		N/A	N/A
OH870		6/1/2009	6/7/2010				Separation		5.5	0.50	0.00		N/A	N/A
OH870		6/1/2009	6/7/2010				Separation		2.5	2.00	0.25	SW	8.3	0.25
OH870		6/1/2009	6/7/2010				Separation		1.8	0.50	0.13	SW	4.2	0.12

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH588	E140-S2520	6/16/2005	6/7/2010				BOH		20.7	0.00	0.00		N/A	N/A
OH588		6/16/2005	6/7/2010	1		5.4	Separation	5.40	5.4	1.00	1.75	E	58.3	0.35
OH588		6/16/2005	6/7/2010				Separation		1.5	0.25	0.25	E	8.3	0.05
OH468-1	E140-S2640	6/1/2009	6/7/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH468-1		6/1/2009	6/7/2010				Separation		6.4	0.50	0.25	W	8.3	0.25
OH468-1		6/1/2009	6/7/2010	4		4.5	Separation	1.13	4.5	5.00	2.00	E	66.7	1.97
OH468-1		6/1/2009	6/7/2010				Separation		3.9	0.50	0.00		N/A	N/A
OH468-1		6/1/2009	6/7/2010				Separation		2.1	1.00	0.13	E	4.2	0.12
OH468-1		6/1/2009	6/7/2010				Separation		1.2	2.00	0.25	E	8.3	0.25
OH468-1		6/1/2009	6/7/2010				Separation		0.8	0.25	0.25	E	8.3	0.25
OH589-1	E140-S2750	6/1/2009	6/7/2010				BOH		20.1	0.00	0.00		N/A	N/A
OH589-1		6/1/2009	6/7/2010				Separation		7.8	1.00	0.50	E	16.7	0.49
OH589-1		6/1/2009	6/7/2010	1		6.7	Separation	6.70	6.7	0.50	0.00		N/A	N/A
OH589-1		6/1/2009	6/7/2010				Separation		5.6	0.25	0.00		N/A	N/A
OH500-1	E140-S2920	6/1/2009	6/7/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH500-1		6/1/2009	6/7/2010				Separation		7.8	2.00	0.75	E	25.0	0.74
OH500-1		6/1/2009	6/7/2010				Separation		6.5	0.13	1.00	E	33.3	0.98
OH500-1		6/1/2009	6/7/2010				Separation		6.1	2.50	0.50	E	16.7	0.49
OH500-1		6/1/2009	6/7/2010	4		5.6	Separation	1.40	5.6	4.00	0.50	E	16.7	0.49
OH500-1		6/1/2009	6/7/2010				Separation		5.1	0.75	0.25	E	8.3	0.25
OH500-1		6/1/2009	6/7/2010				Separation		2.1	0.13	0.00		N/A	N/A
OH500-1		6/1/2009	6/7/2010				Separation		2.0	0.25	0.13	E	4.2	0.12
OH500-1		6/1/2009	6/7/2010				Separation		1.0	0.13	0.25	E	8.3	0.25

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH501-1	E140-S2984	6/1/2009	6/7/2010	4		5.8	BOH	1.45	5.8	0.00	2.50	E	83.3	2.51
OH501-1		6/1/2009	6/7/2010				Separation		5.5	1.50	0.00		N/A	N/A
OH501-1		6/1/2009	6/7/2010				Separation		4.8	0.25	0.00		N/A	N/A
OH501-1		6/1/2009	6/7/2010				Separation		1.8	3.00	0.25	E	8.3	0.25
OH501-1		6/1/2009	6/7/2010				Separation		0.7	1.00	0.25	E	8.3	0.25
OH590-1	E140-S3080	6/1/2009	6/7/2010				BOH		20.1	0.00	0.00		N/A	N/A
OH590-1		6/1/2009	6/7/2010				Separation		6.1	0.13	0.00		N/A	N/A
OH590-1		6/1/2009	6/7/2010	3		5.8	Separation	1.93	5.8	3.00	0.50	W	16.7	0.49
OH590-1		6/1/2009	6/7/2010				Separation		5.4	0.50	0.25	E	8.3	0.25
OH590-1		6/1/2009	6/7/2010				Separation		1.5	0.50	0.00		N/A	N/A
OH590-1		6/1/2009	6/7/2010				Rough Spot		0.5	0.00	0.00		N/A	N/A
OH590-1		6/1/2009	6/7/2010				Separation		0.4	0.50	0.00		N/A	N/A
OH493-1	E140-S3180	6/1/2009	6/7/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH493-1		6/1/2009	6/7/2010				Separation		8.0	0.25	0.00		N/A	N/A
OH493-1		6/1/2009	6/7/2010				Separation		6.4	1.00	0.50	NW	16.7	0.49
OH493-1		6/1/2009	6/7/2010	2		5.8	Separation	2.90	5.8	1.00	0.50	E	16.7	0.49
OH493-1		6/1/2009	6/7/2010				Separation		5.6	0.25	0.25	SW	8.3	0.25
OH493-1		6/1/2009	6/7/2010				Hangup		1.5	0.00	0.00		N/A	N/A
OH493-1		6/1/2009	6/7/2010				Separation		1.0	5.00	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH605-1	E140-S3380	6/1/2009	6/7/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH605-1		6/1/2009	6/7/2010				Separation		7.7	1.00	0.00		N/A	N/A
OH605-1		6/1/2009	6/7/2010				Separation		5.5	0.50	0.00		N/A	N/A
OH605-1		6/1/2009	6/7/2010	3		4.6	Separation	1.53	4.6	3.00	1.25	E	41.7	1.23
OH605-1		6/1/2009	6/7/2010				Separation		4.0	0.25	0.00		N/A	N/A
OH605-1		6/1/2009	6/7/2010				Separation		2.0	2.00	0.13	E	4.2	0.12
OH605-1		6/1/2009	6/7/2010				Separation		1.2	0.75	0.13	E	4.2	0.12
OH606-1	E140-S3480	6/1/2009	6/7/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH606-1		6/1/2009	6/7/2010				Separation		6.8	1.00	0.00		N/A	N/A
OH606-1		6/1/2009	6/7/2010				Separation		5.3	0.13	0.00		N/A	N/A
OH606-1		6/1/2009	6/7/2010	2		4.7	Separation	2.35	4.7	1.00	0.50	W	16.7	0.49
OH606-1		6/1/2009	6/7/2010				Rough Spot		4.5	0.00	0.00		N/A	N/A
OH606-1		6/1/2009	6/7/2010				Rough Spot		0.3	0.00	0.00		N/A	N/A
OH571	E140-S3527	2/23/2005	6/7/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH571		2/23/2005	6/7/2010	2		5.0	Separation	2.50	5.0	0.25	0.75	E	25.0	0.14
OH571		2/23/2005	6/7/2010				Separation		4.4	0.25	0.25	E	8.3	0.05
OH571		2/23/2005	6/7/2010				Separation		3.9	0.13	0.00		N/A	N/A
OH607	E140-S3580	9/1/2005	6/7/2010				BOH		20.9	0.00	0.00		N/A	N/A
OH607		9/1/2005	6/7/2010				Separation		7.0	0.50	0.00		N/A	N/A
OH607		9/1/2005	6/7/2010	2		5.3	Separation	2.65	5.3	1.00	0.00		N/A	N/A
OH607		9/1/2005	6/7/2010				Separation		4.5	0.13	0.00		N/A	N/A
OH607		9/1/2005	6/7/2010				Separation		0.8	0.63	0.25	E	8.3	0.05

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH567	E140-S3650	2/23/2005	6/7/2010				BOH		20.5	0.00	0.00		N/A	N/A
OH567		2/23/2005	6/7/2010				Separation		6.5	0.25	0.75	N	25.0	0.14
OH567		2/23/2005	6/7/2010	0		5.2	Separation	N/A	5.2	0.25	1.75	N	58.3	0.33
OH567		2/23/2005	6/7/2010				Hangup		3.7	0.00	0.00		N/A	N/A
OH860	0E-N1266	3/8/2009	6/8/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH860		3/8/2009	6/8/2010				Separation		3.2	2.00	0.00		N/A	N/A
OH860		3/8/2009	6/8/2010				Separation		1.5	3.00	0.00		N/A	N/A
OH488	E0-N1100	1/7/2004	6/8/2010				BOH		20.2	0.00	0.00		N/A	N/A
OH488		1/7/2004	6/8/2010	1		6.0	Separation	6.00	6.0	0.50	0.25	W	8.3	0.04
OH488		1/7/2004	6/8/2010				Separation		1.1	0.75	0.00		N/A	N/A
OH859	0E-N920	3/8/2009	6/8/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH859		3/8/2009	6/8/2010				Rough Spot		6.4	0.00	0.00		N/A	N/A
OH859		3/8/2009	6/8/2010	1		5.9	Separation	5.90	5.9	0.25	0.00		N/A	N/A
OH859		3/8/2009	6/8/2010				Separation		1.0	0.38	0.00		N/A	N/A
OH490	E0-N780	1/9/2004	6/8/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH490		1/9/2004	6/8/2010				Rough Spot		16.2	0.00	0.00		N/A	N/A
OH490		1/9/2004	6/8/2010				Hangup		6.5	0.00	0.50	E	16.7	0.08
OH490		1/9/2004	6/8/2010	2		6.0	Separation	3.00	6.0	1.00	0.50	E	16.7	0.08
OH490		1/9/2004	6/8/2010				Separation		1.4	0.13	0.00		N/A	N/A
OH490		1/9/2004	6/8/2010				Separation		0.7	0.13	0.00		N/A	N/A
OH491	E0-N620	1/9/2004	6/8/2010				BOH		20.2	0.00	0.00		N/A	N/A
OH491		1/9/2004	6/8/2010	2		6.4	Separation	3.20	6.4	0.38	1.38	W	45.8	0.21
OH491		1/9/2004	6/8/2010				Separation		1.5	0.50	0.07	W	2.3	0.01
OH491		1/9/2004	6/8/2010				Separation		1.4	0.50	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH888	W30-S700	3/8/2009	6/8/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH888		3/8/2009	6/8/2010	0		8.4	Rough Spot	N/A	8.4	0.00	0.00		N/A	N/A
OH887	W30-S850	3/10/2009	6/8/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH887		3/10/2009	6/8/2010	0		8.5	Separation	N/A	8.5	0.25	0.00		N/A	N/A
OH886	W30-S1000	3/3/2009	6/8/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH885	W30-S1150	3/3/2009	6/8/2010				BOH		20.1	0.00	0.00		N/A	N/A
OH885		3/3/2009	6/8/2010				Separation		6.5	0.38	0.25	W	8.3	0.20
OH885		3/3/2009	6/8/2010	4		6.0	Separation	1.50	6.0	0.50	0.25	W	8.3	0.20
OH885		3/3/2009	6/8/2010				Separation		2.4	0.50	0.00		N/A	N/A
OH885		3/3/2009	6/8/2010				Separation		1.4	0.50	0.07	W	2.3	0.05
OH885		3/3/2009	6/8/2010				Separation		0.7	0.25	0.07	W	2.3	0.05
OH885		3/3/2009	6/8/2010				Separation		0.5	0.25	0.07	W	2.3	0.05
OH884	W30-S1300	3/3/2009	6/8/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH884		3/3/2009	6/8/2010				Separation		0.8	0.25	0.00		N/A	N/A
OH883	W30-S1485	3/3/2009	6/28/2010				BOH		20.1	0.00	0.00		N/A	N/A
OH882	W30-S1600	3/3/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH882		3/3/2009	6/2/2010				Separation		8.9	0.25	0.00		N/A	N/A
OH882		3/3/2009	6/2/2010	1		8.3	Separation	8.30	8.3	0.25	0.00		N/A	N/A
OH882		3/3/2009	6/2/2010				Separation		0.4	0.25	0.00		N/A	N/A
OH881	W30-S1780	3/3/2009	6/2/2010				BOH		19.9	0.00	0.00		N/A	N/A
OH880	W30-S1950	3/3/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH879	W30-S2060	3/3/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH878	W30-S2180	3/11/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH877	W30-S2350	3/11/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH877		3/11/2009	6/2/2010	1		7.0	Separation	7.00	7.0	0.25	0.00		N/A	N/A
OH877		3/11/2009	6/2/2010				Separation		0.7	0.25	0.00		N/A	N/A
OH876	W30-S2520	3/3/2009	6/2/2010				BOH		17.6	0.00	0.00		N/A	N/A
OH876		3/3/2009	6/2/2010				Separation		2.5	0.13	0.00		N/A	N/A
OH876		3/3/2009	6/2/2010				Separation		0.7	0.25	0.00		N/A	N/A
OH875	W30-S2750	3/3/2009	6/2/2010				BOH		20.1	0.00	0.00		N/A	N/A
OH875		3/3/2009	6/2/2010	0		6.4	Fracture	N/A	6.4	2.00	0.00		N/A	N/A
OH455	W30-S2850	8/28/2003	6/8/2010				BOH		18.8	0.00	0.00		N/A	N/A
OH455		8/28/2003	6/8/2010	3		6.3	Separation	2.10	6.3	0.50	0.00		N/A	N/A
OH455		8/28/2003	6/8/2010				Separation		5.6	0.13	0.00		N/A	N/A
OH455		8/28/2003	6/8/2010				Rough Spot		4.8	0.00	0.00		N/A	N/A
OH455		8/28/2003	6/8/2010				Separation		1.8	0.50	0.13	W	4.2	0.02
OH456	W30-S2950	8/28/2003	6/8/2010				BOH		23.5	0.00	0.00		N/A	N/A
OH456		8/28/2003	6/8/2010	5		6.0	Separation	1.20	6.0	0.50	0.00		N/A	N/A
OH456		8/28/2003	6/8/2010				Separation		5.7	0.38	0.00		N/A	N/A
OH456		8/28/2003	6/8/2010				Separation		5.4	0.25	0.00		N/A	N/A
OH456		8/28/2003	6/8/2010				Separation		2.6	5.00	0.00		N/A	N/A
OH456		8/28/2003	6/8/2010				Separation		1.5	3.00	0.25	SW	8.3	0.04
OH456		8/28/2003	6/8/2010				Separation		0.8	0.75	0.13	SW	4.2	0.02

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH463	W30-S3080	9/3/2003	6/8/2010				BOH		21.3	0.00	0.00		N/A	N/A
OH463		9/3/2003	6/8/2010				Separation		7.5	0.13	0.00		N/A	N/A
OH463		9/3/2003	6/8/2010				Separation		6.6	0.25	0.00		N/A	N/A
OH463		9/3/2003	6/8/2010				Separation		6.5	0.25	0.00		N/A	N/A
OH463		9/3/2003	6/8/2010				Separation		6.2	0.25	0.00		N/A	N/A
OH463		9/3/2003	6/8/2010	2		5.8	Separation	2.90	5.8	0.25	1.25	NE	41.7	0.18
OH463		9/3/2003	6/8/2010				Separation		5.3	0.13	0.00		N/A	N/A
OH463		9/3/2003	6/8/2010				Separation		1.4	5.00	1.50	NE	N/A	N/A
OH465	W30-S3200	9/3/2003	6/14/2010				BOH		22.0	0.00	0.00		N/A	N/A
OH465		9/3/2003	6/14/2010	2		5.2	Rough Spot	2.60	5.2	0.00	0.00		N/A	N/A
OH465		9/3/2003	6/14/2010				Separation		1.4	0.50	0.13	E	4.2	0.02
OH465		9/3/2003	6/14/2010				Separation		0.9	0.25	0.38	E	12.5	0.06
OH449	W30-S3310	8/18/2003	6/14/2010				BOH		21.5	0.00	0.00		N/A	N/A
OH449		8/18/2003	6/14/2010				Separation		6.4	0.13	0.00		N/A	N/A
OH449		8/18/2003	6/14/2010				Separation		5.9	0.25	0.00		N/A	N/A
OH449		8/18/2003	6/14/2010	1		5.7	Separation	5.70	5.7	0.25	0.50	SE	16.7	0.07
OH449		8/18/2003	6/14/2010				Separation		4.9	0.13	0.13	N	4.2	0.02
OH514-1	W30-S3400	6/5/2009	12/10/2009				BOH		20.1	0.00	0.00		N/A	N/A
OH514-1		6/5/2009	12/10/2009	1		5.4	Separation	5.40	5.4	0.13	0.00		N/A	N/A
OH514-1		6/5/2009	12/10/2009				Separation		1.3	0.13	0.00		N/A	N/A
OH515-1	W30-S3490	6/5/2009	12/10/2009				BOH		20.1	0.00	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH565	W30-S3650	2/23/2005	6/7/2010				BOH		20.7	0.00	0.00		N/A	N/A
OH565		2/23/2005	6/7/2010				Rough Spot		16.1	0.00	0.00		N/A	N/A
OH565		2/23/2005	6/7/2010				Separation		7.2	0.13	0.00		N/A	N/A
OH565		2/23/2005	6/7/2010				Separation		6.1	0.13	0.00		N/A	N/A
OH565		2/23/2005	6/7/2010	1		5.6	Separation	5.60	5.6	0.13	1.25	N	41.7	0.24
OH565		2/23/2005	6/7/2010				Separation		5.1	0.13	0.00		N/A	N/A
OH899	W170-S1000	3/24/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH899		3/24/2009	6/2/2010	1		9.1	Rough Spot	9.10	9.1	0.00	0.25	E	8.3	0.21
OH899		3/24/2009	6/2/2010				Separation		2.0	0.25	0.00		N/A	N/A
OH898	W170-S1150	3/24/2009	6/2/2010				BOH		21.0	0.00	0.00		N/A	N/A
OH898		3/24/2009	6/2/2010	0		8.8	Hangup	N/A	8.8	0.00	0.00		N/A	N/A
OH897	W170-S1300	6/8/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH897		6/8/2009	6/2/2010	0		8.4	Rough Spot	N/A	8.4	0.00	0.25	NE	8.3	0.25
OH896	W170-S1482	6/8/2009	6/2/2010				BOH		17.3	0.00	0.00		N/A	N/A
OH896		6/8/2009	6/2/2010	0		8.1	Hangup	N/A	8.1	0.00	0.13	W	4.2	0.13
OH895	W170-S1600	6/8/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH895		6/8/2009	6/2/2010	0		8.6	Separation	N/A	8.6	0.50	0.25	E	8.3	0.25
OH894	W170-S1780	6/8/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH894		6/8/2009	6/2/2010	0		9.4	Separation	N/A	9.4	0.25	0.25	E	8.3	0.25
OH893	W170-S1950	6/8/2009	6/2/2010				BOH		19.9	0.00	0.00		N/A	N/A
OH893		6/8/2009	6/2/2010	0		8.4	Separation	N/A	8.4	0.13	0.25	E	8.3	0.25

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH892	W170-S2055	6/8/2009	6/2/2010				BOH		19.4	0.00	0.00		N/A	N/A
OH892		6/8/2009	6/2/2010	2		7.8	Separation	3.90	7.8	0.25	0.00		N/A	N/A
OH892		6/8/2009	6/2/2010				Separation		1.1	0.25	0.00		N/A	N/A
OH892		6/8/2009	6/2/2010				Separation		1.0	0.25	0.00		N/A	N/A
OH891	W170-S2180	6/8/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH891		6/8/2009	6/2/2010	0		7.6	Separation	N/A	7.6	0.25	0.25	E	8.3	0.25
OH890	W170-S2345	3/11/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH890		3/11/2009	6/2/2010	0		7.8	Separation	N/A	7.8	0.25	0.13	E	4.2	0.10
OH889	W170-S2520	3/11/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH889		3/11/2009	6/2/2010	1		7.8	Separation	7.80	7.8	0.50	0.25	E	8.3	0.20
OH889		3/11/2009	6/2/2010				Separation		1.5	0.25	0.00		N/A	N/A
OH900	W170-S2635	3/17/2010	6/28/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH900		3/17/2010	6/28/2010	3		4.4	Separation	1.47	4.4	0.13	0.00		N/A	N/A
OH900		3/17/2010	6/28/2010				Separation		4.0	0.13	0.00		N/A	N/A
OH900		3/17/2010	6/28/2010				Separation		3.7	0.13	0.00		N/A	N/A
OH900		3/17/2010	6/28/2010				Separation		3.1	0.13	0.00		N/A	N/A
OH442	W170-S2820	8/18/2003	6/28/2010				BOH		13.1	0.00	0.00		N/A	N/A
OH442		8/18/2003	6/28/2010	2		5.7	Separation	2.85	5.7	0.13	0.00		N/A	N/A
OH442		8/18/2003	6/28/2010				Separation		2.4	1.25	0.00		N/A	N/A
OH442		8/18/2003	6/28/2010				Separation		1.5	0.50	0.25	W	8.3	0.04
OH443-1	W170-S2900	6/8/2009	6/28/2010				BOH		13.0	0.00	0.00		N/A	N/A
OH443-1		6/8/2009	6/28/2010	4		3.8	Separation	0.95	3.8	1.50	0.00		N/A	N/A
OH443-1		6/8/2009	6/28/2010				Separation		3.7	0.50	0.00		N/A	N/A
OH443-1		6/8/2009	6/28/2010				Separation		2.8	0.25	0.00		N/A	N/A
OH443-1		6/8/2009	6/28/2010				Separation		2.6	0.50	0.00		N/A	N/A
OH443-1		6/8/2009	6/28/2010				Separation		0.5	1.00	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH444	W170-S3000	8/18/2003	6/28/2010				BOH		20.6	0.00	0.00		N/A	N/A
OH444		8/18/2003	6/28/2010				Separation		6.9	0.13	0.00		N/A	N/A
OH444		8/18/2003	6/28/2010				Rough Spot		6.6	0.00	0.00		N/A	N/A
OH444		8/18/2003	6/28/2010	6		6.3	Separation	1.05	6.3	0.13	0.38	W	12.5	0.05
OH444		8/18/2003	6/28/2010				Separation		5.5	0.13	0.00		N/A	N/A
OH444		8/18/2003	6/28/2010				Separation		4.9	0.13	0.00		N/A	N/A
OH444		8/18/2003	6/28/2010				Separation		4.7	0.13	0.00		N/A	N/A
OH444		8/18/2003	6/28/2010				Separation		2.8	0.13	0.38	S	12.5	0.05
OH444		8/18/2003	6/28/2010				Separation		1.3	2.00	0.13	S	4.2	0.02
OH444		8/18/2003	6/28/2010				Separation		1.0	0.13	0.00		N/A	N/A
OH445	W170-S3080	8/18/2003	12/10/2009				Separation		5.5	0.00	0.00		N/A	N/A
OH445		8/18/2003	12/10/2009	2		5.2	Separation	2.60	5.2	3.00	0.00		N/A	N/A
OH445		8/18/2003	12/10/2009				Separation		0.8	0.13	1.00	E	33.3	0.16
OH445		8/18/2003	12/10/2009				Separation		0.4	0.13	1.00	E	33.3	0.16
OH446	W170-S3200	8/18/2003	6/14/2010				BOH		24.0	0.00	0.00		N/A	N/A
OH446		8/18/2003	6/14/2010	1		5.3	Separation	5.30	5.3	2.00	1.00	E	33.3	0.15
OH446		8/18/2003	6/14/2010				Separation		1.4	0.50	1.00	E	33.3	0.15
OH447	W170-S3310	8/18/2003	6/14/2010				BOH		22.9	0.00	0.00		N/A	N/A
OH447		8/18/2003	6/14/2010	0		5.8	Separation	N/A	5.8	0.25	1.00	E	33.3	0.15

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH608-1	W170-S3395	6/10/2009	6/14/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH608-1		6/10/2009	6/14/2010	3		6.0	Rough Spot	2.00	6.0	0.00	0.00		N/A	N/A
OH608-1		6/10/2009	6/14/2010				Separation		2.0	2.50	0.07	E	2.3	0.07
OH608-1		6/10/2009	6/14/2010				Separation		1.0	1.00	0.25	NE	8.3	0.25
OH608-1		6/10/2009	6/14/2010				Separation		0.7	0.13	0.13	NE	4.2	0.12
OH609-1	W170-S3485	6/10/2009	6/14/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH609-1		6/10/2009	6/14/2010	3		6.0	Separation	2.00	2.3	2.00	0.25	E	8.3	0.25
OH609-1		6/10/2009	6/14/2010				Separation		1.3	0.13	0.00		N/A	N/A
OH609-1		6/10/2009	6/14/2010				Separation		1.2	0.13	0.07	E	2.3	0.07
OH610-1	W170-S3580	6/10/2009	6/14/2010	0		6.0	BOH	N/A	20.0	0.00	0.00		N/A	N/A
OH573	W170-S3650	4/14/2005	6/7/2010				BOH		50.0	0.00	0.00		N/A	N/A
OH573		4/14/2005	6/7/2010	0		5.4	Separation	N/A	5.4	0.25	0.00		N/A	N/A
OH869	E300-S1430	6/15/2009	6/21/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH868	E300-S1780	6/15/2009	6/21/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH867	E300-S2060	6/15/2009	6/21/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH866	E300-S2340	6/15/2009	6/21/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH866		6/15/2009	6/21/2010				Separation		1.1	0.13	0.00		N/A	N/A
OH865	E300-S2630	6/15/2009	6/21/2010				BOH		20.2	0.00	0.00		N/A	N/A
OH865		6/15/2009	6/21/2010	0		4.2	Separation	N/A	4.2	0.38	0.75	E	25.0	0.74
OH422	E300-S2825	8/6/2003	6/21/2010				BOH		20.7	0.00	0.00		N/A	N/A
OH422		8/6/2003	6/21/2010	0		6.5	Separation	N/A	6.5	0.38	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH423	E300-S2890	8/6/2003	6/21/2010				BOH		18.6	0.00	0.00		N/A	N/A
OH423		8/6/2003	6/21/2010				Rough Spot		6.3	0.00	0.00		N/A	N/A
OH423		8/6/2003	6/21/2010	4		5.6	Separation	1.40	5.6	1.00	0.00		N/A	N/A
OH423		8/6/2003	6/21/2010				Rough Spot		4.0	0.00	0.00		N/A	N/A
OH423		8/6/2003	6/21/2010				Separation		1.7	0.13	0.00		N/A	N/A
OH423		8/6/2003	6/21/2010				Separation		1.3	0.50	0.38		12.5	0.05
OH423		8/6/2003	6/21/2010				Separation		1.0	0.13	0.00		N/A	N/A
OH424	E300-S2950	8/6/2003	6/21/2010				BOH		1.5	0.00	3.00		100.0	0.44
OH424		8/6/2003	6/21/2010	N/A		N/A	Separation	N/A	1.2	3.50	0.00		N/A	N/A
OH425	E300-S3020	8/6/2003	6/21/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH425		8/6/2003	6/21/2010				Rough Spot		11.7	0.00	0.00		N/A	N/A
OH425		8/6/2003	6/21/2010				Rough Spot		9.5	0.00	0.00		N/A	N/A
OH425		8/6/2003	6/21/2010				Rough Spot		7.9	0.00	0.00		N/A	N/A
OH425		8/6/2003	6/21/2010				Rough Spot		6.6	0.00	0.00		N/A	N/A
OH425		8/6/2003	6/21/2010	2		5.7	Separation	2.85	5.7	0.38	0.00		N/A	N/A
OH425		8/6/2003	6/21/2010				Separation		1.6	2.00	0.00		N/A	N/A
OH425		8/6/2003	6/21/2010				Separation		0.4	0.25	0.00		N/A	N/A
OH459	E300-S3140	8/28/2003	6/21/2010				BOH		20.5	0.00	0.00		N/A	N/A
OH459		8/28/2003	6/21/2010	3		5.5	Separation	1.83	5.5	0.13	0.00		N/A	N/A
OH459		8/28/2003	6/21/2010				Separation		5.1	0.13	0.00		N/A	N/A
OH459		8/28/2003	6/21/2010				Separation		1.5	0.13	0.00		N/A	N/A
OH459		8/28/2003	6/21/2010				Separation		1.0	0.13	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH458	E300-S3200	8/28/2003	6/21/2010				BOH		20.5	0.00	0.00		N/A	N/A
OH458		8/28/2003	6/21/2010	3		6.3	Separation	2.10	6.3	0.38	0.00		N/A	N/A
OH458		8/28/2003	6/21/2010				Separation		5.3	0.13	0.00		N/A	N/A
OH458		8/28/2003	6/21/2010				Separation		4.8	0.13	0.00		N/A	N/A
OH458		8/28/2003	6/21/2010				Separation		1.6	0.50	0.00		N/A	N/A
OH457	E300-S3260	8/28/2003	6/21/2010				BOH		21.6	0.00	0.00		N/A	N/A
OH457		8/28/2003	6/21/2010	3		5.3	Separation	1.77	5.3	0.25	0.13	E	4.2	0.02
OH457		8/28/2003	6/21/2010				Separation		4.8	0.13	0.00		N/A	N/A
OH457		8/28/2003	6/21/2010				Separation		1.2	0.25	0.00		N/A	N/A
OH457		8/28/2003	6/21/2010				Separation		0.8	0.25	0.19	E	6.3	0.03
OH453	E300-S3310	8/18/2003	6/28/2010				BOH		20.9	0.00	0.00		N/A	N/A
OH453		8/18/2003	6/28/2010				Separation		6.4	0.25	0.00		N/A	N/A
OH453		8/18/2003	6/28/2010				Separation		6.0	0.25	0.00		N/A	N/A
OH453		8/18/2003	6/28/2010	0		5.2	Separation	N/A	5.2	0.13	1.00	W	33.3	0.15
OH622	E300-S3400	6/15/2006	6/28/2010				BOH		20.6	0.00	0.00		N/A	N/A
OH622		6/15/2006	6/28/2010	1		5.5	Separation	5.50	5.5	0.13	0.00		N/A	N/A
OH622		6/15/2006	6/28/2010				Separation		0.8	0.13	0.00		N/A	N/A
OH604	E300-S3480	7/18/2005	6/28/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH604		7/18/2005	6/28/2010				Separation		5.9	0.25	0.00		N/A	N/A
OH604		7/18/2005	6/28/2010	2		5.5	Separation	2.75	5.5	0.75	0.00		N/A	N/A
OH604		7/18/2005	6/28/2010				Rough Spot		4.8	0.00	0.00		N/A	N/A
OH604		7/18/2005	6/28/2010				Separation		4.7	0.38	0.00		N/A	N/A
OH604		7/18/2005	6/28/2010				Separation		1.2	0.50	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH623	E300-S3450	6/15/2006	6/28/2010				BOH		20.6	0.00	0.00		N/A	N/A
OH623		6/15/2006	6/28/2010	2		5.7	Separation	2.85	5.7	0.13	0.00		N/A	N/A
OH623		6/15/2006	6/28/2010				Separation		5.6	0.13	0.00		N/A	N/A
OH623		6/15/2006	6/28/2010				Separation		1.2	0.13	0.06	E	2.1	0.02
OH624	E300-S3550	6/15/2006	6/28/2010				BOH		20.6	0.00	0.00		N/A	N/A
OH624		6/15/2006	6/28/2010	1		5.7	Rough Spot	5.70	5.7	0.00	0.06	E	2.1	0.02
OH624		6/15/2006	6/28/2010				Rough Spot		5.1	0.00	0.00		N/A	N/A
OH569	E300-S3650	4/20/2005	6/28/2010				BOH		20.6	0.00	0.00		N/A	N/A
OH569		4/20/2005	6/28/2010	1		5.7	Separation	5.70	5.7	0.13	0.50	N	16.7	0.10
OH569		4/20/2005	6/28/2010				Separation		5.0	0.13	0.00		N/A	N/A
OH564	S3650-W90	4/20/2005	6/7/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH564		4/20/2005	6/7/2010				Separation		5.9	0.13	0.00		N/A	N/A
OH564		4/20/2005	6/7/2010	2		5.8	Separation	2.90	5.8	1.00	0.25	N	8.3	0.05
OH564		4/20/2005	6/7/2010				Separation		5.0	0.25	0.00		N/A	N/A
OH564		4/20/2005	6/7/2010				Separation		1.4	0.25	0.13	S	4.2	0.02
OH566	S3650-E50	4/20/2005	6/7/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH566		4/20/2005	6/7/2010	1		5.8	Separation	5.80	5.8	0.13	0.25	S	8.3	0.05
OH566		4/20/2005	6/7/2010				Separation		5.1	0.13	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH623	E300-S3450	6/15/2006	6/28/2010				BOH		20.6	0.00	0.00		N/A	N/A
OH623		6/15/2006	6/28/2010	2		5.7	Separation	2.85	5.7	0.13	0.00		N/A	N/A
OH623		6/15/2006	6/28/2010				Separation		5.6	0.13	0.00		N/A	N/A
OH623		6/15/2006	6/28/2010				Separation		1.2	0.13	0.06	E	2.1	0.02
OH624	E300-S3550	6/15/2006	6/28/2010				BOH		20.6	0.00	0.00		N/A	N/A
OH624		6/15/2006	6/28/2010	1		5.7	Rough Spot	5.70	5.7	0.00	0.06	E	2.1	0.02
OH624		6/15/2006	6/28/2010				Rough Spot		5.1	0.00	0.00		N/A	N/A
OH569	E300-S3650	4/20/2005	6/28/2010				BOH		20.6	0.00	0.00		N/A	N/A
OH569		4/20/2005	6/28/2010	1		5.7	Separation	5.70	5.7	0.13	0.50	N	16.7	0.10
OH569		4/20/2005	6/28/2010				Separation		5.0	0.13	0.00		N/A	N/A
OH564	S3650-W90	4/20/2005	6/7/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH564		4/20/2005	6/7/2010				Separation		5.9	0.13	0.00		N/A	N/A
OH564		4/20/2005	6/7/2010	2		5.8	Separation	2.90	5.8	1.00	0.25	N	8.3	0.05
OH564		4/20/2005	6/7/2010				Separation		5.0	0.25	0.00		N/A	N/A
OH564		4/20/2005	6/7/2010				Separation		1.4	0.25	0.13	S	4.2	0.02
OH566	S3650-E50	4/20/2005	6/7/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH566		4/20/2005	6/7/2010	1		5.8	Separation	5.80	5.8	0.13	0.25	S	8.3	0.05
OH566		4/20/2005	6/7/2010				Separation		5.1	0.13	0.00		N/A	N/A
OH464	S3080-E65	9/3/2003	6/8/2010				BOH		18.0	0.00	0.00		N/A	N/A
OH464		9/3/2003	6/8/2010				Separation		6.2	0.25	0.00		N/A	N/A
OH464		9/3/2003	6/8/2010	4		5.5	Separation	1.38	5.5	0.25	0.00		N/A	N/A
OH464		9/3/2003	6/8/2010				Separation		5.4	0.13	0.00		N/A	N/A
OH464		9/3/2003	6/8/2010				Separation		4.8	0.25	0.00		N/A	N/A
OH464		9/3/2003	6/8/2010				Separation		4.7	0.50	0.00		N/A	N/A
OH464		9/3/2003	6/8/2010				Separation		1.1	1.00	0.50	S	16.7	0.07

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH462	S3080-W100	9/3/2003	6/8/2010				BOH		22.5	0.00	0.00		N/A	N/A
OH462		9/3/2003	6/8/2010				Separation		6.5	0.25	0.00		N/A	N/A
OH462		9/3/2003	6/8/2010				Separation		6.2	0.25	0.00		N/A	N/A
OH462		9/3/2003	6/8/2010				Separation		5.8	0.25	0.00		N/A	N/A
OH462		9/3/2003	6/8/2010	4		5.2	Separation	1.30	5.2	0.50	0.00		N/A	N/A
OH462		9/3/2003	6/8/2010				Separation		5.1	0.50	0.00		N/A	N/A
OH462		9/3/2003	6/8/2010				Separation		4.4	0.13	0.00		N/A	N/A
OH462		9/3/2003	6/8/2010				Separation		2.7	1.00	0.00		N/A	N/A
OH462		9/3/2003	6/8/2010				Separation		1.8	0.25	0.25	S	8.3	0.04
OH503-1	S3080-E230	6/1/2009	6/14/2010				BOH		19.9	0.00	0.00		N/A	N/A
OH503-1		6/1/2009	6/14/2010	1		5.5	Separation	5.50	5.5	0.50	0.00		N/A	N/A
OH503-1		6/1/2009	6/14/2010				Separation		1.3	3.00	0.25	S	8.3	0.24
OH460	S2750-W100	9/3/2003	6/14/2010				BOH		6.7	0.75	0.00		N/A	N/A
OH460		9/3/2003	6/14/2010	2		5.1	Separation	2.55	5.1	0.25	0.00		N/A	N/A
OH460		9/3/2003	6/14/2010				Separation		2.6	5.00	0.50	S	16.7	0.07
OH460		9/3/2003	6/14/2010				Separation		1.5	2.00	0.50	S	16.7	0.07
OH861	S1950-E386	6/15/2009	6/21/2010				BOH		201.0	0.00	0.00		N/A	N/A
OH861		6/15/2009	6/21/2010				Separation		6.4	0.25	1.00	N	33.3	0.98
OH861		6/15/2009	6/21/2010	3		5.4	Separation	1.57	5.4	0.50	0.75	SW	25.0	0.74
OH861		6/15/2009	6/21/2010				Hangup		4.1	0.00	0.00		N/A	N/A
OH861		6/15/2009	6/21/2010				Separation		3.5	1.00	0.13	NW	4.2	0.12
OH862	S1950-E227	6/10/2009	6/21/2010				BOH		20.2	0.00	0.00		N/A	N/A
OH862		6/10/2009	6/21/2010	1		4.7	Separation	4.70	4.7	0.50	0.50	S	16.7	0.49
OH862		6/10/2009	6/21/2010				Separation		4.5	0.25	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH863	S1600-E386	6/15/2009	6/21/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH864	S1600-E227	6/10/2009	6/21/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH855	S90-W380	3/4/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH856	S90-W620	3/4/2009	6/2/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH856		3/4/2009	6/2/2010	0		8.9	Rough Spot	N/A	8.9	0.00	0.00		N/A	N/A
OH857	S90-W880	3/4/2009	6/2/2010				BOH		20.5	0.00	0.00		N/A	N/A
OH850	N300-W80	3/8/2009	6/8/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH850		3/8/2009	6/8/2010				Separation		8.2	0.50	0.50	S	16.7	0.40
OH850		3/8/2009	6/8/2010	0		6.9	Separation	N/A	6.9	1.50	0.00		N/A	N/A
OH858	N216-W469	3/11/2009	6/21/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH858		3/11/2009	6/21/2010				Separation		5.8	0.13	0.00		N/A	N/A
OH858		3/11/2009	6/21/2010	0		5.5	Separation	N/A	5.5	0.38	0.00		N/A	N/A
OH852	N785 - E195	6/8/2009	6/21/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH852		6/8/2009	6/21/2010				Separation		7.8	0.13	0.00		N/A	N/A
OH852		6/8/2009	6/21/2010	4		7.0	Separation	1.75	7.0	0.75	0.63	N	20.9	0.61
OH852		6/8/2009	6/21/2010				Separation		6.5	0.50	0.00		N/A	N/A
OH852		6/8/2009	6/21/2010				Separation		6.4	0.13	0.38	S	12.5	0.36
OH852		6/8/2009	6/21/2010				Separation		6.3	0.13	0.00		N/A	N/A
OH852		6/8/2009	6/21/2010				Separation		5.0	0.13	0.00		N/A	N/A
OH701	W390-S3392	10/6/2006	6/14/2010	1		5.1	BOH		5.1	1.50	1.00	W	N/A	N/A
OH701		10/6/2006	6/14/2010				Separation		1.4	0.13	1.25	E	N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH702	W390-S3483	10/6/2006	3/16/2010				BOH		20.7	0.00	0.00		N/A	N/A
OH702		10/6/2006	3/16/2010				Separation		7.1	0.13	0.00		N/A	N/A
OH702		10/6/2006	3/16/2010	6		5.5	Separation	0.92	5.5	1.00	0.38	E	12.5	0.11
OH702		10/6/2006	3/16/2010				Separation		5.4	0.13	0.19	W	6.3	0.05
OH702		10/6/2006	3/16/2010				Separation		5.3	0.13	0.00		N/A	N/A
OH702		10/6/2006	3/16/2010				Separation		5.2	0.13	0.25	N	8.3	0.07
OH702		10/6/2006	3/16/2010				Separation		4.8	0.13	0.00		N/A	N/A
OH702		10/6/2006	3/16/2010				Separation		4.4	0.13	0.00		N/A	N/A
OH702		10/6/2006	3/16/2010				Separation		4.3	0.13	0.00		N/A	N/A
OH703	W390-S3566	9/14/2006	3/16/2010				BOH		5.7	0.50	0.00		N/A	N/A
OH703		9/14/2006	3/16/2010				Separation		5.3	0.25	0.00		N/A	N/A
OH703		9/14/2006	3/16/2010	0		5.1	Separation	N/A	5.1	2.00	2.00	E	66.7	0.57
OH704	W530-S3395	1/21/2007	6/14/2010				BOH		21.4	0.00	0.00		N/A	N/A
OH704		1/21/2007	6/14/2010				Separation		6.3	0.13	0.00		N/A	N/A
OH704		1/21/2007	6/14/2010				Hangup		5.8	0.00	0.00		N/A	N/A
OH704		1/21/2007	6/14/2010	2		5.3	Separation	2.65	5.3	0.50	1.00	E	33.3	0.29
OH704		1/21/2007	6/14/2010				Separation		5.2	0.25	0.00		N/A	N/A
OH704		1/21/2007	6/14/2010				Separation		2.0	0.25	0.25	E	8.3	0.07
OH705	W530-S3479	12/21/2006	6/14/2010				BOH		20.6	0.00	0.00		N/A	N/A
OH705		12/21/2006	6/14/2010	2		5.4	Separation	2.70	5.4	2.00	0.50	E	16.7	0.14
OH705		12/21/2006	6/14/2010				Hangup		4.3	0.00	0.50	E	16.7	0.14
OH705		12/21/2006	6/14/2010				Separation		3.7	0.13	0.00		N/A	N/A
OH705		12/21/2006	6/14/2010				Separation		1.2	0.50	0.25	E	8.3	0.07

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH706	W530-S3562	1/4/2007	6/14/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH706		1/4/2007	6/14/2010	3		5.1	Separation	1.70	5.1	2.00	0.50	NE	16.7	0.15
OH706		1/4/2007	6/14/2010				Separation		5.0	0.13	0.00		N/A	N/A
OH706		1/4/2007	6/14/2010				Separation		4.8	0.13	0.00		N/A	N/A
OH706		1/4/2007	6/14/2010				Separation		4.6	0.13	0.00		N/A	N/A
OH707	W660-S3396	3/15/2007	12/8/2009				BOH		20.5	0.00	0.00		N/A	N/A
OH707		3/15/2007	12/8/2009	1		5.8	Separation	5.80	5.8	1.50	0.00		N/A	N/A
OH707		3/15/2007	12/8/2009				Separation		5.0	0.13	0.00		N/A	N/A
OH708	W660-S3481	3/15/2007	12/8/2009				BOH		20.6	0.00	0.00		N/A	N/A
OH708		3/15/2007	12/8/2009				Separation		5.7	0.38	0.38	E	12.5	0.14
OH708		3/15/2007	12/8/2009	0		5.6	Separation	N/A	5.6	1.00	0.38	W	12.5	0.14
OH709	W660-S3565	3/15/2007	12/15/2009				BOH		20.5	0.00	0.00		N/A	N/A
OH709		3/15/2007	12/15/2009				Separation		6.2	0.13	0.00		N/A	N/A
OH709		3/15/2007	12/15/2009	1		5.9	Separation	5.90	5.9	0.38	0.25	E	8.3	0.09
OH709		3/15/2007	12/15/2009				Separation		5.5	0.38	0.00		N/A	N/A
OH710	W790-S3413	5/5/2007	9/22/2009				BOH		20.4	0.00	0.00		N/A	N/A
OH710		5/5/2007	9/22/2009	1		5.8	Separation	5.80	5.8	1.50	0.13	E	4.2	0.05
OH710		5/5/2007	9/22/2009				Separation		5.4	0.13	0.00		N/A	N/A
OH711	W790-S3479	5/5/2007	9/22/2009	1		5.8	Separation	5.80	5.8	0.25	2.50	E	83.3	1.05
OH711		5/5/2007	9/22/2009				Separation		5.7	0.13	0.00		N/A	N/A
OH712	W790-S3552	5/5/2007	9/22/2009				BOH		20.5	0.00	0.00		N/A	N/A
OH712		5/5/2007	9/22/2009				Separation		6.0	0.13	0.00		N/A	N/A
OH712		5/5/2007	9/22/2009				Separation		5.8	0.13	0.00		N/A	N/A
OH712		5/5/2007	9/22/2009	1		5.6	Separation	5.60	5.6	0.25	0.00		N/A	N/A
OH712		5/5/2007	9/22/2009				Separation		5.0	0.25	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH722	W390-S3310	10/6/2006	6/14/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH722		10/6/2006	6/14/2010				Separation		5.6	0.13	1.00	S	33.3	0.27
OH722		10/6/2006	6/14/2010	0		5.3	Separation	N/A	5.3	1.00	1.50	SW	50.0	0.41
OH723	W460-S3310	1/4/2007	6/14/2010				BOH		20.5	0.00	0.00		N/A	N/A
OH723		1/4/2007	6/14/2010				Separation		5.7	0.75	0.25	SW	8.3	0.07
OH723		1/4/2007	6/14/2010	1		5.3	Separation	5.30	5.3	0.50	0.50	NE	16.7	0.15
OH723		1/4/2007	6/14/2010				Separation		5.2	0.50	0.00		N/A	N/A
OH724	W535-S3310	1/27/2007	6/14/2010	1		5.8	Separation	5.80	5.8	3.00	3.00		N/A	N/A
OH724		1/27/2007	6/14/2010				Separation		1.6	0.75	0.00		N/A	N/A
OH724		1/27/2007	6/14/2010				Rough Spot		0.5	0.00	0.00		N/A	N/A
OH725	W592-S3310	3/11/2007	3/16/2010				BOH		20.7	0.00	0.00		N/A	N/A
OH725		3/11/2007	3/16/2010	1		5.8	Separation	5.80	5.8	2.00	0.75	S	25.0	0.25
OH725		3/11/2007	3/16/2010				Separation		5.6	0.25	0.00		N/A	N/A
OH726	W660-S3310	3/11/2007	12/8/2009				BOH		20.6	0.00	0.00		N/A	N/A
OH726		3/11/2007	12/8/2009				Hangup		16.5	0.00	0.00		N/A	N/A
OH726		3/11/2007	12/8/2009				Separation		6.6	0.13	0.00		N/A	N/A
OH726		3/11/2007	12/8/2009	0		5.9	Separation	N/A	5.9	2.50	2.00	S	66.7	0.73
OH727	W738-S3310	3/11/2007	12/8/2009				BOH		20.8	0.00	0.00		N/A	N/A
OH727		3/11/2007	12/8/2009				Separation		7.2	0.38	0.00		N/A	N/A
OH727		3/11/2007	12/8/2009	4		5.6	Separation	1.40	5.6	2.00	0.00		N/A	N/A
OH727		3/11/2007	12/8/2009				Separation		5.4	0.75	1.00	S	33.3	0.36
OH727		3/11/2007	12/8/2009				Separation		4.5	0.13	0.00		N/A	N/A
OH727		3/11/2007	12/8/2009				Separation		1.5	0.13	0.38	S	12.5	0.14
OH727		3/11/2007	12/8/2009				Separation		0.4	0.13	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH728	W791-S3310	3/11/2007	10/5/2009				BOH		20.6	0.00	0.00		N/A	N/A
OH728		3/11/2007	10/5/2009				Hangup		16.0	0.00	0.00		N/A	N/A
OH728		3/11/2007	10/5/2009	2		5.6	Separation	2.80	5.6	1.00	1.00	S	33.3	0.39
OH728		3/11/2007	10/5/2009				Separation		5.5	0.25	0.38	N	12.5	0.15
OH728		3/11/2007	10/5/2009				Separation		1.5	0.13	0.00		N/A	N/A
OH729	W871-S3310	3/11/2007	10/5/2009				Separation		5.5	0.13	3.00	S	N/A	N/A
OH729		3/11/2007	10/5/2009	1		5.4	Separation	5.40	5.4	0.13	0.00		N/A	N/A
OH729		3/11/2007	10/5/2009				Separation		5.3	0.13	0.00		N/A	N/A
OH735	W396-S3650	8/31/2006	6/14/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH735		8/31/2006	6/14/2010				Separation		7.3	1.00	1.00	N	33.3	0.26
OH735		8/31/2006	6/14/2010				Separation		5.8	1.00	0.50	W	16.7	0.13
OH735		8/31/2006	6/14/2010	0		5.3	Separation	N/A	5.4	0.75	0.13	SE	4.2	0.03
OH736	W463-S3650	9/2/2006	3/16/2010				BOH		20.9	0.00	0.00		N/A	N/A
OH736		9/2/2006	3/16/2010				Separation		7.0	0.75	0.00		N/A	N/A
OH736		9/2/2006	3/16/2010				Separation		6.1	0.13	0.00		N/A	N/A
OH736		9/2/2006	3/16/2010	1		5.5	Separation	5.50	5.5	2.00	0.00		N/A	N/A
OH736		9/2/2006	3/16/2010				Separation		5.1	0.13	0.00		N/A	N/A
OH737	W534-S3650	8/31/2006	6/14/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH737		8/31/2006	6/14/2010				Hangup		15.4	0.00	0.00		N/A	N/A
OH737		8/31/2006	6/14/2010				Separation		6.1	2.00	0.25	N	8.3	0.07
OH737		8/31/2006	6/14/2010	2		5.7	Separation	2.85	5.7	0.50	1.75	N	58.3	0.46
OH737		8/31/2006	6/14/2010				Separation		5.4	0.25	0.00		N/A	N/A
OH737		8/31/2006	6/14/2010				Separation		4.8	0.25	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH738	W592-S3650	9/2/2006	6/14/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH738		9/2/2006	6/14/2010				Rough Spot		12.8	0.00	0.00		N/A	N/A
OH738		9/2/2006	6/14/2010				Separation		6.4	0.25	0.00		N/A	N/A
OH738		9/2/2006	6/14/2010	1		5.8	Separation	5.80	5.8	1.50	0.38	N	12.5	0.10
OH738		9/2/2006	6/14/2010				Separation		5.4	0.50	0.00		N/A	N/A
OH739	W660-S3650	1/27/2007	6/15/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH739		1/27/2007	6/15/2010				Separation		7.0	0.50	0.00		N/A	N/A
OH739		1/27/2007	6/15/2010	3		5.5	Separation	1.83	5.5	1.50	0.00		N/A	N/A
OH739		1/27/2007	6/15/2010				Separation		4.8	0.50	0.13	N	4.2	0.04
OH739		1/27/2007	6/15/2010				Separation		4.6	0.13	0.00		N/A	N/A
OH739		1/27/2007	6/15/2010				Separation		4.4	0.13	0.00		N/A	N/A
OH740	W725-S3650	1/27/2007	12/8/2009				BOH		22.9	0.00	0.00		N/A	N/A
OH740		1/27/2007	12/8/2009	2		5.9	Separation	2.95	5.9	1.00	1.50	N	50.0	0.52
OH740		1/27/2007	12/8/2009				Separation		5.6	0.13	0.00		N/A	N/A
OH740		1/27/2007	12/8/2009				Separation		5.4	0.13	0.00		N/A	N/A
OH741	W792-S3650	2/11/2007	9/22/2009				BOH		20.5	0.00	0.00		N/A	N/A
OH741		2/11/2007	9/22/2009				Separation		7.0	0.13	0.00		N/A	N/A
OH741		2/11/2007	9/22/2009				Separation		6.0	0.13	0.00		N/A	N/A
OH741		2/11/2007	9/22/2009	0		5.3	Separation	N/A	5.3	2.00	0.25	N	8.3	0.10
OH742	W862-S3650	3/5/2007	9/22/2009				BOH		20.4	0.00	0.00		N/A	N/A
OH742		3/5/2007	9/22/2009	2		5.4	Separation	2.70	5.4	0.13	0.50	S	16.7	0.20
OH742		3/5/2007	9/22/2009				Separation		5.1	0.25	0.00		N/A	N/A
OH742		3/5/2007	9/22/2009				Separation		4.8	0.38	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH901	W395-S2832	12/16/2008	6/1/2010				BOH		20.5	0.00	0.00		N/A	N/A
OH901		12/16/2008	6/1/2010	3		5.4	Separation	1.80	5.4	0.25	0.00		N/A	N/A
OH901		12/16/2008	6/1/2010				Separation		4.8	1.00	0.38	E	12.5	0.26
OH901		12/16/2008	6/1/2010				Separation		4.5	0.13	0.25	E	8.3	0.17
OH901		12/16/2008	6/1/2010				Separation		4.4	0.13	0.00		N/A	N/A
OH902	W395-S2912	12/16/2008	6/1/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH902		12/16/2008	6/1/2010	2		5.6	Separation	2.80	5.6	1.00	1.00	E	33.3	0.69
OH902		12/16/2008	6/1/2010				Separation		5.1	0.13	0.00		N/A	N/A
OH902		12/16/2008	6/1/2010				Separation		4.3	0.13	0.00		N/A	N/A
OH903	W395-S2994	12/16/2008	6/2/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH903		12/16/2008	6/2/2010	3		4.8	Separation	1.60	4.8	0.50	0.75	E	25.0	0.51
OH903		12/16/2008	6/2/2010				Separation		4.4	0.25	1.00	E	33.3	0.68
OH903		12/16/2008	6/2/2010				Separation		1.7	0.06	0.00		N/A	N/A
OH903		12/16/2008	6/2/2010				Separation		0.4	0.25	0.13	E	4.2	0.09
OH904	W525-S2843	12/16/2008	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH904		12/16/2008	6/1/2010	1		5.3	Separation	5.30	5.3	0.13	0.38	E	12.5	0.26
OH904		12/16/2008	6/1/2010				Separation		1.0	0.06	0.00		N/A	N/A
OH905	W525-S2912	3/12/2009	6/1/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH905		3/12/2009	6/1/2010	2		5.9	Separation	2.95	5.9	0.50	0.00		N/A	N/A
OH905		3/12/2009	6/1/2010				Separation		4.9	0.13	0.00		N/A	N/A
OH905		3/12/2009	6/1/2010				Separation		1.6	0.13	0.00		N/A	N/A
OH906	W525-S2994	3/12/2009	6/1/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH906		3/12/2009	6/1/2010	0		5.3	Separation	N/A	5.3	2.00	0.50	SE	16.7	0.41

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH907	W656-S2800	6/5/2009	6/1/2010				BOH		20.7	0.00	0.00		N/A	N/A
OH907		6/5/2009	6/1/2010	2		5.3	Separation	2.65	5.3	0.75	0.25	E	8.3	0.25
OH907		6/5/2009	6/1/2010				Separation		5.2	0.13	0.00		N/A	N/A
OH907		6/5/2009	6/1/2010				Separation		1.1	0.13	0.00		N/A	N/A
OH908	W656-S2895	6/5/2009	6/1/2010				BOH		20.7	0.00	0.00		N/A	N/A
OH908		6/5/2009	6/1/2010	0		5.1	Separation	N/A	5.1	0.50	0.06	E	2.1	0.06
OH909	W656-S3000	6/5/2009	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH909		6/5/2009	6/1/2010	0		5.3	Separation	N/A	5.3	1.00	0.38	E	12.5	0.38
OH910	W790-S2800	9/17/2009	6/1/2010				BOH		20.2	0.00	0.00		N/A	N/A
OH910		9/17/2009	6/1/2010	1		5.4	Separation	5.40	5.4	1.00	0.00		N/A	N/A
OH910		9/17/2009	6/1/2010				Separation		5.3	0.13	0.00		N/A	N/A
OH911	W790-S2895	9/17/2009	6/1/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH911		9/17/2009	6/1/2010	1		5.4	Separation	5.40	5.4	0.75	0.00		N/A	N/A
OH911		9/17/2009	6/1/2010				Separation		5.2	0.13	0.00		N/A	N/A
OH912	W790-S3000	9/17/2009	6/1/2010				BOH		20.5	0.00	0.00		N/A	N/A
OH912		9/17/2009	6/1/2010	2		5.5	Separation	2.75	5.5	0.50	0.06	E	2.1	0.09
OH912		9/17/2009	6/1/2010				Separation		5.3	0.13	0.00		N/A	N/A
OH912		9/17/2009	6/1/2010				Separation		5.1	0.13	0.00		N/A	N/A
OH913	W920-S2800	9/17/2009	6/1/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH913		9/17/2009	6/1/2010	1		5.1	Separation	5.10	5.1	0.50	0.06	W	2.1	0.09
OH913		9/17/2009	6/1/2010				Separation		4.5	0.13	0.06	S	2.1	0.09
OH914	W920-S2895	9/17/2009	6/1/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH914		9/17/2009	6/1/2010	0		5.1	Separation	N/A	5.1	1.00	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH915	W920-S3000	9/17/2009	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH915		9/17/2009	6/1/2010	3		5.5	Separation	1.83	5.5	0.25	0.25	E	8.3	0.36
OH915		9/17/2009	6/1/2010				Separation		5.4	0.13	0.00		N/A	N/A
OH915		9/17/2009	6/1/2010				Rough Spot		4.5	0.00	0.00		N/A	N/A
OH915		9/17/2009	6/1/2010				Separation		4.0	0.13	0.00		N/A	N/A
OH916	W1060-S2842	12/16/2009	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH916		12/16/2009	6/1/2010	0		5.2	Separation	N/A	5.2	0.13	0.00		N/A	N/A
OH917	W1060-S2918	12/16/2009	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH917		12/16/2009	6/1/2010	0		4.6	Separation	N/A	4.6	1.00	0.06	E	2.1	0.14
OH918	W1060-S2993	12/16/2009	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH918		12/16/2009	6/1/2010				Separation		6.6	0.13	0.00		N/A	N/A
OH918		12/16/2009	6/1/2010	0		5.1	Separation	N/A	5.1	0.19	0.06	E	2.1	0.14
OH919	W1195-S2837	12/16/2009	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH919		12/16/2009	6/1/2010				Rough Spot		6.7	0.00	0.13	E	4.2	0.27
OH919		12/16/2009	6/1/2010	0		5.3	Separation	N/A	5.3	0.25	0.13	W	4.2	0.27
OH920	W1195-S2921	12/16/2009	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH920		12/16/2009	6/1/2010	0		5.0	Separation	N/A	5.0	0.25	0.13	E	4.2	0.27
OH921	W1195-S2990	12/16/2009	6/1/2010				BOH		20.5	0.00	0.00		N/A	N/A
OH921		12/16/2009	6/1/2010				Separation		6.5	0.13	0.13	E	4.2	0.27
OH921		12/16/2009	6/1/2010	0		5.1	Separation	N/A	5.1	0.13	0.13	W	4.2	0.27

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH922	S2750-W394	12/26/2008	6/1/2010				Separation		15.8	0.25	0.00		N/A	N/A
OH922		12/26/2008	6/1/2010				Separation		7.0	0.25	0.00		N/A	N/A
OH922		12/26/2008	6/1/2010				Separation		5.6	0.25	1.25	S	41.7	0.87
OH922		12/26/2008	6/1/2010	1		5.3	Separation	5.30	5.3	0.50	1.00	S	33.3	0.70
OH922		12/26/2008	6/1/2010				Hangup		3.5	0.00	0.00		N/A	N/A
OH922		12/26/2008	6/1/2010				Separation		1.0	1.00	0.50	SW	16.7	0.35
OH923	S2750-W461	12/26/2008	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH923		12/26/2008	6/1/2010				Separation		5.8	0.25	0.00		N/A	N/A
OH923		12/26/2008	6/1/2010				Separation		5.6	0.25	0.00		N/A	N/A
OH923		12/26/2008	6/1/2010	4		5.3	Separation	1.33	5.3	0.25	1.00	S	33.3	0.70
OH923		12/26/2008	6/1/2010				Separation		5.1	0.25	0.25	N	8.3	0.17
OH923		12/26/2008	6/1/2010				Separation		3.5	0.25	0.13	S	4.2	0.09
OH923		12/26/2008	6/1/2010				Separation		2.9	0.13	0.13	S	4.2	0.09
OH923		12/26/2008	6/1/2010				Rough Spot		1.4	0.00	0.13	S	4.2	0.09
OH923		12/26/2008	6/1/2010				Separation		1.3	0.50	1.00	S	33.3	0.70
OH924	S2750-W528	12/26/2008	6/2/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH924		12/26/2008	6/2/2010				Separation		5.5	1.25	0.25	S	8.3	0.17
OH924		12/26/2008	6/2/2010	1		5.0	Separation	5.00	5.0	0.13	0.75	S	25.0	0.52
OH924		12/26/2008	6/2/2010				Separation		0.9	0.19	0.38	S	12.5	0.26

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH925	S2750-W618	12/26/2008	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH925		12/26/2008	6/1/2010	2		5.0	Separation	2.50	5.0	0.25	1.00	S	33.3	0.70
OH925		12/26/2008	6/1/2010				Separation		4.9	0.13	0.00		N/A	N/A
OH925		12/26/2008	6/1/2010				Separation		3.9	0.13	0.00		N/A	N/A
OH926	S2750-W656	6/5/2009	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH926		6/5/2009	6/1/2010	1		5.3	Separation	5.30	5.3	1.00	1.50	S	50.0	1.52
OH926		6/5/2009	6/1/2010				Separation		1.0	0.13	0.13	S	4.2	0.13
OH927	S2750-W725	6/5/2009	6/1/2010				BOH		20.1	0.00	0.00		N/A	N/A
OH927		6/5/2009	6/1/2010				Separation		6.4	0.13	0.00		N/A	N/A
OH927		6/5/2009	6/1/2010				Separation		6.0	0.13	0.13	S	4.2	0.13
OH927		6/5/2009	6/1/2010	1		4.9	Separation	4.90	4.9	0.25	0.00		N/A	N/A
OH927		6/5/2009	6/1/2010				Separation		0.8	0.13	0.13	S	4.2	0.13
OH928	S2750-W790	6/5/2009	6/1/2010				BOH		20.2	0.00	0.00		N/A	N/A
OH928		6/5/2009	6/1/2010				Hangup		15.6	0.00	0.13	S	4.2	0.13
OH928		6/5/2009	6/1/2010				Separation		6.8	0.25	0.75	S	25.0	0.76
OH928		6/5/2009	6/1/2010	0		6.5	Separation	N/A	6.5	0.13	0.75	S	25.0	0.76
OH929	S2750-W860	6/5/2009	6/1/2010				BOH		20.0	0.00	0.00		N/A	N/A
OH929		6/5/2009	6/1/2010				Hangup		6.8	0.00	0.00		N/A	N/A
OH929		6/5/2009	6/1/2010	0		5.3	Separation	N/A	5.3	0.25	0.13	S	4.2	0.13
OH930	S2750-W920	6/5/2009	6/1/2010				BOH		20.8	0.00	0.00		N/A	N/A
OH930		6/5/2009	6/1/2010				Rough Spot		15.7	0.00	0.00		N/A	N/A
OH930		6/5/2009	6/1/2010				Separation		6.6	0.13	0.25	S	8.3	0.25
OH930		6/5/2009	6/1/2010				Separation		6.0	0.13	0.25	S	8.3	0.25
OH930		6/5/2009	6/1/2010	0		5.3	Separation	N/A	5.3	0.25	1.00	S	33.3	1.01

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH931	S2750-W985	6/5/2009	3/2/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH931		6/5/2009	3/2/2010	0		5.8	Separation	N/A	5.8	0.13	0.00		N/A	N/A
OH932	S2750-W1060	6/5/2009	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH932		6/5/2009	6/1/2010				Separation		15.8	0.13	1.25	S	41.7	1.26
OH932		6/5/2009	6/1/2010				Separation		6.4	0.13	0.06	S	2.1	0.06
OH932		6/5/2009	6/1/2010	0		5.8	Separation	N/A	5.8	0.13	0.00		N/A	N/A
OH933	S2750-W1125	6/5/2009	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH933		6/5/2009	6/1/2010	0		5.6	Separation	N/A	5.6	0.25	0.13	SE	N/A	N/A
OH934	S2750-W1185	6/5/2009	3/2/2010				BOH		20.2	0.00	0.00		N/A	N/A
OH934		6/5/2009	3/2/2010				Separation		6.1	0.13	0.00		N/A	N/A
OH934		6/5/2009	3/2/2010				Separation		5.8	0.13	0.38	NE	12.5	0.51
OH934		6/5/2009	3/2/2010	0		5.5	Separation	N/A	5.5	0.13	0.25	NE	8.3	0.34
OH935	S3080-W395	12/26/2008	6/1/2010				BOH		21.5	0.00	0.00		N/A	N/A
OH935		12/26/2008	6/1/2010				Separation		5.6	0.50	1.00	NW	33.3	0.70
OH935		12/26/2008	6/1/2010	1		5.2	Separation	5.20	5.2	0.25	0.50	NW	16.7	0.35
OH935		12/26/2008	6/1/2010				Separation		5.1	0.25	0.00		N/A	N/A
OH936	S3080-W463	12/26/2008	6/1/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH936		12/26/2008	6/1/2010	1		5.5	Separation	5.50	5.5	1.00	0.75	S	25.0	0.52
OH936		12/26/2008	6/1/2010				Separation		1.3	1.00	1.50	S	50.0	1.05

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH937	S3080-W525	12/26/2008	6/2/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH937		12/26/2008	6/2/2010	4		5.4	Separation	1.35	5.4	1.50	1.25	N	41.7	0.87
OH937		12/26/2008	6/2/2010				Separation		5.0	0.25	0.00		N/A	N/A
OH937		12/26/2008	6/2/2010				Separation		4.9	0.13	0.00		N/A	N/A
OH937		12/26/2008	6/2/2010				Separation		1.1	0.13	0.00		N/A	N/A
OH937		12/26/2008	6/2/2010				Separation		0.7	0.13	0.00		N/A	N/A
OH938	S3080-W590	12/26/2008	6/2/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH938		12/26/2008	6/2/2010				Separation		5.8	1.00	0.25	S	8.3	0.17
OH938		12/26/2008	6/2/2010				Separation		5.5	1.00	0.00		N/A	N/A
OH938		12/26/2008	6/2/2010	2		5.0	Separation	2.50	5.0	1.00	0.25	N	8.3	0.17
OH938		12/26/2008	6/2/2010				Separation		4.8	0.13	0.00		N/A	N/A
OH938		12/26/2008	6/2/2010				Separation		1.0	0.13	0.25	S	8.3	0.17
OH939	S3080-W660	3/12/2009	6/2/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH939		3/12/2009	6/2/2010				Separation		5.6	0.25	0.00		N/A	N/A
OH939		3/12/2009	6/2/2010	0		5.4	Separation	N/A	5.4	2.00	0.50	NW	N/A	N/A
OH940	S3080-W730	3/12/2009	6/2/2010				BOH		20.4	0.00	0.00		N/A	N/A
OH940		3/12/2009	6/2/2010				Rough Spot		16.5	0.00	0.00		N/A	N/A
OH940		3/12/2009	6/2/2010	4		5.8	Separation	1.45	5.8	0.75	0.25	S	8.3	0.20
OH940		3/12/2009	6/2/2010				Separation		5.5	0.50	0.00		N/A	N/A
OH940		3/12/2009	6/2/2010				Separation		4.7	0.38	0.13	NW	4.2	0.10
OH940		3/12/2009	6/2/2010				Hangup		3.5	0.00	0.00		N/A	N/A
OH940		3/12/2009	6/2/2010				Separation		1.5	0.25	0.13	S	4.2	0.10
OH940		3/12/2009	6/2/2010				Separation		0.4	0.25	0.00		N/A	N/A

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH941	S3080-W790	6/5/2009	6/2/2010				BOH		21.8	0.00	0.00		N/A	N/A
OH941		6/5/2009	6/2/2010				Rough Spot		16.0	0.00	0.00		N/A	N/A
OH941		6/5/2009	6/2/2010				Separation		5.4	0.25	0.00		N/A	N/A
OH941		6/5/2009	6/2/2010	3		4.9	Separation	1.63	5.3	0.50	0.00		N/A	N/A
OH941		6/5/2009	6/2/2010				Separation		4.9	1.00	0.75	NM	25.0	0.76
OH941		6/5/2009	6/2/2010				Separation		4.6	0.25	0.00		N/A	N/A
OH941		6/5/2009	6/2/2010				Separation		4.5	0.25	0.00		N/A	N/A
OH942	S3080-W860	6/5/2009	6/2/2010				BOH		21.8	0.00	0.00		N/A	N/A
OH942		6/5/2009	6/2/2010				Hangup		15.7	0.00	0.00		N/A	N/A
OH942		6/5/2009	6/2/2010	2		4.6	Separation	2.30	4.6	0.25	0.50	NW	16.7	0.50
OH942		6/5/2009	6/2/2010				Separation		4.3	0.25	0.25	N	8.3	0.25
OH942		6/5/2009	6/2/2010				Separation		4.2	0.25	0.00		N/A	N/A
OH943	S3080-W920	9/19/2009	6/1/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH943		9/19/2009	6/1/2010				Separation		15.3	0.13	0.00		N/A	N/A
OH943		9/19/2009	6/1/2010	0		5.0	Separation	N/A	5.0	1.00	1.00	N	33.3	1.43
OH944	S3080-W980	9/18/2009	6/1/2010				BOH		20.2	0.00	0.00		N/A	N/A
OH944		9/18/2009	6/1/2010	0		5.3	Separation	N/A	5.3	1.00	0.00		N/A	N/A
OH945	S3080-W1060	9/18/2009	6/1/2010				BOH		20.2	0.00	0.00		N/A	N/A
OH945		9/18/2009	6/1/2010				Rough Spot		15.5	0.00	0.00		N/A	N/A
OH945		9/18/2009	6/1/2010				Separation		5.7	0.25	0.00		N/A	N/A
OH945		9/18/2009	6/1/2010	0		5.2	Separation	N/A	5.2	0.25	1.00	NW	33.3	1.43
OH946	S3080-W1120	9/18/2009	6/1/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH946		9/18/2009	6/1/2010	0		5.3	Separation	N/A	5.3	0.25	0.13	NE	4.2	0.18

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

Table 6-1

Observation Borehole Fractures and Offset Data Summary

Hole	Location	Initial Inspection Date	Recent Inspection Date	FR[1]	FZ[2]	Beam Height (ft)	Feature	Fracture Density[3]	Feature Depth (ft)	Separation (in)	Offset (in.)	Compass	Hole Closure (%)	Offset Rate (in/yr)
OH947	S3080-W1185	9/18/2009	6/1/2010				BOH		20.3	0.00	0.00		N/A	N/A
OH947		9/18/2009	6/1/2010				Rough Spot		15.3	0.00	0.00		N/A	N/A
OH947		9/18/2009	6/1/2010	0		5.3	Separation	N/A	5.3	0.25	1.00	NE	33.3	1.43

[1] Number of fractures (FR) in immediate roof beam

[2] Number of fracture zones (FZ) in immediate roof beam

[3] Fracture Density = (FR + 2 FZ)/Beam Height

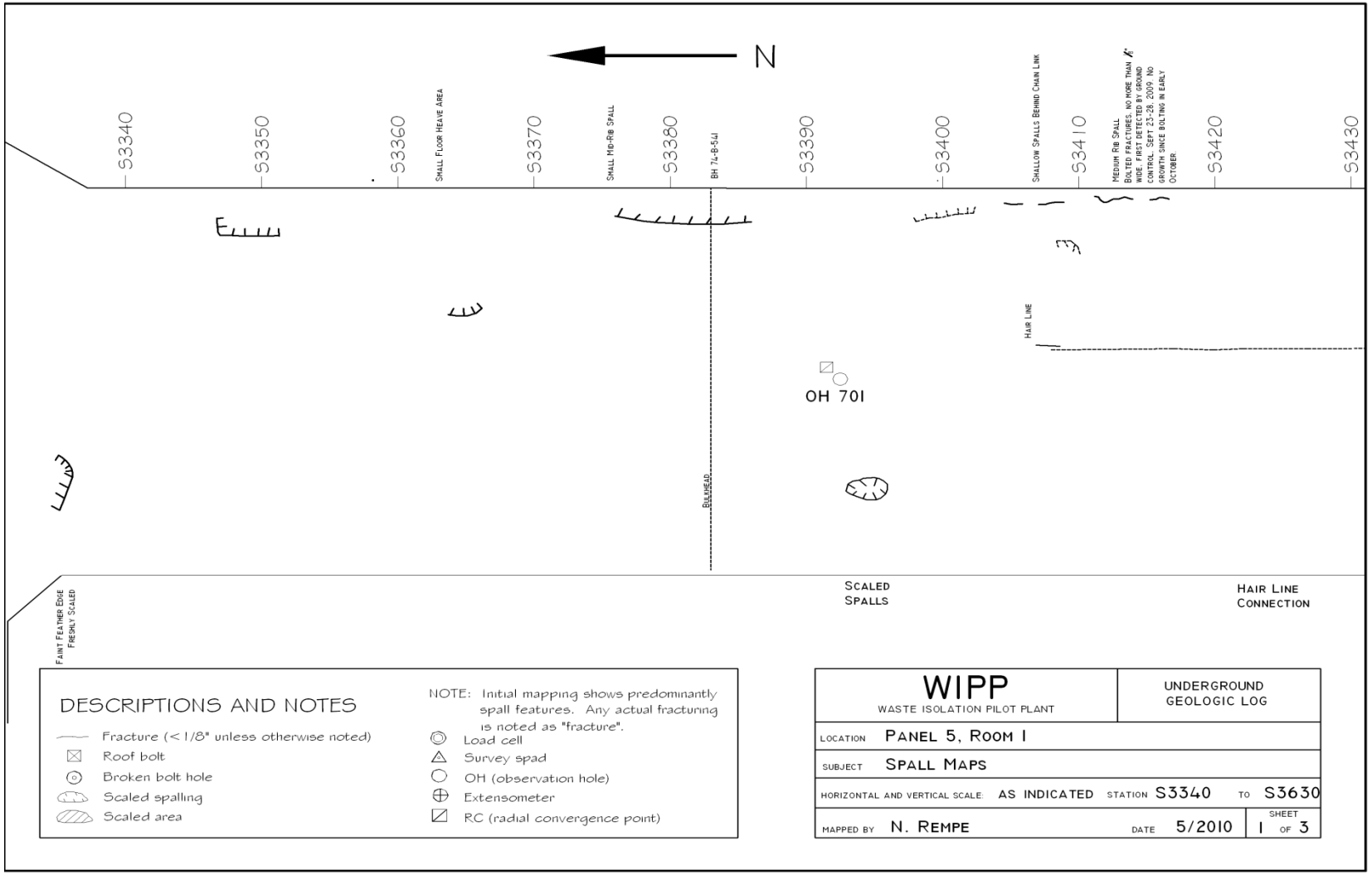


Figure 6-1
Panel 5 Room 1, S3340-S3630 Roof Fractures (Sheet 1 of 3)

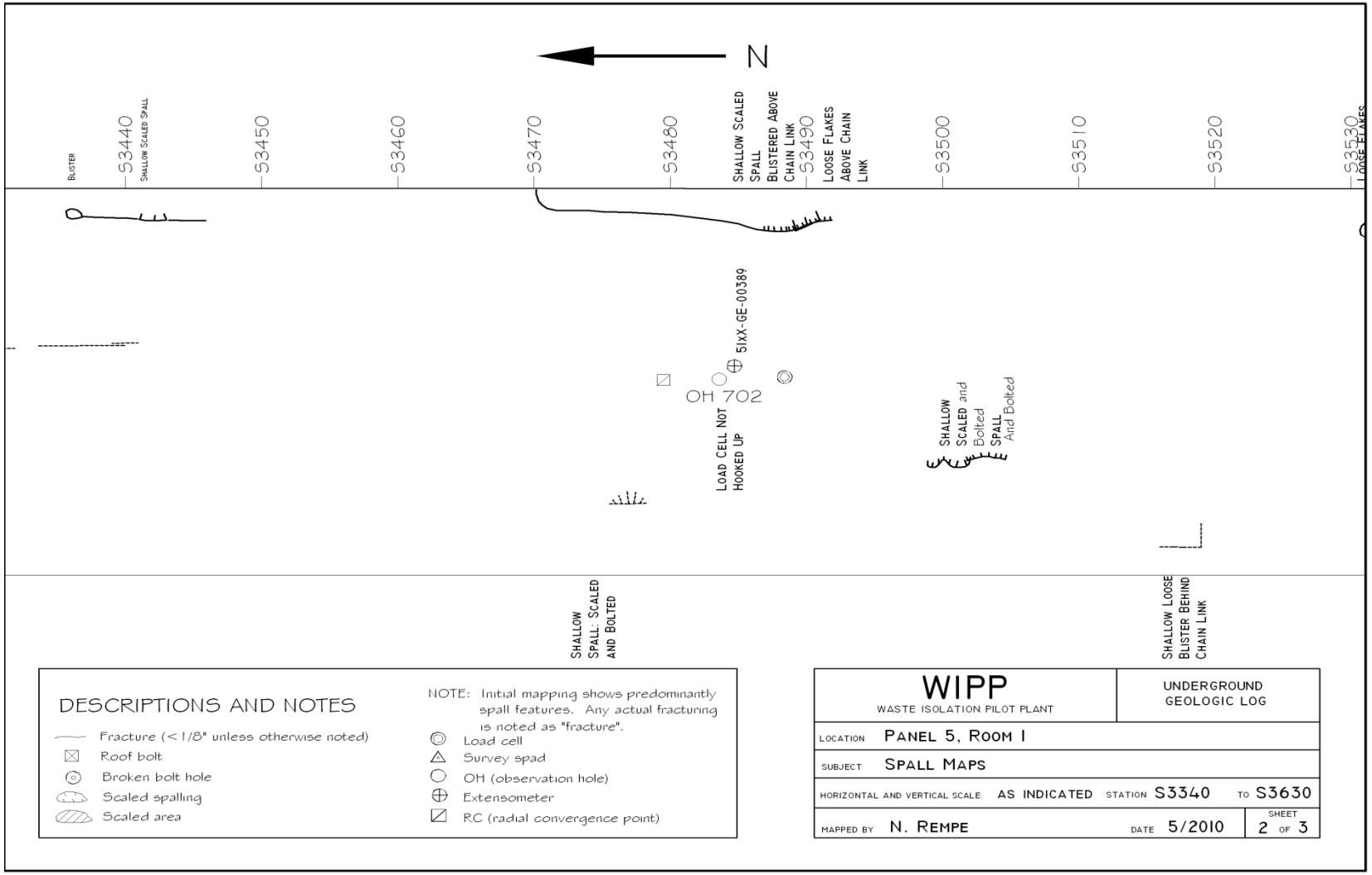


Figure 6-2
Panel 5 Room 1, S3340-S3630 Roof Fractures (Sheet 2 of 3)

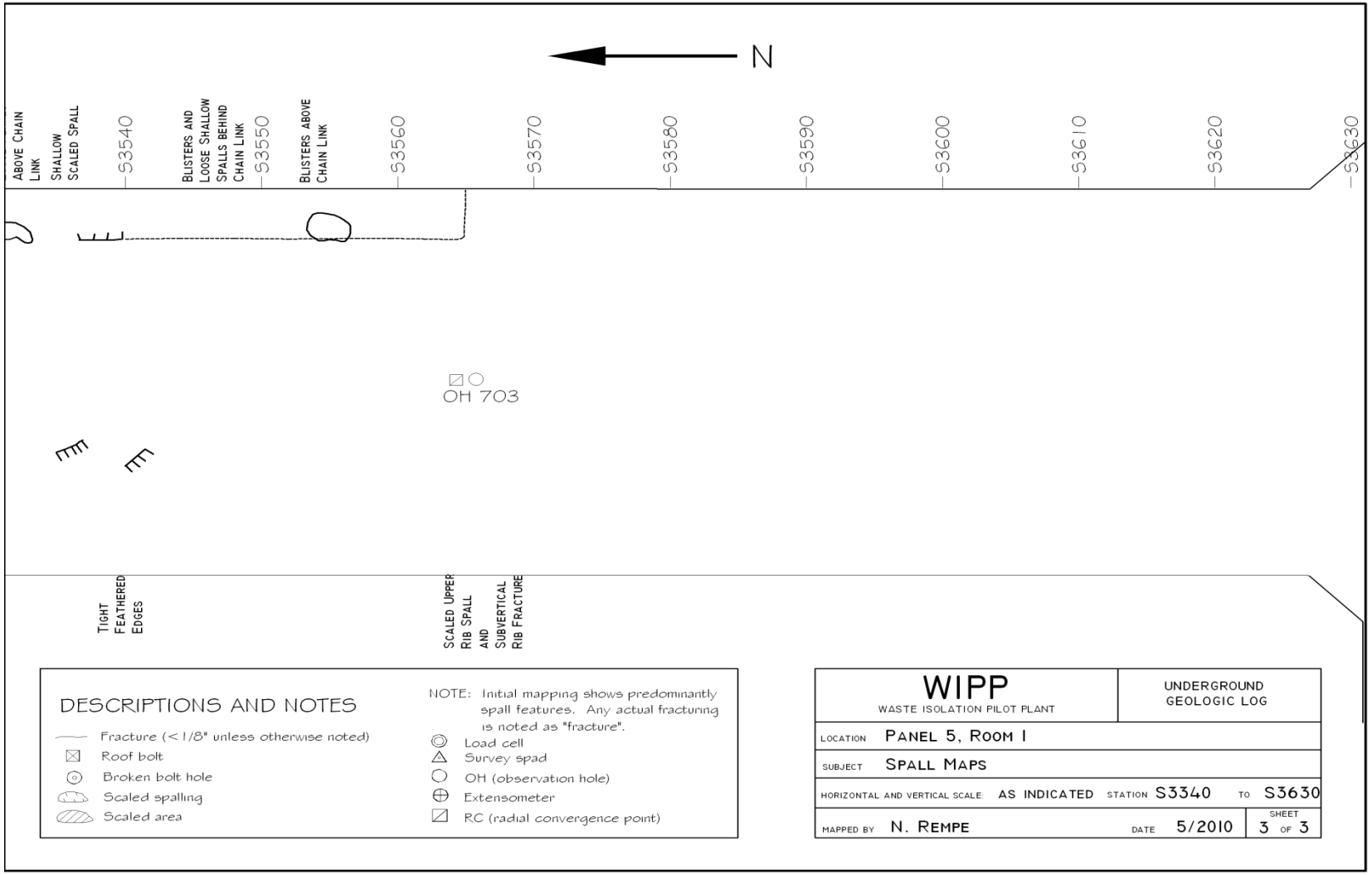


Figure 6-3
Panel 5 Room 1, S3340-S3630 Roof Fractures (Sheet 3 of 3)

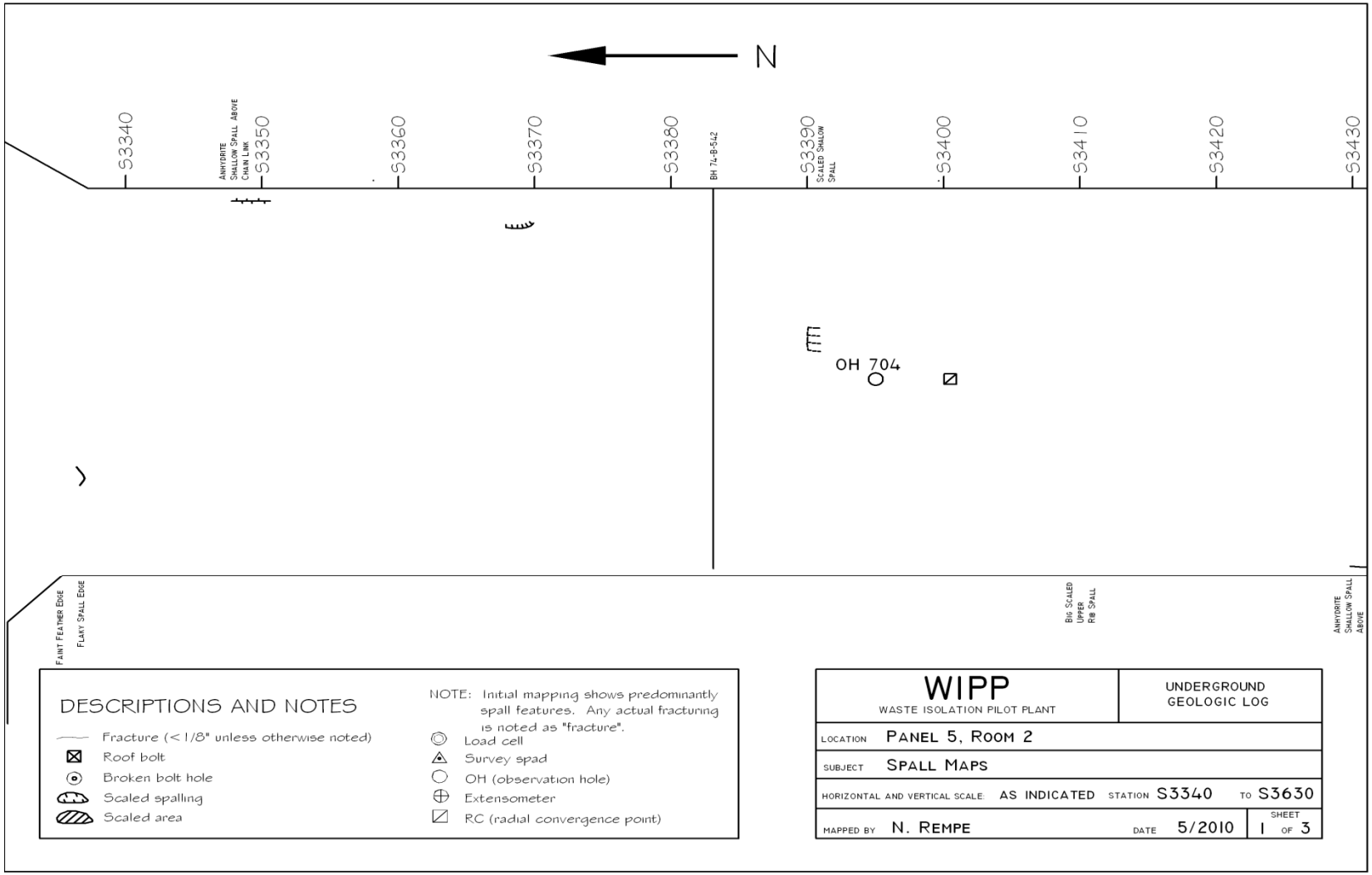


Figure 6-4
Panel 5 Room 2, S3340-S3630 Roof Fractures (Sheet 1 of 3)

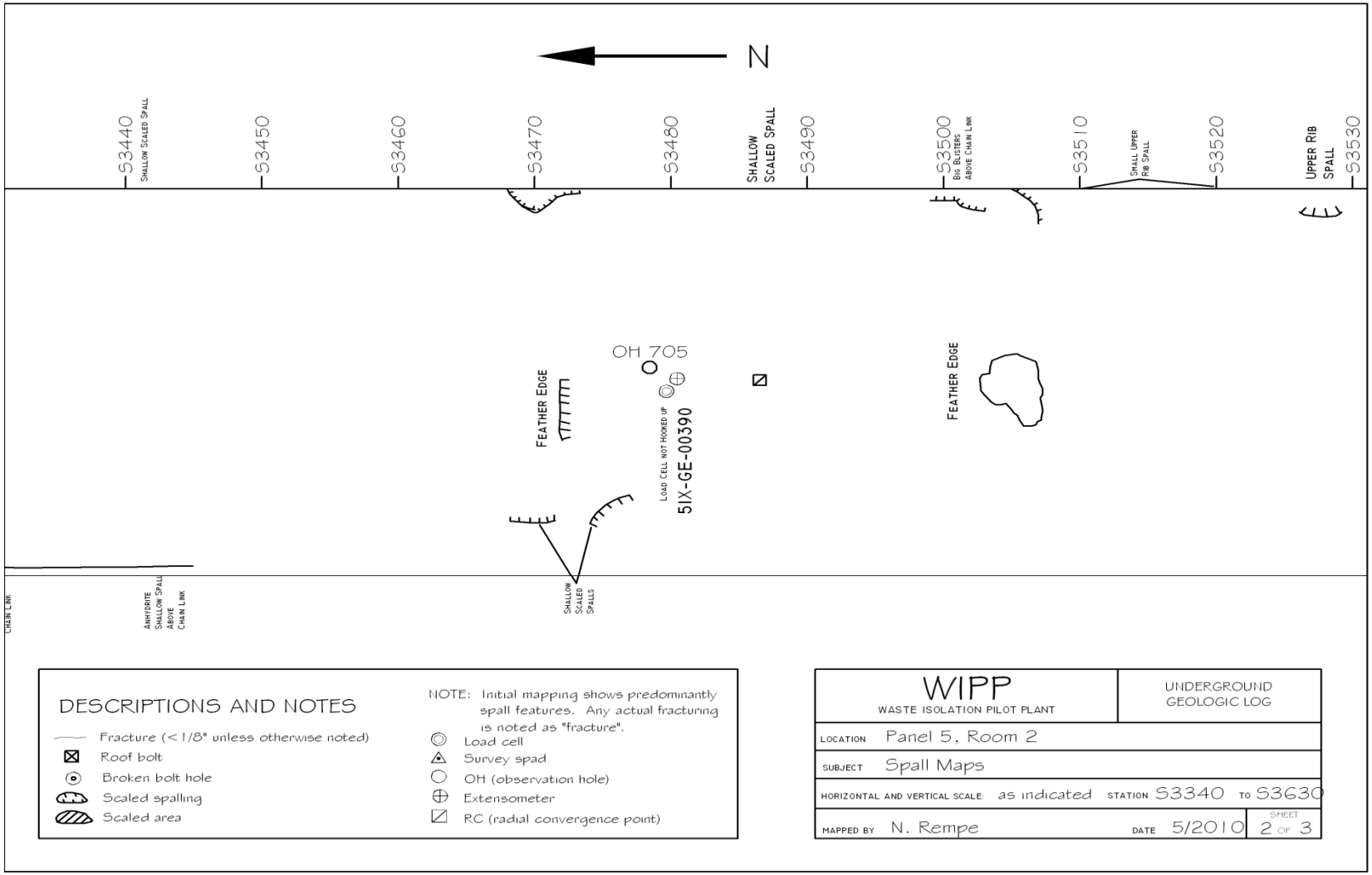


Figure 6-5
Panel 5 Room 2, S3340-S3630 Roof Fractures (Sheet 2 of 3)

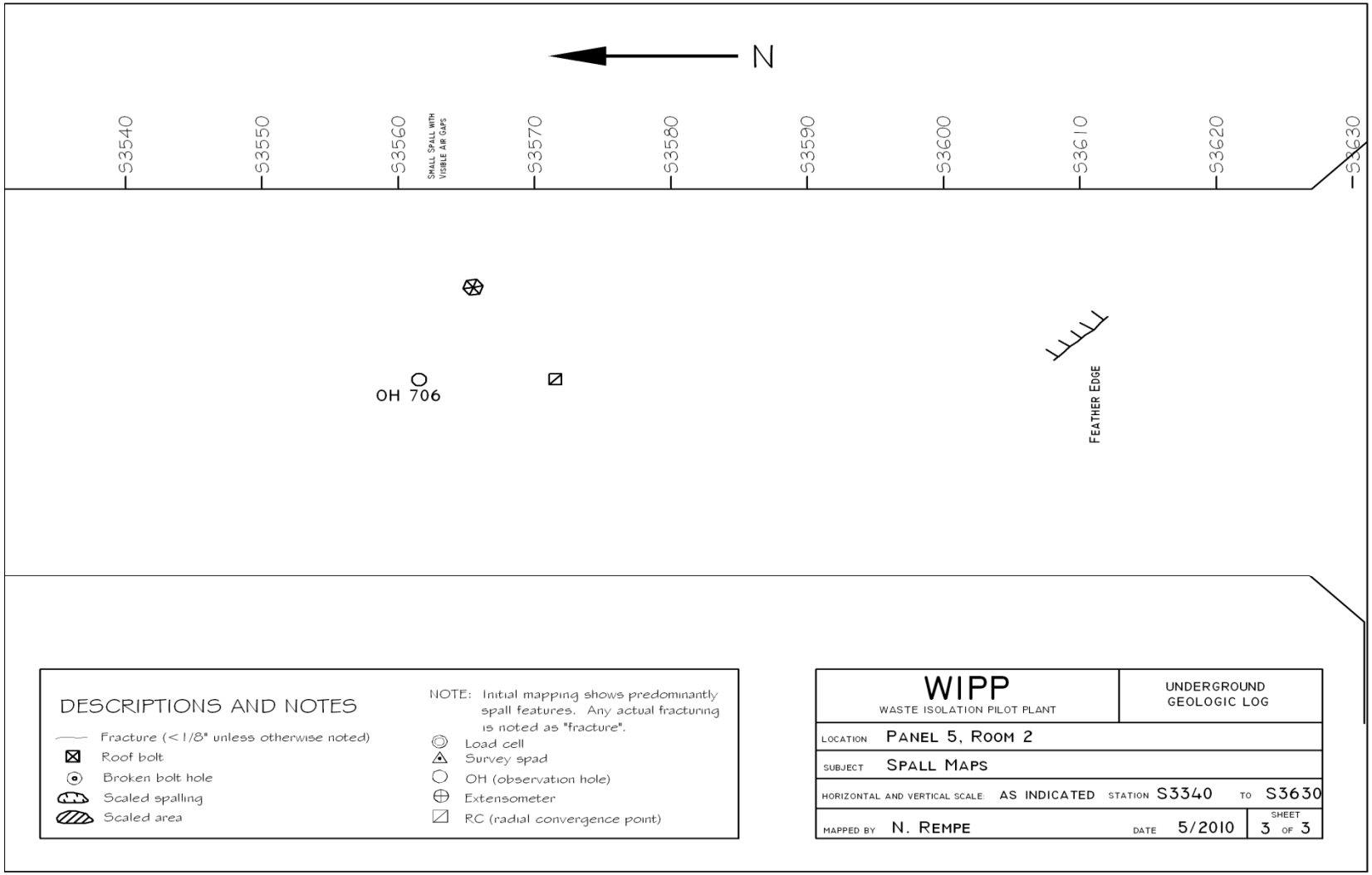


Figure 6-6
Panel 5 Room 2, S3340-S3630 Roof Fractures (Sheet 3 of 3)

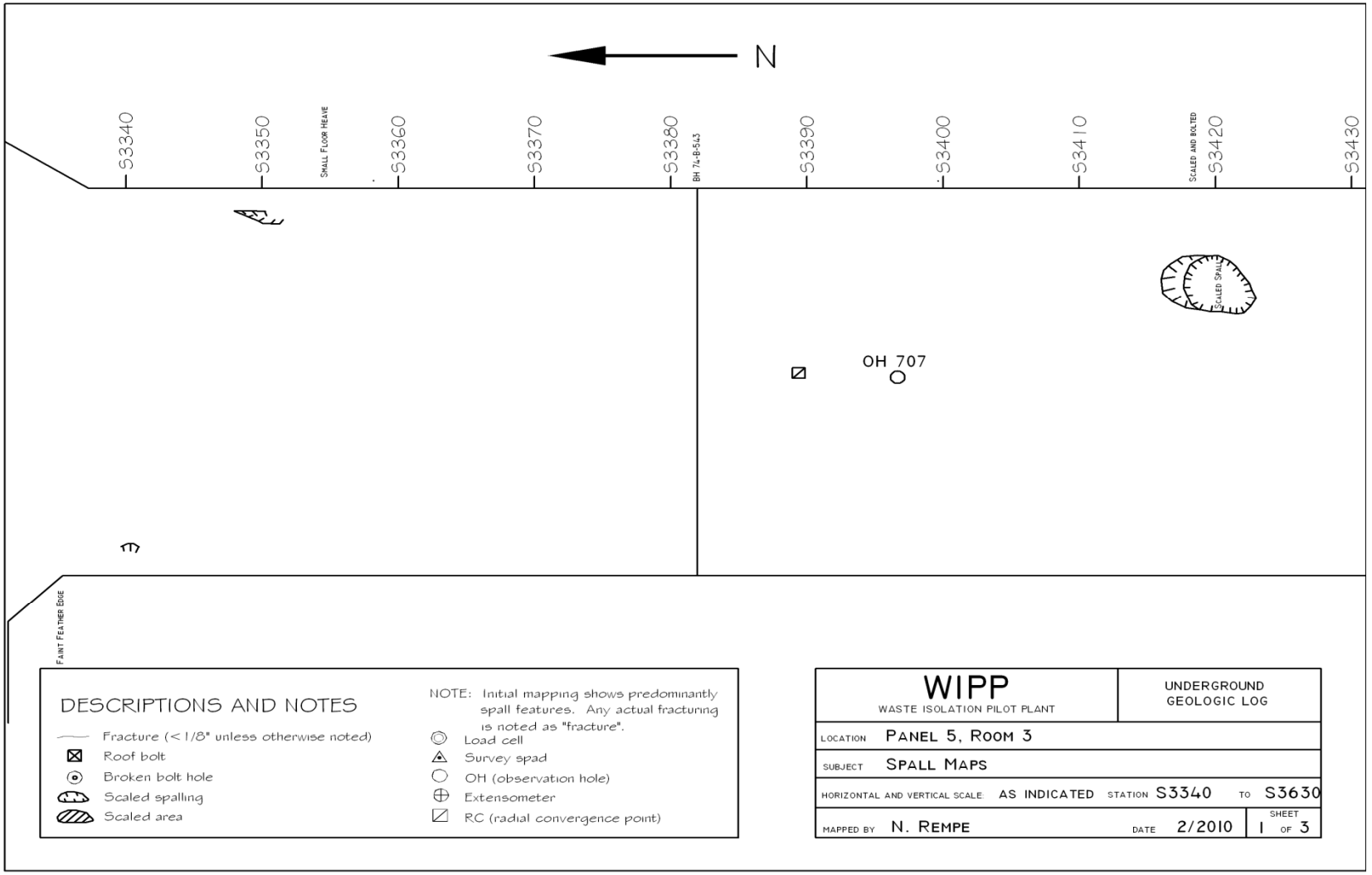


Figure 6-7
Panel 5 Room 3, S3340-S3630 Roof Fractures (Sheet 1 of 3)

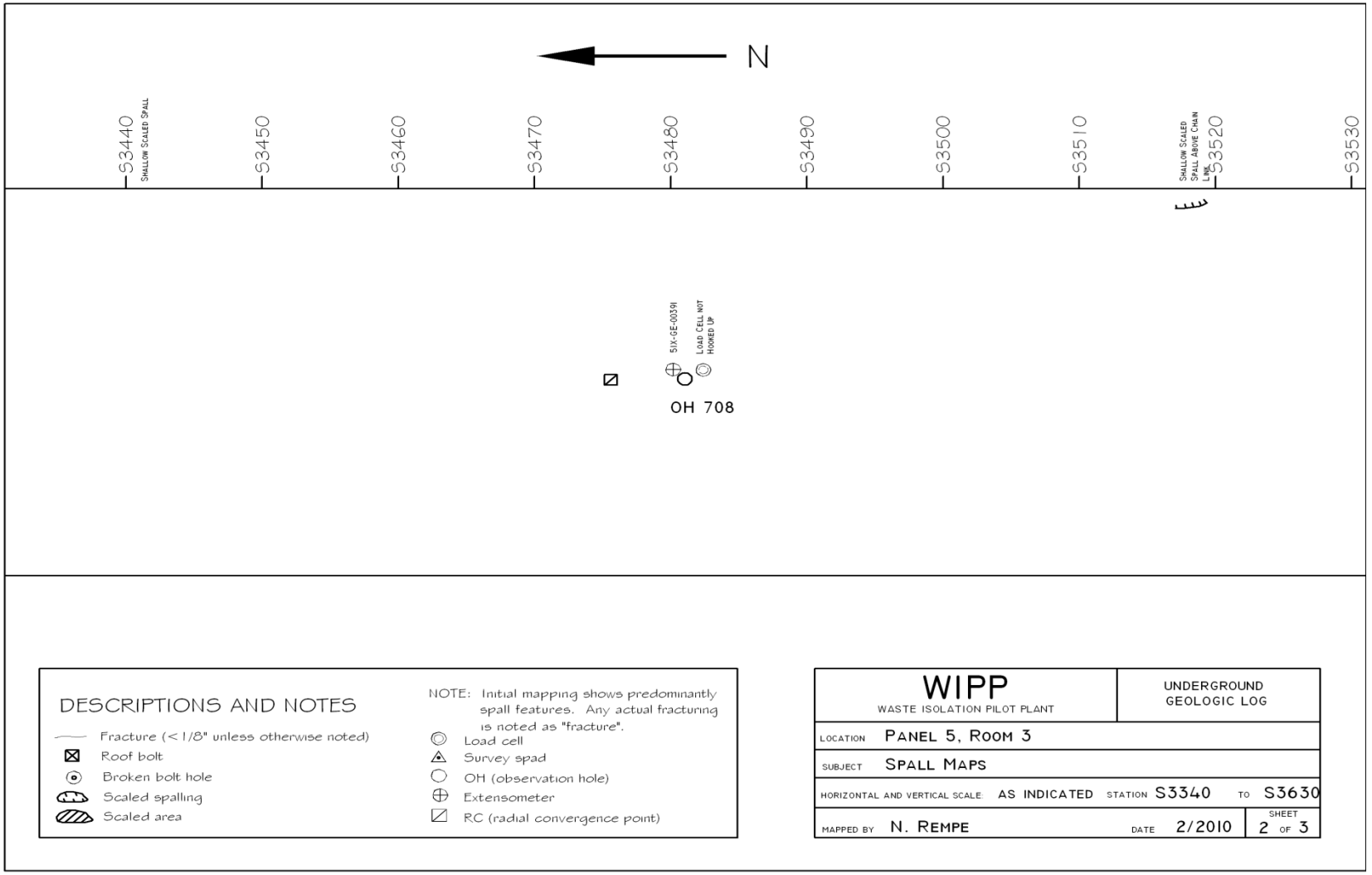


Figure 6-8
Panel 5 Room 3, S3340-S3630 Roof Fractures (Sheet 2 of 3)

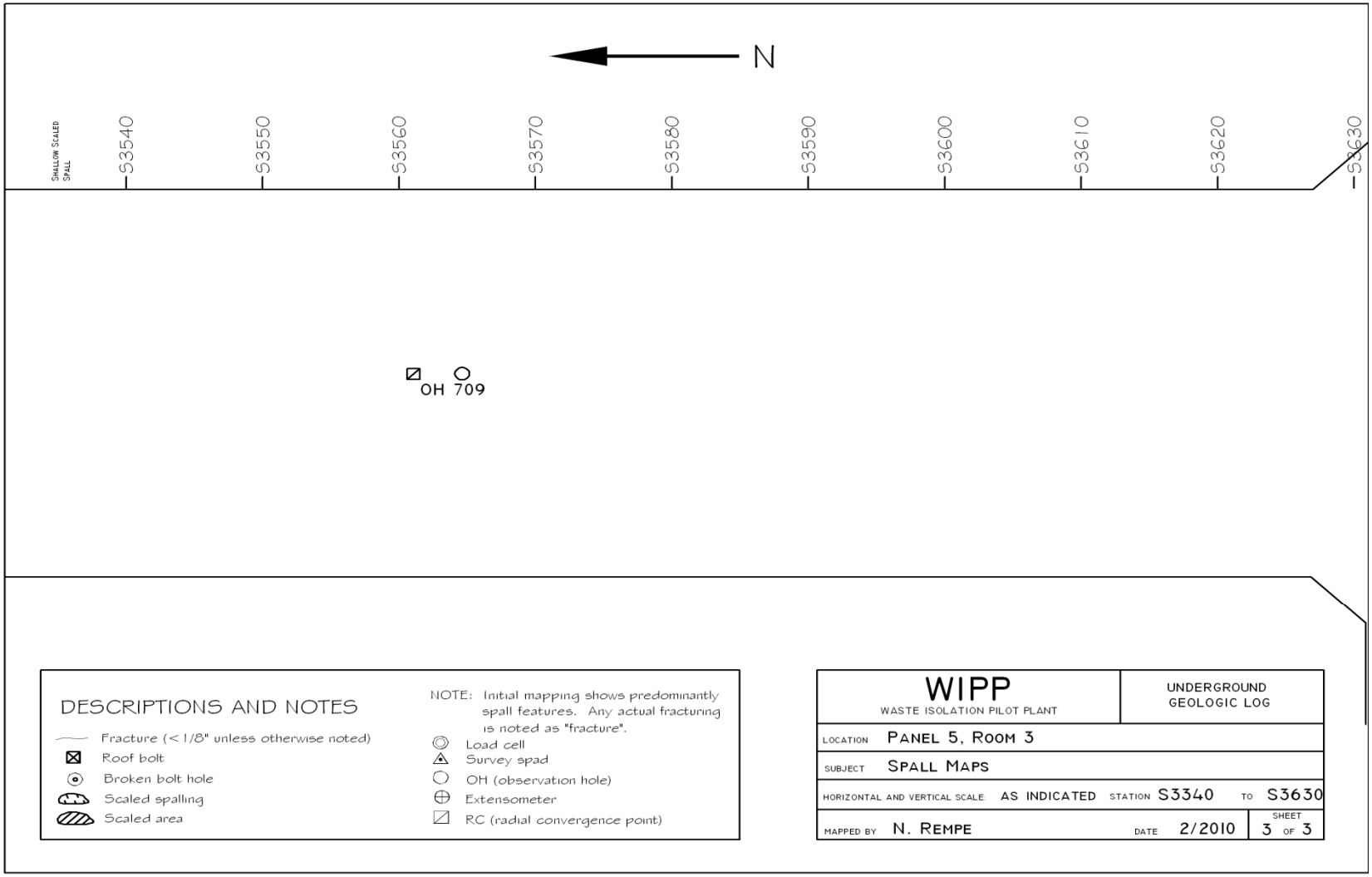


Figure 6-9
Panel 5 Room 3, S3340-S3630 Roof Fractures (Sheet 3 of 3)

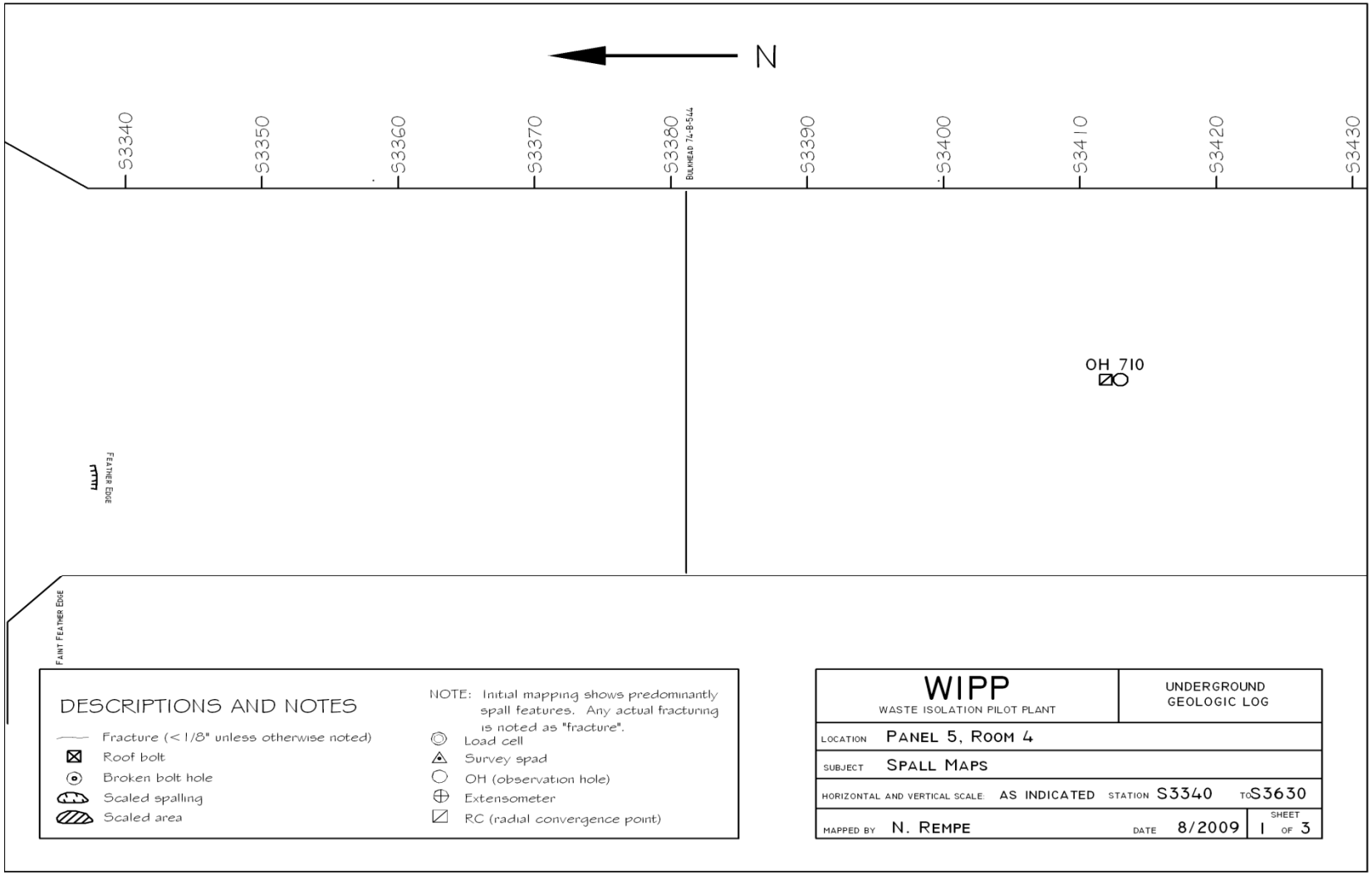


Figure 6-10
Panel 5 Room 4, S3340-S3630 Roof Fractures (Sheet 1 of 3)

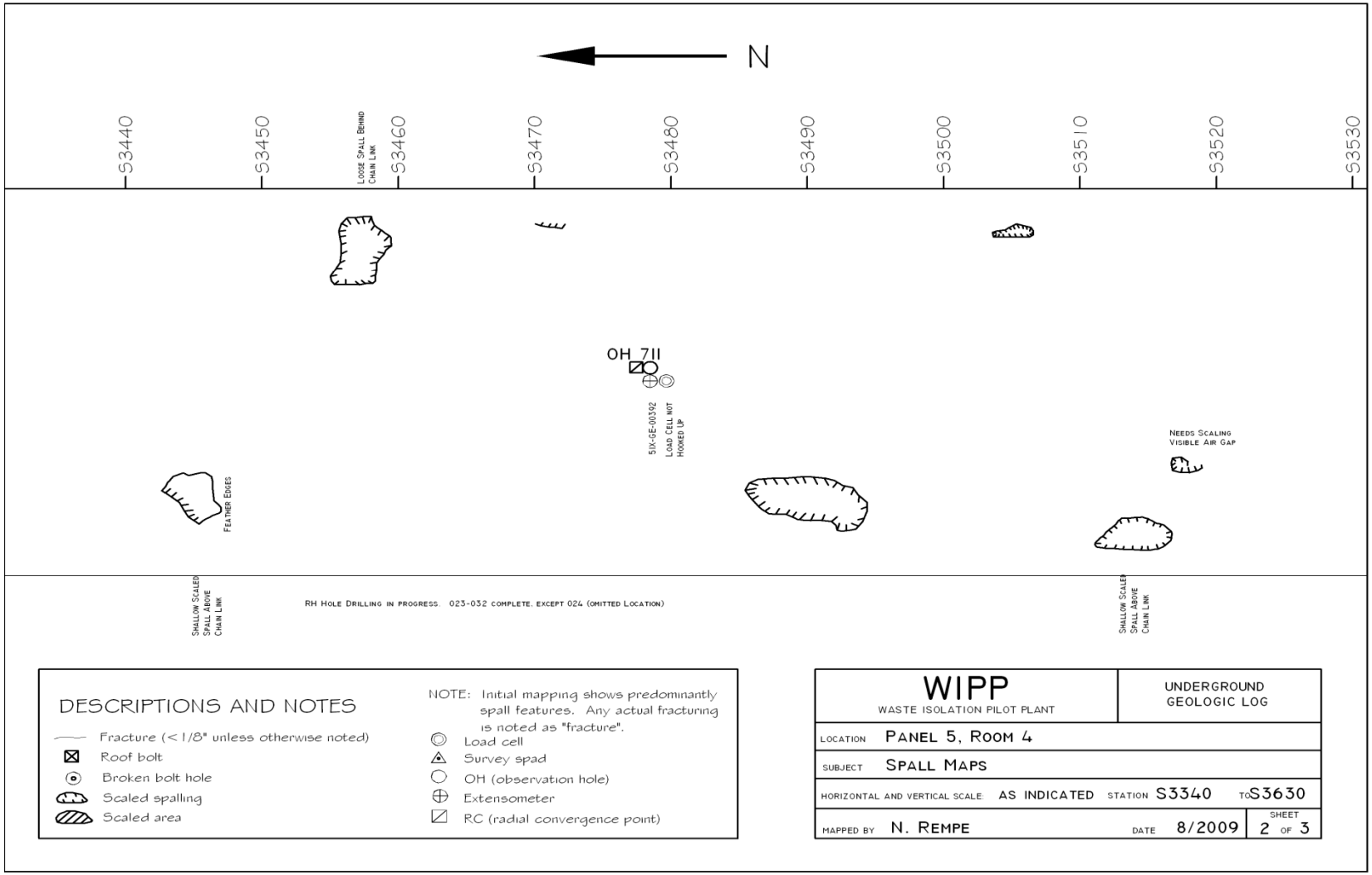


Figure 6-11
Panel 5 Room 4, S3340-S3630 Roof Fractures (Sheet 2 of 3)

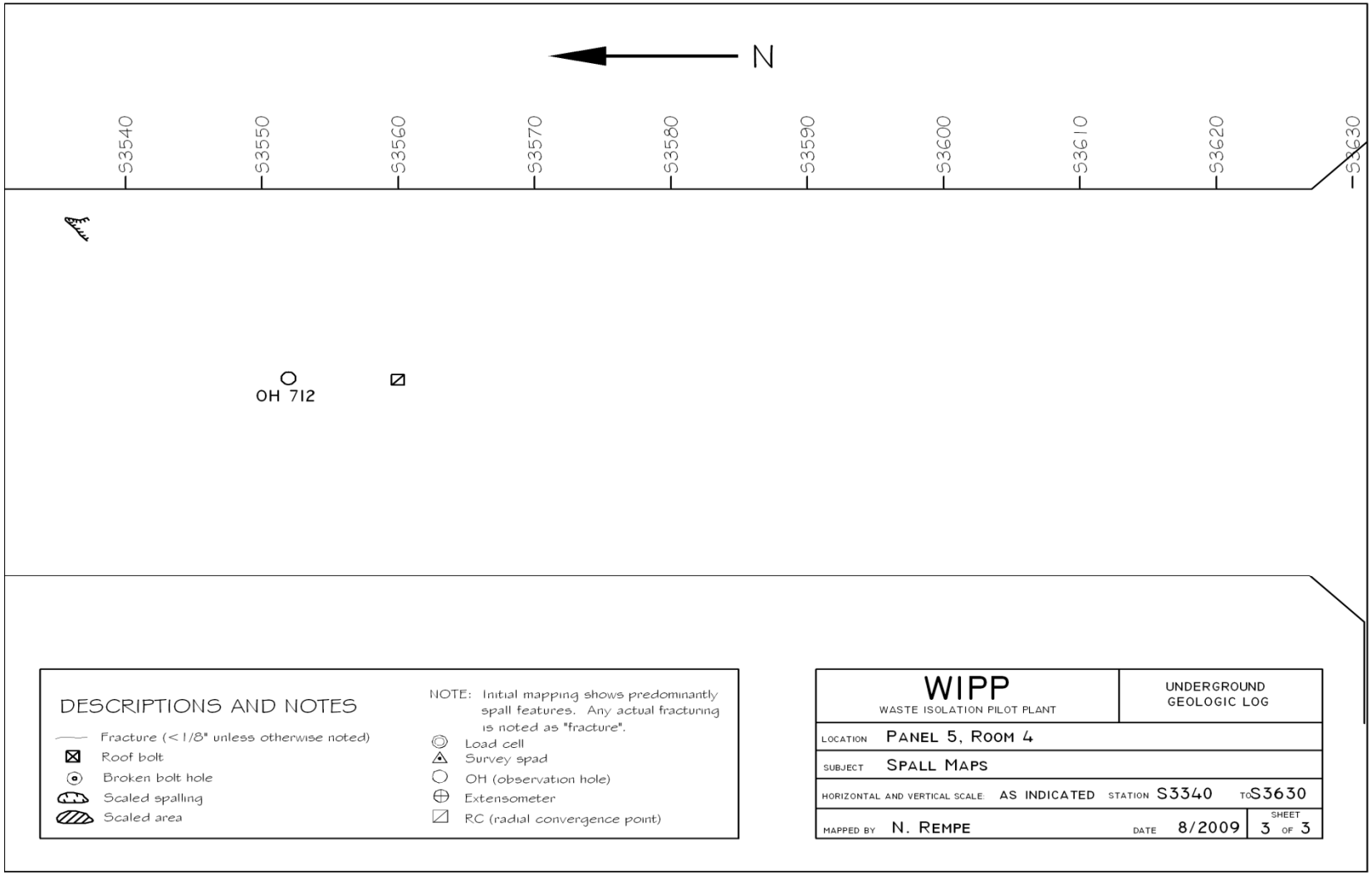


Figure 6-12
Panel 5 Room 4, S3340-S3630 Roof Fractures (Sheet 3 of 3)

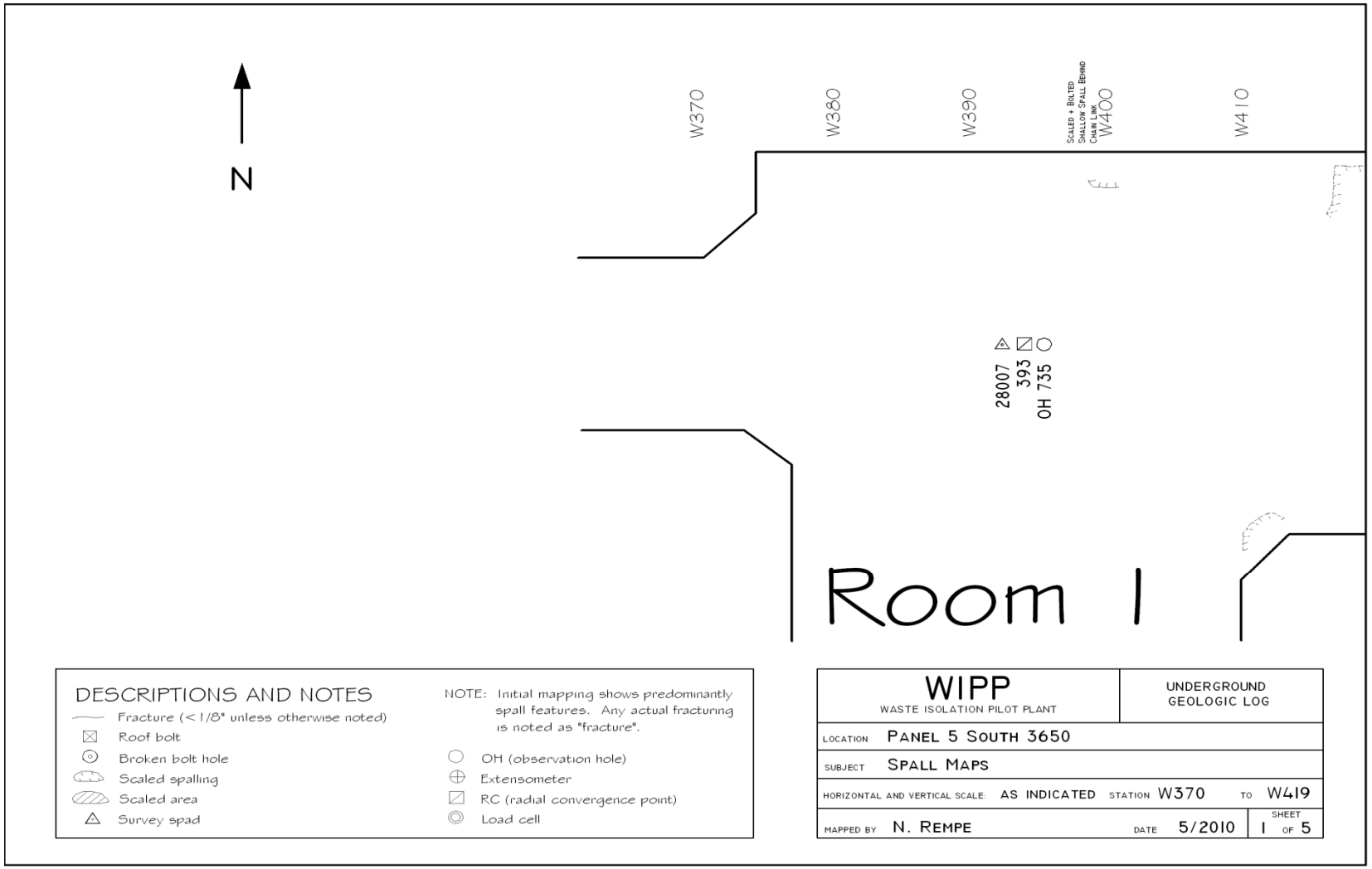


Figure 6-13
Panel 5 South 3650, W370-S419 Roof Fractures (Sheet 1 of 5)

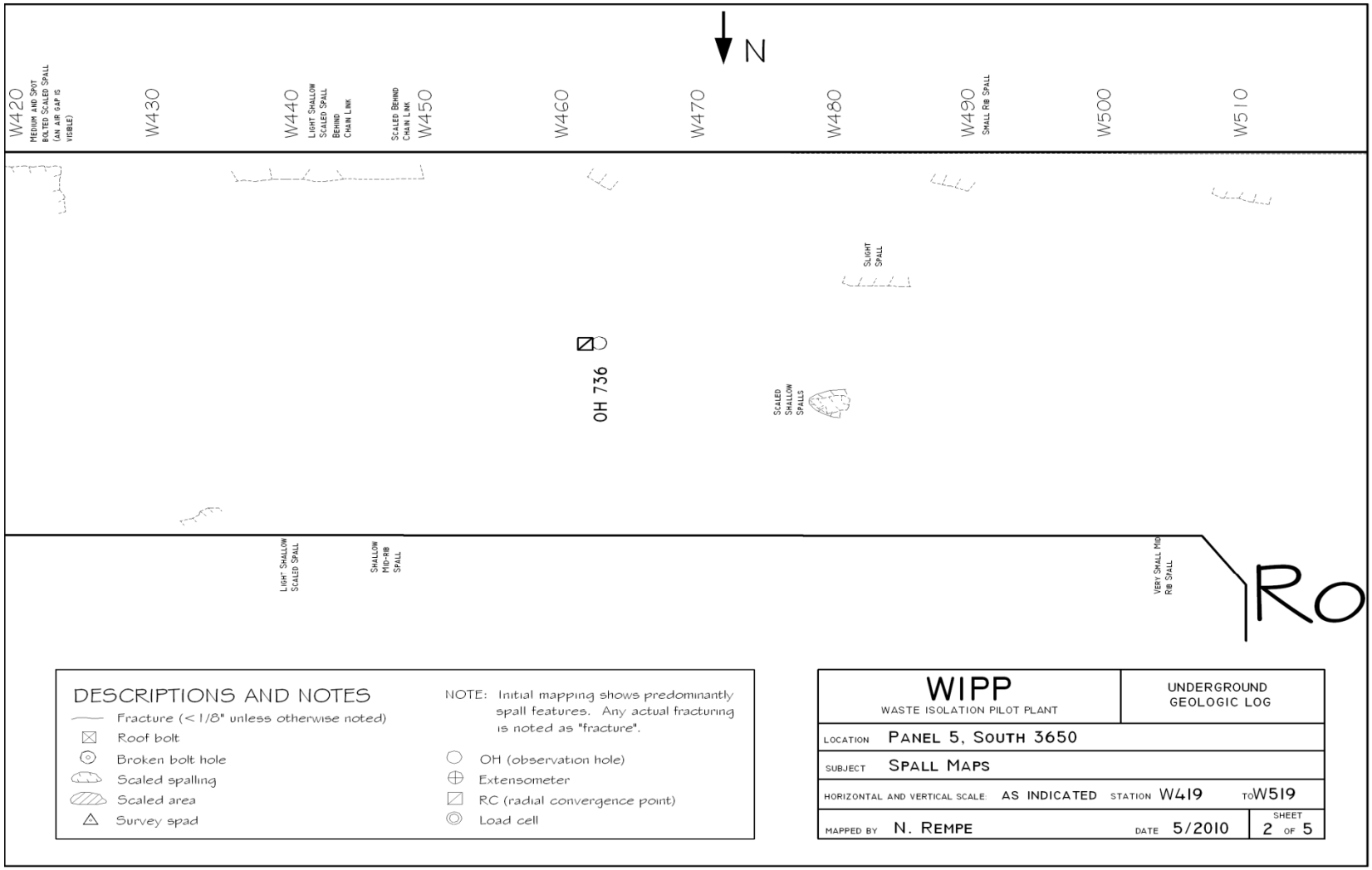


Figure 6-14
Panel 5 South 3650, W419-S519 Roof Fractures (Sheet 2 of 5)

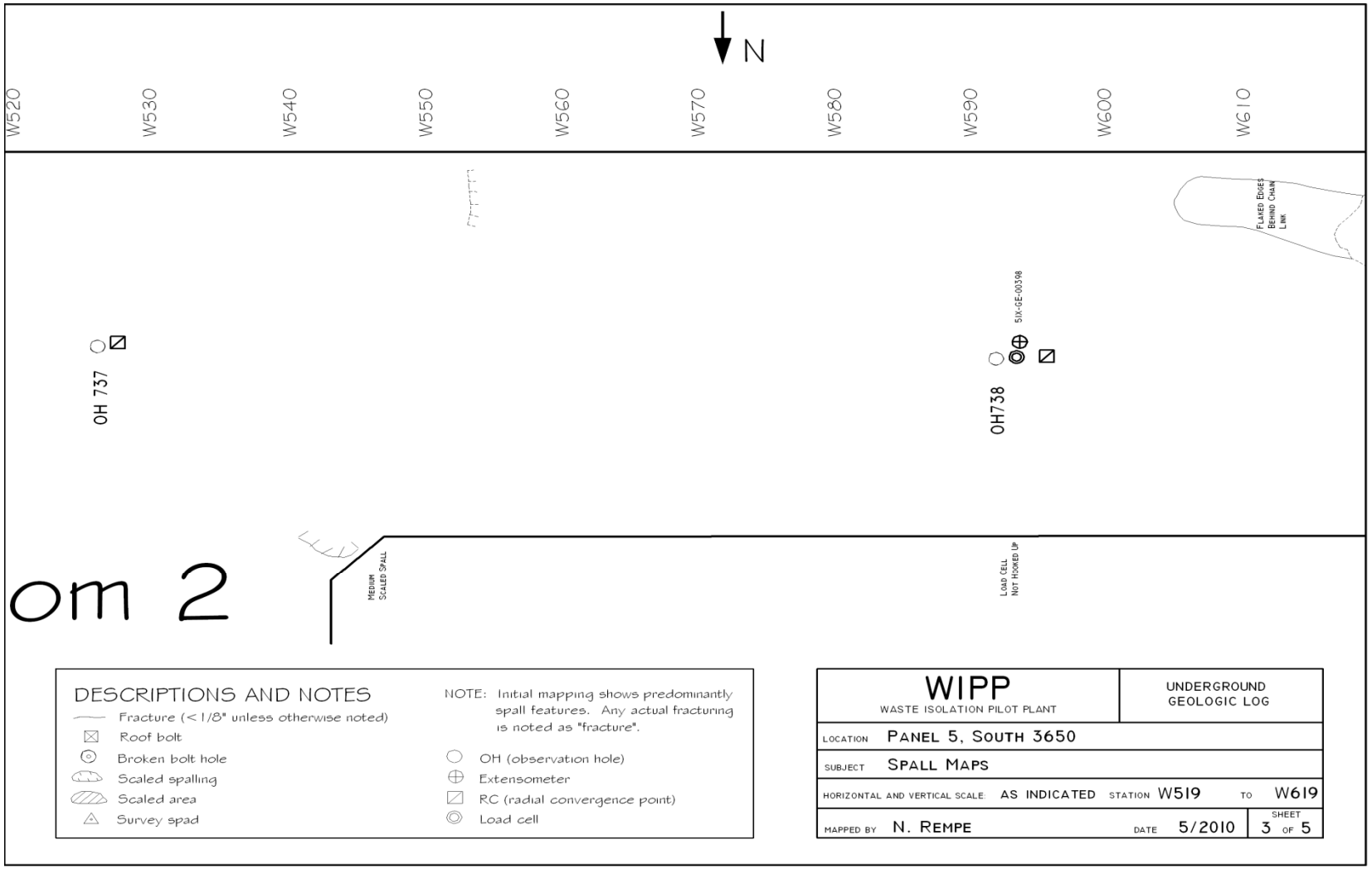


Figure 6-15
Panel 5 South 3650, W519-S619 Roof Fractures (Sheet 3 of 5)

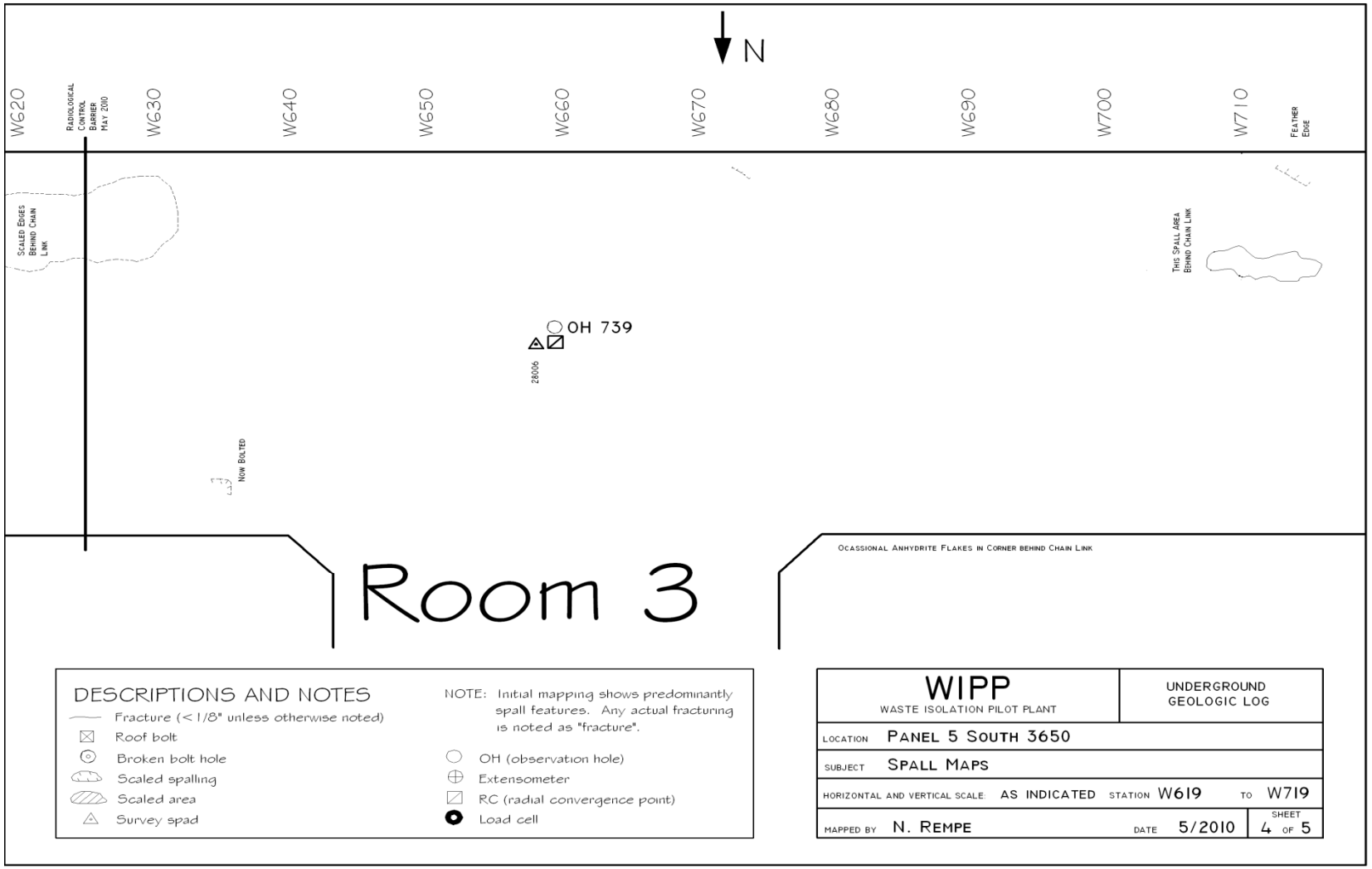


Figure 6-16
Panel 5 South 3650, W619-S719 Roof Fractures (Sheet 4 of 5)

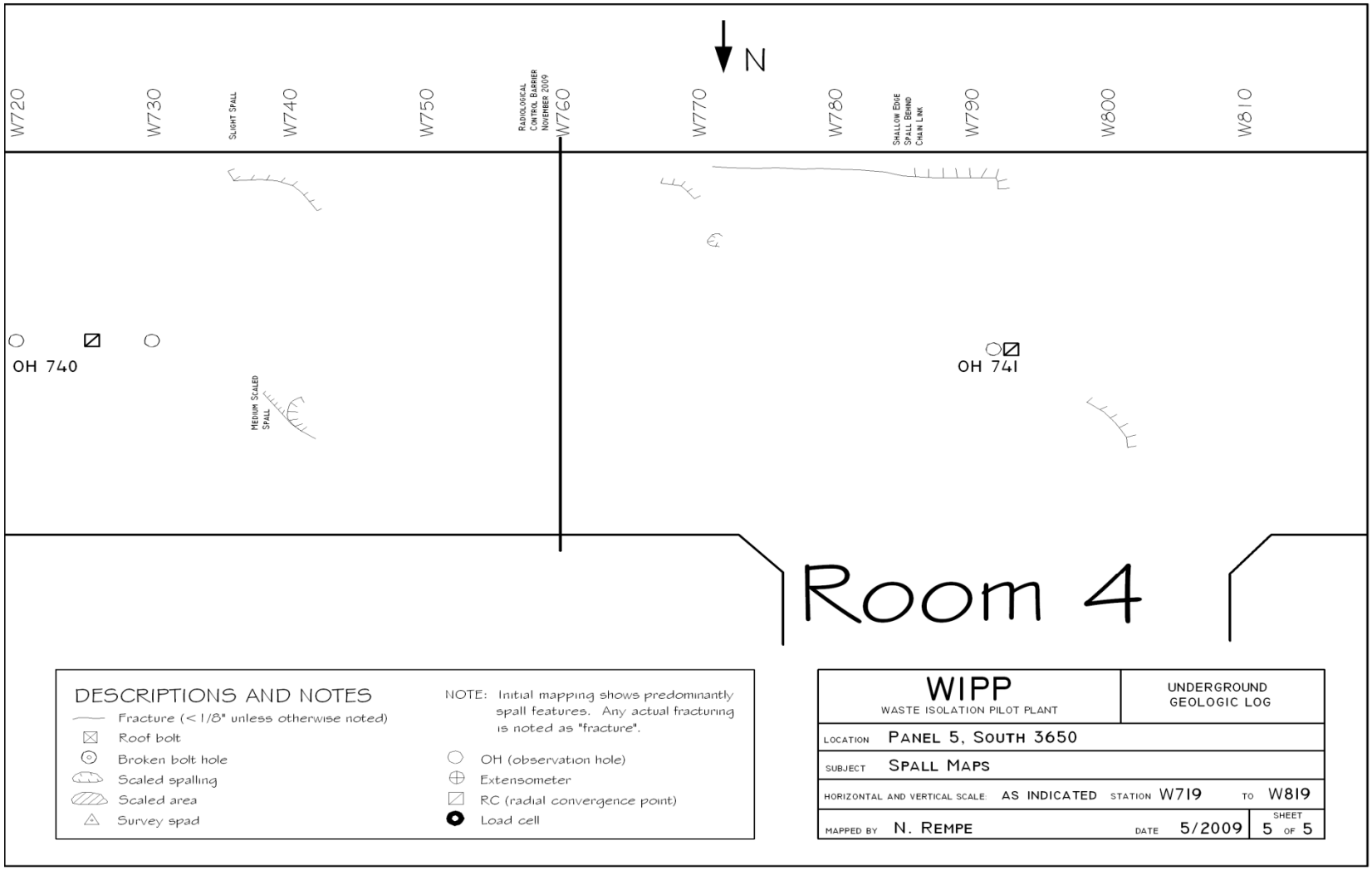


Figure 6-17
Panel 5 South 3650, W719-S819 Roof Fractures (Sheet 5 of 5)

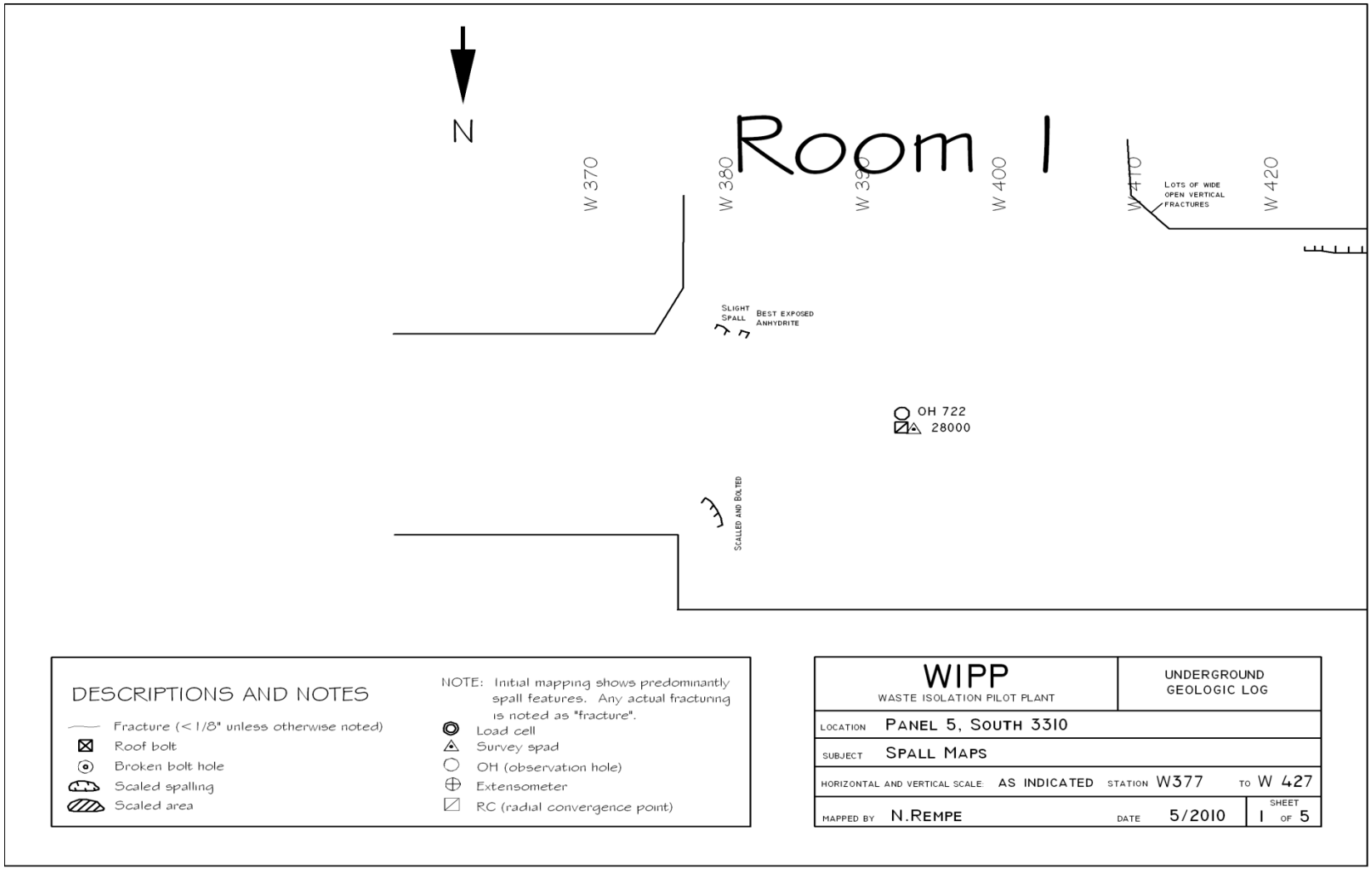


Figure 6-18
Panel 5 South 3310, W377-S427 Roof Fractures (Sheet 1 of 5)

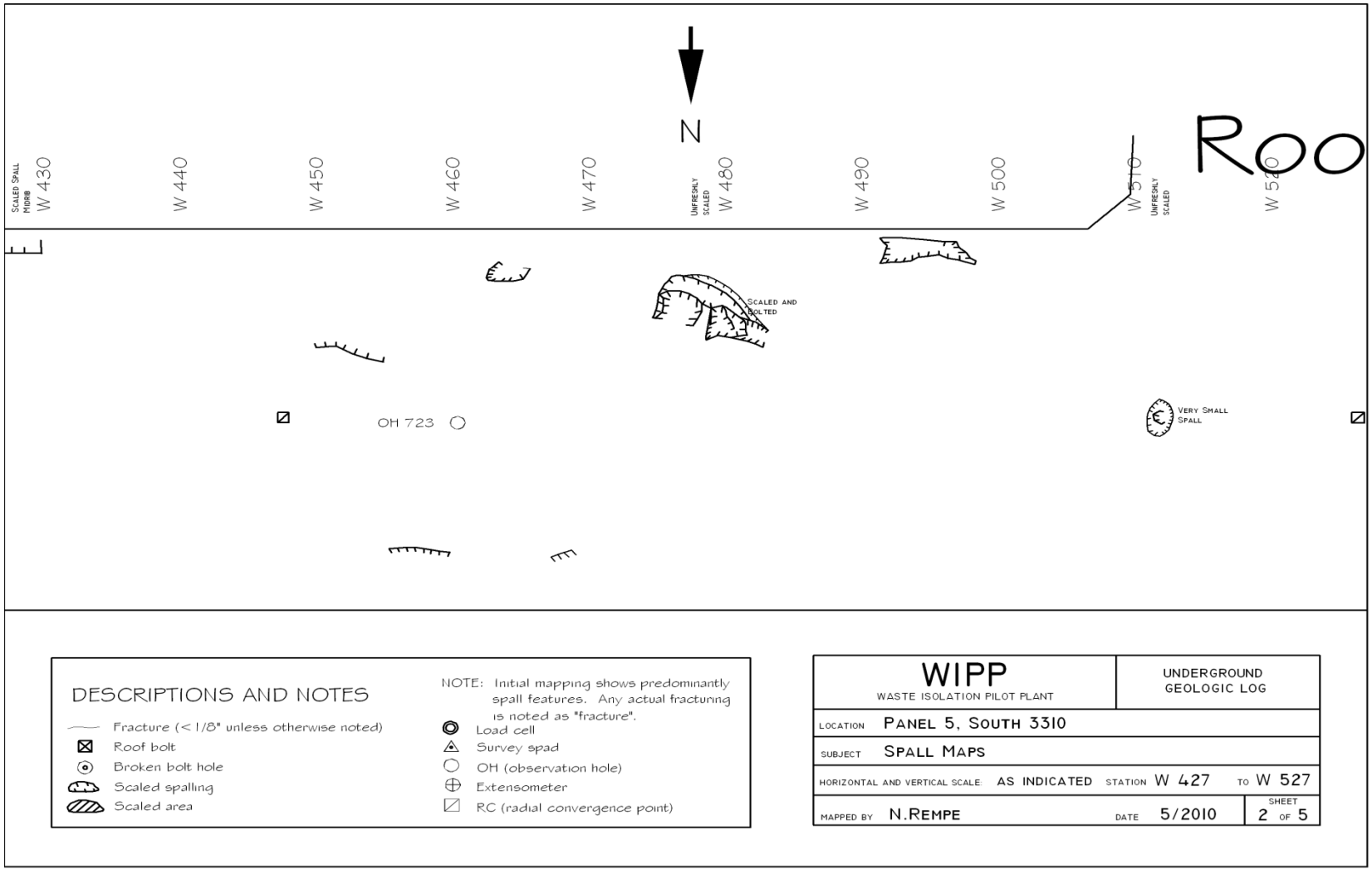


Figure 6-19
Panel 5 South 3310, W427-S527 Roof Fractures (Sheet 2 of 5)

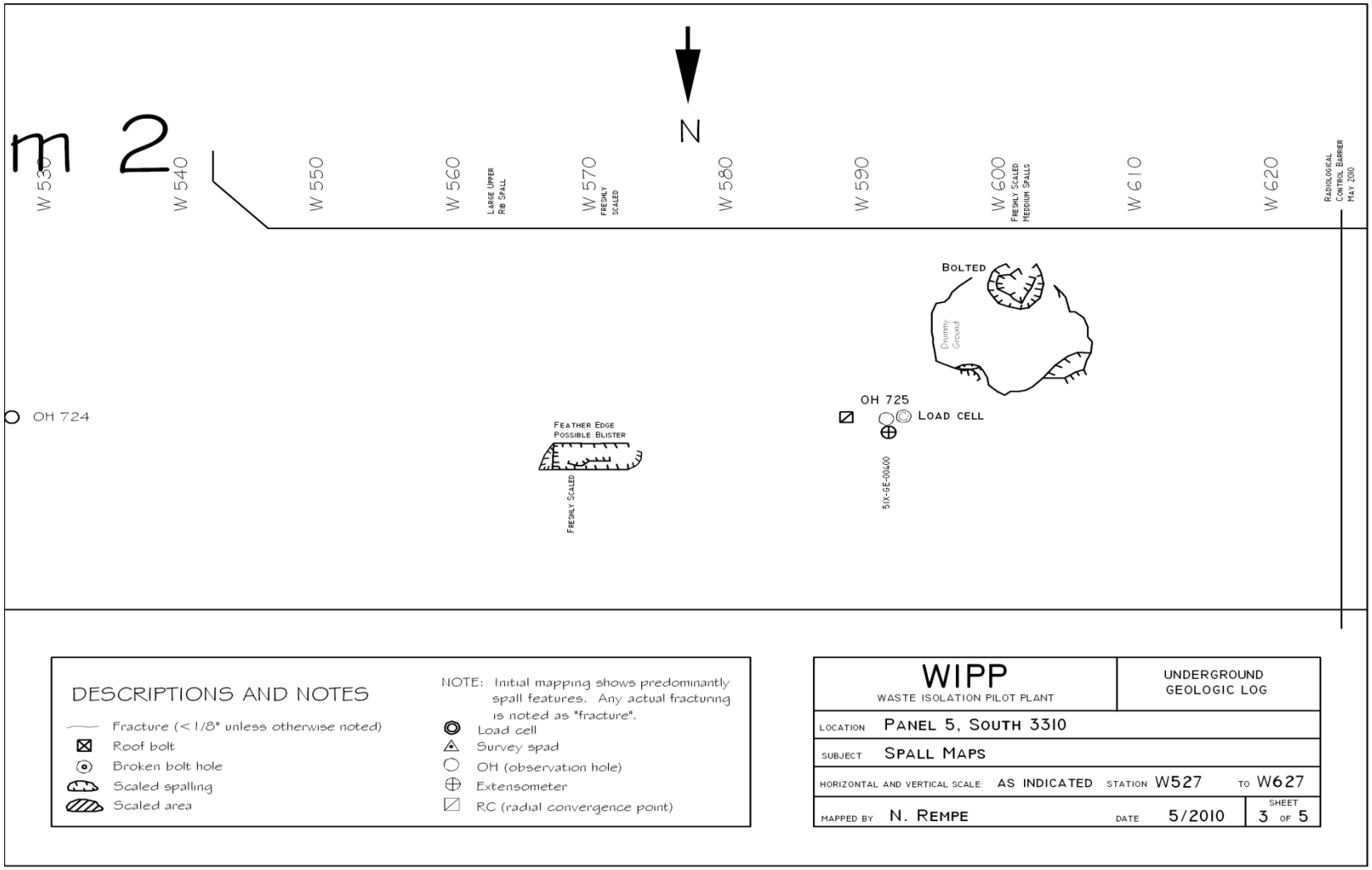


Figure 6-20
Panel 5 South 3310, W527-S627 Roof Fractures (Sheet 3 of 5)

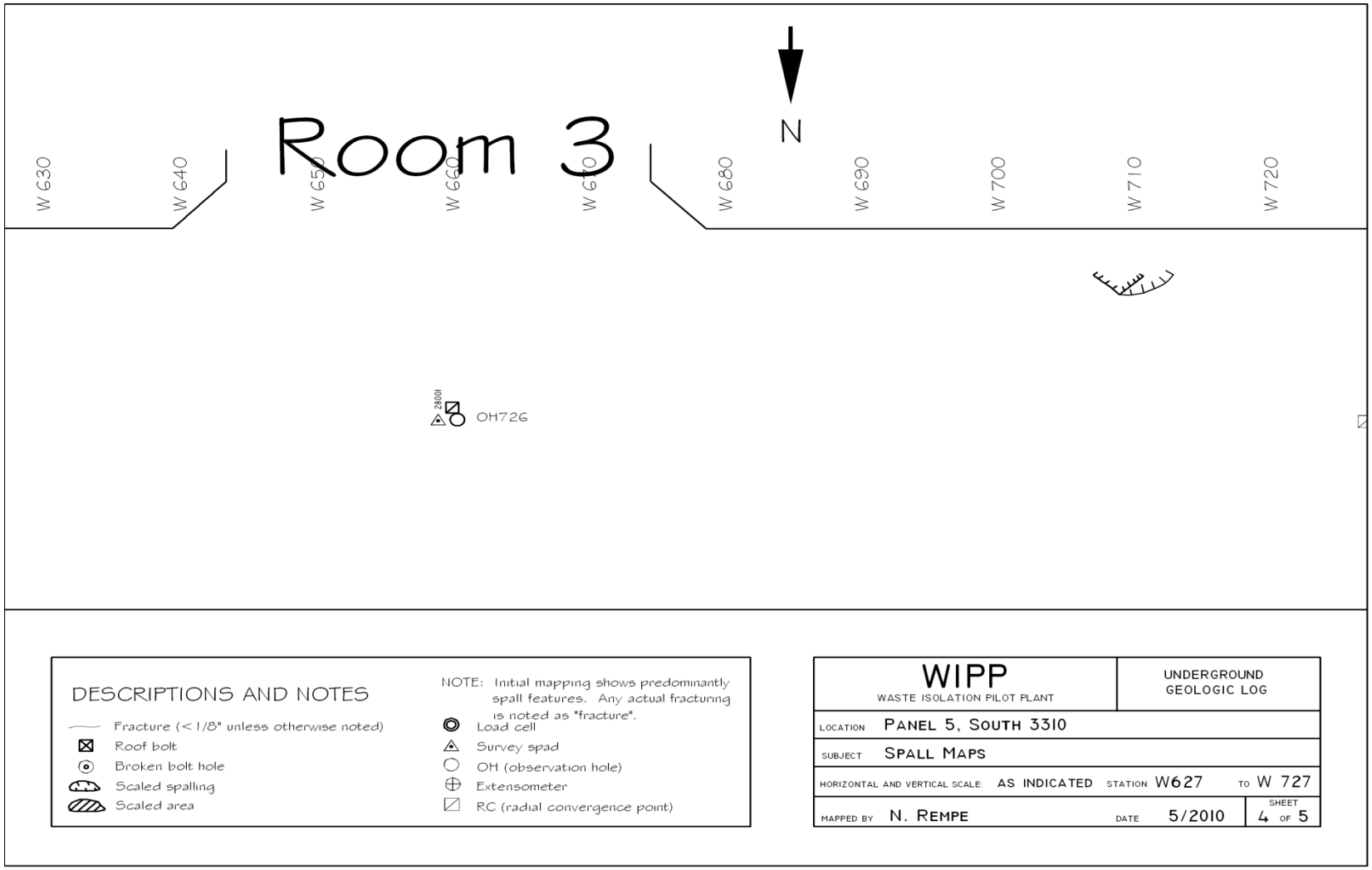


Figure 6-21
Panel 5 South 3310, W627-S727 Roof Fractures (Sheet 4 of 5)

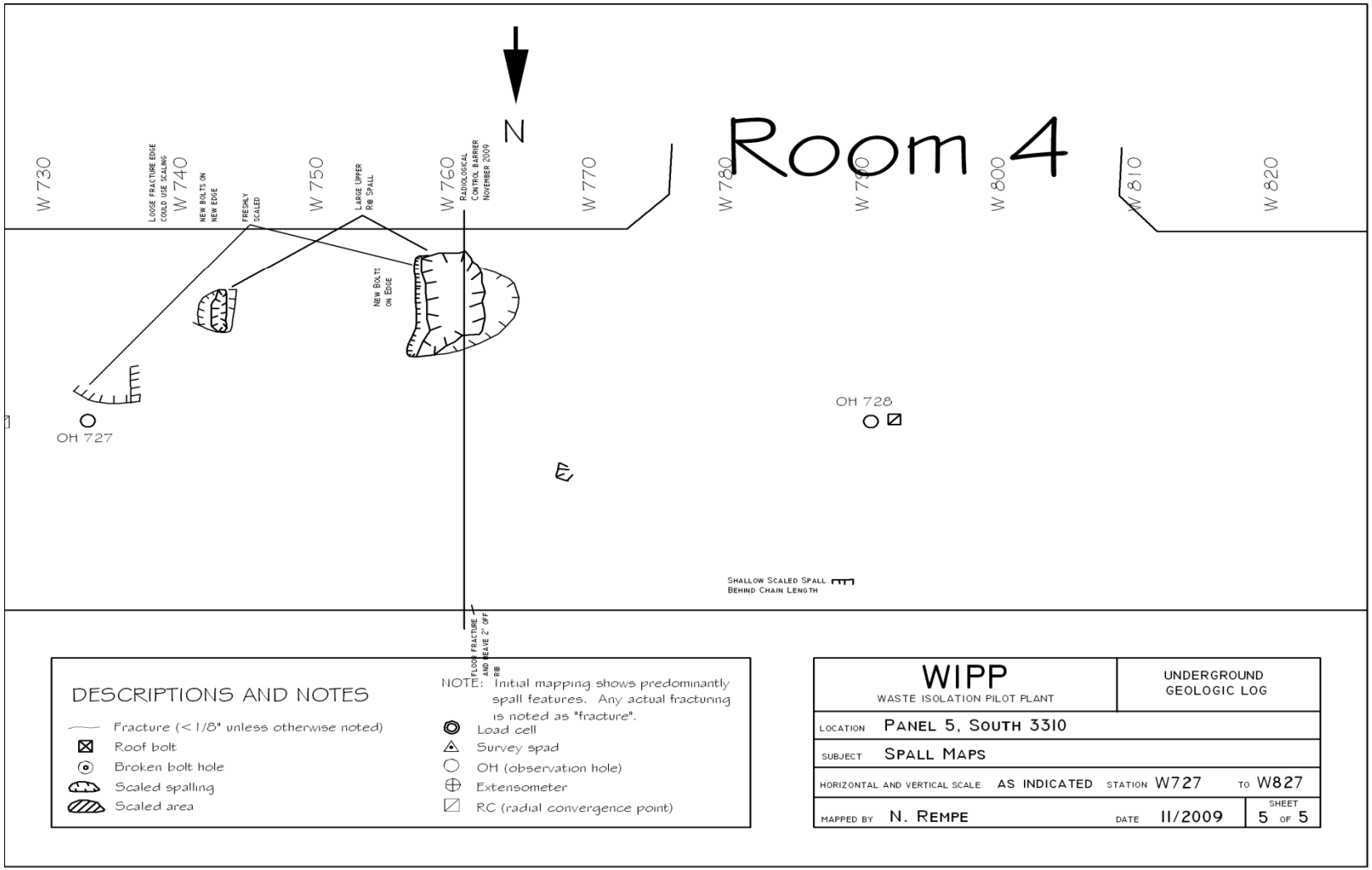


Figure 6-22
Panel 5 South 3310, W727-S827 Roof Fractures (Sheet 5 of 5)

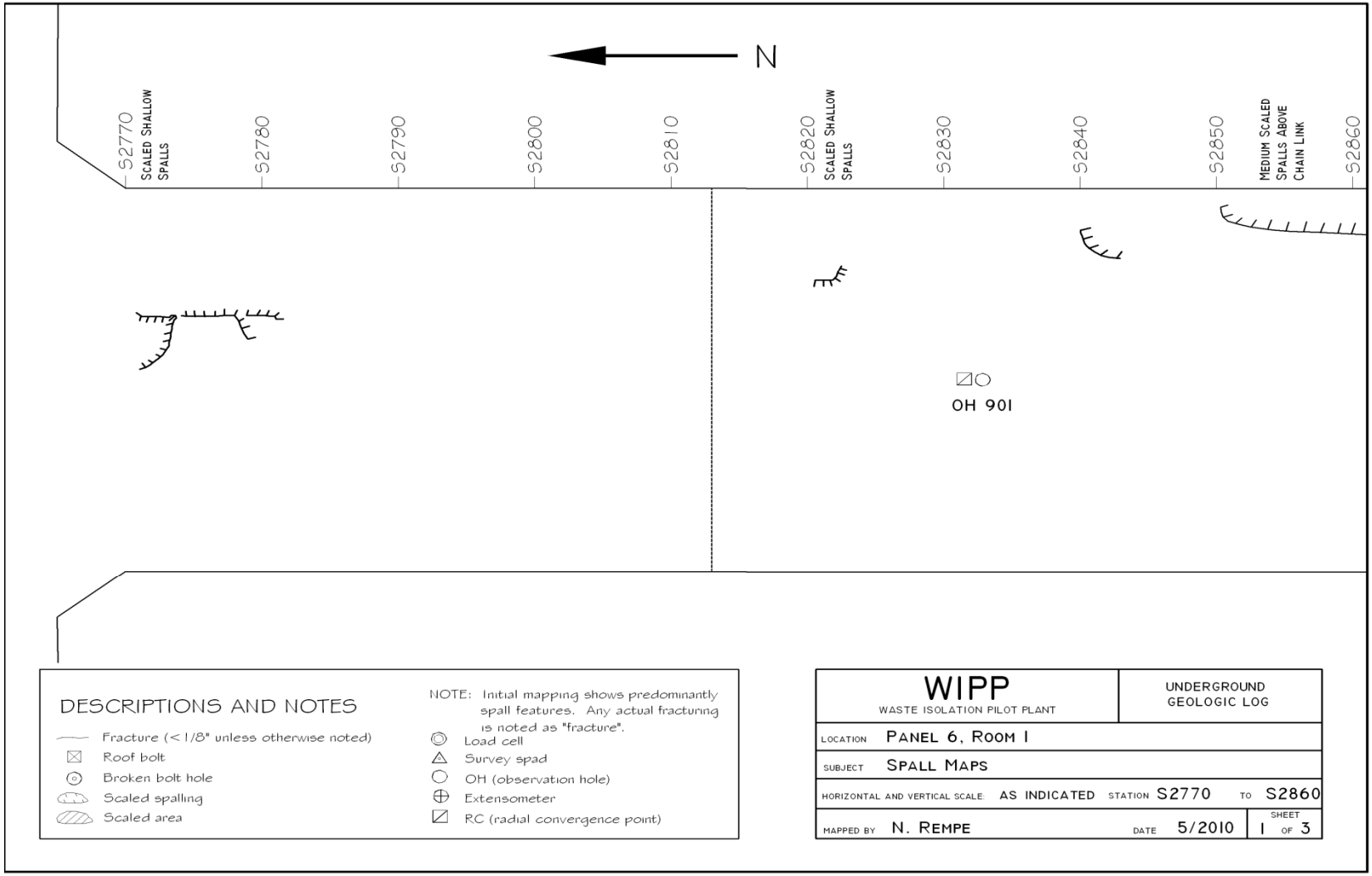


Figure 6-23
Panel 6 Room 1, S2770-S2860 Roof Fractures (Sheet 1 of 3)

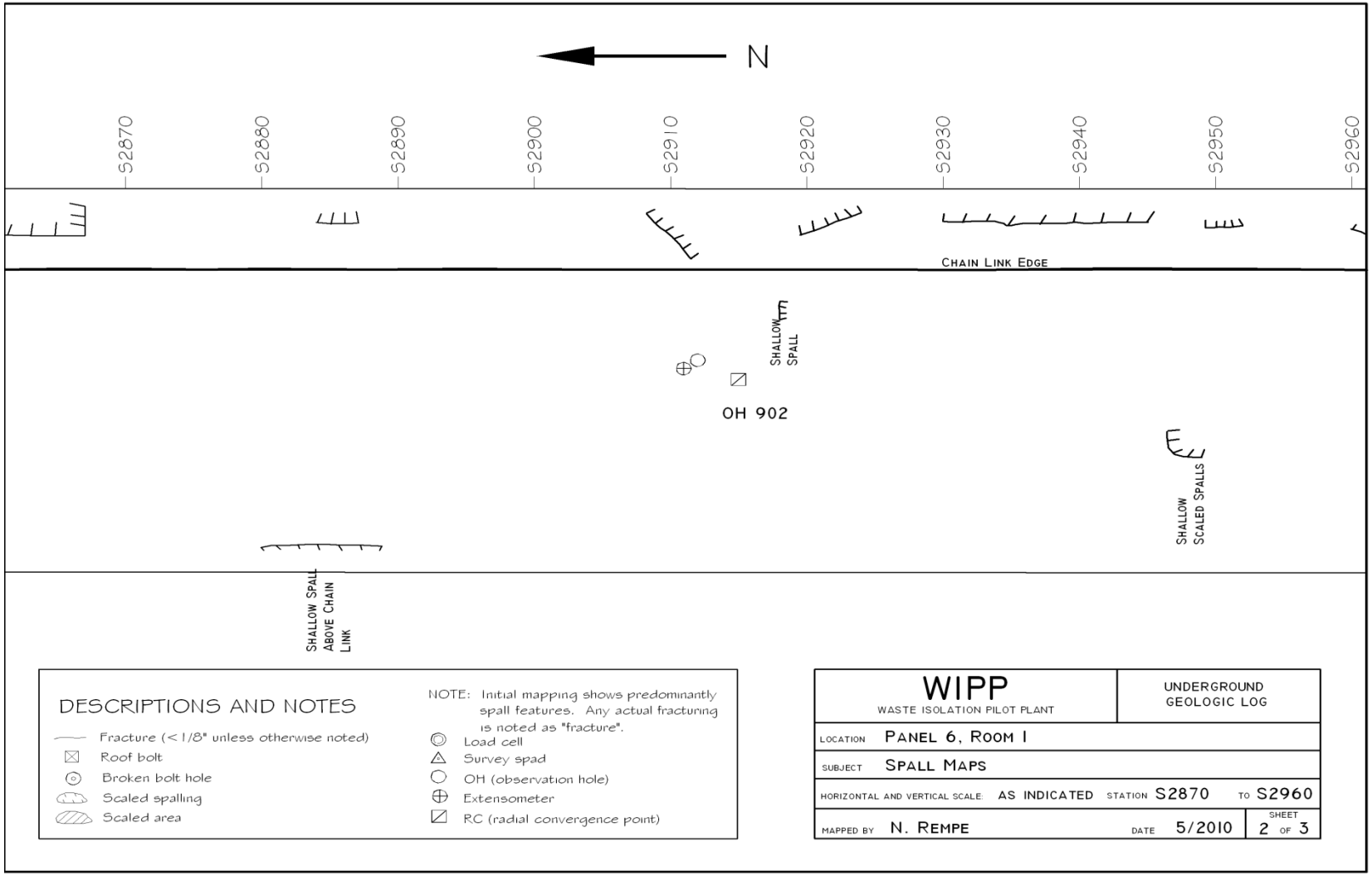


Figure 6-24
Panel 6 Room 1, S2870-S2960 Roof Fractures (Sheet 2 of 3)

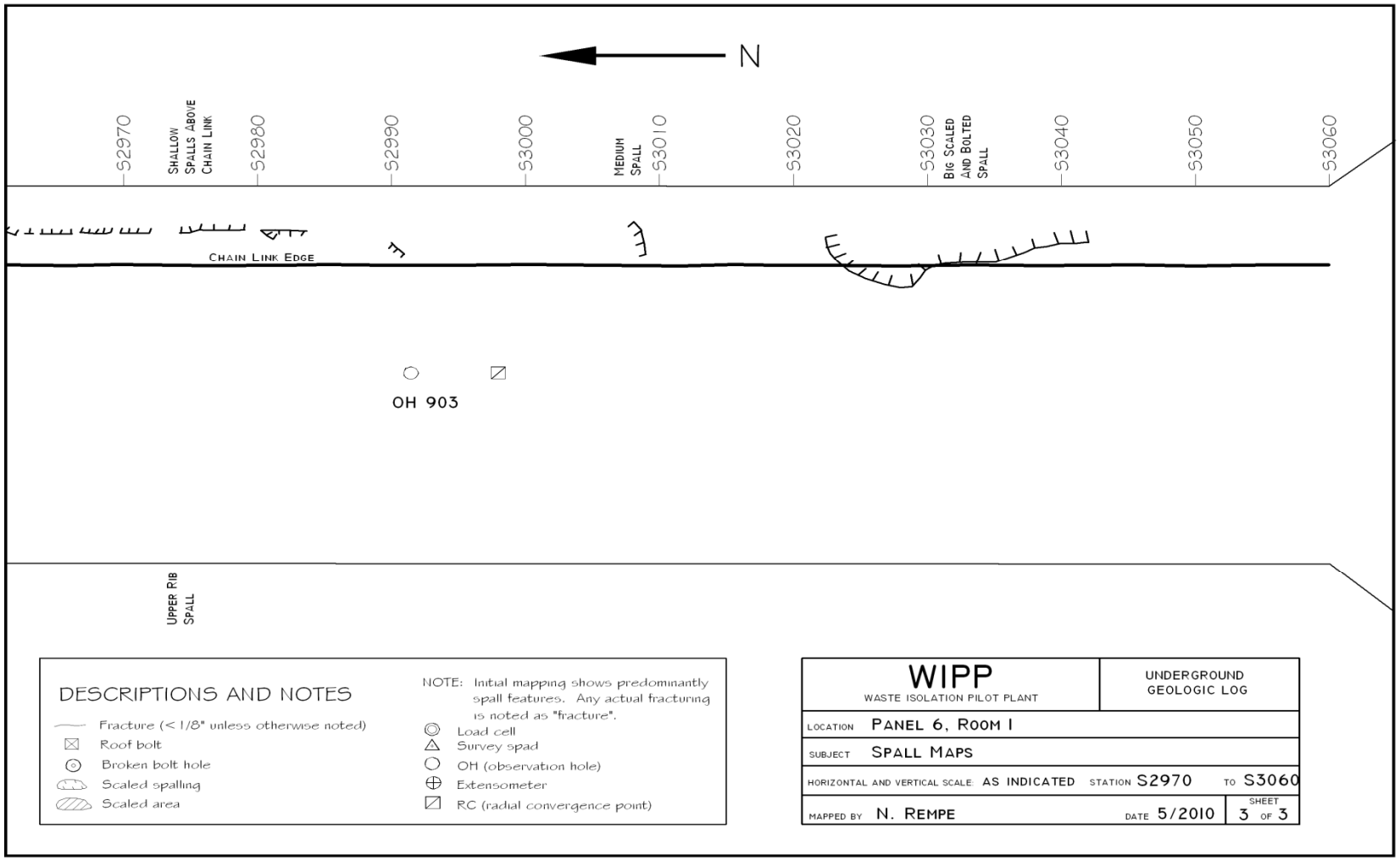


Figure 6-25
Panel 6 Room 1, S2970-S3060 Roof Fractures (Sheet 3 of 3)

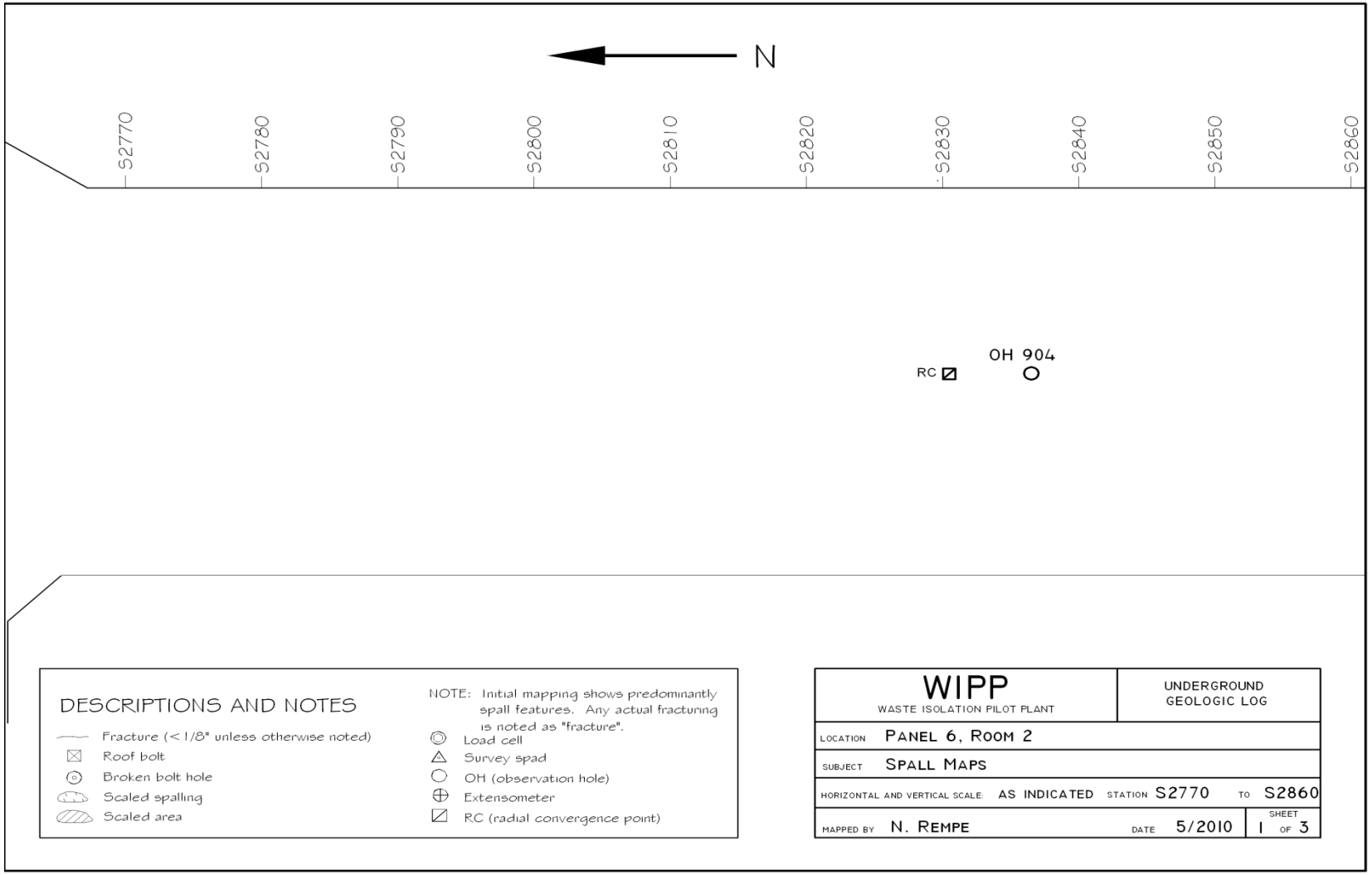


Figure 6-26
Panel 6 Room 2, S2770-S2860 Roof Fractures (Sheet 1 of 3)

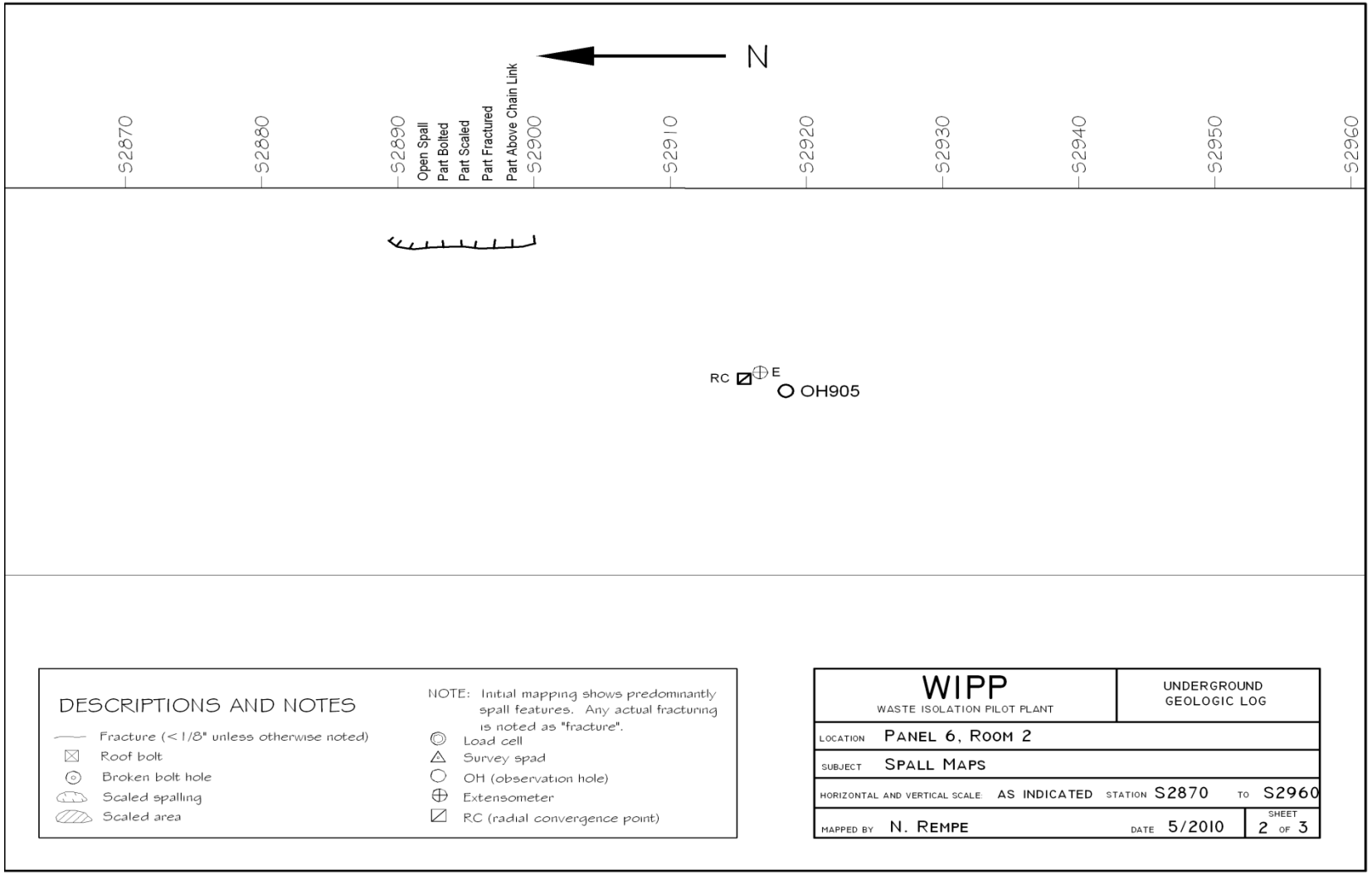


Figure 6-27
Panel 6 Room 2, S2870-S2960 Roof Fractures (Sheet 2 of 3)

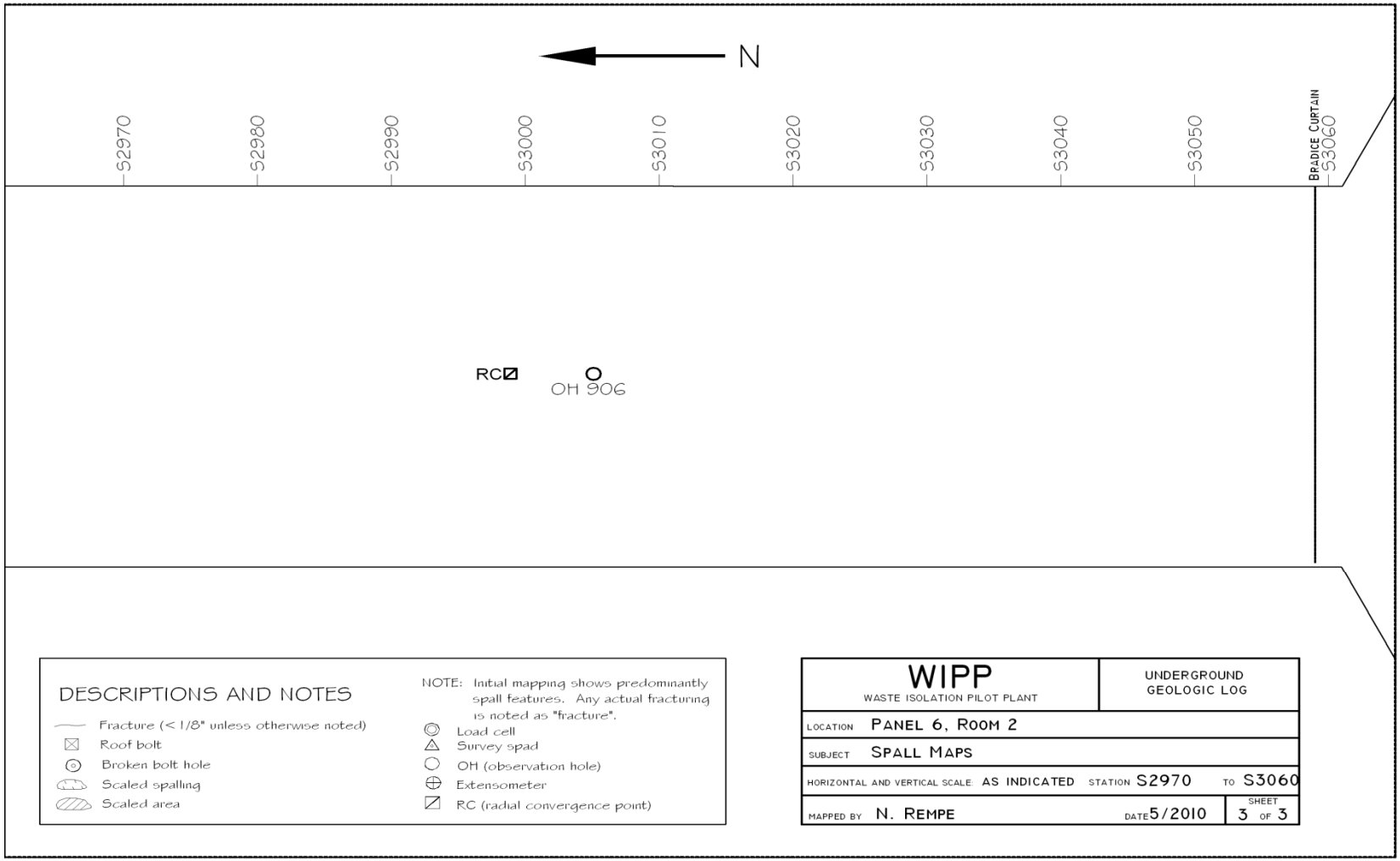


Figure 6-28
Panel 6 Room 2, S2970-S3060 Roof Fractures (Sheet 3 of 3)

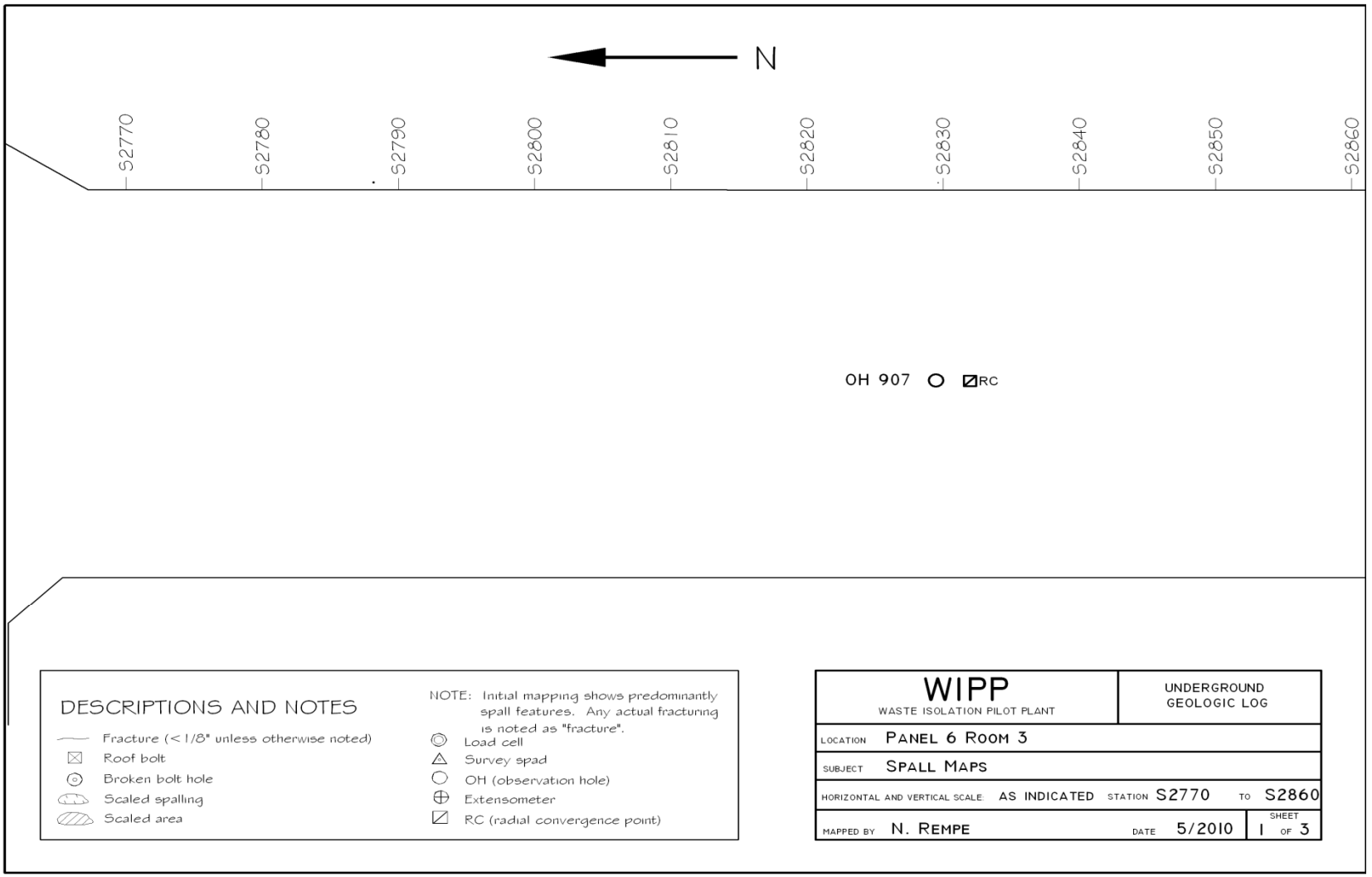


Figure 6-29
Panel 6 Room 3, S2770-S2860 Roof Fractures (Sheet 1 of 3)

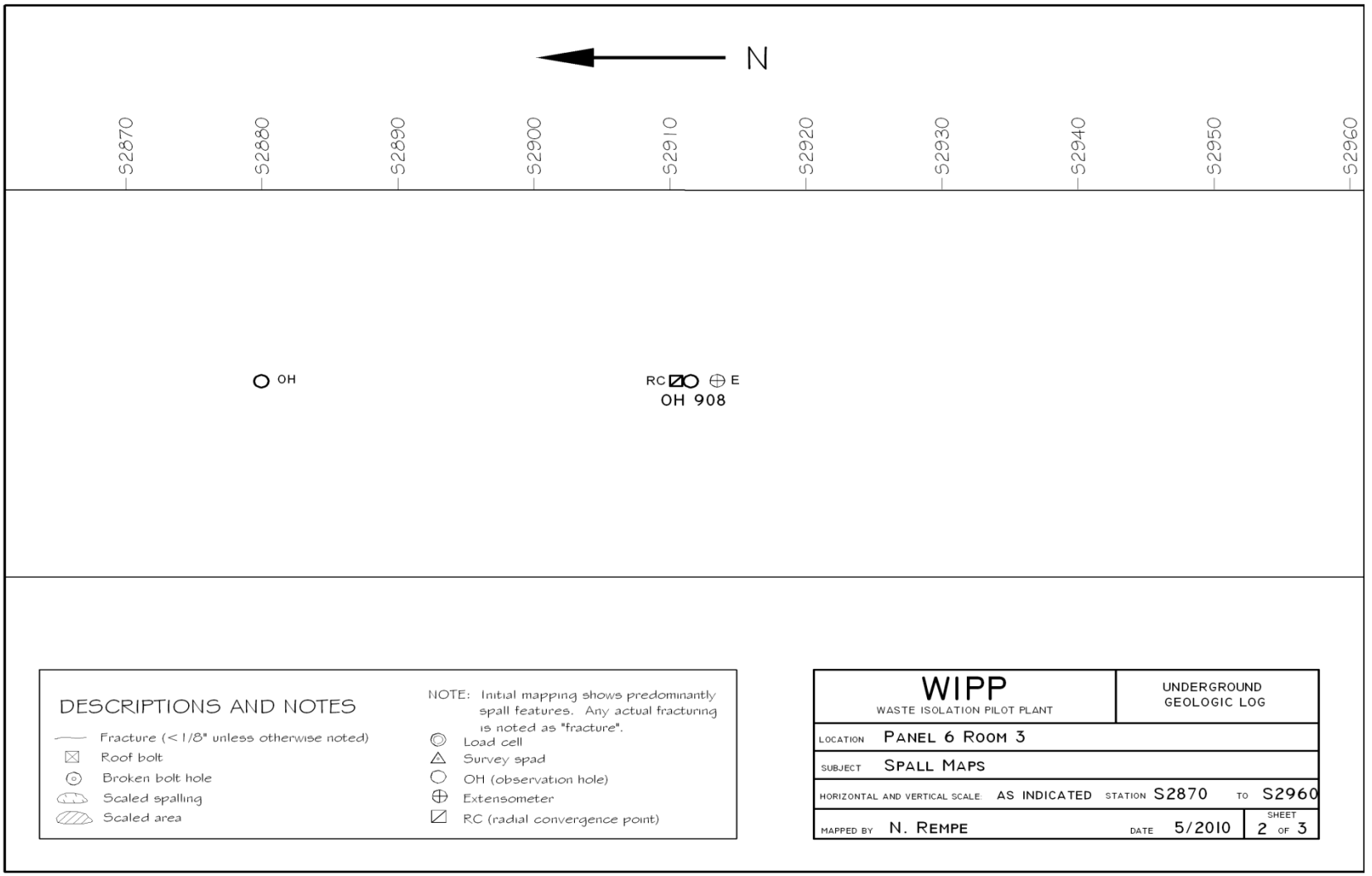


Figure 6-30
Panel 6 Room 3, S2870-S2960 Roof Fractures (Sheet 2 of 3)

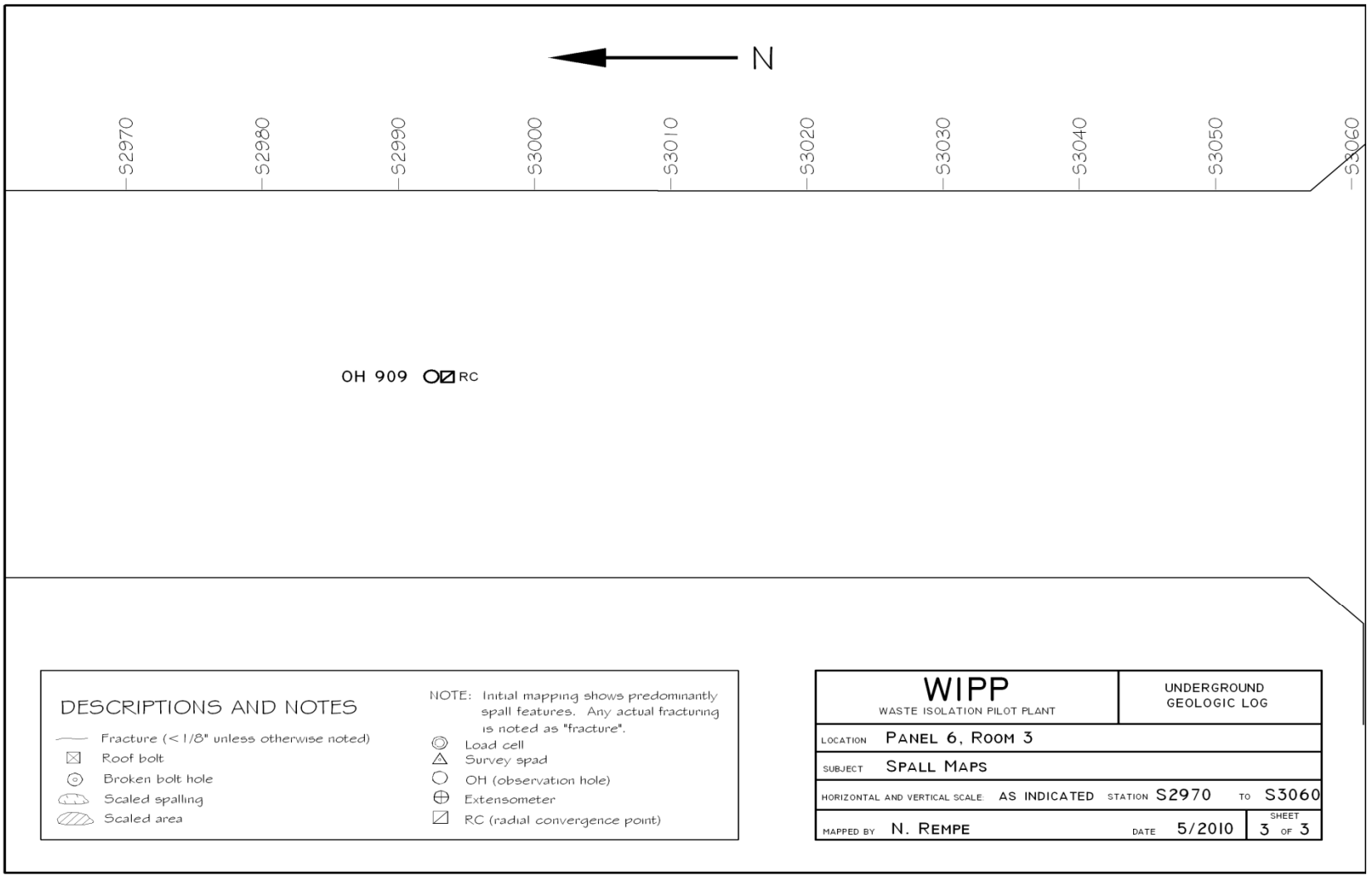


Figure 6-31
Panel 6 Room 3, S2970-S3060 Roof Fractures (Sheet 3 of 3)

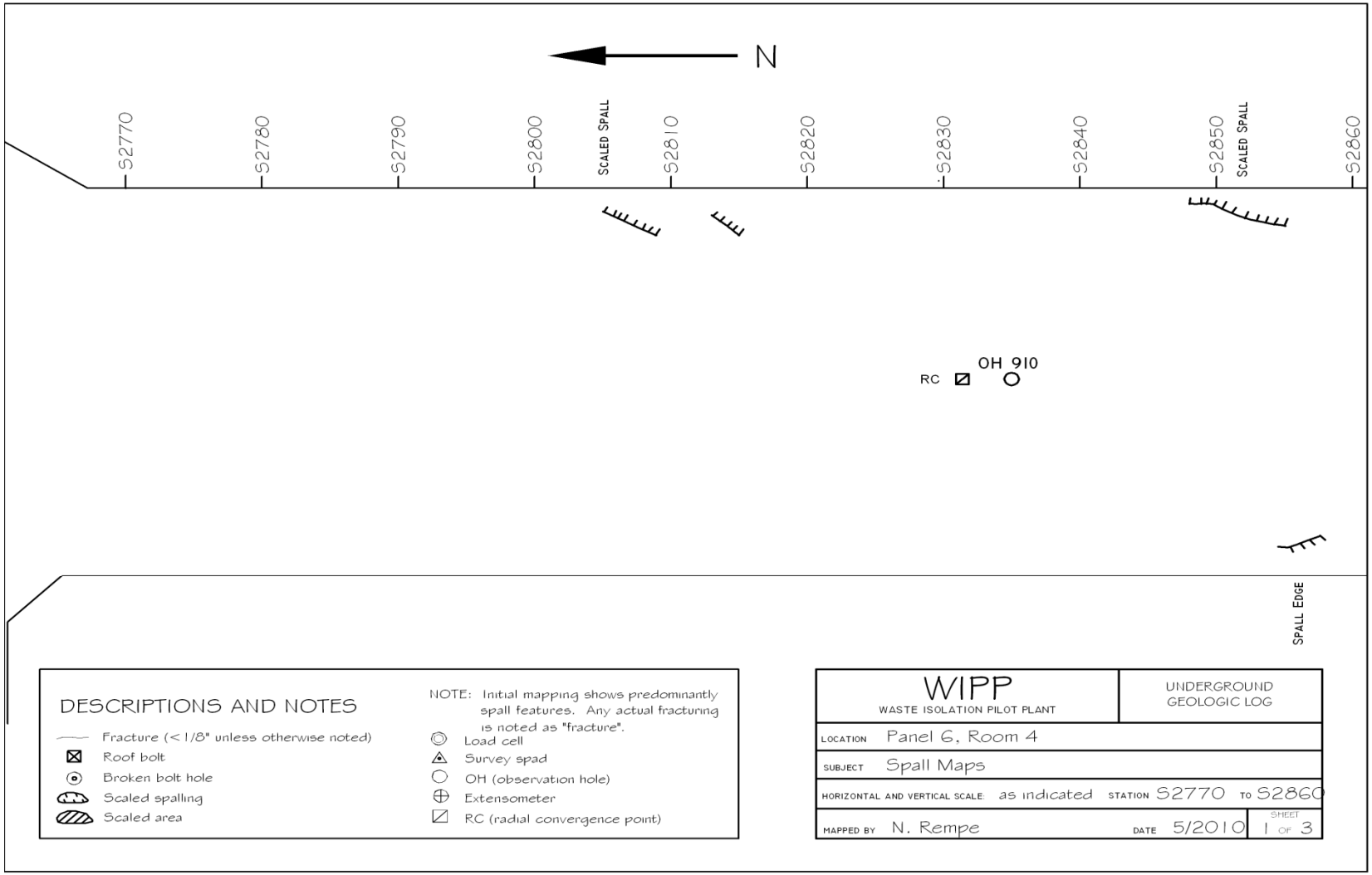


Figure 6-32
Panel 6 Room 4, S2770-S2860 Roof Fractures (Sheet 1 of 3)

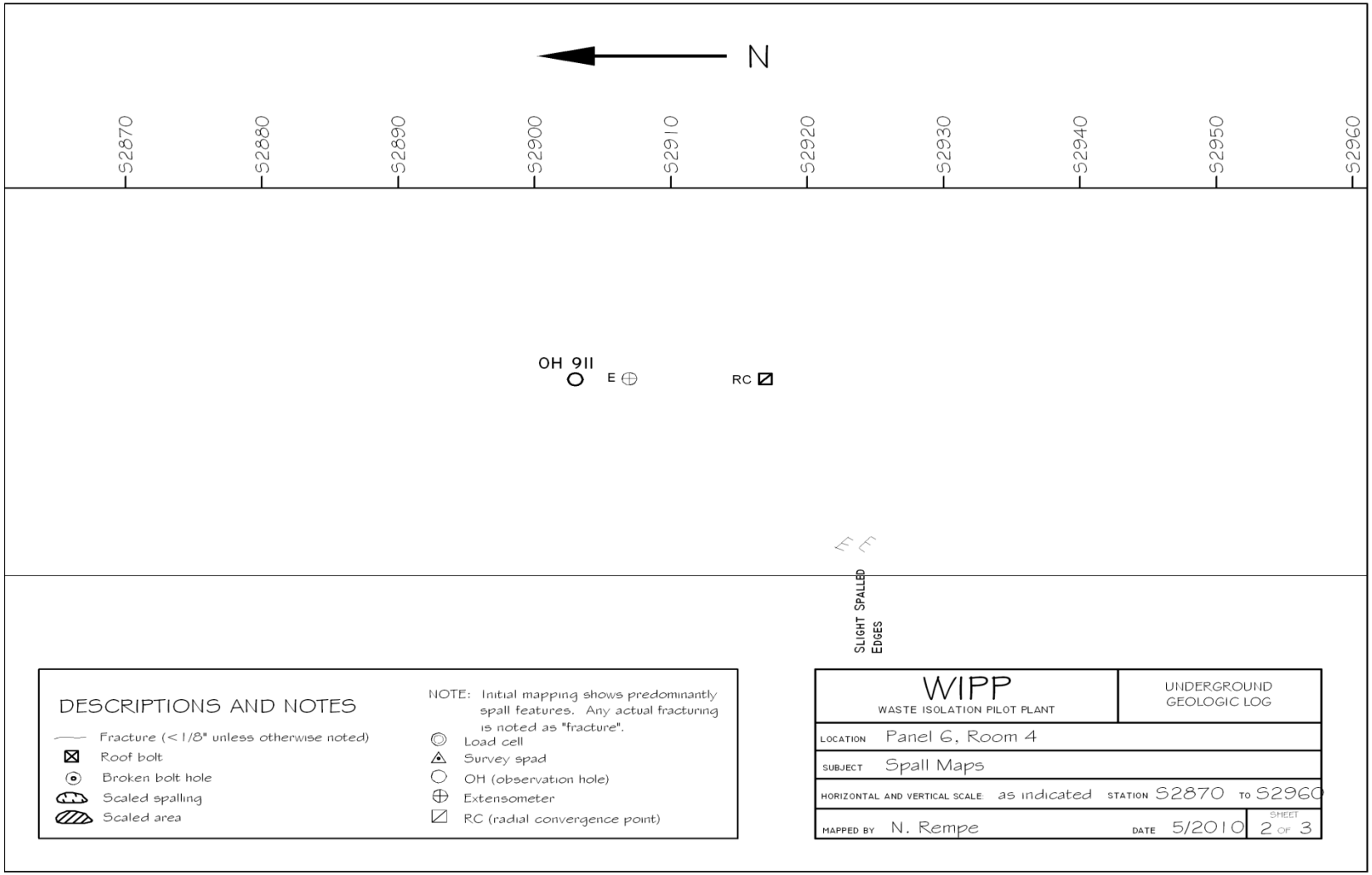


Figure 6-33
Panel 6 Room 4, S2870-S2960 Roof Fractures (Sheet 2 of 3)

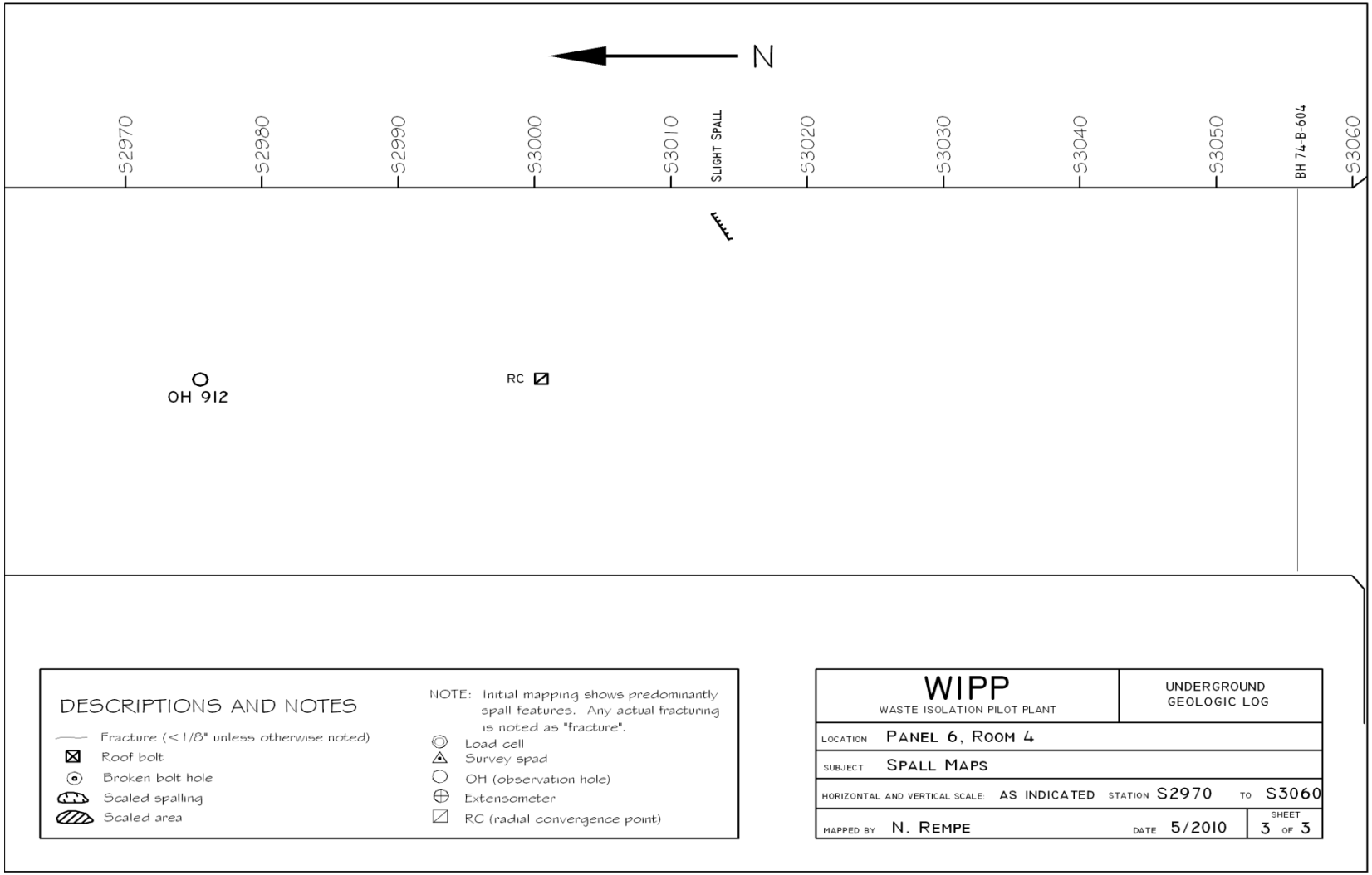


Figure 6-34
Panel 6 Room 4, S2970-S3060 Roof Fractures (Sheet 3 of 3)

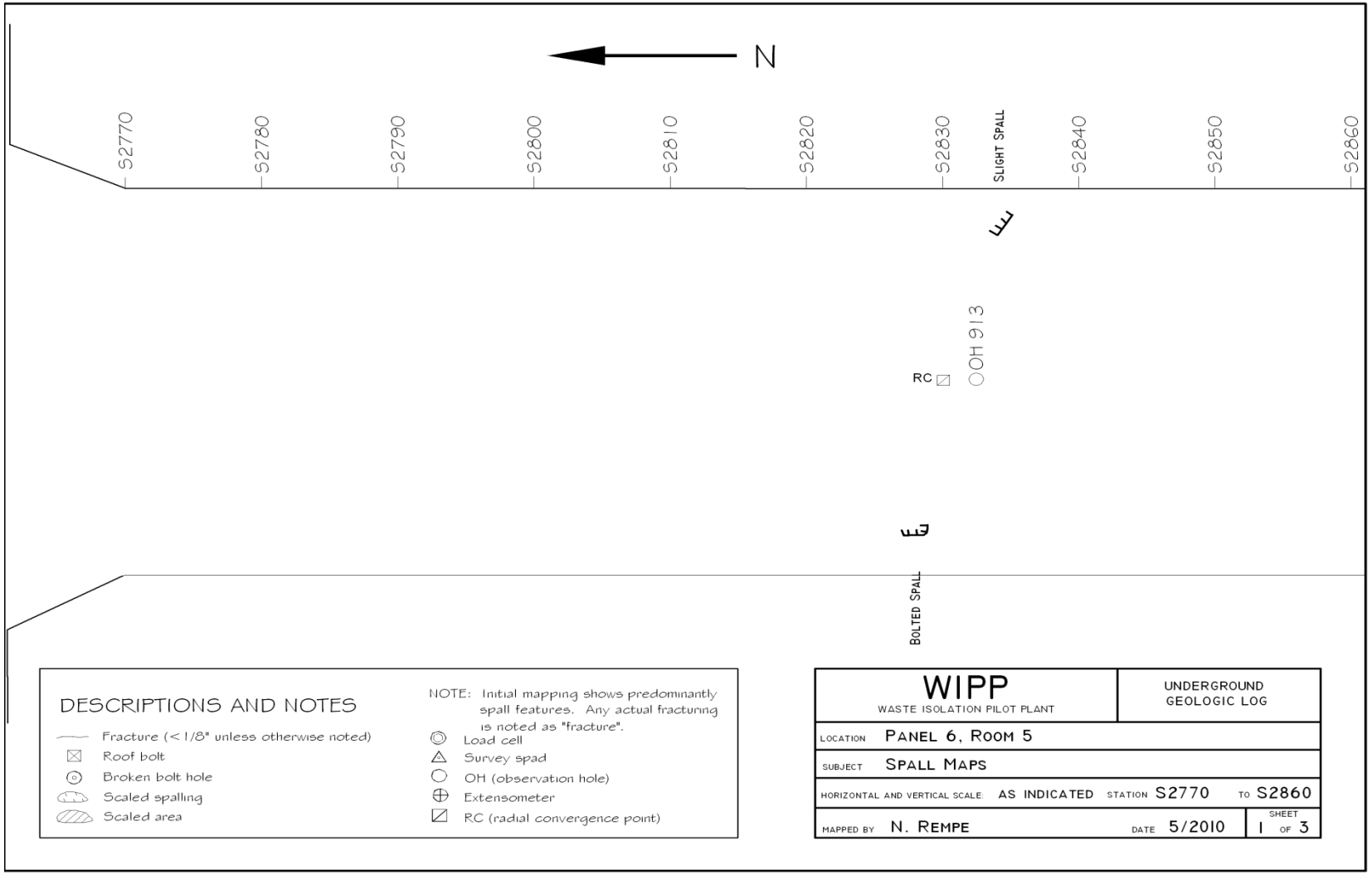


Figure 6-35
Panel 6 Room 5, S2770-S2860 Roof Fractures (Sheet 1 of 3)

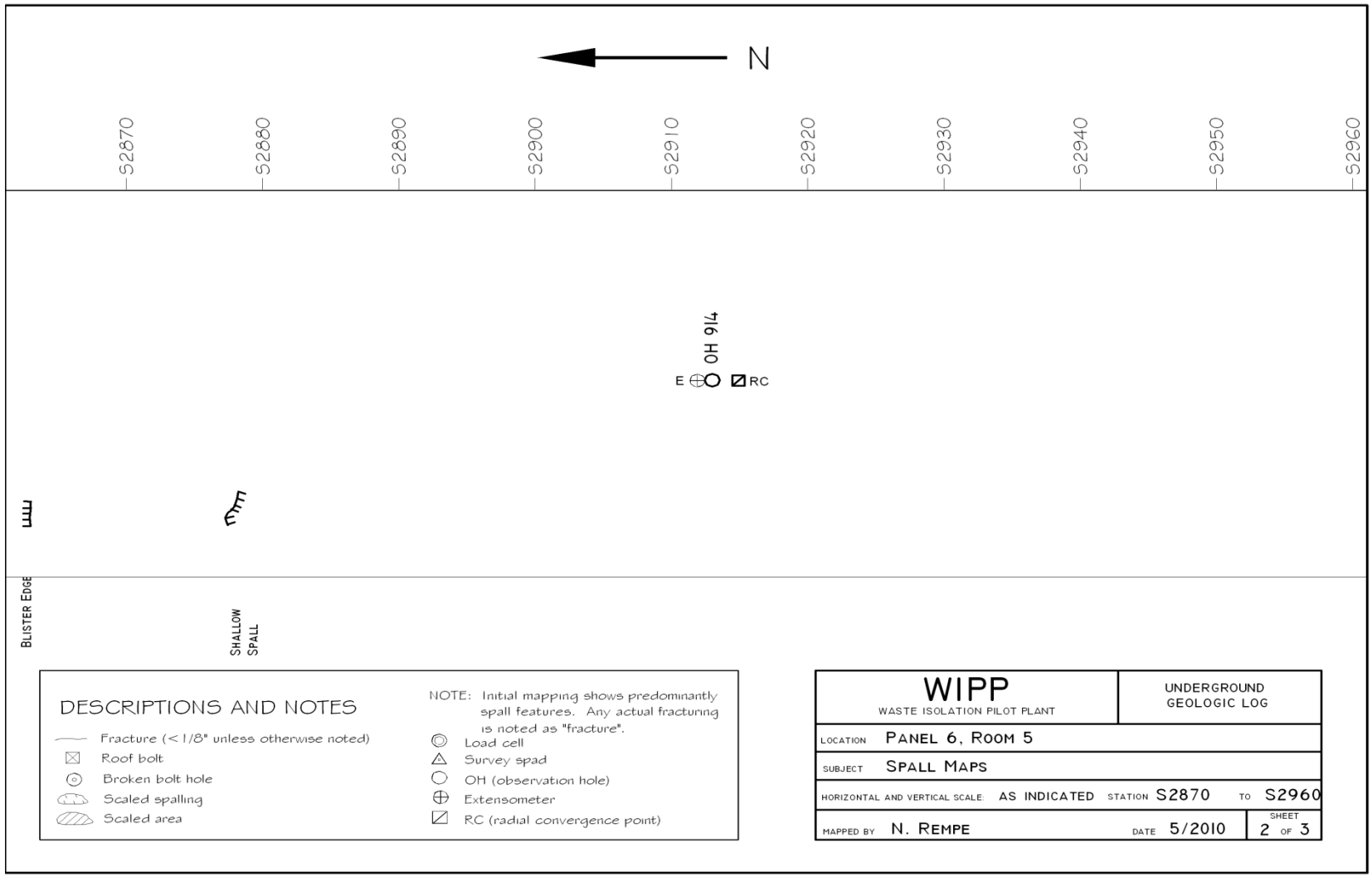


Figure 6-36
Panel 6 Room 5, S2870-S2960 Roof Fractures (Sheet 2 of 3)

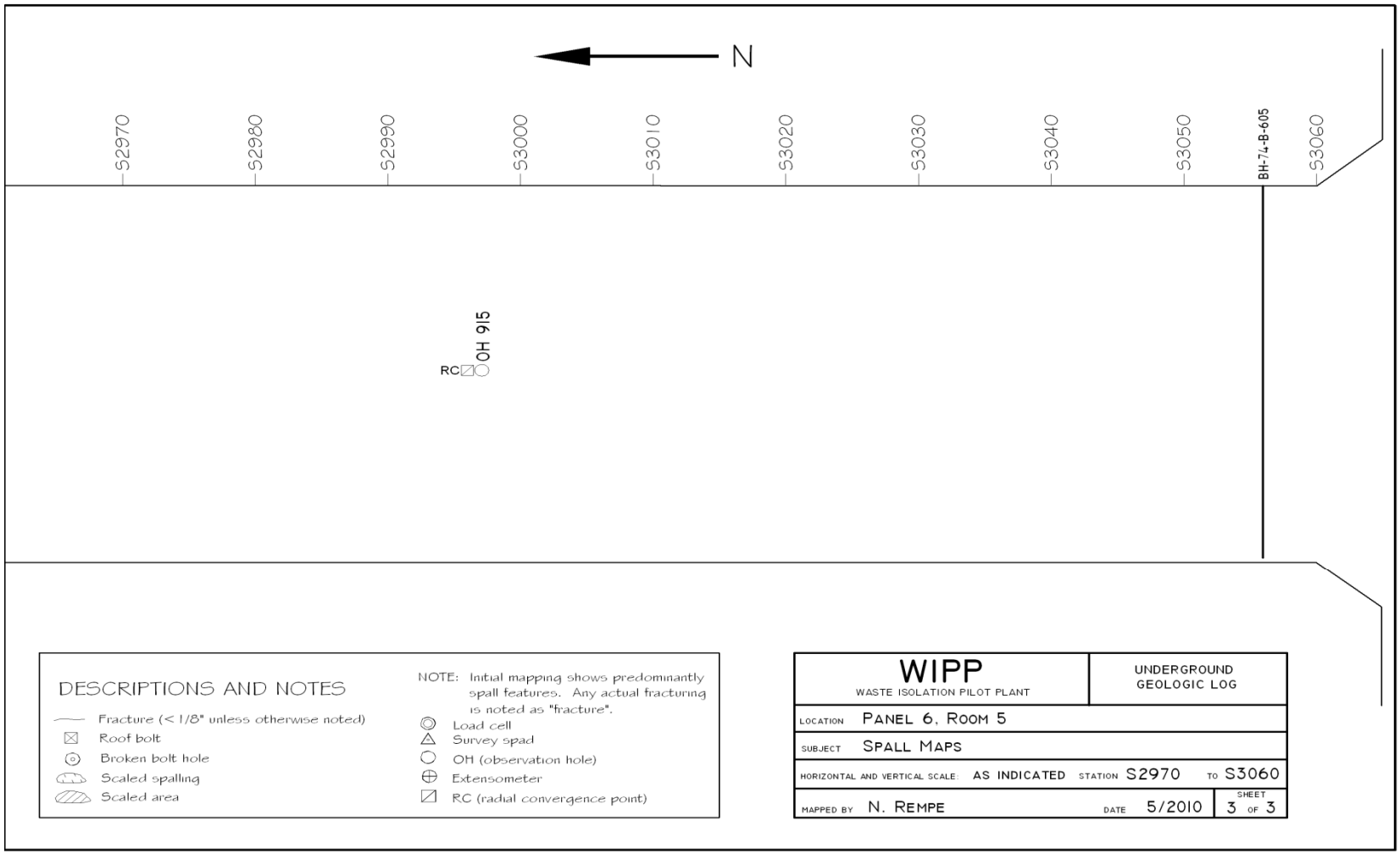


Figure 6-37
Panel 6 Room 5, S2970-S3060 Roof Fractures (Sheet 3 of 3)

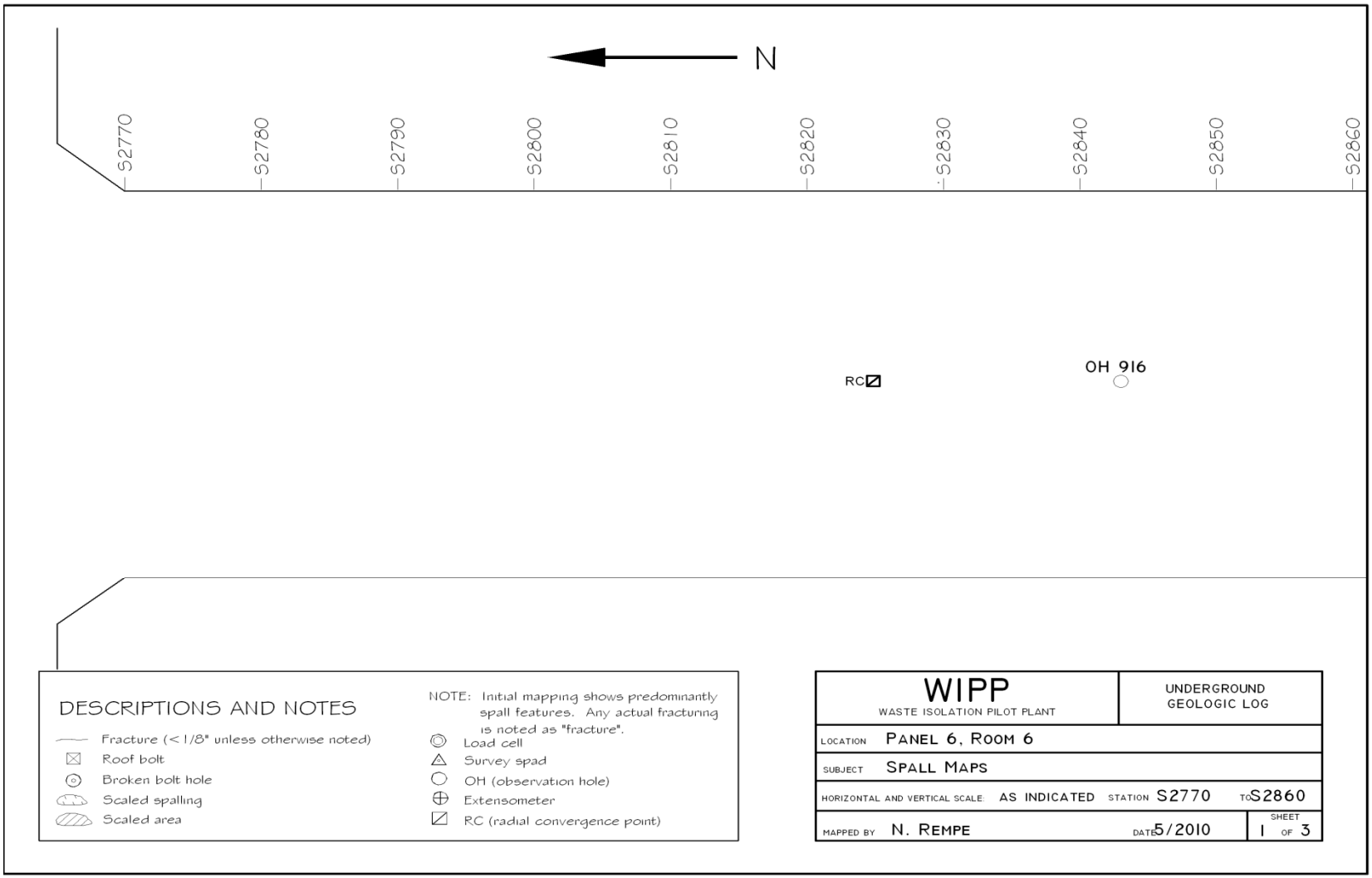


Figure 6-38
Panel 6 Room 6, S2770-S2860 Roof Fractures (Sheet 1 of 3)

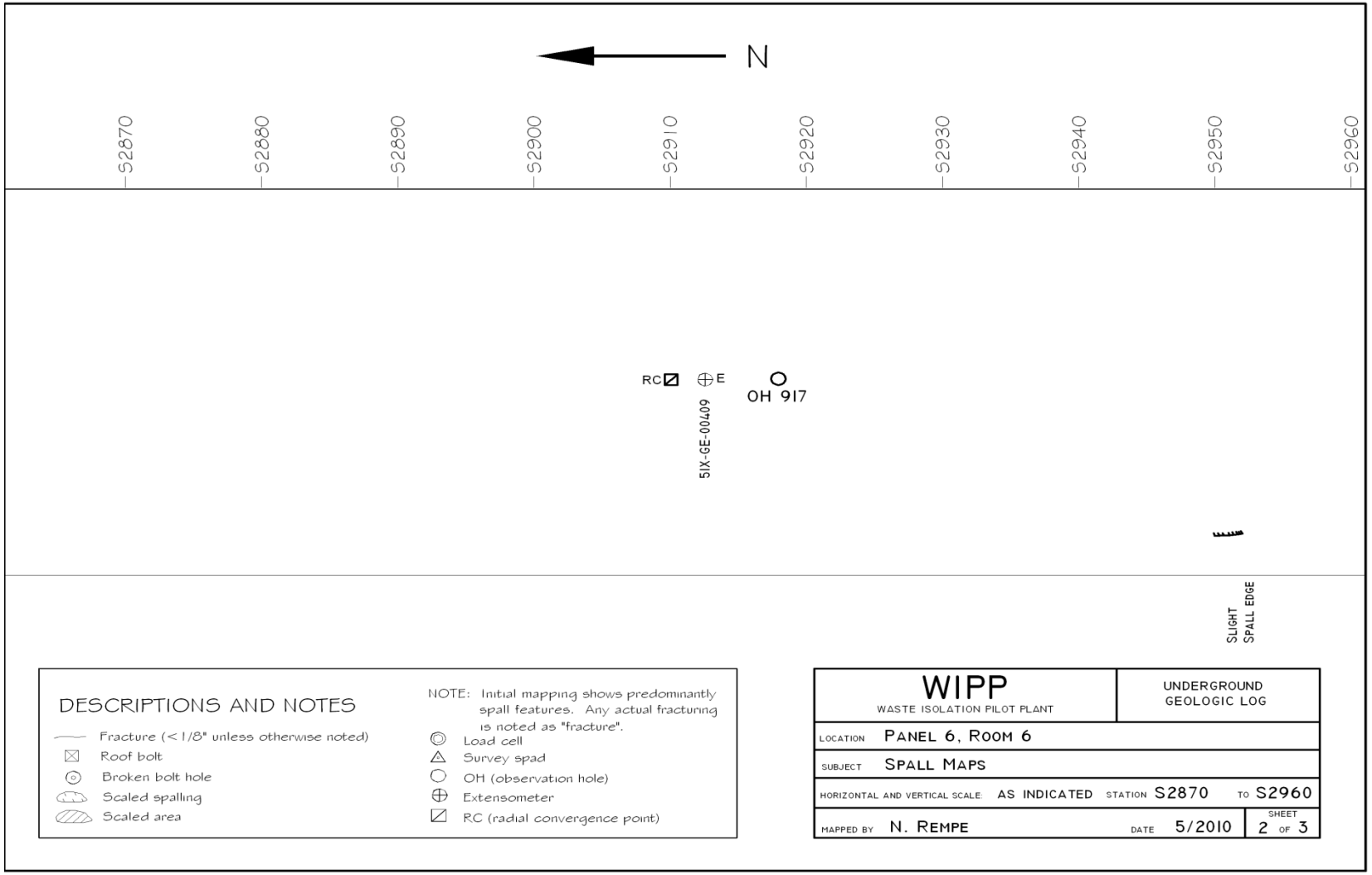


Figure 6-39
Panel 6 Room 6, S2870-S2960 Roof Fractures (Sheet 2 of 3)

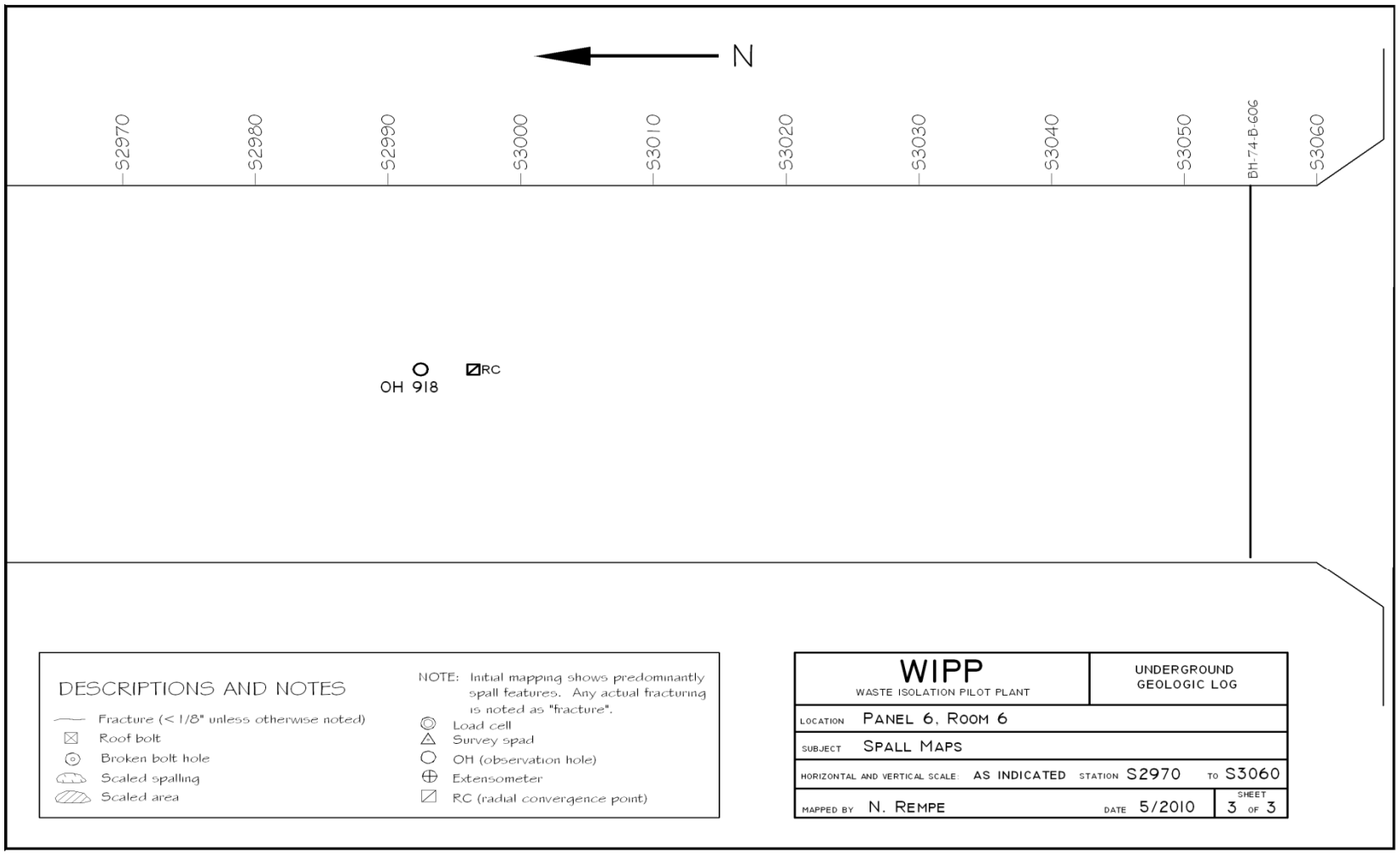


Figure 6-40
Panel 6 Room 6, S2970-S3060 Roof Fractures (Sheet 3 of 3)

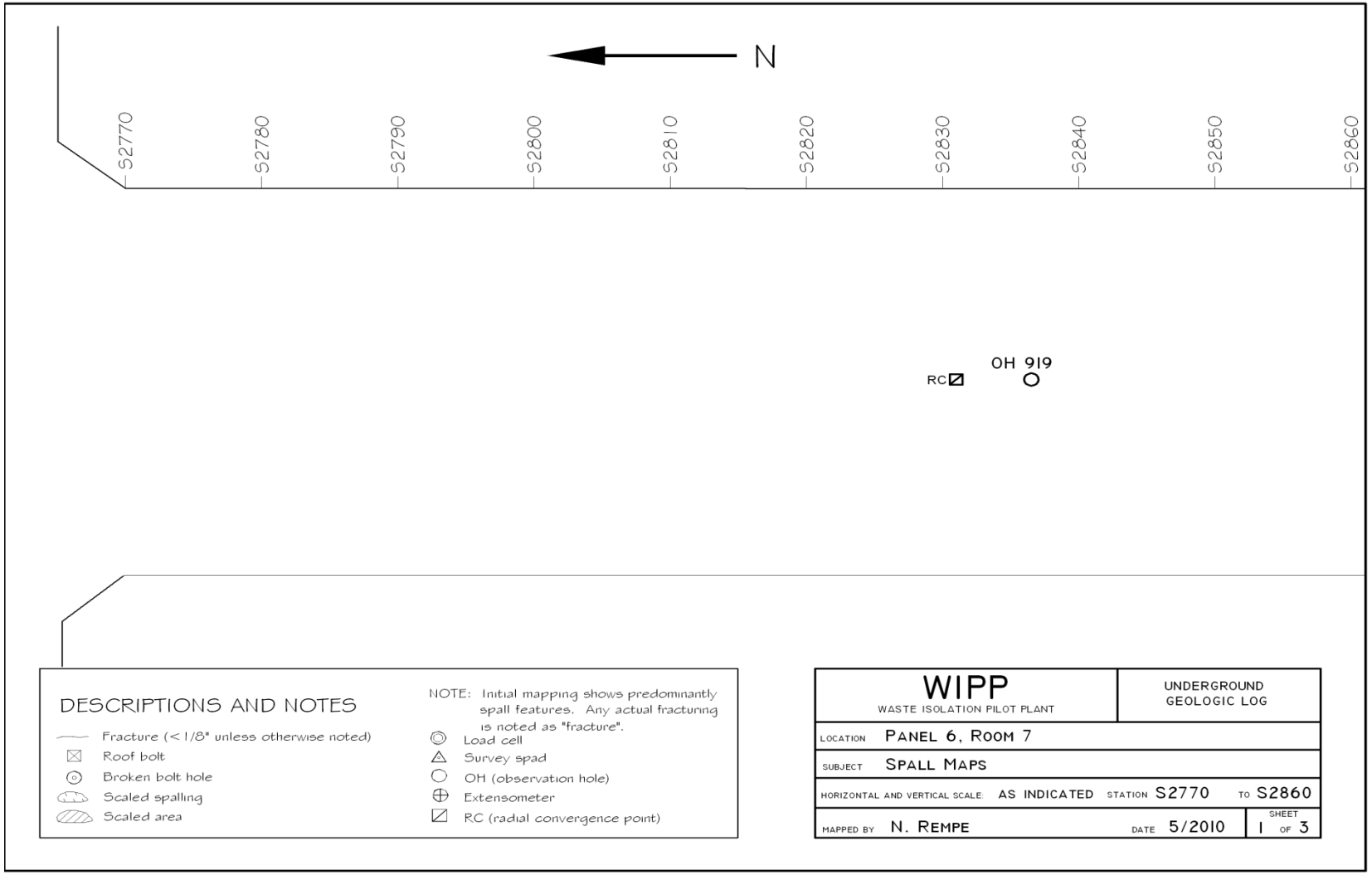


Figure 6-41
Panel 6 Room 7, S2770-S2860 Roof Fractures (Sheet 1 of 3)

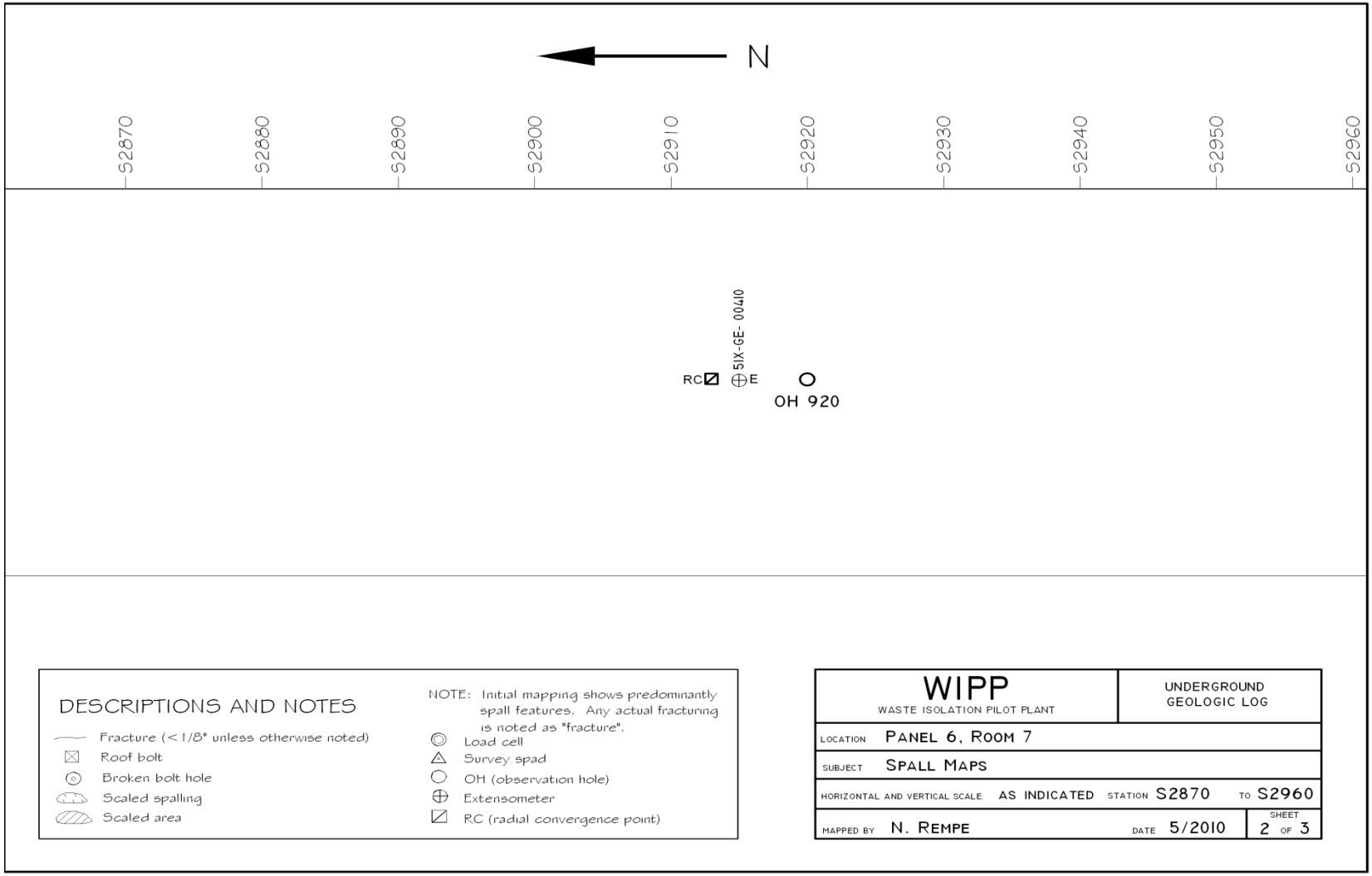


Figure 6-42
Panel 6 Room 7, S2870-S2960 Roof Fractures (Sheet 2 of 3)

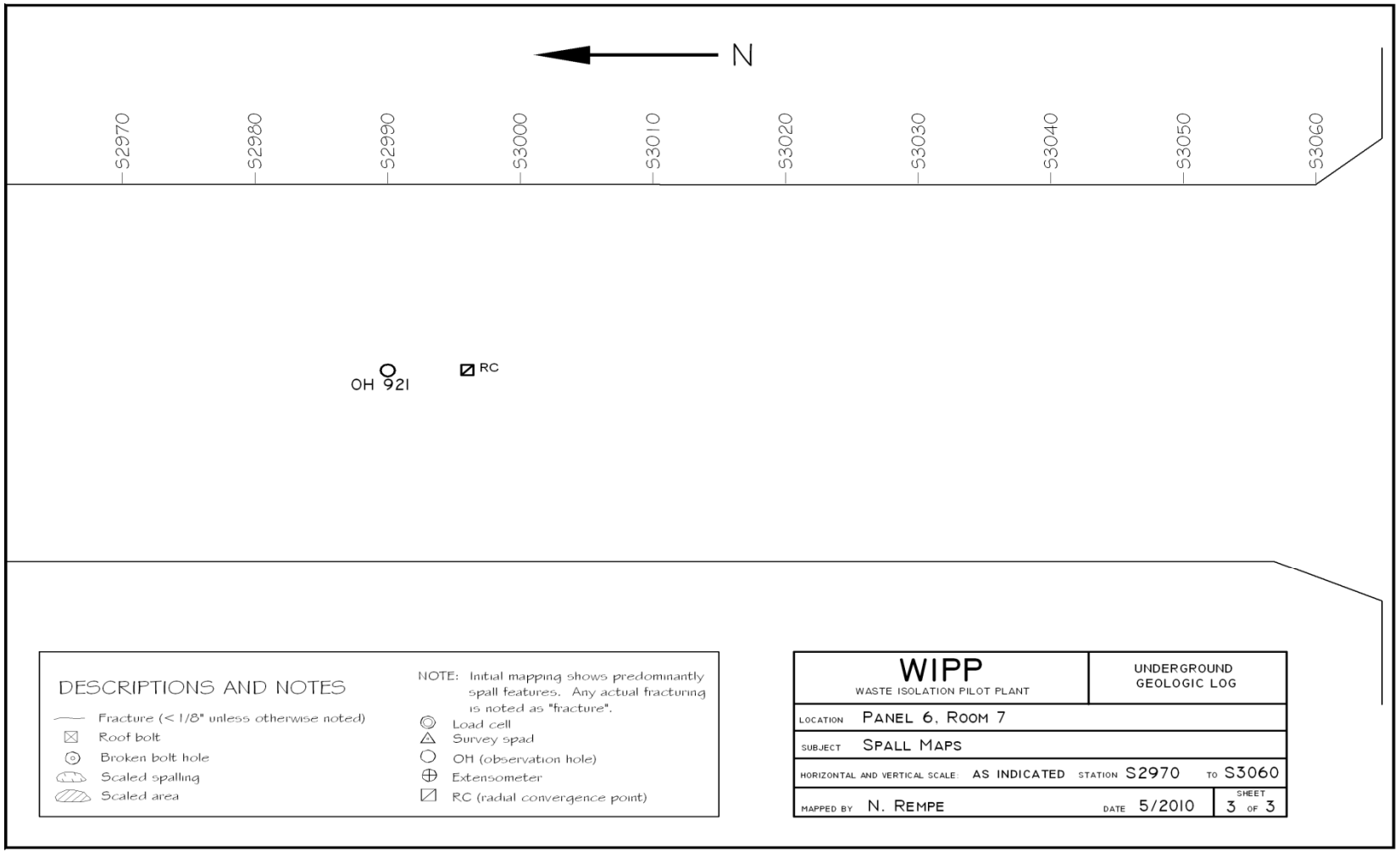


Figure 6-43
Panel 6 Room 7, S2870-S3060 Roof Fractures (Sheet 3 of 3)

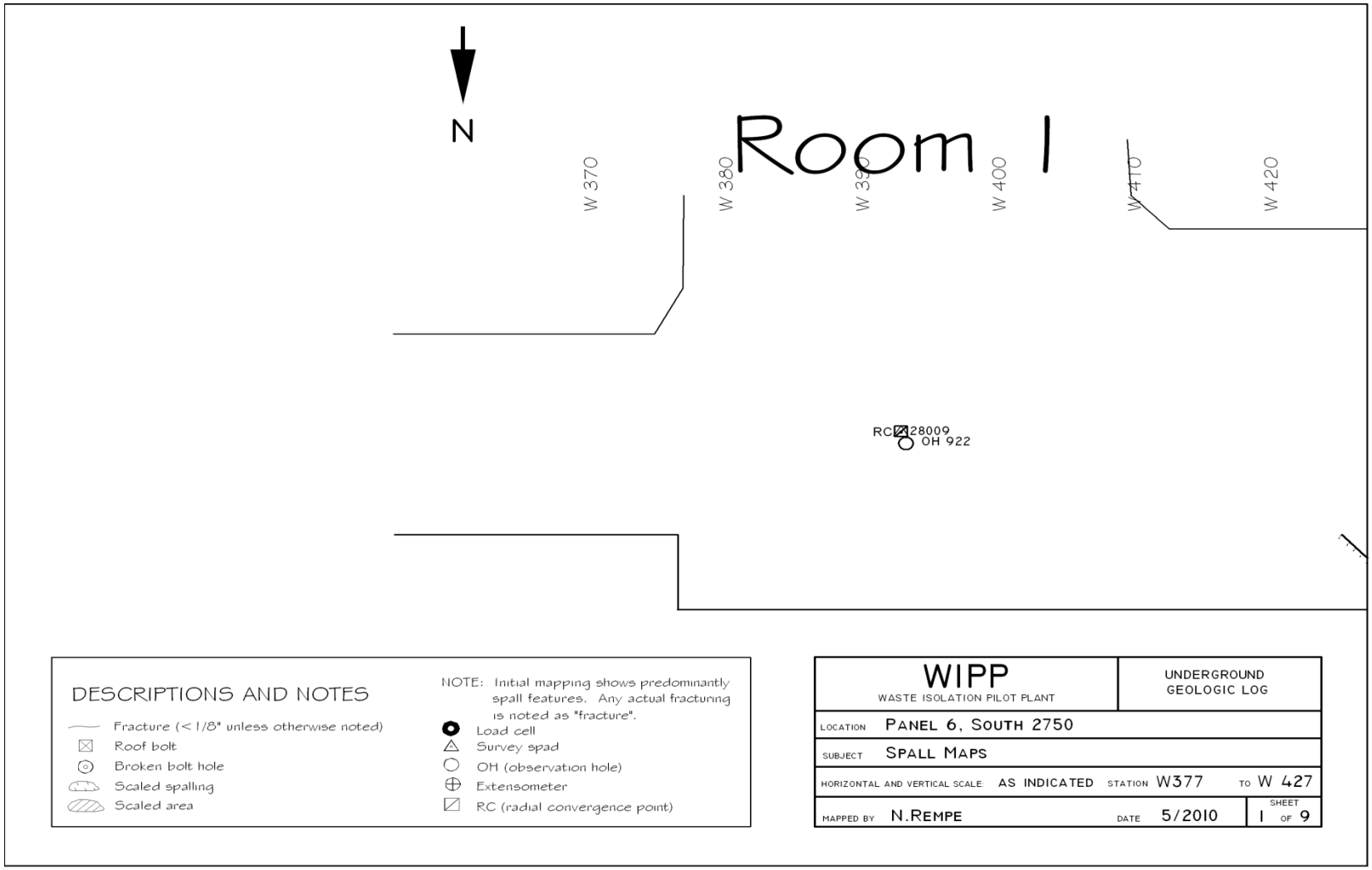


Figure 6-44
Panel 6 South 2750, W377 – W427 Roof Fractures (Sheet 1 of 9)

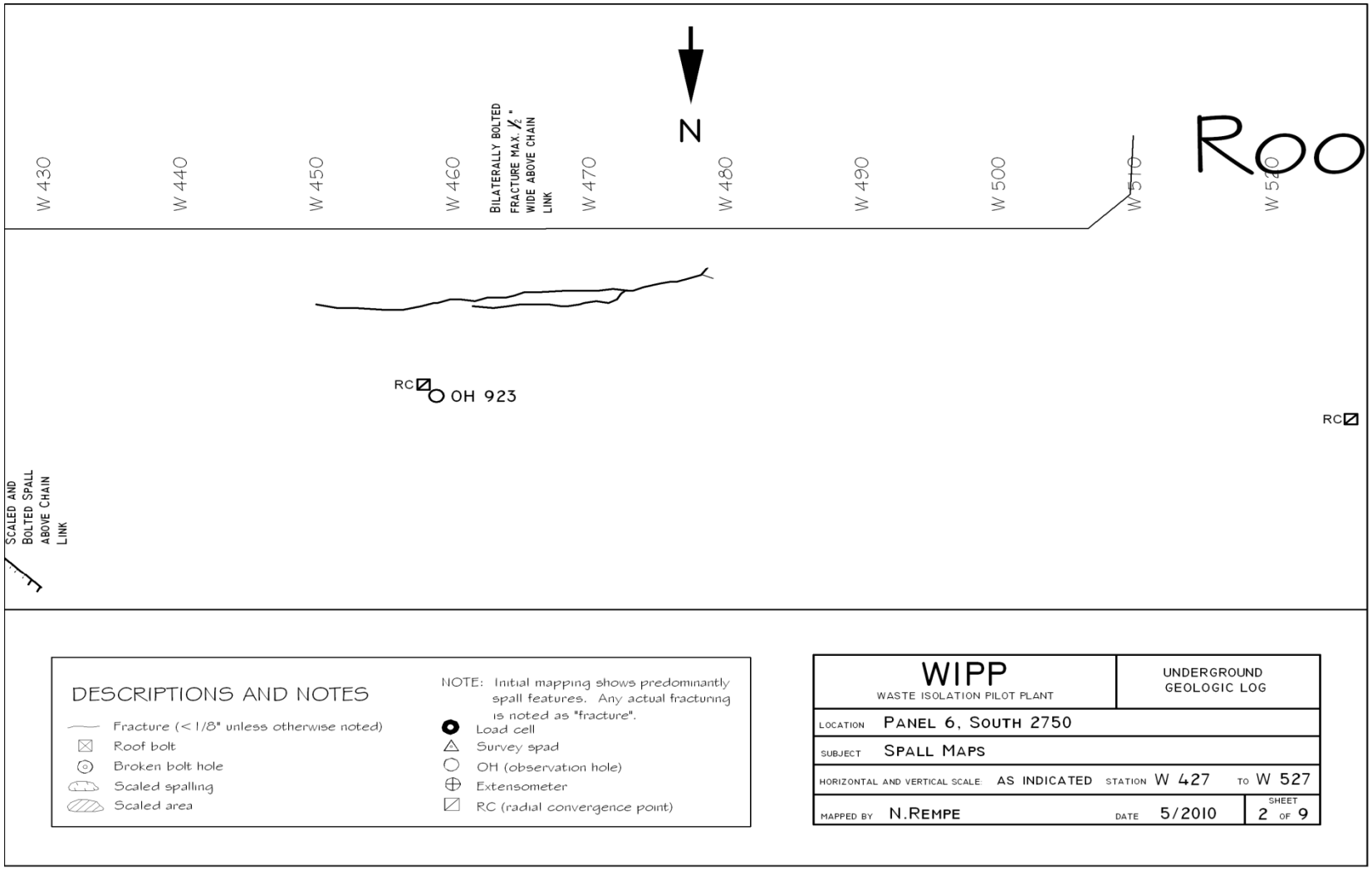


Figure 6-45
Panel 6 South 2750, W427 – W527 Roof Fractures (Sheet 2 of 9)

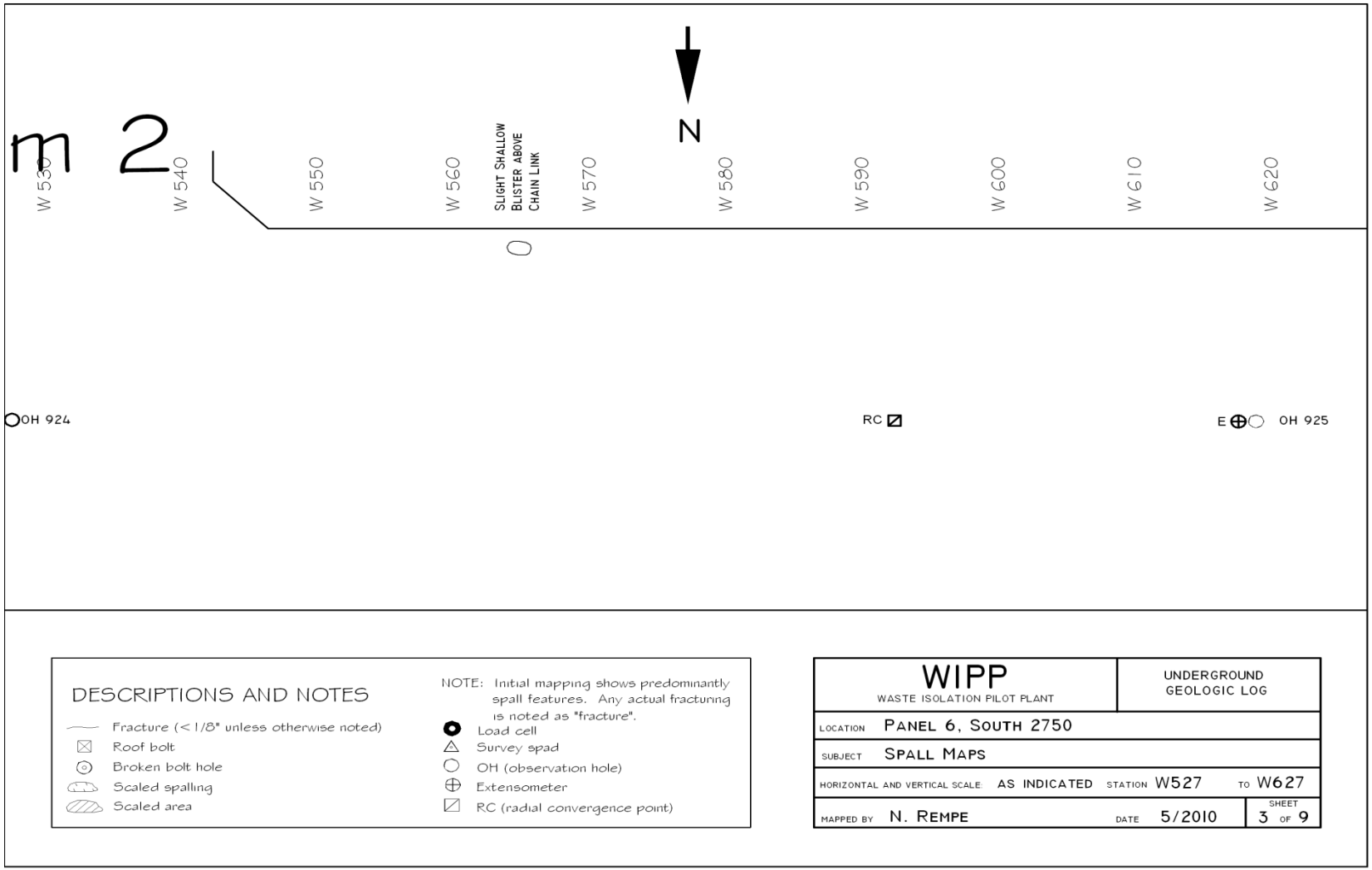


Figure 6-46
Panel 6 South 2750, W527 – W627 Roof Fractures (Sheet 3 of 9)

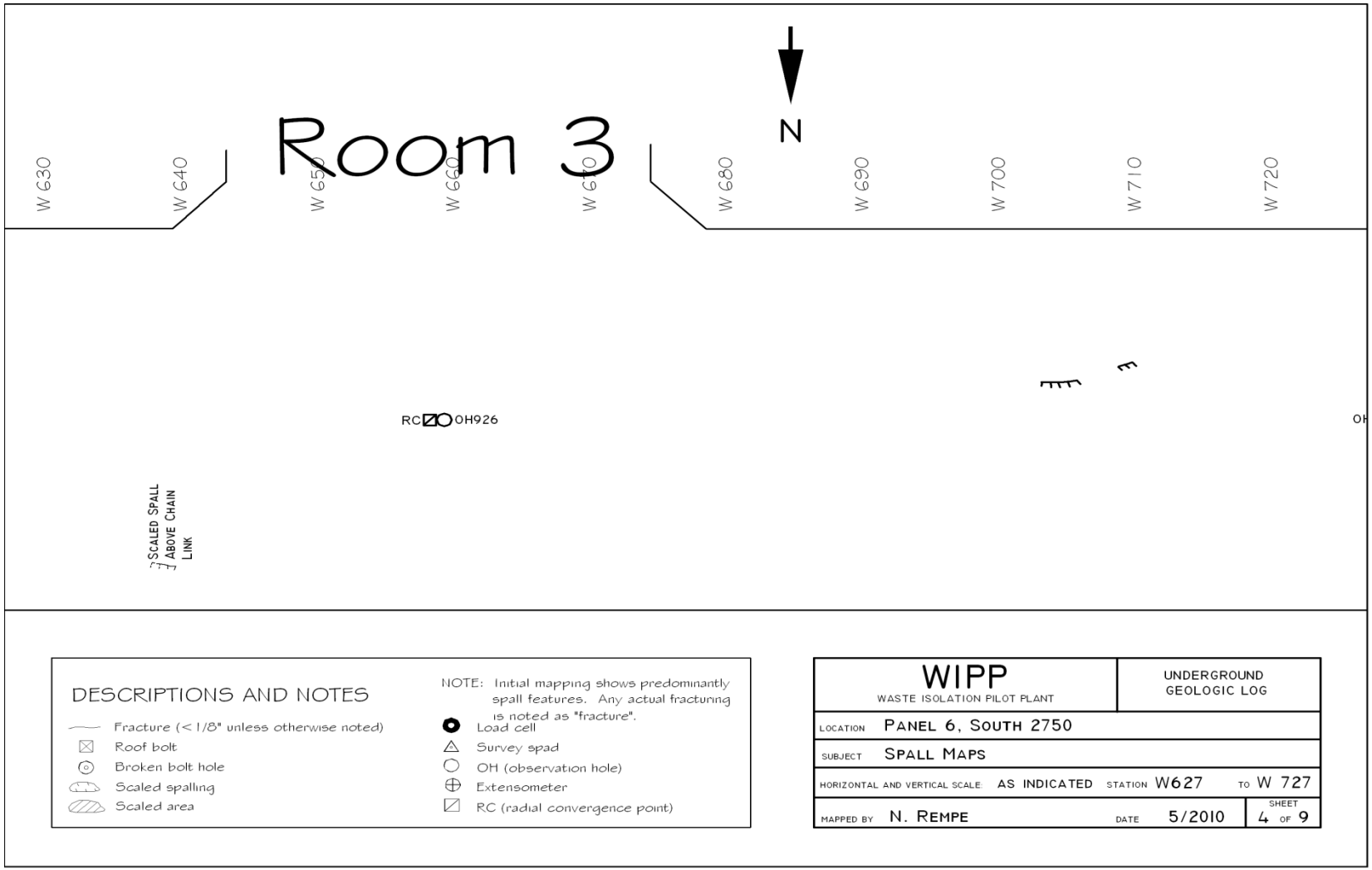


Figure 6-47
Panel 6 South 2750, W627 – W727 Roof Fractures (Sheet 4 of 9)

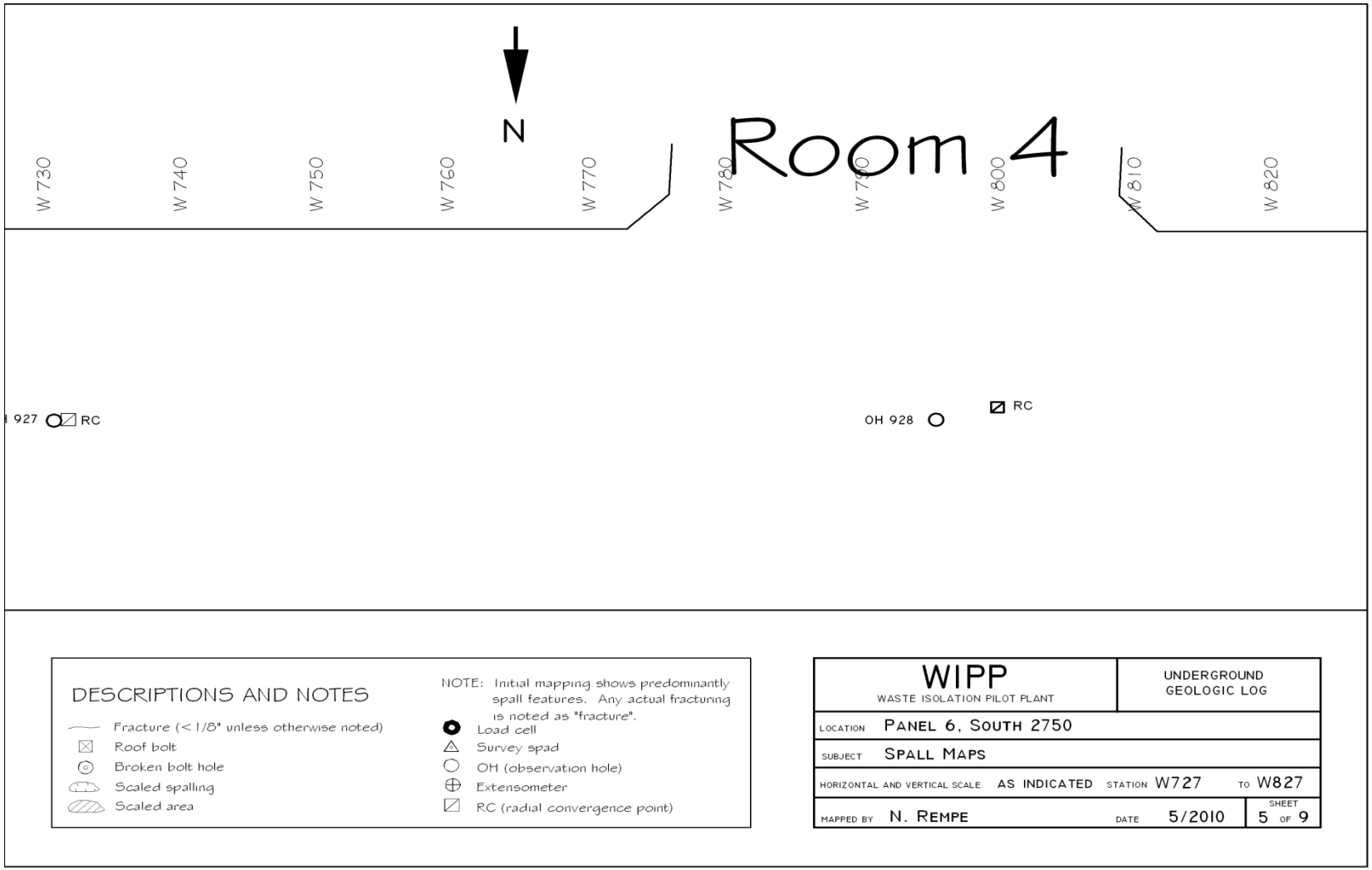


Figure 6-48
Panel 6 South 2750, W727 – W827 Roof Fractures (Sheet 5 of 9)

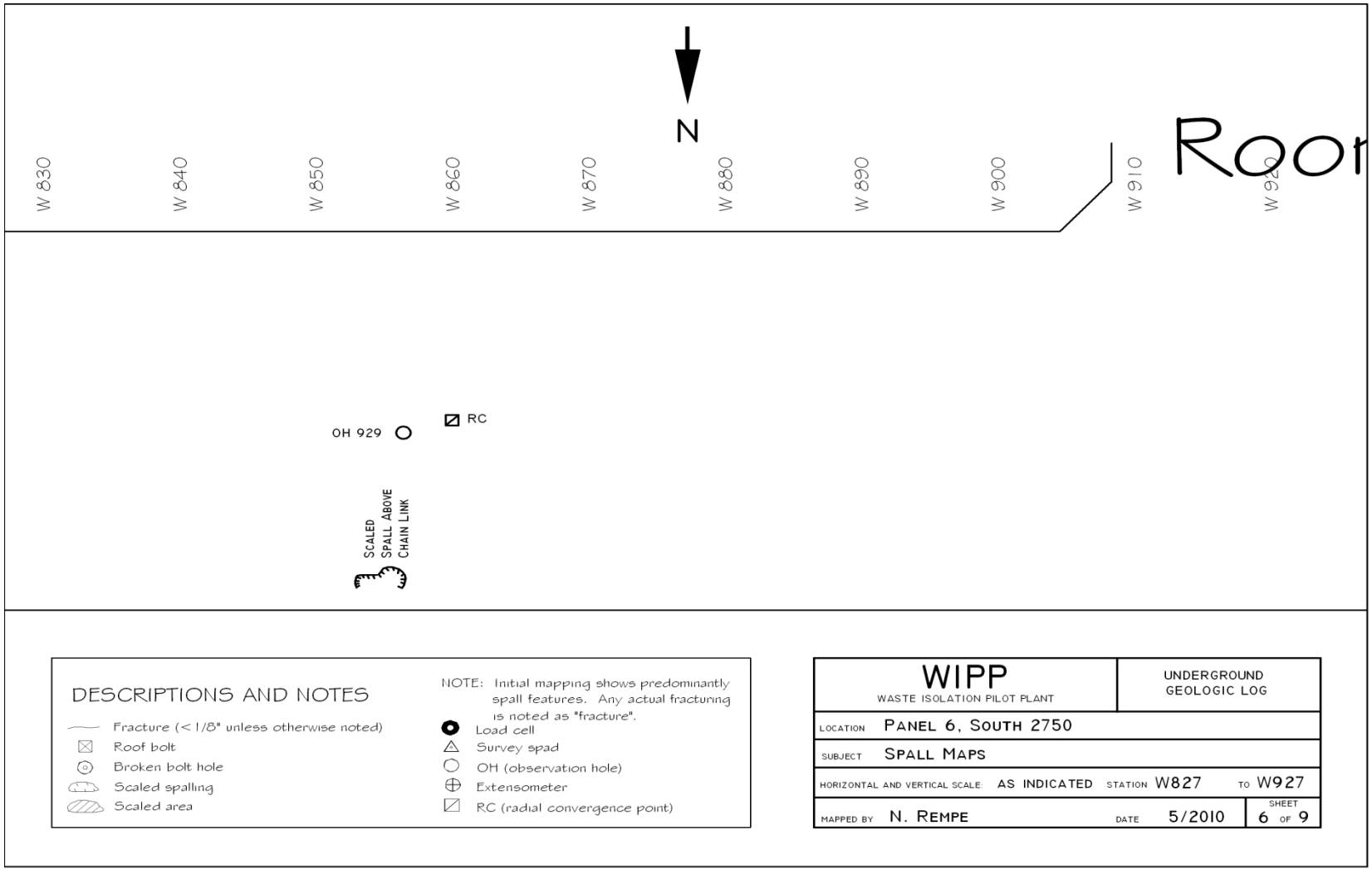


Figure 6-49
Panel 6 South 2750, W827 – W927 Roof Fractures (Sheet 6 of 9)

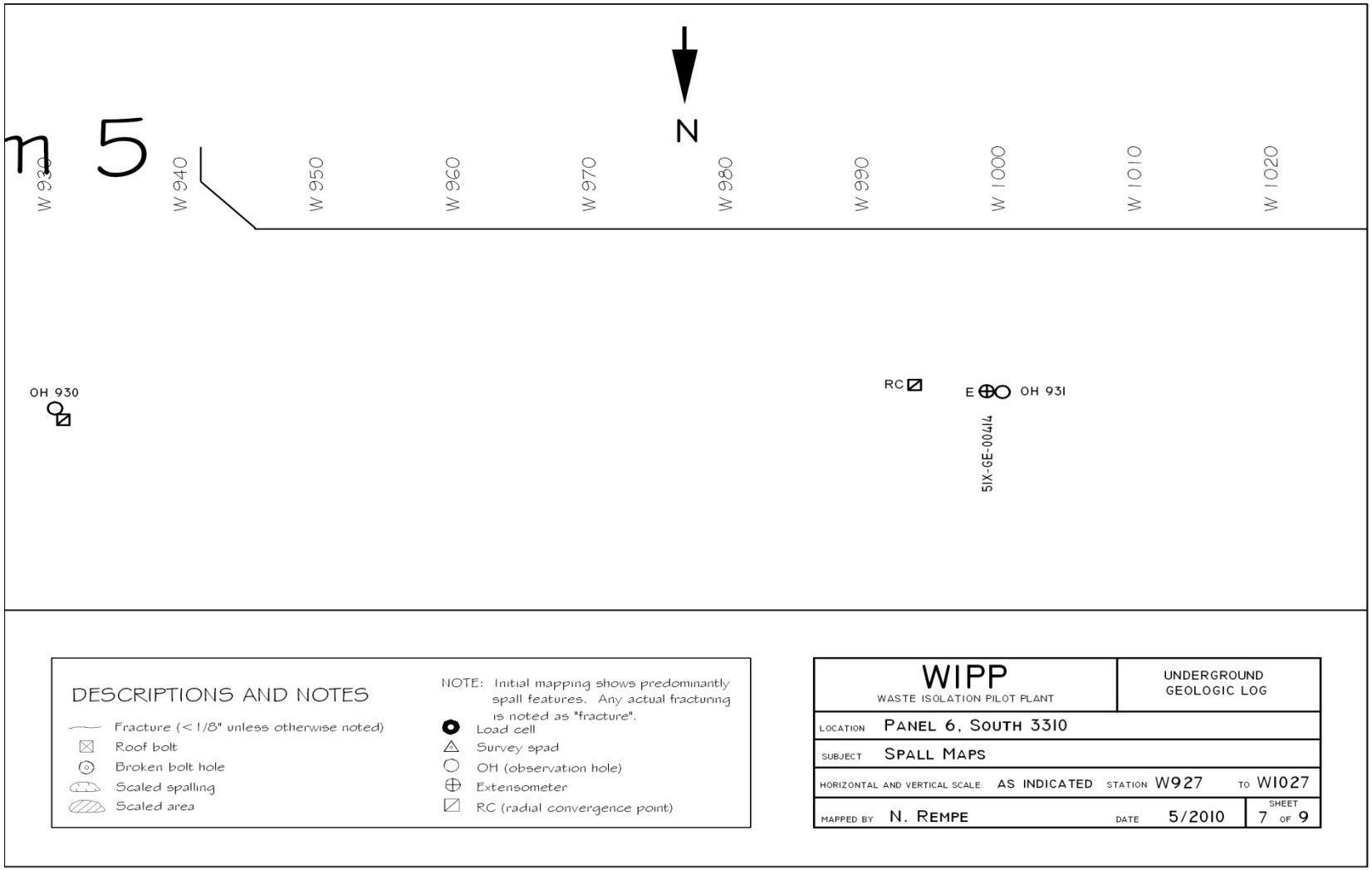


Figure 6-50
Panel 6 South 2750, W927 – W1027 Roof Fractures (Sheet 7 of 9)

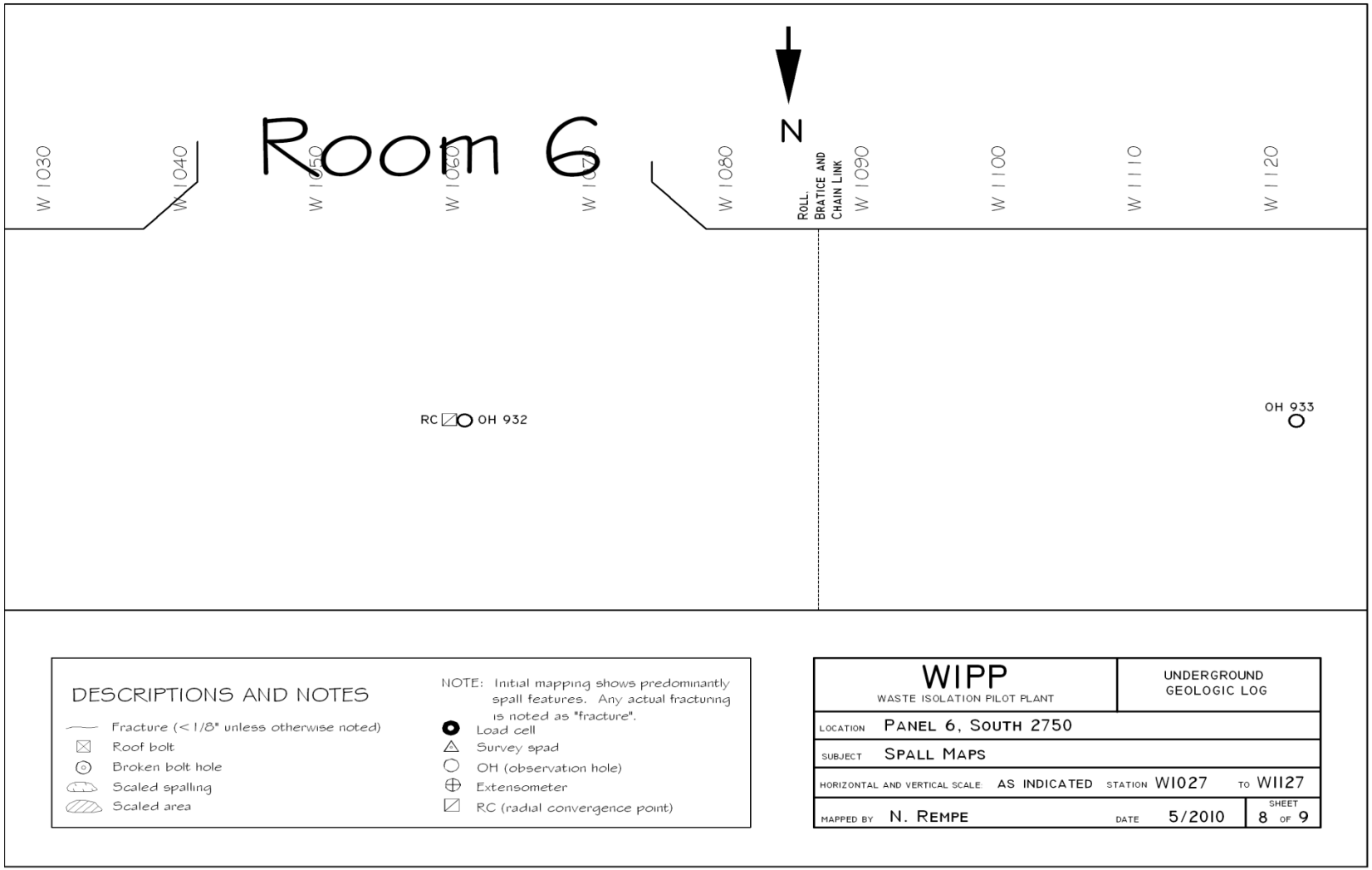


Figure 6-51
Panel 6 South 2750, W1027 – W1127 Roof Fractures (Sheet 8 of 9)

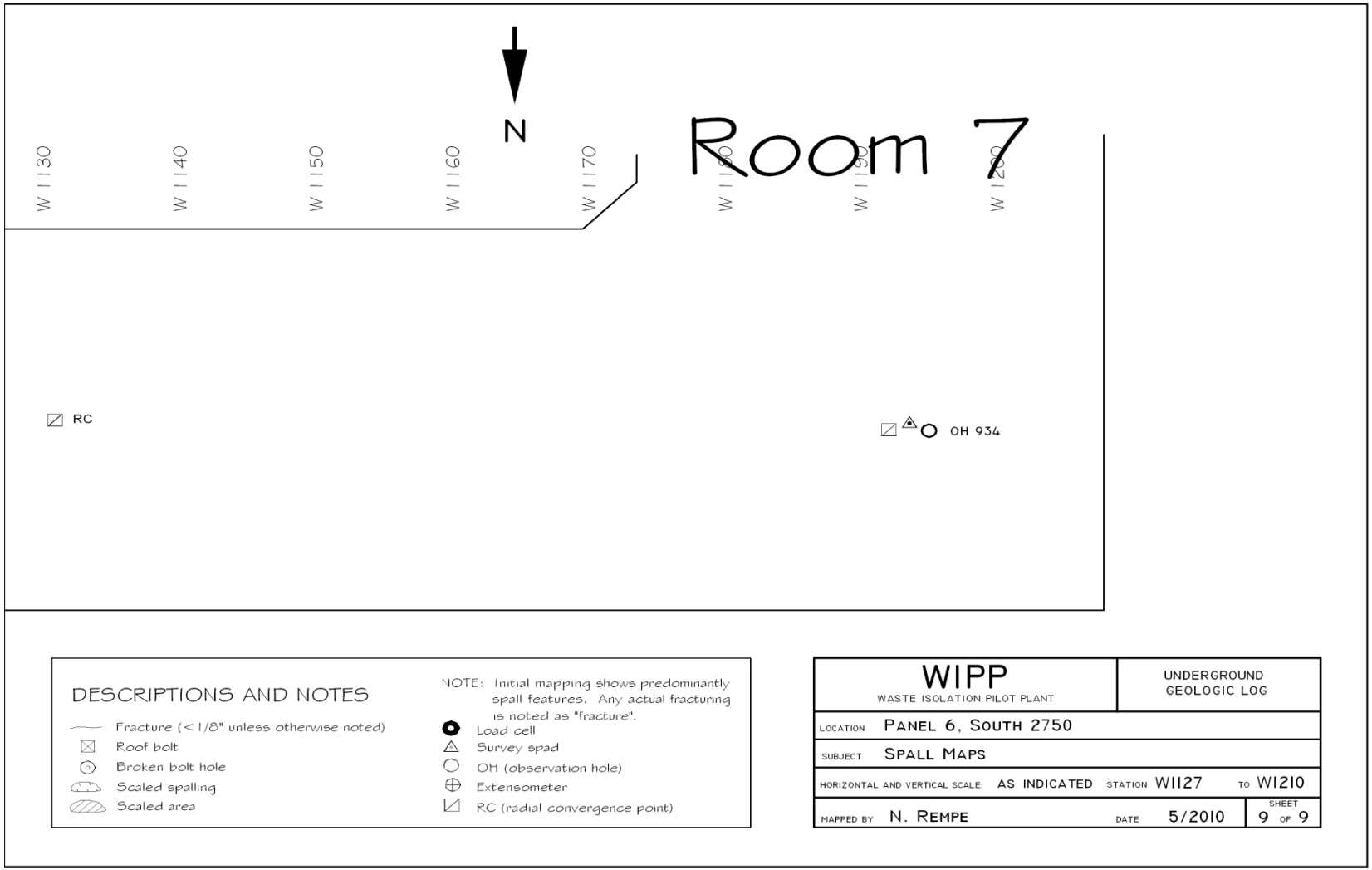


Figure 6-52
Panel 6 South 2750, W1127 – W1210 Roof Fractures (Sheet 9 of 9)

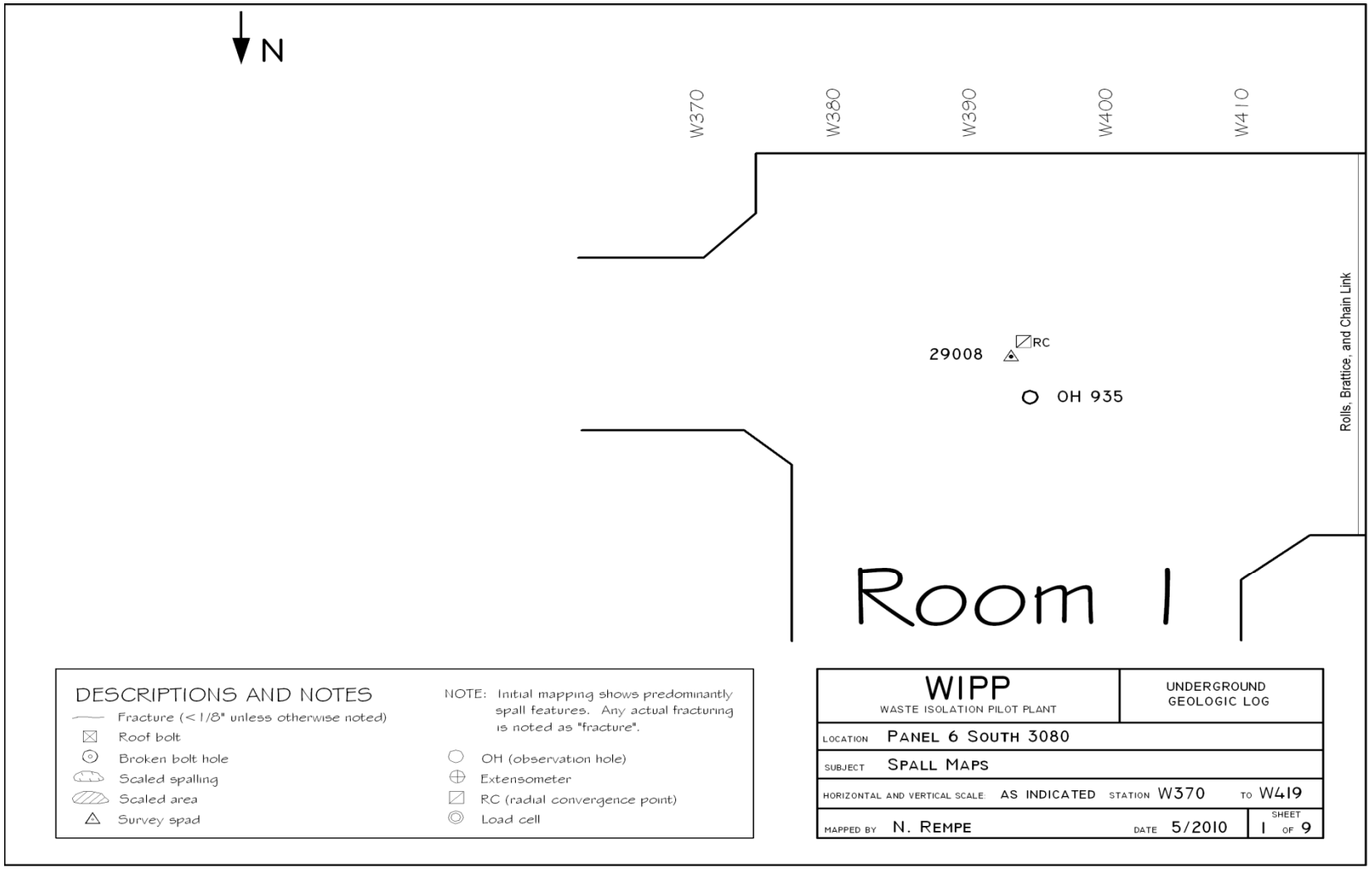


Figure 6-53
Panel 6 South 3080, W370 – W419 Roof Fractures (Sheet 1 of 9)

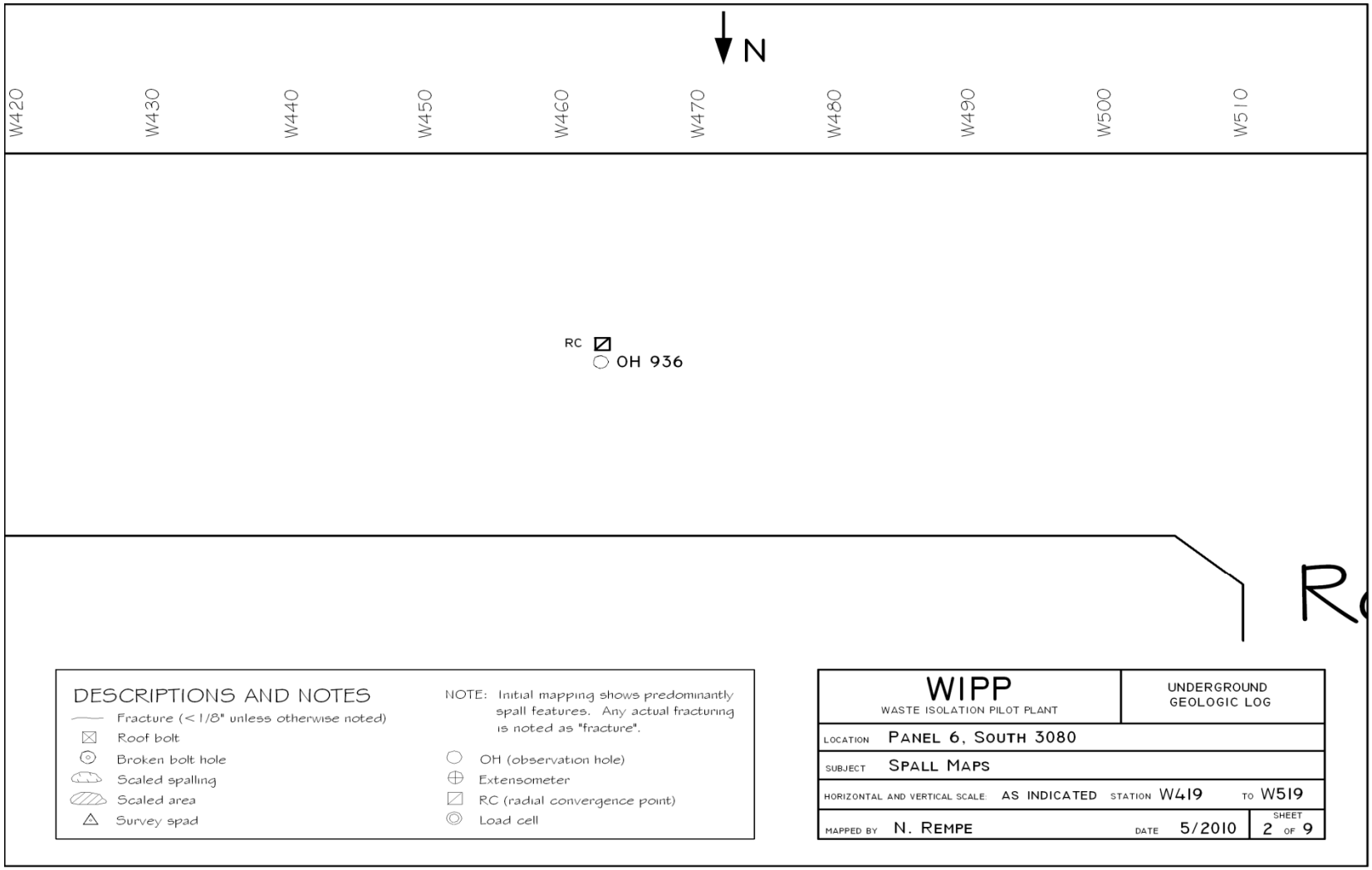
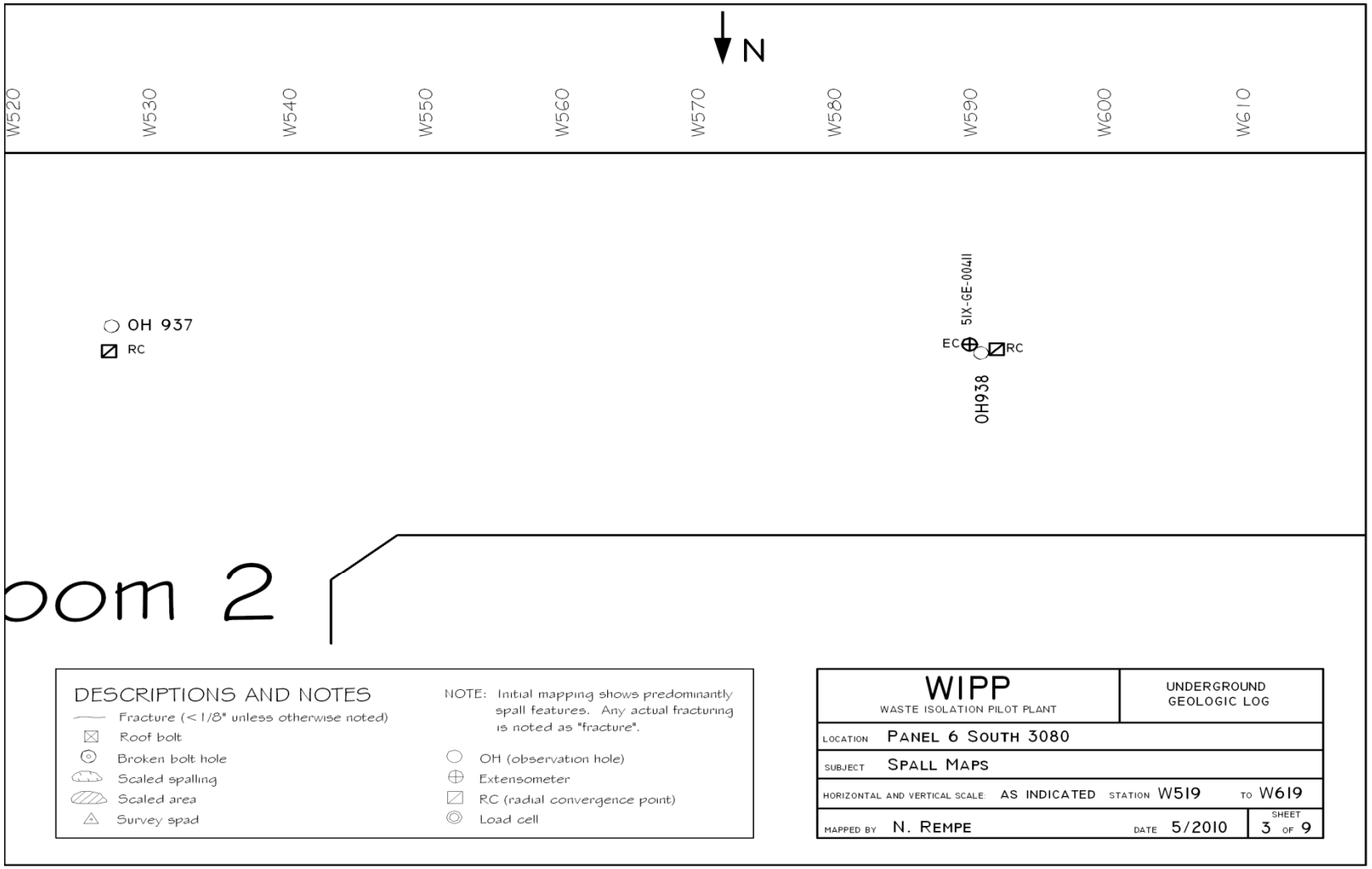


Figure 6-54
Panel 6 South 3080, W419 – W519 Roof Fractures (Sheet 2 of 9)



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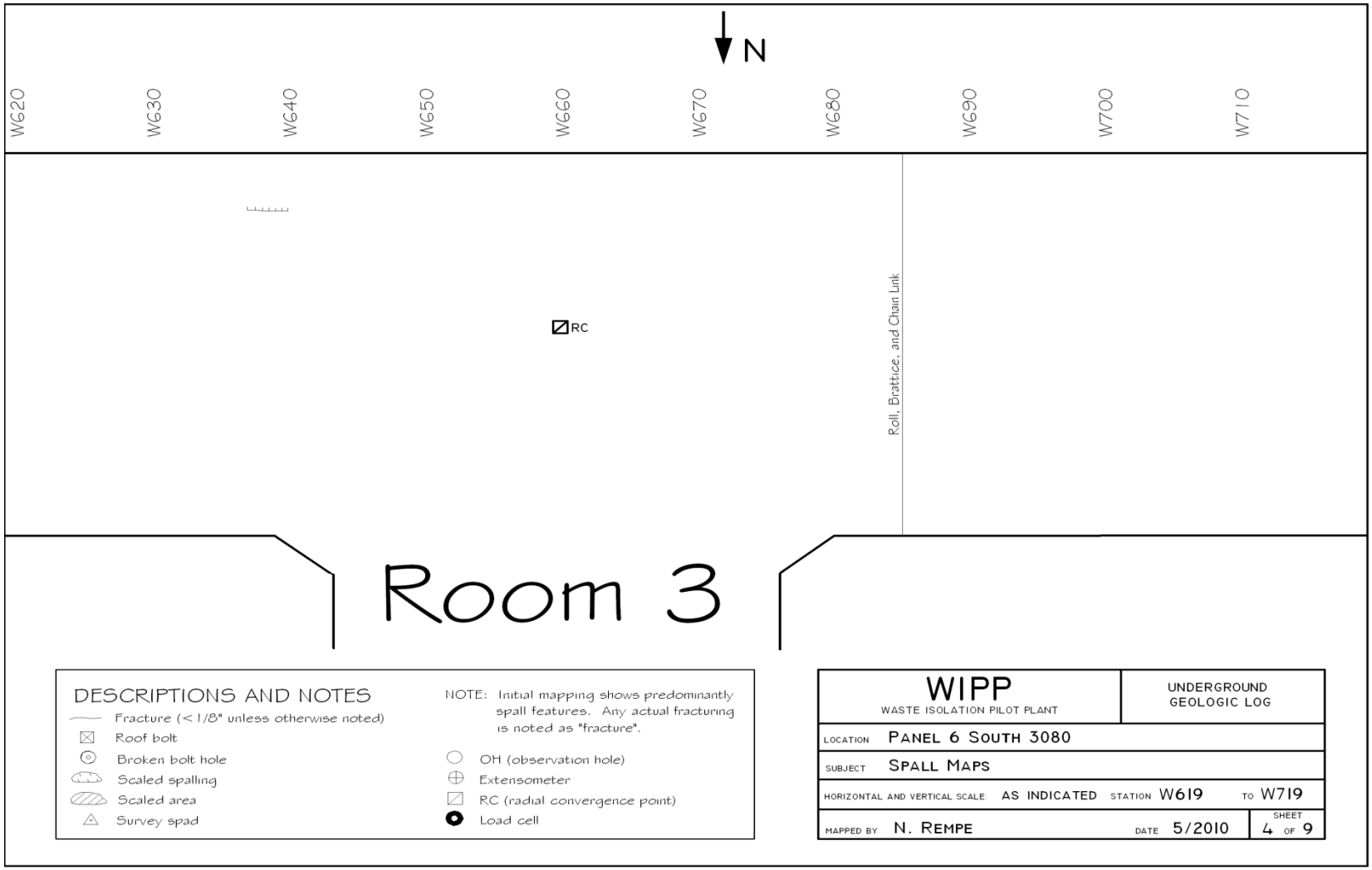

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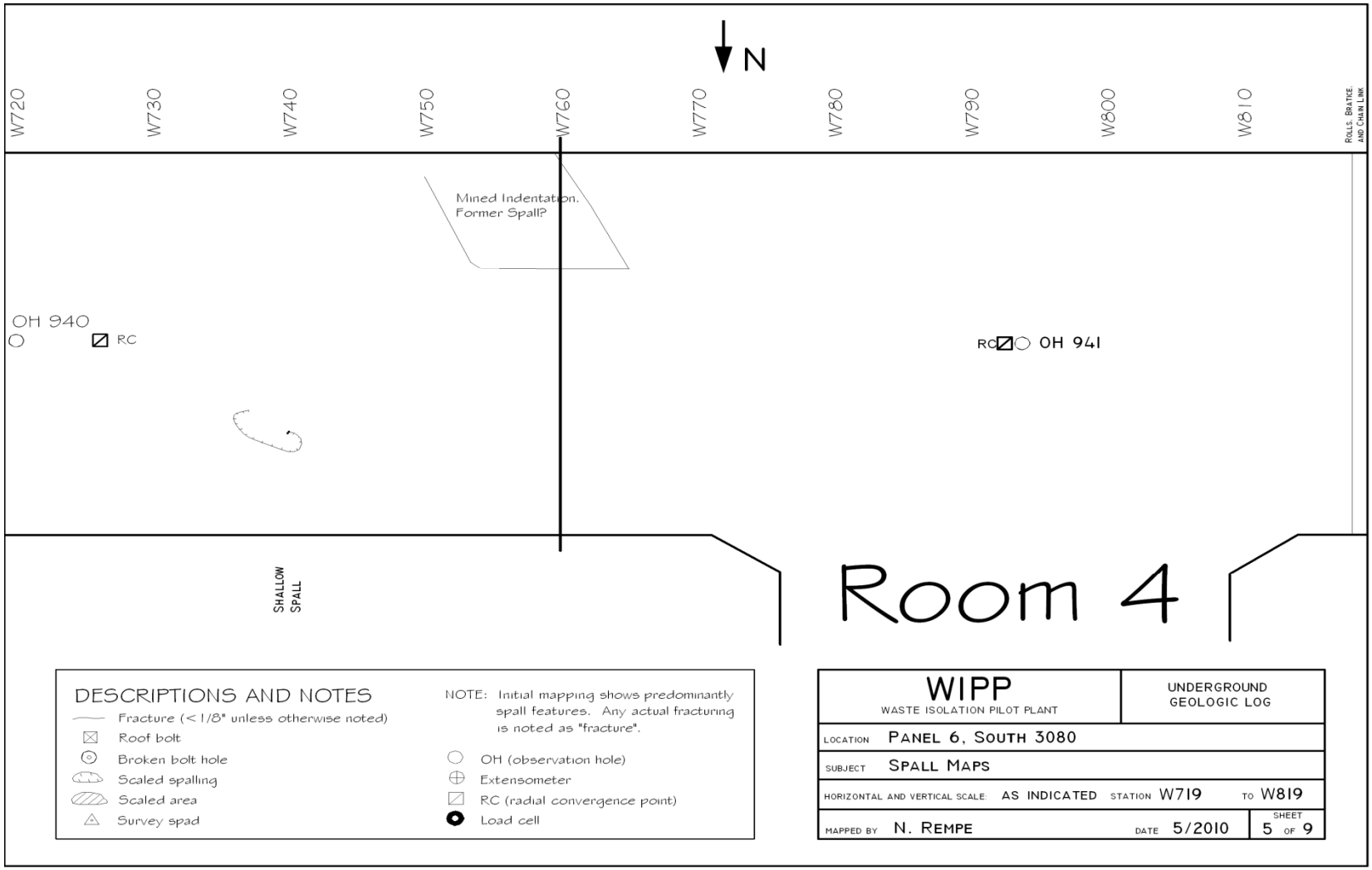

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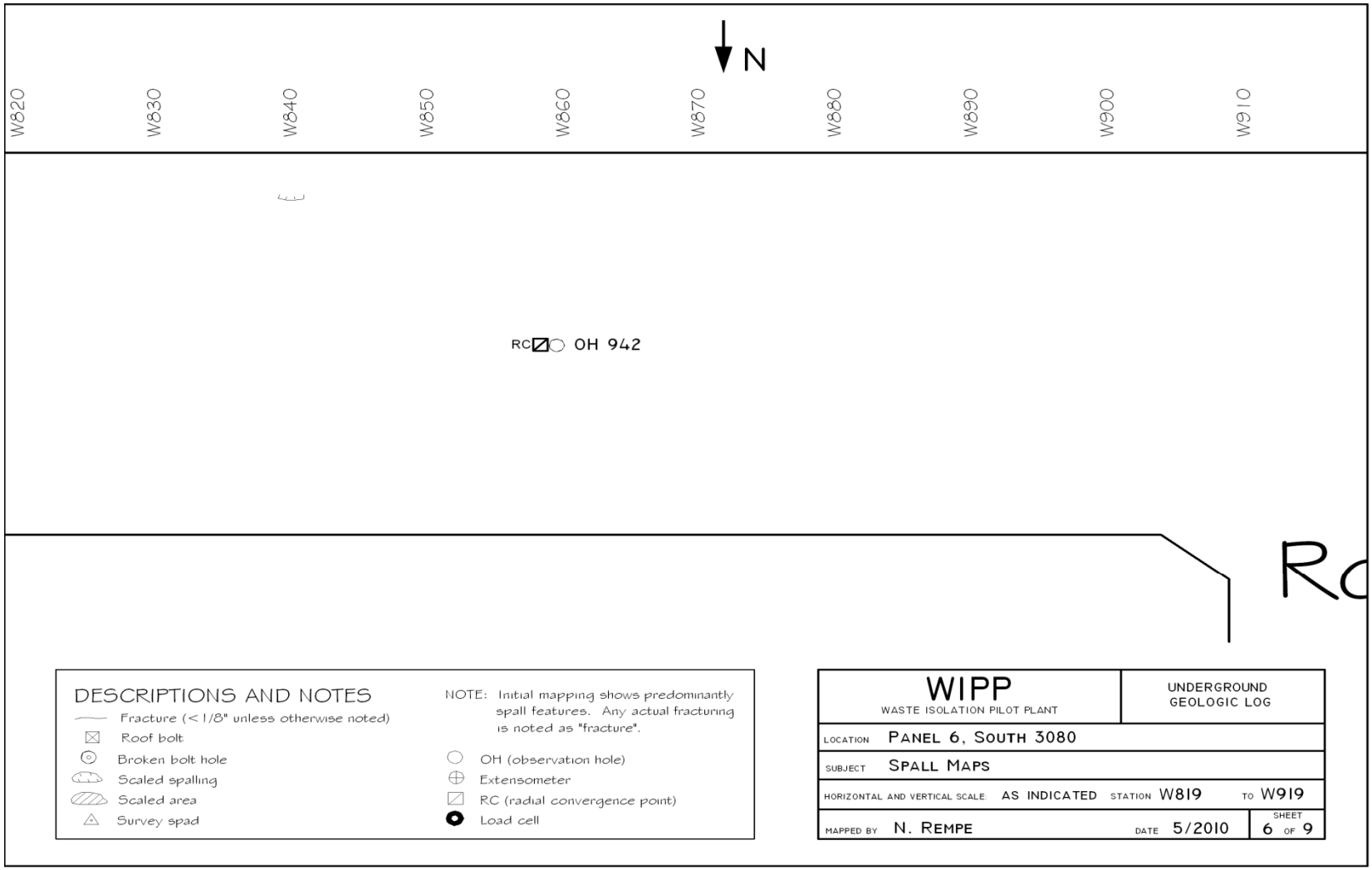

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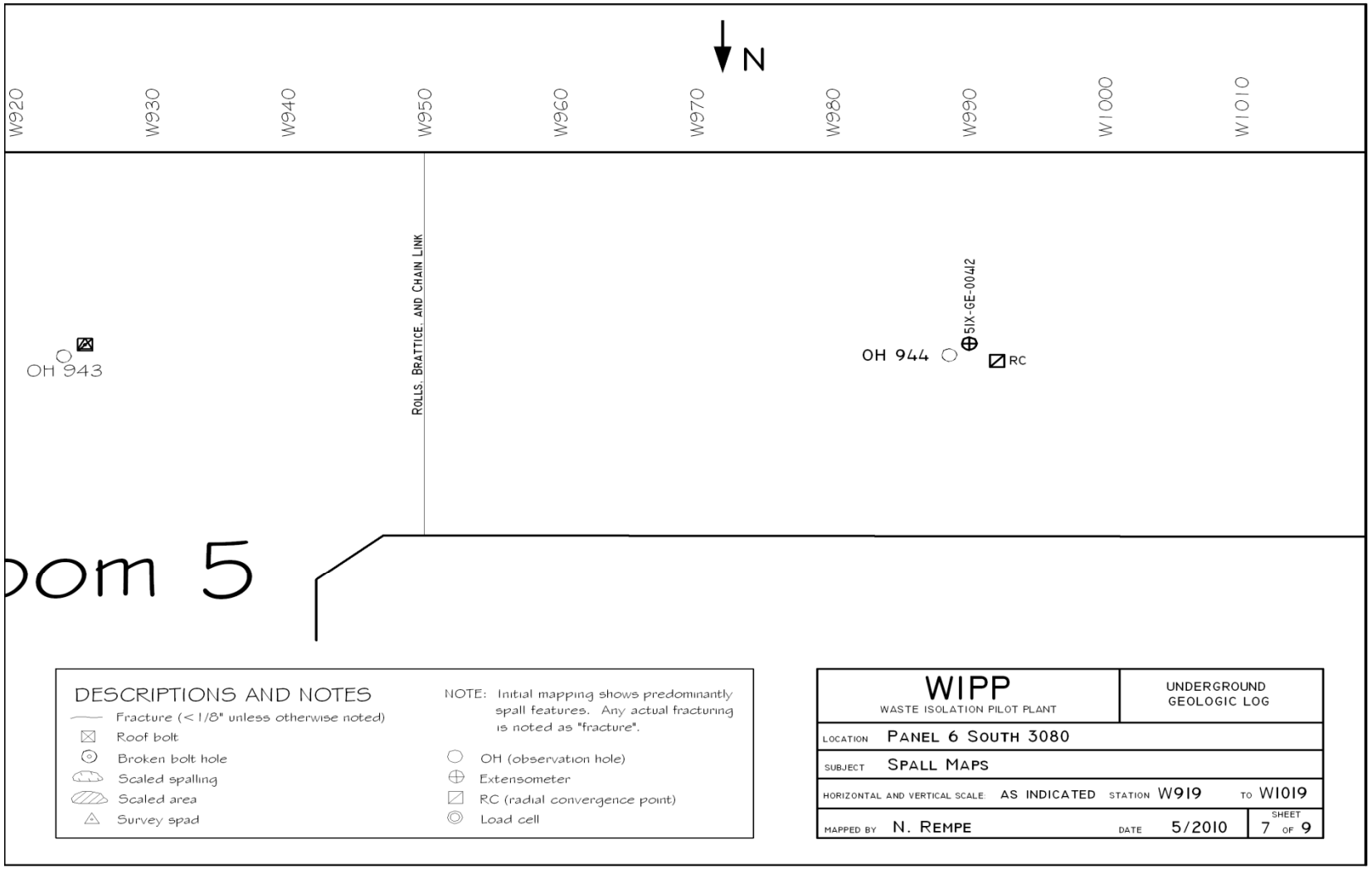

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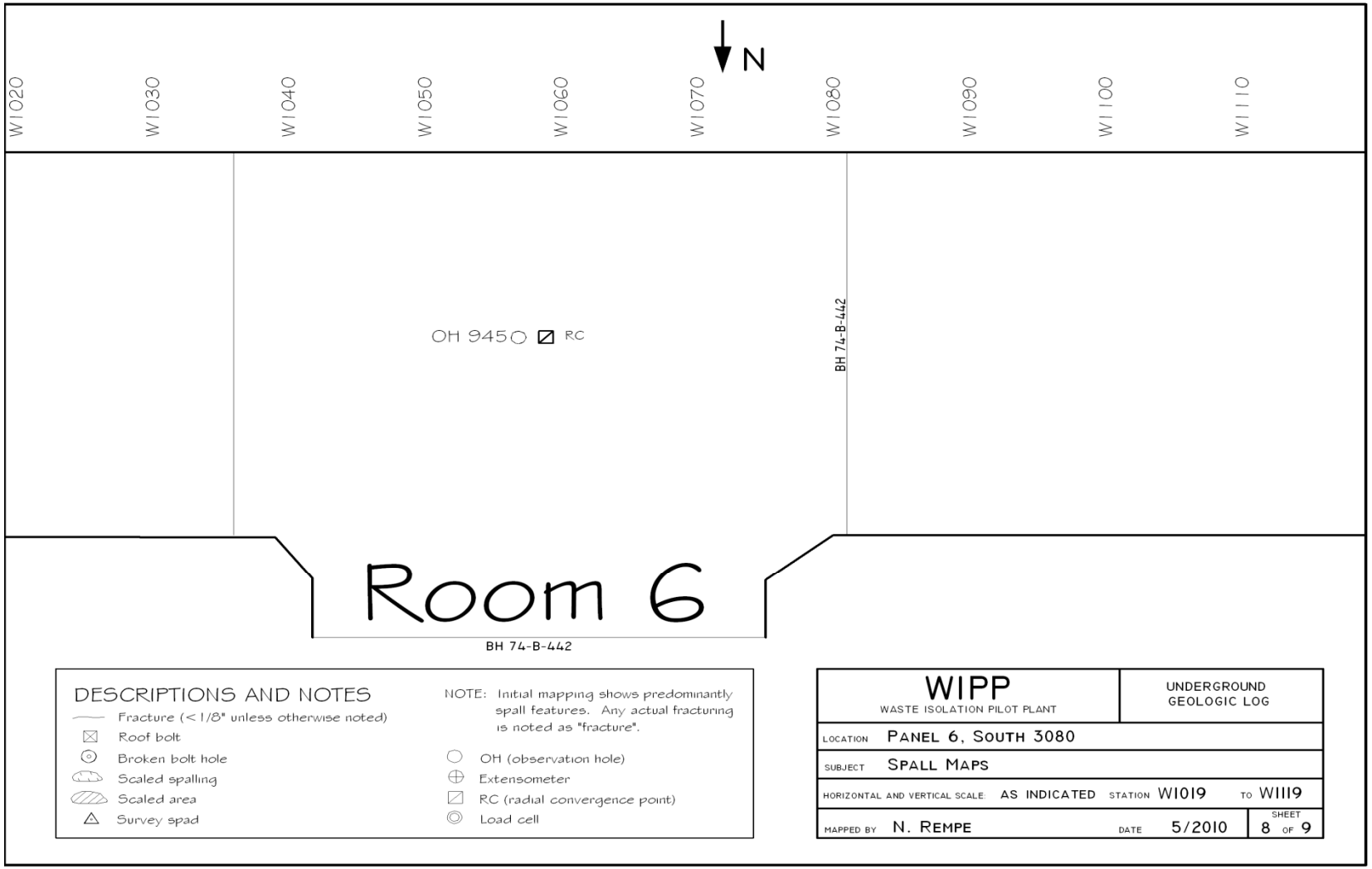

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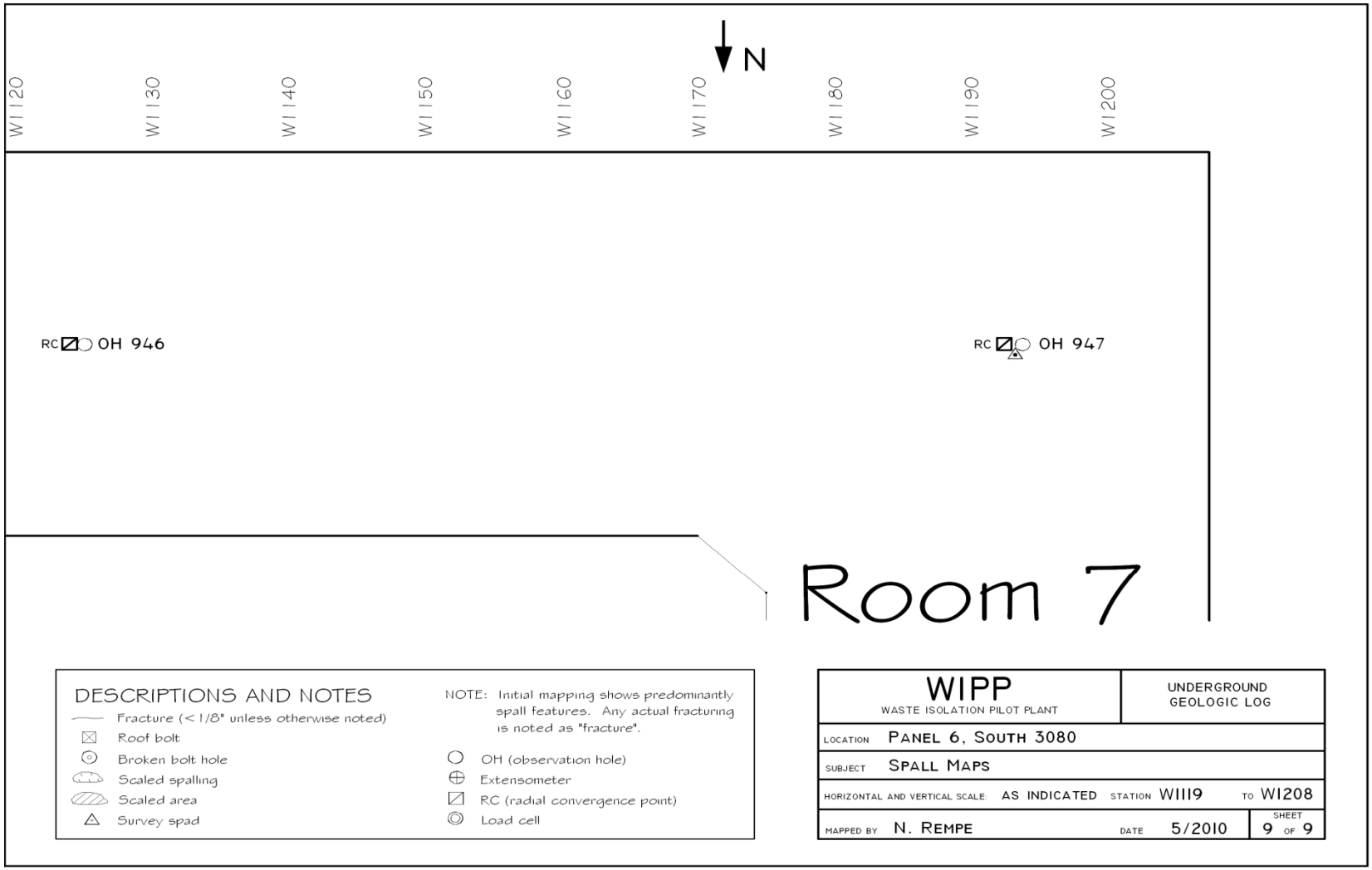

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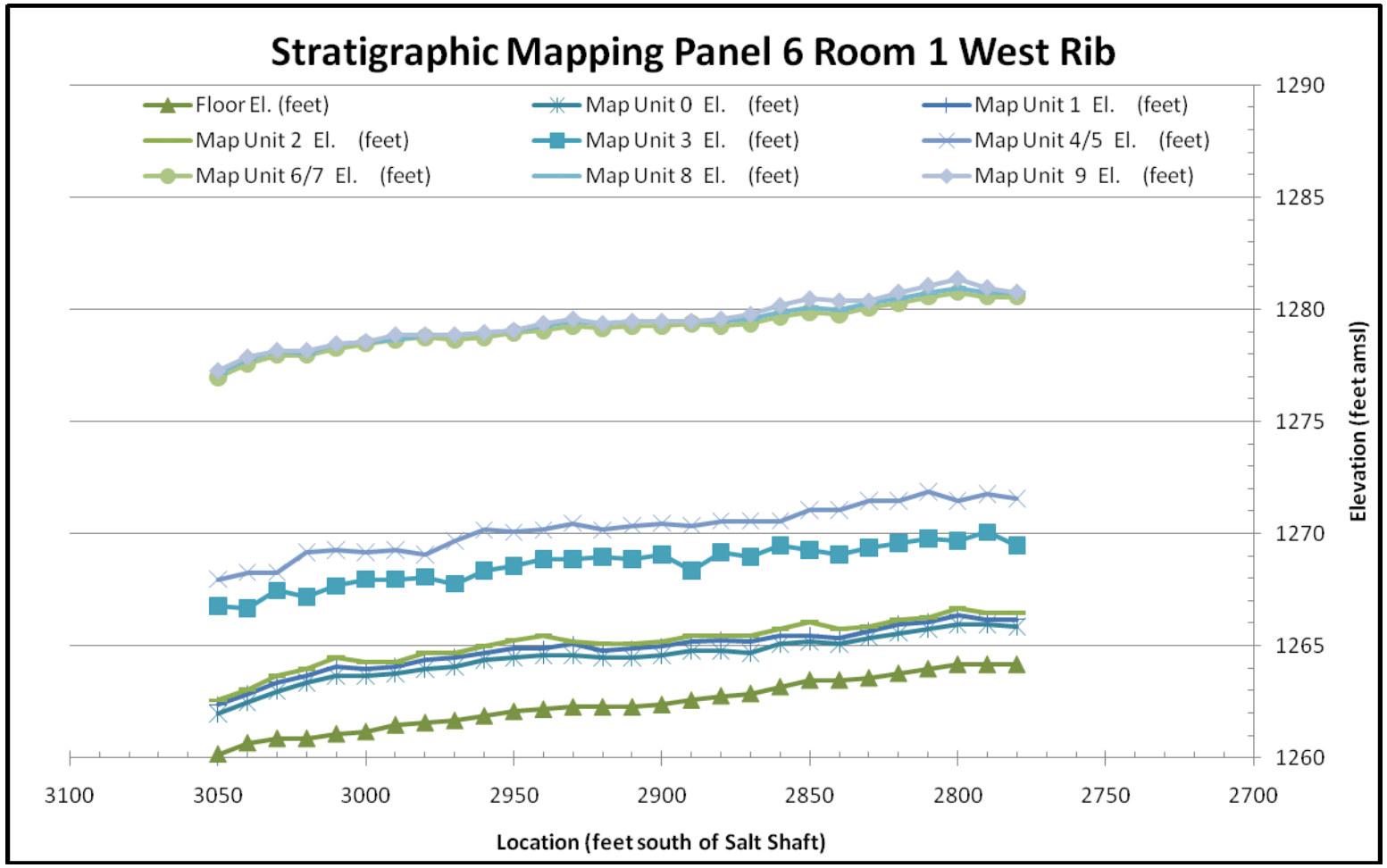


Figure 6-62: Panel 6, Room 1, S2780-S3050 Stratigraphic Map

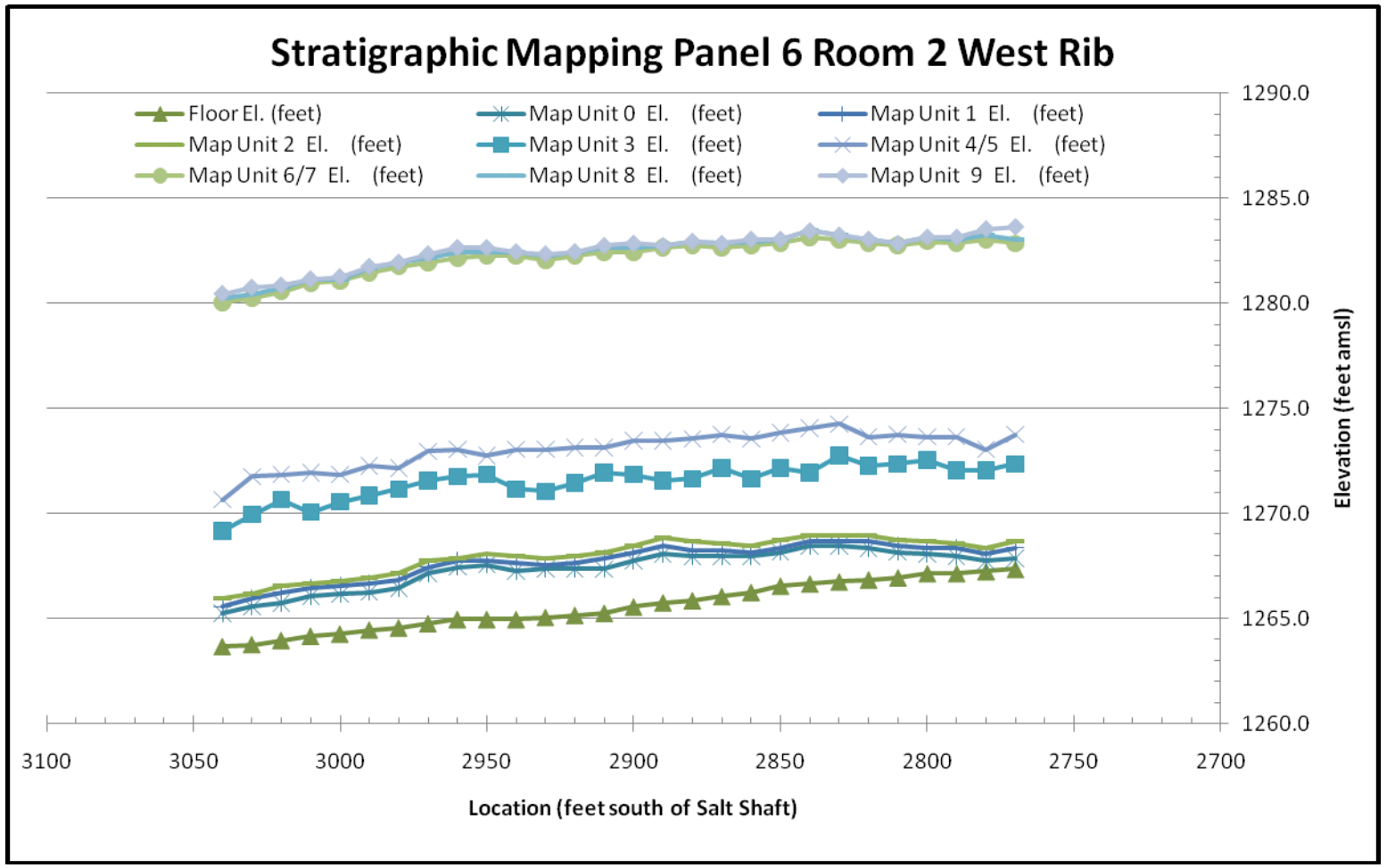
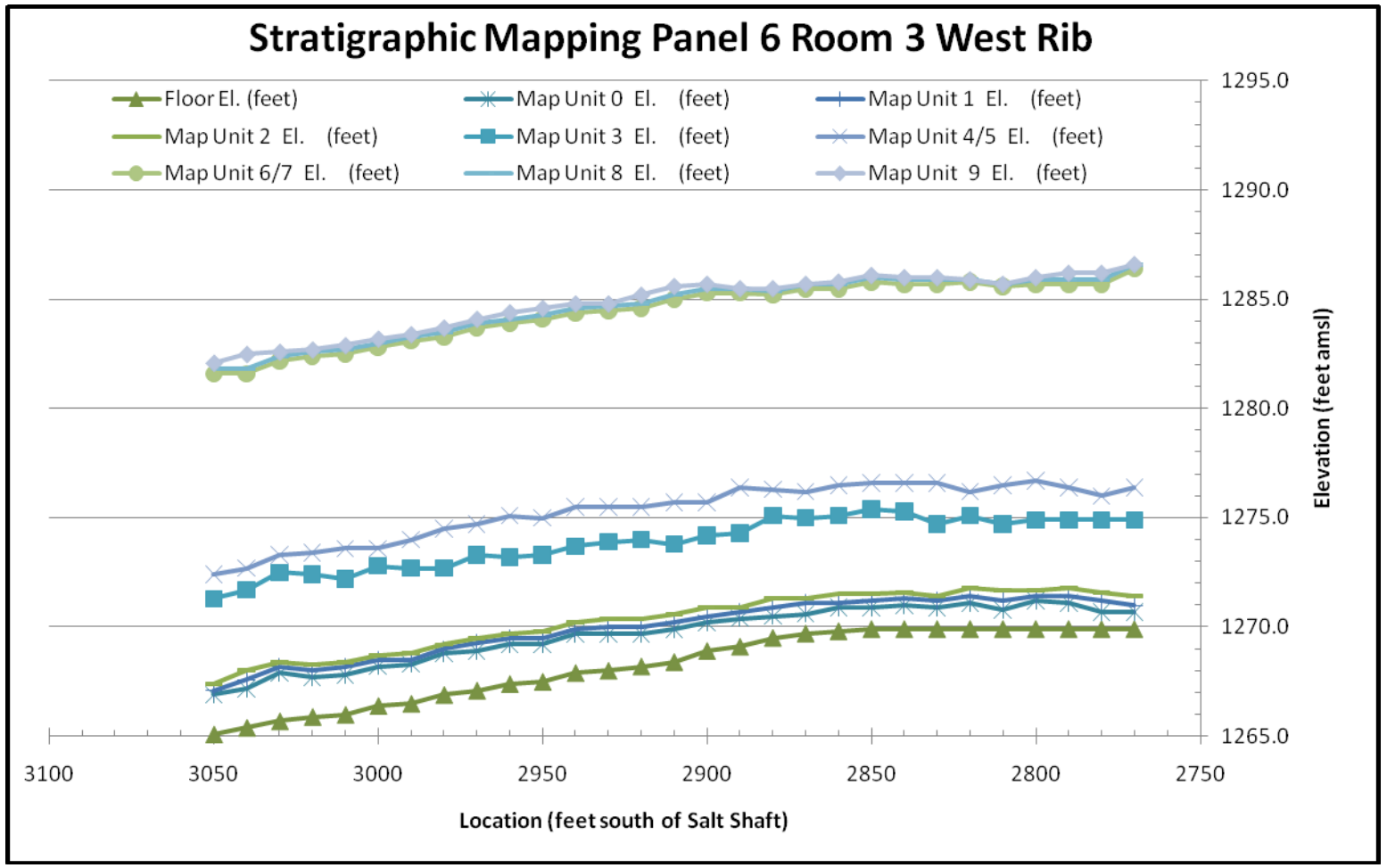


Figure 6-63: Panel 6, Room 2, S2770-S3050 Stratigraphic Map



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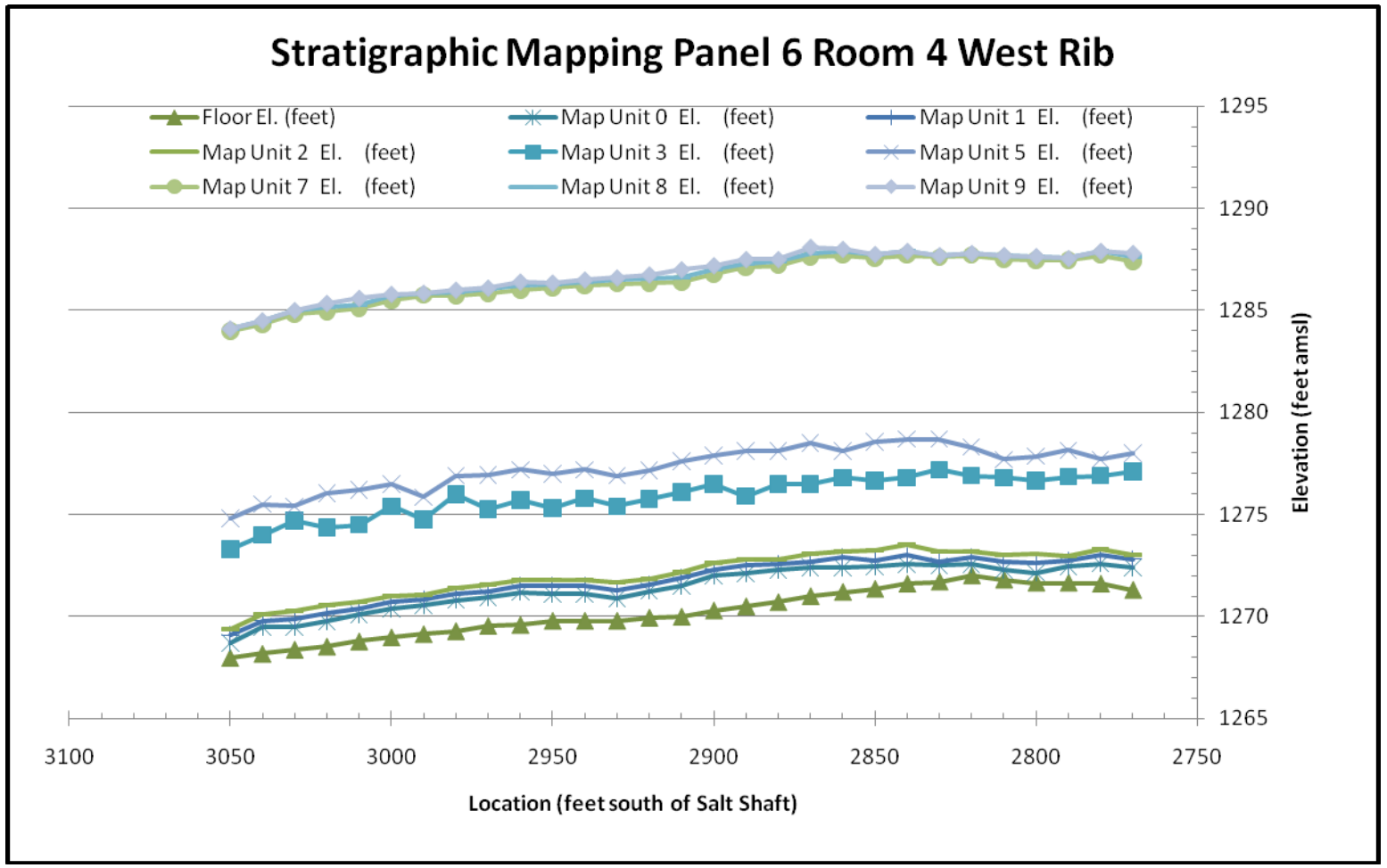

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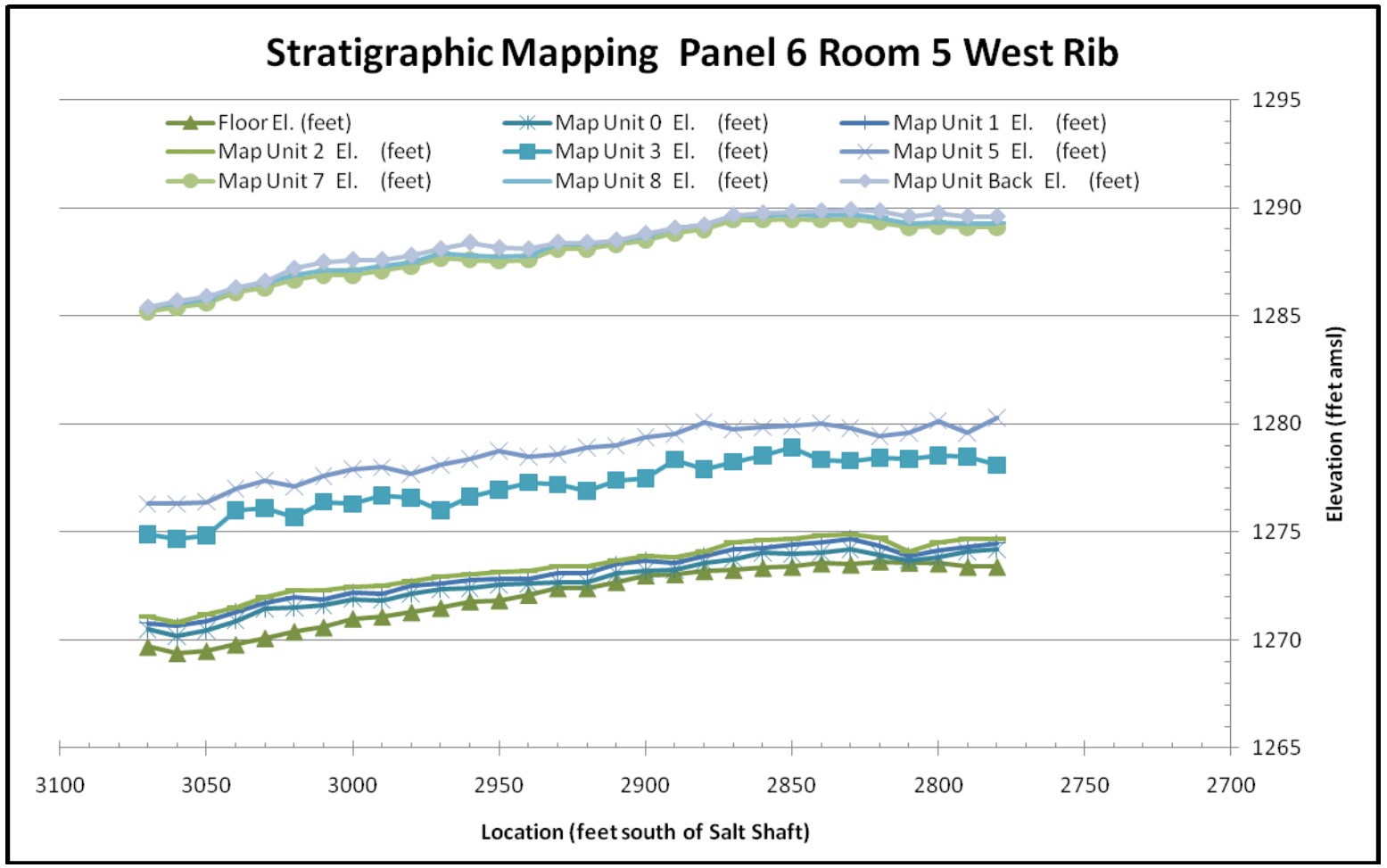


Figure 6-66: Panel 6, Room 5, S2770-S3050 Stratigraphic Map

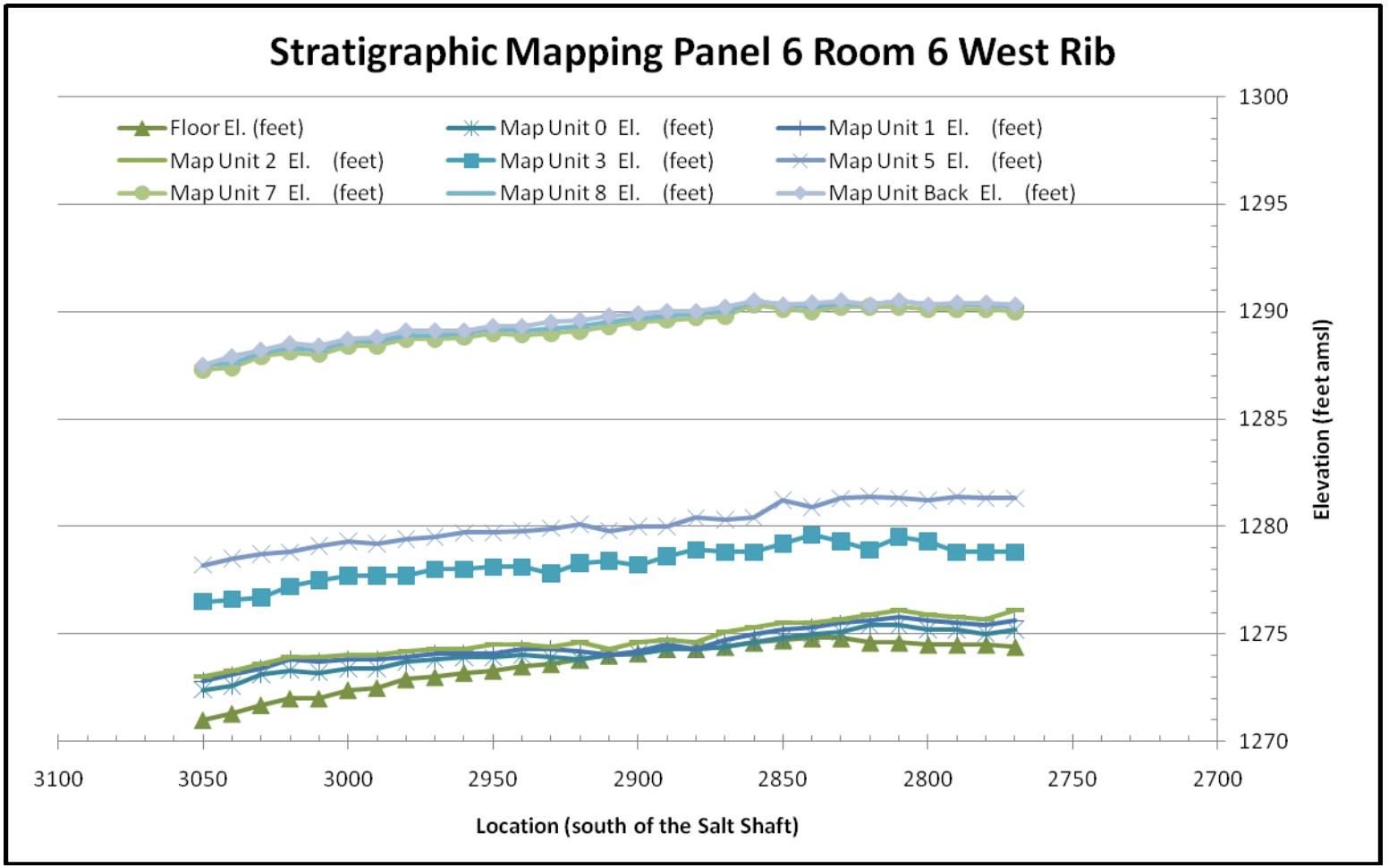


Figure 6-67: Panel 6, Room 6, S2770-S3050 Stratigraphic Map

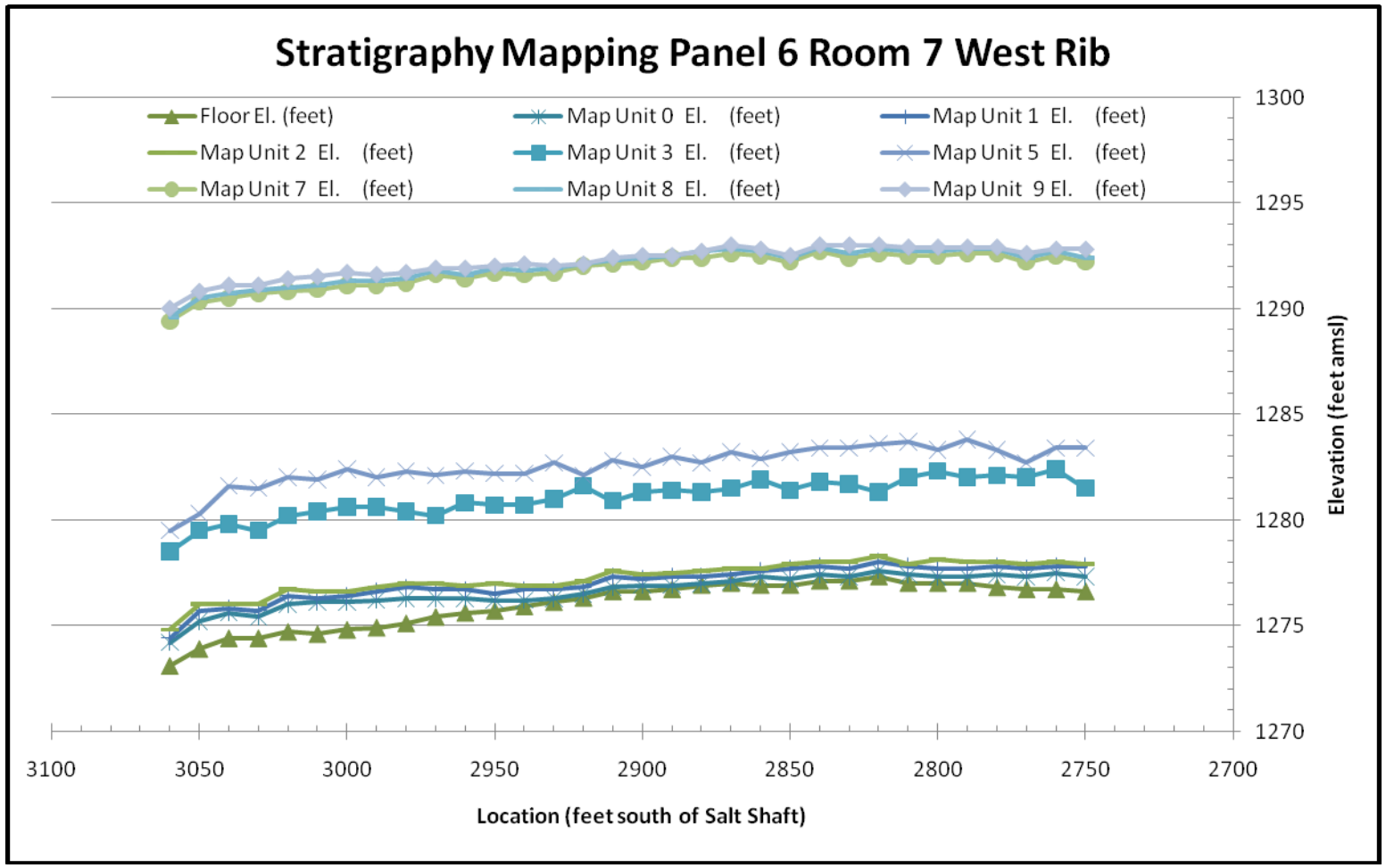
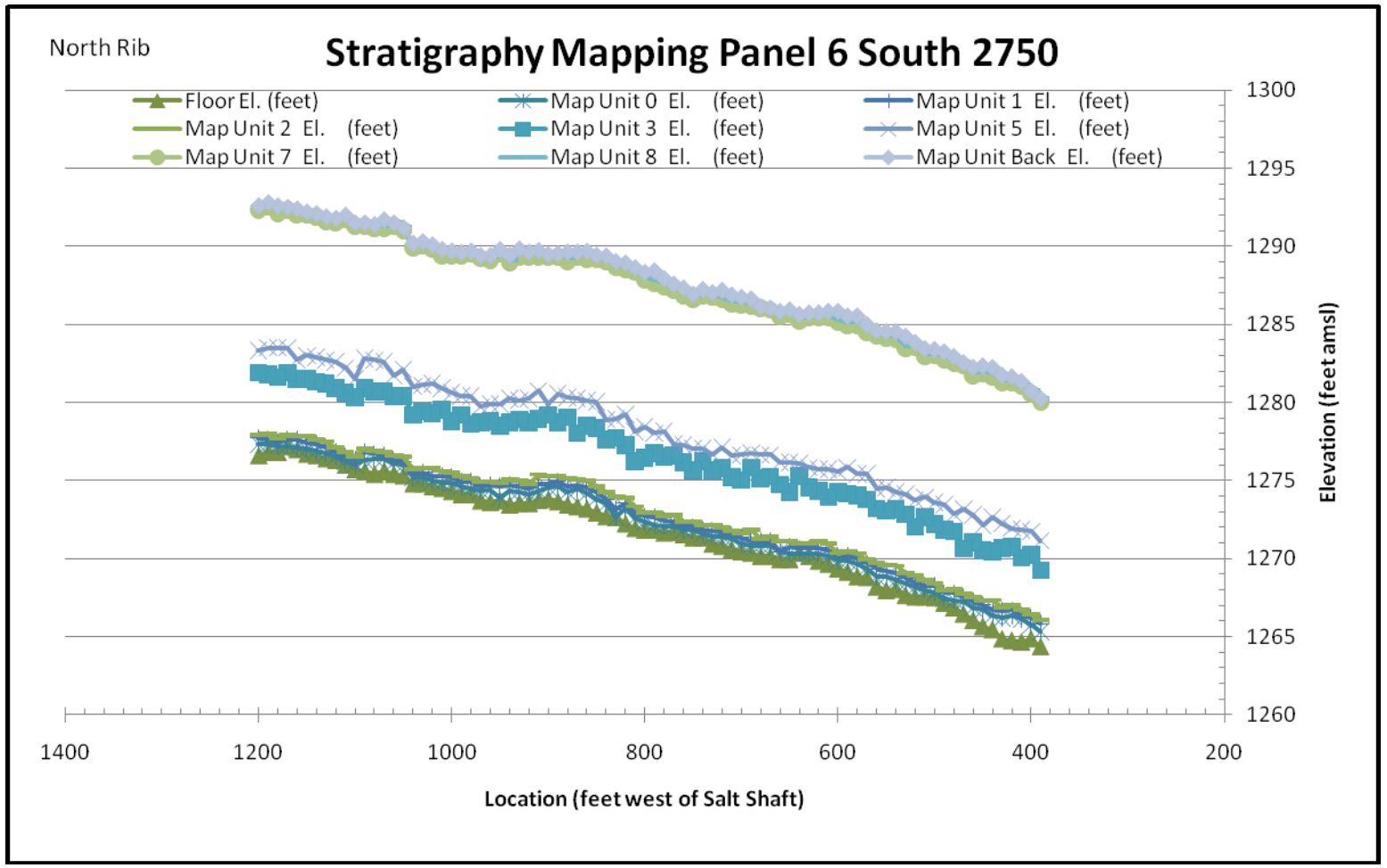


Figure 6-68: Panel 6, Room 7, S2770-S3050 Stratigraphic Map



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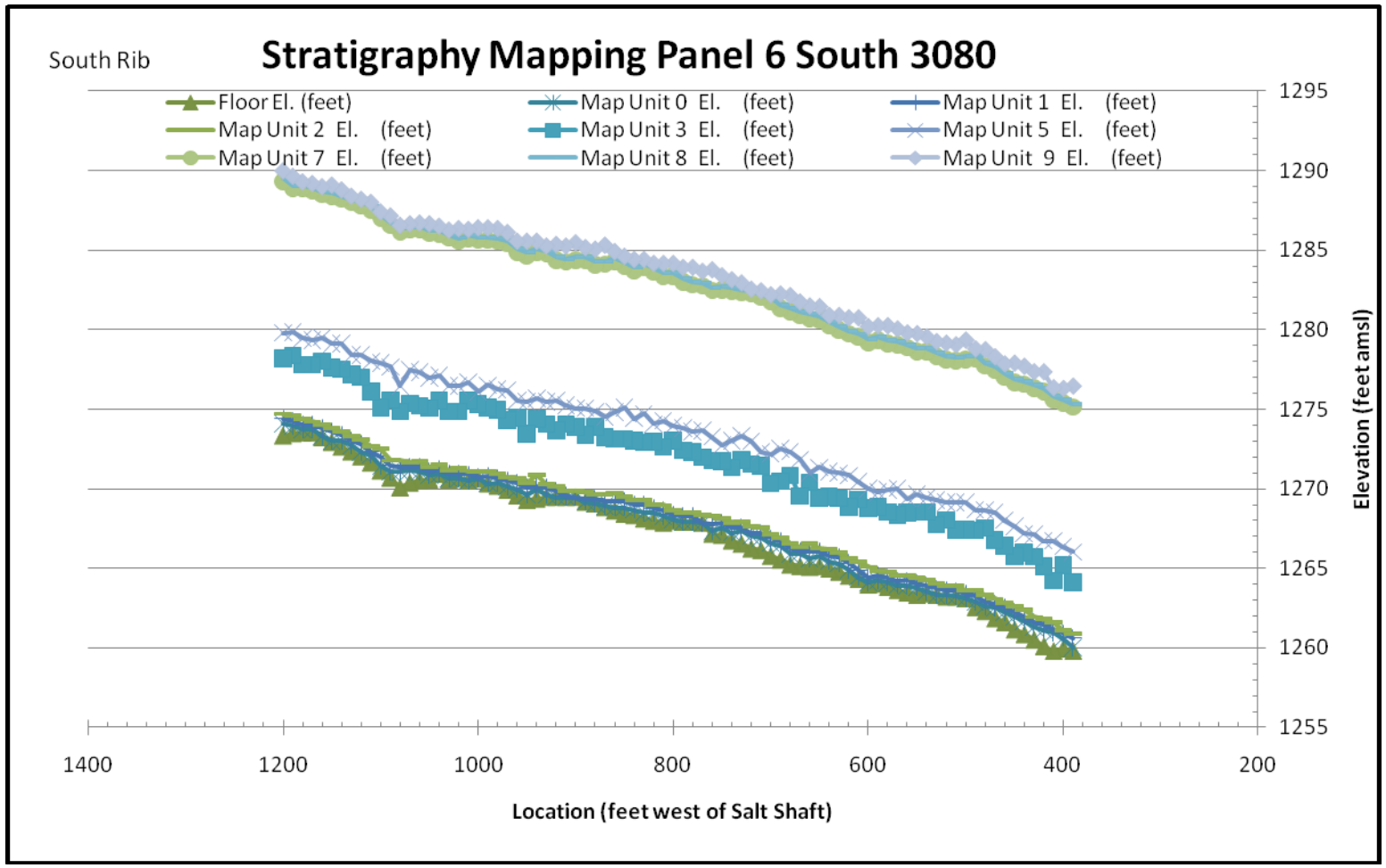


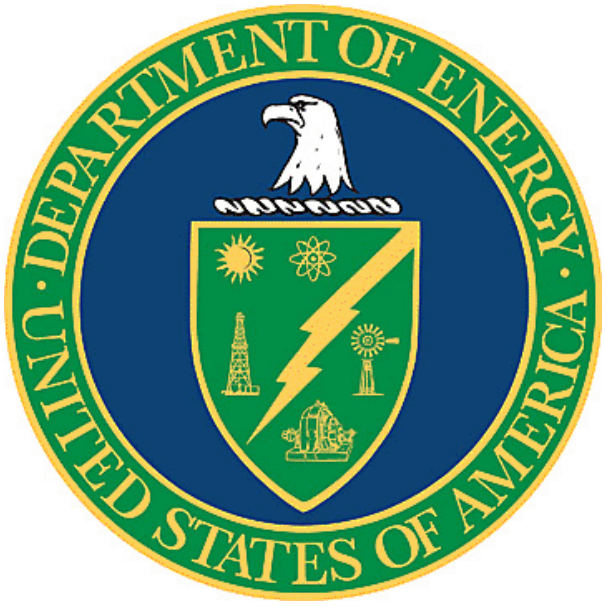
Figure 6-70 Panel 6, S3080, W390-W1200 Stratigraphic Map

ANNUAL TRANSURANIC WASTE INVENTORY REPORT – 2012
(Data Cutoff Date 12/31/2011)

DOE/TRU-12-3425

Revision 0

Date: October 2012



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History of Revisions

Revision Number	Pages Revised	Reason for Revision
0	All	Original Release

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ACRONYMS AND ABBREVIATIONS

For a list of Site Identifiers, refer to Figure 1-1.

AK	Acceptable knowledge
ANL	Argonne National Laboratory (formerly known as Argonne National Laboratory – East)
ATWIR	Annual Transuranic Waste Inventory Report
BAPL	Bettis Atomic Power Laboratory
CBFO	Carlsbad Field Office
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CH	Contact-handled
Ci	Curie
CID	Comprehensive Inventory Database
CIT	CID Import Template
CPR	Cellulose, plastic, and rubber
CY	Calendar year
D&D	Decontamination and decommissioning
DOE	U.S. Department of Energy
DT	Data template
EDTA	Ethylenediaminetetraacetic acid
EPA	U.S. Environmental Protection Agency
INL	Idaho National Laboratory
KAPL-NFS	Knolls Atomic Power Laboratory – Nuclear Fuel Services
KAPL-S	Knolls Atomic Power Laboratory– Schenectady
kg	Kilograms
LANL	Los Alamos National Laboratory
LANL-CO	Los Alamos National Laboratory – Carlsbad Operations
LBNL	Lawrence Berkeley National Laboratory
l	Liter
LLNL	Lawrence Livermore National Laboratory
LLW	Low-level waste
LQS	Large quantity site
LWA	Land Withdrawal Act
m^3	Cubic meters

MFC	Materials and Fuels Complex (formerly known as Argonne National Laboratory – West)
MgO	Magnesium oxide
MLLW	Mixed low-level waste
mrem	Millirem
NEPA	National Environmental Policy Act
NNSS	Nevada National Security Site (formerly Nevada Test Site)
NRD	Nuclear Radiation Development Site
NTP	National TRU Program
ORIGEN-S	Oak Ridge Isotope Generation and Depletion Code (a module of SCALE version 6)
ORNL	Oak Ridge National Laboratory
OSRP	Off-Site Source Recovery Program
PA	Performance assessment
PAIR	Performance Assessment Inventory Report
PDCF	Pit Disassembly and Conversion Facility
PM	Packaging material
QA	Quality assurance
QAPD	Quality Assurance Program Document
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
RH	Remote-handled
RL	Hanford Site –Richland Operations
ROD	Record of Decision
RP	Hanford Site – Office of River Protection
SCALE	Standardized Computer Analysis for Licensing Evaluation
SNL	Sandia National Laboratories
SQS	Small quantity site
SRS	Savannah River Site
TDOP	Ten-drum overpack
TRU	Transuranic
TWBIR	Transuranic Waste Baseline Inventory Report
WAC	Waste Acceptance Criteria
WAP	Waste Analysis Plan
WDS	Waste Data System
WIPP	Waste Isolation Pilot Plant
WMP	Waste material parameter
WPR	Waste profile report
WV	West Valley Demonstration Project

EXECUTIVE SUMMARY

The U.S. Department of Energy's (DOE's) Waste Isolation Pilot Plant (WIPP) began accepting defense-related transuranic (TRU) waste on March 26, 1999, becoming the nation's first and only deep geologic repository for the permanent disposal of defense-generated TRU waste. As of December 31, 2011 (the cutoff date for inventory data for this report), there have been 10,244 shipments (9,708 contact-handled [CH] and 536 remote-handled [RH]) of TRU waste to WIPP for emplacement since WIPP's opening (DOE 2012).

This *Annual Transuranic Waste Inventory Report – 2012* (ATWIR-2012) (hereafter referred to as "this report" or "ATWIR-2012") reflects the changes that have occurred and provides an update to the defense-related TRU waste inventory data since the last published report, the *Annual Transuranic Waste Inventory Report – 2011* (ATWIR-2011) (DOE 2011). This report focuses on the TRU waste remaining at the TRU waste sites and only presents emplaced waste in section 3.0 in Table 3-3, Table 3-5, and Table 3-13. Changes in waste volume, waste material parameters (WMPs), packaging materials (PMs), complexing agents, oxyanions, and radionuclides are also discussed in section 3.0 (see section 6.0 for definitions of these components).

The ATWIR-2012 was developed from an annual inventory data update campaign involving the TRU waste sites. TRU waste generation has occurred at both large quantity and small quantity sites (LQSs and SQSs) across the country. Many of these sites have emplaced their waste at WIPP, found other compliant disposition pathways for the waste, or transferred the waste to other sites for further disposition.

The updated data received from the TRU waste sites were entered into the Comprehensive Inventory Database (CID). The CID is a DOE Carlsbad Field Office (CBFO) database qualified in accordance with the Los Alamos National Laboratory – Carlsbad Operations (LANL-CO) Quality Assurance (QA) Program, which is in compliance with the CBFO *Quality Assurance Program Document* (QAPD) (DOE 2010). The CID includes estimates for: TRU waste volumes, WMPs, PMs, complexing agents, oxyanions, and radionuclides (decayed to common years 2011 and 2033 [WIPP proposed closure date]).

The purpose of this report is to document the total inventory of TRU waste as defined by the TRU waste sites to provide current TRU waste inventory information for the DOE complex, WIPP stakeholders, and regulators, and to provide the CBFO with updated strategic inventory information. The TRU waste inventory also supports CBFO input into National Environmental Policy Act (NEPA) analyses, the development of new containers or shipping packages, and planned change requests for containers and other design changes that may take place in the repository.

TRU waste must meet the WIPP requirements (e.g., WIPP Waste Acceptance Criteria [WAC] and the WIPP Hazardous Waste Facility Permit Waste Analysis Plan [WAP]) before it can be disposed of at WIPP, regardless of its designation in this inventory report.

The following tables summarize the TRU waste anticipated (stored plus projected) inventory volume; WMP and PM masses; complexing agent and oxyanion masses; radionuclide activity, and inventory change estimates as of December 31, 2011. All site data are validated by the DOE TRU waste site representative to ensure the data best represent the site's inventory at the time of the data cutoff.

Table ES-1. Anticipated CH/RH Waste Inventory Volume by Site

TRU Waste Site	CH Volumes (m^3)	RH Volumes (m^3)	Total Volumes (m^3)
Hanford (Richland) Site	2.01E+04	2.44E+03	2.25E+04
Idaho National Laboratory	2.83E+04	2.30E+02	2.85E+04
Los Alamos National Laboratory	9.88E+03	7.92E+01	9.96E+03
Oak Ridge National Laboratory	9.45E+02	6.13E+02	1.56E+03
Savannah River Site	7.35E+03	4.09E+01	7.39E+03
Small Quantity Sites	1.44E+03	1.63E+02	1.60E+03
Grand Total	**6.80E+04**	**3.57E+03**	**7.15E+04**

Data Source: CID Data Version D.11.00 (LANL-CO 2012). Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams.

Table ES-2. Anticipated CH/RH Waste and Packaging Material Inventory

Waste Material	CH Mass (kg)	RH Mass (kg)	Total Mass (kg)
Iron-based Metal/Alloys	2.70E+06	6.70E+05	3.37E+06
Aluminum-based Metal/Alloys	2.08E+05	1.42E+04	2.23E+05
Other Metal/Alloys	2.54E+05	3.71E+05	6.26E+05
Other Inorganic Materials	2.31E+06	8.84E+05	3.19E+06
Cellulose	9.20E+05	9.19E+04	1.01E+06
Rubber	4.29E+05	6.89E+04	4.98E+05
Plastic	1.53E+06	1.83E+05	1.71E+06
Cement	2.48E+06	3.60E+05	2.84E+06
Solidified Inorganic Material	3.49E+06	1.71E+04	3.51E+06
Solidified Organic Material	1.61E+06	1.85E+03	1.61E+06
Soils	2.41E+06	1.39E+05	2.55E+06
Vitrified	--	--	--
Packaging Material, Cellulose	2.85E+04	--	2.85E+04
Packaging Material, Plastic	9.04E+05	1.49E+05	1.05E+06
Packaging Material, Rubber	2.62E+04	2.05E+03	2.82E+04
Packaging Material, Steel	1.13E+07	3.39E+06	1.47E+07

Table ES-2. Anticipated CH/RH Waste and Packaging Material Inventory
Continued

Waste Material	CH Mass (kg)	RH Mass (kg)	Total Mass (kg)
Packaging Material, Lead	--	8.44E+02	8.44E+02
Grand Total	**3.06E+07**	**6.34E+06**	**3.69E+07**

Data Source: CID Data Version D.11.00 (LANL-CO 2012). Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams.

Table ES-3. Anticipated CH/RH Complexing Agent and Oxyanion Inventory

Site	Complexing Agent Mass (kg)	Oxyanion Mass (kg)
Hanford (Richland) Site	1.38E+04	2.59E+05
Idaho National Laboratory	3.19E+03	4.02E+05
Los Alamos National Laboratory	2.53E+03	4.05E+05
Small Quantity Sites	5.59E+01	2.28E+01
Grand Total	**1.95E+04**	**1.07E+06**

Data Source: CID Data Version D.11.00 (LANL-CO 2012). Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams.

Table ES-4. Anticipated CH/RH Radionuclide Activity by Site Decayed through 2011

TRU Waste Site	CH Activity (Ci)	RH Activity (Ci)	Total Activity (Ci)
Hanford (Richland) Site	7.36E+05	7.75E+05	1.51E+06
Idaho National Laboratory	6.94E+04	1.37E+05	2.06E+05
Los Alamos National Laboratory	3.81E+05	2.95E+03	3.84E+05
Oak Ridge National Laboratory	9.10E+04	8.43E+03	9.94E+04
Savannah River Site	1.56E+05	5.19E+03	1.61E+05
Small Quantity Sites	2.45E+04	2.24E+05	2.48E+05
Grand Total	**1.46E+06**	**1.15E+06**	**2.61E+06**

Data Source: CID Data Version D.11.00 (LANL-CO 2012). Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams.

Table ES-5. Anticipated CH/RH Inventory Changes

Inventory Parameter	ATWIR-2011	ATWIR-2012	Total Net Change
Volume (m^3)	8.00E+04	7.15E+04	-8.50E+03
Waste & Packaging Material (kg)	4.10E+07	3.69E+07	-4.06E+06
Complexing Agents (kg)	2.17E+04	1.95E+04	-2.14E+03
Oxyanions (kg)	1.18E+06	1.07E+06	-1.14E+05
Radionuclide Activity (Ci as of 2033)	1.80E+06	1.55E+06	-2.46E+05

Data Source: CID Data Versions D.10.01 (LANL-CO 2011e) and D.11.00 (LANL-CO 2012).
Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams.

1.0 INTRODUCTION

This *Annual Transuranic Waste Inventory Report – 2012* (ATWIR-2012) (hereafter referred to as "this report" or "ATWIR-2012") provides the National TRU Program (NTP) with a strategic inventory to be used for initiatives such as the development of transuranic (TRU) waste site-specific project plans or National Environmental Policy Act (NEPA) analyses. Also, if requested by the U.S. Department of Energy (DOE) Carlsbad Field Office (CBFO), this report will provide the basis for the Performance Assessment Inventory Report (PAIR) for performance assessment (PA) modeling purposes. This report includes the background and history of the TRU waste inventory, the information sources used to collect and prepare the inventory, descriptions of the ways inventory information is used, methodology used to develop the inventory, TRU waste inventory estimates, and changes since the *Annual Transuranic Waste Inventory Report – 2011* (ATWIR-2011) (DOE 2011).

TRU waste must meet the requirements of the Waste Isolation Pilot Plant (WIPP) Waste Acceptance Criteria (WAC) and the WIPP Hazardous Waste Facility Permit Waste Analysis Plan (WAP) before it can be disposed of at WIPP.

Section 1.1, Background and History, explains how the TRU waste inventory was collected and used for the initial certification of WIPP. Currently, the inventory is collected on an annual basis to monitor how it is changing. Section 1.2, Sources of Transuranic Waste Inventory Information, includes a description of all information sources used to update the Comprehensive Inventory Database (CID). Examples of sources include acceptable knowledge (AK) reports, TRU waste site information, and the WIPP's Waste Data System (WDS). Section 1.3, Uses of Transuranic Waste Inventory Information, includes uses of TRU waste inventory.

Section 2.0, Methodology, describes the methodologies undertaken in order to prepare this report. These include:

- Collection, screening, and analyses of raw inventory data from the TRU waste sites
- Analysis of emplaced inventory data reported from the WDS
- Verification and validation of data entered into the CID
- Decay and buildup correction of radionuclide data using the Oak Ridge Isotope Generation and Depletion (ORIGEN-S) module of SCALE [Standardized Computer Analysis for Licensing Evaluation]*: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, Version 6 (Scale 6) (ORNL 2009)
- Calculations performed within the CID

Section 3.0, Transuranic Waste Inventory Estimates and Changes, discusses the TRU waste inventory estimates, with summaries of the inventory information collected from the TRU waste sites, and discusses changes in the inventory information for each of the following sections. Section 3.1 presents rolled-up TRU waste volume estimates by site of contact-handled (CH) and remote-handled (RH) TRU waste reported as stored, projected, and anticipated. Section 3.2 presents the inventory of non-radiological material estimates including: waste material

parameters (WMPs), packaging materials (PMs), and chemical components. Section 3.3 presents the TRU waste radionuclide activity inventory from each site, rolled up and decayed through the end of calendar year (CY) 2011. All site data are validated by the DOE TRU waste site representative to ensure the data best represent the site's inventory at the time of the data cutoff.

Section 4.0 discusses the potential TRU waste streams that have been excluded in accordance with CBFO guidance criteria. These criteria are documented in a "screening memorandum" (Patterson 2010) that determines whether a waste stream is WIPP-bound or potential (see Appendix D). Also found in section 4.0 is a table showing waste streams that have been moved from potential to WIPP-bound status during this collection period.

Section 5.0 presents the conclusion of this report, section 6.0 provides the glossary, and section 7.0 provides the references that were used for this report.

This report also contains four appendices. Appendix A presents the WIPP-bound waste profile reports (WPRs), Appendix B presents the potential TRU waste WPRs, and Appendix C presents the historic crosswalk of waste streams. Note: If a waste stream is identified as a *new waste stream*, it means that the waste stream has never been reported. If a waste stream is identified as a *deleted waste stream*, the explanation for why it is deleted is provided, if available. Appendix D contains the screening memo for determining whether or not a waste stream is potential.

This report includes comprehensive data from each TRU waste site and WDS summation data for emplaced waste. More specific information on the emplaced waste can be obtained from the CBFO WDS administrator at the WIPP Information Center at 1-800-336-WIPP (9477) or at infocntr@wipp.ws**.** The WDS administrator administers the official database that contains container-level data on the emplaced TRU waste.

1.1 Background and History

The WIPP Land Withdrawal Act (LWA)[1] (U.S. Congress 1992 and 1996) required the U.S. Environmental Protection Agency (EPA) to issue final disposal regulations to certify WIPP. On May 18, 1998, the EPA certified that WIPP complied with the final disposal regulations and criteria of Title 40 Code of Federal Regulations (CFR) Parts 191 and 194 (EPA 1993; EPA 1996). DOE opened WIPP on March 26, 1999, with the initial receipt of TRU waste, thus becoming the nation's first deep geologic repository for the permanent disposal of defense-generated TRU waste. The disposal regulations require that WIPP be recertified every five years from the time of the first receipt of waste; WIPP has been recertified twice. DOE submitted the first recertification application, CRA-2004 (DOE 2004), to the EPA in March 2004, and the EPA recertified WIPP in March 2006. DOE submitted the second recertification application, CRA-2009 (DOE 2009), to the EPA in March 2009, and WIPP was recertified in November 2010. The third recertification application is due to the EPA in March 2014.

[1]See Pub. L. No. 102-579, § 8, 106 Stat. 4777, 4786-4788 (U.S. Congress 1992), as amended, Waste Isolation Pilot Plant Land Withdrawal Act Amendments, Pub. L. No. 104-201, § 3187, 110 Stat. 2422, 2852 (U.S. Congress 1996).

Table 1-1 lists the historical TRU waste inventory documents and their intended purpose.

Table 1-1. Historical Inventory Documents

Date	Title	Purpose
June 1994	WIPP Transuranic Waste Baseline Inventory Report	First attempt made by DOE complex to report all of its TRU waste at the waste-stream level.
December 1995	Transuranic Waste Baseline Inventory Report (TWBIR), Revision 2	Revisions 2 and 3 provided the inventory information to the Sandia National Laboratories-Carlsbad for the initial certification of WIPP.
June 1996	TWBIR, Revision 3	
March 2004	Appendix DATA, Attachment F of *Title 40 CFR 191, Subparts B and C, Compliance Recertification 2004*	Provided updated inventory information for the first recertification of WIPP in 2004.
March 2006	Transuranic Waste Baseline Inventory Report 2004	This was a revision of Appendix DATA, Attachment F. Provided updated inventory to support the Performance Assessment Baseline Calculation.
August 2008	Annual Transuranic Waste Inventory Report (ATWIR)–2007	The first annual inventory report that contained both scaled (calculations to represent a full repository) and unscaled data.
December 2008	ATWIR–2008	Annual inventory report that reported only unscaled data.
April 2009	Performance Assessment Inventory Report–2008	Provided data from ATWIR-2008 in the required format for performance assessment calculations.
December 2009	ATWIR–2009	Provided updated annual inventory information.
December 2010	ATWIR–2010	Provided updated annual inventory information.
December 2011	ATWIR–2011	Provided updated annual inventory information.

Depending upon programmatic needs, site waste management decisions, and characterization data, TRU waste inventory information is re-evaluated frequently and the TRU waste inventory is updated annually. This report is an update based on the TRU waste complex's known inventory as of December 31, 2011.

Since the ATWIR-2011 was published, a number of changes and improvements have occurred that affected the volume, waste material, and radiological characteristics of TRU waste streams. Also, five (5) waste streams have been moved from potential to WIPP-bound status to be in alignment with the CBFO screening memorandum (Patterson 2010) provided in Appendix D. The list of these waste streams (presented in Table 4-2) also includes the reasons for the moves. The other primary inventory changes observed and addressed in this report are attributed to the following:

- Waste emplacement since the ATWIR-2011.

- Hanford Richland Operations Office added waste as a result of the issuance of a new Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Record of Decision (ROD). (EPA, Ecology, and DOE 2011)

- A Savannah River Site project (the Pit Disassembly and Conversion Facility [PDCF]) was cancelled, thus decreasing the volume of waste.

- Twenty-one new waste streams were added to the inventory. This includes both three from potential and 18 new WIPP-bound waste streams (see Table C-1 in Appendix C).

- Intersite shipments occurred between Argonne National Laboratory and Sandia National Laboratories to Idaho National Laboratory (INL).

- The waste at the Paducah Gaseous Diffusion Plant was re-sampled and was determined not to be TRU waste.

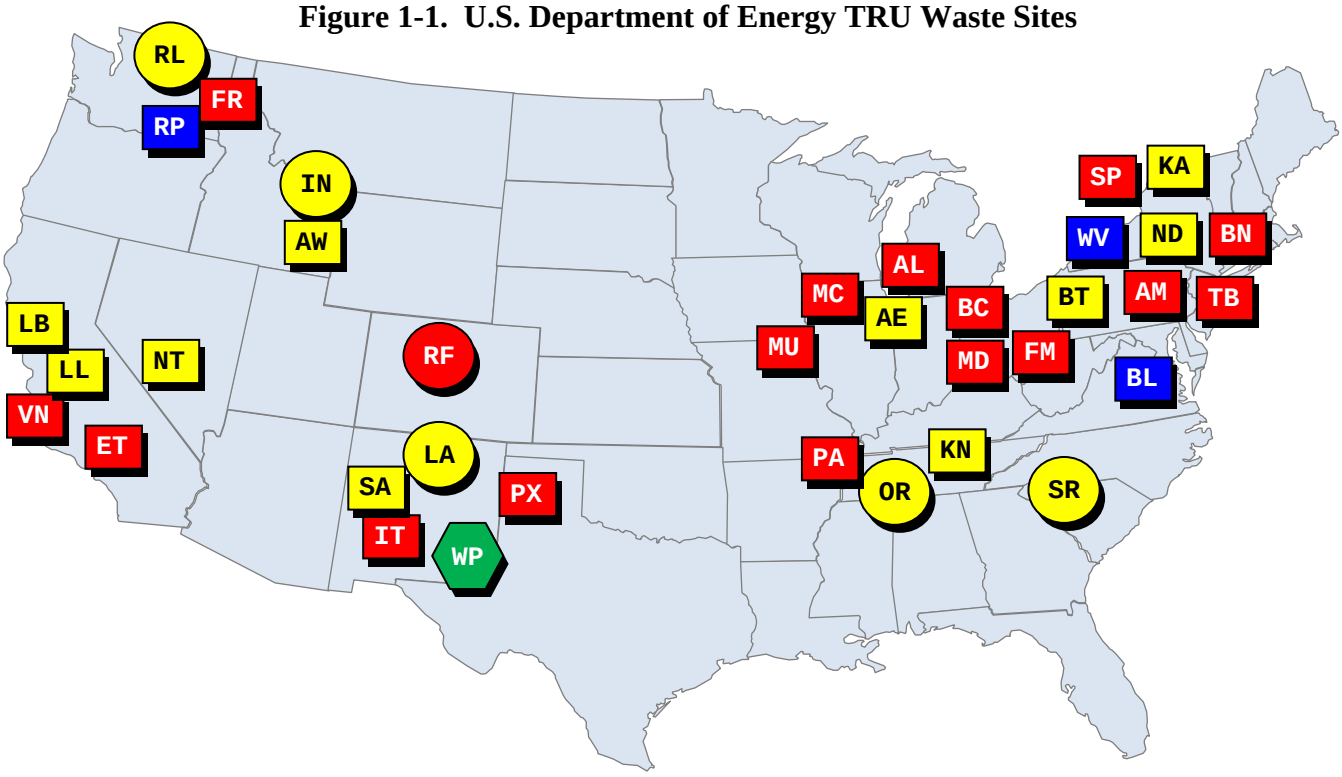
- Final disposition for the U.S. Army Materiel Command waste was provided by the Joint Munitions Command.

- One INL waste stream was declared mixed low-level waste (MLLW) and removed from the TRU waste inventory.

TRU waste generation has occurred at both small quantity sites (SQSs) and large quantity sites (LQSs) across the country, as seen in Figure 1-1. This figure represents data as of December 31, 2011. Circles identify LQSs, boxes identify SQSs, yellow indicates active sites, red indicates sites that have been de-inventoried of their legacy TRU waste, and blue indicates sites containing only potential TRU waste.

This report was prepared by the Los Alamos National Laboratory – Carlsbad Operations (LANL-CO) TRU Waste Inventory Team. The work for this report was performed under the CBFO *Quality Assurance Program Document* (QAPD) (DOE 2010). The processes used by the LANL-CO TRU Waste Inventory Team to collect, maintain, and report inventory information are graded and implemented to Nuclear Quality Assurance-1 standards under the LANL-CO Quality Assurance (QA) Program. This includes the software QA procedures used to qualify the CID and other software, including ORIGEN-S, used to analyze TRU waste inventory information. LANL-CO software QA is documented in LCO-QPD-02, *LANL-CO Software Quality Assurance Plan* (LANL-CO 2011c), and LCO-QP19-1, *Software Quality Assurance* (LANL-CO 2011d).

Figure 1-1. U.S. Department of Energy TRU Waste Sites



Yellow – Active TRU Waste Sites **Red – De-inventoried Legacy TRU Waste Sites** **Blue – Potential TRU Waste Sites**

AE	Argonne National Laboratory
AL	Ames Laboratory — de-inventoried
AM	ARCO Medical Products — de-inventoried - shipped to the Offsite Source Recovery Program (OSRP)
AW	Materials and Fuels Complex
BC	Battelle Columbus Laboratories— de-inventoried - shipped to RL and SR
BL	Babcock and Wilcox Nuclear Energy Services (Potential)
BN	Brookhaven National Laboratory— de-inventoried - shipped to OSRP
BT	Bettis Atomic Power Laboratory —de-inventoried of legacy TRU waste; has continuing mission
ET	Energy Technology Engineering Center— de-inventoried - shipped to RL
FM	Fernald Environmental Management Project— de-inventoried - shipped to OSRP
FR	Framatome— de-inventoried - shipped to RL
IN	Idaho National Laboratory
IT	Inhalation Toxicology Research Institute (Lovelace Respiratory Research Institute) — de-inventoried - shipped to SA
KA	Knolls Atomic Power Laboratory-Schenectady
KN	Knolls Atomic Power Laboratory-Nuclear Fuel Services — de-inventoried of legacy TRU waste; has continuing mission
LA	Los Alamos National Laboratory
LB	Lawrence Berkeley National Laboratory — de-inventoried of legacy TRU waste; has continuing mission
LL	Lawrence Livermore National Laboratory — de-inventoried of legacy TRU waste; has continuing mission
MC	U.S. Army Materiel Command (Army) — de-inventoried of legacy TRU waste
MD	Mound Plant – de-inventoried - shipped to SRS
MU	University of Missouri Research Reactor — de-inventoried - shipped to AE, then to WIPP
ND	Nuclear Radiation Development Site, Inc. —de-inventoried of legacy waste; has continuing mission
NT	Nevada Nuclear Security Site – de-inventoried of legacy waste; has continuing mission
OR	Oak Ridge National Laboratory
PA	Paducah Gaseous Diffusion Plant (found to be non-TRU waste)
PX	Pantex Plant—shipped to LA then to WIPP
RF	Rocky Flats Environmental Technology Site — de-inventoried - shipped to WIPP
RL	Hanford Site (Richland Operations Office)
RP	Hanford Site (Office of River Protection) (Potential)
SA	Sandia National Laboratories — de-inventoried of legacy TRU waste; has continuing mission
SP	Separations Process Research Unit (found to be low level waste)
SR	Savannah River Site
TB	Teledyne Brown Engineering — de-inventoried - shipped to RF, then to WIPP
VN	General Electric Vallecitos Nuclear Center — de-inventoried - RH shipped to WIPP, CH shipped to IN
WV	West Valley Demonstration Project (Potential)
WP	Waste Isolation Pilot Plant

1.2 Sources of Transuranic Waste Inventory Information

This report includes information taken from: 1) the ATWIR-2011, 2) updated information provided by the TRU waste sites, 3) AK reports, and 4) the WIPP WDS (DOE 2012). Each year, the sites are asked to update their data from the previous year. As an example, the sites used the ATWIR-2011 (data cutoff 12/31/2010) information to update the data used for this report. TRU waste sites may use information obtained from site-specific AK reports, which provide the most current information on waste streams being characterized and shipped to WIPP, such as chemical lists and radionuclides. All TRU waste inventory information for emplaced waste is obtained from the CBFO WDS administrator.

1.3 Uses of Transuranic Waste Inventory Information

Waste stream volumes are accounted for in both "current form" (current packaging) and "final form" (planned WIPP-compliant packaging) configurations. These configurations are useful in various waste management scenarios. CBFO management has used this strategic inventory information for decisions related to waste retrieval, treatment, repackaging, characterization, shipment, and disposal for both stored and projected waste initiatives in past years. Also, site-specific project plans and schedules, which detail approaches for moving TRU waste to WIPP, have been developed and are updated based on current TRU waste inventory information. As mentioned earlier, when inventory data are needed for PA modeling, CBFO will request a PAIR to be prepared that provides the latest inventory data available that are scaled using a defined methodology in order to model a full repository.

In addition to radiological information, DOE has many reasons for obtaining and tracking non-radiological information about the TRU waste destined for WIPP. For example, DOE tracks the waste materials that go into the WIPP repository, such as cellulose, plastic, and rubber (CPR), which might affect gas generation and emplacement of magnesium oxide (MgO) in the repository.

As noted earlier, additional TRU waste inventory information is provided in Appendices A, B, C, and D.

2.0 METHODOLOGY

This report was generated using documented processes and methods that are qualified under the LANL-CO QA Program (see section 1.1). The following steps were completed in order to generate this report:

1. Collected TRU waste stream information from the TRU waste sites and then entered and verified the updated information in the CID (see Figure 2-1).

2. Performed a complete review of all data to check for inconsistencies, erroneous data, and completeness.

3. Generated the required data tables, using the CID.

4. Performed analyses, where appropriate, to supplement CID data for publication within this report.

The following sections describe the three basic process steps leading to the issuance of this report. Section 2.1 discusses collection, compilation, verification, and validation of TRU waste inventory information. Section 2.2 describes the calculations used in the CID reports, including the decay correction of radionuclides. Section 2.3 describes the transformation activities performed on the WDS emplaced waste data prior to input in the CID.

2.1 Collection, Compilation, Verification, and Validation of Inventory Information

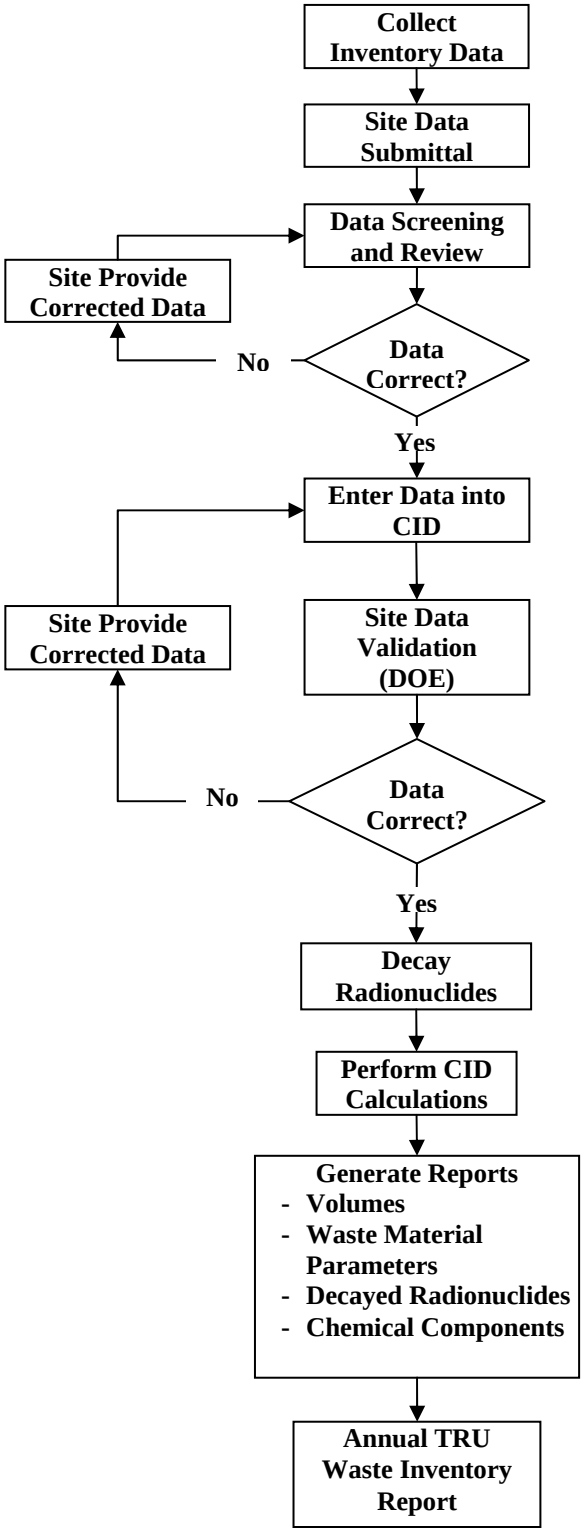
The process used to collect information from the TRU waste sites is captured in LANL-CO Procedure INV-SP-01, *Data Collection, Data Management and Control for the Comprehensive Inventory* (LANL-CO 2011a). On January 24, 2012, in accordance with this procedure, a letter (Patterson 2012) was sent to TRU waste sites requesting the annual TRU waste inventory update. The Inventory Team then sent each site a notification of the update with an attached file of the Microsoft® Excel data template (DT) workbook containing last year's validated data along with guidance explaining the steps required to update the DT with the site's new information. The Inventory Team worked with personnel from every site to assist in the updating process and to resolve any issues that arose.

After the DTs were completed, the team checked them for accuracy and consistency. During these data checks, the Inventory Team verified that the inventory updates included all of the requested information. The Inventory Team contacted the sites if there were discrepancies in the data. Examples of the data checks were:

- Verification of radionuclide isotopic inputs (i.e., checked for presence of all fission products);
- Verification of isotopic distribution for material type codes (e.g., plutonium [Pu]-52 and mixed fission products);
- Verification of radionuclide threshold limits to determine if the waste stream appeared to be categorized correctly as CH or RH;
- Verification that activity concentration for RH-TRU waste did not exceed the LWA limits (i.e., waste streams reported with greater than 23 Ci/l [curies per liter] averaged over the volume of the RH-TRU canister were screened out of the WIPP-bound inventory);
- Verification that if cement was reported in a comment field, it was also reported as a WMP in kilograms (kg);
- Verification that any hazardous waste that is prohibited at WIPP had an appropriate treatment identified;
- Comparison of the ATWIR-2012 waste stream data to the ATWIR-2011 waste stream data to identify any significant differences found.

The process followed for entering TRU waste inventory information into the CID is captured in LANL-CO Procedure INV-SP-02, *Entry, Verification, and Validation of Inventory Information in the Comprehensive Inventory Database* (LANL-CO 2011b). In accordance with this procedure, the TRU waste inventory information was uploaded from the Excel DT or entered manually into the CID. Once the data were entered, waste stream data (validation) reports were prepared and sent to the DOE TRU waste managers at the sites. A validation letter signed by the DOE site representative and site contractor (contractor signature optional) documented the correctness of the information as reported in the CID. Hard copies of the validation report and signed validation letters were then submitted to the LANL-CO Record Center (see Figure 2-1 for a flow chart of the TRU waste inventory process). The CID data were then labeled as data version D.11.00 and protected from further revision.

Figure 2-1. TRU Waste Inventory Process Flowchart



2.2 Calculations Used for CID Reports

Data tables included in this report were generated using the CID. The CID is a database developed by LANL-CO and qualified for use under the LANL-CO QA Program in accordance with the *LANL-CO Software Quality Assurance Plan* (LANL-CO 2011c) and *Software Quality Assurance* (LANL-CO 2011d). The CID is used to manage, maintain, and perform specific qualified calculations using inventory data. The data are then used to generate qualified data reports and tables.

Stored, projected, and anticipated values presented throughout this report are summations of the individual waste stream values for the specified categories (site, handling designation, etc.).

The following sections describe how the data were prepared for this report.

2.2.1 Volume Reporting

As part of the data call for this report, the TRU waste sites were asked to update the current form container information for their stored (already generated and stored at the site) and projected (future generation) TRU waste. For each waste stream, the sites also provided WIPP-compliant final form container type(s) that would ultimately be used to ship the waste to the WIPP and determined the respective stored and projected counts for each container type based on the current form volume of the waste. The emplaced waste streams' container counts and volumes were obtained from the CBFO WDS administrator (see section 2.3). The emplaced waste stream volumes were directly imported from the WDS and used in reporting the emplaced portion of the inventory. Final form stored and projected site waste stream volumes found within this report were derived by applying standardized container type volumes, which are maintained within the CID.

2.2.2 Waste Material Parameter and Packaging Materials Reporting

As part of the data call for this report, the TRU waste sites were asked to update each waste stream's mass, in kg, for WMPs, or physical materials contained in the waste. See section 3.2.1 for a description of these WMPs.

The sites were directed to only report the mass of the stored waste at their sites, even if they had a projected component in the waste stream. The CID then derived a projected mass using the projected-to-stored volume ratio for each waste stream. The anticipated mass was calculated by summing the stored and projected masses. However, if a waste stream consisted only of projected waste, then the sites were requested to report their estimates of the projected mass for each WMP for that particular waste stream.

The PMs, as described in section 3.2.2, are specific to each of the individual final form container types, with each PM being a proportional contributor to a waste stream's overall PM makeup based upon the respective container counts reported. These PMs are standardized and defined for each container type and reported in INV-SAR-19, *Analysis of Container Material Masses* (French 2009).

Appendices A and B present a list of average WMP and PM densities (kilograms per cubic meter [kg/m^3]) for each waste stream. These were calculated by dividing the total mass of each material in the waste stream by the total final form volume of the waste stream.

2.2.3 Radionuclide Reporting

The TRU waste sites were asked to update information about the radiological components in their TRU waste. For each waste stream, they were asked to assess and update, if necessary, radionuclides and their associated activity in curies (Ci). In addition, the TRU waste sites were asked to provide the generation or last assay date for each waste stream. This date was then used to determine the time basis for decay and buildup calculations.

The sites were directed to only report the activity of the waste stored at their sites, even if a waste stream had a projected component. The CID then derived a projected activity using the projected-to-stored volume ratio for each waste stream for that projected component. The anticipated activity was calculated by summing the stored and projected activities. However, if a waste stream consisted only of projected waste, then the activity reported by the site, and subsequently by the CID, was categorized as projected activity for that particular waste stream.

Since radionuclide data provided by the TRU waste sites consisted of radionuclide activities at the date of assay (generation or as calculated), they were decay-corrected to common dates for reporting purposes. All radionuclide data provided in this report in Table 3-10, Table 3-11, Table 3-12**,** and in Appendix A were decay-corrected to the end of the common base CY 2011. In order to identify changes in the radionuclide inventory (discussed in section 3.3.2, from previous TRU waste inventory reports, radionuclide activities were decay-corrected to the end of the WIPP proposed closure year, CY 2033.

The CID automates the radionuclide decay process by utilizing the ORIGEN-S module of SCALE 6 (ORNL 2009), which is a depletion and decay library that has been qualified for use under the LANL-CO QA Program, in accordance with *LANL-CO Software Quality Assurance Plan* (LANL-CO 2011c), and *Software Quality Assurance* (LANL-CO 2011d). The CID first takes the radionuclide activities reported by the TRU waste sites and exports them in the form of ORIGEN-S input files for each waste stream. It then executes ORIGEN-S in a sequential fashion for each input file, where the radionuclide decay and buildup calculations are performed and written to an output file. Finally, each output file is read and imported back into the CID, resulting in decay-corrected radionuclide tables to be generated for this report.

Appendices A and B present a list of average radionuclide concentrations (curies per cubic meter [Ci/m^3]) for each waste stream. These were calculated by dividing the total activity of each radionuclide in the waste stream by the total final form volume of the waste stream.

2.2.4 Chemical Constituent Reporting

As part of the data call for this report, the TRU waste sites were asked to update information about the chemical constituents of their waste. The sites were requested to report stored and projected mass separately for their complexing agents (acetic acid, citric acid, oxalic acid, acetate, citrate, oxalate, and ethylenediaminetetraacetic acid [EDTA]), oxyanions (nitrates, phosphates, and sulfates), and other chemical constituents in units of mass (kg).

2.3 Analyses Supporting the Annual Transuranic Waste Inventory Report

In addition to collecting and processing information from the DOE TRU waste sites and securing the site information in a qualified database for future use, an analysis was performed and documented in accordance with LANL-CO QA Procedure LCO-QP9-1, *Analyses* (LANL-CO 2010), in order to support the preparation of this report. To account for TRU waste emplaced in the WIPP repository from January 1, 2011, through December 31, 2011 (the ATWIR-2012 "reporting period"), a documented request was made of the CBFO WDS database administrator to supply data for the waste emplaced as of December 31, 2011. To update the TRU waste emplaced inventory data within the CID, the WDS data submittal was first migrated into a standardized CID Import Template (CIT) file. This migration required that the original WDS data submittal undergo various transformations, including, but not limited to, calculations, aggregations, and data mapping. These activities and calculations are documented in INV-SAR-26, *WDS Data Transformation for Insertion in the 2011 Inventory CID Import Template* (Van Soest 2012). The CIT file was subsequently used to update the CID.

The emplaced inventory is presented as a repository-level summation under "WIPP (Emplaced)" in section 3.0, under specific component sections, e.g., volumes, WMPs and PMs, and radionuclides. Chemical constituents are not reported in the emplaced inventory because the WDS does not track these constituents. The readers of this report who want more specific information on emplaced waste should make a request of CBFO so that the data can be obtained directly from the WDS, which is the official database of record for emplaced waste.

3.0 TRANSURANIC WASTE INVENTORY ESTIMATES AND CHANGES

This section presents the TRU waste inventory data that were collected and entered into the CID, internally reviewed and verified, validated by the TRU waste sites, and labeled as data version D.11.00 (LANL-CO 2012), as discussed in section 2.1. It should be noted that all table values in this report are presented to three significant figures.

This report is different in two respects from ATWIR-2011. In this report, the net changes in volumes, waste and packaging materials masses, complexing agent mass, oxyanion mass, and radionuclide activity between ATWIR-2011 and ATWIR-2012 are presented in tables within the report (Table 3-3, Table 3-5, Table 3-7, Table 3-9, and Table 3-13). In prior reports, these changes were listed and discussed in a separate appendix. Secondly, to be consistent with the other data presented in section 3.0, the complexing agent and oxyanion data are reported as site totals in this report rather than by individual site waste streams.

Section 3.1 presents the final form TRU waste volume for CH- and RH-TRU waste and a discussion of changes since ATWIR-2011 was issued. Section 3.2 presents the non-radiological properties of the TRU waste inventory as reported by the sites and a discussion of changes that have occurred during this reporting period. This includes roll-ups of the WMPs, PMs, chemical components, and includes a discussion of changes since ATWIR-2011. Section 3.3 presents the TRU waste radionuclide activities reported by the sites, which have been decayed through common base CY 2011. This section also presents a discussion of changes that have occurred in the total CH- and RH-TRU waste activity since ATWIR-2011.

3.1 TRU Waste Volume Estimates

This section presents the TRU waste inventory final form volume estimates that were collected for this report.

3.1.1 TRU Waste Inventory Total Volumes by Site

As stated earlier, TRU waste volume information requested from the TRU waste sites falls into two categories: stored waste (waste that currently exists at the site, regardless of whether it is in its final form) and projected waste (waste that will be generated in the future at the site, including decontamination and decommissioning [D&D] waste). The total waste stream volume information collected from the sites included stored and projected components as applicable for each TRU waste stream. The sites also reported both current form and final form waste container information for their waste streams. The current form accounts for the current packaging configuration of the waste, while the final form volume accounts for the eventual packaging configuration suitable for WIPP emplacement**.** The information presented in the tables of this section contains only final form data. The sites' current form container types and volumes can be found in Appendices A and B.

Table 3-1 shows the total CH-TRU waste volume stored, projected, and anticipated (stored plus projected) totals. An estimated anticipated final form total of approximately 68,000 m^3 of CH-TRU waste is currently being reported at the sites and could be shipped to WIPP in the future, provided all WIPP requirements are met. Almost 98% of the anticipated CH-TRU waste is stored or will be generated at LQSs: Hanford Richland (RL), Idaho National Laboratory (INL), Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), and the Savannah River Site (SRS). During the inventory collection period of January through December 2011, INL, LANL, ORNL, RL, and SRS shipped CH-TRU waste to WIPP. (See Table 3-3 for changes to CH-TRU waste volumes reported between ATWIR-2011 and ATWIR-2012.)

Table 3-2 shows the total RH-TRU waste volume stored, projected, and anticipated. An estimated anticipated final form total of about 3,570 m^3 of RH-TRU waste is currently being reported by the sites and could be shipped to WIPP in the future, provided all of the WIPP requirements are met. Approximately 95% of the anticipated RH-TRU waste is stored or will be generated at LQSs: RL, INL, LANL, ORNL, and SRS. During the inventory collection period of January through December 2011, Argonne National Laboratory (ANL), Bettis Atomic Power Laboratory (BAPL), INL, ORNL, Sandia National Laboratories (SNL) and SRS shipped RH-TRU waste to WIPP. (See Table 3-3 for changes to RH-TRU waste volumes reported between ATWIR-2011 and ATWIR-2012.)

Table 3-1. CH Waste Inventory Total Volumes

TRU Waste Site	Stored Volumes (m^3)	Projected Volumes (m^3)	Anticipated Volumes (m^3)
Argonne National Laboratory - East	1.41E+01	6.66E+01	8.07E+01
Hanford (Richland) Site	1.58E+04	4.30E+03	2.01E+04
Idaho National Laboratory	2.81E+04	1.50E+02	2.83E+04
Knolls Atomic Power Laboratory - Nuclear Fuel Services	3.02E+01	2.93E+02	3.24E+02
Lawrence Berkeley National Laboratory	4.16E-01	4.16E-01	8.32E-01
Lawrence Livermore National Laboratory	1.94E+02	6.97E+02	8.91E+02
Los Alamos National Laboratory	6.80E+03	3.08E+03	9.88E+03
Material and Fuels Complex	4.37E+00	3.20E+01	3.64E+01
Nevada National Security Site	3.94E+01	5.10E+01	9.05E+01
Nuclear Radiation Development Site	1.87E+00	4.99E+00	6.86E+00
Oak Ridge National Laboratory	8.35E+02	1.10E+02	9.45E+02
Sandia National Laboratories	8.32E-01	4.99E+00	5.82E+00
Savannah River Site	3.37E+03	3.98E+03	7.35E+03
Grand Total	**5.52E+04**	**1.28E+04**	**6.80E+04**

Data Source: CID Data Version D.11.00 LANL-CO 2012. Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams.

Table 3-2. RH Waste Inventory Total Volumes

TRU Waste Site	Stored Volumes (m^3)	Projected Volumes (m^3)	Anticipated Volumes (m^3)
Argonne National Laboratory - East	1.99E+01	1.80E+01	3.79E+01
Bettis Atomic Power Laboratory	--	4.99E+00	4.99E+00
Hanford (Richland) Site	1.53E+03	9.14E+02	2.44E+03
Idaho National Laboratory	2.30E+02	--	2.30E+02
Knolls Atomic Power Laboratory - Schenectady	--	1.31E+01	1.31E+01
Los Alamos National Laboratory	7.92E+01	--	7.92E+01
Material and Fuels Complex	8.85E+00	9.61E+01	1.05E+02
Oak Ridge National Laboratory	4.58E+02	1.55E+02	6.13E+02
Sandia National Laboratories	2.50E+00	--	2.50E+00

Table 3-2. RH Waste Inventory Total Volumes
Continued

TRU Waste Site	Stored Volumes (m^3)	Projected Volumes (m^3)	Anticipated Volumes (m^3)
Savannah River Site	2.97E+01	1.12E+01	4.09E+01
Grand Total	**2.36E+03**	**1.21E+03**	**3.57E+03**

Data Source: CID Data Version D.11.00 LANL-CO 2012. Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams.

3.1.2 Changes to TRU Waste Volumes

Table 3-3 shows the total net changes for final form total volumes (anticipated) of CH- and RH-TRU waste between ATWIR-2011 and this report. The net change column applies to the total net changes, which include both increases and decreases as reported by the sites and the amount of emplaced waste taken from the WDS. As shown, the total net change is a decrease of nearly 8,500 m^3, with the bulk of that decrease resulting from emplacement of about 7,230 m^3. The remaining decrease of almost 1,270 m^3 is attributed mainly to one waste stream, SR-W026-PDCF-1, with a volume of approximately 1,130 m^3, which was deleted because the project that would have generated the waste, the Pit Disassembly and Conversion Facility (PDCF), was cancelled.

Table 3-3. CH/RH Waste Volume Changes

TRU Waste Site	ATWIR-2011 Total Inventory (m^3)	ATWIR-2012 Total Inventory (m^3)	Total Net Change (m^3)
Hanford (Richland) Site	2.17E+04	2.25E+04	8.53E+02
Idaho National Laboratory	3.53E+04	2.85E+04	-6.76E+03
Los Alamos National Laboratory	1.02E+04	9.96E+03	-2.90E+02
Oak Ridge National Laboratory	1.42E+03	1.56E+03	1.38E+02
Savannah River Site	9.70E+03	7.39E+03	-2.32E+03
Small Quantity Sites	1.73E+03	1.60E+03	-1.26E+02
Anticipated Total	**8.00E+04**	**7.15E+04**	**-8.50E+03**
WIPP (Emplaced)	7.24E+04	7.97E+04	7.23E+03
Grand Total	**1.52E+05**	**1.51E+05**	**-1.27E+03**

Data Source: CID Data Versions D.10.01 (LANL-CO 2011e) and D.11.00 (LANL-CO 2012).

3.2 Non-Radiological Material Estimates

This section presents the non-radiological properties of the TRU waste inventory collected for this report. DOE has many reasons for obtaining and tracking non-radiological information about the TRU waste inventory destined for WIPP. For example, DOE tracks waste materials that are emplaced in the repository, such as CPR materials that might affect gas generation in the repository.

Section 3.2.1 presents the inventory of waste material parameters, section 3.2.2 presents packaging materials, and section 3.2.3 presents the chemical components.

3.2.1 Waste Material Parameters

WMPs are reported as final form mass (kg). If a waste stream includes stored and projected waste, the site provides the stored mass and the projected mass is derived in the CID based on the stored final form mass. If a site only has projected waste, then the site provides the projected final form mass. See section 2.2.2 for details on how WMPs are reported.

The following WMP descriptions are used for this report:

- Iron-Based Metal/Alloys – Includes iron and steel alloys in the waste, but does not include the waste container materials. Also includes an iron-based metallic phase associated with any vitrification process, if applicable.

- Aluminum-Based Metal/Alloys – Aluminum or aluminum-based alloys in the waste materials.

- Other Metal/Alloys – All other metal/alloys (e.g., copper, zirconium, tantalum) found in the waste materials, including the lead portion of leaded rubber gloves/aprons.

- Other Inorganic Materials – Inorganic non-metal waste materials such as concrete, glass, firebrick, ceramics, graphite, sand, and inorganic sorbents.

- Vitrified – Waste that has been melted or fused at high temperatures with glass-forming additives, such as soil or silica, in appropriate proportions to result in a homogeneous glass-like matrix. (Note that any unoxidized metallic phases, if present, are included in the iron-based metal/alloys WMP.)

- Cellulosics – Materials generally derived from high-polymer plant carbohydrates such as paper, cardboard, Kimwipes®, wood, cellophane, and cloth.

- Plastic – Generally man-made, often derived from petroleum feedstock. Examples are polyethylene, polyvinyl chloride, Lucite®, and Teflon®.

- Rubber – Natural or manmade elastic latex materials, such as Hypalon®, neoprene, surgical gloves, and leaded-rubber gloves (rubber part only).

- Solidified Inorganic Material (Inorganic Matrix) – Any homogeneous materials consisting of sludge or aqueous-based liquids that have been solidified. Examples are wastewater treatment sludge and inorganic particulates.

- Solidified Organic Material (Organic Matrix) – Organic resins, solidified organic liquids, and sludges.

- Cement – An agent used to solidify liquids, particulates, and sludge. Cement may be reacted, unreacted, or both.

- Soils – Generally consist of naturally occurring soils that have been contaminated with radioactive waste materials at a high enough level to be considered TRU waste.

The estimated WMP and PM anticipated masses for CH- and RH-TRU waste are presented in Table 3-4.

Table 3-4. CH/RH Waste and Packaging Material Inventory

Waste Material	CH Mass (kg)	RH Mass (kg)	Total Mass (kg)
Iron-based Metal/Alloys	2.70E+06	6.70E+05	3.37E+06
Aluminum-based Metal/Alloys	2.08E+05	1.42E+04	2.23E+05
Other Metal/Alloys	2.54E+05	3.71E+05	6.26E+05
Other Inorganic Materials	2.31E+06	8.84E+05	3.19E+06
Cellulose	9.20E+05	9.19E+04	1.01E+06
Rubber	4.29E+05	6.89E+04	4.98E+05
Plastic	1.53E+06	1.83E+05	1.71E+06
Cement	2.48E+06	3.60E+05	2.84E+06
Solidified Inorganic Material	3.49E+06	1.71E+04	3.51E+06
Solidified Organic Material	1.61E+06	1.85E+03	1.61E+06
Soils	2.41E+06	1.39E+05	2.55E+06
Vitrified	--	--	--
Packaging Material, Cellulose	2.85E+04	--	2.85E+04
Packaging Material, Plastic	9.04E+05	1.49E+05	1.05E+06
Packaging Material, Rubber	2.62E+04	2.05E+03	2.82E+04
Packaging Material, Steel	1.13E+07	3.39E+06	1.47E+07
Packaging Material, Lead	--	8.44E+02	8.44E+02
Grand Total	**3.06E+07**	**6.34E+06**	**3.69E+07**

Data Source: CID Data Version D.11.00, LANL-CO 2012. Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams.

3.2.2 Packaging Materials

PMs (such as steel, plastic, cellulose, lead, and rubber) are the materials used to construct the containers that hold TRU waste. The PM masses for the WIPP-approved payload containers are fixed values in the CID. The sites report the final form container type, and the CID generates the PM masses using consistent values associated with the container type. An analysis was performed (French 2009) to calculate the PM masses to be assigned to the various WIPP-approved container types in the CID. The purpose of that analysis was to document the calculations that provide the PM masses for steel, plastic, cellulose, lead, and rubber used in the containers that package CH- and RH-TRU waste for shipment to WIPP. The estimated PM anticipated masses for CH- and RH-TRU waste are presented in Table 3-4.

3.2.3 Waste and Packaging Material Parameter Changes

The changes in WMP and PM data between ATWIR-2011 and this report are presented in Table 3-5 for the total CH- and RH-TRU waste and packaging materials. Data for the WMPs and PMs improve as additional waste is characterized and the sites use that characterization data to estimate the waste remaining in that waste stream at the site. As stated earlier, the net change column applies to the total net changes, which include both increases and decreases as reported by the sites and the amount of emplaced waste taken from the WDS. As shown in Table 3-5, there was a total decrease in WMPs of about 2.33 million kg and a decrease of about 1.73 million kg of PMs. A total of approximately 2.75 million kg WMPs and 1.38 million kg PMs were emplaced during this reporting period. All the WMP masses decreased except soils, which show an increase of nearly 1.32 million kg that comes mostly from the addition of approximately 2,200 m^3 of waste containing roughly 1.2 million kg of soils (associated with waste stream RL200-02). This waste is a result of additional soil cleanup based on the issuance of a CERCLA ROD (EPA, Ecology, and DOE 2011). There was a decrease in cement of about 1.01 million kg. The largest contributing waste stream to this net reduction is KN-B234TRU, with a reduction of nearly 462,000 million kg resulting from the site's decision not to use cement to solidify the waste. A lesser contributor to this decrease stems from waste stream IN-W216R; upon rolling the waste stream into IN-BNINW216, it was discovered that approximately 289,000 kg had been double-counted. The iron-based metal/alloys decreased by nearly 1.14 million kg, with most of this decrease coming from waste stream LA-MHD01.001 (about 826,000 kg), which is a result of a decrease in the projected volume and re-evaluation of the WMPs in the waste stream based on characterization.

Table 3-5. CH/RH Waste and Packaging Material Inventory Changes

Waste Material Parameter	ATWIR-2011 Mass (kg)	ATWIR-2012 Mass (kg)	Mass Net Change (kg)
Iron-based Metal/Alloys	4.52E+06	3.37E+06	-1.14E+06
Aluminum-based Metal/Alloys	2.69E+05	2.23E+05	-4.69E+04
Other Metal/Alloys	7.84E+05	6.26E+05	-1.58E+05
Other Inorganic Materials	3.16E+06	3.19E+06	2.69E+04

Table 3-5. CH/RH Waste and Packaging Material Inventory Changes
Continued

Waste Material Parameter	ATWIR-2011 Mass (kg)	ATWIR-2012 Mass (kg)	Mass Net Change (kg)
Cellulose	1.07E+06	1.01E+06	-5.47E+04
Rubber	6.25E+05	4.98E+05	-1.27E+05
Plastic	2.08E+06	1.71E+06	-3.75E+05
Cement	3.85E+06	2.84E+06	-1.01E+06
Solidified Inorganic Material	3.92E+06	3.51E+06	-4.11E+05
Solidified Organic Material	1.96E+06	1.61E+06	-3.54E+05
Soils	1.23E+06	2.55E+06	1.32E+06
Vitrified	--	--	--
Anticipated Waste Total	**2.35E+07**	**2.11E+07**	**-2.33E+06**
WIPP (Emplaced) Waste Total	2.18E+07	2.46E+07	2.75E+06
Package Material			
Packaging Material, Cellulose	2.02E+04	2.85E+04	8.39E+03
Packaging Material, Plastic	1.18E+06	1.05E+06	-1.23E+05
Packaging Material, Rubber	3.22E+04	2.82E+04	-3.96E+03
Packaging Material, Steel	1.63E+07	1.47E+07	-1.60E+06
Packaging Material, Lead	1.20E+04	8.44E+02	-1.11E+04
Anticipated Packaging Total	**1.75E+07**	**1.58E+07**	**-1.73E+06**
WIPP (Emplaced) Packaging Total	1.68E+07	1.81E+07	1.38E+06
Grand Total	**7.96E+07**	**7.97E+07**	**6.67E+04**

Data Source: CID Data Versions D.10.01 (LANL-CO 2011e) and D.11.00 (LANL-CO 2012).

3.2.4 Chemical Components

DOE tracks the mass (kg) of complexing agents and oxyanions as part of the non-radiological components. This report is the mechanism that DOE uses to track these components for currently stored and projected TRU waste at the sites. These masses for this report are presented in Table 3-6 and Table 3-8. For details on the reporting methods on chemical components, see section 2.2.4.

3.2.4.1 Complexing Agents

DOE tracks the mass (kg) of complexing agents destined for emplacement in the WIPP repository because of their potential impact on solubilities of actinides in the waste. For this inventory report, the TRU waste sites were asked to update their estimates of complexing agents in the waste streams (Patterson 2012). Table 3-6 presents a summary of the estimated CH- and RH-TRU waste complexing agents mass by site and the grand total of the masses.

Table 3-6. CH/RH Complexing Agent Mass by Site

TRU Waste Site	Acetate (kg)	Acetic Acid (kg)	Citrate (kg)	Citric Acid (kg)	EDTA (kg)	Oxalate (kg)	Oxalic Acid (kg)
Argonne National Laboratory - East	--	--	--	--	--	--	2.68E+01
Hanford (Richland) Site	6.25E+03	3.00E+03	3.65E+01	1.01E+03	5.21E+00	1.96E+01	3.44E+03
Idaho National Laboratory	5.07E+02	2.23E+03	1.77E+02	4.58E+01	1.43E+02	--	8.43E+01
Lawrence Livermore National Laboratory	--	7.28E+00	--	7.28E+00	7.28E+00	--	7.28E+00
Los Alamos National Laboratory	--	7.35E+00	--	3.87E+02	--	--	2.13E+03
Grand Total	**6.76E+03**	**5.25E+03**	**2.14E+02**	**1.45E+03**	**1.56E+02**	**1.96E+01**	**5.69E+03**

Data Source: CID Data Version D.11.00 LANL-CO 2012. Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams**.**

3.2.4.2 Changes to Complexing Agents

Table 3-7 shows the changes in the estimated CH- and RH-TRU waste complexing agent masses (kg) between the ATWIR-2011 and this report. These data represent only the complexing agents that are currently being reported by the sites in their anticipated TRU waste inventory and do not include complexing agents that have been emplaced at WIPP because these components are not tracked in the WDS.

There was an overall net decrease of approximately 2,140 kg in the estimated CH- and RH-TRU waste complexing agents mass for this reporting period. The majority of this decrease comes from the acetic acid constituent of about 1,200 kg that results from waste streams RL-PFP-01 (nearly 387 kg decrease) and IN-ID-SDA-Sludge (around 792 kg decrease). Since the WDS does not contain these data, it is assumed that these decreases occurred because these waste streams are actively being shipped to and emplaced at WIPP.

Table 3-7. CH/RH Complexing Agent Changes

Complexing Agent	ATWIR-2011 Total Mass (kg)	ATWIR-2012 Total Mass (kg)	Total Net Change (kg)
Acetate	7.56E+03	6.76E+03	-8.04E+02
Acetic Acid	6.44E+03	5.25E+03	-1.20E+03
Citrate	2.18E+02	2.14E+02	-3.59E+00

Table 3-7. CH/RH Complexing Agent Changes
Continued

Complexing Agent	ATWIR-2011 Total Mass (kg)	ATWIR-2012 Total Mass (kg)	Total Net Change (kg)
Citric Acid	1.51E+03	1.45E+03	-6.44E+01
EDTA	1.56E+02	1.56E+02	-1.17E-02
Oxalate	2.11E+01	1.96E+01	-1.51E+00
Oxalic Acid	5.76E+03	5.69E+03	-7.12E+01
Grand Total	**2.17E+04**	**1.95E+04**	**-2.14E+03**

Data Source: CID Data Versions D.10.01 (LANL-CO 2011e) and D.11.00 (LANL-CO 2012). Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams**.**

3.2.4.3 Oxyanions

Estimates of the masses of nitrates, phosphates, and sulfates expected in the TRU waste were also requested from the TRU waste sites. The sites reported estimates of oxyanions in their waste as mass (kg) for both stored and projected waste. Table 3-8 presents the estimated CH- and RH-TRU waste oxyanion mass by site.

Table 3-8. CH/RH Oxyanion Mass by Site

TRU Waste Site	Nitrate (kg)	Phosphate (kg)	Sulfate (kg)
Argonne National Laboratory - East	5.22E-01	1.45E-01	2.23E-01
Hanford (Richland) Site	1.24E+05	1.17E+05	1.82E+04
Idaho National Laboratory	3.09E+05	2.38E+04	6.99E+04
Lawrence Berkeley National Laboratory	9.60E-02	--	--
Lawrence Livermore National Laboratory	7.28E+00	7.28E+00	7.28E+00
Los Alamos National Laboratory	3.30E+05	--	7.47E+04
Sandia National Laboratories	1.00E-06	--	--
Grand Total	**7.62E+05**	**1.41E+05**	**1.63E+05**

Data Source: CID Data Version D.11.00 (LANL-CO 2012). Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams**.**

3.2.4.4 Changes to Oxyanions

Table 3-9 shows the changes in the estimated CH- and RH-TRU waste oxyanion masses (kg) since they were reported in the ATWIR-2011. These data represent only the oxyanions that are

currently being reported by the sites as anticipated TRU waste inventory and do not include oxyanions that have been emplaced at WIPP.

An overall net decrease of approximately 114,000 kg of oxyanions is attributed to three waste streams. Waste stream IN-BN005 was determined to be low-level waste (LLW) and has been removed from the TRU waste inventory, which accounts for a reduction of nearly 32,500 kg of nitrates. Waste stream IN-ID-SDA-Sludge is actively being characterized and shipped and accounts for a decrease in nitrates of approximately 17,200 kg and a decrease in sulfates of about 24,200 kg. RL-PFP-01 was actively being characterized and shipped in CY2011 and accounts for a decrease of around 14,600 kg of nitrates and almost 14,400 kg of phosphates. Since the WDS does not contain these data, it is assumed that these decreases are a result of the waste being shipped to WIPP.

Table 3-9. CH/RH Oxyanion Changes

Oxyanion	ATWIR-2011 Total Mass (kg)	ATWIR-2012 Total Mass (kg)	Total Net Change (kg)
Nitrate	8.25E+05	7.62E+05	-6.27E+04
Phosphate	1.66E+05	1.41E+05	-2.45E+04
Sulfate	1.90E+05	1.63E+05	-2.68E+04
Grand Total	**1.18E+06**	**1.07E+06**	**-1.14E+05**

Data Source: CID Data Versions D.10.01 (LANL-CO 2011e) and D.11.00 (LANL-CO 2012)

3.3 TRU Waste Radionuclide Estimates

This section presents the TRU waste radionuclide activity inventory collected from the sites as of the end of CY 2011. The sites' TRU waste stream radionuclide activities are decay-corrected through the end of CY 2011 (as described in section 2.2.3), in curies. The data are then aggregated using the CID and placed into tables by site for CH- and RH-TRU wastes.

The radionuclides in the WPRs in Appendix A (WIPP-bound TRU Waste Profile Reports) are reported in activity concentrations (Ci/m^3) based on the final form waste stream volume. These concentrations are calculated by dividing the decay-corrected activity of each radionuclide in the waste stream by the total volume of the waste stream as discussed in section 2.2.3 of this report. Radionuclide activity concentrations presented in Appendix B (Potential TRU Waste Profile Reports) are not decay-corrected**.**

3.3.1 Radionuclide Inventory by Site

Table 3-10 and Table 3-11 provide the comprehensive WIPP-bound anticipated activity (Ci) inventory estimates for CH- and RH-TRU waste, respectively. Table 3-12 sums the CH and RH site totals to produce a total anticipated activity by site.

Table 3-10. Total CH Radionuclide Activity (Ci) on a Site Basis Decayed through 2011

Radionuclide	ANLE	Hanford	INL	KAPL-NFS	LANL	LBNL	LLNL	MFC	NNSS	NRD	ORNL	SNL	SRS	Grand Total
Ac-225	3.83E-07	2.93E-06	1.87E-04	7.97E-03	1.26E-01	--	1.97E-03	4.25E-11	1.61E-12	8.51E-16	1.74E-03	5.21E-18	3.36E-03	**1.41E-01**
Ac-227	1.37E-08	9.42E-09	1.34E-06	4.75E-05	6.28E-01	--	1.02E-02	5.77E-10	2.55E-10	--	1.16E-01	9.78E-16	1.72E-02	**7.71E-01**
Ac-228	1.10E-06	1.45E-05	2.57E-04	3.45E-01	1.04E-03	--	3.14E-06	7.85E-10	3.65E-16	--	5.40E-02	6.00E-20	1.20E-01	**5.20E-01**
Ag-108	8.16E-05	--	--	--	2.98E-07	--	--	--	--	--	--	--	--	**8.19E-05**
Ag-108m	9.38E-04	--	--	--	3.43E-06	--	--	--	--	--	--	--	--	**9.41E-04**
Ag-109m	2.63E-06	--	--	--	2.37E+03	--	4.48E-03	--	--	--	3.67E-12	--	--	**2.37E+03**
Ag-110m	--	--	--	--	--	--	--	--	--	--	1.50E+00	--	--	**1.50E+00**
Am-241	5.31E+00	5.64E+04	3.39E+04	8.02E+02	5.68E+04	3.21E-02	1.72E+03	8.20E+01	1.47E+01	3.32E+02	8.64E+02	2.68E-01	7.87E+04	**2.30E+05**
Am-242	6.67E-04	2.00E-02	--	--	--	--	7.89E+00	--	--	--	9.68E-01	--	1.20E-01	**9.00E+00**
Am-242m	6.70E-04	2.01E-02	--	--	--	--	7.93E+00	--	--	--	9.68E-01	--	1.21E-01	**9.04E+00**
Am-243	1.17E+00	6.58E-01	2.14E-02	--	1.00E+00	4.40E-05	2.41E-01	1.23E-01	--	--	5.23E+00	--	6.16E+00	**1.46E+01**
Am-244	--	--	--	--	--	--	--	--	--	--	1.00E-06	--	--	**1.00E-06**
Am-245	2.99E-08	--	--	--	7.64E-09	--	--	--	--	--	1.69E-19	--	--	**3.76E-08**
At-217	3.83E-07	2.93E-06	1.87E-04	7.97E-03	1.26E-01	--	1.97E-03	4.25E-11	1.61E-12	8.51E-16	1.74E-03	5.21E-18	3.36E-03	**1.41E-01**
Ba-133	1.82E-04	3.31E-04	--	--	1.08E-05	--	--	--	--	--	1.80E-07	--	1.21E-05	**5.36E-04**
Ba-137m	3.31E+00	3.50E+03	2.62E-03	--	9.01E+00	--	7.27E-01	3.18E-02	--	--	1.70E-01	--	2.93E+00	**3.52E+03**
Bi-210	8.91E-05	5.66E-05	1.51E-06	7.76E-04	1.21E-04	--	7.37E-09	1.24E-10	9.16E-12	--	3.00E-01	4.01E-18	2.48E-04	**3.01E-01**
Bi-211	1.37E-08	9.42E-09	1.34E-06	4.75E-05	6.29E-01	--	1.02E-02	5.77E-10	2.55E-10	--	6.66E-04	9.78E-16	1.73E-02	**6.57E-01**
Bi-212	7.67E-04	1.52E-04	2.42E-03	4.68E-01	6.86E-04	--	2.68E-03	3.22E-04	1.64E-16	--	2.91E-02	5.09E-21	2.34E-01	**7.38E-01**
Bi-213	3.83E-07	2.93E-06	1.87E-04	7.97E-03	1.26E-01	--	1.97E-03	4.25E-11	1.61E-12	8.51E-16	1.74E-03	5.21E-18	3.36E-03	**1.41E-01**
Bi-214	3.53E-04	1.88E-03	1.25E-05	6.08E-03	3.50E-04	--	2.44E-07	4.15E-09	2.27E-10	--	5.40E-01	5.27E-16	4.83E-04	**5.49E-01**
Bk-249	2.06E-03	--	--	--	5.27E-04	--	--	--	--	--	1.85E+01	--	--	**1.85E+01**
Bk-250	1.91E-09	--	--	--	--	--	--	--	--	--	--	--	--	**1.91E-09**
C-14	2.13E-03	6.00E-04	--	--	--	--	--	--	--	--	4.06E-04	--	7.33E-03	**1.05E-02**
Ca-45	5.33E-06	--	--	--	--	--	--	--	--	--	--	--	--	**5.33E-06**
Cd-109	2.63E-06	--	--	--	2.37E+03	--	4.48E-03	--	--	--	6.52E-05	--	--	**2.37E+03**
Cd-113	6.24E-04	--	--	--	--	--	--	--	--	--	--	--	--	**6.24E-04**
Cd-113m	3.46E-04	--	--	--	--	--	--	--	--	--	--	--	--	**3.46E-04**
Ce-139	--	--	--	--	--	--	--	--	--	--	7.52E-05	--	--	**7.52E-05**
Ce-141	--	--	--	--	--	--	--	--	--	--	2.38E+00	--	--	**2.38E+00**
Ce-144	4.52E-03	--	--	--	2.56E-04	--	--	3.20E-04	--	--	1.04E+00	--	3.68E-11	**1.05E+00**
Cf-249	2.35E-01	1.79E-02	3.72E-03	--	8.62E-03	4.20E+00	7.44E+00	--	--	--	1.00E+00	--	2.30E-03	**1.29E+01**
Cf-250	8.70E-03	--	--	--	--	1.42E-04	--	--	--	--	2.36E-01	--	1.71E-10	**2.45E-01**
Cf-251	1.18E-03	--	--	--	--	--	2.63E-04	--	--	--	2.84E-03	--	1.27E-03	**5.56E-03**
Cf-252	1.26E-03	--	--	--	--	--	3.35E-03	--	--	--	2.02E+02	--	--	**2.02E+02**
Cf-253	--	--	--	--	--	--	--	--	--	--	6.70E-04	--	--	**6.70E-04**
Cf-254	--	--	--	--	--	--	--	--	--	--	1.82E-05	--	--	**1.82E-05**
Cl-36	1.17E-07	--	--	--	2.78E-03	--	--	--	--	--	--	--	--	**2.78E-03**
Cm-242	5.38E-04	1.58E-02	2.31E-14	--	2.92E-04	--	6.24E+00	1.52E-13	--	--	1.18E+02	--	9.96E-02	**1.25E+02**
Cm-243	4.15E-02	6.16E-01	3.30E-03	--	5.87E-01	--	8.53E-02	4.20E-09	--	--	1.19E+02	--	8.51E-02	**1.21E+02**
Cm-244	2.46E+02	7.11E+01	6.31E-01	--	3.25E+03	--	8.13E+02	8.79E-01	--	--	4.64E+03	--	1.97E+02	**9.22E+03**
Cm-245	1.93E-04	--	1.97E-08	--	4.85E-04	--	4.16E-02	--	--	--	1.67E-02	--	6.41E-02	**1.23E-01**
Cm-246	1.08E-02	--	--	--	5.76E-01	--	--	--	--	--	6.37E-01	--	8.84E-02	**1.31E+00**
Cm-247	1.02E-09	--	--	--	--	--	3.52E-06	--	--	--	7.57E-05	--	1.09E-02	**1.10E-02**
Cm-248	6.37E-04	--	--	--	--	1.69E-04	1.79E-02	--	--	--	4.90E-02	--	2.05E-06	**6.77E-02**

Table 3-10. Total CH Radionuclide Activity (Ci) on a Site Basis Decayed through 2011

Continued

Radionuclide	ANLE	Hanford	INL	KAPL-NFS	LANL	LBNL	LLNL	MFC	NNSS	NRD	ORNL	SNL	SRS	Grand Total
Cm-250	1.36E-08	--	--	--	--	--	--	--	--	--	2.23E-03	--	--	**2.23E-03**
Co-60	1.23E-02	2.07E-01	2.13E-05	--	5.00E-04	--	1.44E-03	3.16E-04	--	--	5.06E-02	--	5.96E-03	**2.78E-01**
Cr-51	--	--	--	--	--	--	--	--	--	--	2.79E-01	--	--	**2.79E-01**
Cs-134	8.40E-02	1.07E+00	1.58E-07	--	1.43E-05	--	--	2.38E-04	--	--	6.52E-01	--	2.08E-04	**1.80E+00**
Cs-135	3.45E-07	--	--	--	--	--	--	--	--	--	--	--	--	**3.45E-07**
Cs-137	3.50E+00	3.72E+03	7.04E-02	--	9.60E+00	1.90E-04	7.70E-01	3.37E-02	--	--	1.32E+01	--	3.10E+00	**3.75E+03**
Es-253	--	--	--	--	--	--	--	--	--	--	8.02E+00	--	--	**8.02E+00**
Es-254	--	--	--	--	--	--	--	--	--	--	3.99E-04	--	--	**3.99E-04**
Eu-152	3.40E-04	3.75E-03	1.89E-06	--	3.15E-04	--	3.90E-04	--	--	--	1.29E+00	--	1.16E-04	**1.30E+00**
Eu-154	5.40E-02	5.11E+00	1.05E-04	--	4.07E-04	--	3.73E-03	2.14E-04	--	--	1.64E+00	--	3.07E-02	**6.84E+00**
Eu-155	1.08E-02	3.51E-06	3.95E-06	--	6.19E-02	--	--	5.31E-04	--	--	7.95E-01	--	2.06E-04	**8.68E-01**
Fe-55	2.00E-02	--	--	--	--	--	--	--	--	--	2.91E-06	--	--	**2.00E-02**
Fe-59	2.25E-08	--	--	--	--	--	--	--	--	--	4.31E-04	--	--	**4.31E-04**
Fr-221	3.83E-07	2.93E-06	1.87E-04	7.97E-03	1.26E-01	--	1.97E-03	4.25E-11	1.61E-12	8.51E-16	1.74E-03	5.21E-18	3.36E-03	**1.41E-01**
Fr-223	1.89E-10	1.30E-10	1.85E-08	6.55E-07	8.66E-03	--	1.41E-04	7.96E-12	3.52E-12	--	2.89E-09	1.35E-17	2.38E-04	**9.04E-03**
Gd-152	6.26E-19	1.41E-18	--	--	2.31E-18	--	1.47E-18	--	--	--	7.07E-16	--	1.81E-18	**7.15E-16**
H-3	8.29E-03	1.16E-04	--	--	9.30E+03	--	--	--	--	--	9.69E-03	--	4.13E-03	**9.30E+03**
Ho-166m	2.17E-09	--	--	--	--	--	--	--	--	--	--	--	1.36E-05	**1.36E-05**
I-125	--	--	--	--	5.65E-06	--	--	--	--	--	--	--	--	**5.65E-06**
I-129	7.38E-07	1.58E-06	--	--	1.20E-06	--	--	--	--	--	--	--	3.93E-03	**3.94E-03**
I-131	--	--	--	--	--	--	--	--	--	--	2.03E-03	--	--	**2.03E-03**
K-40	4.73E-04	3.91E-04	--	--	--	--	6.79E-08	--	--	--	4.26E-05	4.98E-10	--	**9.06E-04**
Kr-85	2.37E-02	1.84E+00	--	--	5.02E-01	--	--	--	--	--	--	--	4.29E-02	**2.40E+00**
Mn-54	5.55E-04	4.90E-08	--	--	1.89E-08	--	--	--	--	--	6.94E-16	--	--	**5.55E-04**
Mn-56	--	--	--	--	5.09E-07	--	--	--	--	--	--	--	--	**5.09E-07**
Na-22	2.95E-04	1.41E-02	--	--	6.57E-04	--	3.51E-05	--	--	--	7.33E-06	--	3.86E-04	**1.54E-02**
Nb-93m	2.26E-03	--	--	--	--	--	--	--	--	--	--	--	--	**2.26E-03**
Nb-94	5.94E-06	1.18E-03	--	--	--	--	2.59E-08	--	--	--	--	--	4.61E-07	**1.18E-03**
Nb-95	9.79E-08	--	2.46E-10	--	--	--	--	4.81E-08	--	--	9.27E-02	--	--	**9.27E-02**
Nb-95m	5.26E-10	--	1.32E-12	--	--	--	--	2.57E-10	--	--	--	--	--	**7.84E-10**
Nd-144	2.42E-18	--	--	--	1.41E-18	--	--	5.86E-19	--	--	2.80E-45	--	1.74E-18	**6.15E-18**
Ni-59	--	--	--	--	--	--	--	--	--	--	--	--	1.32E-05	**1.32E-05**
Ni-63	9.37E-06	--	--	--	--	--	--	--	--	--	1.64E-01	--	--	**1.64E-01**
Np-237	4.68E-02	7.39E-01	8.28E-01	2.29E-03	3.77E-01	1.72E-02	1.91E-02	5.56E-02	9.12E-05	3.33E-06	7.96E-01	8.36E-08	1.09E+00	**3.97E+00**
Np-238	3.02E-06	9.04E-05	--	--	--	--	3.57E-02	--	--	--	9.58E-07	--	5.45E-04	**3.63E-02**
Np-239	1.17E+00	7.58E-02	2.12E-02	--	1.00E+00	--	2.41E-01	1.23E-01	--	--	2.22E+00	--	6.16E+00	**1.10E+01**
Np-240	4.44E-09	--	--	--	5.20E-09	--	3.40E-13	--	--	--	6.95E-07	--	6.24E-16	**7.04E-07**
Np-240m	3.70E-06	--	--	--	4.34E-06	--	2.83E-10	--	--	--	5.79E-04	--	5.20E-13	**5.87E-04**
P-32	9.07E-12	--	--	--	--	--	--	--	--	--	--	--	--	**9.07E-12**
Pa-231	1.11E-07	2.80E-07	7.43E-06	3.64E-04	3.24E-03	--	5.65E-02	1.85E-08	4.15E-09	--	3.85E-01	9.29E-14	8.84E-03	**4.54E-01**
Pa-233	4.68E-02	9.68E-02	7.39E-01	2.29E-03	3.77E-01	--	1.91E-02	5.56E-02	9.12E-05	3.33E-06	2.38E-01	8.36E-08	1.09E+00	**2.67E+00**
Pa-234	8.33E-07	1.39E-04	3.19E-03	3.21E-04	6.31E-04	--	1.99E-05	2.59E-08	3.22E-06	--	4.30E-05	1.44E-17	1.12E-04	**4.46E-03**
Pa-234m	6.41E-04	1.07E-01	2.46E+00	2.47E-01	4.85E-01	--	1.53E-02	1.99E-05	2.48E-03	--	3.31E-02	1.11E-14	8.60E-02	**3.43E+00**
Pb-209	3.83E-07	2.93E-06	1.87E-04	7.97E-03	1.26E-01	--	1.97E-03	4.25E-11	1.61E-12	8.51E-16	1.74E-03	5.21E-18	3.36E-03	**1.41E-01**
Pb-210	8.90E-05	5.66E-05	1.51E-06	7.76E-04	2.95E-04	--	7.37E-09	1.24E-10	9.16E-12	--	3.00E-01	4.01E-18	2.48E-04	**3.02E-01**
Pb-211	1.37E-08	9.42E-09	1.34E-06	4.75E-05	6.29E-01	--	1.02E-02	5.77E-10	2.55E-10	--	2.10E-07	9.78E-16	1.73E-02	**6.57E-01**
Pb-212	7.67E-04	1.52E-04	2.42E-03	4.68E-01	6.86E-04	--	2.68E-03	3.22E-04	1.64E-16	--	3.02E-02	5.09E-21	2.34E-01	**7.39E-01**

Table 3-10. Total CH Radionuclide Activity (Ci) on a Site Basis Decayed through 2011

Continued

Radionuclide	ANLE	Hanford	INL	KAPL-NFS	LANL	LBNL	LLNL	MFC	NNSS	NRD	ORNL	SNL	SRS	Grand Total
Pb-214	3.53E-04	1.88E-03	1.25E-05	6.08E-03	3.50E-04	--	2.44E-07	4.15E-09	2.27E-10	--	5.40E-01	5.27E-16	4.83E-04	**5.49E-01**
Pd-107	1.84E-05	--	--	--	--	--	--	--	--	--	--	--	--	**1.84E-05**
Pm-147	8.95E-01	1.94E+01	--	--	6.12E-02	--	--	--	--	--	4.73E+00	--	8.47E-04	**2.51E+01**
Po-210	1.86E-04	3.01E-05	1.51E-06	7.76E-04	1.14E-04	--	4.39E-09	7.37E-11	9.16E-12	--	1.61E+00	1.09E-18	2.48E-04	**1.61E+00**
Po-211	3.77E-11	2.59E-11	3.68E-09	1.31E-07	1.73E-03	--	2.81E-05	1.59E-12	7.02E-13	--	5.77E-10	2.69E-18	4.75E-05	**1.81E-03**
Po-212	4.91E-04	9.73E-05	1.55E-03	3.00E-01	4.39E-04	--	1.72E-03	2.06E-04	1.05E-16	--	3.52E-06	3.26E-21	1.50E-01	**4.54E-01**
Po-213	3.74E-07	2.87E-06	1.83E-04	7.80E-03	1.23E-01	--	1.93E-03	4.16E-11	1.57E-12	8.33E-16	1.71E-03	5.10E-18	3.29E-03	**1.38E-01**
Po-214	3.53E-04	1.88E-03	1.25E-05	6.08E-03	3.50E-04	--	2.44E-07	4.15E-09	2.27E-10	--	5.39E-01	5.27E-16	4.83E-04	**5.48E-01**
Po-215	1.37E-08	9.42E-09	1.34E-06	4.75E-05	6.29E-01	--	1.02E-02	5.77E-10	2.55E-10	--	2.10E-07	9.78E-16	1.73E-02	**6.57E-01**
Po-216	7.67E-04	1.52E-04	2.42E-03	4.68E-01	6.86E-04	--	2.68E-03	3.22E-04	1.64E-16	--	5.50E-06	5.09E-21	2.34E-01	**7.09E-01**
Po-218	3.53E-04	1.88E-03	1.25E-05	6.08E-03	3.50E-04	--	2.44E-07	4.15E-09	2.27E-10	--	5.39E-01	5.27E-16	4.83E-04	**5.48E-01**
Pr-144	4.53E-03	--	--	--	2.56E-04	--	--	3.20E-04	--	--	--	--	3.68E-11	**5.10E-03**
Pr-144m	6.33E-05	--	--	--	3.59E-06	--	--	4.47E-06	--	--	--	--	5.16E-13	**7.14E-05**
Pu-236	2.08E-09	--	8.10E-06	--	4.31E-09	--	--	--	--	--	1.80E-13	--	--	**8.11E-06**
Pu-238	4.81E+00	1.76E+04	2.04E+03	8.73E+01	1.25E+05	--	1.69E+03	1.09E+00	5.38E+00	--	3.97E+03	2.80E-01	3.89E+04	**1.89E+05**
Pu-239	1.25E+01	8.29E+04	1.13E+04	2.81E+03	3.74E+04	7.26E-01	1.89E+03	2.32E+01	1.77E+02	--	6.81E+02	8.92E+00	1.11E+04	**1.48E+05**
Pu-240	9.07E+00	3.17E+04	2.84E+03	2.81E+03	9.86E+03	2.00E-02	5.49E+02	6.21E+00	4.05E+01	--	8.54E+02	2.11E+00	3.79E+03	**5.24E+04**
Pu-241	3.38E+01	5.31E+05	1.93E+04	2.70E+03	1.35E+05	5.14E-01	6.20E+03	1.05E+03	2.42E+02	--	7.93E+04	1.40E+01	2.35E+04	**7.98E+05**
Pu-242	2.08E-02	1.59E+03	3.93E-01	--	1.51E+01	--	1.70E-01	1.23E-03	2.61E-03	--	2.33E+00	7.16E-05	1.02E+00	**1.61E+03**
Pu-243	1.02E-09	--	--	--	--	--	3.52E-06	--	--	--	--	--	1.09E-02	**1.09E-02**
Pu-244	3.71E-06	2.27E-11	--	--	1.79E-04	--	2.84E-10	--	--	--	9.95E-03	--	5.20E-13	**1.01E-02**
Ra-223	1.37E-08	9.42E-09	1.34E-06	4.75E-05	6.29E-01	--	1.02E-02	5.77E-10	2.55E-10	--	6.60E-03	9.78E-16	1.73E-02	**6.63E-01**
Ra-224	7.67E-04	1.52E-04	2.42E-03	4.68E-01	6.86E-04	--	2.68E-03	3.22E-04	1.64E-16	--	5.50E-06	5.09E-21	2.34E-01	**7.09E-01**
Ra-225	3.83E-07	2.93E-06	1.87E-04	7.97E-03	1.26E-01	--	1.97E-03	4.25E-11	1.61E-12	8.51E-16	1.74E-03	5.21E-18	3.36E-03	**1.41E-01**
Ra-226	3.53E-04	4.84E-03	6.32E-05	6.08E-03	3.52E-04	--	2.44E-07	4.15E-09	2.27E-10	--	5.48E-01	5.27E-16	4.83E-04	**5.60E-01**
Ra-228	1.10E-06	1.45E-05	2.57E-04	3.45E-01	1.04E-03	--	3.14E-06	7.85E-10	3.65E-16	--	4.34E-06	6.00E-20	1.20E-01	**4.66E-01**
Rb-87	1.24E-10	--	--	--	--	--	--	--	--	--	--	--	--	**1.24E-10**
Rh-106	8.35E-03	--	--	--	4.35E-03	--	--	4.41E-04	--	--	3.16E-11	--	7.45E-08	**1.31E-02**
Rn-219	1.37E-08	9.42E-09	1.34E-06	4.75E-05	6.29E-01	--	1.02E-02	5.77E-10	2.55E-10	--	2.10E-07	9.78E-16	1.73E-02	**6.57E-01**
Rn-220	7.67E-04	1.52E-04	2.42E-03	4.68E-01	6.86E-04	--	2.68E-03	3.22E-04	1.64E-16	--	5.50E-06	5.09E-21	2.34E-01	**7.09E-01**
Rn-222	3.53E-04	1.88E-03	1.25E-05	6.08E-03	3.50E-04	--	2.44E-07	4.15E-09	2.27E-10	--	5.39E-01	5.27E-16	4.83E-04	**5.48E-01**
Ru-103	--	--	--	--	--	--	--	--	--	--	1.27E+00	--	--	**1.27E+00**
Ru-106	8.35E-03	--	--	--	4.35E-03	--	--	4.41E-04	--	--	5.32E+00	--	7.45E-08	**5.34E+00**
S-35	2.56E-04	--	--	--	--	--	--	--	--	--	--	--	--	**2.56E-04**
Sb-125	2.47E-03	1.26E+00	--	--	4.53E-02	--	2.69E-06	--	--	--	2.89E-01	--	4.20E-04	**1.59E+00**
Sb-126	2.57E-06	1.46E-01	--	--	1.79E-05	--	--	--	--	--	--	--	6.71E-07	**1.46E-01**
Sb-126m	1.83E-05	1.04E+00	--	--	1.28E-04	--	--	--	--	--	--	--	4.80E-06	**1.04E+00**
Sc-46	--	--	--	--	3.19E-09	--	--	--	--	--	--	--	--	**3.19E-09**
Se-79	6.32E-06	--	--	--	--	--	--	--	--	--	--	--	9.73E-06	**1.60E-05**
Sm-147	6.70E-12	3.34E-10	--	--	1.83E-12	--	--	--	--	--	--	--	5.36E-12	**3.48E-10**
Sm-148	2.76E-35	1.25E-34	--	--	4.01E-34	--	1.31E-34	--	--	--	9.80E-31	--	1.20E-33	**9.82E-31**
Sm-151	3.21E-03	1.58E+00	--	--	1.01E-03	--	--	--	--	--	5.76E+00	--	2.73E-02	**7.38E+00**
Sn-121	--	--	--	--	5.79E-04	--	--	--	--	--	--	--	--	**5.79E-04**
Sn-121m	--	--	--	--	7.46E-04	--	--	--	--	--	--	--	--	**7.46E-04**
Sn-126	1.83E-05	1.04E+00	--	--	1.28E-04	--	--	--	--	--	--	--	4.80E-06	**1.04E+00**
Sr-85	1.75E-06	--	--	--	--	--	--	--	--	--	--	--	--	**1.75E-06**
Sr-90	2.97E+00	3.80E+03	7.79E-02	--	4.71E+00	--	8.29E-01	7.56E-02	--	--	4.40E+01	--	4.17E+00	**3.86E+03**

Table 3-10. Total CH Radionuclide Activity (Ci) on a Site Basis Decayed through 2011

Continued

Radionuclide	ANLE	Hanford	INL	KAPL-NFS	LANL	LBNL	LLNL	MFC	NNSS	NRD	ORNL	SNL	SRS	Grand Total
Tc-99	3.71E-03	2.10E+00	--	1.74E+01	--	--	--	--	--	--	2.03E+01	--	1.49E-04	**3.97E+01**
Te-123	--	--	--	--	--	--	--	--	--	--	1.13E-03	--	--	**1.13E-03**
Te-123m	--	--	--	--	--	--	--	--	--	--	6.14E-04	--	--	**6.14E-04**
Te-125m	5.92E-04	3.07E-01	--	--	1.11E-02	--	6.56E-07	--	--	--	--	--	1.03E-04	**3.19E-01**
Th-227	1.35E-08	9.29E-09	1.32E-06	4.68E-05	6.20E-01	--	1.01E-02	5.69E-10	2.52E-10	--	7.65E-03	9.65E-16	1.70E-02	**6.55E-01**
Th-228	7.63E-04	5.64E-04	2.42E-03	4.67E-01	6.85E-04	--	2.68E-03	3.22E-04	1.64E-16	--	3.10E-02	5.09E-21	2.34E-01	**7.40E-01**
Th-229	3.83E-07	2.93E-06	1.87E-04	7.97E-03	1.26E-01	--	1.97E-03	4.25E-11	1.61E-12	8.51E-16	6.18E-02	5.21E-18	3.36E-03	**2.01E-01**
Th-230	3.77E-03	4.70E-06	1.78E-05	1.56E+00	2.19E-03	--	2.83E-04	4.93E-06	2.61E-07	--	5.22E-02	3.65E-12	2.60E-03	**1.62E+00**
Th-231	8.74E-05	7.29E-03	5.50E-02	1.91E+00	5.85E-02	--	3.65E-03	4.37E-04	4.92E-05	--	1.19E-03	8.78E-09	8.06E-03	**2.04E+00**
Th-232	5.23E-06	3.08E-03	2.77E-04	5.21E-01	2.71E-03	1.12E-03	1.46E-05	3.66E-09	1.48E-15	--	1.91E-03	1.54E-18	1.21E-01	**6.51E-01**
Th-234	6.41E-04	1.07E-01	2.46E+00	2.47E-01	4.87E-01	--	1.53E-02	1.99E-05	2.48E-03	--	3.53E-02	1.11E-14	8.60E-02	**3.44E+00**
Tl-204	1.42E-04	--	--	--	--	--	--	--	--	--	4.25E-07	--	--	**1.42E-04**
Tl-207	1.37E-08	9.40E-09	1.34E-06	4.73E-05	6.27E-01	--	1.02E-02	5.75E-10	2.54E-10	--	2.09E-07	9.76E-16	1.72E-02	**6.55E-01**
Tl-208	2.76E-04	5.46E-05	8.70E-04	1.68E-01	2.46E-04	--	9.64E-04	1.16E-04	5.91E-17	--	8.62E-03	1.83E-21	8.42E-02	**2.64E-01**
Tl-209	8.03E-09	6.15E-08	3.93E-06	1.67E-04	2.64E-03	--	4.14E-05	8.93E-13	3.37E-14	1.79E-17	3.66E-05	1.09E-19	7.06E-05	**2.96E-03**
Tm-171	2.57E-09	--	--	--	9.72E-04	--	--	--	--	--	--	--	--	**9.72E-04**
U-232	2.49E-04	3.33E-01	2.84E-03	--	2.04E-04	--	4.85E-03	6.18E-04	--	--	7.63E-02	--	1.12E-01	**5.31E-01**
U-233	2.98E-03	4.05E+00	4.96E-01	1.01E+01	4.26E+01	--	2.61E+00	4.84E-07	4.70E-09	1.45E-11	1.04E+01	1.79E-13	1.47E+00	**7.17E+01**
U-234	6.16E-03	3.22E+00	1.56E+00	1.01E+01	1.70E+01	--	6.82E-02	1.48E-02	7.10E-03	--	7.35E+00	7.93E-07	1.25E+01	**5.18E+01**
U-235	8.74E-05	1.08E-01	1.06E-01	1.91E+00	5.89E-02	--	3.65E-03	4.37E-04	4.92E-05	--	3.58E-03	8.78E-09	1.66E-02	**2.21E+00**
U-236	1.18E-05	1.25E-03	4.16E-04	1.91E+00	2.65E-03	--	3.29E-05	7.15E-05	8.20E-06	--	1.37E-01	6.23E-08	3.96E-03	**2.06E+00**
U-237	8.08E-04	3.21E-01	3.39E-01	6.46E-02	3.21E+00	--	1.48E-01	2.51E-02	5.79E-03	--	1.05E-03	3.35E-04	1.75E-01	**4.29E+00**
U-238	6.41E-04	1.76E+00	7.09E+00	2.47E-01	4.87E-01	7.80E-07	1.53E-02	1.99E-05	2.48E-03	--	5.14E-02	1.11E-14	8.61E-02	**9.74E+00**
U-240	3.70E-06	--	--	--	4.34E-06	--	2.83E-10	--	--	--	5.79E-04	--	5.20E-13	**5.87E-04**
Xe-133	3.12E-29	--	--	--	--	--	--	--	--	--	--	--	--	**3.12E-29**
Y-90	2.97E+00	3.72E+03	5.23E-03	--	4.70E+00	--	8.29E-01	7.56E-02	--	--	6.66E-02	--	4.18E+00	**3.74E+03**
Zn-65	3.54E-07	--	--	--	--	--	--	--	--	--	--	--	--	**3.54E-07**
Zr-93	1.01E-05	--	--	--	--	--	--	--	--	--	--	--	--	**1.01E-05**
Zr-95	4.47E-08	--	1.12E-10	--	--	--	--	2.19E-08	--	--	7.12E-01	--	--	**7.12E-01**
Grand Total	**3.29E+02**	**7.36E+05**	**6.94E+04**	**9.26E+03**	**3.81E+05**	**5.51E+00**	**1.29E+04**	**1.16E+03**	**4.80E+02**	**3.32E+02**	**9.10E+04**	**2.56E+01**	**1.56E+05**	**1.46E+06**

Data Source: CID Data Version D.11.00 (LANL-CO 2012). Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams.

Table 3-11. Total RH Radionuclide Activity (Ci) on a Site Basis Decayed through 2011

Radionuclide	ANLE	BAPL	Hanford	INL	KAPL-S	LANL	MFC	ORNL	SNL	SRS	Grand Total
Ac-225	5.27E-03	7.31E-05	2.11E-04	1.00E-03	--	1.49E-12	3.27E-09	8.69E-01	--	1.70E-05	**8.76E-01**
Ac-227	2.35E-01	7.62E-05	9.33E-03	3.72E-06	2.22E-09	1.68E-06	1.02E-03	4.50E-03	--	1.15E-08	**2.49E-01**
Ac-228	2.04E-02	2.07E-06	6.13E-06	4.07E-05	--	8.99E-15	1.85E-13	9.93E-03	--	3.95E-13	**3.04E-02**
Ag-108	1.10E-03	--	--	--	--	--	--	--	--	--	**1.10E-03**
Ag-108m	1.26E-02	--	--	--	--	--	--	--	--	--	**1.26E-02**
Ag-109m	1.57E-01	--	--	--	--	--	--	6.31E-08	--	--	**1.57E-01**
Ag-110	1.58E-04	--	2.64E-07	--	--	--	--	8.46E-15	--	--	**1.58E-04**
Ag-110m	1.16E-02	--	1.94E-05	--	--	--	--	6.22E-13	--	--	**1.16E-02**
Am-241	1.54E+02	8.98E-02	4.10E+03	1.43E+01	1.14E-02	4.62E+00	2.32E+02	1.69E+02	8.95E-01	2.89E+02	**4.96E+03**
Am-242	5.37E-01	1.46E-07	1.23E+00	2.55E-04	--	--	--	4.82E-03	--	8.13E-02	**1.85E+00**
Am-242m	5.39E-01	4.84E-06	1.23E+00	2.56E-04	--	--	--	4.84E-03	1.78E-03	8.16E-02	**1.86E+00**
Am-243	3.04E+00	3.86E-04	4.01E+00	6.89E-04	2.49E-06	--	1.96E-04	1.10E+00	6.72E-05	3.50E+00	**1.17E+01**
Am-245	6.15E-13	--	--	--	--	--	--	8.78E-16	--	--	**6.16E-13**
Ar-37	6.43E-16	--	--	--	--	--	--	--	--	--	**6.43E-16**
Ar-39	8.80E-03	--	--	--	--	--	--	--	--	--	**8.80E-03**
Ar-42	2.26E-02	--	--	--	--	--	--	--	--	--	**2.26E-02**
At-217	5.27E-03	7.31E-05	2.11E-04	1.00E-03	--	1.49E-12	3.27E-09	8.69E-01	--	1.70E-05	**8.76E-01**
Ba-133	1.71E+00	3.47E-10	--	--	--	--	--	--	--	--	**1.71E+00**
Ba-137m	2.95E+03	2.00E+02	2.17E+05	2.83E+04	2.84E+01	7.79E+02	2.90E+04	2.15E+03	--	8.43E+01	**2.80E+05**
Bi-210	8.07E-01	6.28E-09	2.34E-10	1.23E-08	--	7.19E-10	8.31E-08	6.97E+00	--	1.03E-08	**7.77E+00**
Bi-211	2.35E-01	--	2.26E-06	3.72E-06	--	1.68E-06	1.02E-03	4.50E-03	--	1.15E-08	**2.41E-01**
Bi-212	2.42E+00	2.66E-02	2.08E-05	3.60E-02	--	8.99E-15	9.98E-14	1.79E+00	--	2.88E-13	**4.28E+00**
Bi-213	5.27E-03	7.31E-05	2.11E-04	1.00E-03	--	1.49E-12	3.27E-09	8.69E-01	--	1.70E-05	**8.76E-01**
Bi-214	3.14E-08	1.06E-08	5.85E-09	1.02E-07	--	3.05E-09	1.07E-06	1.25E+01	--	6.20E-08	**1.25E+01**
Bk-249	4.24E-08	--	--	--	--	--	--	6.05E-11	--	--	**4.24E-08**
Bk-250	--	--	--	--	--	--	--	5.70E-09	--	--	**5.70E-09**
C-14	--	5.12E-03	4.41E-04	9.34E+01	1.48E-01	--	3.58E+01	1.09E-03	--	6.69E-05	**1.29E+02**
Ca-45	2.40E-04	--	--	--	--	--	--	--	--	--	**2.40E-04**
Cd-109	1.57E-01	--	--	--	--	--	--	6.31E-08	--	--	**1.57E-01**
Cd-113	3.75E-19	--	1.84E-19	--	--	--	--	--	--	--	**5.58E-19**
Cd-113m	8.12E-01	3.93E-05	1.71E+00	--	--	--	--	--	--	--	**2.53E+00**
Cd-115m	1.32E-11	--	--	--	--	--	--	--	--	--	**1.32E-11**
Ce-139	7.93E-04	--	--	--	--	--	--	--	--	--	**7.93E-04**
Ce-141	1.16E-14	--	--	--	--	--	7.78E-07	--	--	--	**7.78E-07**
Ce-144	1.61E+00	6.53E-10	9.95E-03	2.61E-02	--	6.40E-11	2.85E+01	1.56E-10	--	2.38E-04	**3.01E+01**
Cf-249	6.58E-01	--	--	--	1.89E-13	--	--	2.21E-01	--	5.08E-06	**8.79E-01**
Cf-250	7.20E-02	--	--	--	--	--	--	5.46E-01	--	6.52E-05	**6.18E-01**
Cf-251	8.04E-09	--	--	--	2.38E-15	--	--	3.06E-02	--	1.99E-06	**3.06E-02**
Cf-252	3.34E-04	--	--	--	1.15E-16	--	--	1.66E-02	--	1.02E-01	**1.19E-01**
Cm-242	4.45E-01	4.00E-06	1.43E+00	2.11E-04	5.11E-05	--	4.96E-12	3.99E-03	1.47E-03	6.72E-02	**1.95E+00**
Cm-243	5.49E-01	8.35E-06	2.93E+01	6.70E-03	7.44E-05	--	--	1.95E-02	--	6.84E-03	**2.99E+01**
Cm-244	1.72E+02	4.14E-04	7.84E+02	1.71E+00	6.96E-03	--	4.30E-06	4.39E+02	--	3.18E+02	**1.72E+03**
Cm-245	1.58E-02	6.21E-10	8.82E-02	--	2.30E-08	--	--	2.86E-03	--	4.31E-02	**1.50E-01**
Cm-246	4.70E-05	--	3.94E-02	--	3.00E-09	--	--	2.65E+00	--	5.77E-02	**2.74E+00**
Cm-247	6.24E-10	--	1.24E-10	--	7.07E-15	--	--	6.77E-08	--	1.09E-07	**1.78E-07**
Cm-248	4.66E-09	--	1.88E-06	1.57E-16	1.40E-14	--	--	9.45E-03	--	2.00E-05	**9.48E-03**
Cm-250	--	--	--	--	--	--	--	4.07E-08	--	--	**4.07E-08**
Co-58	3.63E-07	--	--	--	--	--	1.34E+01	--	--	--	**1.34E+01**

Table 3-11. Total RH Radionuclide Activity (Ci) on a Site Basis Decayed through 2011
Continued

Radionuclide	ANLE	BAPL	Hanford	INL	KAPL-S	LANL	MFC	ORNL	SNL	SRS	Grand Total
Co-60	2.85E+01	2.90E+00	1.46E+02	3.30E+02	2.96E+00	5.13E-01	4.00E+04	2.02E+00	2.00E+01	1.23E-03	**4.05E+04**
Cr-51	1.08E-17	--	--	--	--	--	--	--	--	--	**1.08E-17**
Cs-134	2.16E+01	3.84E-01	1.18E+03	2.59E+00	--	--	4.07E+01	1.09E-02	8.29E-03	5.25E-01	**1.24E+03**
Cs-135	8.37E-08	6.32E-06	6.32E-04	2.83E-03	1.90E-05	--	1.74E+01	--	--	--	**1.74E+01**
Cs-137	3.12E+03	2.11E+02	2.30E+05	3.00E+04	3.00E+01	8.25E+02	3.08E+04	2.27E+03	3.17E+01	8.93E+01	**2.97E+05**
Dy-159	1.26E-04	--	--	--	--	--	--	--	--	--	**1.26E-04**
Es-254	--	--	--	--	--	--	--	4.30E-14	--	--	**4.30E-14**
Eu-149	1.83E-06	--	--	--	--	--	--	--	--	--	**1.83E-06**
Eu-152	7.74E-01	2.09E+01	2.48E+00	9.62E-07	--	--	--	1.61E+01	--	--	**4.02E+01**
Eu-154	6.19E+01	9.66E+00	8.83E+02	8.31E+00	--	8.24E-03	6.64E+00	8.18E+00	8.85E-02	1.69E+00	**9.80E+02**
Eu-155	2.79E+00	2.83E-01	6.07E+02	5.65E+00	--	8.64E-03	4.65E+01	1.28E-01	--	3.71E-02	**6.62E+02**
Fe-55	2.53E+01	2.47E-01	5.14E-02	7.30E+00	1.77E+01	--	1.15E+04	--	--	--	**1.15E+04**
Fe-59	4.13E-12	--	--	--	--	--	--	--	--	--	**4.13E-12**
Fr-221	5.27E-03	7.31E-05	2.11E-04	1.00E-03	--	1.49E-12	3.27E-09	8.69E-01	--	1.70E-05	**8.76E-01**
Fr-223	3.24E-03	--	3.12E-08	5.14E-08	--	2.31E-08	1.41E-05	6.21E-05	--	1.58E-10	**3.31E-03**
Gd-152	6.17E-15	--	8.89E-15	3.92E-20	--	--	--	1.59E-12	--	--	**1.60E-12**
Gd-153	4.51E-03	--	1.96E-07	--	--	--	--	--	--	--	**4.51E-03**
H-3	1.39E+01	5.77E-01	9.76E+02	2.50E-01	9.00E-02	--	1.10E-04	--	1.07E-03	1.85E-01	**9.91E+02**
Hf-175	2.78E-08	--	--	--	--	--	--	--	--	--	**2.78E-08**
Hf-181	9.26E-14	--	--	--	--	--	--	--	--	--	**9.26E-14**
Ho-166m	--	1.43E-10	--	--	--	--	--	--	--	--	**1.43E-10**
I-125	1.29E-08	--	--	--	--	--	--	--	--	--	**1.29E-08**
I-129	9.10E-07	6.85E-05	2.42E-03	2.06E-02	1.51E-05	--	9.22E-02	1.75E-06	--	3.02E-02	**1.46E-01**
In-113m	2.93E-05	--	--	--	--	--	--	--	--	--	**2.93E-05**
In-114	2.72E-11	--	--	--	--	--	--	--	--	--	**2.72E-11**
In-114m	2.84E-11	--	--	--	--	--	--	--	--	--	**2.84E-11**
In-115	2.67E-17	--	--	--	--	--	--	--	--	--	**2.67E-17**
In-115m	1.46E-15	--	--	--	--	--	--	--	--	--	**1.46E-15**
Ir-194	8.15E-03	--	--	--	--	--	--	--	--	--	**8.15E-03**
K-42	2.26E-02	--	--	--	--	--	--	--	--	--	**2.26E-02**
Kr-85	7.45E+01	1.04E+01	4.79E+02	6.09E+00	1.13E+00	1.02E+02	--	--	--	2.49E+00	**6.76E+02**
Lu-177m	3.86E-06	--	--	--	--	--	--	--	--	--	**3.86E-06**
Mn-54	3.93E-01	--	4.83E+01	3.36E-02	--	--	3.52E+03	--	--	--	**3.57E+03**
Mo-93	--	--	1.25E-04	2.11E-02	--	--	--	--	--	--	**2.12E-02**
Na-22	1.25E-02	--	1.86E-04	9.71E-08	--	--	--	9.31E-09	--	--	**1.27E-02**
Nb-91	1.44E-02	--	--	--	--	--	--	--	--	--	**1.44E-02**
Nb-93m	4.20E-01	7.92E-03	3.19E-04	8.24E-03	--	--	--	--	--	--	**4.36E-01**
Nb-94	--	1.32E-08	8.47E-02	4.84E-03	9.00E-03	--	5.65E-01	--	--	--	**6.64E-01**
Nb-95	2.47E-06	--	--	--	--	--	--	--	--	--	**2.47E-06**
Nb-95m	1.32E-08	--	--	--	--	--	--	--	--	--	**1.32E-08**
Nd-144	2.04E-14	--	1.74E-14	5.97E-12	--	1.52E-15	8.87E-12	6.27E-16	--	6.87E-17	**1.49E-11**
Ni-59	1.17E-02	3.35E-01	8.44E-04	9.33E+02	5.91E-02	--	3.45E+02	--	--	1.33E-04	**1.28E+03**
Ni-63	2.74E+01	2.74E+01	3.04E-02	8.57E+00	8.87E+00	--	7.62E+02	--	--	--	**8.35E+02**
Np-235	1.10E-01	--	--	--	--	--	--	--	--	--	**1.10E-01**
Np-237	4.59E-03	5.51E-04	2.21E-01	1.63E-03	8.71E-05	3.48E-05	1.03E-01	2.68E-02	3.32E-06	2.10E+00	**2.46E+00**
Np-238	2.43E-03	--	5.55E-03	1.15E-06	--	--	--	2.18E-05	--	3.67E-04	**8.37E-03**
Np-239	3.04E+00	1.82E-05	3.85E+00	6.89E-04	--	--	1.96E-04	1.10E+00	--	3.50E+00	**1.15E+01**
Np-240	1.04E-19	--	2.79E-09	2.24E-26	--	--	--	4.55E-09	--	1.24E-15	**7.34E-09**

Table 3-11. Total RH Radionuclide Activity (Ci) on a Site Basis Decayed through 2011
Continued

Radionuclide	ANLE	BAPL	Hanford	INL	KAPL-S	LANL	MFC	ORNL	SNL	SRS	Grand Total
Np-240m	8.67E-17	--	2.32E-06	1.87E-23	--	--	--	3.79E-06	--	1.03E-12	**6.12E-06**
Os-185	4.39E-08	--	--	--	--	--	--	--	--	--	**4.39E-08**
Os-194	8.15E-03	--	--	--	--	--	--	--	--	--	**8.15E-03**
Pa-231	3.27E-07	1.22E-04	1.32E-05	1.82E-05	4.52E-09	4.95E-06	9.85E-03	7.22E-03	--	6.43E-08	**1.72E-02**
Pa-233	4.59E-03	1.22E-07	1.05E-01	1.63E-03	--	3.48E-05	1.03E-01	2.68E-02	3.32E-06	2.10E+00	**2.35E+00**
Pa-234	8.72E-05	4.51E-11	1.42E-04	3.13E-04	7.44E-11	5.36E-08	1.09E-02	1.60E-05	--	4.16E-06	**1.14E-02**
Pa-234m	6.71E-02	7.13E-08	1.09E-01	2.41E-01	4.65E-08	4.12E-05	8.36E+00	1.23E-02	--	3.20E-03	**8.79E+00**
Pb-209	5.27E-03	7.31E-05	2.11E-04	1.00E-03	--	1.49E-12	3.27E-09	8.69E-01	--	1.70E-05	**8.76E-01**
Pb-210	8.07E-01	6.28E-09	9.73E-03	1.23E-08	1.09E-10	7.19E-10	8.31E-08	6.97E+00	--	1.03E-08	**7.78E+00**
Pb-211	2.35E-01	--	2.26E-06	3.72E-06	--	1.68E-06	1.02E-03	4.50E-03	--	1.15E-08	**2.41E-01**
Pb-212	2.42E+00	2.66E-02	2.08E-05	3.60E-02	--	8.99E-15	9.98E-14	1.79E+00	--	2.88E-13	**4.28E+00**
Pb-214	3.14E-08	1.06E-08	5.85E-09	1.02E-07	--	3.05E-09	1.07E-06	1.25E+01	--	6.20E-08	**1.25E+01**
Pd-107	2.33E-06	1.93E-07	8.64E-05	--	7.97E-07	--	--	--	--	--	**8.97E-05**
Pm-145	5.16E-01	--	--	--	--	--	--	--	--	--	**5.16E-01**
Pm-146	4.71E-01	--	--	--	--	--	--	--	--	--	**4.71E-01**
Pm-147	3.74E+01	2.59E+00	5.01E+01	4.80E+00	3.64E-03	--	--	2.02E-02	8.00E-02	8.03E-01	**9.57E+01**
Pm-148	8.36E-15	--	--	--	--	--	--	--	--	--	**8.36E-15**
Pm-148m	1.58E-13	--	--	--	--	--	--	--	--	--	**1.58E-13**
Po-210	8.08E-01	6.28E-09	9.73E-03	1.21E-08	--	7.19E-10	8.31E-08	6.97E+00	--	1.03E-08	**7.79E+00**
Po-211	6.47E-04	--	6.22E-09	1.02E-08	--	4.61E-09	2.81E-06	1.24E-05	--	3.15E-11	**6.62E-04**
Po-212	1.55E+00	1.70E-02	1.33E-05	2.31E-02	--	5.76E-15	6.39E-14	1.15E+00	--	1.85E-13	**2.74E+00**
Po-213	5.16E-03	7.15E-05	2.07E-04	9.82E-04	--	1.46E-12	3.20E-09	8.51E-01	--	1.66E-05	**8.57E-01**
Po-214	3.14E-08	1.06E-08	5.85E-09	1.02E-07	--	3.05E-09	1.07E-06	1.25E+01	--	6.19E-08	**1.25E+01**
Po-215	2.35E-01	--	2.26E-06	3.72E-06	--	1.68E-06	1.02E-03	4.50E-03	--	1.15E-08	**2.41E-01**
Po-216	2.42E+00	2.66E-02	2.08E-05	3.60E-02	--	8.99E-15	9.98E-14	1.79E+00	--	2.88E-13	**4.28E+00**
Po-218	3.14E-08	1.06E-08	5.85E-09	1.02E-07	--	3.05E-09	1.07E-06	1.25E+01	--	6.20E-08	**1.25E+01**
Pr-144	1.61E+00	6.53E-10	9.95E-03	2.61E-02	--	6.40E-11	2.85E+01	1.56E-10	--	2.38E-04	**3.01E+01**
Pr-144m	2.25E-02	--	1.39E-04	3.65E-04	--	8.96E-13	3.99E-01	2.18E-12	--	3.33E-06	**4.22E-01**
Pu-236	2.25E-01	--	9.27E-06	6.75E-03	--	--	--	--	--	--	**2.32E-01**
Pu-238	1.41E+02	4.48E+00	1.84E+03	8.07E+02	5.00E-01	1.26E+00	1.02E+01	3.75E+02	3.45E-01	2.21E+03	**5.39E+03**
Pu-239	9.16E+01	3.69E-03	1.88E+03	4.47E+02	7.75E-04	9.37E+01	8.86E+02	2.75E+01	5.96E-01	2.47E+01	**3.45E+03**
Pu-240	5.88E+01	3.93E-04	5.49E+03	2.20E+02	6.24E-04	2.53E+00	3.86E+02	2.56E+01	4.21E-02	8.56E+00	**6.19E+03**
Pu-241	1.32E+03	7.77E-01	1.92E+04	9.43E+01	2.00E-01	2.37E+01	3.31E+01	8.66E+01	4.06E+00	2.04E+03	**2.28E+04**
Pu-242	7.15E-02	6.28E-05	6.44E+03	1.69E-01	3.94E-06	1.52E-03	1.07E-02	8.82E-02	3.60E-05	4.51E-03	**6.44E+03**
Pu-243	6.24E-10	--	1.24E-10	--	--	--	--	6.77E-08	--	1.09E-07	**1.78E-07**
Pu-244	8.68E-17	--	2.33E-06	1.87E-23	8.10E-14	--	--	3.80E-06	--	1.03E-12	**6.12E-06**
Ra-223	2.35E-01	--	2.26E-06	3.72E-06	--	1.68E-06	1.02E-03	4.50E-03	--	1.15E-08	**2.41E-01**
Ra-224	2.42E+00	2.66E-02	2.08E-05	3.60E-02	--	8.99E-15	9.98E-14	1.79E+00	--	2.88E-13	**4.28E+00**
Ra-225	5.27E-03	7.31E-05	2.11E-04	1.00E-03	--	1.49E-12	3.27E-09	8.69E-01	--	1.70E-05	**8.76E-01**
Ra-226	3.14E-08	1.06E-08	6.79E-02	1.02E-07	4.25E-10	3.05E-09	1.07E-06	1.25E+01	--	6.20E-08	**1.26E+01**
Ra-228	2.04E-02	2.07E-06	6.82E-06	4.07E-05	1.89E-12	8.99E-15	1.85E-13	9.93E-03	--	3.95E-13	**3.04E-02**
Rb-87	--	6.77E-10	--	--	--	--	--	--	--	--	**6.77E-10**
Re-188	1.39E-09	--	--	--	--	--	--	--	--	--	**1.39E-09**
Rh-102	6.08E-03	--	--	--	--	--	--	--	--	--	**6.08E-03**
Rh-103m	7.82E-12	--	--	--	--	--	--	--	--	--	**7.82E-12**
Rh-106	4.45E+00	2.12E-08	1.48E-01	8.06E-04	--	9.16E-08	7.07E+00	2.14E-07	--	3.01E-03	**1.17E+01**
Rn-219	2.35E-01	--	2.26E-06	3.72E-06	--	1.68E-06	1.02E-03	4.50E-03	--	1.15E-08	**2.41E-01**
Rn-220	2.42E+00	2.66E-02	2.08E-05	3.60E-02	--	8.99E-15	9.98E-14	1.79E+00	--	2.88E-13	**4.28E+00**

Table 3-11. Total RH Radionuclide Activity (Ci) on a Site Basis Decayed through 2011
Continued

Radionuclide	ANLE	BAPL	Hanford	INL	KAPL-S	LANL	MFC	ORNL	SNL	SRS	Grand Total
Rn-222	3.14E-08	1.06E-08	5.85E-09	1.02E-07	--	3.05E-09	1.07E-06	1.25E+01	--	6.20E-08	**1.25E+01**
Ru-103	7.84E-12	--	--	--	--	--	--	--	--	--	**7.84E-12**
Ru-106	4.45E+00	2.12E-08	1.48E-01	8.06E-04	--	9.16E-08	7.07E+00	2.14E-07	--	3.01E-03	**1.17E+01**
S-35	1.52E-07	--	--	--	--	--	--	--	--	--	**1.52E-07**
Sb-124	1.35E-08	--	--	--	--	--	1.03E-12	--	--	--	**1.35E-08**
Sb-125	2.21E+01	5.08E-02	2.60E+02	1.06E+00	--	4.01E-04	8.53E+00	8.17E-04	--	--	**2.92E+02**
Sb-126	6.00E-06	3.23E-06	1.16E-01	--	--	1.82E-02	--	--	--	--	**1.34E-01**
Sb-126m	4.29E-05	2.31E-05	8.28E-01	--	--	1.30E-01	--	--	--	--	**9.58E-01**
Sc-46	6.78E-07	--	--	--	--	--	--	--	--	--	**6.78E-07**
Se-75	2.18E-05	--	--	--	--	--	--	--	--	--	**2.18E-05**
Se-79	5.45E-06	6.42E-05	1.38E-01	--	4.88E-06	--	--	--	--	8.90E-04	**1.39E-01**
Sm-145	1.65E-02	--	--	--	--	--	--	--	--	--	**1.65E-02**
Sm-146	5.59E-09	--	--	--	--	--	--	--	--	--	**5.59E-09**
Sm-147	1.74E-09	--	1.35E-09	6.17E-09	--	--	--	4.80E-10	--	1.06E-10	**9.84E-09**
Sm-148	1.01E-19	--	8.02E-31	2.90E-35	--	--	--	2.20E-27	--	--	**1.01E-19**
Sm-151	1.85E+00	5.69E-01	3.45E+01	6.90E+00	5.50E-02	1.86E-02	1.33E+00	--	3.41E-02	7.14E-01	**4.60E+01**
Sn-113	2.93E-05	--	--	--	--	--	--	--	--	--	**2.93E-05**
Sn-119m	3.48E-02	--	8.52E-07	--	--	--	--	--	--	--	**3.48E-02**
Sn-121	3.79E-01	2.43E-05	3.07E-04	--	--	4.29E-01	--	--	--	--	**8.09E-01**
Sn-121m	4.89E-01	3.13E-05	3.95E-04	--	1.44E-04	5.53E-01	--	--	--	--	**1.04E+00**
Sn-123	4.52E-04	--	--	--	--	--	--	--	--	--	**4.52E-04**
Sn-126	4.29E-05	2.31E-05	8.28E-01	--	1.59E-05	1.30E-01	--	--	--	--	**9.58E-01**
Sr-85	1.21E-08	--	--	--	--	--	--	--	--	--	**1.21E-08**
Sr-89	5.01E-09	--	--	--	--	--	--	--	--	--	**5.01E-09**
Sr-90	2.37E+03	2.11E+02	1.43E+05	3.77E+04	3.00E+01	5.57E+02	4.59E+04	1.35E+03	1.15E+01	5.04E+01	**2.31E+05**
Ta-182	5.41E-02	--	--	1.02E-15	--	--	--	--	--	--	**5.41E-02**
Tb-157	3.90E-02	--	--	--	--	--	--	--	--	--	**3.90E-02**
Tb-160	2.78E-08	--	--	--	--	--	--	--	--	--	**2.78E-08**
Tc-97m	1.88E-06	--	--	--	--	--	--	--	--	--	**1.88E-06**
Tc-99	6.18E-03	4.55E-02	7.24E+00	7.70E-02	9.00E-03	--	1.61E+00	2.01E-02	--	2.46E-03	**9.00E+00**
Te-121	2.96E-04	--	--	--	--	--	--	--	--	--	**2.96E-04**
Te-121m	2.97E-04	--	--	--	--	--	--	--	--	--	**2.97E-04**
Te-123	6.84E-15	--	--	--	--	--	--	--	--	--	**6.84E-15**
Te-123m	5.47E-05	--	--	--	--	--	--	--	--	--	**5.47E-05**
Te-125m	5.39E+00	7.97E-06	6.25E+01	2.58E-01	--	9.79E-05	2.08E+00	2.00E-04	--	8.95E-15	**7.02E+01**
Te-127	2.37E-04	--	--	--	--	--	--	--	--	--	**2.37E-04**
Te-127m	2.42E-04	--	--	--	--	--	--	--	--	--	**2.42E-04**
Te-129	3.52E-15	--	--	--	--	--	--	--	--	--	**3.52E-15**
Te-129m	5.50E-15	--	--	--	--	--	--	--	--	--	**5.50E-15**
Th-227	2.32E-01	--	2.23E-06	3.67E-06	--	1.65E-06	1.01E-03	4.44E-03	--	1.13E-08	**2.37E-01**
Th-228	2.42E+00	1.42E-02	2.48E-03	3.60E-02	--	8.99E-15	9.98E-14	1.79E+00	--	2.88E-13	**4.26E+00**
Th-229	5.27E-03	7.31E-05	2.11E-04	1.00E-03	4.36E-11	1.49E-12	3.27E-09	8.69E-01	--	1.70E-05	**8.76E-01**
Th-230	1.83E-05	8.88E-07	8.78E-06	5.30E-05	6.35E-08	5.10E-07	6.17E-04	1.37E-03	--	1.75E-05	**2.09E-03**
Th-231	3.86E-03	1.21E-05	4.37E-03	5.85E-02	1.21E-05	8.36E-03	6.65E+01	1.94E-03	--	3.18E-04	**6.65E+01**
Th-232	2.07E-10	2.12E-06	6.68E-05	4.67E-05	1.95E-12	1.29E-14	5.86E-13	1.44E-02	--	9.42E-13	**1.45E-02**
Th-234	6.71E-02	7.13E-08	1.09E-01	2.41E-01	4.65E-08	4.12E-05	8.36E+00	1.23E-02	3.04E-06	3.20E-03	**8.79E+00**
Tl-207	2.34E-01	--	2.26E-06	3.71E-06	--	1.67E-06	1.02E-03	4.49E-03	--	1.14E-08	**2.40E-01**
Tl-208	8.71E-01	9.56E-03	7.48E-06	1.30E-02	--	3.23E-15	3.59E-14	6.44E-01	--	1.04E-13	**1.54E+00**

Table 3-11. Total RH Radionuclide Activity (Ci) on a Site Basis Decayed through 2011
Continued

Radionuclide	ANLE	BAPL	Hanford	INL	KAPL-S	LANL	MFC	ORNL	SNL	SRS	Grand Total
Tl-209	1.11E-04	1.59E-06	4.44E-06	2.11E-05	--	3.14E-14	6.87E-11	1.83E-02	--	3.56E-07	**1.84E-02**
Tm-170	1.46E-05	--	--	--	--	--	--	--	--	--	**1.46E-05**
Tm-171	1.12E-01	--	--	--	--	--	--	--	--	--	**1.12E-01**
U-232	1.50E+00	2.62E-02	1.08E-03	3.56E-02	1.63E-06	--	--	1.78E+00	--	--	**3.34E+00**
U-233	5.40E-03	2.30E-02	6.40E-01	2.78E+00	1.82E-08	1.93E-09	1.45E-05	2.71E+01	1.20E-08	1.86E-02	**3.05E+01**
U-234	7.83E-03	1.52E-03	4.30E-01	1.17E+00	5.76E-04	2.03E-03	8.41E+00	1.11E-01	2.18E-04	1.57E-01	**1.03E+01**
U-235	3.86E-03	1.21E-05	5.35E-03	5.85E-02	1.21E-05	8.36E-03	6.65E+01	1.94E-03	1.22E-05	3.18E-04	**6.65E+01**
U-236	3.62E-05	1.41E-04	1.08E-01	7.25E-04	1.17E-04	1.04E-05	2.23E-03	1.21E-03	5.26E-07	2.21E-03	**1.14E-01**
U-237	3.17E-02	--	3.06E-01	2.26E-03	--	5.67E-04	7.93E-04	2.07E-03	--	4.88E-02	**3.93E-01**
U-238	6.71E-02	7.13E-08	1.11E-01	2.41E-01	4.65E-08	4.12E-05	8.36E+00	1.23E-02	3.04E-06	3.20E-03	**8.79E+00**
U-240	8.67E-17	--	2.32E-06	1.87E-23	--	--	--	3.79E-06	--	1.03E-12	**6.12E-06**
V-49	2.02E-01	--	--	--	--	--	--	--	--	--	**2.02E-01**
W-181	2.75E-06	--	--	--	--	--	--	--	--	--	**2.75E-06**
W-185	1.99E-08	--	--	--	--	--	--	--	--	--	**1.99E-08**
W-188	1.38E-09	--	--	--	--	--	--	--	--	--	**1.38E-09**
Xe-127	1.70E-14	--	--	--	--	--	--	--	--	--	**1.70E-14**
Y-90	2.37E+03	2.11E+02	1.41E+05	3.77E+04	3.00E+01	5.57E+02	4.59E+04	1.35E+03	--	5.04E+01	**2.29E+05**
Y-91	1.58E-07	--	--	--	--	--	--	--	--	--	**1.58E-07**
Zn-65	1.30E-03	--	8.14E-03	--	--	--	--	6.04E-15	--	--	**9.44E-03**
Zr-93	4.82E-05	1.12E-02	6.72E-04	--	1.22E-04	--	--	--	--	--	**1.20E-02**
Zr-95	1.12E-06	--	2.78E-03	--	--	--	--	--	--	--	**2.78E-03**
Grand Total	**1.31E+04**	**9.15E+02**	**7.75E+05**	**1.37E+05**	**1.50E+02**	**2.95E+03**	**2.10E+05**	**8.43E+03**	**6.94E+01**	**5.19E+03**	**1.15E+06**

Data Source: CID Data Version D.11.00 (LANL-CO 2012). Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams.

Table 3-12. Total Activity by Site Decayed through 2011

TRU Waste Site	CH Activity (Ci)	RH Activity (Ci)	Total Activity (Ci)
Argonne National Laboratory - East	3.29E+02	1.31E+04	**1.35E+04**
Bettis Atomic Power Laboratory	--	9.15E+02	**9.15E+02**
Hanford (Richland) Site	7.36E+05	7.75E+05	**1.51E+06**
Idaho National Laboratory	6.94E+04	1.37E+05	**2.06E+05**
Knolls Atomic Power Laboratory - Nuclear Fuel Services	9.26E+03	--	**9.26E+03**
Knolls Atomic Power Laboratory - Schenectady	--	1.50E+02	**1.50E+02**
Lawrence Berkeley National Laboratory	5.51E+00	--	**5.51E+00**
Lawrence Livermore National Laboratory	1.29E+04	--	**1.29E+04**
Los Alamos National Laboratory	3.81E+05	2.95E+03	**3.84E+05**
Material and Fuels Complex	1.16E+03	2.10E+05	**2.11E+05**
Nevada National Security Site	4.80E+02	--	**4.80E+02**
Nuclear Radiation Development Site	3.32E+02	--	**3.32E+02**
Oak Ridge National Laboratory	9.10E+04	8.43E+03	**9.94E+04**
Sandia National Laboratories	2.56E+01	6.94E+01	**9.49E+01**
Savannah River Site	1.56E+05	5.19E+03	**1.61E+05**
Grand Total	**1.46E+06**	**1.15E+06**	**2.61E+06**

Data Source: CID Data Version D.11.00 (LANL-CO 2012). Note: This table contains data for WIPP-bound waste streams only; it does not include data for emplaced or potential waste streams**.**

3.3.2 Radionuclide Changes

Radionuclide activity data improve as additional waste is characterized and emplaced at WIPP. Characterization data were used by the sites for this report that were not available at the time that inventory information was collected for the ATWIR-2011 (DOE 2011). Table 3-13 presents the changes in the total activity between the ATWIR-2011 and this report. For the purpose of this discussion of changes, the activities reported in this table were decayed to WIPP closure in 2033.

As stated earlier, the net change column applies to the total net changes, which include both increases and decreases as reported by the sites and taken from the WDS.

Table 3-13. CH/RH Activity Changes Decayed through 2033

Site	ATWIR-2011 Total Inventory (Ci)	ATWIR-2012 Total Inventory (Ci)	Total Net Change (Ci)
Hanford (Richland) Site	9.44E+05	8.51E+05	-9.30E+04
Idaho National Laboratory	1.55E+05	1.37E+05	-1.84E+04
Los Alamos National Laboratory	2.93E+05	2.62E+05	-3.06E+04
Oak Ridge National Laboratory	1.92E+04	4.22E+04	2.30E+04
Savannah River Site	2.06E+05	1.37E+05	-6.91E+04
Small Quantity Sites	1.78E+05	1.20E+05	-5.83E+04
Anticipated Total	**1.80E+06**	**1.55E+06**	**-2.46E+05**
WIPP (Emplaced)	1.27E+06	1.43E+06	1.56E+05
Grand Total	**3.07E+06**	**2.98E+06**	**-8.98E+04**

Data Source: CID Data Versions D.10.01 (LANL-CO 2011e) and D.11.00 (LANL-CO 2012).

As shown in Table 3-13, the CH- and RH-TRU waste activity reported by the sites has decreased approximately 246,000 Ci. This total decrease is offset with the emplacement of 156,000 Ci at WIPP during CY11, leaving a net decrease at the sites of about 90,000 Ci. The largest contributing waste stream to this net reduction is RL300-08 (RH, Hanford RL), with a reduction of approximately 60,500 Ci stemming from the elimination of their projected waste generation estimate. Almost as significant is LL-M001 (CH, Lawrence Livermore National Laboratory), with a decrease of 55,500 Ci attributed to a radionuclide activity calculation correction by the site. These reductions, among others, are countered by less significant gains in other waste stream inventories to achieve the overall net decrease in activity.

4.0 POTENTIAL TRU WASTE

A waste stream can be designated either “WIPP-bound” or “potential.” All TRU waste must meet all WIPP requirements (e.g., WIPP WAC, WIPP Hazardous Waste Facility Permit WAP) before it can be disposed of at WIPP.

Approximately 12% of the final form TRU waste volume reported by the TRU waste sites during this year’s data collection has been identified as potential TRU waste. While a site may

designate waste streams as potential for many different reasons, it is usually because of regulatory or physical constraints, such as the lack of characterization data. Section 4.1 identifies the reasons waste streams are designated as potential waste streams.

4.1 Categories of Potential TRU Waste

DOE has listed the criteria (Patterson 2010) for categorizing waste streams as potential. Below are the categories for which TRU waste sites would consider a waste stream to be potential TRU waste.

- TRU Determination – Any waste that is categorized as "undetermined" will remain potential until the waste stream has been officially determined to be TRU. If the waste stream is determined to be non-TRU, it will be removed from the inventory.

- Defense Determination – WIPP can only accept TRU waste resulting from defense-related activities, as stated in the WIPP LWA (U.S. Congress 1992 and 1996). Any waste that has an "unknown" defense determination will remain potential until the waste stream has been officially determined to be defense waste. If the waste stream is determined to be non-defense, it will be removed from the inventory.

- Regulatory Restrictions – There are numerous regulatory restrictions that would prevent waste in its current form from coming to WIPP. Examples include limits on curies and dose rates on RH canisters, limits for total emplacement curies on RH waste, prohibited Resource Conservation and Recovery Act (RCRA) hazardous waste, etc. Sites must treat, repackage, or remove any restricted items before such waste can be accepted for disposal at WIPP.

- Incomplete Data – Waste that has missing or incomplete data, such as radionuclide activities, WMP masses, final form container data, or unknown waste stream information, is deemed potential until required data are obtained.

- Directed by DOE to Move to Potential – Waste will be moved to potential at the direction of DOE.

Waste streams categorized as "potential" may become eligible for disposal at WIPP if all requirements, as noted above, are met and the waste meets all WIPP requirements (e.g., WIPP WAC, WIPP Hazardous Waste Facility Permit WAP). Table 4-1 identifies the current potential CH- and RH-TRU waste streams. Table 4-2 identifies waste streams that were moved from potential to WIPP-bound during this reporting period.

Table 4-1. Potential WIPP CH/RH-TRU Waste Streams

Waste Stream ID[1]	Handling	Final Form Anticipated Volume (m^3)	Categories of Potential WIPP CH/RH-TRU Waste
AW-IN-TRA-BE-01	RH	3.12E+01	Regulatory Restrictions
AW-W018	RH	2.67E+00	Regulatory Restrictions

Table 4-1. Potential WIPP CH/RH-TRU Waste Streams
Continued

Waste Stream ID[1]	Handling	Final Form Anticipated Volume (m^3)	Categories of Potential WIPP CH/RH-TRU Waste
AW-W019	RH	8.90E-01	Regulatory Restrictions
BL-Parks	CH	9.62E+00	Incomplete Data
BL-Parks-A	RH	6.24E-01	Incomplete Data
IN-JH826CH	CH	8.32E-01	Incomplete Data
IN-SBW-01A	RH	5.99E+02	TRU Waste Determination
IN-SBW-01B	RH	8.90E+01	TRU Waste Determination
IN-W139	CH	8.32E-01	Incomplete Data
IN-W269	CH	2.41E+01	Incomplete Data
IN-W322	CH	5.67E+00	Defense Determination
IN-W338	CH	1.25E+00	Incomplete Data
IN-W339	CH	1.02E+01	Incomplete Data
IN-W342R	RH	6.24E-01	Defense Determination
IN-W350	CH	2.08E-01	Incomplete Data
IN-W359R	RH	6.24E-01	Incomplete Data
IN-W360	CH	1.89E+00	Regulatory Restrictions
LA-OS-00-04	CH	2.08E-01	Incomplete Data
LA-TA-00-04	CH	2.08E-01	Regulatory Restrictions
LA-TA-03-17	CH	1.89E+01	Incomplete Data
LA-TA-03-21	CH	9.45E+01	Incomplete Data
LA-TA-03-23	CH	6.62E+01	Incomplete Data
LA-TA-03-33	CH	2.08E-01	Incomplete Data
LA-TA-21-11	CH	1.70E+01	Incomplete Data
LA-TA-50-12	CH	9.66E+00	Incomplete Data
LA-TA-50-15	CH	7.56E+00	Regulatory Restrictions
LA-TA-50-20	CH	4.16E-01	Incomplete Data
LA-TRU-Empty	CH	3.21E+01	Incomplete Data
RL300-11	RH	7.49E+00	Regulatory Restrictions
RLCH2-08	RH	2.82E+02	TRU Waste Determination
RLPFP-10	RH	2.31E+01	Incomplete Data
RLPRC-01	CH	1.89E+00	Defense Determination
RP-TFC001	CH	4.39E+02	Directed by DOE to Move to Potential
RP-W754	CH	3.23E+02	Directed by DOE to Move to Potential
RP-W755	CH	7.94E+02	Directed by DOE to Move to Potential
SR-T001-WSB-1	CH	4.51E+03	Incomplete Data

Table 4-1. Potential WIPP CH/RH-TRU Waste Streams
Continued

Waste Stream ID[1]	Handling	Final Form Anticipated Volume (m^3)	Categories of Potential WIPP CH/RH-TRU Waste
SR-W027-773A-HET-CLAS	CH	1.89E+01	Incomplete Data
SR-W027-UNK	CH	3.65E+01	Incomplete Data
WV-M010a	CH	9.45E+00	Directed by DOE to Move to Potential
WV-T004	CH	3.33E+00	Directed by DOE to Move to Potential
WV-T006a	CH	3.25E+02	Directed by DOE to Move to Potential
WV-T006b	RH	3.55E+02	Directed by DOE to Move to Potential
WV-T017b	RH	2.37E+01	Directed by DOE to Move to Potential
WV-W024a	CH	2.92E+01	Directed by DOE to Move to Potential
WV-W024b	RH	9.48E+01	Directed by DOE to Move to Potential
WV-Z001	CH	1.35E+03	Directed by DOE to Move to Potential
Grand Total		**9.66E+03**	

[1]See Figure 1-1 for site designators; Data Source: CID Data Version D.11.00 (LANL-CO 2012).

Table 4-2. Potential to WIPP-Bound Waste Streams

Waste Stream ID[1]	Reason
IN-BN203	Received complete data
IN-W337	Determined to be defense waste
RL221U-01	Regulatory restrictions were resolved (moved into RL221U-03)
SR-W027-221H-HET-B	Received complete data (moved into SR-W027-221H-HET-C)
SR-W027-321-322M-HET	Received complete data (a portion moved into SR-W027-321M-HOM)

[1]See Figure 1-1 for site designators; Data Source: CID Data Version D.11.00 (LANL-CO 2012).

5.0 CONCLUSION

WIPP has been receiving TRU waste since March 26, 1999. As of December 31, 2011, WIPP had received 10,244 shipments of TRU waste (9,708 CH shipments and 536 RH shipments) (DOE 2012). During this reporting period (January through December 2011), 7,192 m^3 of CH-

TRU waste, 39.98 m^3 of RH-TRU waste (DOE 2012), and 4.13 million kg of waste and packaging materials have been emplaced at WIPP, totaling 156,000 curies of activity.

This report is an update to the ATWIR-2011. Like the ATWIR-2011, this report focuses on changes resulting from characterization, improved estimations, and continued waste generation. It also identifies the waste streams that have been moved from the designation of "potential" waste streams to the designation of "WIPP-bound" waste streams. The cutoff date for data collection was December 31, 2011. This report provides current TRU waste inventory information for CBFO, the DOE complex, WIPP stakeholders, and regulators.

This report's appendices include WIPP-bound and potential TRU WPRs, a historic crosswalk of TRU waste streams, and the CBFO screening memorandum (Patterson 2010). These can be found in Appendices A, B, C, and D, respectively.

6.0 GLOSSARY

Acceptable Knowledge – Title 40 CFR 194.2 defines acceptable knowledge as any information about the process used to generate waste, material inputs to the process, and the time period during which the waste was generated, as well as data resulting from the analysis of waste, conducted prior to or separate from the waste certification process authorized by EPA's certification decision, to show compliance with Condition 3 of the certification decision. (U.S. EPA 1996)

Anticipated Inventory – As defined in this report, the sum of the total stored and total projected inventory volumes reported by the TRU waste sites.

Complexing Agents – Organic molecules that are capable of binding to metals. These organic molecules include, but are not limited to, acetate, citrate, oxalate, and EDTA.

Contact-Handled TRU Waste – Packaged TRU waste with an external surface dose rate not greater than 200 millirem (mrem) per hour.

Current Form Waste – The chemical and physical state of waste when it is generated and as it is currently being stored on site.

Defense Waste – (1) Radioactive waste from any activity performed in whole or in part in support of DOE atomic energy defense activities. Excludes waste under the purview of the Nuclear Regulatory Commission or generated by the commercial nuclear power industry. (2) Nuclear waste derived mostly from the manufacturer of nuclear weapons, weapons-related research programs, the operation of naval reactors, and the decontamination of nuclear weapons production facilities.

Department of Energy Site – A DOE-owned or controlled tract used for DOE operations. Either a tract owned by DOE or a tract leased or otherwise made available to the federal government under terms that afford to DOE rights of access and control substantially equal to those that DOE would possess if it were the holder of the fee (or pertinent interest therein) as agent of and on behalf of the government. One or more DOE operations/program activities are carried out within the boundaries of the described tract.

Disposal – Emplacement of waste in a manner that assures isolation from the biosphere for the foreseeable future with no intent of retrieval and that requires deliberate action to regain access to the waste.

Emplaced Inventory – Waste that has been disposed of at WIPP as of the inventory date (December 31, 2011) for this report.

Final Form Waste – Form of waste in approved packaging that will be shipped to and emplaced at WIPP.

Land Withdrawal Act – The 1992 legislation passed by the U.S. Congress as Public Law 102-579, withdrawing the surface land and underlying minerals at the WIPP site from public use, transferring the property from the Bureau of Land Management to DOE, and enabling the start of the WIPP Test Phase. This act was amended in 1996 by Public Law 104-201.

Mixed TRU Waste – TRU waste that contains both radioactive and hazardous components as defined by the Atomic Energy Act (U.S. Congress 1954) and the RCRA as codified in Title 40 CFR 261.3. The RCRA test phase was removed by Public Law 104-201 in the 1996 LWA Amendments.

Oxyanions – Negatively-charged ionic species containing oxygen, such as sulfate, nitrate, and phosphate.

Payload Container Volume – For the purpose of this document, the payload container volume is the volume that the final form package occupies at the time it is emplaced in the repository. An example of payload container volume used in this context is a ten-drum overpack (TDOP) with a volume of 4.50 m^3.

Performance Assessment – PA is an analysis that: (1) identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates are incorporated into an overall probability distribution of cumulative release to the extent practicable.

Performance Assessment Baseline Calculations – A PA run during the recertification that incorporates EPA requested changes. The results of this PA become the WIPP regulatory performance baseline that demonstrates compliance with EPA's radioactive waste containment requirements.

Potential Inventory – For this report, a designation for a waste stream that will not be included in PA calculations. This designation is not intended to identify whether the waste stream may or may not be emplaced at WIPP.

Projected Inventory – That part of the inventory that has not been generated (does not physically exist) but is estimated to be generated at some time in the future by the TRU waste sites. TRU waste in projected waste streams includes waste from programs that have not come on line at this time, as well as waste from ongoing projects and D&D waste that has not yet been packaged.

Radioactive – Term used to refer to an unstable atomic nucleus that decays with the spontaneous emission of ionizing radiation (see also "radionuclide").

Radionuclide – (1) A species of atom having an unstable nucleus that is subject to spontaneous decay or disintegration and usually accompanied by the emission of ionizing radiation. (2) Any nuclide that emits radiation. A nuclide is a species of atom characterized by the constitution of its nucleus and hence by the number of protons, the number of neutrons, and the energy content.

Reacted Cement – Cement that has been hydrated by setting up under aqueous conditions.

Remote-Handled TRU Waste – Packaged TRU waste with an external surface dose rate equal to or exceeding 200 mrem per hour.

Retrievably Stored Waste – Stored waste that includes waste stored in buildings or berms with earthen cover since 1970, but does not include waste buried prior to 1970. Retrievably stored waste also includes waste that is stored in underground storage tanks or ponds.

Stored Inventory – That part of the TRU waste inventory that is currently in retrievable storage as of the data cutoff date for inventory information. Stored inventory can be "current form waste" or "final form waste."

Transuranic – Pertaining to elements that have atomic numbers greater than 92, including neptunium, plutonium, americium, and curium. All are radioactive, are not naturally occurring, and are members of the actinide group.

Transuranic Waste – The LWA definition of transuranic waste is: "Transuranic waste is radioactive waste containing more than 100 nanocuries (3700 becquerels) of alpha-emitting transuranic isotopes per gram of waste, with half lives greater than 20 years, except for: (1) high-level radioactive waste; (2) waste that the Secretary of Energy has determined, with the concurrence of the Administration of the Environmental Protection Agency, does not need the degree of isolation required by 40 CFR Part 191 disposal regulations; (3) waste that the Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61."

TRU Waste Sites – The five major DOE facilities and several smaller sites throughout the U.S. that generate and store TRU waste.

Unreacted Cement – Dry cement that was added as an absorbent or neutralizer to a waste stream, but under dry, non-aqueous conditions.

Waste Acceptance Criteria – The criteria used to determine if waste is acceptable for disposal at WIPP. For the purposes of this document, WAC refers to the WIPP WAC.

Waste Form – The physical form of the waste, such as sludges, combustibles, metals.

Waste Isolation Pilot Plant– The project authorized under Section 213 of the DOE National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (U.S. Congress 1979) to demonstrate the safe and environmentally-sound disposal of radioactive waste materials generated by atomic energy defense activities.

Waste Material Parameter– A non-radiological material that is found in TRU waste. As an example, CPR is monitored as a contributor to the generation of gas at WIPP.

Waste Stream – Waste material generated from a single process or from an activity that is similar in material, physical form, and hazardous constituents.

Waste Stream Profile – A description of a CH- or RH-TRU waste stream that has been designated as WIPP-bound or potential. The waste profile is presented in tabular format and is intended to provide a summary of the important information about a particular waste stream**.**

WIPP-Bound Inventory – For this report, the designation for a waste stream that will be included in performance assessment calculations. This designation is not intended to identify whether or not the waste stream will be emplaced at WIPP.

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APPENDIX A WIPP-BOUND TRU WASTE PROFILE REPORTS

The following waste profile reports contain information on waste streams that are placed in the WIPP-bound category as of the inventory date, December 31, 2011.

The TRU waste sites that have reported WIPP-bound waste streams are:

AE Argonne National Laboratory - East
AW Material and Fuels Complex
BT Bettis Atomic Power Laboratory
IN Idaho National Laboratory
KA Knolls Atomic Power Laboratory - Schenectady
KN Knolls Atomic Power Laboratory - Nuclear Fuel Services
LA Los Alamos National Laboratory
LB Lawrence Berkeley National Laboratory
LL Lawrence Livermore National Laboratory
ND Nuclear Radiation Development Site
NT Nevada National Security Site
OR Oak Ridge National Laboratory
RL Hanford (Richland) Site
SA Sandia National Laboratories
SR Savannah River Site

Waste Stream ID: **AE-T001**

Appendix A

Waste Profile Report

Site	Argonne National Laboratory - East	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ANL-E Contact-Handled Mixed Heterogeneous Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	7.3	66.6	73.8
Box-Misc	5.5	0.0	5.5
Current Form Total	12.8	66.6	79.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	11.0	66.6	77.6
Final Form Total	11.0	66.6	77.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	55.95
Aluminum-based Metal/Alloys	6.31
Other Metal/Alloys	16.93
Other Inorganic Materials	3.47
Cellulosics	4.35
Rubber	5.32
Plastics	46.07
Cement	0.00
Solidified Inorganic Material	1.19
Solidified Organic Material	0.31
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.55E-02
Am-243	1.46E-02
Cm-244	3.18E+00
Cs-137	4.14E-02
Np-237	5.80E-04
Pu-238	2.11E-02
Pu-239	1.41E-01
Pu-240	9.80E-02
Pu-241	2.52E-01
Pu-242	9.25E-05
Pu-244	4.60E-08
Sr-90	3.57E-02
Th-229	4.78E-09
Th-230	4.73E-05
Th-232	5.28E-08
U-233	3.68E-05
U-234	7.83E-05
U-235	1.08E-06
U-236	1.18E-07
U-238	7.10E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D027, D028, D029, D030, D037, F002, F004, F005

TRUCON Code(s)

116/216, 125/225

Waste Stream Description

The debris waste consists primarily of organic and inorganic laboratory debris. Organic debris materials includes paper, cardboard, cloth, (e.g., rags, towels, trays), plastic (e.g., bags, caps, containers, tubing, fittings, filters, sheeting, tape, vials, syringes), rubber (e.g., tubing, gloves. Inorganic debris materials include aluminum items, glass (e.g., bottles, labware, dishes, vials), tools, lead (e.g., scrap, shielding), metal cans, scrap metal (e.g., piping, valves, bolts, clamps, rings, rods, screws, tubing, wire), laboratory equipment (electric motors, pumps, and circuit boards).

Waste Stream ID: **AE-T003**

Appendix A

Waste Profile Report

Site	Argonne National Laboratory - East	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	ANL-E Contact-Handled Solidified Organic and Inorganic Homogenous Solids					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.7	0.0	1.7
Box-Misc	0.5	0.0	0.5
Current Form Total	2.1	0.0	2.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.1	0.0	3.1
Final Form Total	3.1	0.0	3.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	96.32
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	281.63
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.21E-01
Am-243	1.10E-02
Cm-244	3.26E-03
Cs-137	9.24E-02
Np-237	5.93E-04
Pu-238	1.02E+00
Pu-239	5.09E-01
Pu-240	4.71E-01
Pu-241	4.56E+00
Pu-242	4.35E-03
Pu-244	4.34E-08
Sr-90	6.53E-02
Th-229	3.74E-09
Th-230	3.29E-05
Th-232	3.64E-07
U-233	3.83E-05
U-234	2.88E-05
U-235	1.20E-06
U-236	8.50E-07
U-238	2.90E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D027, D028, D029, D030, D037, F002, F004, F005

TRUCON Code(s)

111/211, 113/213, 129/229

Waste Stream Description

Waste stream consists of mixed homogeneous solids generated during the neutralization and solidification of aqueous and inorganic liquids originating from Argonne laboratory and maintenance operations.

Waste Stream ID: **AE-T009**

Appendix A

Waste Profile Report

Site	Argonne National Laboratory - East	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	2.9	17.5	20.5
55-gal Drum Dir Ld w/o Liner	7.7	0.0	7.7
Miscellaneous	8.5	0.0	8.5
Current Form Total	19.1	17.5	36.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 30-gal w/o Liner	3.1	18.0	21.0
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	16.8	0.0	16.8
Final Form Total	19.9	18.0	37.9

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	54.79
Aluminum-based Metal/Alloys	16.54
Other Metal/Alloys	70.80
Other Inorganic Materials	9.61
Cellulosics	0.80
Rubber	8.00
Plastics	18.77
Cement	0.00
Solidified Inorganic Material	9.25
Solidified Organic Material	11.74
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	12.76
Packaging Material, Rubber	0.83
Packaging Material, Steel	1311.55
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	4.06E+00
Am-243	8.04E-02
Cm-244	4.53E+00
Cs-137	8.25E+01
Np-237	1.21E-04
Pu-238	3.73E+00
Pu-239	2.42E+00
Pu-240	1.55E+00
Pu-241	3.49E+01
Pu-242	1.89E-03
Pu-244	2.29E-18
Sr-90	6.25E+01
Th-229	1.39E-04
Th-230	4.82E-07
Th-232	5.48E-12
U-233	1.43E-04
U-234	2.07E-04
U-235	1.02E-04
U-236	9.57E-07
U-238	1.77E-03

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D028, D029, F002, F005

TRUCON Code(s)

321, 322, 325

Waste Stream Description

Waste stream consists of RH TRU debris generated by destructive and nondestructive examination of radiological materials such as fuel pins, reactor structural materials, and targets in waste cans. Some of the wastes are contaminated primarily with fissile materials, mixed fission products (MFP), and activation products. This waste stream consists predominantly of organic and inorganic debris generated during the destructive and nondestructive examinations, and contains the following materials. Cellulosic items including paper, cellophane tape, cardboard, cotton, leather, rags, cloth, towels, grinding paper, boxes, liners, High-Efficiency Particulate Air (HEPA) filter media, filter paper, tissues, string, boxes, rope, swabs, mop heads, and gloves. Wooden items including brooms, mop head and handles, HEPA filter frames, rulers, brushes, blocks, and Masonite, plywood, cork, fiber board, and chipboard items. Plastic materials including polyethylene, polypropylene, polyvinyl chloride, phthalate, Koroseal, Tygon, styrene butadiene, polyurethane, Lucite, Nylon, Teflon, Nalgene, and epoxy (hardened), metallurgical (Bakelite) sample mounts, bottles, cups, dishes, pipettes, tubing, funnels, pipe, bags, filter cartridges, sheeting, vials, tape, syringes, markers, and other miscellaneous items. Rubber items including Neoprene, Viton, butyl,

latex, and silicone O-rings, gaskets, stoppers, hose, tubing, gloves, wire/cord insulation, and other miscellaneous items. Glass items including glass, ceramic, alumina, porcelain, quartz, Pyrex, Vycor, and boron nitrite bottles, jars, tubing, caps, condensers, beakers, flasks, graduated cylinders, Petri dishes, plates, syringes, insulation (fiber glass), firebrick, insulators, light bulbs, thermometers, lenses, and other items. Metal items (ferrous materials), including carbon steel, stainless steel, and cast iron cans, buckets, dies, slings, equipment, tools, tubing, fittings, rods, rings, rounds, chain, saw blades, dustpans, motors, fixtures, heating mantles, hot plates, mortar and pestles, steel wool, manipulator parts and tape, trays, variacs, vessels, capsules, and other miscellaneous scrap items. Non-ferrous metals items including aluminum, brass, bronze, copper, lead, gold,tungsten, tantalum, tin, vanadium, zinc, zirconium, cans (including punctured aerosol cans), cladding, vials, mesh sample holders, sheeting, foils, tools, wire, shot, rods, cable, tubing, capsules, fittings, gaskets, gauges, plates, motors, pumps, samples, solenoid valves, thermocouples, variacs, light fixtures (no PCB ballasts), and other miscellaneous scrap items. In addition to the debris materials described above, waste stream will also contain lesser amounts (less than 50 percent in any container) of homogeneous organic and inorganic materials. Clay and vermiculite based absorbents are used during the neutralization and evaporation of acids, etchants, and solutions generated during the passivation of reactive metals. Solidifications agents such as Acid Bond, Aquaset, Petroset, or Petrobond may also be used to immobilize some liquids. Wastes are visually inspected at packaging to ensure that the waste is compliant per the ANL Acceptable Knowledge document.

Waste Stream ID: **AW-5410N**

Appendix A

Waste Profile Report

Site	Material and Fuels Complex	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU ATR Complex Legacy from Hot-Cell Cleanup					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Steel w/ lead-lined 55-gal drum	2.7	0.0	2.7
Current Form Total	2.7	0.0	2.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Lead Shielded Cntr w/ 1 - 30 gal w/o Liner	0.1	0.0	0.1
Final Form Total	0.1	0.0	0.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	50.62
Aluminum-based Metal/Alloys	16.90
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	8.43
Rubber	0.00
Plastics	8.43
Cement	0.00
Solidified Inorganic Material	7.63
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.60
Packaging Material, Rubber	1.04
Packaging Material, Steel	3619.47
Packaging Material, Lead	3814.16

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.86E-01
Am-243	1.73E-03
Cm-244	1.64E-05
Cs-137	2.44E+00
Np-237	4.35E-05
Pu-238	1.95E-01
Pu-239	5.32E-02
Pu-240	8.01E-02
Pu-241	2.98E+00
Pu-242	2.17E-04
Sr-90	5.16E+00
Th-229	3.32E-14
Th-230	2.82E-10
Th-232	2.34E-19
U-233	3.78E-10
U-234	1.59E-05
U-235	2.74E-06
U-236	4.74E-09
U-238	5.44E-05

No Hazardous Waste Numbers Provided

TRUCON Code(s)

325

Waste Stream Description

Lab debris: fuel examination waste rod pieces (Severe Fuel Damage tests), met mounts, small plastic and metal containers, Tygon tubing, etc.

Waste Stream ID: **AW-5649N**

Appendix A

Waste Profile Report

Site	Material and Fuels Complex	**Summary Category**	S3000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	CH TRU ATR Complex					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	67.79
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.28E-03
Np-237	2.00E-09
Pu-238	3.42E-05
Pu-239	1.18E-02
Pu-240	5.86E-03
Pu-241	8.78E-02
Th-229	1.09E-18
Th-230	4.06E-15
Th-232	3.85E-20
U-233	1.26E-14
U-234	2.93E-10
U-235	3.48E-11
U-236	5.21E-10

No Hazardous Waste Numbers Provided

TRUCON Code(s)

113/213

Waste Stream Description

This waste stream consists of solidified actinide solutions using Aquaset-II.

Waste Stream ID: **AW-5882N**

Appendix A

Waste Profile Report

Site	Material and Fuels Complex	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU INL ATR Complex ARMF Capsules					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	1.24
Other Metal/Alloys	0.00
Other Inorganic Materials	0.14
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.01E-01
Cs-137	3.54E-01
Np-237	4.58E-07
Sr-90	3.50E-01
Th-229	1.41E-15
U-233	6.88E-12
U-235	1.06E+02

No Hazardous Waste Numbers Provided

TRUCON Code(s)

325

Waste Stream Description

ARMF/CRMF encapsulated irradiated fuel examination waste and ATR hot-cell debris.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **AW-N027.531**

Appendix A

Waste Profile Report

Site	Material and Fuels Complex	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	MFC CH-MTRU Due to RCRA Metals					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	4.6	6.0
Current Form Total	1.5	4.6	6.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	1.5	4.6	6.0
Final Form Total	1.5	4.6	6.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	117.45
Aluminum-based Metal/Alloys	3.43
Other Metal/Alloys	9.62
Other Inorganic Materials	74.18
Cellulosics	3.43
Rubber	0.00
Plastics	5.49
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	2.06
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.56E-01
Am-243	1.24E-16
Cm-244	2.61E-10
Cs-137	4.45E-03
Np-237	2.90E-04
Pu-238	2.51E-02
Pu-239	4.35E-01
Pu-240	1.91E-01
Pu-241	9.73E-01
Pu-242	5.27E-05
Sr-90	8.96E-03
Th-229	2.22E-13
Th-230	3.25E-07
Th-232	5.64E-10
U-233	2.52E-09
U-234	9.69E-04
U-235	3.26E-05
U-236	3.51E-06
U-238	3.14E-07

Haz. Waste No(s).

D006, D007, D008

TRUCON Code(s)

125/225

Waste Stream Description

This waste stream is debris generated in the Casting Lab, Analytical Laboratory and Fuel Manufacuring Facility glove boxes. This waste stream consists of miscellaneous generated debris (lead-lined gloves, metals, cellulosics, plastics, water (dried) and/or air filters, crucibles, etc.) contaminated with RCRA-metals (typically cadmium, lead, chromium, silver). The waste is contaminated with activation and fission products and TRU radionuclides.

Waste Stream ID: **AW-T031.1322**

Appendix A

Waste Profile Report

Site	Material and Fuels Complex	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU Hot Cell Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	2.1	13.7	15.7
Canister - (MFC) o/p 45-gal Drums	5.4	269.3	274.7
Liner - RSWF	0.4	0.0	0.4
Current Form Total	7.9	283.0	290.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	6.9	82.4	89.2
Final Form Total	6.9	82.4	89.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	1036.36
Aluminum-based Metal/Alloys	8.03
Other Metal/Alloys	317.94
Other Inorganic Materials	11.60
Cellulosics	9.84
Rubber	0.00
Plastics	10.85
Cement	0.00
Solidified Inorganic Material	1.57
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.58E+00
Am-243	1.19E-10
Cm-244	2.74E-08
Cs-137	3.26E+02
Np-237	1.13E-03
Pu-238	4.05E-02
Pu-239	9.64E+00
Pu-240	4.23E+00
Pu-241	1.87E-01
Pu-242	1.16E-04
Sr-90	5.01E+02
Th-229	1.52E-11
Th-230	6.91E-06
Th-232	5.53E-15
U-233	4.09E-08
U-234	9.39E-02
U-235	5.12E-03
U-236	1.45E-05
U-238	9.37E-02

No Hazardous Waste Numbers Provided

TRUCON Code(s)

325

Waste Stream Description

Fuel Conditioning Facility (FCF), Hot Fuel Examination Facility (HFEF), Analytical Lab (AL) Remote-handled (RH) Radioactive Transuranic Miscellaneous waste: hot-cell laboratory waste, metals, cellulosics, plastics, solidified samples, filters, etc. Stored at Radioactive Scrap and Waste Facility (RSWF). Waste may also include analytical samples, EBR-I waste and small quantities of subassembly hardware.

Waste Stream ID: **AW-T033.1325**

Appendix A

Waste Profile Report

Site	Material and Fuels Complex	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Analytical Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	MFC CH-TRU Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	2.7	27.5	30.2
Current Form Total	2.7	27.5	30.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	2.7	27.5	30.2
Final Form Total	2.7	27.5	30.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	107.74
Aluminum-based Metal/Alloys	24.69
Other Metal/Alloys	45.89
Other Inorganic Materials	88.51
Cellulosics	0.00
Rubber	0.00
Plastics	37.59
Cement	0.00
Solidified Inorganic Material	6.99
Solidified Organic Material	19.45
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.69E+00
Am-243	4.09E-03
Cm-244	2.91E-02
Cs-137	2.27E-04
Np-237	1.78E-03
Pu-238	3.10E-02
Pu-239	6.82E-01
Pu-240	1.68E-01
Pu-241	3.45E+01
Pu-242	3.02E-05
Sr-90	7.16E-04
Th-229	1.37E-12
Th-230	9.83E-08
Th-232	8.68E-12
U-233	1.55E-08
U-234	2.97E-04
U-235	7.98E-06
U-236	1.67E-06
U-238	5.97E-07

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Transuranic debris waste generated from Casting Laboratory (CL), formerly known as Plutonium Casting Lab (PCL) and the Experimental Fuels Lab (EFL), Fuel Manufacturing Facility (FMF) and Analytical Laboratory (AL) Hot cell operations. This waste is typically packaged in 55-gallon drums.

Waste Stream ID: **AW-W020.13**

Appendix A

Waste Profile Report

Site	Material and Fuels Complex	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH MTRU Hot Cell Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
45-gal Drum	0.2	11.2	11.4
Liner - RSWF	0.6	0.0	0.6
Current Form Total	0.8	11.2	12.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	1.2	13.7	15.0
Final Form Total	1.2	13.7	15.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	1094.84
Aluminum-based Metal/Alloys	8.09
Other Metal/Alloys	21.73
Other Inorganic Materials	41.03
Cellulosics	19.82
Rubber	0.00
Plastics	25.76
Cement	0.00
Solidified Inorganic Material	8.15
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.02E-01
Cs-137	1.13E+02
Np-237	1.93E-04
Pu-238	4.39E-01
Pu-239	1.72E+00
Pu-240	5.38E-01
Pu-241	1.07E+00
Pu-242	2.38E-05
Sr-90	7.98E+01
Th-229	1.28E-10
Th-230	3.95E-08
Th-232	6.17E-15
U-233	7.27E-07
U-234	2.15E-03
U-235	1.22E-04
U-236	6.26E-05
U-238	2.42E-04

Haz. Waste No(s).

D006, D007, D008, D009

TRUCON Code(s)

325

Waste Stream Description

This waste stream consists of miscellaneous FCF, HFEF and AL generated debris (metals, cellulosics, plastics, water (dried) and/or air filters, crucibles, etc.)

Waste Stream ID: **BT-T001**

Appendix A

Waste Profile Report

Site	Bettis Atomic Power Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Irradiated TRU material waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Hot Cell	0.0	4.9	4.9
Current Form Total	0.0	4.9	4.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	0.0	5.0	5.0
Final Form Total	0.0	5.0	5.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	297.28
Other Inorganic Materials	0.00
Cellulosics	49.68
Rubber	0.00
Plastics	148.64
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.80E-02
Am-243	7.73E-05
Cm-244	8.29E-05
Cs-137	4.23E+01
Np-237	1.10E-04
Pu-238	8.97E-01
Pu-239	7.39E-04
Pu-240	7.87E-05
Pu-241	1.56E-01
Pu-242	1.26E-05
Sr-90	4.23E+01
Th-229	1.46E-05
Th-230	1.78E-07
Th-232	4.25E-07
U-233	4.61E-03
U-234	3.04E-04
U-235	2.42E-06
U-236	2.82E-05
U-238	1.43E-08

No Hazardous Waste Numbers Provided

TRUCON Code(s)

322

Waste Stream Description

Specimen processing fines, material, and debris.

Waste Stream ID: **IN-AE-AGHC-02**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	MFC Retrievable ANL-E RH TRU Containers - Stage 2					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum	8.5	0.0	8.5
Canister - (ANL-E)	2.1	0.0	2.1
Current Form Total	10.6	0.0	10.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	156.0	0.0	156.0
Final Form Total	156.0	0.0	156.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	38.55
Aluminum-based Metal/Alloys	2.62
Other Metal/Alloys	3.97
Other Inorganic Materials	2.62
Cellulosics	4.76
Rubber	0.87
Plastics	7.25
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.12
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Cs-137	1.00E+02
Pu-239	2.72E+00
Pu-240	1.36E+00
Sr-90	1.54E+02
Th-230	1.16E-12
Th-232	5.65E-08
U-234	1.68E-08
U-235	2.86E-04
U-236	6.03E-07
U-238	3.99E-04

Haz. Waste No(s).

D004, D006, D007, D008, D009, D010, D011, D019, D028, D029, F002, F005

TRUCON Code(s)

321, 322, 325

Waste Stream Description

The Stage 2 waste originally consisted of 48 ANL-E Canisters filled with combustible and non-combustible scrap, recoverable and non-recoverable fissile material, bonded clad material, irradiated structural material, grinding papers, fuel fines, fuel pin pieces, and fuel impregnated with epoxy, from the destructive examination of irradiated fuel pins in the Alpha-Gamma Hot Cell at ANL-E. The contents of 13 ANL-E canisters has been repacked into 41 55-gallon drums. One canister, ANLE44, is noted to have a single 2R inner container, that contains 39 whole elements.

Waste Stream ID: **IN-AE-AGHC-02T**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Noncompliant Waste segregated From Waste stream IN-AE-AGHC-02 during repackaging.					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum	0.8	0.0	0.8
Current Form Total	0.8	0.0	0.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	1.2	0.0	1.2
Final Form Total	1.2	0.0	1.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	48.19
Aluminum-based Metal/Alloys	3.28
Other Metal/Alloys	4.96
Other Inorganic Materials	3.28
Cellulosics	5.95
Rubber	1.09
Plastics	9.06
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.15
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Cs-137	1.31E+02
Pu-239	3.55E+00
Pu-240	1.77E+00
Sr-90	2.01E+02
Th-230	1.51E-12
Th-232	7.36E-08
U-234	2.19E-08
U-235	3.73E-04
U-236	7.86E-07
U-238	5.20E-04

Haz. Waste No(s).

D004, D006, D007, D008, D009, D010, D011, D019, D028, D029, F002, F005

TRUCON Code(s)

321, 322, 325

Waste Stream Description

This waste stream consists of four 55 gallon drums . The waste contained in these four drums had experienced spontaneous combustion during waste sorting and repackaging operations. The waste in these drums was generated at ANL-E during destructive examination of the irradiated fuel pins and mostly contains fuel pieces and fines. In response to the spontaneous combustion Met-L-X was added to extinguish the fire and Sodium Carbonate was added to prevent further reactions. The waste will be treated in future for meeting WIPP disposition requirements.

Waste Stream ID: **IN-AECHDM-PK**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Waste from ANL-E Maintenance and Lab Operations					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2576.92
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	35.10
Other Inorganic Materials	932.69
Cellulosics	200.00
Rubber	29.81
Plastics	1018.27
Cement	0.00
Solidified Inorganic Material	10.58
Solidified Organic Material	23.08
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.30E+01
Am-243	6.18E-04
Cs-137	7.25E-02
Np-237	1.90E-03
Pu-238	7.50E-01
Pu-239	9.28E+00
Pu-240	3.35E+00
Pu-241	2.89E+01
Pu-242	2.47E-04
Sr-90	7.25E-02
U-234	8.89E-04
U-235	2.03E-05
U-238	4.65E-03

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D027, D028, D029, D030, D037, F002, F004, F005

TRUCON Code(s)

116/216, 125/225

Waste Stream Description

Waste stream ID-AECHDM-PK consists of repackaged mixed heterogeneous debris generated during laboratory and maintenance operations at Argonne.

Waste Stream ID: **IN-BN004**

Appendix A
Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Special Setups Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	228.6	0.0	228.6
Box - Misc	3.2	0.0	3.2
Current Form Total	231.8	0.0	231.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	548.1	0.0	548.1
Final Form Total	548.1	0.0	548.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.02
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.04
Other Inorganic Materials	2.43
Cellulosics	0.03
Rubber	0.01
Plastics	0.22
Cement	280.97
Solidified Inorganic Material	180.62
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.12E-01
Cs-137	1.22E-08
Np-237	1.92E-05
Pu-238	4.43E-02
Pu-239	1.15E+00
Pu-240	2.60E-01
Pu-241	1.68E+00
Pu-242	2.75E-05
Sr-90	1.33E-08
Th-229	1.46E-14
Th-230	2.14E-10
Th-232	7.58E-19
U-233	1.66E-10
U-234	1.18E-05
U-235	1.74E-06
U-236	1.54E-08
U-238	9.46E-05

Haz. Waste No(s).

D006, D007, D008, D011, D029, F001, F002, F005, F006, F007, F009

TRUCON Code(s)

111/211

Waste Stream Description

IN-BN004 (Special Setups) waste was generated from a waste treatment process that solidified process waste (predominately laboratory waste) generated in support of plutonium operations at Rocky Flats. Resins and electrochemical milling sludges were also solidified with the liquid waste. This waste stream is comprised of solidified waste assigned IDC ID-RF-004, ID-RF-744 and ID-RF-802. ID-RF-744 is used to identify special setups retrieved from the INL Subsurface Disposal Area (SDA) Pits 11 and 12.

Waste Stream ID: **IN-BN050**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Solidified Solutions					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	185.10
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	2.75
Cellulosics	123.56
Rubber	0.00
Plastics	1.64
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Np-237	3.33E-04
Pu-239	1.20E-01
Th-229	3.07E-11
U-233	3.17E-08
U-235	2.60E-09

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream is from Bettis Atomic Power Laboratory. No more information is available, but the waste is thought to be solidified inorganic solutions.

Waste Stream ID: **IN-BN090**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Spill Clean-ups/Emergency Response Actions	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Dirt					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	228.6	0.0	228.6
Current Form Total	228.6	0.0	228.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	544.3	0.0	544.3
Final Form Total	544.3	0.0	544.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.85
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	6.65
Cellulosics	3.45
Rubber	0.00
Plastics	0.36
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.24
Soils	463.19
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.47E-03
Cs-137	2.43E-08
Np-237	6.45E-08
Pu-238	8.68E-04
Pu-239	1.57E-02
Pu-240	3.59E-03
Pu-241	2.02E-02
Pu-242	3.07E-07
Sr-90	2.66E-08
Th-229	4.79E-17
Th-230	2.23E-11
Th-232	1.05E-20
U-233	5.49E-13
U-234	1.21E-06
U-235	2.97E-07
U-236	2.12E-10
U-238	4.42E-06

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste generated at the Rocky Flats Plant consists of dry dirt or soil generated from cleanup of spills, leaks, etc. Waste may be damp and may include evaporator pond sludge (S3000). Waste may also contain limited amounts (<50% by volume) of combustibles such as coveralls and gloves.

Waste Stream ID: **IN-BN095**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Pollution Control or Waste Treatment Process	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	Sewer Sludge					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	93.0	0.0	93.0
Box - Misc	25.4	0.0	25.4
Current Form Total	118.3	0.0	118.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	236.3	0.0	236.3
Final Form Total	236.3	0.0	236.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.53
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	46.14
Solidified Inorganic Material	250.58
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.62E-03
Cs-137	1.80E-08
Np-237	5.98E-09
Pu-238	8.81E-05
Pu-239	3.09E-03
Pu-240	6.86E-04
Pu-241	6.01E-03
Pu-242	8.91E-08
Sr-90	1.96E-08
Th-229	5.94E-18
Th-230	9.68E-11
Th-232	8.02E-21
U-233	5.07E-14
U-234	2.63E-06
U-235	6.50E-07
U-236	8.12E-11
U-238	9.75E-06

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at the Rocky Flats Plant, consists of moist to dry sewer sludge generated from cleaning the stabilization ponds at the Sewer Treatment Plant

Waste Stream ID: **IN-BN203**

Appendix A
Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Paper, Cloth, Metal, Glass					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	5.4	0.0	5.4
Bin - Misc	21.0	0.0	21.0
Current Form Total	26.4	0.0	26.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
TDOP w/ 10 - 55-gal Drums w/ Liners	72.0	0.0	72.0
Final Form Total	72.0	0.0	72.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.01
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	17.13
Packaging Material, Rubber	0.44
Packaging Material, Steel	231.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.07E-01
Cs-137	1.82E-08
Np-237	3.03E-06
Pu-238	1.45E-02
Pu-239	2.41E-01
Pu-240	5.82E-02
Pu-241	4.75E-01
Pu-242	6.72E-06
Sr-90	2.00E-08
Th-229	5.77E-16
Th-230	1.81E-10
Th-232	4.25E-20
U-233	1.31E-11
U-234	1.97E-05
U-235	6.13E-06
U-236	1.72E-09
U-238	1.04E-05

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011, F001, F002, F003

No TRUCON Codes Provided

Waste Stream Description

This waste stream was generated by D&D activities at the Battelle Columbus Laboratory. It consists of a mixture of combustible and non-combustible items in roughly equal weights. The combustible wastes are primarily paper and plastic products and the non-combustible wastes are primarily metal with some glass.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-BN204**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Solidified Solutions					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
Current Form Total	1.5	0.0	1.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	3.8	0.0	3.8
Final Form Total	3.8	0.0	3.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	196.75
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	199.14
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.37E-02
Cs-137	8.27E-08
Np-237	6.69E-06
Pu-238	1.37E+00
Pu-239	9.50E-02
Pu-240	2.67E-02
Pu-241	1.97E-01
Pu-242	1.83E-05
Sr-90	9.06E-08
Th-229	1.15E-14
Th-230	2.60E-10
Th-232	1.76E-19
U-233	8.70E-11
U-234	1.53E-05
U-235	1.06E-06
U-236	2.37E-09
U-238	8.50E-15

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste comes from Battelle Columbus Labs. It is a turco soap decontamination solution (used to decontaminate glove boxes from a Pu lab) which is solidified in plaster-of-paris.

Waste Stream ID: **IN-BN222**

Appendix A
Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Pollution Control or Waste Treatment Process	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Solidified Plutonium Recovery Incinerator Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	86.7	0.0	86.7
Current Form Total	86.7	0.0	86.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/o Liners	207.9	0.0	207.9
Final Form Total	207.9	0.0	207.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	4.50
Aluminum-based Metal/Alloys	0.02
Other Metal/Alloys	0.14
Other Inorganic Materials	1.81
Cellulosics	0.02
Rubber	0.04
Plastics	13.32
Cement	82.74
Solidified Inorganic Material	97.16
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.94E-01
Cs-137	2.88E-09
Np-237	2.38E-04
Pu-238	1.56E-01
Pu-239	4.02E+00
Pu-240	9.14E-01
Pu-241	6.63E+00
Pu-242	7.08E-05
Sr-90	3.15E-09
Th-229	4.09E-13
Th-230	3.55E-11
Th-232	6.01E-18
U-233	3.10E-09
U-234	1.95E-06
U-235	1.75E-07
U-236	8.12E-08
U-238	1.94E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, F001, F002, F005, F006, F007, F009

TRUCON Code(s)

111/211, 114/214

Waste Stream Description

The waste is comprised of plutonium recovery incinerator waste. This waste stream includes solidified ash from the incinerator burn chamber and solidified soot and scrubber sludge from the incinerator off-gas system of the plutonium recovery incinerator. Although individual drums may also contain small amounts of debris (PPE, plastic, metal, glass, cement bags, Ful-Flo filters, unburned feed material and broken plastic molds) each container in this waste stream will contain >50% by volume solidified homogeneous solids. The IN-BN222 waste stream includes IDCs ID-RF-292, ID-RF-807b/696, ID-RF-818, and ID-RF-820.

Waste Stream ID: **IN-BN290**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Filter Sludge					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
Current Form Total	1.5	0.0	1.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
TDOP w/ 10 - 55-gal Drums w/ Liners	4.5	0.0	4.5
Final Form Total	4.5	0.0	4.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	12.20
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	22.44
Cellulosics	0.00
Rubber	0.00
Plastics	4.47
Cement	0.00
Solidified Inorganic Material	111.56
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	17.13
Packaging Material, Rubber	0.44
Packaging Material, Steel	231.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.64E-01
Np-237	3.81E-06
Pu-238	7.98E-02
Pu-239	1.92E+00
Pu-240	4.25E-01
Pu-241	1.88E+00
Pu-242	3.16E-05
Th-229	7.15E-16
Th-230	1.04E-12
Th-232	3.11E-19
U-233	1.63E-11
U-234	2.26E-07
U-235	1.89E-09
U-236	1.26E-08
U-238	4.90E-15

Haz. Waste No(s).

D006, D008, F001, F002

No TRUCON Codes Provided

Waste Stream Description

This waste stream was generated by the Rocky Flats Plant and consists of sludge generated from the incinerator off-gas system associated with the plutonium recovery operations in Building 771.

Waste Stream ID: **IN-BN311**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Process Heels					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	13.1	0.0	13.1
Box - Misc	3.2	0.0	3.2
Current Form Total	16.3	0.0	16.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
TDOP w/ 10 - 55-gal Drums w/ Liners	36.0	0.0	36.0
Final Form Total	36.0	0.0	36.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	1.02
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.33
Other Inorganic Materials	91.67
Cellulosics	0.00
Rubber	0.00
Plastics	19.67
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	17.13
Packaging Material, Rubber	0.44
Packaging Material, Steel	231.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.98E+00
Np-237	2.26E-05
Pu-238	6.19E-01
Pu-239	1.05E+01
Pu-240	2.46E+00
Pu-241	1.21E+01
Pu-242	1.93E-04
Th-229	2.89E-13
Th-230	6.82E-10
Th-232	1.46E-16
U-233	7.65E-10
U-234	1.63E-05
U-235	9.30E-08
U-236	6.56E-07
U-238	2.69E-13

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at the RFETS, consists of miscellaneous residues generated by laboratory operations, plutonium recovery, and R&D activities. This waste stream is comprised of IDCs ID-RF-311, ID-RF-361, and ID-RF-393

Waste Stream ID: **IN-BN375**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Oil-Dri-Residue From Incinerator					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.0	0.0	4.0
Current Form Total	4.0	0.0	4.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	9.5	0.0	9.5
Final Form Total	9.5	0.0	9.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	7.08
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.89
Other Inorganic Materials	137.57
Cellulosics	1.83
Rubber	0.04
Plastics	7.84
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.50E-01
Cs-137	1.09E-08
Np-237	4.21E-06
Pu-238	2.33E-02
Pu-239	6.31E-01
Pu-240	1.48E-01
Pu-241	7.74E-01
Pu-242	1.34E-05
Sr-90	1.23E-08
Th-229	1.79E-14
Th-230	1.33E-11
Th-232	2.70E-18
U-233	8.36E-11
U-234	4.54E-07
U-235	4.18E-08
U-236	2.19E-08
U-238	1.04E-14

Haz. Waste No(s).

F001, F002

TRUCON Code(s)

122/222

Waste Stream Description

This waste, from the Rocky Flats Plant, consists of spent clay absorbent materials such as oil-dri, floor dry, vermiculite, and sorbent booms. Waste may also contain <50% by volume debris (i.e., rags).

Waste Stream ID: **IN-BN409**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Salt Waste			**Inventory Date**	12/31/2011
Stream Name	Chloride Salts					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	16.6	0.0	16.6
Current Form Total	16.6	0.0	16.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
TDOP w/ 10 - 55-gal Drums w/ Liners	40.5	0.0	40.5
Final Form Total	40.5	0.0	40.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	11.46
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.61
Other Inorganic Materials	105.68
Cellulosics	0.77
Rubber	0.00
Plastics	5.90
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	17.13
Packaging Material, Rubber	0.44
Packaging Material, Steel	231.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.06E+00
Cs-137	1.62E-07
Np-237	5.07E-05
Pu-238	3.04E-01
Pu-239	6.24E+00
Pu-240	1.44E+00
Pu-241	9.10E+00
Pu-242	2.00E-04
Sr-90	1.78E-07
Th-229	8.06E-14
Th-230	3.72E-11
Th-232	9.48E-18
U-233	6.23E-10
U-234	2.65E-06
U-235	3.14E-08
U-236	1.28E-07
U-238	9.29E-14

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at the RFETS, includes spent salts generated by production and experimental pyrochemical operations used to recover and purify plutonium metal. This waste stream is comprised of IDCs ID-RF-409, ID-RF-410, ID-RF-411, ID-RF-412, and ID-RF-414

Waste Stream ID: **IN-BN421**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Uncemented Ash/Soot					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	31.4	0.0	31.4
Current Form Total	31.4	0.0	31.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
TDOP w/ 10 - 55-gal Drums w/ Liners	72.0	0.0	72.0
Final Form Total	72.0	0.0	72.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	9.74
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.17
Other Inorganic Materials	133.47
Cellulosics	0.00
Rubber	0.00
Plastics	18.89
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	17.13
Packaging Material, Rubber	0.44
Packaging Material, Steel	231.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.08E+00
Cs-137	6.63E-08
Np-237	5.83E-05
Pu-238	9.92E-01
Pu-239	1.57E+01
Pu-240	3.62E+00
Pu-241	1.89E+01
Pu-242	3.25E-04
Sr-90	7.28E-08
Th-229	3.60E-13
Th-230	5.49E-10
Th-232	9.52E-17
U-233	1.40E-09
U-234	1.85E-05
U-235	4.30E-07
U-236	6.43E-07
U-238	4.19E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, F001, F002, F005

TRUCON Code(s)

114/214

Waste Stream Description

This waste stream includes ash materials generated from the treatment of plutonium-containing combustible materials that were generated during plutonium production and recovery operations at Rocky Flats. The ash materials include incinerator ash (IDC RF-420), incinerator ash heels (IDC RF-421), and incinerator soot (IDC RF-422).

Waste Stream ID: **IN-BN425**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Fluid Bed Ash					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.7	0.0	1.7
Current Form Total	1.7	0.0	1.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
TDOP w/ 10 - 55-gal Drums w/ Liners	4.5	0.0	4.5
Final Form Total	4.5	0.0	4.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.49
Cellulosics	0.00
Rubber	0.00
Plastics	1.37
Cement	0.00
Solidified Inorganic Material	262.22
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	17.13
Packaging Material, Rubber	0.44
Packaging Material, Steel	231.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.29E-04
Np-237	1.56E-10
Pu-238	1.60E-04
Pu-239	5.70E-03
Pu-240	1.27E-03
Pu-241	9.76E-03
Pu-242	1.66E-07
Th-229	2.52E-19
Th-230	1.31E-10
Th-232	4.53E-20
U-233	1.61E-15
U-234	2.03E-06
U-235	2.79E-07
U-236	2.62E-10
U-238	1.91E-05

Haz. Waste No(s).

D007, F005

TRUCON Code(s)

114/214

Waste Stream Description

This waste consists of fluidized bed ash which is a fine powder generated by the fluid bed incinerator (FBI) .

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-BN430**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Combustible Waste			**Inventory Date**	12/31/2011
Stream Name	Unleached Ion Column Resin					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	6.0	0.0	6.0
Current Form Total	6.0	0.0	6.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
TDOP w/ 10 - 55-gal Drums w/o Liners	18.0	0.0	18.0
Final Form Total	18.0	0.0	18.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	12.83
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.99
Cellulosics	0.00
Rubber	0.00
Plastics	148.89
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.44
Packaging Material, Steel	231.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.00E-01
Cs-137	9.30E-08
Np-237	6.48E-06
Pu-238	1.08E-01
Pu-239	3.18E+00
Pu-240	7.11E-01
Pu-241	3.17E+00
Pu-242	5.30E-05
Sr-90	1.02E-07
Th-229	4.73E-15
Th-230	5.68E-12
Th-232	2.08E-18
U-233	5.45E-11
U-234	6.17E-07
U-235	6.27E-09
U-236	4.21E-08
U-238	1.65E-14

No Hazardous Waste Numbers Provided

TRUCON Code(s)

126/226

Waste Stream Description

This waste, generated at the Rocky Flats Plant, consists of anionic and cationic exchange resins used in the purification and recovery of plutonium and americium, respectively. The resins were not rinsed with water or leached with nitric acid and are uncemented . After 1972, the resins were leached, cemented and assigned IDC 432 and after August 1986 the cemented resins were assigned to IDC 806.

Waste Stream ID: **IN-BN431**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Combustible Waste			**Inventory Date**	12/31/2011
Stream Name	Leached Resin					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.2	0.0	1.2
Current Form Total	1.2	0.0	1.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	3.8	0.0	3.8
Final Form Total	3.8	0.0	3.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	12.62
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.98
Cellulosics	0.00
Rubber	0.00
Plastics	146.83
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.70E-01
Np-237	3.57E-04
Pu-238	1.19E-01
Pu-239	2.78E+00
Pu-240	6.42E-01
Pu-241	2.64E+00
Pu-242	4.75E-05
Th-229	6.84E-14
Th-230	1.56E-12
Th-232	4.69E-19
U-233	1.56E-09
U-234	3.38E-07
U-235	2.74E-09
U-236	1.90E-08
U-238	7.38E-15

No Hazardous Waste Numbers Provided

TRUCON Code(s)

126/226

Waste Stream Description

This waste, generated at the Rocky Flats Plant, consists of spent anionic and cationic exchange resins used in the purification and recovery of plutonium and americium, respectively. The resins were leached with nitric acid then rinsed and are uncemented. After 1972, leached resins were cemented and assigned IDC 432.

Waste Stream ID: **IN-BN432**

Appendix A
Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	Solidified Ion Exchange Resin from Actinide Recovery					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	65.1	0.0	65.1
Current Form Total	65.1	0.0	65.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
TDOP w/ 10 - 55-gal Drums w/ Liners	144.0	0.0	144.0
Final Form Total	144.0	0.0	144.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	9.17
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	11.67
Other Inorganic Materials	7.78
Cellulosics	0.43
Rubber	0.00
Plastics	13.40
Cement	90.28
Solidified Inorganic Material	0.00
Solidified Organic Material	105.56
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	17.13
Packaging Material, Rubber	0.44
Packaging Material, Steel	231.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.22E+01
Cs-137	3.71E-06
Np-237	6.14E-05
Pu-238	1.70E-01
Pu-239	3.86E+00
Pu-240	8.82E-01
Pu-241	5.52E+00
Pu-242	7.63E-05
Sr-90	4.06E-06
Th-229	1.02E-08
Th-230	7.46E-11
Th-232	1.61E-17
U-233	2.33E-05
U-234	2.83E-06
U-235	1.46E-07
U-236	1.31E-07
U-238	5.92E-14

Haz. Waste No(s).

D007, D008, D022, D029, F001, F002, F005

TRUCON Code(s)

126/226

Waste Stream Description

This waste stream consists of spent anionic and cationic exchange resins used in the actinide purification and recovery processes at the RFP. Spent ion exchange resins are polystyrene and divinylbenzene copolymers. The resins were leached with nitric acid, rinsed with water and solidified with Portland cement. This waste stream is comprised of IDCs ID-RF-432, and ID-RF-822

Waste Stream ID: **IN-BN510**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Supercompacted Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
100-gal Drum Dir Ld w/o Liner	57.2	0.0	57.2
Current Form Total	57.2	0.0	57.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
100-gal Drum Dir Ld w/o Liner	57.2	0.0	57.2
Final Form Total	57.2	0.0	57.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	321.35
Aluminum-based Metal/Alloys	2.53
Other Metal/Alloys	5.53
Other Inorganic Materials	28.69
Cellulosics	196.94
Rubber	6.28
Plastics	119.98
Cement	0.00
Solidified Inorganic Material	0.07
Solidified Organic Material	0.00
Soils	0.07
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.31
Packaging Material, Steel	113.72
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.75E-01
Am-243	6.52E-08
Cm-244	2.13E-04
Cs-137	9.73E-08
Np-237	1.10E-05
Pu-238	1.68E-01
Pu-239	1.12E+00
Pu-240	2.43E-01
Pu-241	1.60E+00
Pu-242	2.24E-05
Sr-90	1.74E-07
Th-229	2.92E-09
Th-230	3.99E-09
Th-232	2.84E-18
U-233	8.30E-06
U-234	1.10E-04
U-235	1.01E-04
U-236	2.87E-08
U-238	3.34E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, D028, D029, F001, F002, F005, F006, F007, F009

TRUCON Code(s)

121/221

Waste Stream Description

BN510 is a debris waste stream generated from supercompacted 55-gallon containers of debris waste.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-BN510.1**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Supercompacted Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	6429.5	0.0	6429.5
Bin - Misc	406.0	0.0	406.0
Box - Misc	3360.2	0.0	3360.2
Current Form Total	10195.7	0.0	10195.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
100-gal Drum Dir Ld w/o Liner	4754.9	0.0	4754.9
SWB Dir Ld w/o Liner	18.9	0.0	18.9
Final Form Total	4773.8	0.0	4773.8

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	16.73
Aluminum-based Metal/Alloys	0.03
Other Metal/Alloys	0.32
Other Inorganic Materials	0.44
Cellulosics	2.98
Rubber	0.17
Plastics	1.94
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.31
Packaging Material, Steel	113.88
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	1.05E-02
Am-243	1.68E-11
Cs-137	9.78E-10
Np-237	1.65E-07
Pu-238	5.84E-02
Pu-239	1.83E-02
Pu-240	3.88E-03
Pu-241	2.57E-02
Pu-242	4.23E-07
Sr-90	1.08E-09
U-233	5.37E-07
U-234	6.31E-08
U-235	1.86E-08
U-238	1.11E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, D027, D028, D029, D030, D034, D037, D043, F001, F002, F004, F005, F006, F007, F009

TRUCON Code(s)

121/221

Waste Stream Description

BN510.1 is a debris waste stream generated from supercompacted 55-gallon containers of debris waste.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-BN600**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	AMWTP WMF-676 PCB Contaminated Debris (BN600)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	5.4	149.6	155.0
Current Form Total	5.4	149.6	155.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	5.4	149.6	155.0
Final Form Total	5.4	149.6	155.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	909.76
Aluminum-based Metal/Alloys	1.43
Other Metal/Alloys	21.45
Other Inorganic Materials	43.08
Cellulosics	128.14
Rubber	0.00
Plastics	236.69
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.11
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.57E-02
Np-237	2.22E-06
Pu-238	2.48E-02
Pu-239	4.47E-01
Pu-240	1.02E-01
Pu-241	5.69E-01
Pu-242	8.71E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, D027, D028, D029, D030, D032, D034, D037, D043, F001, F002, F004, F005, F006, F007, F009

TRUCON Code(s)

125/225

Waste Stream Description

AMWTP WMF-676 PCB contaminated debris is generated as a result of removing and/or treating prohibited PCB waste within the AMWTF WMF-676 north and south box lines and the drummed waste packaging glovebox (DWPG) and special-case waste (SCW) areas.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-BN806**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Solidified Process Solids					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	8.5	0.0	8.5
Current Form Total	8.5	0.0	8.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	20.8	0.0	20.8
Final Form Total	20.8	0.0	20.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.31
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.12
Cellulosics	0.02
Rubber	0.04
Plastics	3.21
Cement	97.16
Solidified Inorganic Material	114.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.23E-01
Cs-137	1.29E-08
Np-237	3.63E-06
Pu-238	6.57E-02
Pu-239	1.52E+00
Pu-240	3.47E-01
Pu-241	2.45E+00
Pu-242	2.50E-05
Sr-90	1.40E-08
Th-229	2.27E-14
Th-230	3.16E-11
Th-232	9.13E-18
U-233	8.77E-11
U-234	1.14E-06
U-235	8.97E-09
U-236	6.17E-08
U-238	2.32E-14

Haz. Waste No(s).

D008, F001, F002, F003, F005

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at Rocky Flats includes all inorganic particulate and inorganic sludge that is immobilized into a solid with Portland Cement. Each waste type was preconditioned (neutralized, thickened) with Portland cement.Cemented wastes were cast into 1-gallon molds allowed to cure. The cured "pucks" were removed from the molds in the form of a solid monolith.

Waste Stream ID: **IN-BN811**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Pollution Control or Waste Treatment Process	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Evaporator and Dissolver Sludge					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.8	0.0	0.8
Current Form Total	0.8	0.0	0.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	3.8	0.0	3.8
Final Form Total	3.8	0.0	3.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	1.29
Aluminum-based Metal/Alloys	1.51
Other Metal/Alloys	0.00
Other Inorganic Materials	0.75
Cellulosics	4.60
Rubber	2.75
Plastics	4.68
Cement	0.00
Solidified Inorganic Material	48.14
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.95E-02
Np-237	3.66E-06
Pu-238	2.03E+01
Pu-239	4.40E-02
Pu-240	2.62E-02
Pu-241	8.19E-02
Pu-242	2.83E-05
Th-229	2.98E-13
Th-230	1.44E-07
Th-232	9.28E-18
U-233	3.19E-10
U-234	1.38E-03
U-235	9.54E-10
U-236	1.71E-08
U-238	5.98E-05

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

"This waste stream, generated at Mound Laboratory, consists of dry evaporator and dissolver sludge in the form of powder or sand-like particles.

Waste Stream ID: **IN-BN817**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Cemented Sand, Slag, Crucible Heels					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	5.6	0.0	5.6
Current Form Total	5.6	0.0	5.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	15.1	0.0	15.1
Final Form Total	15.1	0.0	15.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.06
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.01
Cellulosics	0.00
Rubber	0.00
Plastics	3.26
Cement	123.02
Solidified Inorganic Material	144.84
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.51E-01
Np-237	2.67E-06
Pu-238	5.14E-02
Pu-239	1.15E+00
Pu-240	2.62E-01
Pu-241	1.78E+00
Pu-242	1.85E-05
Th-229	2.27E-14
Th-230	3.39E-11
Th-232	9.39E-18
U-233	7.52E-11
U-234	1.04E-06
U-235	7.91E-09
U-236	5.44E-08
U-238	2.01E-14

Haz. Waste No(s).

D007

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at Rocky Flats consists of the remaining insoluable residues general following plutonium leaching and hot nitric acid. After leaching, the insoluable solution residue (heel) was collected on a filter and dried on a hotplate. The waste was preconditioned (neutralized, thickened), and portland cement was added. Cemented wastes were cast into 1-gallon molds and allowed to cure. The cured "pucks" were removed from the molds in the form of a solid monolith.

Waste Stream ID: **IN-BN823**

Appendix A
Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Cemented Miscellaneous Sludge					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.7	0.0	3.7
Current Form Total	3.7	0.0	3.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	9.5	0.0	9.5
Final Form Total	9.5	0.0	9.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.24
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	3.16
Cement	104.87
Solidified Inorganic Material	122.75
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.15E-03
Np-237	2.87E-02
Pu-238	1.40E-03
Pu-239	2.53E-02
Pu-240	5.79E-03
Pu-241	4.18E-02
Pu-242	6.35E-07
Th-229	2.65E-10
Th-230	9.21E-13
Th-232	2.07E-19
U-233	8.61E-07
U-234	2.84E-08
U-235	1.74E-10
U-236	1.20E-09
U-238	6.89E-16

Haz. Waste No(s).

D008, F001, F002, F003

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at Rocky Flats includes all inorganic sludge that is immobilized into a solid with Portland Cement. Each waste type was preconditioned (neutralized, thickened) with Portland Cement. Cemented wastes were cast into 1-gallon molds allowed to cure. The cured "pucks" were removed from the molds in the form of a solid monolith.

Waste Stream ID: **IN-BN835**

Appendix A
Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Solidified Acid/Caustic Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	31.0	0.0	31.0
Current Form Total	31.0	0.0	31.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	75.6	0.0	75.6
Final Form Total	75.6	0.0	75.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.02
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.06
Cellulosics	5.51
Rubber	0.02
Plastics	0.26
Cement	0.00
Solidified Inorganic Material	239.42
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.89E-02
Cs-137	2.67E-08
Np-237	3.69E-06
Pu-238	2.53E+00
Pu-239	4.09E-03
Pu-240	2.60E-03
Pu-241	8.15E-03
Pu-242	2.90E-06
Sr-90	2.92E-08
Th-229	1.09E-14
Th-230	5.39E-10
Th-232	3.04E-20
U-233	6.23E-11
U-234	2.91E-05
U-235	2.04E-09
U-236	3.08E-10
U-238	1.26E-06

Haz. Waste No(s).

D007, D008, D009, F001, F002

TRUCON Code(s)

111/211

Waste Stream Description

IN-BN835 waste stream consists of drums containing solidified acid (IDC 834) and caustic (IDC 835) wastes combined with nonhazardous absorbent. This waste stream was generated from pressed plutonium oxides sphere or plutonium molybdenum cermet production, isotope recovery, cleaning or leaching of items and construction of standards. Acidic and caustic waste was commingled during the wastewater treatment process. This waste stream consists of waste that is primarily inorganic particulate absorbent materials (>50% by volume) including absorbed aqueous liquids, if present.

Waste Stream ID: **IN-BN836**

Appendix A
Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Pollution Control or Waste Treatment Process	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Cemented Sludge					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	64.3	0.0	64.3
Current Form Total	64.3	0.0	64.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	153.1	0.0	153.1
Final Form Total	153.1	0.0	153.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.01
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.01
Other Inorganic Materials	0.23
Cellulosics	0.12
Rubber	0.00
Plastics	0.05
Cement	232.54
Solidified Inorganic Material	306.36
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.89E-03
Cs-137	5.29E-06
Np-237	8.68E-07
Pu-238	7.85E-02
Pu-239	2.86E-03
Pu-240	7.78E-04
Pu-241	5.55E-03
Pu-242	1.92E-07
Sr-90	5.78E-06
Th-229	1.49E-15
Th-230	1.16E-11
Th-232	5.12E-21
U-233	1.13E-11
U-234	7.57E-07
U-235	1.05E-08
U-236	6.91E-11
U-238	4.32E-09

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, F001, F002, F005

TRUCON Code(s)

111/211

Waste Stream Description

IN-BN836 consists of drums containing Mound cemented sludge (IDC 836). The sludge was generated from the treatment of alpha-contaminated wastewaters at the Waste Disposal Building. The wastewater originated outside process gloveboxes from sources such as floor drains, laboratory sinks, and sumps, as well as the old alpha waste line. The wastewaters were generated from decontamination, laundry, research and analytical operations. IN-BN836 consists of >50% by volume sludge from a wastewater treatment process that was solidified with Portland Cement. Florco, a non-hazardous absorbent, may have also been added to this waste stream.

Waste Stream ID: **IN-BN842**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Contaminated Soil					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Box - Misc	123.6	0.0	123.6
Current Form Total	123.8	0.0	123.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	77.5	0.0	77.5
Final Form Total	77.5	0.0	77.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	34.59
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.35E-04
Np-237	1.41E-09
Pu-238	1.96E+00
Pu-239	1.08E-01
Pu-240	1.72E-04
Pu-241	5.44E-03
Pu-242	1.51E-07
Th-229	2.48E-17
Th-230	1.38E-08
Th-232	6.08E-20
U-233	4.88E-14
U-234	1.33E-04
U-235	2.35E-09
U-236	1.12E-10
U-238	5.14E-16

Haz. Waste No(s).

D006, D007, D008, D009, D010, D011

No TRUCON Codes Provided

Waste Stream Description

This waste, generated at Mound Laboratories, consists of soil, including small rocks and pebbles, generated from cleanup of a leak. All soil waste was dry when packaged. A few waste boxes also include picks, shovels, metal cans, rubber gloves, booties, respirators, plastic, and possibly an air hammer and chisel. Soils waste was packaged in small, plastic lined plywood boxes (42 x 20 x 39 inchs) other waste was then placed on top of the soil before the box was sealed. Four of the small boxes were then packaged in a standard larger waste box (4 x 4 x 7 feet) lined with fiberglass-reinforced polyester. Assay was performed using radiochemical analysis on core samples taken from the contaminated area.

Waste Stream ID: **IN-BN976**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Bldg. 776 Process Sludge					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
Box - Misc	63.4	0.0	63.4
Current Form Total	64.9	0.0	64.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	52.9	0.0	52.9
Final Form Total	52.9	0.0	52.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	1.02
Cellulosics	0.00
Rubber	0.00
Plastics	0.22
Cement	0.02
Solidified Inorganic Material	264.55
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.77E+00
Cs-137	2.12E-07
Np-237	2.44E-05
Pu-238	2.72E-01
Pu-239	7.15E+00
Pu-240	1.65E+00
Pu-241	7.49E+00
Pu-242	1.36E-04
Sr-90	2.31E-07
Th-229	1.06E-13
Th-230	5.92E-10
Th-232	3.01E-17
U-233	4.90E-10
U-234	1.48E-05
U-235	1.97E-06
U-236	2.44E-07
U-238	5.61E-05

Haz. Waste No(s).

D006, D007, D008, D009, D022, D028, F001, F002, F003

No TRUCON Codes Provided

Waste Stream Description

This waste is from Rocky Flats and consists of sludge from floor drains in a Pu process facility that have been cemented in portland. The cement is described as a poor grade. Also may be laundry sludges, material contents given are for an organic laundry sludge.

Waste Stream ID: **IN-BN978**

Appendix A
Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Laundry Sludge					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Misc	34.9	0.0	34.9
Current Form Total	34.9	0.0	34.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
TDOP w/ 10 - 55-gal Drums w/ Liners	22.5	0.0	22.5
Final Form Total	22.5	0.0	22.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	2.96
Other Inorganic Materials	30.25
Cellulosics	30.25
Rubber	40.10
Plastics	8.18
Cement	268.45
Solidified Inorganic Material	402.68
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	17.13
Packaging Material, Rubber	0.44
Packaging Material, Steel	231.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.91E-03
Np-237	7.78E-09
Pu-238	5.84E-04
Pu-239	2.15E-02
Pu-240	4.78E-03
Pu-241	3.07E-02
Pu-242	6.21E-07
Th-229	1.20E-17
Th-230	3.32E-10
Th-232	8.72E-20
U-233	8.21E-14
U-234	7.22E-06
U-235	1.53E-06
U-236	7.07E-10
U-238	4.01E-05

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste consists of sludge (lint, spent detergent, dirt, and other similar waste) mixed with Portland cement generated by laundry operations. The sludge was removed from two laundry tanks located north of Building 776. Both tanks collected liquid effluent from the laundry in Building 776.

Waste Stream ID: **IN-BNINW216**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Pollution Control or Waste Treatment Process	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	First/Second Stage Sludge					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2576.3	0.0	2576.3
Box - Misc	22.2	0.0	22.2
Current Form Total	2598.5	0.0	2598.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	6152.0	0.0	6152.0
Final Form Total	6152.0	0.0	6152.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.05
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.07
Other Inorganic Materials	3.82
Cellulosics	0.03
Rubber	0.02
Plastics	0.34
Cement	46.98
Solidified Inorganic Material	347.86
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.00E+00
Am-243	8.26E-09
Cs-137	1.83E-08
Np-237	4.96E-05
Pu-238	2.63E-02
Pu-239	3.41E-01
Pu-240	8.67E-02
Pu-241	9.52E-01
Pu-242	2.75E-05
Sr-90	2.00E-08
Th-229	3.67E-14
Th-230	3.71E-10
Th-232	2.53E-19
U-233	4.21E-10
U-234	2.03E-05
U-235	4.13E-06
U-236	5.14E-09
U-238	1.16E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, F001, F002, F003, F005, F006, F007, F009

TRUCON Code(s)

111/211, 132/232

Waste Stream Description

IN-BNINW216 (aqueous sludge wastes from Building 774) were generated from a carrier precipitation and immobilization process (sludge mixed with diatomite and Portland Cement) The First/Second Sludge waste stream is comprised of IDCs ID-RF-001. ID-RF-002, ID-RF-741. ID-RF-742 and ID-RF-800. ID-RF-741 and ID-RF-742 are used to identify first and second stage sludge drums retrieved from the INL Subsurface Disposal Area (SDA) Pits 11 and 12 prior to 1979. The First/Second Sludge waste stream consists of >50% by volume secondary sludge or filter cake from wastewater treatment processes or heavy metal sludges from recovery processes. Two waste matrix codes have been assigned to this waste stream because the immobilization process for this waste stream was changed in 1986. Prior to 1986 the first/second stage sludge was placed into a drum with Portland Cement. The excess liquid was immobilized but a solid monolith was not formed. Subsequent to 1986 the sludge was co-fed into a drum with a diatomite and Portland cement mixture, which formed a solid monolith after curing.

Waste Stream ID: **IN-BNINW218**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Building 374 Sludge					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	216.9	0.0	216.9
Box - Misc	6.3	0.0	6.3
Current Form Total	223.3	0.0	223.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	521.6	0.0	521.6
Final Form Total	521.6	0.0	521.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.02
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	23.77
Cellulosics	0.00
Rubber	0.01
Plastics	2.17
Cement	24.15
Solidified Inorganic Material	362.32
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.91E-02
Cs-137	3.65E-09
Np-237	2.16E-05
Pu-238	1.15E-02
Pu-239	2.07E-02
Pu-240	4.38E-03
Pu-241	3.08E-02
Pu-242	6.74E-07
Sr-90	3.98E-09
Th-229	1.99E-13
Th-230	1.74E-08
Th-232	1.57E-19
U-233	6.47E-10
U-234	2.70E-04
U-235	2.42E-05
U-236	9.07E-10
U-238	3.19E-03

Haz. Waste No(s).

D006, D007, D008, D009, D010, D011, D032, F001, F002, F005, F006, F007, F009

TRUCON Code(s)

111/211

Waste Stream Description

The Building 374 Sludge waste stream (BNINW218) consists of two waste matrix codes because the cementation immobilization process for this waste stream was changed in the 1986-1987 timeframe. The feed streams to the process did not change over time. Waste matrix code S3121, Waste Water Treatment Sludge (DC 007 and IDC 807) was secondary sludge or filtercake from waste water treatment processes or heavy metal sludge resulting from recovery. Waste matrix code S3150, Solidified Homogeneous Solids (IDC 803) were from a direct cementation process. The aqueous sludge wastes from Building 374 were immobilized with cement and cured into a solidified form.

Waste Stream ID: **IN-ID-BTO-030**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Solidified Waste Sludge from Bettis Atomic Power Lab.					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum	0.8	0.0	0.8
Current Form Total	0.8	0.0	0.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	1.2	0.0	1.2
Final Form Total	1.2	0.0	1.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	89.74
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	1.50
Other Inorganic Materials	0.13
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	53.51
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.28E-03
Am-243	5.52E-04
Cs-137	3.35E+01
Np-237	5.82E-04
Pu-238	4.50E+00
Pu-239	4.95E-03
Pu-240	4.99E-03
Pu-242	4.82E-05
Sr-90	3.19E+01
Th-229	2.30E-04
Th-230	3.48E-08
Th-232	1.18E-05
U-233	1.14E-01
U-234	3.20E-04
U-235	6.39E-05
U-236	3.40E-09
U-238	1.72E-13

Haz. Waste No(s).

D004, D005, D006, D007, D008, D010, D011, D039, D040, F002

TRUCON Code(s)

327

Waste Stream Description

This waste stream consists of predominantly inorganic waste materials generated during sectioning of fuel elements, grinding, mounting and polishing of metallographic specimens solidified in concrete matrix and placed in IN-41 containers (5 in dia. x16 in long). Thirteen of these IN-41 containers were shipped from BAPL to ANL-W where IN-41 containers were placed in HFEF-5 liners (6 ft. tall x 12 in dia.). The HFEF-5 liners were sent to RWMC for interim storage in 1988. The HFEF liners have been retrieved and repackaged into 4-55 gallon drums for characterization and shipment to WIPP.

Waste Stream ID: **IN-ID-EBR-S5000**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Uncategorized Metal Waste			**Inventory Date**	12/31/2011
Stream Name	RH-TRU Debris Waste From Experimental Breeder Reactor					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum	4.4	0.0	4.4
Current Form Total	4.4	0.0	4.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	4.4	0.0	4.4
Final Form Total	4.4	0.0	4.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	3.66
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	77.84
Other Inorganic Materials	0.00
Cellulosics	0.46
Rubber	0.00
Plastics	0.82
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Cs-137	4.79E-02
Pu-239	2.55E-01
Sr-90	5.17E-02
Th-230	3.36E-06
U-234	2.44E-02
U-235	1.13E-03
U-238	2.45E-02

No Hazardous Waste Numbers Provided

TRUCON Code(s)

321, 322, 325

Waste Stream Description

Waste stream consists of waste generated from decommissioning the EBR-1 reactor after 12 years of operation. The debris consists of the reactor outer blanket components composed of natural uranium clad with stainless steel

Waste Stream ID: **IN-ID-INL-152**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH-TRU Debris Waste From Materials and Fuels Complex Hot Fuel Examination Facility at the INL.					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum	0.4	0.0	0.4
Current Form Total	0.4	0.0	0.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	55.17
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	3.06
Other Inorganic Materials	1.23
Cellulosics	13.26
Rubber	1.02
Plastics	15.29
Cement	0.00
Solidified Inorganic Material	1.02
Solidified Organic Material	0.09
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Cs-137	2.65E+01
Np-237	1.35E-06
Pu-239	3.69E-01
Pu-240	1.43E-01
Sr-90	2.43E+01
Th-229	7.63E-06
Th-230	2.57E-13
Th-232	2.32E-06
U-233	3.77E-03
U-234	2.43E-09
U-235	1.49E-04
U-236	9.74E-08
U-238	3.76E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D038, F002, F005

TRUCON Code(s)

321, 322, 325

Waste Stream Description

This waste stream consists of 2-55 gallon drums repackaged from 1 insert (12 in Diax6 ft. tall). 2-55-gallon drums will be placed in a RH TRU Removable Lid Canister with one dunnage drum.

Waste Stream ID: **IN-ID-INL-152M**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH-TRU Debris Waste From Materials and Fuels Complex Hot Fuel Examination Facility at the INL.					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum	16.4	0.0	16.4
HFEF-5 RH Insert	0.1	0.0	0.1
Current Form Total	16.6	0.0	16.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	16.8	0.0	16.8
Final Form Total	16.8	0.0	16.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	47.88
Aluminum-based Metal/Alloys	0.88
Other Metal/Alloys	2.65
Other Inorganic Materials	10.62
Cellulosics	11.52
Rubber	0.89
Plastics	13.25
Cement	0.00
Solidified Inorganic Material	0.89
Solidified Organic Material	0.08
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.91E-01
Am-243	1.07E-12
Cm-244	1.01E-01
Cs-137	1.02E+02
Np-237	5.27E-05
Pu-238	3.45E-01
Pu-239	8.17E-01
Pu-240	2.59E-01
Pu-241	8.78E-01
Pu-242	9.85E-03
Pu-244	1.11E-24
Sr-90	1.01E+02
Th-229	1.21E-06
Th-230	6.77E-07
Th-232	1.28E-06
U-233	9.15E-04
U-234	4.92E-03
U-235	3.65E-04
U-236	3.74E-05
U-238	4.20E-03

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D038, F002, F005

TRUCON Code(s)

321, 322, 325

Waste Stream Description

This waste stream consists of 1 HFEF insert (12 in. Dia. x 6 ft. tall) and 79 55-gallon drums. Three 55-gallon will be placed in a RH TRU Removable Lid Canister for transport to WIPP. Some of the containers in this waste stream have hazardous waste codes applied by the generator.

Waste Stream ID: **IN-ID-MFC-S5400**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	MFC generated debris waste (Leaded Gloves)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Current Form Total	0.6	0.0	0.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	280.45
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.28E-02
Cs-137	1.14E-05
Np-237	1.60E-06
Pu-238	2.54E-03
Pu-239	8.03E-02
Pu-240	1.80E-02
Pu-241	1.44E-01
Pu-242	2.80E-06
Sr-90	1.26E-05
U-234	1.41E-05
U-235	3.78E-07

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225, 127/227, 154

Waste Stream Description

Heterogeneous debris from plutonium alloy casting operations and analytical laboratory operations conducted in the MFC Analytical Laboratory. Originally generated from the MFC and were repackaged at INTEC in Building CPP-659.

Waste Stream ID: **IN-ID-MFC-SOLID**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Analytical Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	RH-TRU Waste From Materials and Fuels Complex at the INL.					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum	0.8	0.0	0.8
Current Form Total	0.8	0.0	0.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	1.2	0.0	1.2
Final Form Total	1.2	0.0	1.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	59.29
Aluminum-based Metal/Alloys	12.22
Other Metal/Alloys	0.26
Other Inorganic Materials	0.30
Cellulosics	4.63
Rubber	0.00
Plastics	13.29
Cement	0.00
Solidified Inorganic Material	17.90
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Cs-137	3.45E+01
Pu-239	2.35E-01
Pu-240	1.41E-01
Sr-90	3.61E+01
Th-230	2.63E-13
Th-232	2.32E-17
U-234	3.81E-09
U-235	4.36E-04
U-236	6.27E-08
U-238	9.05E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D038, F002, F005

TRUCON Code(s)

311

Waste Stream Description

This waste stream consists of 4 55-gallon drums of repackaged waste form 24-inch diameter by 148-inch long carbon steel liners each containing one 1-litre bottle of solidified sample solution from Analytical Laboratory hot cells.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-ID-RF-S3114**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	Organic Setups					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1619.5	0.0	1619.5
Box - Misc	38.0	0.0	38.0
Current Form Total	1657.5	0.0	1657.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	268.4	0.0	268.4
TDOP w/ 10 - 55-gal Drums w/ Liners	3280.5	0.0	3280.5
Final Form Total	3548.9	0.0	3548.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	1.45
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.21
Other Inorganic Materials	2.35
Cellulosics	0.02
Rubber	0.14
Plastics	1.24
Cement	0.00
Solidified Inorganic Material	0.05
Solidified Organic Material	126.23
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	17.07
Packaging Material, Rubber	0.44
Packaging Material, Steel	229.60
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.62E-03
Am-243	8.85E-10
Cs-137	2.33E-09
Np-237	1.20E-07
Pu-238	7.17E-04
Pu-239	2.46E-02
Pu-240	4.93E-03
Pu-241	3.99E-02
Pu-242	4.88E-07
Sr-90	1.78E-08
Th-229	3.40E-16
Th-230	2.35E-11
Th-232	5.76E-20
U-233	1.96E-12
U-234	6.43E-07
U-235	2.07E-08
U-236	5.84E-10
U-238	9.24E-07

Haz. Waste No(s).

D022, D026, D027, D028, D029, D030, D032, D034, D036, D037, F001, F002, F005

TRUCON Code(s)

112/212, 154

Waste Stream Description

This waste consists of various organic liquids that were transferred to Building 774 where they were immobilized using Micro-cel E (a synthetic calcium silicate) to form a grease or paste-like material. The organic liquids were primarily a mixture of oils and chlorinated solvents. Small amounts of Oil-Dri were sometimes added to the mixture as well. This process was shutdown in 1985 and replaced by the OASIS process.

Waste Stream ID: **IN-ID-RF-S3150-A**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	Organic and Sludge Imobilization System Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	25.6	0.0	25.6
Current Form Total	25.6	0.0	25.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	24.6	0.0	24.6
TDOP w/ 10 - 55-gal Drums w/ Liners	36.0	0.0	36.0
Final Form Total	60.6	0.0	60.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.19
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	70.50
Other Inorganic Materials	16.49
Cellulosics	0.00
Rubber	6.48
Plastics	12.17
Cement	2.82
Solidified Inorganic Material	0.00
Solidified Organic Material	2477.82
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.79
Packaging Material, Rubber	0.44
Packaging Material, Steel	223.00
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.09E-01
Cs-137	2.06E-07
Np-237	1.17E-05
Pu-238	8.00E-02
Pu-239	2.07E+00
Pu-240	4.41E-01
Pu-241	3.71E+00
Pu-242	3.61E-05
Sr-90	2.25E-07
Th-229	5.25E-14
Th-230	1.77E-09
Th-232	8.06E-18
U-233	2.42E-10
U-234	3.91E-05
U-235	1.26E-06
U-236	6.53E-08
U-238	3.71E-06

Haz. Waste No(s).

D022, D028, D029, D030, D032, D034, D036, D043, F001, F002, F005

TRUCON Code(s)

112/212, 154

Waste Stream Description

This waste consists of various organic liquids immobilized into a solid monolith by the Organic and Sludge Immobilization System (OASIS) in Building 774.Oil and chlorinated solvent mixtures were the primary liquids treated by OASIS. The organic liquids were immobilized by mixing water, Envirostone emulsifier, accelerator, and gypsum cement. The emulsifier was a polyethylene glycol ether, and the accelerator contained gypsum and potassium sulfate. This waste may also include small amounts of metal and plastic wastes.

Waste Stream ID: **IN-ID-RF-S5126**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Graphite Waste			**Inventory Date**	12/31/2011
Stream Name	Rocky Flats Transuranic Graphite Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	17.5	0.0	17.5
Current Form Total	17.5	0.0	17.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	39.7	0.0	39.7
Final Form Total	39.7	0.0	39.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2.83
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.19
Other Inorganic Materials	1470.72
Cellulosics	33.90
Rubber	0.31
Plastics	29.82
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.42E+00
Cs-137	2.11E-07
Np-237	4.86E-05
Pu-238	5.95E-01
Pu-239	1.78E+01
Pu-240	4.07E+00
Pu-241	2.56E+01
Pu-242	3.32E-04
Sr-90	2.31E-07
Th-229	1.80E-06
Th-230	4.16E-10
Th-232	7.43E-17
U-233	4.10E-03
U-234	1.33E-05
U-235	2.37E-07
U-236	6.02E-07
U-238	2.21E-05

Haz. Waste No(s).

D008, D029, F001, F002, F005

TRUCON Code(s)

115/215, 154

Waste Stream Description

Waste Stream IN-ID-RF-S5126 is comprised of graphite generated by production, recovery, laboratory, size reduction, and research and development activities associated with plutonium operations at Rocky Flats. .

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-ID-RF-S5300-A**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Combustible Waste			**Inventory Date**	12/31/2011
Stream Name	Rocky Flats Combustibles and Plastic Stored at INL					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2939.7	0.0	2939.7
Current Form Total	2939.7	0.0	2939.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	340.2	0.0	340.2
TDOP w/ 10 - 55-gal Drums w/ Liners	6354.0	0.0	6354.0
Final Form Total	6694.2	0.0	6694.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	1.78
Aluminum-based Metal/Alloys	0.08
Other Metal/Alloys	0.19
Other Inorganic Materials	2.63
Cellulosics	23.24
Rubber	2.03
Plastics	20.02
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	17.09
Packaging Material, Rubber	0.44
Packaging Material, Steel	230.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.12E-03
Am-243	1.90E-12
Cm-244	5.65E-05
Cs-137	2.34E-09
Np-237	5.03E-07
Pu-238	9.32E-04
Pu-239	3.12E-02
Pu-240	6.97E-03
Pu-241	3.80E-02
Pu-242	6.03E-07
Sr-90	2.56E-09
Th-229	1.70E-08
Th-230	1.11E-10
Th-232	1.27E-19
U-233	3.86E-05
U-234	2.43E-06
U-235	7.64E-08
U-236	1.03E-09
U-238	1.10E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, D028, D029, F001, F002, F005, F006, F007, F009

TRUCON Code(s)

116/216, 154

Waste Stream Description

Waste stream ID-RF-S5300-A is comprised of combustible and plastic waste items assigned Item IDCs 330, 336, and 337. Contains greater than 80% (by volume), organic combustible and plastic debris

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-ID-SA-T001**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	LRRI CH TRU stored at SNL shipped to AMWTP					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.7	0.0	3.7
Current Form Total	3.7	0.0	3.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.7	0.0	3.7
Final Form Total	3.7	0.0	3.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	69.87
Aluminum-based Metal/Alloys	2.03
Other Metal/Alloys	3.93
Other Inorganic Materials	12.93
Cellulosics	1.28
Rubber	1.92
Plastics	18.43
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.87E-02
Cm-244	5.68E-03
Cs-137	1.11E-08
Np-237	1.05E-06
Pu-238	1.61E+00
Pu-239	2.33E-01
Pu-240	2.04E-02
Pu-241	5.79E-02
Pu-242	6.56E-07
Sr-90	1.11E-08
U-234	5.78E-05
U-235	1.83E-06
U-238	1.77E-04

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011, D019, F005

TRUCON Code(s)

125/225

Waste Stream Description

This waste stream consists of combustible and noncombustible debris waste generated from the preparation of aerosols of TRU isotopes for inhalation studies. The waste includes metals, cellulosics, rubber, plastics, organic matrices, and inorganic materials. It consists of dry, heterogeneous combustible and non-combustible debris.

Waste Stream ID: **IN-ID-SDA-Debris**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ICP Retrieved Debris Waste (Filters/Graphite)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	633.4	0.0	633.4
SWB Dir Ld w/o Liner	1.9	0.0	1.9
Current Form Total	635.2	0.0	635.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	633.4	0.0	633.4
SWB Dir Ld w/o Liner	1.9	0.0	1.9
Final Form Total	635.3	0.0	635.3

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	1.41
Aluminum-based Metal/Alloys	0.24
Other Metal/Alloys	0.27
Other Inorganic Materials	233.87
Cellulosics	101.27
Rubber	0.68
Plastics	9.61
Cement	0.92
Solidified Inorganic Material	4.79
Solidified Organic Material	1.11
Soils	20.49
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	36.96
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.84
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	8.43E-01
Cs-137	9.08E-07
Np-237	1.28E-05
Pu-238	7.21E-02
Pu-239	1.99E+00
Pu-240	4.46E-01
Pu-241	2.38E+00
Pu-242	4.58E-05
Sr-90	1.00E-06
Th-232	6.51E-13
U-233	1.17E-05
U-234	2.74E-04
U-235	6.95E-06
U-238	5.41E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, D027, D028, D029, D030, D032, D033, D034, D037, D038, D043, F001, F002, F004, F005, F006, F007, F009, P098, P106

TRUCON Code(s)

112/212, 119/219, 122/222, 127/227, 154

Waste Stream Description

Pre-1970 buried waste retrieved for the Idaho Completion Project

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-ID-SDA-Sludge**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	ICP Retrieved Sludge Waste (Inorganic/Organic Sludge/Roaster Oxide)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2424.4	0.0	2424.4
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Current Form Total	2426.3	0.0	2426.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2424.4	0.0	2424.4
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	2426.3	0.0	2426.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.10
Aluminum-based Metal/Alloys	0.01
Other Metal/Alloys	0.02
Other Inorganic Materials	44.62
Cellulosics	0.46
Rubber	0.11
Plastics	0.88
Cement	0.17
Solidified Inorganic Material	191.00
Solidified Organic Material	394.93
Soils	15.87
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.05
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.83
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.00E+00
Cm-244	3.56E-05
Cs-137	1.72E-05
Np-237	2.99E-05
Pu-238	2.69E-02
Pu-239	6.22E-01
Pu-240	1.40E-01
Pu-241	1.19E+00
Pu-242	2.47E-05
Sr-90	1.89E-05
U-233	2.43E-05
U-234	3.60E-04
U-235	9.49E-06
U-238	1.58E-03

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, D027, D028, D029, D030, D032, D033, D034, D037, D038, D043, F001, F002, F004, F005, F006, F007, F009, P098, P106

TRUCON Code(s)

111/211, 112/212, 122/222, 127/227, 154

Waste Stream Description

Pre-1970 buried waste retrieved for the Idaho Completion Project

Waste Stream ID: **IN-ID-SDA-Soil**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ICP Retrieved Soils					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	476.3	0.0	476.3
Current Form Total	476.3	0.0	476.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	476.3	0.0	476.3
Final Form Total	476.3	0.0	476.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.59
Aluminum-based Metal/Alloys	0.03
Other Metal/Alloys	0.12
Other Inorganic Materials	23.66
Cellulosics	15.00
Rubber	0.34
Plastics	6.32
Cement	0.23
Solidified Inorganic Material	10.85
Solidified Organic Material	5.65
Soils	586.43
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	9.82E-01
Cs-137	1.80E-05
Np-237	1.45E-05
Pu-238	2.82E-02
Pu-239	7.25E-01
Pu-240	1.61E-01
Pu-241	1.09E+00
Pu-242	2.33E-05
Sr-90	1.98E-05
Th-232	4.34E-10
U-233	3.34E-06
U-234	3.18E-04
U-235	4.89E-05
U-238	9.85E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, D027, D028, D029, D030, D032, D033, D034, D037, D038, D043, F001, F002, F004, F005, F006, F007, F009, P098, P106

TRUCON Code(s)

112/212, 122/222, 127/227, 154

Waste Stream Description

Pre-1970 buried waste retrieved for the Idaho Completion Project

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-ID-SNL-HCF-S5400**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Sandia National Laboratories/New Mexico Hot Cell Facility Contact Handled Transuranic Waste (Debris)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.0	0.0	1.0
Current Form Total	1.0	0.0	1.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.0	0.0	1.0
Final Form Total	1.0	0.0	1.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	31.25
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.19
Other Inorganic Materials	3.37
Cellulosics	1.06
Rubber	0.19
Plastics	9.52
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.32E-04
Cs-137	1.66E-03
Pu-238	5.93E-06
Pu-239	8.06E-03
Pu-240	6.30E-04
Sr-90	1.66E-03
U-234	1.96E-05
U-235	6.20E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D011, D019, D022, D028, F002, F005

TRUCON Code(s)

125/225

Waste Stream Description

This waste stream consists of organic and inorganic debris generated during the destructive and nondestructive examinations conducted in the HCF, and includes personal protective equipment and plastic from decontamination and repackaging activities. In addition to the debris materials described above, waste stream ID-SNL-HCF-S5400 will also contain lesser amounts (less than 50 percent in any container) of homogeneous organic and inorganic materials. Clay and vermiculite based absorbents are used during the neutralization and solidification of liquids. Solidifications agents such as Quik Solid and Aquaset were also used to immobilize small amounts of acidic solutions

Waste Stream ID: **IN-MFC-S5490**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Analytical Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	MFC CH-TRU Heterogeneous Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	15.4	0.0	15.4
Current Form Total	15.4	0.0	15.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
TDOP w/ 10 - 55-gal Drums w/o Liners	36.0	0.0	36.0
Final Form Total	36.0	0.0	36.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	13.69
Aluminum-based Metal/Alloys	3.14
Other Metal/Alloys	5.83
Other Inorganic Materials	11.25
Cellulosics	0.00
Rubber	0.00
Plastics	4.78
Cement	0.00
Solidified Inorganic Material	0.89
Solidified Organic Material	2.47
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.44
Packaging Material, Steel	231.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.41E-01
Am-243	5.19E-04
Cm-244	3.71E-03
Cs-137	2.89E-05
Np-237	2.27E-04
Pu-238	3.94E-03
Pu-239	8.67E-02
Pu-240	2.13E-02
Pu-241	4.39E+00
Pu-242	3.83E-06
Sr-90	9.10E-05
Th-229	1.74E-13
Th-230	1.25E-08
Th-232	1.10E-12
U-233	1.97E-09
U-234	3.78E-05
U-235	1.01E-06
U-236	2.12E-07
U-238	7.58E-08

Haz. Waste No(s).

D006, D007, D008, D011

TRUCON Code(s)

125/225

Waste Stream Description

This waste stream consists of solid heterogeneous debris such as glass, metals, ceramics, neutralized and solidified dissolved fuel samples, PPE, paper, rags, and plastic.

Waste Stream ID: **IN-NRF-SPC**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU Sludge Pan Container waste from Naval Reactor Facility at Idaho Site.					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum	12.9	0.0	12.9
Met Storage Container	0.1	0.0	0.1
Sludge Pan Container	0.5	0.0	0.5
Current Form Total	13.5	0.0	13.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	20.6	0.0	20.6
Final Form Total	20.6	0.0	20.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	170.45
Aluminum-based Metal/Alloys	25.01
Other Metal/Alloys	0.16
Other Inorganic Materials	5.83
Cellulosics	3.39
Rubber	0.13
Plastics	4.30
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.04E-02
Cs-137	1.16E+01
Np-237	9.92E-09
Pu-238	7.43E-01
Pu-239	2.02E-03
Pu-240	8.83E-04
Pu-241	7.42E-02
Pu-242	2.64E-06
Sr-90	1.08E+01
Th-229	6.45E-07
Th-230	2.51E-08
Th-232	5.81E-21
U-233	2.45E-03
U-234	9.12E-04
U-235	1.43E-06
U-236	7.84E-11
U-238	1.38E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D010, D011

TRUCON Code(s)

321, 322, 325

Waste Stream Description

This waste stream was generated at the Naval Reactors Facility. A total of 89 RH TRU containers were generated by this waste stream [87 Sludge Pan Containers (SPCs) and 2 Metallurgical Storage Containers (MSCs)]. The 87 SPCs have been shipped to INTEC. The 2 MSCs are planned to be shipped to INTEC for processing.

Waste Stream ID: **IN-NRF-SPC-103**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH-TRU Debris Waste from the Naval Nuclear Propulsion Program (NNPP)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Can	0.7	0.0	0.7
Current Form Total	0.7	0.0	0.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	27.5	0.0	27.5
Final Form Total	27.5	0.0	27.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	339.09
Aluminum-based Metal/Alloys	49.53
Other Metal/Alloys	0.32
Other Inorganic Materials	11.58
Cellulosics	6.74
Rubber	0.27
Plastics	8.56
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.97E-01
Cs-137	4.42E+02
Np-237	3.80E-07
Pu-238	2.84E+01
Pu-239	7.75E-02
Pu-240	3.38E-02
Pu-241	2.84E+00
Pu-242	1.01E-04
Sr-90	4.15E+02
Th-229	2.47E-05
Th-230	9.59E-07
Th-232	2.22E-19
U-233	9.35E-02
U-234	3.49E-02
U-235	5.46E-05
U-236	3.00E-09
U-238	5.28E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D010, D011

No TRUCON Codes Provided

Waste Stream Description

This waste stream was generated at NNPP facilities and consists of 103 containers in storage at the INL. Waste was generated during the same or similar process that generated the SPC waste. AK information is being collected to assure the waste stream meets WIPP requirements. Waste stream includes debris waste generated during analysis of post-irradiated nuclear fuel from Naval Reactors programs using destructive examination methods.

Waste Stream ID: **IN-W170**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	D&D Waste Comp. And Comb. Solids					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Current Form Total	0.4	0.0	0.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Final Form Total	0.4	0.0	0.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	22.50
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	1.60
Cellulosics	130.30
Rubber	1.50
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.95E+00
Np-237	3.59E-05
Pu-239	2.06E+01
Th-229	1.11E-12
U-233	1.72E-09
U-235	4.46E-07

Haz. Waste No(s).

D004, D006, D008, F003

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at Argonne National Laboratory-East, is derived from decontamination and disposal of facilities and ancillary systems (e.g., gloveboxes)..

Waste Stream ID: **IN-W171**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Research Generated Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Box - Misc	3.2	0.0	3.2
Current Form Total	3.6	0.0	3.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
Final Form Total	1.5	0.0	1.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2.90
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	2.90
Cellulosics	175.90
Rubber	2.00
Plastics	22.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.49E+00
Am-243	1.70E-03
Np-237	7.46E-06
Pu-239	5.12E+00
Pu-241	1.80E+01
Th-229	1.69E-13
U-233	2.95E-10
U-235	1.11E-07

Haz. Waste No(s).

D004, D006, D008, F003

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at Argonne National Laboratory-East, is derived from research activities performed in a laboratory environment. The waste includes soft plastics, cardboard, rags, paper, and cloth from various processes.

Waste Stream ID: **IN-W259**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Alpha Hot Cell Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	54.1	0.0	54.1
Bin - Misc	21.0	0.0	21.0
Current Form Total	75.1	0.0	75.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
TDOP w/ 10 - 55-gal Drums w/ Liners	139.5	0.0	139.5
Final Form Total	139.5	0.0	139.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	70.99
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.08
Other Inorganic Materials	1.78
Cellulosics	59.70
Rubber	5.35
Plastics	47.89
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	17.13
Packaging Material, Rubber	0.44
Packaging Material, Steel	231.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-239	2.08E-01
Pu-240	2.30E-02
Th-232	8.13E-18
U-235	5.17E-05
U-236	1.50E-08

Haz. Waste No(s).

D008

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at Argonne National Laboratory-East, contains alpha hot cell waste. Noncombustible and combustible wastes are segregated. Sodium in the waste is reacted with ethyl alcohol, mixed with pelletized clay, and dried. Nitrates and oxidizing agents are neutralized or reduced, mixed with peletized clay, and dried to ferrous or ferric salts.

Waste Stream ID: **IN-W283**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Americium Process Residues:					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	24.8	0.0	24.8
Current Form Total	24.8	0.0	24.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	24.8	0.0	24.8
Final Form Total	24.8	0.0	24.8

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	156.33
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	126.83
Cellulosics	13.27
Rubber	0.00
Plastics	80.52
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	1.29E+00
Np-237	1.05E-05
Pu-238	2.09E-01
Pu-239	7.99E+00
Pu-240	1.81E+00
Pu-241	7.70E+00
Pu-242	1.31E-04
Th-229	5.93E-13
Th-230	4.79E-09
Th-232	1.92E-15
U-233	6.56E-10
U-234	2.61E-05
U-235	2.99E-07
U-236	2.04E-06
U-238	7.71E-13

Haz. Waste No(s).

D008, F002, F003

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at the Rocky Flats Plant, consists of piping, flanges, valves, tools, equipment, PVC piping, glassware (flasks ion exchange columns), glass filters, PE bottles, leaded glovebox gloves, paper, and plastics. Some of the containers are lead-lined.

Waste Stream ID: **IN-W287**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Cut-Up Gloveboxes					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Bin - Misc	234.5	0.0	234.5
Box - Misc	15.9	0.0	15.9
Current Form Total	250.4	0.0	250.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	87.8	0.0	87.8
Final Form Total	87.8	0.0	87.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	169.25
Aluminum-based Metal/Alloys	27.15
Other Metal/Alloys	12.54
Other Inorganic Materials	30.88
Cellulosics	45.09
Rubber	0.48
Plastics	4.52
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.35E-03
Np-237	6.26E-04
Pu-239	2.05E-01
Pu-240	2.43E+00
Pu-241	7.84E-02
Th-229	5.77E-11
Th-230	2.93E-13
Th-232	8.61E-16
U-233	5.96E-08
U-234	2.90E-09
U-235	1.43E-08
U-236	1.59E-06
U-238	4.69E-05

Haz. Waste No(s).

D008

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at Argonne National Laboratory-East, contains glovebox sections and associated equipment from decontamination and decommissioning operations. This waste is predominantly noncombustible

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-W323**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Combustible Lab Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	6.7	0.0	6.7
Current Form Total	6.7	0.0	6.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	15.1	0.0	15.1
Final Form Total	15.1	0.0	15.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	12.15
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.86
Cellulosics	70.39
Rubber	0.79
Plastics	7.03
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.28E-02
Np-237	1.38E-07
Pu-238	6.03E-01
Pu-239	1.32E-01
Pu-241	5.32E-01
Th-229	2.43E-15
Th-230	4.26E-09
U-233	4.77E-12
U-234	4.09E-05
U-235	5.07E-05

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream was generated at the Argonne National Laboratory-West at the INEL. Most of the waste is organic and combustible materials including paper, wood, PVC and plastic containers and items, rubber gaskets and gloves, leather, rags, towels, Q-tips, tubing, filter media, abrasive media, and metal pieces. Small residuals of moderators and fuel are trapped on the filters.

Waste Stream ID: **IN-W337**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Inorganic Nonmetal Waste			**Inventory Date**	12/31/2011
Stream Name	Sources					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	139.10
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-239	1.46E+01
Pu-240	3.03E+00
Th-232	1.07E-15
U-235	3.96E-04
U-236	1.97E-06

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

"This waste was generated at the Idaho National Engineering Laboratory. It consists of a neutron source. No other wastes were included in the drum."

Waste Stream ID: **IN-W345**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	TRU Scrap					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.0	0.0	4.0
Box - Misc	3.2	0.0	3.2
Current Form Total	7.1	0.0	7.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	7.1	0.0	7.1
Final Form Total	7.1	0.0	7.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	96.20
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.10
Other Inorganic Materials	2.40
Cellulosics	80.90
Rubber	7.30
Plastics	64.90
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.75E+00
Np-237	4.17E-05
Pu-238	1.40E+00
Pu-239	1.35E+00
Pu-240	8.57E-01
Th-229	1.29E-12
Th-230	9.90E-09
Th-232	3.91E-05
U-233	2.00E-09
U-234	9.51E-05
U-235	1.79E-05
U-236	5.59E-07

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at the Idaho Engineering Laboratory, consists of a plastic glovebox, hydraulic pump containing oil, vacuum pumps, centrifuges, tools and experimental fuel capsules.

Waste Stream ID: **IN-W347**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Absorbed Liquids					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	21.8	0.0	21.8
Bin - Misc	45.5	0.0	45.5
Current Form Total	67.3	0.0	67.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	38.1	0.0	38.1
Final Form Total	38.1	0.0	38.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	54.88
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	117.54
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.61E+00
Cs-137	4.56E-06
Np-237	3.36E-05
Pu-238	2.06E-01
Pu-239	3.05E+00
Pu-240	9.77E-01
Pu-241	7.45E+00
Pu-242	1.08E-04
Sr-90	5.00E-06
Th-229	2.52E-14
Th-230	7.24E-10
Th-232	2.85E-18
U-233	2.88E-10
U-234	3.99E-05
U-235	9.33E-06
U-236	5.78E-08
U-238	1.59E-04

Haz. Waste No(s).

F003

No TRUCON Codes Provided

Waste Stream Description

This waste comes from Argonne National Laboratory-East. It consists of liquids adjusted to pH 10 using NaOH which are then absorbed in vermiculite.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-W351**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Empty Bottles and Absorbent					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
Current Form Total	1.5	0.0	1.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
Final Form Total	1.5	0.0	1.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	3.40
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	3.40
Cellulosics	202.10
Rubber	2.30
Plastics	25.30
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.41E+00
Np-237	1.40E-05
Pu-238	1.74E-01
Pu-239	1.66E+00
Pu-240	8.69E-01
Pu-241	8.23E+00
Pu-242	2.90E-04
Th-229	1.03E-14
Th-230	9.14E-12
Th-232	2.54E-18
U-233	1.18E-10
U-234	9.91E-07
U-235	3.27E-09
U-236	5.15E-08
U-238	9.01E-14

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at Argonne National Laboratory-East, consists of polyethylene and glass bottles used to collect liquid waste are emptied and filled with vermiculite to absorb any remaining liquid. The tops were replaced to contain the liquid. No free liquids should be present, except for small quantities of wet vermiculite.

Waste Stream ID: **IN-W358**

Appendix A

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Uncategorized Metal Waste			**Inventory Date**	12/31/2011
Stream Name	PU Neutron Sources					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.2	0.0	1.2
Bin - Misc	3.5	0.0	3.5
Current Form Total	4.7	0.0	4.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.5	0.0	2.5
Final Form Total	2.5	0.0	2.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	48.10
Aluminum-based Metal/Alloys	0.40
Other Metal/Alloys	0.05
Other Inorganic Materials	1.20
Cellulosics	40.45
Rubber	3.65
Plastics	32.45
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-238	2.93E+02
Pu-239	1.51E+00
Pu-240	2.90E+00
Th-230	1.06E-06
Th-232	5.42E-16
U-234	1.41E-02
U-235	2.38E-08
U-236	1.37E-06

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream was generated at the INEL [NTEC (formerly CPP), NRF, and TAN]. This wastes includes Pu-Be sources, Pu standard, Pu foil, tools, and non-combustible waste.

Waste Stream ID: **KA-T001**

Appendix A

Waste Profile Report

Site	Knolls Atomic Power Laboratory - Schenectady	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Transuranic Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Can	0.0	0.1	0.1
Current Form Total	0.0	0.1	0.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.0	12.5	12.5
Final Form Total	0.0	12.5	12.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	1.87
Aluminum-based Metal/Alloys	0.01
Other Metal/Alloys	0.00
Other Inorganic Materials	0.05
Cellulosics	1.54
Rubber	0.14
Plastics	1.24
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.97E-04
Am-243	1.34E-07
Cm-244	5.48E-04
Cs-137	2.36E+00
Np-237	6.86E-06
Pu-238	3.94E-02
Pu-239	6.11E-05
Pu-240	4.92E-05
Pu-241	1.58E-02
Pu-242	3.10E-07
Pu-244	4.34E-15
Sr-90	2.36E+00
Th-229	2.34E-12
Th-230	3.40E-09
Th-232	1.05E-13
U-233	9.76E-10
U-234	4.54E-05
U-235	9.54E-07
U-236	9.21E-06
U-238	3.66E-09

No Hazardous Waste Numbers Provided

TRUCON Code(s)

325

Waste Stream Description

Organic and inorganic particulate and debris.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **KA-W016**

Appendix A

Waste Profile Report

Site	Knolls Atomic Power Laboratory - Schenectady	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Transuranic Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Can	0.0	0.0	0.0
Current Form Total	0.0	0.0	0.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.0	0.6	0.6
Final Form Total	0.0	0.6	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	18.73
Aluminum-based Metal/Alloys	0.11
Other Metal/Alloys	0.02
Other Inorganic Materials	0.46
Cellulosics	15.43
Rubber	1.39
Plastics	12.38
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.03E-04
Am-243	1.32E-06
Cm-244	1.86E-04
Cs-137	8.01E-01
Np-237	2.32E-06
Pu-238	1.34E-02
Pu-239	2.07E-05
Pu-240	1.67E-05
Pu-241	5.34E-03
Pu-242	1.05E-07
Pu-244	4.30E-14
Sr-90	8.01E-01
Th-229	2.32E-11
Th-230	3.37E-08
Th-232	1.04E-12
U-233	9.67E-09
U-234	1.54E-05
U-235	3.22E-07
U-236	3.11E-06
U-238	1.24E-09

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D035, D039, D040, F001, F002, F003, F005

TRUCON Code(s)

325

Waste Stream Description

This transuranic mixed waste has not yet been generated. Waste will be segregated to the extent possible (considering ALARA) into inorganic, organic and heterogeneous waste streams and packaged separately. Details of waste characteristics will be developed upon generation. This waste stream will not be moratorium waste.

Waste Stream ID: **KN-B234TRU**

Appendix A
Waste Profile Report

Site	Knolls Atomic Power Laboratory - Nuclear Fuel Services	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Building 234 TRU Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	4.8	0.0	4.8
Box - Crate	28.0	0.0	28.0
Uncontained	0.0	293.5	293.5
Current Form Total	32.8	293.5	326.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	30.2	293.5	323.6
Final Form Total	30.2	293.5	323.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	35.81
Aluminum-based Metal/Alloys	2.60
Other Metal/Alloys	0.00
Other Inorganic Materials	33.49
Cellulosics	5.11
Rubber	0.30
Plastics	31.50
Cement	0.00
Solidified Inorganic Material	600.13
Solidified Organic Material	0.00
Soils	1601.46
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.48E+00
Np-237	7.07E-06
Pu-238	2.70E-01
Pu-239	8.69E+00
Pu-240	8.68E+00
Pu-241	8.34E+00
Th-229	2.46E-05
Th-230	4.83E-03
Th-232	1.61E-03
U-233	3.11E-02
U-234	3.11E-02
U-235	5.90E-03
U-236	5.90E-03
U-238	7.62E-04

No Hazardous Waste Numbers Provided

TRUCON Code(s)

111/211, 125/225

Waste Stream Description

This waste is non-hazardous soil and debris from Building 234 decommissioning. The majority of the waste to be generated, estimated 90%, will be soil. All process equipment and glove boxes were removed in the early 1990s and are not part of this waste stream. The remaining debris consists of concrete block, metal, PPE, plywood, plexiglass, plastic, HEPA filters, piping, duct work, glass, cheese cloth, paper, rubber and small tools.

Waste Stream ID: **LA-CIN01.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Cemented TRU Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum w/ 1 - 55-gal Drum w/ Liner	5.1	0.0	5.1
55-gal Drum Dir Ld w/ Liner	376.3	91.5	467.8
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	252.0	0.0	252.0
Cask - Misc w/ 1 - 30-gal Drum	4.4	0.0	4.4
Cask - Misc w/ 2 - 30-gal Drums	0.8	0.0	0.8
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Current Form Total	640.5	91.5	732.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	554.7	91.5	646.3
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Final Form Total	556.6	91.5	648.1

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	32.62
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	5.80
Cement	912.59
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	36.96
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.84
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	4.73E+01
Am-243	7.28E-04
Cs-137	9.94E-04
Np-237	6.94E-05
Pu-238	4.45E+00
Pu-239	1.65E+01
Pu-240	4.41E+00
Pu-241	7.17E+01
Pu-242	5.54E-03
Pu-244	1.32E-09
Sr-90	9.87E-04
Th-229	7.07E-08
Th-230	3.27E-08
Th-232	4.19E-06
U-233	1.75E-04
U-234	9.13E-04
U-235	1.72E-05
U-236	1.24E-06
U-238	5.68E-04

Haz. Waste No(s).

D006, D007, D008, D011, D019, D021, D039, F001, F002, F003

TRUCON Code(s)

114/214, 126/226

Waste Stream Description

Solidified homogenous solid waste(cemented TRU waste) generated TA-55 R&D/fabrication and associated recovery, facility and equipment maintenance, D&D, waste repackaging, and below-grade retrieval operations.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-CIN02.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Cemented TRU Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum w/ 1 - 55-gal Drum w/ Liner	4.6	0.0	4.6
55-gal Drum Dir Ld w/ Liner	21.8	68.6	90.5
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	12.6	0.0	12.6
SWB w/ 4 - 55-gal Drums w/ Liners	144.4	0.0	144.4
Current Form Total	183.4	68.6	252.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	32.7	68.6	101.3
SWB w/ 4 - 55-gal Drums w/ Liners	143.6	0.0	143.6
Final Form Total	176.3	68.6	244.9

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.67
Cement	670.83
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	24.89
Packaging Material, Rubber	0.49
Packaging Material, Steel	177.88
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	2.50E+00
Am-243	2.55E-06
Cs-137	1.11E-03
Np-237	1.22E-05
Pu-238	3.35E-01
Pu-239	3.56E+00
Pu-240	1.19E-01
Pu-241	1.21E+00
Pu-242	2.02E-05
Sr-90	3.05E-05
Th-229	8.52E-15
Th-230	1.67E-09
Th-232	4.88E-19
U-233	9.93E-11
U-234	9.17E-05
U-235	1.61E-05
U-236	8.46E-09
U-238	3.73E-08

Haz. Waste No(s).

D004, D006, D007, D008, D009, D010, D011, F001, F002, F005

TRUCON Code(s)

111/211, 114/214

Waste Stream Description

Homogeneous cemented inorganics generated in the TA-50-01 RLWTF pretreatment process.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-CIN03.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Cemented TRU Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.3	0.0	2.3
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	1.6	0.0	1.6
Current Form Total	3.9	0.0	3.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.3	0.0	3.3
Final Form Total	3.3	0.0	3.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.05
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	1.77
Cement	588.45
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.96E-01
Cs-137	8.92E-05
Np-237	1.08E-06
Pu-238	6.68E-02
Pu-239	1.09E+00
Pu-240	2.36E-01
Pu-241	3.80E+00
Pu-242	3.23E-05
Sr-90	8.87E-05
Th-229	1.79E-07
Th-230	2.94E-09
Th-232	2.76E-18
U-233	1.62E-11
U-234	8.02E-05
U-235	1.80E-06
U-236	2.80E-08
U-238	3.17E-05

Haz. Waste No(s).

D007, D019, F001, F002

TRUCON Code(s)

114/214, 126/226

Waste Stream Description

Cemented TRU waste generated in the CMR during facility and equipment operations and maintenance processes.

Waste Stream ID: **LA-LAMHD02238**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Current Form Total	0.4	0.0	0.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Final Form Total	0.4	0.0	0.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	43.14
Aluminum-based Metal/Alloys	0.17
Other Metal/Alloys	5.17
Other Inorganic Materials	27.98
Cellulosics	3.57
Rubber	5.36
Plastics	16.52
Cement	0.00
Solidified Inorganic Material	0.69
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.70E-02
Pu-238	3.77E+01
Pu-239	2.24E-02
Pu-240	1.13E-02
Pu-241	8.67E-01
Pu-242	9.30E-06
U-234	4.24E-03
U-235	1.13E-09

Haz. Waste No(s).

D005, D006, D007, D008, D009, D010, D011

TRUCON Code(s)

125/225, 154

Waste Stream Description

Mixed heterogeneous debris waste generated during TA-55 R&D/fabrication and associated recovery, facility and equipment maintenance, decontamination and decomissioning(D&D), waste repackaging, and below-grade retrieval operations.

Waste Stream ID: **LA-LAMHD04001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Current Form Total	1.9	0.0	1.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	39.47
Aluminum-based Metal/Alloys	15.05
Other Metal/Alloys	30.26
Other Inorganic Materials	8.60
Cellulosics	25.65
Rubber	19.81
Plastics	14.75
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.92E-04
Cs-137	2.66E-04
Pu-238	1.08E-04
Pu-239	2.16E-02
Sr-90	3.93E-05
U-234	2.33E-05
U-235	1.26E-06
U-238	2.44E-05

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

Mixed heterogeneous combustible and non-combustible debris.

Waste Stream ID: **LA-LAMIN04S**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Salt Waste			**Inventory Date**	12/31/2011
Stream Name	INORGANIC HOMOGENEOUS WASTE					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
55-gal POC - 12" w/ Liner	0.4	0.0	0.4
Current Form Total	1.9	0.0	1.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
55-gal POC - 12" w/ Liner	0.4	0.0	0.4
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	10.88
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.67
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	5.70
Cement	0.00
Solidified Inorganic Material	34.55
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	30.02
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	219.23
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.42E+00
Pu-238	1.06E+00
Pu-239	3.59E+01
Pu-240	8.39E+00
Pu-241	1.27E+02
Pu-242	4.86E-04
U-234	7.67E-05
U-235	1.33E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D021, D022, D035, D038, D039, D040, F001, F002, F003, F005

TRUCON Code(s)

124/224

Waste Stream Description

INORGANIC HOMOGENEOUS WASTE

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-LAMSG04001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Spill Clean-ups/Emergency Response Actions	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Contaminated Soil					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	34.2	0.0	34.2
Current Form Total	34.2	0.0	34.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	34.0	0.0	34.0
Final Form Total	34.0	0.0	34.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.06
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.06
Cement	0.00
Solidified Inorganic Material	0.20
Solidified Organic Material	0.00
Soils	656.33
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.97E-03
Cs-137	1.40E-03
Pu-238	9.40E-04
Pu-239	1.66E-01
Sr-90	3.42E-04
U-234	9.98E-05
U-235	1.14E-05
U-238	4.79E-05

No Hazardous Waste Numbers Provided

TRUCON Code(s)

111/211

Waste Stream Description

Mixed contaminated soil generated during D&D, sampling activities, and nonstandard events such as the cleanup of spills at the TA-21 DP West Facility.

Waste Stream ID: **LA-LANHD01**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.0	0.0	1.0
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Current Form Total	2.9	0.0	2.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.0	0.0	1.0
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Final Form Total	2.9	0.0	2.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	180.38
Aluminum-based Metal/Alloys	0.73
Other Metal/Alloys	21.62
Other Inorganic Materials	116.98
Cellulosics	14.93
Rubber	22.39
Plastics	69.06
Cement	0.00
Solidified Inorganic Material	2.87
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	13.93
Packaging Material, Rubber	0.33
Packaging Material, Steel	145.39
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.32E+00
Pu-238	4.06E-01
Pu-239	1.02E+01
Pu-240	2.55E+00
Pu-241	4.12E+01
Pu-242	1.99E-04
U-234	3.07E-05
U-235	3.69E-07

No Hazardous Waste Numbers Provided

TRUCON Code(s)

117/217, 125/225, 154

Waste Stream Description

Heterogeneous debris waste generated during plutonium recovery, fabrication, R&D, facility and equipment operations, and maintenance processes.

Waste Stream ID: **LA-LANHD02238**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	NON-MIXED HETEROGENEOUS DEBRIS WASTE, PU238					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Current Form Total	0.6	0.0	0.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	28.34
Aluminum-based Metal/Alloys	0.11
Other Metal/Alloys	3.40
Other Inorganic Materials	18.38
Cellulosics	2.34
Rubber	3.52
Plastics	10.85
Cement	0.00
Solidified Inorganic Material	0.45
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	9.63E-02
Pu-238	1.34E+02
Pu-239	8.00E-02
Pu-240	4.03E-02
Pu-241	3.09E+00
Pu-242	3.31E-05
U-234	1.51E-02
U-235	4.04E-09

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

NON-MIXED HETEROGENEOUS DEBRIS WASTE, PU238

Waste Stream ID: **LA-LANIN03NC**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Salt Waste			**Inventory Date**	12/31/2011
Stream Name	NON-CEMENTED SOLID INORGANIC (HOMOGENEOUS)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
55-gal POC - 12" w/ Liner	0.6	0.0	0.6
Current Form Total	1.0	0.0	1.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
55-gal POC - 12" w/ Liner	0.6	0.0	0.6
Final Form Total	1.0	0.0	1.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.13
Cement	0.00
Solidified Inorganic Material	23.64
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	81.06
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	369.62
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.77E+01
Pu-238	9.00E-01
Pu-239	3.06E+01
Pu-240	7.15E+00
Pu-241	1.09E+02
Pu-242	4.14E-04
U-234	6.54E-05
U-235	1.13E-06

No Hazardous Waste Numbers Provided

TRUCON Code(s)

111/211, 124/224

Waste Stream Description

NON-CEMENTED SOLID INORGANIC (HOMOGENEOUS)

Waste Stream ID: **LA-MHD01.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum w/ 1 - 55-gal Drum w/ Liner	1.0	0.0	1.0
55-gal Drum Dir Ld w/ Liner	255.7	2654.1	2909.8
55-gal POC - 12" w/ Liner	80.1	0.0	80.1
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	126.9	0.0	126.9
Box - Crate	177.7	0.0	177.7
Box - FRP	196.4	0.0	196.4
Cask - Misc w/ 1 - 30-gal Drum	65.6	0.0	65.6
Cask - Misc w/ 2 - 30-gal Drums	4.0	0.0	4.0
Other	364.5	0.0	364.5
SWB Dir Ld w/ Liner	267.9	125.4	393.3
SWB w/ 4 - 55-gal Drums w/ Liners	47.5	0.0	47.5
Current Form Total	1587.4	2779.5	4366.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	488.0	2654.1	3142.0
55-gal POC - 12" w/ Liner	80.1	0.0	80.1
SWB Dir Ld w/ Liner	1005.5	124.7	1130.2
SWB w/ 4 - 55-gal Drums w/ Liners	47.3	0.0	47.3
Final Form Total	1620.8	2778.8	4399.6

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	76.20
Aluminum-based Metal/Alloys	0.31
Other Metal/Alloys	9.13
Other Inorganic Materials	49.42
Cellulosics	6.31
Rubber	9.46
Plastics	29.18
Cement	0.00
Solidified Inorganic Material	1.21
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	2.46
Packaging Material, Plastic	27.63
Packaging Material, Rubber	0.47
Packaging Material, Steel	144.70
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	2.26E+00
Am-243	9.62E-05
Cm-244	1.84E-02
Cs-137	9.73E-05
Np-237	4.25E-05
Pu-238	1.18E+01
Pu-239	5.13E+00
Pu-240	1.39E+00
Pu-241	1.82E+01
Pu-242	2.53E-03
Pu-244	7.84E-10
Sr-90	9.70E-05
Th-229	3.31E-08
Th-230	2.51E-08
Th-232	6.83E-11
U-233	1.18E-04
U-234	1.40E-03
U-235	1.21E-06
U-236	1.23E-07
U-238	2.16E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D021, D022, D035, D038, D039, D040, F001, F002, F003, F005

TRUCON Code(s)

112/212, 115/215, 116/216, 117/217, 118/218, 119/219, 122/222, 124/224, 125/225, 154

Waste Stream Description

Mixed heterogeneous debris waste generated during TA-55 R&D/fabrication and associated recovery, facility and equipment maintenance, decontamination and decomissioning(D&D), waste repackaging, and below-grade retrieval operations.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-MHD03.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum w/ 1 - 55-gal Drum w/ Liner	0.8	0.0	0.8
30-gal Drum	4.6	0.0	4.6
55-gal Drum Dir Ld w/ Liner	95.4	137.3	232.7
55-gal POC - 12" w/ Liner	0.4	0.0	0.4
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	21.3	0.0	21.3
Box - Crate	43.7	0.0	43.7
Cask - Misc w/ 1 - 30-gal Drum	0.8	0.0	0.8
Other	7.7	0.0	7.7
SWB Dir Ld w/ Liner	79.8	0.0	79.8
Current Form Total	254.5	137.3	391.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	115.2	137.3	252.5
55-gal POC - 12" w/ Liner	0.4	0.0	0.4
SWB Dir Ld w/ Liner	130.4	0.0	130.4
Final Form Total	246.1	137.3	383.3

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	30.81
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	10.08
Other Inorganic Materials	48.87
Cellulosics	39.37
Rubber	3.99
Plastics	115.58
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.77
Vitrified	0.00
Packaging Material, Cellulosics	0.15
Packaging Material, Plastic	24.87
Packaging Material, Rubber	0.44
Packaging Material, Steel	138.91
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	1.31E-01
Am-243	9.71E-05
Cm-244	5.96E-01
Cs-137	1.03E-02
Np-237	2.69E-04
Pu-238	1.84E+00
Pu-239	5.05E-01
Pu-240	1.39E-01
Pu-241	2.19E+00
Pu-242	4.01E-05
Pu-244	1.49E-11
Sr-90	8.84E-03
Th-229	2.74E-09
Th-230	7.83E-09
Th-232	4.37E-18
U-233	3.51E-09
U-234	2.92E-04
U-235	8.57E-06
U-236	3.57E-08
U-238	2.73E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D021, D022, D026, D027, D028, D029, D030, D035, D036, D037, D038, D039, D040, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

116/216, 117/217, 118/218, 119/219, 125/225, 154

Waste Stream Description

Mixed heterogeneous combustible and non-combustible debris.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-MHD04.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum w/ 1 - 55-gal Drum w/ Liner	0.4	0.0	0.4
30-gal Drum	0.1	0.0	0.1
55-gal Drum Dir Ld w/ Liner	1.2	0.0	1.2
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	2.2	0.0	2.2
Box - Crate	925.9	0.0	925.9
Box - FRP	479.6	0.0	479.6
Other	146.3	0.0	146.3
SWB Dir Ld w/ Liner	26.6	0.0	26.6
Current Form Total	1582.3	0.0	1582.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.1	0.0	3.1
SWB Dir Ld w/ Liner	1578.2	0.0	1578.2
Final Form Total	1581.3	0.0	1581.3

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	20.59
Aluminum-based Metal/Alloys	7.85
Other Metal/Alloys	15.79
Other Inorganic Materials	4.49
Cellulosics	13.38
Rubber	10.34
Plastics	7.69
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.27
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.39
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	2.06E-02
Am-243	1.74E-09
Cs-137	1.63E-06
Np-237	3.10E-07
Pu-238	1.80E+00
Pu-239	2.97E-01
Pu-240	1.78E-02
Pu-241	1.87E-01
Pu-242	4.30E-07
Sr-90	1.62E-06
Th-229	8.73E-16
Th-230	2.00E-09
Th-232	2.08E-19
U-233	5.03E-12
U-234	6.47E-05
U-235	2.86E-08
U-236	2.10E-09
U-238	2.67E-16

Haz. Waste No(s).

D004, D006, D007, D008, D009, F001, F002

TRUCON Code(s)

117/217, 125/225, 154

Waste Stream Description

Mixed heterogeneous combustible and non-combustible debris.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-MHD05-ITRI.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	6.0	0.0	6.0
55-gal POC - 12" w/ Liner	0.2	0.0	0.2
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	0.3	0.0	0.3
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Current Form Total	8.5	0.0	8.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	6.2	0.0	6.2
55-gal POC - 12" w/ Liner	0.2	0.0	0.2
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Final Form Total	8.3	0.0	8.3

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	127.96
Aluminum-based Metal/Alloys	3.96
Other Metal/Alloys	7.68
Other Inorganic Materials	19.08
Cellulosics	3.96
Rubber	6.28
Plastics	6.28
Cement	0.00
Solidified Inorganic Material	51.18
Solidified Organic Material	6.28
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	3.37
Packaging Material, Plastic	28.94
Packaging Material, Rubber	0.48
Packaging Material, Steel	145.84
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	2.58E+00
Am-243	3.41E-03
Cm-244	1.56E+00
Cs-137	2.54E-07
Np-237	1.90E-06
Pu-238	4.85E+00
Pu-239	4.04E-01
Pu-240	3.28E-02
Pu-241	5.42E-01
Pu-242	3.79E-06
Sr-90	2.54E-07
Th-229	2.57E-16
Th-230	1.07E-09
Th-232	2.39E-20
U-233	6.46E-12
U-234	1.24E-04
U-235	3.98E-10
U-236	9.68E-10
U-238	5.88E-16

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225, 154

Waste Stream Description

Mixed CH-TRU waste stored at LANL resulting from the preparation of aerosols of TRU isotopes for inhalation studies performed at the LRRI.

Waste Stream ID: **LA-MHD08.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.1	0.0	2.1
55-gal POC - 12" w/ Liner	0.2	0.0	0.2
Current Form Total	2.3	0.0	2.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.1	0.0	2.1
55-gal POC - 12" w/ Liner	0.2	0.0	0.2
Final Form Total	2.3	0.0	2.3

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	7.95
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	2.65
Other Inorganic Materials	12.82
Cellulosics	10.29
Rubber	1.05
Plastics	30.28
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	12.28
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	166.96
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	2.51E-01
Am-243	3.82E-03
Cm-244	1.54E-05
Cs-137	2.43E-05
Np-237	1.30E-03
Pu-238	4.31E-02
Pu-239	1.23E-01
Pu-240	1.93E-02
Pu-241	1.55E-01
Pu-242	4.37E-02
Sr-90	2.42E-05
Th-229	9.98E-13
Th-230	2.26E-12
Th-232	4.81E-08
U-233	1.13E-08
U-234	2.45E-07
U-235	2.42E-10
U-236	1.14E-09
U-238	1.36E-11

Haz. Waste No(s).

D008, D011

TRUCON Code(s)

111/211, 116/216, 125/225, 154

Waste Stream Description

Mixed heterogeneous combustible and non-combustible debris generated during plutonium and uranium R&D processes in the Alpha Facility.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-MHD09.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.3	0.0	2.3
55-gal POC - 12" w/ Liner	0.2	0.0	0.2
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	1.6	0.0	1.6
Other	29.6	0.0	29.6
SWB Dir Ld w/ Liner	25.4	0.0	25.4
Current Form Total	59.1	0.0	59.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.3	0.0	3.3
55-gal POC - 12" w/ Liner	0.2	0.0	0.2
SWB Dir Ld w/ Liner	56.7	0.0	56.7
Final Form Total	60.2	0.0	60.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	148.07
Aluminum-based Metal/Alloys	53.90
Other Metal/Alloys	54.71
Other Inorganic Materials	6.01
Cellulosics	11.07
Rubber	10.21
Plastics	11.19
Cement	0.00
Solidified Inorganic Material	2.47
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.47
Packaging Material, Plastic	3.31
Packaging Material, Rubber	0.21
Packaging Material, Steel	153.48
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.55E+00
Am-243	1.36E-04
Cs-137	1.16E-03
Np-237	9.75E-05
Pu-238	2.04E+00
Pu-239	2.69E-01
Pu-240	5.43E-02
Pu-241	9.19E-01
Pu-242	1.71E-05
Sr-90	1.65E-05
Th-229	7.32E-14
Th-230	5.76E-09
Th-232	1.59E-19
U-233	8.37E-10
U-234	3.19E-04
U-235	4.29E-07
U-236	3.21E-09
U-238	8.63E-07

Haz. Waste No(s).

D007, D008, D009, F001

TRUCON Code(s)

116/216, 117/217, 125/225, 154

Waste Stream Description

Mixed heterogeneous combustible and non-combustible debris from the TA-50-01 RLWTF, TA-50-37 CAI, and TA-50-69 WCRR Facility generated during facility and equipment maintenance, decontamination and decommissioning (D&D), and waste repackaging activities.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-MIN02-V.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	Absorbed Liquid Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	7.5	0.0	7.5
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	1.3	0.0	1.3
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Current Form Total	10.7	0.0	10.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	8.3	0.0	8.3
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Final Form Total	10.2	0.0	10.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	11.65
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	4.28
Cellulosics	0.00
Rubber	0.00
Plastics	18.26
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	92.86
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	30.43
Packaging Material, Rubber	0.50
Packaging Material, Steel	134.97
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.33E-01
Am-243	1.35E-05
Cs-137	5.05E-06
Np-237	4.76E-05
Pu-238	4.06E+00
Pu-239	2.80E+00
Pu-240	7.07E-01
Pu-241	8.19E+00
Pu-242	6.23E-05
Sr-90	5.03E-06
Th-229	8.16E-14
Th-230	3.86E-09
Th-232	4.65E-18
U-233	6.19E-10
U-234	1.57E-04
U-235	3.46E-06
U-236	6.28E-08
U-238	1.29E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D021, D022, D035, D038, D039, D040, F001, F002, F003, F005

TRUCON Code(s)

112/212

Waste Stream Description

Inorganic particulate waste generated during TA-55 R&D/fabrication and associated recovery, facility and equipment maintenance, D&D, waste repackaging, and below-grade retrieval operations.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-MIN03-NC.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Homogeneous Inorganic Solids					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum w/ 1 - 55-gal Drum w/ Liner	2.0	0.0	2.0
55-gal Drum Dir Ld w/ Liner	33.6	0.0	33.6
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	63.1	0.0	63.1
Current Form Total	98.7	0.0	98.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	74.3	0.0	74.3
Final Form Total	74.3	0.0	74.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.08
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.08
Cellulosics	0.00
Rubber	0.00
Plastics	4.42
Cement	0.00
Solidified Inorganic Material	829.20
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.15E-01
Am-243	2.60E-06
Cs-137	9.36E-06
Np-237	1.41E-06
Pu-238	1.11E-01
Pu-239	4.36E-01
Pu-240	2.07E-02
Pu-241	3.71E-01
Pu-242	1.49E-06
Sr-90	9.30E-06
Th-229	4.46E-08
Th-230	9.24E-10
Th-232	7.50E-19
U-233	1.94E-11
U-234	2.58E-05
U-235	8.58E-07
U-236	5.02E-09
U-238	1.14E-06

Haz. Waste No(s).

D005, D006, D007, D008, D009, D010, D011, F001, F002

TRUCON Code(s)

111/211, 122/222, 125/225

Waste Stream Description

Homogeneous dewatered sludge generated in the TA-50-01 RLWTF main treatment process.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-MIN04-S.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Salt Waste			**Inventory Date**	12/31/2011
Stream Name	Salt Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	13.1	0.0	13.1
55-gal POC - 12" w/ Liner	1.0	0.0	1.0
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	0.3	0.0	0.3
Current Form Total	14.5	0.0	14.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	13.3	0.0	13.3
55-gal POC - 12" w/ Liner	1.0	0.0	1.0
Final Form Total	14.4	0.0	14.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	15.70
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.97
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	8.23
Cement	0.00
Solidified Inorganic Material	49.87
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	9.79
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	159.62
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.77E+00
Am-243	1.65E-03
Cm-244	2.93E-02
Cs-137	6.67E-05
Np-237	1.53E-04
Pu-238	1.59E+00
Pu-239	3.41E+01
Pu-240	8.60E+00
Pu-241	6.82E+01
Pu-242	7.04E-04
Sr-90	6.66E-05
Th-229	2.91E-14
Th-230	9.22E-10
Th-232	6.28E-18
U-233	6.63E-10
U-234	1.03E-04
U-235	2.44E-06
U-236	2.55E-07
U-238	1.09E-13

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D021, D022, D035, D038, D039, D040, F001, F002, F003, F005

TRUCON Code(s)

124/224, 125/225

Waste Stream Description

Inorganic homogeneous solid waste generated during TA-55 R&D/fabrication and associated recovery, facility and equipment maintenance, D&D, waste repackaging, and below-grade retrieval operations.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-MSG04.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Spill Clean-ups/Emergency Response Actions	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Contaminated Soil					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	10.0	0.0	10.0
Box - Crate	23.8	0.0	23.8
SWB Dir Ld w/ Liner	3.8	0.0	3.8
Current Form Total	37.6	0.0	37.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	10.0	0.0	10.0
SWB Dir Ld w/ Liner	28.4	0.0	28.4
Final Form Total	38.3	0.0	38.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.05
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.05
Cement	0.00
Solidified Inorganic Material	0.16
Solidified Organic Material	0.00
Soils	527.64
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	10.54
Packaging Material, Rubber	0.29
Packaging Material, Steel	147.53
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.48E-02
Cs-137	3.27E-08
Np-237	5.16E-07
Pu-238	5.48E-06
Pu-239	2.86E-01
Pu-240	4.92E-04
Pu-241	4.15E-03
Pu-242	7.80E-07
Pu-244	4.57E-06
Sr-90	1.80E-07
U-233	1.35E-07
U-234	1.35E-07
U-238	3.55E-08

No Hazardous Waste Numbers Provided

TRUCON Code(s)

111/211, 125/225

Waste Stream Description

Mixed contaminated soil generated during D&D, sampling activities, and nonstandard events such as the cleanup of spills at the TA-21 DP West Facility.

Waste Stream ID: **LA-OS-00-01.001**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Discarding Excess/Expired Materials	**Waste Matrix Code Group**	Uncategorized Metal Waste			**Inventory Date**	12/31/2011
Stream Name	Metal debris from Off-Site Source Recovery (OSR) project					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal POC - 12" w/ Liner	8.3	0.0	8.3
55-gal POC - 6" w/ Liner	38.9	0.0	38.9
Current Form Total	47.2	0.0	47.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal POC - 12" w/ Liner	8.3	0.0	8.3
55-gal POC - 6" w/ Liner	38.9	0.0	38.9
Final Form Total	47.2	0.0	47.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	24.57
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	4.34
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	200.84
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	357.36
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.82E+01
Cm-244	6.19E+01
Cs-137	8.25E-02
Np-237	5.08E-05
Pu-238	1.66E+01
Pu-240	3.33E-01
Pu-242	4.40E-08
Th-229	1.30E-14
Th-230	8.72E-10
Th-232	9.47E-19
U-233	2.21E-10
U-234	9.45E-05
U-236	1.93E-08
U-238	6.82E-18

No Hazardous Waste Numbers Provided

TRUCON Code(s)

120/220

Waste Stream Description

Off-Site Source Recovery (OSR) sealed sources are radionuclide (actinide) solids (e.g., Am, Pu, AmBe, or PuBe) that are encapsulated in metal jackets. The actinides are either metal or metal oxides.

Waste Stream ID: **LA-TA-00-01**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Containers waiting assignment to waste streams					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	8.5	0.0	8.5
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	1.0	0.0	1.0
Box - Crate	113.1	0.0	113.1
Other	5.7	0.0	5.7
Current Form Total	128.3	0.0	128.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	9.2	0.0	9.2
SWB Dir Ld w/ Liner	119.1	0.0	119.1
Final Form Total	128.2	0.0	128.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	28.94
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	9.63
Other Inorganic Materials	46.64
Cellulosics	37.43
Rubber	3.81
Plastics	110.17
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	3.76
Packaging Material, Rubber	0.22
Packaging Material, Steel	151.82
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.76E-02
Am-243	4.17E-10
Cs-137	1.40E-05
Np-237	1.67E-05
Pu-238	1.80E-02
Pu-239	3.56E-01
Pu-240	5.17E-02
Pu-241	6.06E-01
Pu-242	2.86E-06
Sr-90	1.39E-05
Th-229	7.82E-14
Th-230	2.68E-11
Th-232	9.44E-19
U-233	3.56E-10
U-234	7.11E-07
U-235	9.59E-09
U-236	7.66E-09
U-238	2.22E-15

Haz. Waste No(s).

D008, F001

TRUCON Code(s)

125/225, 154

Waste Stream Description

Miscellaneous Containers waiting assignment to waste streams

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-00-03**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	NON-PN EQUIPMENT					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Canister - (LANL-RH)	2.1	0.0	2.1
Current Form Total	2.1	0.0	2.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid - Dir Ld	1.8	0.0	1.8
Final Form Total	1.8	0.0	1.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.37
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.33
Cellulosics	0.00
Rubber	0.00
Plastics	19.45
Cement	0.00
Solidified Inorganic Material	3650.35
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.00
Packaging Material, Steel	560.67
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-239	7.06E+00
U-235	2.16E-07

Haz. Waste No(s).

D008

No TRUCON Codes Provided

Waste Stream Description

LAMPRE REACTOR VESSEL SEALED IN CASK VESSEL

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-03-01**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	Solidified Organics					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	33.80
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	12.42
Cellulosics	0.00
Rubber	0.00
Plastics	52.96
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	269.37
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.77E-01
Np-237	3.24E-05
Pu-238	2.57E-02
Pu-239	9.04E-01
Pu-240	2.11E-01
Pu-241	2.63E+00
Pu-242	1.22E-05
Th-229	9.61E-14
Th-230	5.45E-12
Th-232	2.47E-18
U-233	5.47E-10
U-234	2.95E-07
U-235	3.56E-09
U-236	2.50E-08
U-238	7.55E-15

Haz. Waste No(s).

D006, D008, D009, D011, D019, D021, F001, F002, F005

TRUCON Code(s)

112/212

Waste Stream Description

Solidified Organics

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-03-09**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Current Form Total	0.6	0.0	0.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	28.13
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	9.20
Other Inorganic Materials	44.61
Cellulosics	35.94
Rubber	3.64
Plastics	105.51
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.71
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.01E-01
Am-243	1.23E-03
Cs-137	1.65E-06
Np-237	2.72E-04
Pu-238	2.47E+00
Pu-239	4.94E+00
Pu-240	1.16E+00
Pu-241	1.76E+01
Pu-242	6.75E-05
U-234	2.73E-04
U-235	1.84E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D021, D022, D026, D027, D028, D029, D030, D035, D036, D037, D038, D039, D040, D043, F001, F002, F004, F005

TRUCON Code(s)

125/225, 154

Waste Stream Description

Mixed heterogeneous combustible and non-combustible debris.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-03-10**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Combined Combustible and NonCombustible					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Other	64.0	0.0	64.0
Current Form Total	64.4	0.0	64.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
SWB Dir Ld w/ Liner	64.3	0.0	64.3
Final Form Total	64.7	0.0	64.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.25
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.08
Other Inorganic Materials	0.40
Cellulosics	0.32
Rubber	0.03
Plastics	0.94
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.01
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.43
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.29
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.90E-03
Am-243	2.56E-08
Np-237	1.12E-07
Pu-238	4.72E-04
Pu-239	1.64E-02
Pu-240	3.83E-03
Pu-241	5.24E-02
Pu-242	2.20E-07
Th-229	8.35E-17
Th-230	1.88E-12
Th-232	5.21E-20
U-233	9.55E-13
U-234	1.04E-07
U-235	9.41E-08
U-236	6.41E-10
U-238	1.26E-09

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

Combined Combustible and NonCombustible

Waste Stream ID: **LA-TA-03-12**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Combustible debris waste from chemistry operations in wings 3, 5, and 7 of the CMR facility					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	15.62
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	5.11
Other Inorganic Materials	24.78
Cellulosics	19.96
Rubber	2.02
Plastics	58.60
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.39
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.26E-01
Cs-137	6.26E-05
Np-237	1.53E-07
Pu-238	2.61E-02
Pu-239	9.20E-01
Pu-240	2.15E-01
Pu-241	2.67E+00
Pu-242	1.24E-05
Sr-90	6.23E-05
Th-229	1.46E-16
Th-230	7.81E-11
Th-232	2.51E-18
U-233	1.26E-12
U-234	2.27E-06
U-235	3.78E-08
U-236	2.55E-08
U-238	7.69E-15

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

Combustible waste generated from facility and equipment operations and maintenance. This waste includes paper, rags, plastic, rubber, wood-based HEPA filters, and plastic-based and cellulose-based waste generated at the facility. Plastic-based waste includes, but may not be limited to, tape, polyethylene and vinyl; gloves; plastic vials; polystyrene; Tygon tubing; polyvinyl chloride plastic; Teflon products; Plexiglas; and dry box gloves (unleaded neoprene base). Cellulose-based waste includes, but may not be limited to, rags, wood, paper, cardboard, laboratory coats and coveralls, booties and cotton gloves, and similar materials. The waste stream may also contain a smaller fraction of non-combustible solids (e.g., scrap metal, crucibles, metal lids, zippers, discarded tools) and a small fraction of homogenous solids, salts, leached solids, ash, hydroxide cakes, crucibles, impure oxides.

Waste Stream ID: **LA-TA-03-14**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Metals and Miscellaneous Equipment Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Crate	8.8	0.0	8.8
Current Form Total	8.8	0.0	8.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	9.5	0.0	9.5
Final Form Total	9.5	0.0	9.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	56.34
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	18.43
Other Inorganic Materials	89.36
Cellulosics	71.98
Rubber	7.30
Plastics	211.34
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	1.41
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-238	2.94E-01
Pu-239	6.65E-04
Th-230	6.35E-09
U-234	3.56E-05
U-235	2.42E-11

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225, 154

Waste Stream Description

Metals and Miscellaneous Equipment Debris

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-03-27**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Combined combustible and noncombustible debris waste (RH-TRU) of the CMR facility					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Canister - (LANL-RH)	76.2	0.0	76.2
RH Can w/ Fxd Lid - Dir Ld	1.0	0.0	1.0
Current Form Total	77.2	0.0	77.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Fxd Lid - Dir Ld	0.9	0.0	0.9
RH Can w/ Remov Lid - Dir Ld	76.5	0.0	76.5
Final Form Total	77.4	0.0	77.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	233.37
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	76.34
Other Inorganic Materials	370.19
Cellulosics	298.19
Rubber	30.23
Plastics	875.48
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	5.86
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.00
Packaging Material, Steel	559.21
Packaging Material, Lead	5.33

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.96E-02
Cs-137	1.06E+01
Np-237	4.49E-07
Pu-238	1.63E-02
Pu-239	1.05E+00
Pu-240	3.26E-02
Pu-241	3.06E-01
Pu-242	1.96E-05
Sr-90	7.19E+00
Th-229	1.93E-14
Th-230	6.58E-09
Th-232	1.66E-16
U-233	2.49E-11
U-234	2.63E-05
U-235	1.08E-04
U-236	1.34E-07
U-238	5.32E-07

No Hazardous Waste Numbers Provided

TRUCON Code(s)

117/217, 125/225, 154

Waste Stream Description

Combined combustible and noncombustible debris waste (RH-TRU) from wing 9 of the CMR facility (mixed). Combined Combustible and non-combustible remote handled waste (RH-TRU). This waste stream contains both combustible and non-combustible waste that is classified as "remotely handled". Combustible waste is generated from facility and equipment operations and maintenance. Combustible waste includes paper, rags, plastic, rubber, and plastic-based and cellulose-based waste generated at the facility. Plastic based waste includes, but may not be limited to, tape, polyethylene, and vinyl; gloves; plastic vials; polystyrene; Tygon tubing; polyvinyl chloride plastic; Teflon products; plexiglass; and dry box gloves (unleaded Neoprene base).Cellulose-based waste includes, but may not be limited to rags, wood, paper, cardboard, laboratory coats and coveralls, booties and cotton gloves, and similar materials. Noncombustible scrap waste is also generated from facility and equipment operations and maintenance. Noncombustible waste includes items such as small tools, cans, small equipment items, and broken glass. This waste consists of glass waste including, but not limited to, discarded labware, windows, and bottles; metal waste including motors, pumps, tools, and process equipment; leaded rubber, and metal waste including lead-lined glovebox gloves discarded along with metal waste, such as motors and tools.

Waste Stream ID: **LA-TA-03-28**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Cement paste from CMR building (mixed)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.0	0.0	1.0
Current Form Total	1.0	0.0	1.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.0	0.0	1.0
Final Form Total	1.0	0.0	1.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.09
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	3.05
Cement	1015.09
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-238	2.56E+00
Th-230	5.86E-08
U-234	3.20E-04

Haz. Waste No(s).

D007, F001, F002

TRUCON Code(s)

114/214, 126/226

Waste Stream Description

Cement Past Solidified aqueous waste and cemented sludge generated from facility and equipment operations and maintenance. The sludge is a residue from numerous treatment and filtration operations involving aqueous liquid radioactive waste. This treatment produces a thin sludge (approximately 25 percent solids) that is alkaline and is compatible with Portland cement. Final cemented waste monoliths are produced by mixing the waste in 55-gallon steel drums containing empirically determined quantities of sludge, Portland cement, vermiculite, and sodium silicate.

Waste Stream ID: **LA-TA-03-30**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	Absorbed Organics on vermiculite (mixed)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	0.1	0.0	0.1
Current Form Total	0.1	0.0	0.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	49.48
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	18.18
Cellulosics	0.00
Rubber	0.00
Plastics	77.53
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	394.36
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-238	2.48E-01
Th-230	5.37E-09
U-234	3.01E-05

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

Absorbed Organics on Vermiculite Organic liquids (solvents and oils) generated from facility and equipment operations and maintenance and absorbed on vermiculite.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-03-34**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - FRP	19.5	0.0	19.5
Other	18.4	0.0	18.4
Current Form Total	37.9	0.0	37.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	37.8	0.0	37.8
Final Form Total	37.8	0.0	37.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	7.02
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	2.30
Other Inorganic Materials	11.13
Cellulosics	8.96
Rubber	0.91
Plastics	26.32
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.18
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.70E-05
Cs-137	8.28E-09
Pu-238	4.58E-02
Pu-239	9.89E-05
Pu-240	2.32E-05
Sr-90	3.68E-09
U-234	2.68E-06
U-235	7.68E-08

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

Miscellaneous debris waste including fume hoods and stainless steel gloveboxes.

Waste Stream ID: **LA-TA-03-42**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	HEPA filter debris waste from wings 2, 3, 4, 5, and 7 of CMR Building					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	9.5	0.0	9.5
Current Form Total	9.5	0.0	9.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	9.5	0.0	9.5
Final Form Total	9.5	0.0	9.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	15.74
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	5.15
Other Inorganic Materials	24.97
Cellulosics	20.11
Rubber	2.04
Plastics	59.04
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.40
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.64E-03
Am-243	9.44E-07
Cs-137	2.93E-06
Np-237	1.36E-07
Pu-238	4.25E-02
Pu-239	2.98E-03
Pu-240	6.96E-04
Pu-241	7.20E-03
Pu-242	4.01E-08
Th-229	1.61E-15
Th-230	3.68E-11
Th-232	3.25E-20
U-233	4.59E-12
U-234	9.89E-07
U-235	4.98E-08
U-236	1.65E-10
U-238	4.98E-17

No Hazardous Waste Numbers Provided

TRUCON Code(s)

119/219, 125/225, 154

Waste Stream Description

HEPA filter waste generated from facility and equipment operations and maintenance. A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream.

Waste Stream ID: **LA-TA-21-01**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	3.8	0.0	3.8
Current Form Total	3.8	0.0	3.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	3.8	0.0	3.8
Final Form Total	3.8	0.0	3.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	112.87
Aluminum-based Metal/Alloys	43.04
Other Metal/Alloys	86.52
Other Inorganic Materials	24.59
Cellulosics	73.35
Rubber	56.66
Plastics	42.16
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.50E-02
Cs-137	2.02E-03
Np-237	1.25E-06
Pu-238	1.54E-02
Pu-239	6.50E-01
Pu-240	1.16E-01
Pu-241	1.75E+00
Sr-90	2.94E-04
U-234	3.10E-05
U-235	1.41E-06
U-238	6.69E-06

No Hazardous Waste Numbers Provided

TRUCON Code(s)

111/211, 125/225, 154

Waste Stream Description

Mixed heterogeneous combustible and non-combustible debris.

Waste Stream ID: **LA-TA-21-05**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Graphite					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	0.1	0.0	0.1
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.3	0.0	0.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Final Form Total	0.4	0.0	0.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	49.00
Aluminum-based Metal/Alloys	18.68
Other Metal/Alloys	37.56
Other Inorganic Materials	10.68
Cellulosics	31.84
Rubber	24.59
Plastics	18.30
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.49E-01
Cs-137	8.12E-05
Np-237	5.63E-06
Pu-238	5.91E-02
Pu-239	2.55E+00
Pu-240	6.08E-01
Pu-241	1.59E+00
Pu-242	4.08E-05
Sr-90	7.68E-05
Th-229	4.29E-13
Th-230	3.33E-09
Th-232	6.09E-16
U-233	4.17E-10
U-234	1.32E-05
U-235	4.76E-05
U-236	6.67E-07
U-238	2.34E-13

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

Graphite

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-21-06**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Combustible debris waste (mixed)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	14.9	0.0	14.9
55-gal Drum Dir Ld w/ Liner	184.7	0.0	184.7
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	0.3	0.0	0.3
Cask - Misc w/ 1 - 30-gal Drum	7.9	0.0	7.9
Cask - Misc w/ 2 - 30-gal Drums	73.5	0.0	73.5
Current Form Total	281.3	0.0	281.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	326.4	0.0	326.4
Final Form Total	326.4	0.0	326.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	26.35
Aluminum-based Metal/Alloys	10.05
Other Metal/Alloys	20.20
Other Inorganic Materials	5.74
Cellulosics	17.12
Rubber	13.23
Plastics	9.84
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.36E-01
Cs-137	2.20E-05
Np-237	2.27E-06
Pu-238	4.07E+01
Pu-239	6.29E-01
Pu-240	1.91E-01
Pu-241	7.72E-01
Pu-242	3.57E-05
Sr-90	2.09E-05
Th-229	1.54E-13
Th-230	1.08E-06
Th-232	1.71E-16
U-233	1.59E-10
U-234	5.57E-03
U-235	2.88E-06
U-236	1.98E-07
U-238	1.94E-13

Haz. Waste No(s).

F001, F002

TRUCON Code(s)

125/225, 154

Waste Stream Description

Combustible waste generated from facility and equipment operations and maintenance. This waste includes paper, rags, plastic, rubber, wood-based HEPA filters, and plastic-based and cellulose-based waste generated at the facility. Plastic-based waste includes, but may not be limited to, tape, polyethylene and vinyl; gloves; plastic vials; polystyrene; Tygon tubing; polyvinyl chloride plastic; Teflon products; Plexiglas; and dry box gloves (unleaded neoprene base). Cellulose-based waste includes, but may not be limited to, rags, wood, paper, cardboard, laboratory coats and coveralls, booties and cotton gloves, and similar materials. The waste stream may also contain a smaller fraction of non-combustible solids (e.g., scrap metal, crucibles, metal lids, zippers, discarded tools) and a small fraction of homogenous solids, salts, leached solids, ash, hydroxide cakes, crucibles, impure oxides.

Waste Stream ID: **LA-TA-21-07**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Metal					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	5.7	0.0	5.7
55-gal Drum Dir Ld w/ Liner	66.6	0.0	66.6
Box - Crate	482.3	0.0	482.3
Cask - Misc w/ 1 - 30-gal Drum	3.1	0.0	3.1
Cask - Misc w/ 2 - 30-gal Drums	43.9	0.0	43.9
Other	7.8	0.0	7.8
Current Form Total	609.4	0.0	609.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	142.1	0.0	142.1
SWB Dir Ld w/ Liner	489.5	0.0	489.5
Final Form Total	631.6	0.0	631.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	38.86
Aluminum-based Metal/Alloys	14.82
Other Metal/Alloys	29.79
Other Inorganic Materials	8.47
Cellulosics	25.25
Rubber	19.51
Plastics	14.52
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	9.27
Packaging Material, Rubber	0.28
Packaging Material, Steel	148.34
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.76E-02
Cs-137	8.12E-06
Np-237	5.57E-07
Pu-238	1.67E+01
Pu-239	2.85E-01
Pu-240	6.00E-02
Pu-241	1.86E-01
Pu-242	5.34E-06
Sr-90	7.70E-06
Th-229	3.79E-14
Th-230	3.35E-07
Th-232	5.38E-17
U-233	3.90E-11
U-234	1.94E-03
U-235	1.88E-08
U-236	6.23E-08
U-238	2.90E-14

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225, 154

Waste Stream Description

Metal

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-21-08**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Glass					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	0.3	0.0	0.3
55-gal Drum Dir Ld w/ Liner	2.1	0.0	2.1
Cask - Misc w/ 2 - 30-gal Drums	1.1	0.0	1.1
Current Form Total	3.5	0.0	3.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.2	0.0	4.2
Final Form Total	4.2	0.0	4.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	32.11
Aluminum-based Metal/Alloys	12.24
Other Metal/Alloys	24.61
Other Inorganic Materials	7.00
Cellulosics	20.86
Rubber	16.12
Plastics	11.99
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.10E-01
Cs-137	2.13E-05
Np-237	2.08E-06
Pu-238	2.16E+01
Pu-239	6.47E-01
Pu-240	1.82E-01
Pu-241	6.62E-01
Pu-242	2.70E-05
Sr-90	2.02E-05
Th-229	1.49E-13
Th-230	4.41E-07
Th-232	1.73E-16
U-233	1.49E-10
U-234	2.54E-03
U-235	4.68E-08
U-236	1.94E-07
U-238	1.51E-13

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

Glass

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-21-09**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Hepa Filters					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	0.1	0.0	0.1
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Cask - Misc w/ 2 - 30-gal Drums	7.4	0.0	7.4
Current Form Total	8.1	0.0	8.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	14.1	0.0	14.1
Final Form Total	14.1	0.0	14.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	29.88
Aluminum-based Metal/Alloys	11.39
Other Metal/Alloys	22.90
Other Inorganic Materials	6.51
Cellulosics	19.42
Rubber	15.00
Plastics	11.16
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.25E-03
Cs-137	8.14E-07
Np-237	5.39E-08
Pu-238	1.04E+02
Pu-239	2.56E-02
Pu-240	5.98E-03
Pu-241	1.51E-02
Sr-90	7.70E-07
Th-229	4.11E-15
Th-230	2.24E-06
Th-232	5.99E-18
U-233	3.99E-12
U-234	1.26E-02
U-235	1.89E-09
U-236	6.56E-09
U-238	1.98E-15

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

Hepa Filters

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-21-12**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Non-combustible and combustible debris waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	3.6	0.0	3.6
55-gal Drum Dir Ld w/ Liner	113.4	0.0	113.4
Box - Crate	6.3	0.0	6.3
Cask - Misc w/ 1 - 30-gal Drum	32.4	0.0	32.4
Cask - Misc w/ 2 - 30-gal Drums	89.4	0.0	89.4
Current Form Total	245.1	0.0	245.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	335.7	0.0	335.7
SWB Dir Ld w/ Liner	5.7	0.0	5.7
Final Form Total	341.4	0.0	341.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	25.88
Aluminum-based Metal/Alloys	9.87
Other Metal/Alloys	19.84
Other Inorganic Materials	5.64
Cellulosics	16.82
Rubber	12.99
Plastics	9.67
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	36.47
Packaging Material, Rubber	0.56
Packaging Material, Steel	131.15
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.02E-01
Cs-137	3.25E-05
Np-237	3.84E-06
Pu-238	1.15E+02
Pu-239	8.05E-01
Pu-240	2.71E-01
Pu-241	1.24E+00
Pu-242	7.63E-05
Sr-90	3.09E-05
Th-229	3.67E-04
Th-230	4.02E-06
Th-232	2.29E-16
U-233	1.23E-01
U-234	1.89E-02
U-235	5.80E-06
U-236	2.73E-07
U-238	4.03E-13

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

COMBINED COMBUSTIBLE/NON-COMBUSTIBLE LAB TRASH

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-21-13**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Cemented wastewater treatment sludge (mixed)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	15.0	0.0	15.0
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	0.3	0.0	0.3
Other	489.1	0.0	489.1
Current Form Total	504.4	0.0	504.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	15.2	0.0	15.2
SWB Dir Ld w/ Liner	489.5	0.0	489.5
Final Form Total	504.7	0.0	504.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	76.12
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	13.54
Cement	2129.71
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	2.28
Packaging Material, Rubber	0.20
Packaging Material, Steel	152.76
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.08E+01
Cs-137	4.07E-04
Np-237	2.70E-05
Pu-238	6.14E-02
Pu-239	1.26E-01
Sr-90	2.85E-04
Th-229	2.69E-14
Th-230	4.75E-10
U-233	2.29E-10
U-234	1.33E-05
U-235	4.28E-05
U-238	2.17E-05

Haz. Waste No(s).

D007, F001, F002

No TRUCON Codes Provided

Waste Stream Description

Cemented Wastewater Treatment Sludge Solidified aqueous waste generated from facility and equipment operations and maintenance. Solidified aqueous waste is a dewatered sludge generated by the vacuum filtration of solids from treated aqueous waste slurry. The filter media (diatomaceous earth) with the entrapped filtrate is then placed in drums with dry concreted absorbent.

Waste Stream ID: **LA-TA-21-15**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	Solidified organics					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	0.2	0.0	0.2
55-gal Drum Dir Ld w/ Liner	3.3	0.0	3.3
Current Form Total	3.5	0.0	3.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.5	0.0	3.5
Final Form Total	3.5	0.0	3.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	52.10
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	19.15
Cellulosics	0.00
Rubber	0.00
Plastics	81.64
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	415.27
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.37E-01
Cs-137	6.80E-05
Np-237	1.66E-07
Pu-238	2.84E-02
Pu-239	1.35E+00
Pu-240	2.34E-01
Pu-241	2.90E+00
Pu-242	1.34E-05
Sr-90	6.76E-05
Th-229	1.58E-16
Th-230	8.48E-11
Th-232	2.73E-18
U-233	1.37E-12
U-234	2.47E-06
U-235	4.24E-08
U-236	2.77E-08
U-238	8.35E-15

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

Solidified organics

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-21-16**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	SOLIDIFIED INORGANIC PROCESS SOLID					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	25.9	0.0	25.9
55-gal Drum Dir Ld w/ Liner	31.4	0.0	31.4
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	0.3	0.0	0.3
Current Form Total	57.7	0.0	57.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	57.4	0.0	57.4
Final Form Total	57.4	0.0	57.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	7.34
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	1.31
Cement	205.35
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.66E+00
Cs-137	7.44E-04
Np-237	2.00E-06
Pu-238	4.35E-01
Pu-239	1.12E+01
Pu-240	2.66E+00
Pu-241	3.58E+01
Pu-242	2.17E-04
Sr-90	7.39E-04
Th-229	1.91E-15
Th-230	1.44E-09
Th-232	3.11E-17
U-233	1.65E-11
U-234	4.16E-05
U-235	5.76E-05
U-236	3.15E-07
U-238	1.35E-13

Haz. Waste No(s).

D008

No TRUCON Codes Provided

Waste Stream Description

LEACHED PROCESS RESIDUES

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-21-17**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Process solids					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	0.1	0.0	0.1
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Current Form Total	0.5	0.0	0.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	29.57
Aluminum-based Metal/Alloys	11.28
Other Metal/Alloys	22.67
Other Inorganic Materials	6.44
Cellulosics	19.22
Rubber	14.84
Plastics	11.05
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.68E-03
Cs-137	1.35E-06
Np-237	8.91E-08
Pu-238	9.28E-04
Pu-239	4.24E-02
Pu-240	9.88E-03
Pu-241	2.50E-02
Pu-242	5.71E-07
Sr-90	1.27E-06
Th-229	6.79E-15
Th-230	5.10E-11
Th-232	9.90E-18
U-233	6.60E-12
U-234	2.03E-07
U-235	3.12E-09
U-236	1.08E-08
U-238	3.28E-15

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

Special items (precious metals) requiring tracking by CST-7

Waste Stream ID: **LA-TA-50-18**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Cemented caustic liquid waste (mixed)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Current Form Total	0.4	0.0	0.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Final Form Total	0.4	0.0	0.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	1.03
Cement	1026.98
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.23E-01
Np-237	8.93E-06
Pu-239	1.39E-02
Th-229	7.89E-13
U-233	7.24E-10
U-235	5.07E-10

Haz. Waste No(s).

D007, F001, F002

TRUCON Code(s)

111/211

Waste Stream Description

Cemented Caustic Liquid Waste Solidified (through cementation) caustic aqueous waste from TA-55. The sludge is a residue from numerous treatment and filtration operations involving aqueous liquid radioactive waste.

Waste Stream ID: **LA-TA-50-19**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Homogeneous Inorganic Solids					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	62.8	0.0	62.8
Current Form Total	62.8	0.0	62.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	62.8	0.0	62.8
Final Form Total	62.8	0.0	62.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.09
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.08
Cellulosics	0.00
Rubber	0.00
Plastics	4.52
Cement	0.00
Solidified Inorganic Material	848.58
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.78E-01
Np-237	4.90E-07
Pu-238	3.42E-02
Pu-239	1.28E-01
Pu-240	2.40E-02
Pu-241	3.01E-01
Pu-242	1.39E-06
Th-229	4.88E-16
Th-230	1.53E-11
Th-232	2.81E-19
U-233	4.16E-12
U-234	6.12E-07
U-235	4.32E-09
U-236	2.85E-09
U-238	8.64E-16

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D021, D022, D035, D038, D039, D040, F001, F002, F003, F005

TRUCON Code(s)

111/211, 125/225

Waste Stream Description

Homogeneous dewatered sludge generated in the TA-50-01 RLWTF main treatment process.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-55-14**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Cemented TRU Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Current Form Total	0.6	0.0	0.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	42.06
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	7.48
Cement	1176.76
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.22E+01
Pu-238	6.18E-01
Pu-239	2.10E+01
Pu-240	4.91E+00
Pu-241	7.46E+01
Pu-242	2.84E-04
U-234	4.49E-05
U-235	7.80E-07

No Hazardous Waste Numbers Provided

TRUCON Code(s)

114/214, 126/226

Waste Stream Description

Solidified homogenous solid waste(cemented TRU waste) generated TA-55 R&D/fabrication and associated recovery, facility and equipment maintenance, D&D, waste repackaging, and below-grade retrieval operations.

Waste Stream ID: **LA-TA-55-19**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Combustible debris waste (mixed)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	41.8	0.0	41.8
Cask - Misc w/ 1 - 30-gal Drum	0.4	0.0	0.4
Current Form Total	42.2	0.0	42.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	42.6	0.0	42.6
Final Form Total	42.6	0.0	42.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	65.86
Aluminum-based Metal/Alloys	0.27
Other Metal/Alloys	7.89
Other Inorganic Materials	42.71
Cellulosics	5.45
Rubber	8.18
Plastics	25.21
Cement	0.00
Solidified Inorganic Material	1.05
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.39E+00
Cs-137	2.29E-04
Np-237	7.86E-05
Pu-238	2.71E+00
Pu-239	5.87E+00
Pu-240	2.90E+00
Pu-241	2.34E+01
Pu-242	1.64E-03
Sr-90	2.18E-04
Th-229	8.50E-12
Th-230	1.45E-06
Th-232	3.15E-14
U-233	7.27E-09
U-234	5.21E-03
U-235	1.42E-04
U-236	2.19E-05
U-238	3.32E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D021, D022, D035, D038, D039, D040, F001, F002, F003, F005

TRUCON Code(s)

125/225, 154

Waste Stream Description

Combustible waste generated from facility and equipment operations and maintenance. This waste includes paper, rags, plastic, rubber, wood-based HEPA filters, and plastic-based and cellulose-based waste generated at the facility. Plastic-based waste includes, but may not be limited to, tape, polyethylene and vinyl; gloves; plastic vials; polystyrene; Tygon tubing; polyvinyl chloride plastic; Teflon products; Plexiglas; and dry box gloves (unleaded neoprene base). Cellulose-based waste includes, but may not be limited to, rags, wood, paper, cardboard, laboratory coats and coveralls, booties and cotton gloves, and similar materials. The waste stream may also contain a smaller fraction of non-combustible solids (e.g., scrap metal, crucibles, metal lids, zippers, discarded tools) and a small fraction of homogenous solids, salts, leached solids, ash, hydroxide cakes, crucibles, impure oxides.

Waste Stream ID: **LA-TA-55-21**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Metal debris waste (mixed)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.3	0.0	2.3
Current Form Total	2.3	0.0	2.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.3	0.0	2.3
Final Form Total	2.3	0.0	2.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	121.06
Aluminum-based Metal/Alloys	0.49
Other Metal/Alloys	14.51
Other Inorganic Materials	78.51
Cellulosics	10.02
Rubber	15.03
Plastics	46.35
Cement	0.00
Solidified Inorganic Material	1.93
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.33E-01
Cs-137	1.07E-05
Np-237	1.18E-06
Pu-238	7.65E+00
Pu-239	2.56E-01
Pu-240	9.12E-02
Pu-241	4.95E-01
Pu-242	2.50E-05
Sr-90	1.01E-05
Th-229	6.72E-14
Th-230	5.64E-07
Th-232	6.84E-17
U-233	7.54E-11
U-234	2.29E-03
U-235	1.74E-08
U-236	8.66E-08
U-238	8.92E-07

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225, 154

Waste Stream Description

Metal Noncombustible waste including small tools, small equipment, cans, motors, pumps, process equipment, gloveboxes, ventilation ductwork, and pipes. May also contain some glass, ceramic, porcelain, etc. as well as some small fraction of combustible waste (e.g., paper, rubber, plastics).

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-55-30**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Non-combustible and combustible debris waste (mixed)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	68.0	0.0	68.0
55-gal POC - 12" w/ Liner	0.2	0.0	0.2
Current Form Total	68.2	0.0	68.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	68.0	0.0	68.0
55-gal POC - 12" w/ Liner	0.2	0.0	0.2
Final Form Total	68.2	0.0	68.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	80.66
Aluminum-based Metal/Alloys	0.33
Other Metal/Alloys	9.67
Other Inorganic Materials	52.31
Cellulosics	6.68
Rubber	10.01
Plastics	30.88
Cement	0.00
Solidified Inorganic Material	1.29
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.41
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	131.98
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.87E+00
Cs-137	9.97E-05
Np-237	3.30E-05
Pu-238	2.20E+00
Pu-239	2.67E+00
Pu-240	1.56E+00
Pu-241	1.54E+01
Pu-242	2.11E-03
Pu-244	3.87E-10
Sr-90	9.51E-05
Th-229	1.76E-12
Th-230	1.84E-07
Th-232	1.66E-15
U-233	2.04E-09
U-234	7.52E-04
U-235	8.64E-06
U-236	1.80E-06
U-238	1.24E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D021, D022, D035, D038, D039, D040, F001, F002, F003, F005

TRUCON Code(s)

125/225, 154

Waste Stream Description

Non-combustible and combustible waste generated from facility and equipment operations and maintenance. This waste includes, but may not be limited to, small tools, small equipment, cans, motors, pumps, process equipment, gloveboxes, ventilation ductwork, metal-based HEPA filters, pipes, glass, slag and crucibles, salt, discarded lab ware, windows, and bottles. The waste stream may also contain a smaller fraction of combustible solids (e.g., paper, rags, plastic, rubber, leaded gloves) and a small fraction of homogeneous solids (e.g., leached solids, ash, hydroxide cakes, impure oxides).

Waste Stream ID: **LA-TA-55-32**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Non-combustible and combustible debris waste (mixed)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Current Form Total	1.9	0.0	1.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	29.58
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	1.83
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	15.50
Cement	0.00
Solidified Inorganic Material	93.97
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.36E-03
Np-237	2.18E-07
Pu-238	6.21E-02
Pu-239	1.34E-02
Pu-240	3.13E-03
Pu-241	2.80E-02
Pu-242	1.80E-07
Th-229	2.52E-15
Th-230	5.38E-11
Th-232	1.46E-19
U-233	7.25E-12
U-234	1.45E-06
U-235	1.05E-10
U-236	7.41E-10
U-238	2.24E-16

No Hazardous Waste Numbers Provided

TRUCON Code(s)

124/224, 125/225

Waste Stream Description

MIXED COMBUSTIBLE/NONCOMBUSTIBLE WASTE

Waste Stream ID: **LA-TA-55-38**

Appendix A

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Cemented inorganics (mixed)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Cask - Misc w/ 1 - 30-gal Drum	0.4	0.0	0.4
Current Form Total	0.6	0.0	0.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.0	0.0	1.0
Final Form Total	1.0	0.0	1.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.94
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.17
Cement	26.38
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.35E-02
Cs-137	6.36E-06
Np-237	3.02E-08
Pu-238	2.09E+01
Pu-239	1.83E-02
Pu-240	9.10E-03
Pu-241	7.47E-02
Pu-242	9.43E-06
Sr-90	6.32E-06
Th-229	2.99E-17
Th-230	1.26E-07
Th-232	1.06E-19
U-233	2.55E-13
U-234	3.55E-03
U-235	7.66E-10
U-236	1.08E-09
U-238	5.85E-15

Haz. Waste No(s).

D008

TRUCON Code(s)

114/214, 126/226

Waste Stream Description

Cemented Inorganics and Spent Samples Solidified inorganic process solids generated from facility and equipment operations and maintenance. This waste includes process leached solids, ash, filter cakes, salts, metal oxides, fines, evaporator bottoms, and sample residues (received from the CMR building) stabilized in Portland or gypsum cement.

Waste Stream ID: **LB-T001**

Appendix A

Waste Profile Report

Site	Lawrence Berkeley Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	LBL-Non Mixed Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
12.2-gal Drum	0.0	0.0	0.1
Current Form Total	0.0	0.0	0.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.2	0.4
Final Form Total	0.2	0.2	0.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.19
Other Inorganic Materials	0.08
Cellulosics	4.95
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.49
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.40E-02
Am-243	4.81E-05
Cs-137	4.57E-04
Np-237	4.11E-02
Pu-239	1.48E+00
Pu-240	4.81E-02
Pu-241	7.79E-01
Th-232	2.69E-03
U-238	1.88E-06

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Heterogeneous transuranic, non mixed waste

Waste Stream ID: **LB-T002**

Appendix A

Waste Profile Report

Site	Lawrence Berkeley Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	LBL - Mixed Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
2.5-gal Drum	0.0	0.0	0.0
Current Form Total	0.0	0.0	0.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.2	0.4
Final Form Total	0.2	0.2	0.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.07
Cellulosics	1.78
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.33E-02
Am-243	5.77E-05
Np-237	2.79E-04
Pu-239	2.64E-01
Pu-241	4.57E-01

Haz. Waste No(s).

D007

TRUCON Code(s)

125/225

Waste Stream Description

Heterogeneous transuranic mixed waste

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LL-M001**

Appendix A

Waste Profile Report

Site	Lawrence Livermore National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	R&D Glovebox Waste (Form 1)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	14.1	0.0	14.1
55-gal Drum Dir Ld w/o Liner	33.5	375.2	408.7
55-gal POC - 12" w/ Liner	2.9	18.7	21.6
Current Form Total	50.5	394.0	444.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	47.6	375.2	422.9
55-gal POC - 12" w/ Liner	2.9	18.7	21.6
Final Form Total	50.5	394.0	444.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	71.63
Aluminum-based Metal/Alloys	8.43
Other Metal/Alloys	17.08
Other Inorganic Materials	11.15
Cellulosics	35.41
Rubber	16.46
Plastics	37.13
Cement	18.27
Solidified Inorganic Material	5.83
Solidified Organic Material	0.17
Soils	0.11
Vitrified	0.00
Packaging Material, Cellulosics	6.57
Packaging Material, Plastic	1.80
Packaging Material, Rubber	0.57
Packaging Material, Steel	150.14
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.28E+00
Am-243	5.41E-04
Cm-244	1.83E+00
Cs-137	1.67E-03
Np-237	3.48E-05
Pu-238	3.62E+00
Pu-239	3.76E+00
Pu-240	1.10E+00
Pu-241	1.22E+01
Pu-242	3.59E-04
Pu-244	6.38E-13
Sr-90	1.66E-03
Th-229	3.56E-06
Th-230	6.36E-07
Th-232	3.29E-08
U-233	9.09E-04
U-234	1.51E-04
U-235	6.33E-06
U-236	6.51E-08
U-238	2.48E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D028, D029, D035, D040, F001, F002, F005

TRUCON Code(s)

116/216

Waste Stream Description

Specific waste items in this waste stream may include paper cartons, cardboard, Kimwipes, cotton swabs, tissues, cheesecloth, grinding paper, plastic (e.g., bags, sheet, tape, containers, pipette tips, and glovebox windows), Neoprene and Hypalon gloves (leaded and non-leaded), aluminum foil, tin cans, hardware (e.g., nuts, bolts, washers, fittings, gauges, fixtures, thermocouples), metal tools (e.g., screwdrivers and pliers), metal parts, equipment (with or without circuit boards), copper (wire, tubing, flanges, rods, and molds), sealed sources, aerosol cans, glass (e.g., beakers, vials, and ion exchange columns with resin), graphite molds , crucibles (magnesium oxide, tantalum), epoxy resin chunks, lead metal (e.g., bricks, foil), Kaufman cans (lead seams), lead-lined and cadmium-lined steel cans, mercury batteries, fluorescent and incandescent light bulbs, and small quantities of pyrochemical salts and solidified aqueous or organic liquids (individual drums contain less than 50 percent, by volume, solidified liquids, and/or salts).

Waste Stream ID: **LL-T004**

Appendix A

Waste Profile Report

Site	Lawrence Livermore National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Salt Waste			**Inventory Date**	12/31/2011
Stream Name	Pyrochemical salt waste (Form 4)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	1.2	0.0	1.2
Final Form Total	1.2	0.0	1.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	20.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	290.00
Cellulosics	2.00
Rubber	0.00
Plastics	20.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.11E-02
Cm-244	1.46E-03
Np-237	1.62E-07
Pu-238	8.25E-03
Pu-239	3.97E-02
Pu-240	1.92E-02
Pu-241	2.05E-01
Pu-242	6.24E-06
Th-229	1.17E-16
Th-230	4.32E-13
Th-232	5.62E-20
U-233	1.35E-12
U-234	4.69E-08
U-235	7.83E-11
U-236	1.14E-09
U-238	1.94E-15

No Hazardous Waste Numbers Provided

TRUCON Code(s)

124/224

Waste Stream Description

The waste consists primarily of used chloride and fluoride salts from pyrochemical processes such as electrorefining, molten salt extraction, and direct oxide reduction. There may also be up to 20% heterogeneous organic glovebox bagout waste packaged with the salt waste. This waste does not contain any RCRA listed hazardous materials.

Waste Stream ID: **LL-W018-S5100**

Appendix A

Waste Profile Report

Site	Lawrence Livermore National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Combined metal scrap & incidental combust.(Form 3)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Misc	120.6	0.0	120.6
SLB2 (5' x 5' x 8) Dir Ld	0.0	141.5	141.5
SWB Dir Ld w/o Liner	20.8	138.0	158.8
Current Form Total	141.4	279.5	420.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SLB2 (5' x 5' x 8) Dir Ld	96.2	141.5	237.7
SWB Dir Ld w/o Liner	20.8	138.0	158.8
Final Form Total	117.0	279.5	396.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	65.70
Aluminum-based Metal/Alloys	4.00
Other Metal/Alloys	15.80
Other Inorganic Materials	0.67
Cellulosics	17.57
Rubber	3.32
Plastics	2.54
Cement	1.58
Solidified Inorganic Material	0.00
Solidified Organic Material	3.16
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.16
Packaging Material, Steel	190.68
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.83E-02
Cm-244	5.43E-05
Np-237	1.16E-07
Pu-238	7.12E-03
Pu-239	6.12E-02
Pu-240	1.83E-02
Pu-241	4.46E-01
Pu-242	3.95E-06
Th-229	1.22E-16
Th-230	1.51E-12
Th-232	2.14E-19
U-233	1.01E-12
U-234	8.16E-08
U-235	2.41E-10
U-236	2.17E-09
U-238	2.45E-15

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D028, D029, D035, D040, F001, F002, F005

TRUCON Code(s)

125/225

Waste Stream Description

This waste steram is composed primarily of objects which, because of physical size, cannot be packaged in a 55-gallon drum. Typical objects include decommissioned gloveboxes, hoods, and large pieces of equipment (lathes, mills, etc.). This waste stream may contain lead metal (e.g., bricks, foil), Kaufman cans (lead seams), lead-lined and cadmium-lined steel cans, mercury batteries, fluorescent and incandescent light bulbs. The void space in boxes may be filled with other TRU waste items or with foam in plastic bags.

Waste Stream ID: **LL-W018-SS**

Appendix A

Waste Profile Report

Site	Lawrence Livermore National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Sealed Sources					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	4.2	0.0	4.2
55-gal POC - 12" w/ Liner	0.0	4.2	4.2
Current Form Total	4.2	4.2	8.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal POC - 12" w/ Liner	4.2	4.2	8.3
Final Form Total	4.2	4.2	8.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	7.11
Aluminum-based Metal/Alloys	1.52
Other Metal/Alloys	4.31
Other Inorganic Materials	3.78
Cellulosics	1.54
Rubber	0.00
Plastics	0.03
Cement	0.00
Solidified Inorganic Material	9.30
Solidified Organic Material	4.92
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	135.10
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	528.85
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.89E+01
Am-243	2.50E-06
Cm-244	1.87E-04
Cs-137	3.51E-03
Np-237	2.63E-05
Pu-238	3.06E+00
Pu-239	1.44E-01
Pu-240	4.61E-04
Pu-241	8.61E-02
Pu-244	2.85E-23
Sr-90	1.09E-02
Th-229	2.95E-14
Th-230	6.48E-10
Th-232	5.39E-21
U-233	2.37E-10
U-234	3.50E-05
U-235	1.03E-07
U-236	5.46E-11

No Hazardous Waste Numbers Provided

TRUCON Code(s)

117/217

Waste Stream Description

Specific waste items in this waste stream include sealed sources composed primarily of metal or metal encapsulated in a plastic or resin disk. Other waste items consist of packaging including cans, ice cream cartons, and plastic bags, sheet, and tape, bentonite clay or other inorganic absorbents such as Floor Dry

Waste Stream ID: **LL-W019**

Appendix A

Waste Profile Report

Site	Lawrence Livermore National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	Solidified Waste (Form 2)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	15.4	0.0	15.4
55-gal Drum Dir Ld w/o Liner	5.6	19.8	25.4
Current Form Total	21.0	19.8	40.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	21.0	19.8	40.8
Final Form Total	21.0	19.8	40.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	23.19
Aluminum-based Metal/Alloys	45.07
Other Metal/Alloys	2.12
Other Inorganic Materials	4.51
Cellulosics	4.04
Rubber	5.86
Plastics	33.67
Cement	0.00
Solidified Inorganic Material	103.30
Solidified Organic Material	39.41
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.77E+00
Am-243	1.02E-07
Cm-244	8.17E-04
Cs-137	1.79E-06
Np-237	8.36E-05
Pu-238	1.23E+00
Pu-239	4.77E+00
Pu-240	1.29E+00
Pu-241	1.51E+01
Pu-242	2.19E-04
Sr-90	3.79E-07
Th-229	9.52E-06
Th-230	3.66E-10
Th-232	3.76E-18
U-233	5.41E-02
U-234	2.34E-05
U-235	2.05E-05
U-236	7.62E-08
U-238	1.06E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D028, D029, D035, D040, F001, F002, F005

TRUCON Code(s)

113/213

Waste Stream Description

This waste stream consists of drums with 50 percent or greater by volume solidified aqueous or organic liquids. Additional waste in each container includes glovebox trash.

Waste Stream ID: **ND-T001**

Appendix A

Waste Profile Report

Site	Nuclear Radiation Development Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	AmO2 Bagout/ Silver Bagout					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.4	4.2	4.6
Current Form Total	0.4	4.2	4.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.4	4.2	4.6
Final Form Total	0.4	4.2	4.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	211.54
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	10.63
Other Inorganic Materials	5.41
Cellulosics	211.54
Rubber	31.73
Plastics	52.88
Cement	0.00
Solidified Inorganic Material	531.73
Solidified Organic Material	10.63
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.14E+01

Haz. Waste No(s).

D008, D011, D035, D040, F001, F002, F005

TRUCON Code(s)

125/225

Waste Stream Description

AmO2 Bagout- Material generated from the production of ionization sources containing Am-241. Material consists mainly of consumable items used in the production gloveboxes(e.g tissues paper towels, graphite blocks) but also includes equipment and tools that have exceeded their useful life. Most material is contained in one gallon cans that are placed into fifty five gallon drums. Silver Bagout- Material is mainly a vitrified slag that is created during the recovery of precious metals from scrap Am-241 foil. Also contained are items used in the glovebox during the recovery process (e.g. plastic bags, Carbon/Graphite crucibles, paper towels, induction furnaces).

Waste Stream ID: **ND-T002**

Appendix A

Waste Profile Report

Site	Nuclear Radiation Development Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Discarding Excess/Expired Materials	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Returned Smoke Detector Sources					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	1.5	0.8	2.3
Current Form Total	1.5	0.8	2.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	1.5	0.8	2.3
Final Form Total	1.5	0.8	2.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	36.33
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	3.63
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.24E+00
Np-237	1.46E-06
Th-229	3.72E-16
U-233	6.34E-12

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Sealed sources retrurned from smoke detector manufacturers or other end users.

Waste Stream ID: **NT-JAS-01**

Appendix A

Waste Profile Report

Site	Nevada National Security Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Combined metal scrap and incidental combustibles					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/o Liner	34.0	51.0	85.1
Current Form Total	34.0	51.0	85.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/o Liner	34.0	51.0	85.1
Final Form Total	34.0	51.0	85.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	720.74
Aluminum-based Metal/Alloys	3.68
Other Metal/Alloys	0.00
Other Inorganic Materials	3.68
Cellulosics	0.00
Rubber	3.68
Plastics	3.68
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.47E-02
Np-237	9.61E-07
Pu-238	4.77E-02
Pu-239	1.48E+00
Pu-240	3.38E-01
Pu-241	2.18E+00
Pu-242	1.85E-05
Th-229	1.01E-14
Th-230	4.13E-11
Th-232	1.58E-17
U-233	2.97E-11
U-234	1.11E-06
U-235	1.17E-08
U-236	8.01E-08
U-238	2.30E-14

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Waste stream consists of spent Primary Target Chambers from Jasper gas gun experiments. PTCs are metal chambers used to contain debris from the impact of a sabot on a disk of plutonium metal.

Waste Stream ID: **NT-W021**

Appendix A

Waste Profile Report

Site	Nevada National Security Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	V3XA Spheres					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Crate	5.1	0.0	5.1
Current Form Total	5.1	0.0	5.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	5.4	0.0	5.4
Final Form Total	5.4	0.0	5.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	464.11
Aluminum-based Metal/Alloys	0.98
Other Metal/Alloys	1.56
Other Inorganic Materials	0.00
Cellulosics	1.50
Rubber	0.00
Plastics	0.00
Cement	2.22
Solidified Inorganic Material	81.08
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.38E+00
Np-237	1.75E-06
Pu-238	2.44E-01
Pu-239	9.43E+00
Pu-240	2.17E+00
Pu-241	1.04E+01
Pu-242	1.92E-04
Th-229	1.38E-13
Th-230	4.76E-08
Th-232	2.53E-17
U-233	4.03E-10
U-234	1.30E-03
U-235	8.91E-06
U-236	2.56E-07
U-238	4.59E-04

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

The two steel vessels are 1-inch thick by 3-feet diameter, weighing about 3300 lbs. each. The vessels contain heterogeneous mixtures of the following materials: Plutonium, D-38, Beryllium metal, Completely burned high explosive, Stainless steel, Brass, Polystyrene foam, Aluminum, Coke (degassed coal), Water absorbed by the coke, Steel, Glass, Epoxy resin, Thermalite (aerated cement block), Plaster, Hortag (fly-ash and clay), Wood, and Krypton-85 tracer gas for leak detection. The UK has had similar vessels in storage for over ten years, but none containing plutonium have ever been opened. Vessels containing D-38 only have been opened, with small amounts of water vapor and some loose debris found inside. The bulk of the materials were found to be trapped within the thick coke layer lining the inner surface of the vessel. No more wastes of this type are planned to be generated.

Waste Stream ID: **OR-CHEM-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Analytical Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL Analytical Chemistry CH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum Dir Ld	0.4	0.0	0.4
55-gal Drum Dir Ld w/o Liner	16.0	0.0	16.0
79-gal Drum Dir Ld	1.2	0.0	1.2
Box - Misc	2.9	0.0	2.9
Current Form Total	20.5	0.0	20.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	20.4	0.0	20.4
Final Form Total	20.4	0.0	20.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	19.49
Aluminum-based Metal/Alloys	2.33
Other Metal/Alloys	3.15
Other Inorganic Materials	4.55
Cellulosics	35.83
Rubber	22.88
Plastics	28.24
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.23
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.35E-01
Am-243	2.63E-03
Cm-244	1.29E+00
Cs-137	2.81E-01
Np-237	5.96E-07
Pu-238	1.25E+01
Pu-239	3.07E-01
Pu-240	3.91E-02
Pu-241	2.88E-01
Pu-242	6.37E-05
Sr-90	1.67E-01
Th-232	1.67E-07
U-233	5.41E-02
U-234	1.21E-04
U-235	4.14E-06
U-236	1.20E-09
U-238	1.11E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D011, D019, D022, F002, F005

TRUCON Code(s)

125/225

Waste Stream Description

Waste consists of CH-TRU debris from analytical chemistry operations at ORNL

Waste Stream ID: **OR-GENR-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL General Research & Development CH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum Dir Ld	1.2	0.0	1.2
55-gal Drum Dir Ld w/o Liner	26.4	0.0	26.4
79-gal Drum Dir Ld	0.6	0.0	0.6
Current Form Total	28.3	0.0	28.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	28.1	0.0	28.1
Final Form Total	28.1	0.0	28.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	20.74
Aluminum-based Metal/Alloys	5.15
Other Metal/Alloys	5.15
Other Inorganic Materials	20.74
Cellulosics	38.22
Rubber	25.14
Plastics	10.43
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.13
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.03E-02
Am-243	3.21E-02
Cm-244	1.53E+00
Cs-137	8.43E-04
Np-237	1.32E-03
Pu-238	2.23E-01
Pu-239	2.82E-01
Pu-240	1.04E-02
Pu-241	9.60E-05
Pu-242	1.18E-02
Sr-90	7.17E-04
Th-229	1.88E-07
Th-230	1.98E-05
Th-232	1.29E-07
U-234	4.48E-05
U-235	3.24E-07
U-236	2.99E-11
U-238	5.30E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D028, F002, F005

TRUCON Code(s)

125/225

Waste Stream Description

Waste consists of CH-TRU debris from general R&D at ORNL

Waste Stream ID: **OR-GENR-RH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL General Research & Development RH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	2.9	0.0	2.9
79-gal Drum Dir Ld	0.3	0.0	0.3
Current Form Total	3.2	0.0	3.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	3.1	0.0	3.1
Final Form Total	3.1	0.0	3.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	27.16
Aluminum-based Metal/Alloys	6.75
Other Metal/Alloys	6.75
Other Inorganic Materials	27.16
Cellulosics	50.04
Rubber	32.92
Plastics	13.66
Cement	0.00
Solidified Inorganic Material	0.16
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.57E-03
Am-243	5.51E-02
Cm-244	1.07E-01
Np-237	2.22E-03
Pu-239	3.35E-01
Pu-240	8.45E-04
Pu-241	2.71E-05
Pu-242	1.70E-02
Pu-244	9.32E-12
Th-229	7.32E-04
Th-230	5.79E-13
Th-232	2.72E-19
U-233	3.20E-01
U-234	4.77E-09
U-235	8.59E-09
U-236	4.88E-10
U-238	6.43E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D028, F002, F005

TRUCON Code(s)

325

Waste Stream Description

Waste consists of RH-TRU debris from general R&D at ORNL

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-ISTP-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL Isotopes Facilities CH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum Dir Ld	5.0	0.0	5.0
55-gal Drum Dir Ld w/o Liner	110.0	0.0	110.0
79-gal Drum Dir Ld	18.5	0.0	18.5
85-gal Drum Dir Ld w/o Liner	1.0	0.0	1.0
Box - Misc	8.2	0.0	8.2
Current Form Total	142.7	0.0	142.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	141.4	0.0	141.4
55-gal POC - 6" w/ Liner	5.4	0.0	5.4
Final Form Total	146.8	0.0	146.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	55.71
Aluminum-based Metal/Alloys	2.92
Other Metal/Alloys	15.99
Other Inorganic Materials	3.44
Cellulosics	27.85
Rubber	15.30
Plastics	50.38
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.34
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	7.91
Packaging Material, Plastic	1.37
Packaging Material, Rubber	0.57
Packaging Material, Steel	137.76
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.18E+00
Am-243	9.23E-03
Cm-244	1.72E+01
Cs-137	2.14E-05
Np-237	3.19E-03
Pu-238	2.07E+01
Pu-239	5.69E-01
Pu-240	3.22E+00
Pu-241	4.69E+02
Pu-242	2.06E-03
Pu-244	6.38E-05
Sr-90	2.61E-06
Th-229	1.48E-07
Th-230	3.51E-04
Th-232	8.49E-06
U-233	1.24E-02
U-234	6.35E-04
U-235	6.50E-06
U-236	8.72E-06
U-238	1.26E-05

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011, D019, D022, F002, F005

TRUCON Code(s)

125/225

Waste Stream Description

Waste consists of CH-TRU debris from isotopes production at ORNL

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-ISTP-RH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL Isotopes Facilities RH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	10.8	0.0	10.8
79-gal Drum w/ 1 - 55-gal Drum	2.1	0.0	2.1
Cask - Misc	8.3	0.0	8.3
Current Form Total	21.2	0.0	21.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	20.6	0.0	20.6
Final Form Total	20.6	0.0	20.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	199.59
Aluminum-based Metal/Alloys	10.47
Other Metal/Alloys	57.29
Other Inorganic Materials	12.32
Cellulosics	99.80
Rubber	54.83
Plastics	180.50
Cement	0.00
Solidified Inorganic Material	1.23
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.31E+00
Am-243	9.74E-04
Cm-244	1.16E+01
Np-237	8.13E-04
Pu-238	1.54E+01
Pu-239	4.45E-01
Pu-240	7.48E-01
Pu-241	3.33E+00
Pu-242	7.84E-04
Pu-244	2.58E-10
Th-229	1.47E-05
Th-230	1.55E-07
Th-232	5.09E-05
U-233	6.42E-03
U-234	1.25E-03
U-235	2.70E-06
U-236	5.59E-07
U-238	8.31E-07

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011, D019, D022, F002, F005

TRUCON Code(s)

325

Waste Stream Description

Waste consists of RH-TRU debris from isotopes production at ORNL

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-NBL-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	New Brunswick Laboratory CH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum Dir Ld	0.8	0.0	0.8
55-gal Drum Dir Ld w/o Liner	12.5	0.0	12.5
79-gal Drum Dir Ld	8.4	0.0	8.4
85-gal Drum Dir Ld w/o Liner	0.3	0.0	0.3
Current Form Total	22.0	0.0	22.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	21.6	0.0	21.6
Final Form Total	21.6	0.0	21.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	26.73
Aluminum-based Metal/Alloys	1.75
Other Metal/Alloys	34.59
Other Inorganic Materials	71.62
Cellulosics	10.48
Rubber	18.69
Plastics	10.48
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.35
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.14E-02
Am-243	1.93E-04
Cm-244	1.54E+00
Cs-137	1.83E-02
Np-237	7.73E-08
Pu-238	8.03E-02
Pu-239	9.74E-02
Pu-240	4.29E-02
Pu-241	4.92E-03
Pu-242	7.64E-08
Sr-90	8.80E-03
Th-229	5.13E-07
Th-232	3.47E-07
U-233	1.52E-03
U-234	1.12E-04
U-235	1.50E-05
U-238	9.26E-05

Haz. Waste No(s).

D004, D005, D007, D008, D009, D011, D022, F002, F005

TRUCON Code(s)

125/225

Waste Stream Description

Waste consists of CH-TRU debris from NBL

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-NFS-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Nuclear Fuel Services CH-TRU Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	90.1	0.0	90.1
Box - Misc	5.1	0.0	5.1
Current Form Total	95.2	0.0	95.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	95.1	0.0	95.1
Final Form Total	95.1	0.0	95.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	67.42
Aluminum-based Metal/Alloys	5.95
Other Metal/Alloys	5.45
Other Inorganic Materials	361.40
Cellulosics	13.88
Rubber	2.97
Plastics	38.17
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.50
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.39E-01
Am-243	5.98E-08
Cm-244	3.45E-01
Cs-137	2.07E-07
Np-237	6.07E-07
Pu-238	3.00E-01
Pu-239	2.06E+00
Pu-240	1.12E+00
Pu-241	1.92E+01
Pu-242	1.19E-04
Pu-244	1.49E-11
Sr-90	2.07E-07
Th-229	2.48E-07
Th-232	2.61E-07
U-233	1.10E-04
U-234	6.32E-02
U-235	3.84E-06
U-236	8.37E-09
U-238	6.71E-05

Haz. Waste No(s).

D006, D008, D009, D011, F002

TRUCON Code(s)

125/225

Waste Stream Description

Waste consists of CH-TRU debris from NFS

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-NFS-CH-HOM**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Nuclear Fuel Services CH-TRU Homogeneous Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	11.4	0.0	11.4
Current Form Total	11.4	0.0	11.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	11.4	0.0	11.4
Final Form Total	11.4	0.0	11.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	6.78
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	79.89
Cellulosics	0.00
Rubber	0.00
Plastics	13.56
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	10.89
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.15E+00
Cs-137	4.71E-06
Np-237	1.48E-04
Pu-238	1.59E+00
Pu-239	1.14E+01
Pu-240	4.54E+00
Pu-241	8.19E+01
Pu-242	7.39E-04
Sr-90	4.71E-06
Th-229	1.42E-06
Th-232	7.62E-07
U-233	1.11E-03
U-234	8.00E-02
U-235	1.00E-05
U-238	2.19E-04

Haz. Waste No(s).

D006, D009

TRUCON Code(s)

111/211

Waste Stream Description

Waste consists of homogeneous waste from NFS

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-NFS-CH-SOIL**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Nuclear Fuel Services CH-TRU Soil Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	12.5	0.0	12.5
Current Form Total	12.5	0.0	12.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	12.5	0.0	12.5
Final Form Total	12.5	0.0	12.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	2.56
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	17.04
Soils	832.40
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.44E-01
Cs-137	5.04E-07
Np-237	1.46E-07
Pu-238	8.30E-02
Pu-239	9.45E-01
Pu-240	3.97E-01
Pu-241	4.67E+00
Pu-242	3.30E-05
Sr-90	4.65E-07
Th-230	1.83E-06
Th-232	6.26E-07
U-233	1.35E-03
U-234	1.64E-02
U-235	1.67E-06
U-238	2.15E-05

Haz. Waste No(s).

F002

TRUCON Code(s)

111/211

Waste Stream Description

Waste consists of soils from NFS

Waste Stream ID: **OR-PGDP-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Paducah Gaseous Diffusion Plant CH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	7.7	0.0	7.7
Current Form Total	7.7	0.0	7.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	7.7	0.0	7.7
Final Form Total	7.7	0.0	7.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	51.17
Aluminum-based Metal/Alloys	9.30
Other Metal/Alloys	23.26
Other Inorganic Materials	4.65
Cellulosics	39.54
Rubber	32.56
Plastics	60.47
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	11.63
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Np-237	2.24E-02
Pu-239	7.24E-02
Th-229	2.89E-09
Th-230	6.42E-07
U-233	2.53E-06
U-234	2.68E-03
U-235	1.08E-04
U-238	2.67E-03

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225

Waste Stream Description

Waste consists of CH-TRU debris from PGDP

Waste Stream ID: **OR-RADP-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL Radiochemical Processing Research & Development CH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum Dir Ld	0.4	0.0	0.4
55-gal Drum Dir Ld w/o Liner	26.6	0.0	26.6
79-gal Drum Dir Ld	3.6	0.0	3.6
85-gal Drum Dir Ld w/o Liner	0.6	0.0	0.6
Box - Misc	2.6	0.0	2.6
Current Form Total	33.8	0.0	33.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	33.7	0.0	33.7
Final Form Total	33.7	0.0	33.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	55.72
Aluminum-based Metal/Alloys	2.08
Other Metal/Alloys	7.73
Other Inorganic Materials	6.39
Cellulosics	32.09
Rubber	7.87
Plastics	35.51
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	1.19
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.71E-01
Am-243	4.14E-03
Cm-244	2.97E+00
Cs-137	6.75E-06
Np-237	3.83E-05
Pu-238	4.06E-01
Pu-239	8.42E-01
Pu-240	6.53E-02
Pu-241	1.78E+00
Pu-242	5.70E-05
Pu-244	5.25E-10
Sr-90	5.64E-06
Th-229	4.01E-09
Th-232	3.26E-15
U-233	8.00E-04
U-234	6.26E-05
U-235	5.97E-06
U-238	1.82E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D028, F002, F005

TRUCON Code(s)

125/225

Waste Stream Description

Waste consists of CH-TRU debris from radiochemical processing R&D at ORNL

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-RADP-CH-SOILS**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL Radiochemical Processing Research & Development CH-TRU Soil Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	1.2	0.0	1.2
Current Form Total	1.2	0.0	1.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	1.2	0.0	1.2
Final Form Total	1.2	0.0	1.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	4.78
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	9.57
Soils	464.11
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Cm-244	1.78E-05
Pu-238	3.91E-05
Pu-239	5.28E-02
Pu-240	1.56E-02
Sr-90	2.53E-05
Th-230	3.94E-13
Th-232	7.70E-18
U-234	3.19E-09
U-235	1.35E-09
U-236	1.20E-08
U-238	2.69E-09

Haz. Waste No(s).

F002

TRUCON Code(s)

111/211

Waste Stream Description

Waste consists of CH-TRU soils from radiochemical processing R&D at ORNL

Waste Stream ID: **OR-RADP-RH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL Radiochemical Processing Research & Development RH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	1.2	0.0	1.2
Current Form Total	1.2	0.0	1.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	1.2	0.0	1.2
Final Form Total	1.2	0.0	1.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	70.09
Aluminum-based Metal/Alloys	2.62
Other Metal/Alloys	9.72
Other Inorganic Materials	8.04
Cellulosics	40.37
Rubber	9.91
Plastics	44.67
Cement	0.00
Solidified Inorganic Material	1.50
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.48E-03
Am-243	5.41E-01
Cm-244	2.42E+00
Np-237	1.13E-04
Pu-239	4.16E-01
Pu-240	1.68E-02
Pu-244	6.28E-15
Th-229	1.73E-08
Th-232	5.03E-18
U-233	7.57E-06
U-235	1.39E-05
U-236	9.27E-09

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D028, F002, F005

TRUCON Code(s)

325

Waste Stream Description

Waste consists of RH-TRU debris from radiochemical processing R&D at ORNL

Waste Stream ID: **OR-REDC-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Radiochemical Engineering Development Center CH-TRU Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum Dir Ld	0.4	0.0	0.4
55-gal Drum Dir Ld w/o Liner	297.0	25.0	322.0
79-gal Drum Dir Ld	1.5	0.0	1.5
85-gal Drum Dir Ld w/ Liner	0.3	0.0	0.3
Box - Misc	19.9	0.0	19.9
Current Form Total	319.2	25.0	344.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	324.7	25.0	349.6
Final Form Total	324.7	25.0	349.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	50.08
Aluminum-based Metal/Alloys	2.43
Other Metal/Alloys	1.52
Other Inorganic Materials	19.43
Cellulosics	7.28
Rubber	1.97
Plastics	69.05
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.93E-02
Am-243	2.88E-03
Cm-244	4.09E+00
Cs-137	7.27E-03
Np-237	1.55E-04
Pu-238	5.56E-01
Pu-239	9.05E-02
Pu-240	1.32E-01
Pu-241	1.31E+01
Pu-242	2.31E-05
Pu-244	3.33E-09
Sr-90	3.79E-02
Th-229	1.06E-09
Th-232	3.12E-09
U-233	2.51E-03
U-234	2.12E-04
U-235	3.57E-07
U-236	3.89E-04
U-238	2.96E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, F002, F005

TRUCON Code(s)

125/225

Waste Stream Description

Waste consists of CH-TRU debris from REDC at ORNL

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-REDC-RH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Radiochemical Engineering Development Center RH-TRU Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	6.0	0.0	6.0
Cask - Misc	300.7	146.1	446.8
Current Form Total	306.8	146.1	452.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 30-gal w/ Liner	51.2	67.1	118.3
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	245.2	68.6	313.9
Final Form Total	296.4	135.8	432.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	218.91
Aluminum-based Metal/Alloys	0.04
Other Metal/Alloys	21.88
Other Inorganic Materials	62.12
Cellulosics	24.73
Rubber	6.15
Plastics	31.91
Cement	0.00
Solidified Inorganic Material	4.48
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	56.18
Packaging Material, Rubber	0.70
Packaging Material, Steel	1118.73
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.91E-03
Am-243	5.18E-04
Cm-244	4.44E-01
Cs-137	1.63E-02
Np-237	2.11E-06
Pu-238	4.37E-03
Pu-239	1.85E-03
Pu-240	5.71E-03
Pu-241	1.82E-02
Pu-242	4.33E-05
Pu-244	3.42E-12
Sr-90	1.05E-01
Th-229	7.25E-09
Th-230	9.03E-11
Th-232	4.53E-18
U-233	3.17E-06
U-234	5.49E-07
U-235	6.42E-10
U-236	5.53E-09
U-238	1.57E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, F002, F005

TRUCON Code(s)

325

Waste Stream Description

Waste consists of RH-TRU debris from REDC at ORNL

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-RF-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL Reactor Fuels Research & Development CH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	38.5	0.0	38.5
79-gal Drum Dir Ld	1.5	0.0	1.5
85-gal Drum Dir Ld w/ Liner	0.3	0.0	0.3
Box - Misc	30.6	0.0	30.6
Current Form Total	70.9	0.0	70.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	69.7	0.0	69.7
Final Form Total	69.7	0.0	69.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	91.74
Aluminum-based Metal/Alloys	16.68
Other Metal/Alloys	41.70
Other Inorganic Materials	8.34
Cellulosics	70.89
Rubber	58.38
Plastics	108.43
Cement	0.00
Solidified Inorganic Material	20.85
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.74E-01
Am-243	1.52E-03
Cm-244	5.05E+00
Cs-137	1.08E-02
Np-237	5.27E-06
Pu-238	2.69E+00
Pu-239	1.84E+00
Pu-240	7.20E-01
Pu-241	4.22E+01
Pu-242	2.37E-02
Sr-90	5.65E-03
Th-229	8.61E-04
Th-230	6.29E-07
Th-232	5.25E-06
U-233	7.53E-02
U-234	5.50E-05
U-235	2.54E-06
U-236	2.66E-08
U-238	7.79E-06

Haz. Waste No(s).

D006, D007, D008, D009, D011, D019, F001, F002, F005

TRUCON Code(s)

125/225

Waste Stream Description

Waste consists of CH-TRU debris from reactor fuels R&D at ORNL

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-RF-CH-HOM**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	ORNL Reactor Fuels Research & Development CH-TRU Homogeneous Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	2.5	0.0	2.5
Current Form Total	2.5	0.0	2.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	2.5	0.0	2.5
Final Form Total	2.5	0.0	2.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	31.49
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	377.93
Cellulosics	0.00
Rubber	0.00
Plastics	62.99
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	52.49
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.91E-02
Cs-137	1.02E-03
Np-237	1.65E-07
Pu-238	6.69E-03
Pu-239	1.70E-02
Pu-240	1.67E-02
Sr-90	1.02E-02
Th-229	7.15E-15
Th-230	4.84E-09
Th-232	8.26E-18
U-233	9.35E-12
U-234	2.05E-05
U-235	9.18E-07
U-236	1.29E-08
U-238	3.31E-05

Haz. Waste No(s).

D006, D007, D008, D009, D010

TRUCON Code(s)

111/211

Waste Stream Description

Waste consists of homogeneous waste from reactor fuels R&D at ORNL

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-RF-RH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL Reactor Fuels Research & Development RH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	13.9	0.0	13.9
79-gal Drum Dir Ld	1.8	0.0	1.8
Cask - Misc	46.5	10.0	56.4
Current Form Total	62.2	10.0	72.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	59.9	10.0	69.9
Final Form Total	59.9	10.0	69.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	240.22
Aluminum-based Metal/Alloys	54.60
Other Metal/Alloys	49.14
Other Inorganic Materials	54.60
Cellulosics	76.43
Rubber	16.38
Plastics	43.68
Cement	0.00
Solidified Inorganic Material	10.92
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.16E-02
Am-243	8.84E-05
Cm-244	1.39E-02
Cs-137	2.43E+00
Np-237	5.45E-06
Pu-238	1.26E-02
Pu-239	1.10E-01
Pu-240	4.99E-02
Pu-241	3.63E-02
Pu-242	1.93E-06
Pu-244	3.82E-16
Sr-90	3.30E-01
Th-229	7.42E-04
Th-230	1.89E-08
Th-232	4.59E-06
U-233	3.25E-01
U-234	7.95E-05
U-235	4.93E-06
U-236	3.49E-06
U-238	7.90E-06

Haz. Waste No(s).

D008, D009, D011

TRUCON Code(s)

325

Waste Stream Description

Waste consists of RH-TRU debris from reactor fuels R&D at ORNL

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-SWSA-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL Solid Waste Storage Area 5 North 7802N Trench Area Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	11.9	0.0	11.9
Box - Misc	2.6	0.0	2.6
Current Form Total	14.4	0.0	14.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	14.4	0.0	14.4
Final Form Total	14.4	0.0	14.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	11.86
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	293.90
Cellulosics	1.56
Rubber	0.00
Plastics	1.56
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	3.12
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.39E-04
Am-243	4.35E-07
Cm-244	4.28E+00
Cs-137	1.54E-06
Np-237	5.39E-06
Pu-238	4.99E-04
Pu-239	5.57E-04
Pu-240	3.47E-05
Pu-241	2.04E-04
Pu-242	3.22E-09
Sr-90	1.54E-06
Th-229	7.73E-08
Th-232	9.92E-06
U-233	1.27E-02
U-234	8.85E-08

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D028, F001, F002, F005

TRUCON Code(s)

125/225

Waste Stream Description

Waste consists of CH-TRU debris from SWSA 5 7802N Trench area

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-SWSA-CH-SOIL**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL Solid Waste Storage Area 5 North 7802N Trench Area Soil Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	23.3	0.0	23.3
Current Form Total	23.3	0.0	23.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	23.3	0.0	23.3
Final Form Total	23.3	0.0	23.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2.13
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	1.07
Other Inorganic Materials	4.80
Cellulosics	2.13
Rubber	0.00
Plastics	11.74
Cement	0.00
Solidified Inorganic Material	86.47
Solidified Organic Material	2.13
Soils	423.25
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.80E+00
Am-243	1.87E-06
Cm-244	1.53E+00
Cs-137	4.06E-07
Np-237	1.20E-04
Pu-238	1.31E-04
Pu-239	1.57E-01
Pu-240	4.20E-04
Pu-241	3.60E-03
Pu-242	9.14E-08
Sr-90	4.06E-07
Th-229	3.69E-08
Th-232	4.19E-06
U-233	1.22E-02
U-235	3.71E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D028, F001, F002, F005

TRUCON Code(s)

111/211

Waste Stream Description

Waste consists of CH-TRU soils from SWSA 5 7802N Trench area

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-TBD-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	TBD CH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	13.5	0.0	13.5
79-gal Drum Dir Ld	1.8	0.0	1.8
Current Form Total	15.3	0.0	15.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	15.2	0.0	15.2
Final Form Total	15.2	0.0	15.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	47.92
Aluminum-based Metal/Alloys	8.71
Other Metal/Alloys	21.78
Other Inorganic Materials	4.36
Cellulosics	37.03
Rubber	30.50
Plastics	56.64
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	10.89
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.98E+00
Am-243	1.05E-01
Cm-244	1.12E-01
Cs-137	1.17E-02
Np-237	3.34E-03
Pu-238	1.47E+01
Pu-239	3.38E+00
Pu-240	7.72E+00
Pu-241	2.79E+00
Pu-242	7.93E-04
Pu-244	3.82E-05
Sr-90	2.71E-03
Th-229	1.15E-04
Th-230	3.77E-07
Th-232	2.67E-07
U-233	5.02E-02
U-234	1.22E-03
U-235	1.42E-05
U-236	5.97E-06
U-238	7.80E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, F001, F002, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

CH-TRU Debris Waste Needing Further Evaluation

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-TBD-RH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	TBD RH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	2.9	0.0	2.9
Cask - Misc	64.0	8.3	72.3
Current Form Total	66.9	8.3	75.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	66.1	9.4	75.5
Final Form Total	66.1	9.4	75.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	226.49
Aluminum-based Metal/Alloys	51.47
Other Metal/Alloys	46.33
Other Inorganic Materials	51.47
Cellulosics	72.06
Rubber	15.44
Plastics	41.18
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	10.29
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.54E-01
Am-243	4.15E-11
Cm-244	6.40E-02
Cs-137	2.76E+01
Np-237	7.06E-06
Pu-238	7.30E-01
Pu-239	1.02E-01
Pu-240	5.62E-02
Pu-241	7.45E-02
Pu-242	2.34E-07
Pu-244	5.02E-08
Sr-90	1.70E+01
Th-229	6.62E-05
Th-230	5.62E-08
Th-232	3.45E-07
U-233	2.90E-02
U-234	2.64E-04
U-235	8.35E-06
U-236	4.32E-08
U-238	1.79E-06

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011

TRUCON Code(s)

325

Waste Stream Description

RH-TRU Debris Waste Needing Further Evaluation

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-W203**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL Newly Generated Debris - Post 2013					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.0	84.9	84.9
Current Form Total	0.0	84.9	84.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.0	84.9	84.9
Final Form Total	0.0	84.9	84.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	79.33
Aluminum-based Metal/Alloys	3.85
Other Metal/Alloys	2.40
Other Inorganic Materials	30.77
Cellulosics	11.54
Rubber	3.13
Plastics	109.38
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.14E-02
Am-243	8.13E-04
Cm-244	9.79E-03
Cs-137	4.24E-02
Pu-238	8.57E-03
Pu-239	1.56E-04
Pu-240	7.37E-03
Pu-241	1.02E-01
Pu-242	1.07E-04
Sr-90	3.14E-01
U-234	1.44E-07
U-235	6.35E-09
U-236	7.25E-10
U-238	5.12E-08

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Hot Cell Debris Waste

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-W213-RH-SOILS**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ER RH TRU Soils					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
10-gal Drum Dir Ld w/o Liner	1.6	0.0	1.6
55-gal Drum Dir Ld w/o Liner	0.2	0.0	0.2
5-gal Drum Dir Ld w/o Liner	0.0	0.0	0.0
Box - Misc	43.7	0.0	43.7
Current Form Total	45.6	0.0	45.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	10.6	0.0	10.6
Final Form Total	10.6	0.0	10.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	25.30
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	50.59
Soils	2453.73
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.06E-01
Am-243	3.26E-05
Cm-244	2.74E-04
Cs-137	1.00E+00
Np-237	1.09E-04
Pu-238	1.91E-02
Pu-239	5.18E-02
Pu-240	4.93E-04
Pu-241	1.94E-01
Pu-242	2.86E-05
Sr-90	8.23E-03
Th-229	7.63E-02
Th-230	1.29E-04
Th-232	1.22E-03
U-233	9.91E-02
U-234	5.65E-03
U-235	8.41E-05
U-236	8.91E-05
U-238	1.07E-03

No Hazardous Waste Numbers Provided

TRUCON Code(s)

311

Waste Stream Description

This waste is made up of soils.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **OR-WSTR-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ORNL-Liquid Waste Treatment CH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	5.6	0.0	5.6
79-gal Drum Dir Ld	0.3	0.0	0.3
Current Form Total	5.9	0.0	5.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	5.8	0.0	5.8
Final Form Total	5.8	0.0	5.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	44.82
Aluminum-based Metal/Alloys	8.15
Other Metal/Alloys	20.37
Other Inorganic Materials	4.07
Cellulosics	34.64
Rubber	28.52
Plastics	52.97
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	10.19
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Cm-244	1.71E-03
Pu-238	7.55E-03
Pu-239	8.58E-02
Pu-240	8.05E-06
Th-230	7.60E-11
Th-232	1.66E-21
U-234	6.15E-07
U-235	2.20E-09
U-236	3.61E-12

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225

Waste Stream Description

Waste consists of CH-TRU debris from ORNL liquids waste system.

Waste Stream ID: **OR-Y12-CH-HET**

Appendix A

Waste Profile Report

Site	Oak Ridge National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Oak Ridge Y-12 CH-TRU Debris Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.6	0.0	0.6
79-gal Drum w/ 1 - 55-gal Drum	0.6	0.0	0.6
Current Form Total	1.2	0.0	1.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	1.2	0.0	1.2
Final Form Total	1.2	0.0	1.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	52.53
Aluminum-based Metal/Alloys	9.55
Other Metal/Alloys	23.88
Other Inorganic Materials	4.78
Cellulosics	40.59
Rubber	33.43
Plastics	62.08
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	11.94
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Np-237	5.08E-03
Pu-238	1.73E-04
Pu-239	4.96E-02
Pu-240	1.04E-05
Th-229	6.54E-10
Th-230	1.78E-07
Th-232	5.14E-21
U-233	5.72E-07
U-234	7.45E-04
U-235	1.14E-04
U-236	8.01E-12
U-238	5.01E-04

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225

Waste Stream Description

Waste consists of CH-TRU debris from Y-12

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL105-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	105-C, 105KE, and 105-N Bldg TRU CH Non-mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	29.7	0.0	29.7
85-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Box - Misc	54.2	0.0	54.2
Uncontained	0.0	29.3	29.3
Current Form Total	84.6	29.3	113.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	37.9	0.0	37.9
SWB Dir Ld w/ Liner	68.0	30.2	98.3
Final Form Total	105.9	30.2	136.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	75.59
Aluminum-based Metal/Alloys	3.85
Other Metal/Alloys	0.00
Other Inorganic Materials	25.04
Cellulosics	15.41
Rubber	13.48
Plastics	28.50
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	11.17
Packaging Material, Rubber	0.30
Packaging Material, Steel	147.14
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.74E-01
Am-243	5.20E-04
Cm-244	9.15E-03
Cs-137	1.26E+00
Np-237	2.29E-04
Pu-238	4.43E-02
Pu-239	1.44E-01
Pu-240	5.80E-02
Pu-241	5.51E+00
Pu-242	1.72E-05
Sr-90	4.47E-01
Th-229	1.75E-13
Th-230	6.71E-10
Th-232	7.15E-16
U-233	1.99E-09
U-234	3.66E-05
U-235	2.04E-05
U-236	7.24E-06
U-238	3.33E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, D027, D028, D029, D030, D034, D037, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

CH TRU Combustible and noncombustible debris from Hanford production reactor storage basin operations. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, cartridge-type water filters from the Primary Recirculation System, and absorbed liquids.

Waste Stream ID: **RL105-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	NLOP sludge					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	68.4	0.0	68.4
Current Form Total	68.4	0.0	68.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	68.4	0.0	68.4
Final Form Total	68.4	0.0	68.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	36.09
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	12.59
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	930.62
Solidified Inorganic Material	620.41
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.20E-01
Cs-137	1.62E+00
Np-237	9.00E-06
Pu-238	6.75E-02
Pu-239	3.38E-01
Pu-240	1.86E-01
Pu-241	7.69E+00
Pu-242	8.86E-05
Sr-90	8.08E+00
Th-229	1.49E-14
Th-230	1.65E-08
Th-232	1.22E-18
U-233	1.14E-10
U-234	5.98E-04
U-235	2.25E-05
U-236	1.65E-08
U-238	4.82E-04

No Hazardous Waste Numbers Provided

TRUCON Code(s)

111/211

Waste Stream Description

Solidified inorganic CH TRU waste generated from Facility/Equipment Operation and Maintenance activities at the Reactor facility.

Waste Stream ID: **RL105-08**

Appendix A
Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	105-C, 105KE, and 105-N Bldg RH-TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.7	0.0	3.7
Box - Misc	120.5	0.0	120.5
SWB Dir Ld w/ Liner	3.8	0.0	3.8
Current Form Total	128.0	0.0	128.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	161.0	0.0	161.0
Final Form Total	161.0	0.0	161.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	106.95
Aluminum-based Metal/Alloys	5.45
Other Metal/Alloys	0.00
Other Inorganic Materials	35.42
Cellulosics	21.80
Rubber	19.07
Plastics	38.15
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	9.32E-02
Am-243	3.77E-08
Cm-244	1.00E-03
Cs-137	1.65E+00
Np-237	9.69E-07
Pu-238	2.47E-02
Pu-239	7.76E-02
Pu-240	4.22E-02
Pu-241	1.02E+00
Pu-242	1.73E-06
Sr-90	7.59E-01
Th-229	2.89E-14
Th-230	1.77E-09
Th-232	4.95E-08
U-233	6.65E-11
U-234	3.22E-05
U-235	1.61E-06
U-236	5.63E-06
U-238	3.89E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, D027, D028, D029, D030, D034, D037, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

325

Waste Stream Description

The 105-KE RH waste stream is composed solely of cartridge-type water filters from the Primary Recirculation System. The water filters, accumulated waste and associated packaging. Other 100 area drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters. The waste stream ranges from contaminated clothing to process equipment. The waste is generated from Reactor Facility/Equipment Operation and Maintenance Waste activities.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL105-09**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	105KE TRU RH Non-mixed solidified inorganics					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
85-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Sludge Transport and Storage Container	0.0	151.8	151.8
Current Form Total	0.6	151.8	152.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	1.2	624.0	625.2
Final Form Total	1.2	624.0	625.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	156.95
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	5.86
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	576.13
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.98E-02
Cs-137	2.50E-01
Np-237	1.38E-05
Pu-238	1.06E-02
Pu-239	5.27E-02
Pu-240	2.90E-02
Pu-241	1.22E+00
Pu-242	1.39E-05
Sr-90	9.35E-02
Th-229	6.44E-14
Th-230	4.26E-09
Th-232	3.49E-14
U-233	2.94E-10
U-234	9.28E-05
U-235	3.49E-06
U-236	1.41E-04
U-238	7.55E-05

No Hazardous Waste Numbers Provided

TRUCON Code(s)

311

Waste Stream Description

Solidified inorganic RH TRU waste generated from Facility/Equipment Operation and Maintenance activities at the Reactor facility.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL200-01**

Appendix A
Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Misc 200 Area TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	71.1	0.0	71.1
Box - Misc	46.3	0.0	46.3
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Current Form Total	119.3	0.0	119.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	88.8	0.0	88.8
SWB Dir Ld w/ Liner	60.5	0.0	60.5
Final Form Total	149.3	0.0	149.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	567.18
Aluminum-based Metal/Alloys	128.32
Other Metal/Alloys	0.00
Other Inorganic Materials	33.59
Cellulosics	24.62
Rubber	8.49
Plastics	33.60
Cement	0.00
Solidified Inorganic Material	5.39
Solidified Organic Material	0.00
Soils	2.90
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	22.54
Packaging Material, Rubber	0.42
Packaging Material, Steel	139.95
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.41E-01
Cs-137	3.38E-03
Np-237	8.79E-07
Pu-238	9.28E-04
Pu-239	6.36E-03
Pu-240	2.28E-03
Pu-241	3.45E-02
Pu-242	2.21E-07
Sr-90	2.52E-04
Th-229	1.38E-15
Th-230	3.09E-13
Th-232	4.16E-20
U-233	9.38E-12
U-234	1.34E-08
U-235	3.13E-11
U-236	3.37E-10
U-238	1.71E-16

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, F001, F002, F003, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

Containers with both combustible and noncombustible waste items from various general perations/mantenance/evaporator in 200 area. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL200-02**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Soil from Groundwater projects. And contaiminated soil from PFP					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	7.3	0.0	7.3
85-gal Drum Dir Ld w/ Liner	3.2	0.0	3.2
Uncontained	0.0	2211.4	2211.4
Current Form Total	10.5	2211.4	2221.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	10.4	0.0	10.4
SWB Dir Ld w/ Liner	0.0	2213.2	2213.2
Final Form Total	10.4	2213.2	2223.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	3.59
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	513.52
Cellulosics	4.73
Rubber	2.19
Plastics	9.25
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	543.68
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.37
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.33
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.73E-01
Cs-137	3.16E-04
Np-237	1.19E-05
Pu-238	7.65E-02
Pu-239	1.66E+00
Pu-240	4.38E-01
Pu-241	2.95E+00
Pu-242	3.31E-05
Sr-90	2.87E-04
Th-229	2.27E-15
Th-230	9.97E-13
Th-232	3.20E-19
U-233	5.16E-11
U-234	2.17E-07
U-235	1.64E-09
U-236	1.30E-08
U-238	5.13E-15

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D021, D022, D027, D028, D030, D039, D040, D043, F001, F002, F003, F005

TRUCON Code(s)

125/225

Waste Stream Description

Crib and soil characterization and remediation wastes

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL201-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	201C TRU Mixed Solid Inorganic					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	11.4	0.0	11.4
Current Form Total	11.4	0.0	11.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	13.5	0.0	13.5
Final Form Total	13.5	0.0	13.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	27.63
Other Inorganic Materials	9.16
Cellulosics	64.47
Rubber	119.33
Plastics	32.23
Cement	0.00
Solidified Inorganic Material	0.93
Solidified Organic Material	0.00
Soils	314.38
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.10E+00
Cs-137	1.99E-01
Pu-238	6.87E-05
Pu-239	1.39E-01
Pu-240	3.43E-02
Pu-241	3.49E-03
Pu-242	5.00E-08
Sr-90	5.17E+00
U-238	5.18E-04

Haz. Waste No(s).

D007, D010

TRUCON Code(s)

122/222

Waste Stream Description

Generated from tank CX-70 sludge cleanout/remediation. A vacuuming process loaded sludge waste into cloth lined 16 gal drums. A 16 gal drum was placed into each 55 gal drum. Diatomaceous earth was added to ensure no free liquid process waste.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL202S-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	202S TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.8	0.0	0.8
Current Form Total	0.8	0.0	0.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.0	0.0	1.0
Final Form Total	1.0	0.0	1.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2.74
Aluminum-based Metal/Alloys	0.91
Other Metal/Alloys	0.77
Other Inorganic Materials	0.00
Cellulosics	3.34
Rubber	0.77
Plastics	53.09
Cement	0.00
Solidified Inorganic Material	3.59
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.70E-02
Cs-137	1.11E-07
Np-237	1.85E-06
Pu-238	1.08E-02
Pu-239	6.29E-02
Pu-240	2.35E-02
Pu-241	1.52E-01
Pu-242	2.70E-06
Sr-90	1.00E-07
Th-229	3.53E-16
Th-230	1.41E-13
Th-232	1.72E-20
U-233	8.03E-12
U-234	3.07E-08
U-235	6.19E-11
U-236	6.97E-10
U-238	4.19E-16

Haz. Waste No(s).

D006, D007, D008, D009

TRUCON Code(s)

125/225

Waste Stream Description

Generated from investigations at the North Sample Gallery of the 202-S Canyon (REDOX CANYON AND SERVICE FACILITY).Debris waste of personal protective equipment, sharp metal objects, and cleanup material generated in S canyon investigation, waste characterization samples. Predominant debris waste consists of over 80% plastic.

Waste Stream ID: **RL209E-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	209E TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	12.1	0.0	12.1
85-gal Drum Dir Ld w/ Liner	1.6	0.0	1.6
Box - Misc	327.0	0.0	327.0
SWB Dir Ld w/ Liner	58.6	0.0	58.6
Current Form Total	399.3	0.0	399.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	15.4	0.0	15.4
SWB Dir Ld w/ Liner	468.7	0.0	468.7
Final Form Total	484.1	0.0	484.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	51.21
Aluminum-based Metal/Alloys	0.02
Other Metal/Alloys	0.52
Other Inorganic Materials	6.19
Cellulosics	28.57
Rubber	10.88
Plastics	24.73
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	2.34
Packaging Material, Rubber	0.20
Packaging Material, Steel	152.72
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.30E+00
Cs-137	1.12E-08
Np-237	4.43E-05
Pu-238	1.12E+00
Pu-239	7.91E+00
Pu-240	2.89E+00
Pu-241	3.36E+01
Pu-242	4.23E-04
Sr-90	1.01E-08
U-234	1.60E-04
U-235	5.84E-06
U-238	1.50E-05

Haz. Waste No(s).

D006, D007, D008, D018, D019, D043, F002, F003, F005

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible debris waste generated during operations, cleanout, and D&D of the 209-E Critical Mass Laboratory (CML) at Hanford. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RL209E-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	209E TRU RH Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2.40
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.80
Cellulosics	24.04
Rubber	3.21
Plastics	23.08
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.40E+00
Np-237	6.08E-05
Pu-238	7.23E-01
Pu-239	5.59E+00
Pu-240	1.96E+00
Pu-241	7.93E+00
Pu-242	2.44E-04
Th-229	3.97E-12
Th-230	5.60E-09
Th-232	7.56E-16
U-233	4.45E-09
U-234	5.14E-05
U-235	1.27E-07
U-236	1.33E-06
U-238	8.71E-13

Haz. Waste No(s).

D006, D007, D018, D019, F002, F003, F005

TRUCON Code(s)

325

Waste Stream Description

Combustible and noncombustible debris waste generated during operations, cleanout, and D&D of the 209-E CML. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL216Z-02**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	216-Z-9 TRU Mixed Soil					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	183.5	0.0	183.5
85-gal Drum Dir Ld w/ Liner	28.7	0.0	28.7
Box - Misc	12.7	0.0	12.7
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Current Form Total	226.7	0.0	226.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	290.4	0.0	290.4
SWB Dir Ld w/ Liner	18.9	0.0	18.9
Final Form Total	309.3	0.0	309.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2.12
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	17.18
Cellulosics	0.35
Rubber	0.00
Plastics	1.06
Cement	0.00
Solidified Inorganic Material	18.83
Solidified Organic Material	0.00
Soils	18.85
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	34.88
Packaging Material, Rubber	0.54
Packaging Material, Steel	132.15
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.19E+00
Np-237	1.45E-06
Pu-238	1.22E+00
Pu-239	1.46E+01
Pu-240	3.43E+00
Pu-241	5.40E+01
Pu-242	2.05E-04

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011, D039, F001, F002, F003, F005

TRUCON Code(s)

125/225

Waste Stream Description

Soil contaminated with large quantities of plutonium, americium, organics, and neutralized acid waste solutions that were removed from the 216-Z-9 Crib. Original packaging material (e.g., 10-L stainless steel slip-lid cans, plastic bags, and vermiculite) now waste due to deterioration and TRU contamination.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL221T-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	221-T TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	6.9	0.0	6.9
Current Form Total	6.9	0.0	6.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	8.7	0.0	8.7
Final Form Total	8.7	0.0	8.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	142.38
Aluminum-based Metal/Alloys	22.44
Other Metal/Alloys	0.00
Other Inorganic Materials	11.09
Cellulosics	27.08
Rubber	11.61
Plastics	27.60
Cement	0.00
Solidified Inorganic Material	3.87
Solidified Organic Material	0.00
Soils	4.64
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.81E-02
Np-237	1.94E-07
Pu-238	2.13E-03
Pu-239	1.08E-02
Pu-240	6.11E-03
Pu-241	3.95E-02
Pu-242	2.47E-07
Th-229	1.55E-14
Th-230	4.61E-11
Th-232	6.12E-18
U-233	1.48E-11
U-234	2.58E-07
U-235	3.95E-10
U-236	6.70E-09
U-238	1.42E-15

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Materials contaminated with TRU radionuclides during characterization and certification activities (visual exam, repackaging, and removal and remediation of prohibited items) and generated as waste during maintenance and cleanup operations at 221-T. Include glovebox gloves, rags and other decontamination materials, and plastics contaminated during glovebox operations. Debris items such as equipment and room contamination materials: combustibles include plastic, shoe covers, rags, paper

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL221U-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	221U moved from RL200-01					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	9.89
Aluminum-based Metal/Alloys	1.38
Other Metal/Alloys	0.41
Other Inorganic Materials	1.84
Cellulosics	1.06
Rubber	0.25
Plastics	0.93
Cement	0.00
Solidified Inorganic Material	0.17
Solidified Organic Material	0.00
Soils	0.19
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.53E-04
Cs-137	1.50E-03
Pu-238	7.74E-05
Pu-239	3.26E-03
Pu-240	7.45E-04
Pu-241	4.66E-03
Pu-242	6.35E-08
Sr-90	1.37E-03

Haz. Waste No(s).

D006, D007, D008, D009, D011, D027, D030, D032, D033, D034, D036, D037, F001, F002

TRUCON Code(s)

122/222

Waste Stream Description

Solidified sludge and laboratory sample debris (e.g., glass sample bottles, plastic, and tape) from characterization efforts of U Plant.

Waste Stream ID: **RL221U-09**

Appendix A
Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	U Plant Tank 10 Projected Waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Misc	28.1	0.0	28.1
Current Form Total	28.1	0.0	28.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	35.6	0.0	35.6
Final Form Total	35.6	0.0	35.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	193.99
Solidified Organic Material	1.96
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.34E-01
Am-243	9.77E-09
Cm-244	2.05E-02
Cs-137	1.47E+01
Np-237	1.77E-03
Pu-238	1.85E-01
Pu-239	1.37E+00
Pu-240	3.88E-01
Pu-241	1.89E+01
Pu-242	3.92E-05
Sr-90	1.13E+01
Th-229	5.28E-12
Th-230	1.30E-07
Th-232	2.66E-07
U-233	3.77E-08
U-234	7.07E-03
U-235	7.42E-06
U-236	2.30E-08
U-238	1.39E-04

Haz. Waste No(s).

D007, D008, D010

No TRUCON Codes Provided

Waste Stream Description

RH-TRU Nitrate Salts in the heel of U Plant Tank 10. Waste is under a CERCLA ROD to dispose of TRU constituents at WIPP.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL222S-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	222S TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	54.5	0.0	54.5
85-gal Drum Dir Ld w/ Liner	1.9	0.0	1.9
Box - Misc	44.0	0.0	44.0
Current Form Total	100.4	0.0	100.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	66.8	0.0	66.8
SWB Dir Ld w/ Liner	56.7	0.0	56.7
Final Form Total	123.5	0.0	123.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	520.54
Aluminum-based Metal/Alloys	103.27
Other Metal/Alloys	0.01
Other Inorganic Materials	34.65
Cellulosics	52.66
Rubber	20.79
Plastics	58.43
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	8.69
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	20.60
Packaging Material, Rubber	0.39
Packaging Material, Steel	141.18
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.67E-01
Am-243	3.40E-07
Cs-137	1.35E-03
Np-237	2.49E-05
Pu-238	1.11E-02
Pu-239	6.03E-02
Pu-240	2.73E-02
Pu-241	7.02E-01
Pu-242	1.96E-06
Sr-90	1.20E-03
Th-229	2.26E-08
Th-230	1.32E-12
Th-232	1.99E-20
U-233	2.57E-04
U-234	1.60E-07
U-235	4.58E-09
U-236	8.07E-10
U-238	1.12E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D030, D039, F001, F002, F003, F005

TRUCON Code(s)

125/225

Waste Stream Description

Combustible waste and Noncombustible waste - TRU wastes were generated from multiple operations, primarily from the hot cells, the hoods, or from within the gloveboxes (for standards laboratory tasks) located in the Analytical laboratory.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL222S-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	222S TRU RH Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.8	0.0	0.8
85-gal Drum Dir Ld w/ Liner	0.3	0.0	0.3
Box - Misc	0.1	0.0	0.1
Current Form Total	1.3	0.0	1.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	2.5	0.0	2.5
Final Form Total	2.5	0.0	2.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	379.68
Aluminum-based Metal/Alloys	59.95
Other Metal/Alloys	0.00
Other Inorganic Materials	29.31
Cellulosics	72.03
Rubber	30.74
Plastics	73.76
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	10.55
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.12E-01
Am-243	1.02E-02
Cs-137	1.08E-01
Np-237	1.12E-03
Pu-238	2.32E-02
Pu-239	2.52E+00
Pu-240	6.45E-02
Pu-241	6.15E+00
Pu-242	2.24E-04
Pu-244	9.32E-07
Sr-90	1.79E-01
Th-229	7.72E-05
Th-230	7.78E-12
Th-232	1.18E-18
U-233	1.76E-01
U-234	3.36E-07
U-235	4.25E-06
U-236	9.54E-09
U-238	1.57E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D039, F001, F002, F003, F004, F005

TRUCON Code(s)

325

Waste Stream Description

Combustible waste and Noncombustible waste- TRU wastes were generated from multiple operations, primarily from the hot cells, the hoods, or from within the gloveboxes (for standards laboratory tasks) located in the Analytical laboratory.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL231Z-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	231-Z TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	147.7	0.0	147.7
85-gal Drum Dir Ld w/ Liner	13.5	0.0	13.5
Box - Misc	1054.9	0.0	1054.9
SWB Dir Ld w/ Liner	26.5	0.0	26.5
Current Form Total	1242.6	0.0	1242.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	193.9	0.0	193.9
SWB Dir Ld w/ Liner	1345.7	0.0	1345.7
Final Form Total	1539.5	0.0	1539.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	102.36
Aluminum-based Metal/Alloys	0.44
Other Metal/Alloys	1.64
Other Inorganic Materials	15.50
Cellulosics	20.06
Rubber	3.68
Plastics	26.34
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	5.72
Packaging Material, Rubber	0.24
Packaging Material, Steel	150.58
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.71E-01
Am-243	3.20E-06
Cs-137	3.87E-05
Np-237	1.46E-05
Pu-238	4.54E-02
Pu-239	3.88E-01
Pu-240	1.03E-01
Pu-241	1.26E+00
Pu-242	1.24E-05
Sr-90	3.51E-05
Th-229	2.80E-15
Th-230	5.06E-10
Th-232	7.55E-20
U-233	6.36E-11
U-234	5.51E-05
U-235	1.46E-06
U-236	3.06E-09
U-238	9.12E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D027, D028, D029, D030, D034, D035, D037, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible debris waste generated during operations, cleanout, and D&D activities of the 231-Z Building at Hanford. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. The 231-Z Building has also been called the 231-W Building, the Concentration Building, the Isolation Building, the Plutonium Metallurgical Laboratory, and the 231-Z Materials Engineering Laboratory.

Waste Stream ID: **RL231Z-03**

Appendix A
Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	231Z TRU Mixed Solid Inorganic					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
85-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Current Form Total	0.6	0.0	0.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	104.98
Other Inorganic Materials	0.19
Cellulosics	6.57
Rubber	1.56
Plastics	20.58
Cement	0.00
Solidified Inorganic Material	93.37
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.85E-01
Np-237	1.86E-06
Pu-238	1.33E-04
Pu-239	4.95E-01
Pu-240	1.71E-01
Pu-241	2.09E-01
Pu-242	1.53E-05
Th-229	1.19E-13
Th-230	2.09E-12
Th-232	1.28E-16
U-233	1.28E-10
U-234	1.37E-08
U-235	1.56E-08
U-236	1.62E-07
U-238	7.58E-14

Haz. Waste No(s).

D006, D007, D008, D009, F001, F002, F003, F005

TRUCON Code(s)

122/222

Waste Stream Description

Solidified inorganic waste generated during operations, cleanout, and D&D activities of the 231-Z Building, which has also been called the 231-W Building, the Concentration Building, the Isolation Building, the Plutonium Metallurgical Laboratory, and the 231-Z Materials Engineering Laboratory.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL233S-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	233S TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	6.9	0.0	6.9
85-gal Drum Dir Ld w/ Liner	3.5	0.0	3.5
SWB Dir Ld w/ Liner	28.4	0.0	28.4
Current Form Total	38.8	0.0	38.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	10.0	0.0	10.0
SWB Dir Ld w/ Liner	34.0	0.0	34.0
Final Form Total	44.0	0.0	44.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	197.17
Aluminum-based Metal/Alloys	0.83
Other Metal/Alloys	1.80
Other Inorganic Materials	4.49
Cellulosics	13.49
Rubber	2.92
Plastics	16.01
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.52
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	9.34
Packaging Material, Rubber	0.28
Packaging Material, Steel	148.30
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.16E-01
Cs-137	3.85E-05
Np-237	1.77E-04
Pu-238	8.49E-02
Pu-239	6.31E-01
Pu-240	2.06E-01
Pu-241	2.02E+00
Pu-242	6.20E-05
Sr-90	3.50E-05
Th-229	3.38E-14
Th-230	3.15E-11
Th-232	1.50E-19
U-233	7.69E-10
U-234	3.54E-06
U-235	1.11E-07
U-236	6.09E-09
U-238	1.66E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, F002, F003

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible debris waste generated during cleanout, stabilization, and D&D activities of the 233-S Building (Plutonium Concentration Facility) at Hanford. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RL233S-03**

Appendix A
Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	233S solidified inorganic waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.2	0.0	4.2
Current Form Total	4.2	0.0	4.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	5.2	0.0	5.2
Final Form Total	5.2	0.0	5.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.04
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	513.33
Cellulosics	0.00
Rubber	0.04
Plastics	0.65
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.38E-02
Cs-137	1.16E-06
Np-237	6.00E-05
Pu-238	1.77E-02
Pu-239	7.02E-02
Pu-240	2.83E-02
Pu-241	1.55E-01
Pu-242	1.79E-05
Sr-90	9.66E-07
Th-229	4.59E-14
Th-230	9.28E-13
Th-232	8.27E-20
U-233	5.22E-10
U-234	1.01E-07
U-235	1.38E-10
U-236	1.68E-09
U-238	5.57E-15

Haz. Waste No(s).

D007

TRUCON Code(s)

122/222

Waste Stream Description

Solidified inorganic CH TRU waste generated from 233 Facility/Equipment Operation and Maintenance activities

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL300-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	300 Area TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	17.5	0.0	17.5
85-gal Drum Dir Ld w/ Liner	10.0	0.0	10.0
Box - Misc	89.5	0.0	89.5
SWB Dir Ld w/ Liner	18.9	0.0	18.9
Current Form Total	135.9	0.0	135.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	26.6	0.0	26.6
SWB Dir Ld w/ Liner	132.3	0.0	132.3
Final Form Total	158.9	0.0	158.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	68.30
Aluminum-based Metal/Alloys	0.09
Other Metal/Alloys	7.43
Other Inorganic Materials	30.47
Cellulosics	11.11
Rubber	2.31
Plastics	19.70
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	7.21
Packaging Material, Rubber	0.25
Packaging Material, Steel	149.64
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.69E+00
Am-243	3.18E-05
Cs-137	1.66E-04
Np-237	3.93E-05
Pu-238	4.94E-01
Pu-239	2.44E+00
Pu-240	1.13E+00
Pu-241	1.76E+01
Pu-242	2.18E-04
Sr-90	1.51E-04
Th-232	2.13E-06
U-234	5.23E-04
U-235	2.35E-05
U-238	5.51E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, D027, D028, D029, D030, D034, D037, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible debris waste generated from operations, including fuel fabrication, reactor studies, research and development, maintenance, and laboratory operations in the Hanford 300 Area. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RL300-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	300 Area Mixed Solidified Inorganics					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.5	0.0	2.5
85-gal Drum Dir Ld w/ Liner	1.3	0.0	1.3
Current Form Total	3.8	0.0	3.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.7	0.0	3.7
Final Form Total	3.7	0.0	3.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2.89
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	30.55
Cement	567.31
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.17E+00
Cs-137	5.80E-04
Np-237	1.92E-05
Pu-238	7.63E-01
Pu-239	4.01E+00
Pu-240	2.05E+00
Pu-241	3.26E+01
Pu-242	3.40E-04
Sr-90	7.21E-04
U-234	4.81E-05
U-235	1.68E-06
U-238	2.91E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, D027, D028, D029, D030, D034, D037, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

122/222

Waste Stream Description

Solidified inorganic CH TRU waste generated from operations, including fuel fabrication, reactor studies, research and development, maintenance, and laboratory operations in the Hanford 300 Area.

Waste Stream ID: **RL300-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	300 Area TRU RH Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	28.7	0.0	28.7
85-gal Drum Dir Ld w/ Liner	1.0	0.0	1.0
Box - Misc	202.7	0.0	202.7
SWB Dir Ld w/ Liner	3.8	0.0	3.8
Current Form Total	236.1	0.0	236.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	295.8	0.0	295.8
Final Form Total	295.8	0.0	295.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	79.40
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	607.94
Cellulosics	19.85
Rubber	0.00
Plastics	4.96
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.59E+00
Am-243	1.28E-02
Cm-244	2.47E+00
Cs-137	7.26E+02
Np-237	8.84E-05
Pu-238	1.02E+00
Pu-239	2.54E-01
Pu-240	2.91E-01
Pu-241	2.56E+01
Pu-242	9.98E-04
Pu-244	1.11E-13
Sr-90	4.30E+02
Th-229	5.86E-08
Th-230	2.44E-09
Th-232	2.91E-15
U-233	6.66E-04
U-234	2.66E-04
U-235	5.39E-06
U-236	5.90E-05
U-238	1.68E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D027, D028, D029, D030, D033, D034, D036, D039, D040, D043, F001, F002, F003, F005

TRUCON Code(s)

325

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL308-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	308 TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	24.5	0.0	24.5
85-gal Drum Dir Ld w/ Liner	5.2	0.0	5.2
Box - Misc	308.8	0.0	308.8
SWB Dir Ld w/ Liner	141.8	0.0	141.8
Current Form Total	480.2	0.0	480.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	31.8	0.0	31.8
SWB Dir Ld w/ Liner	529.2	0.0	529.2
Final Form Total	561.0	0.0	561.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	198.98
Aluminum-based Metal/Alloys	0.19
Other Metal/Alloys	3.74
Other Inorganic Materials	3.53
Cellulosics	7.03
Rubber	1.57
Plastics	8.09
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	3.24
Packaging Material, Rubber	0.21
Packaging Material, Steel	152.15
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.50E+01
Am-243	3.31E-06
Cs-137	3.39E-04
Np-237	6.01E-06
Pu-238	1.07E+01
Pu-239	1.69E+01
Pu-240	1.09E+01
Pu-241	2.38E+02
Pu-242	1.03E-02
Sr-90	3.08E-04
Th-232	9.45E-07
U-233	1.33E-04
U-234	2.53E-04
U-235	2.50E-05
U-238	3.62E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D027, D028, D029, D030, D034, D037, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

Debris waste stream associated with the 308 Bldg. fuel development laboratory, fuel fabrication capabilities, and deactivation. Waste items include plutonium alloys, casting skulls, clad plates, plastic mounts, plutonium-aluminum scrap, metal mounts, Pu pellets, rags, wipes, HEPA filters, batteries, stainless steel tubing, tape, thermometers, electrical wire, and a variety of other solid debris items.

Waste Stream ID: **RL308-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	308 Building TRU Solid Inorganics					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
85-gal Drum Dir Ld w/ Liner	0.3	0.0	0.3
Current Form Total	0.3	0.0	0.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Final Form Total	0.4	0.0	0.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	94.95
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	7.21
Cement	228.97
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.05E-01
Np-237	4.43E-06
Pu-238	1.15E-01
Pu-239	8.03E-01
Pu-240	3.05E-01
Pu-241	1.58E+00
Pu-242	3.69E-05
Th-229	1.55E-13
Th-230	9.79E-10
Th-232	1.29E-16
U-233	2.24E-10
U-234	8.60E-06
U-235	1.90E-08
U-236	2.17E-07
U-238	1.37E-13

No Hazardous Waste Numbers Provided

TRUCON Code(s)

122/222

Waste Stream Description

Waste materials consist of inorganic debris (such as aluminum and iron-based metal containers) and absorbed liquids, including oils or hydraulic fluids. Materials associated with waste packaging include plastic liners and various absorbents (including Cleanup-IV, Nochar A610, vermiculite, diatomaceous earth, and Radsorb). A limited amount of debris waste materials (glassware, rags, wipes, etc.) may also be present in the container.

Waste Stream ID: **RL308-08**

Appendix A
Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	308 Building TRU RH Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	16.36
Aluminum-based Metal/Alloys	0.04
Other Metal/Alloys	2.50
Other Inorganic Materials	2.25
Cellulosics	2.88
Rubber	0.92
Plastics	6.26
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.32E-03
Cs-137	1.97E-01
Np-237	1.50E-09
Pu-238	3.01E-03
Pu-239	4.28E-04
Pu-240	7.21E-04
Sr-90	1.03E+01
Th-229	3.84E-19
Th-230	1.58E-13
Th-232	2.11E-21
U-233	6.55E-15
U-234	1.71E-08
U-235	8.43E-13
U-236	4.27E-11

No Hazardous Waste Numbers Provided

TRUCON Code(s)

325

Waste Stream Description

Debris waste stream associated with the 308 Bldg. fuel development laboratory, fuel fabrication capabilities, and deactivation. Examples of waste items in this waste stream include plutonium alloys, casting skulls, clad plates, plastic mounts, plutonium-aluminum scrap, metal mounts, Pu pellets, rags, wipes, HEPA filters, batteries, stainless steel tubing, tape, thermometers, electrical wire, and a variety of other solid debris items.

Waste Stream ID: **RL325-01**

Appendix A
Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	325 TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	537.3	0.0	537.3
85-gal Drum Dir Ld w/ Liner	39.0	0.0	39.0
Box - Misc	301.5	0.0	301.5
SWB Dir Ld w/ Liner	43.5	0.0	43.5
Uncontained	0.0	34.0	34.0
Current Form Total	921.2	34.0	955.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	694.7	0.0	694.7
SWB Dir Ld w/ Liner	421.5	34.0	455.5
Final Form Total	1116.2	34.0	1150.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	72.60
Aluminum-based Metal/Alloys	0.28
Other Metal/Alloys	3.24
Other Inorganic Materials	23.16
Cellulosics	12.83
Rubber	3.32
Plastics	22.30
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.25
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	22.86
Packaging Material, Rubber	0.42
Packaging Material, Steel	139.75
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.50E+00
Am-243	3.90E-04
Cm-244	6.76E-03
Cs-137	8.47E-04
Np-237	1.73E-04
Pu-238	7.43E-01
Pu-239	1.46E+00
Pu-240	5.89E-01
Pu-241	1.06E+01
Pu-242	1.75E-04
Sr-90	8.45E-04
Th-232	1.59E-06
U-233	4.66E-05
U-234	2.70E-04
U-235	9.36E-06
U-238	9.25E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D027, D028, D029, D030, D032, D033, D034, D035, D036, D037, D038, D039, D040, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

Debris waste stream containing waste materials associated with the 325 Bldg. laboratory operations, sample analysis, facility cleanout, and facility waste treatment. Operations waste includes any discarded item used in laboratory analysis (e.g., glass beakers, tweezers, latex gloves, plastic tape, glass pipettes) and facility cleanout (e.g., glassware, wipes, and equipment). Maintenance waste may include filters, wipes, and various types of gloves. Small amounts of solid sample residues (unused samples) generated during lab operations are present in the waste.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL325-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	325 TRU Mixed Solid Inorganic					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	5.4	0.0	5.4
85-gal Drum Dir Ld w/ Liner	10.0	0.0	10.0
Current Form Total	15.4	0.0	15.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	14.4	0.0	14.4
Final Form Total	14.4	0.0	14.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	77.99
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.02
Other Inorganic Materials	474.68
Cellulosics	1.99
Rubber	1.97
Plastics	18.34
Cement	40.65
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	86.18
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.16E+00
Am-243	8.44E-03
Cm-244	4.33E+00
Cs-137	6.63E-03
Np-237	2.97E-04
Pu-238	1.02E+00
Pu-239	3.62E+00
Pu-240	1.68E+00
Pu-241	4.38E+01
Pu-242	3.12E-04
Sr-90	2.58E-02
U-234	6.01E-05
U-235	2.38E-06
U-238	3.63E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D027, D028, D029, D030, D033, D034, D036, D037, D038, D039, D040, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

122/222

Waste Stream Description

The mixed solid inorganic portion of the 325 waste stream from liquid laboratory samples neutralized and solidified using nonhazardous absorbents. Small amounts of neutralized and solidified liquids from hazardous waste treatment may also be present in the waste. Corrosive liquids, such as hydrochloric acid and sodium hydroxide were neutralized and solidified in cement before being packaged as waste.

Waste Stream ID: **RL325-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	325 TRU RH Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	32.7	0.0	32.7
85-gal Drum Dir Ld w/ Liner	2.3	0.0	2.3
Box - Misc	146.9	0.0	146.9
SWB Dir Ld w/ Liner	28.4	0.0	28.4
Uncontained	0.0	30.6	30.6
Current Form Total	210.1	30.6	240.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	262.7	31.2	293.9
Final Form Total	262.7	31.2	293.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	114.39
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	970.96
Cellulosics	0.00
Rubber	0.00
Plastics	24.40
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.94E-01
Am-243	5.51E-04
Cm-244	1.27E-01
Cs-137	1.14E+00
Np-237	3.86E-04
Pu-238	6.49E-01
Pu-239	9.62E-02
Pu-240	9.68E-02
Pu-241	7.95E+00
Pu-242	1.25E-04
Sr-90	7.88E+00
Th-229	5.45E-11
Th-232	1.68E-07
U-233	3.47E-08
U-234	5.07E-05
U-235	3.10E-06
U-236	8.51E-10
U-238	4.82E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D021, D022, D027, D028, D029, D030, D032, D033, D034, D036, D037, D038, D039, D040, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

325

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters. The waste is generated from R&D/R&D Laboratory Waste activities at the RADIOCHEMISTRY BUILDING.

Waste Stream ID: **RL618-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	618 - 10&11 Burial Grounds TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Uncontained	158.2	0.0	158.2
Current Form Total	158.2	0.0	158.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	158.8	0.0	158.8
Final Form Total	158.8	0.0	158.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	13.39
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	24.10
Other Inorganic Materials	23.22
Cellulosics	1.79
Rubber	3.57
Plastics	3.57
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	8.93
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.81E+00
Cs-137	2.16E+01
Np-237	6.15E-06
Pu-238	1.92E+00
Pu-239	8.27E-01
Pu-240	7.87E+00
Pu-241	5.48E+00
Pu-242	9.97E+00
Sr-90	1.96E+01
Th-229	9.59E-15
Th-230	6.38E-10
Th-232	1.44E-16
U-233	6.55E-11
U-234	2.76E-05
U-235	4.07E-09
U-236	1.16E-06
U-238	7.73E-09

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Retrieved containerized debris waste from Burial Grounds 618 - 10 and 11

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RL618-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	618 - 10&11 Burial Grounds TRU RH Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Uncontained	643.3	0.0	643.3
Current Form Total	643.3	0.0	643.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	643.3	0.0	643.3
Final Form Total	643.3	0.0	643.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	262.60
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	473.53
Other Inorganic Materials	507.76
Cellulosics	35.01
Rubber	70.03
Plastics	70.03
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	175.07
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.82E+00
Cs-137	2.16E+01
Np-237	6.17E-06
Pu-238	1.92E+00
Pu-239	8.30E-01
Pu-240	7.89E+00
Pu-241	5.50E+00
Pu-242	1.00E+01
Sr-90	1.96E+01
Th-229	9.62E-15
Th-230	6.40E-10
Th-232	1.44E-16
U-233	6.57E-11
U-234	2.77E-05
U-235	4.09E-09
U-236	1.17E-06
U-238	7.76E-09

No Hazardous Waste Numbers Provided

TRUCON Code(s)

325

Waste Stream Description

Retrieved containerized debris waste from Burial Grounds 618 - 10 and 11.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RLALE-02**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	TRU Soils/Absorbents from the Arid Lands Ecology Reserve					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Current Form Total	0.4	0.0	0.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2.56
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	381.41
Cellulosics	0.00
Rubber	3.21
Plastics	81.41
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.24E-04
Cs-137	5.54E-07
Pu-238	4.21E-05
Pu-239	8.49E-02
Pu-240	2.75E-03
Pu-241	8.75E-03
Pu-242	2.69E-07
Pu-244	3.64E-11
Sr-90	5.05E-07

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Currently 2 drums of soils from the 6652H building.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RLARG-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Argonne Nat Lab TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	10.6	0.0	10.6
Current Form Total	10.6	0.0	10.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	13.3	0.0	13.3
Final Form Total	13.3	0.0	13.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	478.69
Aluminum-based Metal/Alloys	64.94
Other Metal/Alloys	8.00
Other Inorganic Materials	32.10
Cellulosics	78.38
Rubber	33.59
Plastics	79.87
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	21.15
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.39E+00
Np-237	3.31E-05
Pu-238	1.73E+01
Pu-239	3.29E+00
Pu-240	1.67E+00
Pu-241	1.64E+01
Pu-242	5.78E-05
Th-229	1.31E-12
Th-230	1.74E-07
Th-232	1.09E-06
U-233	1.78E-09
U-234	1.41E-03
U-235	8.43E-08
U-236	1.29E-06
U-238	2.33E-13

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters. The waste is generated from R&D/R&D Laboratory Waste activities at the Argonne National Laboratory - East (IL).

Waste Stream ID: **RLBART-08**

Appendix A
Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Bartlesville RH-TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	253.04
Aluminum-based Metal/Alloys	39.95
Other Metal/Alloys	0.00
Other Inorganic Materials	19.54
Cellulosics	48.01
Rubber	20.49
Plastics	49.16
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	7.03
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.15E-01
Np-237	7.12E-06
Pu-238	6.85E-07
Pu-239	5.41E-06
Pu-240	2.62E-06
Pu-241	7.06E-06
Pu-242	7.57E-10
Th-229	4.13E-13
Th-230	9.39E-15
Th-232	1.73E-21
U-233	4.68E-10
U-234	6.55E-11
U-235	1.60E-13
U-236	2.33E-12
U-238	3.52E-18

No Hazardous Waste Numbers Provided

TRUCON Code(s)

325

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters.

Waste Stream ID: **RLBAT-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Battelle Columbus TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	13.3	0.0	13.3
85-gal Drum Dir Ld w/ Liner	3.9	0.0	3.9
Box - Misc	20.4	0.0	20.4
Current Form Total	37.6	0.0	37.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	18.7	0.0	18.7
SWB Dir Ld w/ Liner	26.5	0.0	26.5
Final Form Total	45.2	0.0	45.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	561.11
Aluminum-based Metal/Alloys	118.24
Other Metal/Alloys	0.00
Other Inorganic Materials	35.60
Cellulosics	42.97
Rubber	16.03
Plastics	50.31
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	7.58
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.06
Packaging Material, Rubber	0.35
Packaging Material, Steel	144.05
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.70E-01
Np-237	3.08E-05
Pu-238	2.59E+00
Pu-239	2.43E-01
Pu-240	9.22E-02
Pu-241	2.08E+00
Pu-242	5.22E-06
Th-229	5.89E-15
Th-230	3.58E-09
Th-232	1.16E-07
U-233	1.34E-10
U-234	3.93E-04
U-235	1.46E-05
U-236	2.73E-09
U-238	1.24E-05

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011, F001, F002, F003, F005

TRUCON Code(s)

125/225

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters.

Waste Stream ID: **RLBAT-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	BATCO TRU RH Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.2	0.0	4.2
Box - Misc	0.6	0.0	0.6
Current Form Total	4.7	0.0	4.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	6.9	0.0	6.9
Final Form Total	6.9	0.0	6.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	1492.62
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	13.33
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.63E-01
Am-243	4.18E-03
Cm-244	3.22E-01
Cs-137	9.15E+00
Np-237	1.80E-06
Pu-238	5.07E-01
Pu-239	6.98E-02
Pu-240	1.14E-01
Pu-241	5.93E+00
Pu-242	3.04E-04
Sr-90	5.92E+00
Th-229	1.48E-12
Th-230	5.48E-09
Th-232	5.12E-15
U-233	1.89E-09
U-234	7.28E-05
U-235	2.76E-06
U-236	1.15E-05
U-238	5.34E-05

Haz. Waste No(s).

D006, D008, P015

TRUCON Code(s)

325

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RLBET-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Bettis TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	108.39
Aluminum-based Metal/Alloys	17.08
Other Metal/Alloys	0.00
Other Inorganic Materials	8.44
Cellulosics	20.62
Rubber	8.84
Plastics	21.01
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	2.95
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.54E-03
Cs-137	1.53E-04
Pu-238	3.33E-03
Pu-239	1.58E-02
Pu-240	8.88E-03
Pu-241	9.47E-02
Pu-242	3.53E-07
Sr-90	1.39E-04
U-234	2.58E-04
U-235	9.47E-06
U-238	1.00E-07

No Hazardous Waste Numbers Provided

TRUCON Code(s)

325

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. Drums may be used for disposal of high-efficiency particulate air filters.

Waste Stream ID: **RLBW-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Babcock and Wilcox TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	18.5	0.0	18.5
85-gal Drum Dir Ld w/ Liner	29.3	0.0	29.3
Box - Misc	127.5	0.0	127.5
Current Form Total	175.3	0.0	175.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	43.7	0.0	43.7
SWB Dir Ld w/ Liner	160.7	0.0	160.7
Final Form Total	204.3	0.0	204.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	48.08
Aluminum-based Metal/Alloys	0.21
Other Metal/Alloys	4.84
Other Inorganic Materials	31.92
Cellulosics	23.25
Rubber	4.97
Plastics	25.30
Cement	0.00
Solidified Inorganic Material	0.82
Solidified Organic Material	0.14
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.87
Packaging Material, Rubber	0.27
Packaging Material, Steel	148.59
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.50E+00
Am-243	8.84E-08
Cs-137	3.63E-04
Np-237	8.94E-06
Pu-238	3.61E-01
Pu-239	2.02E+00
Pu-240	9.61E-01
Pu-241	1.41E+01
Pu-242	1.72E-04
Sr-90	3.30E-04
U-233	1.57E-04
U-234	4.23E-05
U-235	1.13E-06
U-238	2.44E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D030, D035, F001, F002, F003, F005

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible debris waste generated from operations and decontamination and decommissioning of the Babcock and Wilcox Parks Township Site Plutonium Facility. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RLBW-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Babcock & Wilcox solidified inorganics					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
85-gal Drum Dir Ld w/ Liner	1.3	0.0	1.3
Current Form Total	2.7	0.0	2.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.7	0.0	2.7
Final Form Total	2.7	0.0	2.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	4.90
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	698.80
Cellulosics	0.00
Rubber	0.00
Plastics	19.59
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.32E+00
Cs-137	2.65E-07
Np-237	2.02E-05
Pu-238	9.49E-01
Pu-239	4.97E+00
Pu-240	2.53E+00
Pu-241	3.90E+01
Pu-242	4.07E-04
Sr-90	2.46E-07
Th-229	3.68E-15
Th-230	1.10E-09
Th-232	1.85E-18
U-233	8.48E-11
U-234	1.21E-04
U-235	3.70E-06
U-236	7.49E-08
U-238	6.05E-05

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011, D035, F001, F002, F003, F005

TRUCON Code(s)

122/222

Waste Stream Description

Solidified inorganic CH TRU waste generated from operations and decontamination and decommissioning of the Babcock and Wilcox Parks Township Site Plutonium Facility.

Waste Stream ID: **RLBW-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Babcock and Wilcox TRU RH Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
85-gal Drum Dir Ld w/ Liner	0.3	0.0	0.3
Current Form Total	0.5	0.0	0.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	1.2	0.0	1.2
Final Form Total	1.2	0.0	1.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	4.08
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.20
Other Inorganic Materials	2.04
Cellulosics	27.35
Rubber	0.31
Plastics	18.37
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.74E-01
Np-237	9.58E-07
Pu-238	1.55E-01
Pu-239	6.09E-01
Pu-240	3.44E-01
Pu-241	1.09E+01
Pu-242	1.39E-05
Th-229	9.29E-16
Th-230	3.29E-11
Th-232	4.02E-18
U-233	7.99E-12
U-234	1.78E-06
U-235	2.40E-09
U-236	4.07E-08
U-238	8.60E-15

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011, F001, F002, F003, F005

TRUCON Code(s)

325

Waste Stream Description

Combustible and noncombustible debris waste generated from operations and decontamination and decommissioning of the Babcock and Wilcox Parks Township Site Plutonium Facility. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RLCFF-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Kerr McGee TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.2	0.0	1.2
85-gal Drum Dir Ld w/ Liner	2.6	0.0	2.6
Current Form Total	3.8	0.0	3.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.3	0.0	3.3
Final Form Total	3.3	0.0	3.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	478.22
Aluminum-based Metal/Alloys	2.23
Other Metal/Alloys	0.47
Other Inorganic Materials	48.06
Cellulosics	53.78
Rubber	11.64
Plastics	76.17
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.12
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.82E+00
Cs-137	8.90E-08
Np-237	9.74E-07
Pu-238	3.68E-01
Pu-239	2.23E+00
Pu-240	1.13E+00
Pu-241	1.57E+01
Pu-242	1.84E-04
Sr-90	8.07E-08
Th-229	1.11E-16
Th-230	1.38E-10
Th-232	4.85E-09
U-233	2.96E-12
U-234	1.55E-05
U-235	5.06E-07
U-236	3.35E-08
U-238	1.35E-05

Haz. Waste No(s).

D007, D008, D009, D040, F001, F002, F003

TRUCON Code(s)

125/225

Waste Stream Description

The CFFD (KM) waste stream consists of heterogeneous debris waste generated at the Cimarron Plutonium Fuel Fabrication Facility, operated by the Kerr-McGee Nuclear Corporation. This facility was a MOX fuel fabrication facility. The waste was generated during D&D activities at the facility. The waste includes typical D&D waste, e.g., paper, plastic, leaded rubber gloves, rags, glass, equipment, dissassembled gloveboxes, and HEPA filters.

Waste Stream ID: **RLCFF-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Kerr McGee TRU Mixed Solid Inorganic					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.8	0.0	4.8
Current Form Total	4.8	0.0	4.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	5.0	0.0	5.0
Final Form Total	5.0	0.0	5.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	31.04
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	22.27
Other Inorganic Materials	456.10
Cellulosics	8.21
Rubber	0.99
Plastics	34.11
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.14E+00
Np-237	3.68E-07
Pu-238	3.58E+00
Pu-239	1.44E+00
Pu-240	7.05E-01
Pu-241	9.60E+00
Pu-242	8.91E-05
Th-229	2.34E-17
Th-230	1.42E-10
Th-232	5.15E-19
U-233	8.00E-13
U-234	2.06E-05
U-235	4.59E-07
U-236	2.09E-08
U-238	9.82E-06

Haz. Waste No(s).

D007, D008, D009, F001, F002, F003

TRUCON Code(s)

122/222

Waste Stream Description

Waste generated from R&D/R&D Laboratory Waste activities at the Kerr McGee.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RLCH2-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Tank Farms TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Current Form Total	2.1	0.0	2.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Final Form Total	2.1	0.0	2.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	21.50
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	19.01
Other Inorganic Materials	11.06
Cellulosics	1.61
Rubber	0.01
Plastics	1.90
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	4.76
Packaging Material, Rubber	0.23
Packaging Material, Steel	151.19
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.37E-02
Cs-137	1.96E-01
Np-237	4.44E-09
Pu-238	1.30E-03
Pu-239	9.63E-03
Pu-240	2.47E-03
Pu-241	2.33E-02
Sr-90	8.75E-01
Th-229	6.62E-08
Th-230	1.72E-14
Th-232	1.81E-21
U-233	7.53E-04
U-234	3.74E-09
U-235	9.77E-07
U-236	7.32E-11
U-238	2.13E-05

Haz. Waste No(s).

D004, D006, D007, D008, D009, D010, F001, F002, F003, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

CH waste- Equipment removed from waste tanks (instrument trees, pumps, circulators, agitators, heaters, sluicers, steam coils, air lances, cameras). The waste stream ranges from contaminated clothing to process equipment contaminated with RCRA constituents.

Waste Stream ID: **RLESG-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Energy Systems Group TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	13.1	0.0	13.1
85-gal Drum Dir Ld w/ Liner	3.5	0.0	3.5
Box - Misc	14.9	0.0	14.9
Current Form Total	31.5	0.0	31.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	16.8	0.0	16.8
SWB Dir Ld w/ Liner	18.9	0.0	18.9
Final Form Total	35.7	0.0	35.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	228.99
Aluminum-based Metal/Alloys	0.68
Other Metal/Alloys	7.31
Other Inorganic Materials	30.12
Cellulosics	28.62
Rubber	19.12
Plastics	38.84
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	18.10
Packaging Material, Rubber	0.37
Packaging Material, Steel	142.75
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.21E-01
Cs-137	3.29E-03
Np-237	6.04E-06
Pu-238	1.10E-01
Pu-239	6.57E-01
Pu-240	2.99E-01
Pu-241	4.92E+00
Pu-242	5.57E-05
Sr-90	2.69E-03
Th-232	2.51E-07
U-234	1.04E-03
U-235	2.65E-05
U-238	2.59E-05

Haz. Waste No(s).

D006, D007, D008, F001, F002, F003

TRUCON Code(s)

125/225

Waste Stream Description

RLETECD waste is composed of heterogeneous debris consisting of organic and inorganic debris material generated from glove box operations at the Energy Technology Engineering Center. Examples of waste items in this waste stream include cardboard tubes, cladding material, plastic, paper, glove port flanges, rubber air hoses, electrical connectors, wooden broom handles, plexiglass windows, steel plates, glove box ventilation piping and valves, lead, stainless steel, nickel-cadmium batteries, paint brushes and rollers, full-face respirators, sphincter cans, tools, copper, poly bottles, shoe covers, aluminum, vermiculite, soda ash, mixer components, glass, rags, molybdenum plates, drying ovens, MOX ash, gloves, fittings, gas line hookups, balance weights, cloth, pumps, castings, small quantities of neutralized/solidified liquids, and concrete.

Waste Stream ID: **RLESG-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Energy Systems Group TRU Solid Inorganics					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.8	0.0	0.8
Current Form Total	0.8	0.0	0.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.0	0.0	1.0
Final Form Total	1.0	0.0	1.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	29.72
Aluminum-based Metal/Alloys	29.72
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	29.72
Rubber	29.72
Plastics	29.72
Cement	22.43
Solidified Inorganic Material	62.50
Solidified Organic Material	0.00
Soils	126.03
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.84E-03
Cs-137	3.73E-03
Pu-238	5.43E-03
Pu-239	1.58E-01
Pu-240	3.89E-02
Pu-241	5.76E-01
Pu-242	2.54E-06
Sr-90	3.39E-03

No Hazardous Waste Numbers Provided

TRUCON Code(s)

122/222

Waste Stream Description

Absorbed/solidified liquids from operations and decommissioning of the Nuclear Materials Development Facility.

Waste Stream ID: **RLESG-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Energy Systems Group RH TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	12.9	0.0	12.9
85-gal Drum Dir Ld w/ Liner	9.0	0.0	9.0
Current Form Total	21.9	0.0	21.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	23.7	0.0	23.7
Final Form Total	23.7	0.0	23.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	6.97
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	33.18
Other Inorganic Materials	3.14
Cellulosics	83.05
Rubber	9.84
Plastics	44.74
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.99E-01
Cs-137	8.22E-02
Pu-238	3.81E-02
Pu-239	1.62E-01
Pu-240	8.78E-02
Pu-241	2.87E+00
Pu-242	3.38E-06
Sr-90	2.52E-02

Haz. Waste No(s).

D006, D007, D008, F001, F002, F003

TRUCON Code(s)

325

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters. The waste is generated from R&D/R&D Laboratory Waste activities at the Rockwell International, Energy Systems Group (CA).

Waste Stream ID: **RLEXX-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Exxon TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	42.8	0.0	42.8
85-gal Drum Dir Ld w/ Liner	1.3	0.0	1.3
Current Form Total	44.1	0.0	44.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	129.8	0.0	129.8
Final Form Total	129.8	0.0	129.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	40.00
Aluminum-based Metal/Alloys	0.16
Other Metal/Alloys	7.91
Other Inorganic Materials	25.93
Cellulosics	4.75
Rubber	1.09
Plastics	5.08
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.24E+00
Np-237	6.65E-06
Pu-238	9.49E-01
Pu-239	5.93E-01
Pu-240	5.06E-01
Pu-241	1.57E+01
Pu-242	6.16E-04
U-234	5.77E-05
U-235	7.59E-07
U-238	3.04E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D030

TRUCON Code(s)

125/225

Waste Stream Description

RLEXXOD waste is comprised of heterogeneous debris consisting of organic and inorganic debris material generated from processing, cleanout, and D&D of the Mixed Oxide Fuel Fabrication Plant. Examples of waste items in this waste stream include unirradiated MOX fuel pellets, MOX powder and scrap, cladding material, MOX standards, plastic, paper, gloves and glove rings, filters, cans, HEPA filters, cardboard, electrical components, tools, scales and scale parts, screens, paint brushes, bags, floor sweepings, pots and pans, tool boxes, steel plates and racks, grinder parts, pellet trays, conduit pipe, motors, filter and vacuum hoses, and rags.

Waste Stream ID: **RLFFTF-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	FFTF TRU Non-Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.8	0.0	0.8
Current Form Total	0.8	0.0	0.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.0	0.0	1.0
Final Form Total	1.0	0.0	1.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	116.67
Aluminum-based Metal/Alloys	0.47
Other Metal/Alloys	23.06
Other Inorganic Materials	75.63
Cellulosics	13.85
Rubber	3.19
Plastics	1.54
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.15E-02
Cs-137	1.12E-02
Pu-238	3.49E-03
Pu-239	1.06E-02
Pu-240	9.15E-03
Pu-241	9.36E-02
Sr-90	7.57E-03

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible debris from Fast Flux Test Reactor operations, maintenance, and clean out. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RLFFTF-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	FFTF RH-TRU Non-Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
85-gal Drum Dir Ld w/ Liner	0.3	0.0	0.3
Current Form Total	0.3	0.0	0.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2.64
Aluminum-based Metal/Alloys	0.01
Other Metal/Alloys	0.52
Other Inorganic Materials	1.71
Cellulosics	0.31
Rubber	0.07
Plastics	0.33
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.20E-03
Am-243	9.32E-12
Cs-137	8.52E-01
Np-237	2.66E-09
Pu-238	1.25E-03
Pu-239	3.77E-03
Pu-240	3.24E-03
Pu-241	6.01E-02
Sr-90	9.18E-04
Th-229	6.71E-19
Th-230	6.54E-14
Th-232	9.45E-21
U-233	1.15E-14
U-234	7.10E-09
U-235	7.42E-12
U-236	1.92E-10

No Hazardous Waste Numbers Provided

TRUCON Code(s)

325

Waste Stream Description

Combustible and noncombustible debris from Fast Flux Test Reactor operations, maintenance, and clean out. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RLGEV-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	GE San Jose and Vallecitos TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	17.3	0.0	17.3
85-gal Drum Dir Ld w/ Liner	7.7	0.0	7.7
Box - Misc	147.2	0.0	147.2
SWB Dir Ld w/ Liner	15.1	0.0	15.1
Current Form Total	187.3	0.0	187.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	23.9	0.0	23.9
SWB Dir Ld w/ Liner	200.3	0.0	200.3
Final Form Total	224.3	0.0	224.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	231.42
Aluminum-based Metal/Alloys	0.26
Other Metal/Alloys	4.60
Other Inorganic Materials	24.63
Cellulosics	20.70
Rubber	5.14
Plastics	51.89
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	5.03
Packaging Material, Rubber	0.23
Packaging Material, Steel	151.02
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.79E-01
Cs-137	1.37E-07
Np-237	2.02E-06
Pu-238	1.20E-01
Pu-239	6.31E-01
Pu-240	2.75E-01
Pu-241	4.67E+00
Pu-242	4.35E-05
Sr-90	1.24E-07
U-234	2.98E-04
U-235	6.32E-06
U-238	2.16E-04

Haz. Waste No(s).

D006, D007, D008, D011, D035

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible debris waste from decontmination and decommissioning of Building 102 at the GE-Vallecitos Nuclear Center. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RLGEV-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	GE Vallecitos TRU Homogeneous Solids					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
Current Form Total	1.5	0.0	1.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	4.72
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.24
Cellulosics	5.42
Rubber	0.04
Plastics	9.41
Cement	0.00
Solidified Inorganic Material	427.04
Solidified Organic Material	6.56
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.39E+00
Cs-137	3.96E-08
Np-237	1.47E-06
Pu-238	9.68E-01
Pu-239	3.71E+00
Pu-240	2.10E+00
Pu-241	7.68E+01
Pu-242	8.45E-05
Sr-90	3.67E-08
Th-229	1.01E-16
Th-230	2.43E-11
Th-232	1.53E-18
U-233	3.32E-12
U-234	4.01E-06
U-235	4.65E-08
U-236	6.20E-08
U-238	6.41E-07

Haz. Waste No(s).

D006, D007, D008, D011, D035

TRUCON Code(s)

122/222

Waste Stream Description

Homogeneous solids from decontamination and decommissioning of Building 102 at the GE-Vallecitos Nuclear Center.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RLGEV-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	GE San Jose and Vallecitos TRU RH Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Misc	5.3	0.0	5.3
Current Form Total	5.3	0.0	5.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	6.9	0.0	6.9
Final Form Total	6.9	0.0	6.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	1062.29
Aluminum-based Metal/Alloys	167.73
Other Metal/Alloys	0.00
Other Inorganic Materials	82.01
Cellulosics	201.53
Rubber	86.00
Plastics	206.38
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	29.52
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.73E+00
Cs-137	1.37E+00
Np-237	1.60E-05
Pu-238	7.22E-02
Pu-239	9.17E+01
Pu-240	9.54E+00
Pu-241	2.01E-01
Pu-242	3.86E-01
Sr-90	1.03E+00
Th-229	8.02E-13
Th-230	8.52E-10
Th-232	5.47E-15
U-233	9.75E-10
U-234	6.39E-06
U-235	2.53E-06
U-236	7.92E-06
U-238	1.68E-09

No Hazardous Waste Numbers Provided

TRUCON Code(s)

325

Waste Stream Description

Combustible and noncombustible debris waste from decontmination and decommissioning of Building 102 at the GE-Vallecitos Nuclear Center. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RLHAN-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Trench Designation waste stream					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	77.6	0.0	77.6
85-gal Drum Dir Ld w/ Liner	108.2	0.0	108.2
Box - Misc	226.3	0.0	226.3
SWB Dir Ld w/ Liner	177.7	0.0	177.7
Current Form Total	589.8	0.0	589.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	165.6	0.0	165.6
SWB Dir Ld w/ Liner	461.2	0.0	461.2
Final Form Total	626.7	0.0	626.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	24.37
Aluminum-based Metal/Alloys	0.09
Other Metal/Alloys	5.76
Other Inorganic Materials	8.03
Cellulosics	21.04
Rubber	7.25
Plastics	25.25
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	10.68
Packaging Material, Rubber	0.29
Packaging Material, Steel	147.45
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.50E-01
Cs-137	8.82E-08
Np-237	1.01E-06
Pu-238	7.06E-02
Pu-239	7.28E-01
Pu-240	2.54E-01
Pu-241	2.58E+00
Pu-242	3.82E-05
Sr-90	8.00E-08
Th-229	1.75E-16
Th-230	9.20E-13
Th-232	1.85E-19
U-233	4.09E-12
U-234	2.00E-07
U-235	7.17E-10
U-236	7.52E-09
U-238	5.93E-15

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D027, D028, D029, D030, D032, D033, D034, D035, D037, D038, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible TRU debris waste retrieved from the Hanford low-level burial grounds that cannot be identified or assigned to an original generator. Combustible waste may include wood, plastics, paper, absorbents, rubber, and rags. Noncombustible waste may include failed machinery, tools, glass, concrete, plumbing, and fixtures.

Waste Stream ID: **RLHAN-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Trench Designation waste stream					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Box - Misc	14.5	0.0	14.5
SWB Dir Ld w/ Liner	3.8	0.0	3.8
Current Form Total	18.5	0.0	18.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	23.7	0.0	23.7
Final Form Total	23.7	0.0	23.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	31.99
Aluminum-based Metal/Alloys	0.11
Other Metal/Alloys	7.45
Other Inorganic Materials	10.55
Cellulosics	27.83
Rubber	9.42
Plastics	33.62
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.94E-01
Am-243	2.66E-06
Cs-137	6.58E-02
Np-237	2.90E-06
Pu-238	1.76E-02
Pu-239	1.77E-01
Pu-240	2.86E-02
Pu-241	1.09E+00
Pu-242	1.14E-06
Sr-90	5.02E-02
U-233	8.43E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D027, D028, D029, D030, D034, D035, D037, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

325

Waste Stream Description

Combustible and noncombustible RH-TRU debris waste retrieved from the Hanford low-level burial grounds that cannot be identified or assigned to an original generator. Combustible waste may include wood, plastics, paper, absorbents, rubber, and rags. Noncombustible waste may include failed machinery, tools, glass, concrete, plumbing, and fixtures.

Waste Stream ID: **RLIAEA-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	International Atomic Energy Agency TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Final Form Total	0.4	0.0	0.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	552.00
Aluminum-based Metal/Alloys	87.00
Other Metal/Alloys	0.00
Other Inorganic Materials	43.00
Cellulosics	105.00
Rubber	45.00
Plastics	107.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	15.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.88E+00
Cs-137	4.23E-05
Np-237	6.10E-07
Pu-238	1.02E+00
Pu-239	5.31E-01
Pu-240	6.83E-01
Pu-241	4.26E+00
Pu-242	1.01E-03
Sr-90	3.85E-05
Th-229	3.89E-17
Th-230	1.32E-11
Th-232	4.98E-19
U-233	1.33E-12
U-234	2.88E-06
U-235	5.23E-10
U-236	2.02E-08
U-238	1.56E-13

No Hazardous Waste Numbers Provided

TRUCON Code(s)

122/222

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters.

Waste Stream ID: **RLMLB-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Lawrence Berkeley Nat Lab TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	401.22
Aluminum-based Metal/Alloys	63.24
Other Metal/Alloys	0.00
Other Inorganic Materials	31.25
Cellulosics	76.32
Rubber	32.71
Plastics	77.77
Cement	0.00
Solidified Inorganic Material	10.90
Solidified Organic Material	0.00
Soils	13.08
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.36E-01
Cm-244	2.12E+01
Np-237	1.14E-06
Pu-238	1.75E-02
Pu-239	8.34E-02
Pu-240	1.66E-01
Pu-241	4.47E-01
Pu-242	1.90E-06
Th-229	5.58E-14
Th-230	2.22E-10
Th-232	6.01E-17
U-233	6.79E-11
U-234	1.61E-06
U-235	2.38E-09
U-236	1.01E-07
U-238	8.55E-15

Haz. Waste No(s).

D005, D007, D008, D009, D011, D019, F002, F003, F005

TRUCON Code(s)

325

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. Drums may be used for disposal of high-efficiency particulate air filters.

Waste Stream ID: **RLMLL-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Lawrence Livermore TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
85-gal Drum Dir Ld w/ Liner	0.3	0.0	0.3
Current Form Total	0.7	0.0	0.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.0	0.0	1.0
Final Form Total	1.0	0.0	1.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	393.83
Aluminum-based Metal/Alloys	62.07
Other Metal/Alloys	0.00
Other Inorganic Materials	30.68
Cellulosics	74.91
Rubber	32.11
Plastics	76.34
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	10.70
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.35E-02
Np-237	9.25E-07
Pu-238	9.76E-03
Pu-239	5.00E-02
Pu-240	2.82E-02
Pu-241	1.74E-01
Pu-242	1.14E-06
Th-229	7.76E-14
Th-230	2.24E-10
Th-232	2.98E-17
U-233	7.22E-11
U-234	1.22E-06
U-235	1.87E-09
U-236	3.18E-08
U-238	6.72E-15

Haz. Waste No(s).

D006, D007, D008, D011

TRUCON Code(s)

125/225

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters.

Waste Stream ID: **RLP11-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	P11 Criticality Facility TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Misc	51.2	0.0	51.2
Current Form Total	51.2	0.0	51.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	64.3	0.0	64.3
Final Form Total	64.3	0.0	64.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	22.61
Aluminum-based Metal/Alloys	11.34
Other Metal/Alloys	0.00
Other Inorganic Materials	22.61
Cellulosics	11.28
Rubber	0.00
Plastics	11.28
Cement	11.34
Solidified Inorganic Material	0.10
Solidified Organic Material	0.10
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.41E-02
Np-237	1.41E-08
Pu-238	9.73E-03
Pu-239	3.73E-02
Pu-240	2.11E-02
Pu-241	7.73E-01
Pu-242	8.49E-07
Th-229	8.95E-19
Th-230	1.27E-13
Th-232	1.54E-20
U-233	3.06E-14
U-234	2.76E-08
U-235	3.67E-11
U-236	6.24E-10
U-238	1.32E-16

Haz. Waste No(s).

D005, D006, D007

TRUCON Code(s)

125/225

Waste Stream Description

Misc. demolition debris.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RLPFP-01**

Appendix A
Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	2345Z TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1556.3	0.0	1556.3
85-gal Drum Dir Ld w/ Liner	174.8	0.0	174.8
Box - Misc	4329.5	0.0	4329.5
SWB Dir Ld w/ Liner	310.0	0.0	310.0
Uncontained	0.0	2009.0	2009.0
Current Form Total	6370.5	2009.0	8379.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2036.9	0.0	2036.9
SWB Dir Ld w/ Liner	5722.9	2009.1	7732.0
Final Form Total	7759.9	2009.1	9768.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	63.17
Aluminum-based Metal/Alloys	0.31
Other Metal/Alloys	1.36
Other Inorganic Materials	10.04
Cellulosics	15.74
Rubber	8.91
Plastics	24.80
Cement	0.00
Solidified Inorganic Material	0.02
Solidified Organic Material	0.02
Soils	0.18
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.68
Packaging Material, Rubber	0.27
Packaging Material, Steel	148.71
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.47E+00
Am-243	4.68E-07
Cs-137	1.24E-05
Np-237	4.03E-05
Pu-238	7.16E-01
Pu-239	5.06E+00
Pu-240	1.66E+00
Pu-241	2.41E+01
Pu-242	3.16E-04
Sr-90	1.13E-05
Th-232	3.55E-08
U-233	2.25E-04
U-234	2.27E-04
U-235	6.49E-06
U-236	2.33E-10
U-238	1.19E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D027, D028, D029, D030, D032, D034, D035, D036, D037, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible debris waste generated from operations, maintenance, and D&D activities at the Plutonium Finishing Plant (PFP), which includes the 234-5Z, 232-Z, 236-Z, 2736-ZB, 242-Z, and 291-Z Buildings. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RLPFP-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	PFP Absorbed Plutonium Nitrate Solutions					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	13.9	0.0	13.9
85-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Current Form Total	14.6	0.0	14.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	15.2	0.0	15.2
Final Form Total	15.2	0.0	15.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	3.34
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.01
Other Inorganic Materials	0.23
Cellulosics	3.95
Rubber	0.04
Plastics	11.12
Cement	0.00
Solidified Inorganic Material	396.63
Solidified Organic Material	18.94
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.09E+00
Cs-137	3.99E-06
Np-237	3.62E-05
Pu-238	1.89E+00
Pu-239	1.44E+01
Pu-240	4.48E+00
Pu-241	6.43E+01
Pu-242	8.31E-04
Sr-90	3.62E-06
U-234	1.08E-03
U-235	5.36E-06
U-238	4.39E-05

Haz. Waste No(s).

D004, D006, D007, D008, D010, D011

TRUCON Code(s)

114/214

Waste Stream Description

Solidified inorganic waste generated from operations, maintenance, and D&D activities at the 325 Laboratory, the 209-E Critical Mass Laboratory, and the Plutonium Reclamation Facility (Bldg 236-Z) at the Plutonium Finishing Plant (PFP).

Waste Stream ID: **RLPFP-04**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	PFP Comprehensive Homogenous Solids					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	15.8	0.0	15.8
85-gal Drum Dir Ld w/ Liner	2.3	0.0	2.3
Current Form Total	18.1	0.0	18.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	19.6	0.0	19.6
Final Form Total	19.6	0.0	19.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	17.98
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.50
Other Inorganic Materials	90.37
Cellulosics	11.72
Rubber	0.23
Plastics	16.66
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.41
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.55E+00
Cs-137	1.30E-04
Np-237	3.11E-05
Pu-238	8.39E-01
Pu-239	9.53E+00
Pu-240	2.69E+00
Pu-241	4.01E+01
Pu-242	3.18E-04
Sr-90	1.18E-04
U-234	1.87E-04
U-235	6.24E-06
U-238	9.36E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D030, D032, D033, F001, F002, F003, F005

TRUCON Code(s)

112/212

Waste Stream Description

Homogenous solids generated from operations, maintenance, and D&D activities at the Plutonium Finishing Plant (PFP), which includes the 234-5Z, 232-Z, 236-Z, 2736-ZB, 242-Z, and 291-Z Buildings.

Waste Stream ID: **RLPFP-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	2345Z RH-TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	18.3	0.0	18.3
85-gal Drum Dir Ld w/ Liner	7.7	0.0	7.7
Uncontained	0.0	183.0	183.0
Current Form Total	26.0	183.0	209.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	29.3	183.5	212.8
Final Form Total	29.3	183.5	212.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	34.01
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	20.82
Other Inorganic Materials	17.54
Cellulosics	4.81
Rubber	9.39
Plastics	26.22
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.64E+00
Cs-137	5.47E-06
Np-237	9.06E-06
Pu-238	4.25E-01
Pu-239	2.36E+00
Pu-240	8.64E-01
Pu-241	1.87E+01
Pu-242	1.63E-04
Sr-90	4.98E-06
U-234	8.85E-06
U-235	2.96E-07
U-236	7.53E-10
U-238	5.84E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D030, F001, F002, F003, F004, F005

TRUCON Code(s)

325

Waste Stream Description

Combustible and noncombustible debris waste generated from operations, maintenance, and D&D activities at the Plutonium Finishing Plant (PFP), which includes the 234-5Z, 232-Z, 236-Z, 2736-ZB, 242-Z, and 291-Z Buildings. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RLPURX-01**

Appendix A
Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	202A and 202AL TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	309.5	0.0	309.5
85-gal Drum Dir Ld w/ Liner	2.9	0.0	2.9
Box - Misc	260.2	0.0	260.2
SWB Dir Ld w/ Liner	7.6	0.0	7.6
Current Form Total	580.2	0.0	580.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	387.3	0.0	387.3
SWB Dir Ld w/ Liner	334.5	0.0	334.5
Final Form Total	721.8	0.0	721.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	37.38
Aluminum-based Metal/Alloys	0.13
Other Metal/Alloys	0.44
Other Inorganic Materials	11.61
Cellulosics	14.97
Rubber	14.29
Plastics	25.30
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.01
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	20.45
Packaging Material, Rubber	0.39
Packaging Material, Steel	141.28
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.74E+00
Am-243	6.24E-07
Cs-137	1.54E-02
Np-237	8.80E-06
Pu-238	1.88E+00
Pu-239	9.70E+00
Pu-240	3.70E+00
Pu-241	1.21E+02
Pu-242	8.69E-04
Sr-90	1.40E-02
U-233	2.30E-03
U-234	5.36E-06
U-235	1.77E-07
U-238	2.90E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D027, D028, D029, D030, D034, D035, D037, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible debris waste generated from facility/equipment operation and maintenance, and analytical laboratory waste activities at the Plutonium Uranium Extraction Facility. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RLPURX-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	202A & 202AL TRU RH Non-mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	13.1	0.0	13.1
Box - Misc	11.5	0.0	11.5
Current Form Total	24.6	0.0	24.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	31.8	0.0	31.8
Final Form Total	31.8	0.0	31.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	21.10
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.53
Other Inorganic Materials	15.83
Cellulosics	10.55
Rubber	35.88
Plastics	26.38
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.61E-02
Np-237	4.50E-07
Pu-238	2.86E-03
Pu-239	9.11E-03
Pu-240	2.17E-03
Pu-241	5.24E-01
Pu-242	1.19E-07
Th-229	1.88E-14
Th-230	4.82E-11
Th-232	1.73E-18
U-233	2.41E-11
U-234	3.05E-07
U-235	2.96E-10
U-236	2.13E-09
U-238	6.07E-16

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011

TRUCON Code(s)

325

Waste Stream Description

Combustible and noncombustible debris waste generated from facility/equipment operation and maintenance, and analytical laboratory waste activities at the Plutonium Uranium Extraction Facility. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RLRFET-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Rocky Flats TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	198.0	0.0	198.0
85-gal Drum Dir Ld w/ Liner	6.8	0.0	6.8
Current Form Total	204.8	0.0	204.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	253.1	0.0	253.1
Final Form Total	253.1	0.0	253.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	362.70
Aluminum-based Metal/Alloys	50.51
Other Metal/Alloys	15.18
Other Inorganic Materials	67.36
Cellulosics	38.72
Rubber	9.19
Plastics	34.16
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.01
Soils	6.41
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.13E-01
Np-237	2.77E-06
Pu-238	3.43E-03
Pu-239	1.61E-02
Pu-240	9.10E-03
Pu-241	9.54E-02
Pu-242	3.68E-07
Th-229	1.29E-13
Th-230	3.75E-11
Th-232	4.85E-18
U-233	1.62E-10
U-234	2.92E-07
U-235	4.29E-10
U-236	7.29E-09
U-238	1.54E-15

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters.

Waste Stream ID: **RLSAN-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	GE San Jose TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.3	0.0	3.3
Current Form Total	3.3	0.0	3.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.2	0.0	4.2
Final Form Total	4.2	0.0	4.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	233.45
Aluminum-based Metal/Alloys	0.23
Other Metal/Alloys	5.58
Other Inorganic Materials	21.84
Cellulosics	18.96
Rubber	4.64
Plastics	49.67
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.29E+01
Np-237	1.04E-04
Pu-238	1.67E+00
Pu-239	7.93E+00
Pu-240	4.47E+00
Pu-241	4.47E+01
Pu-242	1.79E-04
Th-229	4.76E-12
Th-230	1.98E-08
Th-232	2.57E-15
U-233	6.00E-09
U-234	1.48E-04
U-235	2.19E-07
U-236	3.71E-06
U-238	7.79E-13

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible debris waste from decontmination and decommissioning at the GE-San Jose Nuclear Center. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RLSWO-01**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	SWOC TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	31.4	0.0	31.4
85-gal Drum Dir Ld w/ Liner	12.6	0.0	12.6
Box - Misc	166.8	0.0	166.8
SWB Dir Ld w/ Liner	49.1	0.0	49.1
Uncontained	0.0	7.8	7.8
Current Form Total	259.9	7.8	267.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	41.8	0.0	41.8
SWB Dir Ld w/ Liner	258.9	9.5	268.4
Final Form Total	300.7	9.5	310.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	21.64
Aluminum-based Metal/Alloys	0.36
Other Metal/Alloys	0.64
Other Inorganic Materials	4.47
Cellulosics	13.25
Rubber	47.39
Plastics	50.16
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.10
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	6.04
Packaging Material, Rubber	0.24
Packaging Material, Steel	150.38
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.00E-01
Am-243	6.41E-08
Cs-137	3.46E-05
Np-237	4.90E-06
Pu-238	1.20E-01
Pu-239	9.01E-01
Pu-240	2.98E-01
Pu-241	4.56E+00
Pu-242	4.53E-05
Sr-90	3.14E-05
U-234	6.87E-06
U-235	2.52E-07
U-238	1.85E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D027, D028, D029, D030, D034, D035, D037, D039, D043, F001, F002, F003, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible debris waste generated from operations, maintenance, and clean up at the Hanford Solid Waste Operations Complex facilities. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RLWAR-01**

Appendix A
Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Ward TRU Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	26.8	0.0	26.8
85-gal Drum Dir Ld w/ Liner	10.6	0.0	10.6
Box - Misc	328.3	0.0	328.3
Current Form Total	365.8	0.0	365.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	36.8	0.0	36.8
SWB Dir Ld w/ Liner	412.0	0.0	412.0
Final Form Total	448.8	0.0	448.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	88.52
Aluminum-based Metal/Alloys	0.40
Other Metal/Alloys	1.93
Other Inorganic Materials	14.40
Cellulosics	18.71
Rubber	4.91
Plastics	27.66
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.01
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	4.14
Packaging Material, Rubber	0.22
Packaging Material, Steel	151.58
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.08E-01
Cs-137	4.22E-08
Np-237	3.74E-06
Pu-238	2.65E-01
Pu-239	3.28E-01
Pu-240	2.08E-01
Pu-241	5.63E+00
Pu-242	1.63E-04
Sr-90	3.84E-08
Th-232	1.31E-08
U-234	1.51E-04
U-235	5.64E-06
U-238	3.12E-05

Haz. Waste No(s).

D007, D008, D009, D035, F001, F002, F003, F005

TRUCON Code(s)

125/225

Waste Stream Description

Combustible and noncombustible debris waste generated during decontamination and decommissioing of the Westinghouse Advanced Reactors Division facility in Cheswick, PA. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste may include metals, glass, concrete, and absorbed liquids.

Waste Stream ID: **RLWAR-03**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	WARD solidified inorganics					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.8	0.0	4.8
85-gal Drum Dir Ld w/ Liner	1.6	0.0	1.6
Current Form Total	6.4	0.0	6.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	7.3	0.0	7.3
Final Form Total	7.3	0.0	7.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.80
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.11
Other Inorganic Materials	0.00
Cellulosics	3.20
Rubber	0.00
Plastics	41.39
Cement	401.34
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.23E-01
Cs-137	1.04E-07
Np-237	2.16E-06
Pu-238	1.65E-01
Pu-239	5.44E-01
Pu-240	2.64E-01
Pu-241	5.36E+00
Pu-242	1.04E-04
Th-229	3.03E-15
Th-230	2.96E-09
Th-232	1.74E-18
U-233	2.43E-11
U-234	1.08E-04
U-235	5.22E-06
U-236	2.35E-08
U-238	5.00E-06

Haz. Waste No(s).

D007, D008, D009, D035, F001, F002, F003, F005

TRUCON Code(s)

122/222

Waste Stream Description

Solidified inorganic waste generated during decontamination and decommissioing of the Westinghouse Advanced Reactors Division facility in Cheswick, PA.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RLWTP-08**

Appendix A

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Waste Treatment Plant TRU RH Mixed Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Uncontained	0.0	74.5	74.5
Current Form Total	0.0	74.5	74.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.0	74.9	74.9
Final Form Total	0.0	74.9	74.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	44.94
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	11.92
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.25E-03
Cs-137	1.33E+00
Np-237	4.48E-06
Pu-238	3.06E-03
Pu-239	1.49E-03
Pu-240	3.18E-04
Pu-241	7.81E-04
Sr-90	1.50E+00
Th-229	1.84E-08
Th-230	3.26E-10
Th-232	3.44E-17
U-233	4.18E-05
U-234	7.11E-06
U-235	2.79E-07
U-236	1.39E-07
U-238	6.27E-06

No Hazardous Waste Numbers Provided

TRUCON Code(s)

325

Waste Stream Description

RH debris waste generated from future WTP operations

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SA-W135**

Appendix A

Waste Profile Report

Site	Sandia National Laboratory - Albuquerque	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	TRU Waste from SNL/NM - Remote Handled					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	2.1	0.0	2.1
Current Form Total	2.1	0.0	2.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	2.5	0.0	2.5
Final Form Total	2.5	0.0	2.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	50.00
Aluminum-based Metal/Alloys	8.13
Other Metal/Alloys	3.08
Other Inorganic Materials	6.21
Cellulosics	4.53
Rubber	1.28
Plastics	6.69
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.59E-01
Am-243	2.69E-05
Cs-137	1.27E+01
Np-237	1.33E-06
Pu-238	1.38E-01
Pu-239	2.39E-01
Pu-240	1.69E-02
Pu-241	1.63E+00
Pu-242	1.44E-05
Sr-90	4.61E+00
U-233	4.81E-09
U-234	8.73E-05
U-235	4.89E-06
U-236	2.11E-07
U-238	1.22E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D035, D038, F002, F005

TRUCON Code(s)

325

Waste Stream Description

Heterogeneous RH debris from SNL/NM Hot Cell Facility D&D Project and other miscellaneous waste generators.

Waste Stream ID: **SA-W136**

Appendix A

Waste Profile Report

Site	Sandia National Laboratory - Albuquerque	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Uncategorized Metal Waste			**Inventory Date**	12/31/2011
Stream Name	CH TRU Debris waste from Z-machine					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.4	5.0	5.4
Current Form Total	0.4	5.0	5.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.4	5.0	5.4
Final Form Total	0.4	5.0	5.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	1848.56
Aluminum-based Metal/Alloys	25.00
Other Metal/Alloys	28.61
Other Inorganic Materials	0.19
Cellulosics	0.00
Rubber	2.14
Plastics	1.55
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	1.84
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.96E-02
Np-237	1.54E-08
Pu-238	5.18E-02
Pu-239	1.65E+00
Pu-240	3.89E-01
Pu-241	2.59E+00
Pu-242	1.32E-05
Th-229	9.63E-19
Th-230	6.75E-13
Th-232	2.84E-19
U-233	3.31E-14
U-234	1.47E-07
U-235	1.62E-09
U-236	1.15E-08
U-238	2.05E-15

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

CH debris waste from the Z-machine, Pu ICE experiments. Waste generated at SNL/NM, but is LANL waste

Waste Stream ID: **SA-W137**

Appendix A

Waste Profile Report

Site	Sandia National Laboratory - Albuquerque	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	CH TRU solidified waste					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
20-gal Pail	0.1	0.0	0.1
Current Form Total	0.1	0.0	0.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.02
Solidified Inorganic Material	27.40
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	9.09E-06
Pu-239	6.25E-03
Pu-240	6.15E-04
Pu-241	6.49E-04

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

Solidified PuNO3 sample used for instrumental analysis

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SA-W138M**

Appendix A

Waste Profile Report

Site	Sandia National Laboratory - Albuquerque	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH TRU sealed source					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Bag	0.0	0.0	0.0
Current Form Total	0.0	0.0	0.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.01
Other Inorganic Materials	0.05
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.96E-05
Np-237	7.84E-10

Haz. Waste No(s).

D011

TRUCON Code(s)

125/225

Waste Stream Description

Sealed source removed from analytical instrumentation

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-221H-PuOx**

Appendix A
Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Discarding Excess/Expired Materials	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	221H Pu Oxide CH TRU Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal POC - 12" w/ Liner	19.3	0.0	19.3
Current Form Total	19.3	0.0	19.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal POC - 12" w/ Liner	19.1	0.0	19.1
Final Form Total	19.1	0.0	19.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	5.05
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	1.36
Other Inorganic Materials	11.81
Cellulosics	0.00
Rubber	0.00
Plastics	1.03
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	135.10
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	528.85
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.85E+00
Np-237	3.72E-05
Pu-238	1.17E+00
Pu-239	2.76E+01
Pu-240	6.65E+00
Pu-241	7.33E+01
Pu-242	9.22E-04

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

The plutonium oxide material is being blended and packaged specifically for disposal at WIPP.

Waste Stream ID: **SR-AGNS-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	SR-AGNS-HET Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Current Form Total	0.6	0.0	0.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	1.89
Aluminum-based Metal/Alloys	0.01
Other Metal/Alloys	0.47
Other Inorganic Materials	0.76
Cellulosics	0.38
Rubber	0.16
Plastics	1.58
Cement	0.00
Solidified Inorganic Material	0.01
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.66E-02
Am-243	1.81E-07
Cs-137	8.61E-07
Np-237	1.82E-05
Pu-238	8.29E-02
Pu-239	2.47E-02
Pu-240	1.50E-02
Pu-241	7.79E-02
Pu-242	6.80E-06
Sr-90	8.22E-07
Th-229	8.96E-09
Th-230	6.08E-09
Th-232	8.30E-09
U-233	3.29E-06
U-234	2.53E-05
U-235	1.82E-07
U-236	1.38E-08
U-238	3.70E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D011, D019, D022, D029, F002, F005

TRUCON Code(s)

125/225

Waste Stream Description

This waste is comprised of numerous organic and inorganic debris waste and generally consists of paper, cloth, wood, plastic, rubber, glass, and metal.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-AGNS-HOM**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	SR-AGNS-HOM					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.2	0.0	3.2
Current Form Total	3.2	0.0	3.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	7.6	0.0	7.6
Final Form Total	7.6	0.0	7.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	39.08
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	518.35
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.77E-01
Np-237	2.24E-04
Pu-238	2.08E-01
Pu-239	4.44E-01
Pu-240	1.05E-01
Pu-241	1.07E+00
Pu-242	1.83E-05
Th-229	4.08E-11
Th-230	1.13E-08
Th-232	7.35E-17
U-233	3.00E-08
U-234	4.94E-05
U-235	1.44E-06
U-236	9.61E-08
U-238	3.07E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D011, F005

TRUCON Code(s)

111/211

Waste Stream Description

This waste is comprised of aqueous liquids solidified with lime and cement in a 55-gallon drum and aqueous liquid that had been absorbed using Florco-X and then later solidified with cement and water inside a 55-gallon drum.

Waste Stream ID: **SR-BCLDP.003.001**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Discarding Excess/Expired Materials	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	BCL JN-1 CH TRU Homogeneous Sludge					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Current Form Total	0.6	0.0	0.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.53
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.08
Cellulosics	0.62
Rubber	0.00
Plastics	2.03
Cement	0.00
Solidified Inorganic Material	30.58
Solidified Organic Material	54.50
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.85E-03
Am-243	3.60E-05
Cm-244	2.33E-03
Cs-137	7.87E-02
Np-237	4.62E-07
Pu-238	4.80E-03
Pu-239	7.23E-04
Pu-240	1.19E-03
Pu-241	5.39E-02
Pu-242	2.92E-06
Sr-90	3.91E-02
Th-229	4.26E-14
Th-230	2.73E-10
Th-232	1.29E-16
U-233	6.83E-11
U-234	3.76E-06
U-235	1.22E-07
U-236	3.27E-07
U-238	7.23E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D011, D019, F002, F005

TRUCON Code(s)

127/227

Waste Stream Description

This waste consists of CH Hydraulic Sludge and Debris

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-BCLDP.004.004**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Discarding Excess/Expired Materials	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU Cartridge Water Filters(S5000)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/o Liners	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	10.42
Cellulosics	9.93
Rubber	0.38
Plastics	1.91
Cement	0.00
Solidified Inorganic Material	2.91
Solidified Organic Material	3.79
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.09E-02
Cm-244	1.47E-02
Np-237	2.84E-08
Pu-238	4.21E-03
Pu-239	4.36E-04
Pu-240	7.32E-04
Sr-90	9.12E-01
Th-229	1.31E-13
Th-230	4.51E-10
Th-232	4.68E-16
U-233	1.86E-10
U-234	6.18E-06
U-235	8.92E-08
U-236	1.19E-06
U-238	1.73E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D011, D019, F002, F005

TRUCON Code(s)

119/219

Waste Stream Description

This waste consists of CH Cartridge Water Filters

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-BCLDP-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	BCL JN-4 CH TRU Heterogeneous Debris					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.1	0.0	1.1
SWB Dir Ld w/o Liner	10.8	0.0	10.8
Current Form Total	11.9	0.0	11.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/o Liner	11.3	0.0	11.3
SWB w/ 4 - 55-gal Drums w/ Liners	3.8	0.0	3.8
Final Form Total	15.1	0.0	15.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	147.18
Aluminum-based Metal/Alloys	1.51
Other Metal/Alloys	0.75
Other Inorganic Materials	3.01
Cellulosics	39.15
Rubber	8.66
Plastics	60.23
Cement	0.00
Solidified Inorganic Material	116.31
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	4.07
Packaging Material, Rubber	0.25
Packaging Material, Steel	167.86
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.02E-02
Np-237	5.00E-08
Pu-238	5.46E+00
Pu-239	1.96E-02
Pu-240	9.09E-03
Pu-241	1.43E-01
Pu-242	2.81E-06
Th-229	1.96E-16
Th-230	4.73E-09
Th-232	4.25E-19
U-233	8.45E-13
U-234	1.27E-04
U-235	1.55E-10
U-236	2.15E-09
U-238	3.49E-15

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011, F002, F005

TRUCON Code(s)

121/221

Waste Stream Description

Heterogenous debris waste from the D&D of Battelle Columbus Lab Building JN-4

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-KAC-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH TRU Heterogeneous debris from the K Area Plutonium surveillance program					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	1.3	8.4	9.7
Current Form Total	1.3	8.4	9.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	1.2	8.3	9.6
Final Form Total	1.2	8.3	9.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	24.60
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	2.28
Rubber	21.07
Plastics	158.65
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.53E-01
Np-237	5.55E-06
Pu-238	2.39E-01
Pu-239	2.02E+00
Pu-240	5.24E-01
Pu-241	4.85E+00
Pu-242	1.73E-04
Th-229	8.73E-15
Th-230	2.84E-11
Th-232	3.45E-18
U-233	6.78E-11
U-234	2.05E-06
U-235	3.85E-06
U-236	4.66E-08
U-238	1.35E-07

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

This waste stream consists of plutonium contaminated debris resulting from destructive and non-destructive containers used to store plutonium material

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-LA-PAD1**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH TRU Heterogeneous debris from the Los Alamos Scientific Laboratory (LASL)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	27.1	0.0	27.1
Current Form Total	27.1	0.0	27.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/o Liners	102.1	0.0	102.1
Final Form Total	102.1	0.0	102.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	18.69
Aluminum-based Metal/Alloys	0.01
Other Metal/Alloys	0.27
Other Inorganic Materials	2.18
Cellulosics	2.61
Rubber	2.29
Plastics	2.21
Cement	0.00
Solidified Inorganic Material	0.01
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.10E-01
Am-243	1.31E-07
Cs-137	2.54E-07
Np-237	1.52E-05
Pu-238	8.19E+01
Pu-239	1.28E-01
Pu-240	8.93E-02
Pu-241	3.65E-01
Pu-242	2.83E-04
Sr-90	3.20E-07
Th-229	2.09E-07
Th-230	9.42E-06
Th-232	1.05E-16
U-233	5.95E-05
U-234	3.08E-02
U-235	2.75E-07
U-236	1.06E-07
U-238	1.76E-12

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D022, F001, F002, F005

TRUCON Code(s)

125/225, 154

Waste Stream Description

This CH TRU waste stream consists of debris and Impure Oxide shipped to the SRS from the LASL in 1971 and 1972.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-MD-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU/F listed solvents - Heterogeneous debris from Mound Laboratories					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.7	0.0	1.7
55-gal Drum Dir Ld w/o Liner	0.6	0.0	0.6
85-gal Drum Dir Ld w/ Liner	0.3	0.0	0.3
Box - Steel	91.5	0.0	91.5
SLB2 (5' x 5' x 8) Dir Ld	39.8	0.0	39.8
SWB Dir Ld w/o Liner	45.0	0.0	45.0
Current Form Total	178.9	0.0	178.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SLB2 (5' x 5' x 8) Dir Ld	34.0	0.0	34.0
SWB Dir Ld w/o Liner	139.9	0.0	139.9
SWB w/ 4 - 55-gal Drums w/ Liners	3.8	0.0	3.8
SWB w/ 4 - 55-gal Drums w/o Liners	1.9	0.0	1.9
Final Form Total	179.5	0.0	179.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	59.40
Aluminum-based Metal/Alloys	0.79
Other Metal/Alloys	4.99
Other Inorganic Materials	20.74
Cellulosics	20.58
Rubber	13.15
Plastics	36.45
Cement	0.00
Solidified Inorganic Material	0.04
Solidified Organic Material	0.00
Soils	0.73
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.34
Packaging Material, Rubber	0.19
Packaging Material, Steel	167.01
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.28E-01
Am-243	2.66E-07
Cm-244	3.13E-06
Cs-137	8.98E-06
Np-237	2.39E-05
Pu-238	1.34E+01
Pu-239	2.79E-01
Pu-240	4.27E-02
Pu-241	1.75E-01
Pu-242	2.48E-05
Sr-90	8.46E-06
Th-229	1.70E-05
Th-230	1.48E-06
Th-232	6.74E-04
U-233	4.97E-03
U-234	4.95E-03
U-235	1.59E-06
U-236	4.94E-08
U-238	2.86E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D027, D028, D029, D030, D032, D034, D037, D043, F002, F004, F005

TRUCON Code(s)

125/225, 154

Waste Stream Description

This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste.

Waste Stream ID: **SR-MD-HOM-C**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU Solids (S3000)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
55-gal Drum Dir Ld w/o Liner	0.4	0.0	0.4
Current Form Total	0.6	0.0	0.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.33
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.33
Rubber	0.33
Plastics	1.73
Cement	0.00
Solidified Inorganic Material	63.49
Solidified Organic Material	0.33
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.03E-04
Np-237	1.31E-09
Pu-238	1.67E-01
Pu-242	9.94E-10
Th-229	5.30E-18
Th-230	1.45E-10
U-233	2.26E-14
U-234	3.90E-06
U-238	6.21E-19

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, F002, F003, F004, F005

TRUCON Code(s)

111/211

Waste Stream Description

Particulate material with a sand-like consistency from cleanout of a sump and drain lines in R Building

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-MD-PAD1**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH TRU Heterogeneous debris from the Mound Plant					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	64.1	0.0	64.1
83-gal Drum	19.5	0.0	19.5
85-gal Drum Dir Ld w/ Liner	0.3	0.0	0.3
Box - Plywood	60.9	0.0	60.9
SLB2 (5' x 5' x 8) Dir Ld	159.1	0.0	159.1
SWB Dir Ld w/o Liner	9.0	0.0	9.0
Current Form Total	313.0	0.0	313.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	31.6	0.0	31.6
SLB2 (5' x 5' x 8) Dir Ld	135.8	0.0	135.8
SWB Dir Ld w/o Liner	232.5	0.0	232.5
SWB w/ 4 - 55-gal Drums w/ Liners	73.7	0.0	73.7
Final Form Total	473.6	0.0	473.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	51.57
Aluminum-based Metal/Alloys	0.03
Other Metal/Alloys	0.40
Other Inorganic Materials	7.06
Cellulosics	3.12
Rubber	2.45
Plastics	5.70
Cement	0.00
Solidified Inorganic Material	0.30
Solidified Organic Material	0.41
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	5.01
Packaging Material, Rubber	0.24
Packaging Material, Steel	178.71
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.02E-02
Am-243	1.77E-07
Cm-244	3.53E-05
Cs-137	1.52E-04
Np-237	5.48E-06
Pu-238	1.90E+01
Pu-239	2.76E-02
Pu-240	1.71E-02
Pu-241	6.66E-02
Pu-242	5.56E-05
Sr-90	1.43E-04
Th-229	1.52E-12
Th-230	2.21E-06
Th-232	2.00E-17
U-233	8.85E-10
U-234	7.20E-03
U-235	8.12E-08
U-236	2.02E-08
U-238	7.31E-08

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D027, D028, D029, D030, D032, D034, D037, D043, F002, F004, F005

TRUCON Code(s)

125/225, 154

Waste Stream Description

This CH TRU waste stream consists of debris shipped to the SRS from the Mound Plant in 1971 and 1972.

Waste Stream ID: **SR-MD-SOIL**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU Soil / Gravel (S4000)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
55-gal Drum Dir Ld w/o Liner	2.5	0.0	2.5
Box - Steel	14.3	0.0	14.3
SWB Dir Ld w/o Liner	5.4	0.0	5.4
Current Form Total	22.7	0.0	22.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/o Liner	20.8	0.0	20.8
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
SWB w/ 4 - 55-gal Drums w/o Liners	5.7	0.0	5.7
Final Form Total	28.4	0.0	28.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.08
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	54.07
Cellulosics	0.28
Rubber	0.10
Plastics	4.06
Cement	0.00
Solidified Inorganic Material	16.60
Solidified Organic Material	0.00
Soils	646.13
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.09
Packaging Material, Rubber	0.26
Packaging Material, Steel	168.82
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.18E-03
Cs-137	1.77E-06
Np-237	8.50E-07
Pu-238	4.00E-01
Pu-239	1.03E-02
Pu-240	1.49E-03
Pu-241	1.90E-02
Pu-242	1.98E-06
Sr-90	1.77E-06
Th-229	1.62E-16
Th-230	6.30E-10
Th-232	1.09E-21
U-233	3.70E-12
U-234	6.91E-05
U-235	1.02E-11
U-236	4.42E-11
U-238	3.07E-16

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, F002, F003, F004, F005, F007, F009

TRUCON Code(s)

111/211

Waste Stream Description

Soil mixed with absorbent and some commingled debris.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-NIST-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	DOE Owned Plutonium & Uranium waste items.					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/o Liner	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	11.75
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	1.47
Cement	16.15
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.49E+00
Np-237	1.99E-05
Pu-238	3.85E+00
Pu-239	1.36E+00
Pu-240	3.22E-01
Pu-241	6.20E+00
Pu-242	5.76E-05
Th-229	4.03E-13
Th-230	5.56E-08
Th-232	3.70E-14
U-233	7.69E-10
U-234	4.38E-04
U-235	3.34E-06
U-236	4.18E-05
U-238	1.32E-07

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This material consist of a combination of unirradiated PuO/Uo fuel pellets, Pacemaker source and solidified Pu solutions

Waste Stream ID: **SR-RH-221H.01**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU Heterogeneous debris from the HB-Line					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.6	0.0	3.6
Box - SRS Poly Box	0.2	0.0	0.2
Cask - Steel	5.7	0.0	5.7
Current Form Total	9.5	0.0	9.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	3.7	0.0	3.7
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	4.4	0.0	4.4
Final Form Total	8.1	0.0	8.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	62.52
Aluminum-based Metal/Alloys	3.61
Other Metal/Alloys	4.70
Other Inorganic Materials	25.30
Cellulosics	21.32
Rubber	53.48
Plastics	189.00
Cement	0.00
Solidified Inorganic Material	1.08
Solidified Organic Material	0.36
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	25.77
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.66E-02
Np-237	2.53E-01
Pu-238	1.33E+02
Pu-239	1.24E-01
Pu-240	6.39E-02
Pu-241	1.23E+00
Pu-242	7.38E-05
Th-229	2.13E-08
Th-230	1.20E-06
Th-232	1.82E-15
U-233	2.30E-05
U-234	1.04E-02
U-235	6.30E-06
U-236	1.78E-06
U-238	5.52E-09

Haz. Waste No(s).

D006, D008, D009, D019, D022, D029, D039, D040, D043, F001, F002, F003, F005, U133

TRUCON Code(s)

321, 322, 325

Waste Stream Description

This waste stream is defense related, remote handled TRU waste and is composed of metal equipment and debris

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-RH-221H.02**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Discarding Excess/Expired Materials	**Waste Matrix Code Group**	Composite Filter Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU HEPA Filter from the HB-Line					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - SRS Poly Box	4.2	0.0	4.2
Current Form Total	4.2	0.0	4.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	4.4	0.0	4.4
Final Form Total	4.4	0.0	4.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.48
Aluminum-based Metal/Alloys	2.68
Other Metal/Alloys	0.00
Other Inorganic Materials	1.14
Cellulosics	0.75
Rubber	0.01
Plastics	1.55
Cement	0.00
Solidified Inorganic Material	0.01
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.31E-02
Cs-137	6.45E-01
Np-237	5.74E-04
Pu-238	6.22E+01
Pu-239	1.34E-01
Pu-240	9.22E-02
Pu-241	6.42E-01
Pu-242	3.41E-05
Th-229	1.77E-06
Th-230	5.40E-07
Th-232	5.58E-14
U-233	8.39E-04
U-234	4.69E-03
U-235	2.71E-06
U-236	4.71E-05
U-238	2.36E-06

Haz. Waste No(s).

D006, D007, D008, D009, D011, D019, D022, D029, D035, D039, D040, D043

TRUCON Code(s)

322, 325

Waste Stream Description

This waste stream is defense related, remote handled TRU waste and is composed of 24"X24"X12" HEPA Filter

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-RH-235F.01**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU Heterogeneous debris from the 235F facility.					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
Box - SRS Poly Box	0.2	0.0	0.2
Current Form Total	1.7	0.0	1.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	46.05
Aluminum-based Metal/Alloys	2.51
Other Metal/Alloys	1.23
Other Inorganic Materials	13.38
Cellulosics	7.83
Rubber	47.03
Plastics	59.20
Cement	0.00
Solidified Inorganic Material	0.55
Solidified Organic Material	0.11
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.45E+02
Np-237	2.36E-02
Pu-238	2.02E+02
Pu-239	1.92E+00
Pu-240	5.06E-01
Pu-241	9.84E+02
Pu-242	1.85E-04
Th-229	3.42E-09
Th-230	2.38E-06
Th-232	2.90E-16
U-233	2.80E-06
U-234	1.79E-02
U-235	5.30E-08
U-236	4.20E-07
U-238	8.03E-13

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D035, F002

TRUCON Code(s)

322, 325

Waste Stream Description

This waste stream is defense related, remote handled TRU waste and is composed of metal equipment and debris

Waste Stream ID: **SR-RH-772F.01**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Analytical Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU Heterogeneous debris from the 772F and 772-1F laboratories.					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	58.17
Aluminum-based Metal/Alloys	4.27
Other Metal/Alloys	11.74
Other Inorganic Materials	117.40
Cellulosics	29.35
Rubber	21.88
Plastics	290.84
Cement	0.00
Solidified Inorganic Material	0.53
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.15E-03
Cs-137	9.63E-02
Np-237	5.30E-07
Pu-238	4.57E-03
Pu-239	3.58E-03
Pu-240	1.09E-03
Pu-241	7.55E-03
Pu-242	1.78E-07
Sr-90	9.50E-02
Th-229	8.09E-15
Th-230	2.84E-11
Th-232	9.70E-18
U-233	2.05E-11
U-234	4.03E-07
U-235	2.46E-09
U-236	2.20E-08
U-238	2.49E-16

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D028, D029, F002, F003, F005

TRUCON Code(s)

322, 325

Waste Stream Description

This waste stream is defense related remote handled mixed TRU waste. This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, other job control waste, small HEPAs liquids, sludges and resins may also be found in this waste.

Waste Stream ID: **SR-RH-773A.01**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Analytical Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU Heterogeneous debris from the SRNL					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	7.1	0.0	7.1
55-gal Drum Dir Ld w/o Liner	0.0	10.9	10.9
Box - Concrete	14.2	0.0	14.2
Box - Fiberglass	0.9	0.0	0.9
Cask - SRS CMISC	3.8	0.0	3.8
Current Form Total	26.0	10.9	36.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	7.5	0.0	7.5
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	0.0	11.2	11.2
Final Form Total	7.5	11.2	18.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	674.16
Aluminum-based Metal/Alloys	7.40
Other Metal/Alloys	45.15
Other Inorganic Materials	443.83
Cellulosics	241.56
Rubber	365.78
Plastics	757.57
Cement	0.00
Solidified Inorganic Material	15.30
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	23.49
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.32E-01
Am-243	1.82E-01
Cm-244	1.67E+01
Cs-137	3.50E+00
Np-237	1.30E-05
Pu-238	9.80E+00
Pu-239	2.58E-01
Pu-240	1.41E-01
Pu-241	2.20E+00
Pu-242	7.23E-05
Pu-244	5.51E-14
Sr-90	2.58E+00
Th-229	4.84E-07
Th-230	4.23E-08
Th-232	3.50E-14
U-233	7.86E-04
U-234	7.55E-04
U-235	8.08E-06
U-236	1.01E-04
U-238	3.22E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D027, D028, D029, D043, F002, F004, F005

TRUCON Code(s)

321, 322, 325

Waste Stream Description

This waste stream is defense related remote handled mixed TRU waste. This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, other job control waste, small HEPAs liquids, sludges and resins may also be found in this waste.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-RH-FBL.01**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU Heterogeneous debris from the FB-Line					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.9	0.0	1.9
55-gal Drum Dir Ld w/o Liner	1.1	0.0	1.1
Cask - Concrete/Carbon Steel Liner	1.6	0.0	1.6
Current Form Total	4.5	0.0	4.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	1.9	0.0	1.9
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	3.1	0.0	3.1
Final Form Total	5.0	0.0	5.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	45.99
Aluminum-based Metal/Alloys	0.53
Other Metal/Alloys	1.18
Other Inorganic Materials	216.35
Cellulosics	10.16
Rubber	15.47
Plastics	60.45
Cement	0.00
Solidified Inorganic Material	0.14
Solidified Organic Material	0.76
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	22.57
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.41E-01
Cs-137	4.18E+00
Np-237	4.64E-04
Pu-238	1.35E+00
Pu-239	2.53E+00
Pu-240	5.96E-01
Pu-241	1.95E+01
Pu-242	1.00E-04
Sr-90	3.94E-01
Th-229	3.14E-12
Th-230	3.35E-08
Th-232	5.44E-15
U-233	1.19E-08
U-234	6.18E-04
U-235	2.09E-05
U-236	1.84E-05
U-238	6.38E-04

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011, D018, D019, D022, D029, D039, D040, D043, F002, F005, U002, U151

TRUCON Code(s)

321

Waste Stream Description

This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, rags, and other job control waste and silver coated ceramics (burl saddles)

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-RH-MNDPAD1.01**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH Debris from Mound Laboratories					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	25.62
Aluminum-based Metal/Alloys	0.02
Other Metal/Alloys	0.20
Other Inorganic Materials	3.51
Cellulosics	1.55
Rubber	1.22
Plastics	2.83
Cement	0.00
Solidified Inorganic Material	0.15
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.04E-02
Np-237	1.75E-09
Pu-238	3.18E+02
Pu-239	2.22E-01
Pu-240	1.21E-01
Pu-241	6.34E+00
Pu-242	1.45E-04
Th-229	5.78E-20
Th-230	4.15E-09
Th-232	8.87E-20
U-233	2.58E-15
U-234	9.02E-04
U-235	2.19E-10
U-236	3.60E-09
U-238	2.24E-14

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D027, D028, D029, D030, D032, D034, D037, D043, F002, F003, F004, F005

TRUCON Code(s)

322, 325

Waste Stream Description

Process equipment and exchange resin

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-RH-SDD.01**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Discarding Excess/Expired Materials	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Remote Handled PuBe Sources					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/o Liner	5.4	0.0	5.4
Current Form Total	5.4	0.0	5.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 30-gal w/o Liner	0.3	0.0	0.3
Final Form Total	0.3	0.0	0.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	5604.15
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	1401.04
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.02
Packaging Material, Rubber	1.04
Packaging Material, Steel	1616.52
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.69E+01
Np-237	2.14E-05
Pu-238	2.72E+02
Pu-239	4.19E+00
Pu-240	2.53E+00
Pu-241	1.20E+02
Pu-242	4.22E-03
Th-229	2.11E-14
Th-230	5.76E-08
Th-232	2.96E-17
U-233	1.80E-10
U-234	3.12E-03
U-235	1.65E-08
U-236	3.00E-07
U-238	2.62E-12

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream consists of three PuBe sources individually packaged in SWB with polyethylene shielding.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-RH-SWD.01**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Remote Handled (RH) Mixed TRU Debris (S5000)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.1	0.0	1.1
Current Form Total	1.1	0.0	1.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	1.2	0.0	1.2
Final Form Total	1.2	0.0	1.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	1797.12
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	141.49
Cement	0.00
Solidified Inorganic Material	29.52
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.25E-01
Am-243	7.39E-02
Cm-244	4.00E+00
Cs-137	1.49E-02
Np-237	5.37E-04
Pu-238	2.69E-01
Pu-239	3.45E-01
Pu-240	1.16E-01
Pu-241	1.75E+00
Pu-242	3.76E-05
Pu-244	2.86E-15
Sr-90	1.03E-02
Th-229	2.61E-11
Th-230	9.73E-10
Th-232	2.06E-17
U-233	3.71E-08
U-234	1.30E-05
U-235	5.44E-09
U-236	5.30E-08
U-238	9.34E-14

No Hazardous Waste Numbers Provided

TRUCON Code(s)

322, 325

Waste Stream Description

RH Mixed TRU waste resulting from solvent tank emptying and closure in the E-Area of SRS.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-SDD-HET-A**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH TRU - Heterogeneous debris from the D&D of the 211-F-Area					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.1	0.0	2.1
SWB Dir Ld w/o Liner	5.4	0.0	5.4
Current Form Total	7.5	0.0	7.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
SWB Dir Ld w/o Liner	5.7	0.0	5.7
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	9.0	0.0	9.0

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	42.47
Aluminum-based Metal/Alloys	0.41
Other Metal/Alloys	0.03
Other Inorganic Materials	0.40
Cellulosics	1.88
Rubber	0.00
Plastics	18.69
Cement	0.89
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	9.40
Packaging Material, Rubber	0.31
Packaging Material, Steel	161.87
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	1.70E-03
Am-243	4.43E-07
Cm-244	3.80E-05
Cs-137	1.79E-05
Np-237	6.25E-06
Pu-238	4.94E-01
Pu-239	2.82E-02
Pu-240	3.95E-03
Pu-241	5.98E-02
Pu-242	3.49E-06
Sr-90	4.35E-03
Th-229	1.94E-10
Th-230	3.12E-10
Th-232	1.22E-17
U-233	4.41E-07
U-234	1.03E-05
U-235	6.73E-09
U-236	4.96E-08
U-238	1.41E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011

No TRUCON Codes Provided

Waste Stream Description

This waste stream is defense related, contact handled TRU waste and is composed of metal equipment, tools and debris and small amounts of Portland cement

Waste Stream ID: **SR-SDD-HET-B**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Discarding Excess/Expired Materials	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Contact Handled PuBe Sources					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
110-gal Drum	0.4	0.0	0.4
55-gal Drum Dir Ld w/ Liner	1.1	0.0	1.1
55-gal Drum Dir Ld w/o Liner	0.4	0.0	0.4
Current Form Total	1.9	0.0	1.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/o Liner	1.9	0.0	1.9
SWB w/ 4 - 55-gal Drums w/ Liners	3.8	0.0	3.8
SWB w/ 4 - 55-gal Drums w/o Liners	1.9	0.0	1.9
Final Form Total	7.6	0.0	7.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	218.25
Aluminum-based Metal/Alloys	6.31
Other Metal/Alloys	0.00
Other Inorganic Materials	2.89
Cellulosics	11.04
Rubber	0.00
Plastics	93.25
Cement	2.89
Solidified Inorganic Material	1.17
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.15
Packaging Material, Rubber	0.38
Packaging Material, Steel	196.69
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.42E-01
Np-237	1.77E-06
Pu-238	1.24E+01
Pu-239	3.39E-01
Pu-240	8.31E-02
Pu-241	1.10E+00
Pu-242	2.03E-05
Sr-90	2.23E-09
Th-229	6.83E-14
Th-230	1.25E-07
Th-232	4.11E-17
U-233	9.33E-11
U-234	1.01E-03
U-235	8.68E-09
U-236	6.40E-08
U-238	1.20E-10

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011

No TRUCON Codes Provided

Waste Stream Description

This waste stream consists PuBe and Americium sources from various facilities at the SRS

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-SDD-HOM-A**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	Organic Sludge from D&D of the SRS F-Area 800 Series Underground Tanks					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
55-gal Drum Dir Ld w/o Liner	5.0	0.0	5.0
Current Form Total	5.5	0.0	5.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	4.4	0.0	4.4
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
SWB w/ 4 - 55-gal Drums w/o Liners	1.9	0.0	1.9
Final Form Total	8.1	0.0	8.1

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	5.24
Cement	368.84
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	3.78
Packaging Material, Rubber	0.51
Packaging Material, Steel	168.04
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	1.97E-02
Am-243	9.51E-05
Np-237	1.35E-02
Pu-238	1.57E+00
Pu-239	1.45E-01
Pu-240	2.76E-02
Pu-241	3.26E-01
Pu-242	6.30E-02
Th-229	2.71E-05
Th-230	6.39E-06
Th-232	1.02E-13
U-233	6.16E-02
U-234	1.39E-01
U-235	1.10E-04
U-236	4.13E-04
U-238	6.69E-03

Haz. Waste No(s).

D004, D005, D007, D008, D009, D011

TRUCON Code(s)

112/212

Waste Stream Description

Absorbed organic sludge packaged in 55-gallon drums

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-SDD-HOM-B**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Sludge from D&D of the SRS F-Area 800 Series Underground Tanks					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	5.0	0.0	5.0
55-gal Drum Dir Ld w/o Liner	10.3	0.0	10.3
SWB Dir Ld w/o Liner	9.0	0.0	9.0
Current Form Total	24.3	0.0	24.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.4	0.0	4.4
55-gal Drum Dir Ld w/o Liner	10.2	0.0	10.2
SWB Dir Ld w/o Liner	9.5	0.0	9.5
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	25.9	0.0	25.9

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	37.27
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	2.70
Cellulosics	14.22
Rubber	0.00
Plastics	29.18
Cement	162.06
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	7.44
Packaging Material, Rubber	0.42
Packaging Material, Steel	144.90
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	1.42E-01
Am-243	5.50E-05
Cm-244	2.47E-03
Cs-137	4.04E-04
Np-237	5.53E-04
Pu-238	4.37E+01
Pu-239	2.50E+00
Pu-240	3.49E-01
Pu-241	5.16E+00
Pu-242	1.21E-03
Sr-90	1.74E-04
Th-229	2.59E-12
Th-230	2.80E-08
Th-232	1.11E-15
U-233	1.18E-08
U-234	9.23E-04
U-235	2.42E-06
U-236	4.54E-06
U-238	7.12E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011

TRUCON Code(s)

127/227

Waste Stream Description

Absorbed sludge packaged in 55-gallon drums

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-SWMF-HET-A**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU Debris (S5000)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.5	0.0	1.5
55-gal Drum Dir Ld w/o Liner	13.2	56.9	70.1
85-gal Drum Dir Ld w/o Liner	0.3	0.0	0.3
SLB2 (5' x 5' x 8) Dir Ld	6.6	0.0	6.6
SWB Dir Ld w/o Liner	68.4	0.0	68.4
Current Form Total	90.1	56.9	147.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	13.1	56.4	69.5
SLB2 (5' x 5' x 8) Dir Ld	5.7	0.0	5.7
SWB Dir Ld w/o Liner	73.7	0.0	73.7
SWB w/ 4 - 55-gal Drums w/ Liners	3.8	0.0	3.8
Final Form Total	96.3	56.4	152.6

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	68.64
Aluminum-based Metal/Alloys	1.36
Other Metal/Alloys	0.10
Other Inorganic Materials	2.59
Cellulosics	7.04
Rubber	6.03
Plastics	22.52
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.01
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.40
Packaging Material, Rubber	0.37
Packaging Material, Steel	146.85
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	9.02E-02
Am-243	8.67E-06
Cm-244	2.60E-03
Cs-137	6.91E-05
Np-237	9.26E-05
Pu-238	8.42E+00
Pu-239	2.04E-01
Pu-240	5.37E-02
Pu-241	7.98E-01
Pu-242	1.56E-04
Sr-90	6.88E-05
Th-229	2.57E-09
Th-230	2.85E-08
Th-232	2.84E-09
U-233	9.74E-06
U-234	1.07E-03
U-235	2.04E-07
U-236	4.77E-09
U-238	8.28E-06

Haz. Waste No(s).

D008, F001, F002, F004, F005, F007, F009, U133, U151

TRUCON Code(s)

125/225, 154

Waste Stream Description

CH Mixed TRU waste resulting from remediation and re-packaging of Mixed "defense related" TRU waste.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-SWMF-HET-B**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Spill Clean-ups/Emergency Response Actions	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Spill cleanup debris.					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.7	0.0	1.7
Current Form Total	1.7	0.0	1.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	3.8	0.0	3.8
Final Form Total	3.8	0.0	3.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	71.69
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	17.83
Cellulosics	14.26
Rubber	0.00
Plastics	13.54
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.85E-01
Am-243	2.34E-01
Cm-244	6.87E+00
Np-237	1.95E-06
Pu-238	2.95E-01
Pu-239	6.91E-04
Pu-240	1.26E-01
Pu-241	3.63E-02
Pu-242	7.44E-05
Pu-244	2.10E-14
Th-229	1.28E-13
Th-230	4.64E-09
Th-232	7.52E-17
U-233	1.36E-10
U-234	3.03E-05
U-235	1.84E-11
U-236	1.02E-07
U-238	3.69E-13

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D027, D028, D029, D043, F002, F004, F005, U133

TRUCON Code(s)

125/225, 154

Waste Stream Description

Solid Waste Management Facility debris resulting from spill cleanup activities

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-SWMF-SOIL**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Spill Clean-ups/Emergency Response Actions	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU Waste Soil & Gravel					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.2	0.0	3.2
Current Form Total	3.2	0.0	3.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	7.6	0.0	7.6
Final Form Total	7.6	0.0	7.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.49
Rubber	0.00
Plastics	0.91
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	324.07
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.12E-01
Am-243	6.48E-01
Cm-244	1.90E+01
Np-237	5.40E-06
Pu-238	8.18E-01
Pu-239	1.91E-03
Pu-240	3.49E-01
Pu-241	1.00E-01
Pu-242	2.06E-04
Pu-244	5.83E-14
Th-229	3.54E-13
Th-230	1.29E-08
Th-232	2.08E-16
U-233	3.77E-10
U-234	8.39E-05
U-235	5.10E-11
U-236	2.83E-07
U-238	1.02E-12

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D027, D028, D029, D043, F002, F004, F005, U133

TRUCON Code(s)

111/211

Waste Stream Description

Burial Ground Soil and Gravel from spill cleanup / remediation activities.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W026-221F-HEPA**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Composite Filter Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU HEPA Filters (S5000)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
SWB Dir Ld w/o Liner	16.2	0.0	16.2
Current Form Total	16.4	0.0	16.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/o Liner	17.0	0.0	17.0
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	18.9	0.0	18.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	23.03
Aluminum-based Metal/Alloys	0.22
Other Metal/Alloys	0.00
Other Inorganic Materials	1.43
Cellulosics	9.42
Rubber	0.00
Plastics	16.49
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.63
Packaging Material, Rubber	0.22
Packaging Material, Steel	159.21
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.65E-01
Am-243	3.63E-14
Cs-137	8.92E-08
Np-237	3.08E-06
Pu-238	5.34E-02
Pu-239	8.45E-01
Pu-240	2.21E-01
Pu-241	9.87E-01
Pu-242	2.56E-05
Sr-90	8.64E-08
Th-229	4.03E-07
Th-230	5.88E-09
Th-232	7.14E-17
U-233	2.19E-04
U-234	3.21E-05
U-235	6.39E-07
U-236	1.38E-07
U-238	4.74E-08

Haz. Waste No(s).

D005, D007, D009, D011, D019, D022, D028, D029, D043, F002, F005

TRUCON Code(s)

119/219, 154

Waste Stream Description

HEPA Filters in Filtered Polyethylene Boxes

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W026-221F-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU/Thirds Heterogeneous debris from 221F					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	9.7	0.0	9.7
55-gal Drum Dir Ld w/o Liner	0.6	0.0	0.6
85-gal Drum Dir Ld w/o Liner	0.3	0.0	0.3
Box - SRS B-25 OP	18.0	0.0	18.0
SLB2 (5' x 5' x 8) Dir Ld	358.0	0.0	358.0
SWB Dir Ld w/o Liner	91.8	0.0	91.8
Current Form Total	478.5	0.0	478.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	9.6	0.0	9.6
55-gal Drum Dir Ld w/o Liner	0.6	0.0	0.6
SLB2 (5' x 5' x 8) Dir Ld	305.6	0.0	305.6
SWB Dir Ld w/o Liner	117.2	0.0	117.2
Final Form Total	433.0	0.0	433.0

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	67.08
Aluminum-based Metal/Alloys	0.96
Other Metal/Alloys	0.47
Other Inorganic Materials	13.02
Cellulosics	23.64
Rubber	15.00
Plastics	54.68
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.05
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.82
Packaging Material, Rubber	0.17
Packaging Material, Steel	196.74
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	7.58E-01
Am-243	1.33E-07
Cm-244	1.23E-04
Cs-137	2.47E-06
Np-237	1.08E-05
Pu-238	8.04E-01
Pu-239	3.19E+00
Pu-240	8.83E-01
Pu-241	1.05E+01
Pu-242	5.59E-04
Sr-90	2.49E-06
Th-229	8.94E-14
Th-230	2.38E-08
Th-232	1.04E-07
U-233	2.98E-10
U-234	3.78E-04
U-235	4.84E-06
U-236	1.83E-07
U-238	3.23E-05

Haz. Waste No(s).

D006, D007, D008, D009, D022, D028, D029, F001, F002, F003, F005

TRUCON Code(s)

125/225, 154

Waste Stream Description

200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small HEPAs, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.

Waste Stream ID: **SR-W026-221F-HET-A**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU/Thirds Heterogeneous debris from 221F					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
55-gal Drum Dir Ld w/o Liner	0.8	0.0	0.8
Current Form Total	1.1	0.0	1.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
SWB w/ 4 - 55-gal Drums w/o Liners	1.9	0.0	1.9
Final Form Total	3.8	0.0	3.8

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	1.93
Other Inorganic Materials	130.78
Cellulosics	0.17
Rubber	0.00
Plastics	7.52
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.15
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	2.93E-01
Cm-244	6.26E-03
Cs-137	1.91E-01
Np-237	2.91E-06
Pu-238	3.47E-02
Pu-239	6.41E-01
Pu-240	1.61E-01
Pu-241	3.71E+00
Pu-242	2.80E-05
Sr-90	5.31E-02
Th-229	5.15E-09
Th-230	1.31E-08
Th-232	3.24E-16
U-233	8.36E-06
U-234	2.04E-04
U-235	6.46E-06
U-236	9.56E-07
U-238	2.46E-06

Haz. Waste No(s).

D006, D007, D008, D009, D011, D019, D022, D028, D029, F002, F005

TRUCON Code(s)

125/225, 154

Waste Stream Description

200 Areas (F Separations Facilities). This waste consists of silver impregnated ceramic saddles removed from the F-Canyon dissolver off-gas system.

Waste Stream ID: **SR-W026-221F-HOM**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU Solids (S3000)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	10.1	0.0	10.1
Current Form Total	10.1	0.0	10.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	10.0	0.0	10.0
Final Form Total	10.0	0.0	10.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	5.36
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	25.47
Rubber	8.04
Plastics	80.44
Cement	0.00
Solidified Inorganic Material	329.80
Solidified Organic Material	891.53
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.76E-01
Am-243	2.20E-04
Cs-137	2.30E-03
Np-237	1.78E-05
Pu-238	5.32E-01
Pu-239	1.53E+00
Pu-240	3.87E-01
Pu-241	4.22E+00
Pu-242	5.81E-03
Sr-90	1.17E-03
Th-229	1.42E-12
Th-230	1.96E-08
Th-232	1.25E-16
U-233	1.55E-09
U-234	1.18E-04
U-235	1.32E-05
U-236	2.41E-07
U-238	4.46E-04

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011, D019, D022, D028, D029, D043, F002, F004, F005, U151

TRUCON Code(s)

127/227

Waste Stream Description

Absorbed oil, neutralized acids / bases and water

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W026-772F-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU/Thirds Heterogeneous debris from 772F					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	13.2	54.6	67.8
55-gal Drum Dir Ld w/o Liner	0.4	0.0	0.4
Box - SRS B-25 OP	7.2	0.0	7.2
SLB2 (5' x 5' x 8) Dir Ld	26.5	0.0	26.5
SWB Dir Ld w/o Liner	79.2	25.2	104.4
Current Form Total	126.6	79.8	206.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	13.1	54.1	67.2
SLB2 (5' x 5' x 8) Dir Ld	22.6	0.0	22.6
SWB Dir Ld w/o Liner	90.7	26.5	117.2
SWB w/ 4 - 55-gal Drums w/o Liners	1.9	0.0	1.9
Final Form Total	128.4	80.5	208.9

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	9.38
Aluminum-based Metal/Alloys	0.71
Other Metal/Alloys	0.89
Other Inorganic Materials	19.71
Cellulosics	5.47
Rubber	4.32
Plastics	45.70
Cement	0.00
Solidified Inorganic Material	0.09
Solidified Organic Material	0.01
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	11.92
Packaging Material, Rubber	0.31
Packaging Material, Steel	153.40
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	2.60E-01
Am-243	2.24E-06
Cm-244	2.51E-03
Cs-137	8.19E-04
Np-237	2.54E-04
Pu-238	9.10E+00
Pu-239	4.22E-01
Pu-240	1.05E-01
Pu-241	1.61E+00
Pu-242	4.70E-05
Sr-90	8.05E-04
Th-229	5.66E-08
Th-230	1.09E-07
Th-232	5.58E-07
U-233	8.29E-05
U-234	1.79E-03
U-235	1.67E-06
U-236	2.18E-08
U-238	1.13E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D028, D029, F002, F003, F005

TRUCON Code(s)

125/225, 154

Waste Stream Description

Combined waste from former W027-772F-HET and T001-772F-HET. This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and metal equipment.

Waste Stream ID: **SR-W026-DWPF-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Analytical Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH TRU - Heterogeneous debris from the DWPF laboratory					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.4	0.0	0.4
Current Form Total	0.4	0.0	0.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/o Liners	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.78
Aluminum-based Metal/Alloys	0.39
Other Metal/Alloys	0.00
Other Inorganic Materials	1.55
Cellulosics	3.75
Rubber	0.00
Plastics	6.46
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.93E-04
Am-243	3.09E-06
Cm-244	2.11E-04
Cs-137	8.21E-03
Np-237	5.16E-07
Pu-238	5.54E-03
Pu-239	2.82E-04
Pu-240	1.03E-04
Pu-241	1.29E-03
Pu-242	2.15E-07
Sr-90	2.16E-01
Th-229	1.13E-09
Th-230	7.29E-11
Th-232	1.05E-17
U-233	2.57E-06
U-234	1.62E-06
U-235	1.62E-07
U-236	4.26E-08
U-238	5.15E-07

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

CH TRU waste consisting of contaminated laboratory debris

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W026-MFFF-1**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	UNKNOWN					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.0	2999.0	2999.0
Current Form Total	0.0	2999.0	2999.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.0	2970.4	2970.4
Final Form Total	0.0	2970.4	2970.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	19.32
Aluminum-based Metal/Alloys	32.22
Other Metal/Alloys	18.31
Other Inorganic Materials	29.76
Cellulosics	26.60
Rubber	31.91
Plastics	100.66
Cement	0.00
Solidified Inorganic Material	4.44
Solidified Organic Material	3.64
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-238	4.11E-01
Pu-239	2.69E+00
Pu-240	9.86E-01
Pu-241	4.95E+00
U-234	3.00E-06
U-235	9.66E-07
U-236	1.58E-08
U-238	8.75E-09

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225

Waste Stream Description

This waste stream is defense related, contact handled TRU and is composed of heterogeneous debris which can include HEPA filters, plastic, protective clothing, metal, gloves, lead lined gloves and sludges.

Waste Stream ID: **SR-W026-WSB-2**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	N/A					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.0	594.7	594.7
Current Form Total	0.0	594.7	594.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.0	589.1	589.1
Final Form Total	0.0	589.1	589.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	3.41
Aluminum-based Metal/Alloys	0.72
Other Metal/Alloys	12.89
Other Inorganic Materials	8.01
Cellulosics	31.41
Rubber	58.40
Plastics	139.38
Cement	0.00
Solidified Inorganic Material	7.89
Solidified Organic Material	6.45
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.32E+02
Pu-238	9.66E-06
Pu-239	1.98E-01
Pu-240	9.86E-02
Pu-241	1.98E-01
Pu-242	7.54E-06
U-234	3.00E-04
U-235	9.66E-06
U-236	1.56E-07
U-238	9.08E-08

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225

Waste Stream Description

This waste stream is defense related, contact handled TRU and is composed of heterogeneous debris with can include HEPA filters, plastic, protective clothing, metal, gloves, lead lined gloves, and sludges.

Waste Stream ID: **SR-W027-221F-HET-A**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU/F listed solvents - Heterogeneous debris from 221F					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.4	0.0	3.4
Box - SRS Poly Box	0.7	0.0	0.7
SLB2 (5' x 5' x 8) Dir Ld	46.4	0.0	46.4
SWB Dir Ld w/o Liner	37.8	0.0	37.8
Current Form Total	88.2	0.0	88.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SLB2 (5' x 5' x 8) Dir Ld	39.6	0.0	39.6
SWB Dir Ld w/o Liner	41.6	0.0	41.6
SWB w/ 4 - 55-gal Drums w/ Liners	7.6	0.0	7.6
Final Form Total	88.8	0.0	88.8

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	20.94
Aluminum-based Metal/Alloys	0.81
Other Metal/Alloys	0.17
Other Inorganic Materials	9.76
Cellulosics	11.55
Rubber	7.08
Plastics	67.70
Cement	0.00
Solidified Inorganic Material	0.08
Solidified Organic Material	0.02
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.39
Packaging Material, Rubber	0.19
Packaging Material, Steel	186.07
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	7.30E-01
Am-243	3.36E-08
Cm-244	2.00E-06
Cs-137	3.28E-07
Np-237	9.84E-06
Pu-238	1.89E-01
Pu-239	1.90E+00
Pu-240	5.84E-01
Pu-241	3.67E+00
Pu-242	8.81E-05
Sr-90	2.95E-07
Th-229	2.41E-07
Th-230	2.80E-08
Th-232	9.47E-08
U-233	1.10E-04
U-234	1.29E-04
U-235	1.50E-07
U-236	4.33E-07
U-238	1.04E-06

Haz. Waste No(s).

D006, D008, D009, F001, F002, F005

TRUCON Code(s)

125/225, 154

Waste Stream Description

This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.

Waste Stream ID: **SR-W027-221H-HEPA**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Composite Filter Waste			**Inventory Date**	12/31/2011
Stream Name	CH TRU HEPA filters					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.3	0.0	1.3
55-gal Drum Dir Ld w/o Liner	0.0	4.2	4.2
Box - Fiberglass	7.7	0.0	7.7
Box - SRS Poly Box	4.3	0.0	4.3
Box - Steel	5.1	0.0	5.1
SWB Dir Ld w/o Liner	64.8	10.8	75.6
Current Form Total	83.1	15.0	98.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.0	4.2	4.2
SWB Dir Ld w/o Liner	86.9	11.3	98.3
SWB w/ 4 - 55-gal Drums w/ Liners	3.8	0.0	3.8
Final Form Total	90.7	15.5	106.2

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	28.97
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	5.14
Cellulosics	9.81
Rubber	0.06
Plastics	17.79
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.58
Packaging Material, Rubber	0.22
Packaging Material, Steel	154.60
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	9.03E-03
Am-243	1.46E-07
Cs-137	1.78E-03
Np-237	4.25E-05
Pu-238	3.55E+00
Pu-239	4.06E-02
Pu-240	1.01E-02
Pu-241	1.39E-01
Pu-242	1.64E-05
Sr-90	1.76E-03
Th-229	1.99E-13
Th-230	2.96E-08
Th-232	1.84E-19
U-233	9.05E-10
U-234	6.70E-04
U-235	7.98E-08
U-236	1.49E-09
U-238	1.27E-14

Haz. Waste No(s).

D006, D007, D008, D009, D011, D019, D022, D029, D035, D039, D040, D043

TRUCON Code(s)

119/219

Waste Stream Description

This waste stream is defense related, contact handled mixed TRU and is composed of HEPA filters

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W027-221H-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU/F listed solvents - Heterogeneous debris from 221H					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	33.2	0.0	33.2
55-gal Drum Dir Ld w/o Liner	1.5	0.0	1.5
SWB Dir Ld w/o Liner	12.6	0.0	12.6
Current Form Total	47.3	0.0	47.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	32.0	0.0	32.0
SWB Dir Ld w/o Liner	13.2	0.0	13.2
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
SWB w/ 4 - 55-gal Drums w/o Liners	3.8	0.0	3.8
Final Form Total	50.9	0.0	50.9

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	23.88
Aluminum-based Metal/Alloys	1.13
Other Metal/Alloys	0.37
Other Inorganic Materials	8.87
Cellulosics	5.63
Rubber	15.70
Plastics	49.46
Cement	0.00
Solidified Inorganic Material	0.13
Solidified Organic Material	0.01
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	23.92
Packaging Material, Rubber	0.46
Packaging Material, Steel	145.60
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	1.65E-01
Am-243	1.60E-06
Cm-244	2.20E-03
Cs-137	1.24E-05
Np-237	1.40E-03
Pu-238	7.01E+01
Pu-239	2.41E-01
Pu-240	6.72E-02
Pu-241	4.59E+00
Pu-242	1.51E-04
Sr-90	1.23E-05
Th-229	2.12E-07
Th-230	8.84E-07
Th-232	2.19E-06
U-233	3.44E-04
U-234	1.44E-02
U-235	2.23E-06
U-236	1.39E-08
U-238	2.32E-06

Haz. Waste No(s).

D006, D008, D009, D019, D022, D029, D039, D040, D043, F001, F002, F003, F005, U133

TRUCON Code(s)

125/225, 154

Waste Stream Description

This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste. Small HEPA filters, sludges, resins, absorbed liquids, and large metal equipment are also in these waste streams.

Waste Stream ID: **SR-W027-221H-HET-C**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU - Heterogeneous debris from 221H					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	10.1	0.0	10.1
55-gal Drum Dir Ld w/o Liner	33.0	105.8	138.8
SWB Dir Ld w/o Liner	14.4	43.2	57.6
Current Form Total	57.5	149.0	206.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	8.7	0.0	8.7
55-gal Drum Dir Ld w/o Liner	32.0	104.8	136.9
SWB Dir Ld w/o Liner	15.1	45.4	60.5
SWB w/ 4 - 55-gal Drums w/ Liners	3.8	0.0	3.8
SWB w/ 4 - 55-gal Drums w/o Liners	1.9	0.0	1.9
Final Form Total	61.6	150.2	211.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	22.31
Aluminum-based Metal/Alloys	10.05
Other Metal/Alloys	0.61
Other Inorganic Materials	20.05
Cellulosics	2.55
Rubber	13.91
Plastics	58.71
Cement	0.00
Solidified Inorganic Material	3.87
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.82
Packaging Material, Rubber	0.46
Packaging Material, Steel	139.40
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.68E-01
Cs-137	2.58E-05
Np-237	2.72E-03
Pu-238	6.89E-01
Pu-239	9.74E-01
Pu-240	2.41E-01
Pu-241	1.39E+00
Pu-242	5.95E-05
Sr-90	2.55E-05
Th-229	2.51E-11
Th-230	4.82E-08
Th-232	8.61E-18
U-233	8.15E-08
U-234	7.56E-04
U-235	1.58E-05
U-236	4.98E-08
U-238	1.80E-06

Haz. Waste No(s).

D006, D007, D008, D009, D011

TRUCON Code(s)

125/225, 154

Waste Stream Description

This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste. Small HEPA filters, sludges, resins, absorbed liquids, and large metal equipment are also in these waste streams.

Waste Stream ID: **SR-W027-221H-HOM**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU Absorbed / Stabilized Liquids					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
55-gal Drum Dir Ld w/o Liner	2.1	0.0	2.1
Current Form Total	2.7	0.0	2.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	1.5	0.0	1.5
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
SWB w/ 4 - 55-gal Drums w/o Liners	1.9	0.0	1.9
Final Form Total	5.2	0.0	5.2

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	3.36
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	59.42
Cellulosics	2.24
Rubber	2.24
Plastics	25.79
Cement	0.00
Solidified Inorganic Material	17.94
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	5.88
Packaging Material, Rubber	0.48
Packaging Material, Steel	188.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	1.88E-01
Am-243	6.48E-08
Cs-137	2.90E-03
Np-237	7.79E-05
Pu-238	4.23E-01
Pu-239	4.48E-01
Pu-240	1.22E-01
Pu-241	1.27E+00
Pu-242	4.35E-05
Sr-90	2.88E-03
Th-229	1.10E-09
Th-230	3.11E-08
Th-232	6.99E-16
U-233	3.12E-06
U-234	8.47E-04
U-235	1.62E-05
U-236	3.55E-06
U-238	8.50E-07

Haz. Waste No(s).

D006, D007, D008, D009, D011, D019, D022, D029, D043, F002, F005, U133

TRUCON Code(s)

127/227

Waste Stream Description

CH Mixed TRU Absorbed / Stabilized Liquids

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W027-235F/221H-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Commingled waste from HBL and 235F.					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
SLB2 (5' x 5' x 8) Dir Ld	33.2	0.0	33.2
SWB Dir Ld w/o Liner	12.6	0.0	12.6
Current Form Total	46.4	0.0	46.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SLB2 (5' x 5' x 8) Dir Ld	28.3	0.0	28.3
SWB Dir Ld w/o Liner	13.2	0.0	13.2
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	43.4	0.0	43.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	174.57
Aluminum-based Metal/Alloys	12.02
Other Metal/Alloys	19.28
Other Inorganic Materials	19.28
Cellulosics	28.79
Rubber	1.81
Plastics	21.42
Cement	0.00
Solidified Inorganic Material	1.39
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.71
Packaging Material, Rubber	0.17
Packaging Material, Steel	196.43
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.37E-04
Np-237	6.98E-05
Pu-238	4.68E-01
Pu-239	3.82E-04
Pu-240	2.08E-04
Pu-241	4.15E-03
Pu-242	2.49E-07
Th-229	5.86E-12
Th-230	2.99E-09
Th-232	6.72E-20
U-233	6.35E-09
U-234	3.01E-05
U-235	7.89E-12
U-236	1.30E-10
U-238	8.10E-16

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D029, D043, F002, F005, U133

TRUCON Code(s)

125/225, 154

Waste Stream Description

This waste will consist of repackaged waste from a large steel box that was originally loaded from two separate SRS generator facilities (i.e. H-B line and 235F)

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W027-235F-HEPA**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU consisting of HEPA Filters from the 235-F.					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Box - SRS Poly Box	0.2	0.0	0.2
SWB Dir Ld w/o Liner	14.4	0.0	14.4
Current Form Total	15.3	0.0	15.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/o Liner	17.0	0.0	17.0
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	18.9	0.0	18.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2.63
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.63
Cellulosics	24.07
Rubber	0.00
Plastics	15.51
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.63
Packaging Material, Rubber	0.22
Packaging Material, Steel	159.21
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.06E-02
Am-243	1.09E-13
Cs-137	3.35E-08
Np-237	1.62E-04
Pu-238	5.21E-01
Pu-239	5.93E-03
Pu-240	2.58E-03
Pu-241	1.15E-02
Pu-242	4.53E-06
Sr-90	3.21E-08
Th-229	2.42E-11
Th-230	6.31E-08
Th-232	1.48E-18
U-233	1.97E-08
U-234	2.67E-04
U-235	2.38E-06
U-236	2.14E-09
U-238	1.97E-14

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D035

TRUCON Code(s)

119/219, 154

Waste Stream Description

This waste stream is defense related, contact handled TRU waste and is composed of spent HEPA Filters

Waste Stream ID: **SR-W027-235F-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU/F listed solvents - Heterogeneous debris from 235F					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	6.9	0.0	6.9
55-gal Drum Dir Ld w/o Liner	0.4	0.0	0.4
Box - Steel	2.7	0.0	2.7
Pipe - Steel	1.3	0.0	1.3
SWB Dir Ld w/o Liner	7.2	0.0	7.2
Current Form Total	18.5	0.0	18.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	5.8	0.0	5.8
SLB2 (5' x 5' x 8) Dir Ld	11.3	0.0	11.3
SWB Dir Ld w/o Liner	15.1	0.0	15.1
SWB w/ 4 - 55-gal Drums w/ Liners	3.8	0.0	3.8
SWB w/ 4 - 55-gal Drums w/o Liners	1.9	0.0	1.9
Final Form Total	37.9	0.0	37.9

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	31.07
Aluminum-based Metal/Alloys	0.87
Other Metal/Alloys	1.55
Other Inorganic Materials	4.35
Cellulosics	5.37
Rubber	14.64
Plastics	26.43
Cement	0.00
Solidified Inorganic Material	0.10
Solidified Organic Material	0.05
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	7.31
Packaging Material, Rubber	0.27
Packaging Material, Steel	177.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	1.44E-01
Am-243	8.27E-07
Cm-244	1.57E-04
Cs-137	1.26E-06
Np-237	2.40E-03
Pu-238	6.65E+01
Pu-239	9.11E-02
Pu-240	3.92E-02
Pu-241	2.51E+00
Pu-242	7.51E-05
Sr-90	1.25E-06
Th-229	6.56E-08
Th-230	9.84E-07
Th-232	8.47E-07
U-233	1.24E-04
U-234	1.84E-02
U-235	1.79E-06
U-236	6.97E-09
U-238	8.13E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D035, F002, F003

TRUCON Code(s)

125/225, 154

Waste Stream Description

This waste stream is defense related contact handled mixed TRU waste. This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste, small HEPAs, liquids, sludges and resins may also be found in this stream..

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W027-235F-HOM**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	CH mixed TRU S3000 solids from 235F					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.2	0.0	4.2
Current Form Total	4.2	0.0	4.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.9	0.0	2.9
SWB w/ 4 - 55-gal Drums w/ Liners	3.8	0.0	3.8
Final Form Total	6.7	0.0	6.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	1.74
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	1.74
Cellulosics	1.74
Rubber	1.74
Plastics	5.23
Cement	0.00
Solidified Inorganic Material	162.06
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	25.33
Packaging Material, Rubber	0.50
Packaging Material, Steel	176.15
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.27E-01
Np-237	6.49E-07
Pu-238	1.35E+02
Pu-239	1.09E-01
Pu-240	5.98E-02
Pu-241	1.25E+00
Pu-242	7.13E-05
Th-229	1.38E-14
Th-230	7.80E-07
Th-232	1.75E-17
U-233	2.52E-11
U-234	8.26E-03
U-235	2.16E-09
U-236	3.54E-08
U-238	2.21E-13

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, F002

TRUCON Code(s)

122/222

Waste Stream Description

This waste consists of sludge from tank cleanout.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W027-321-322M-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU Debris (S5000)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.4	0.0	4.4
Current Form Total	4.4	0.0	4.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.4	0.0	4.4
Final Form Total	4.4	0.0	4.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	141.74
Aluminum-based Metal/Alloys	3.63
Other Metal/Alloys	8.34
Other Inorganic Materials	18.49
Cellulosics	23.56
Rubber	68.51
Plastics	97.15
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	1.09
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.41E+00
Np-237	5.30E-04
Pu-238	1.97E-02
Pu-239	4.21E-02
Pu-240	9.93E-03
Pu-241	3.40E+01
Pu-242	1.73E-06
Th-229	9.29E-11
Th-230	2.90E-10
Th-232	6.98E-18
U-233	6.89E-08
U-234	1.95E-06
U-235	1.29E-09
U-236	9.12E-09
U-238	8.33E-15

Haz. Waste No(s).

D008, D009, F001, F002

TRUCON Code(s)

125/225, 129/229

Waste Stream Description

CH Mixed TRU waste resulting from target assembly fabrication leading to production of defense related nuclear materials.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W027-321M-HOM**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU Homogeneous Solids (S3000)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2.22
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	3.63
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	61.38
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.76E+00
Np-237	2.84E-05
Pu-238	1.12E+00
Th-229	1.76E-12
Th-230	1.64E-08
U-233	1.93E-09
U-234	1.11E-04

Haz. Waste No(s).

D008, F002

TRUCON Code(s)

127/227

Waste Stream Description

CH Mixed TRU waste resulting from target assembly fabrication leading to production of defense related nuclear materials.

Waste Stream ID: **SR-W027-773A-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU/F listed solvents - Heterogeneous debris from 773A					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	6.1	0.0	6.1
55-gal Drum Dir Ld w/o Liner	16.0	69.9	85.9
Box - Fiberglass	3.4	0.0	3.4
Box - Plywood	1.7	0.0	1.7
Box - Steel	2.6	0.0	2.6
SLB2 (5' x 5' x 8) Dir Ld	66.3	0.0	66.3
SWB Dir Ld w/o Liner	37.8	34.2	72.0
Current Form Total	133.8	104.1	237.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	5.8	0.0	5.8
55-gal Drum Dir Ld w/o Liner	15.8	69.3	85.1
SLB2 (5' x 5' x 8) Dir Ld	56.6	0.0	56.6
SWB Dir Ld w/o Liner	54.8	35.9	90.7
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	134.9	105.2	240.1

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	36.57
Aluminum-based Metal/Alloys	0.73
Other Metal/Alloys	1.69
Other Inorganic Materials	19.37
Cellulosics	10.48
Rubber	9.29
Plastics	37.68
Cement	0.00
Solidified Inorganic Material	0.22
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.03
Packaging Material, Rubber	0.32
Packaging Material, Steel	159.95
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	2.14E-01
Am-243	1.52E-03
Cm-244	1.08E-01
Cs-137	1.00E-03
Np-237	3.19E-04
Pu-238	1.33E+01
Pu-239	4.90E-01
Pu-240	1.13E-01
Pu-241	1.80E+00
Pu-242	2.33E-05
Sr-90	9.92E-04
Th-229	2.99E-08
Th-230	1.42E-07
Th-232	7.63E-07
U-233	5.66E-05
U-234	2.69E-03
U-235	1.37E-06
U-236	2.01E-08
U-238	1.48E-05

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D027, D028, D029, D043, F002, F003, F004, F005

TRUCON Code(s)

125/225

Waste Stream Description

This waste stream is defense related contact handled mixed TRU waste. This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, other job control waste, small HEPAs liquids, sludges and resins may also be found in this waste.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W027-773A-HOM**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Analytical Laboratory Waste	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU Homogeneous Solids (S3000)					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Current Form Total	0.6	0.0	0.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.80
Aluminum-based Metal/Alloys	0.02
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	3.83
Rubber	1.21
Plastics	12.12
Cement	0.00
Solidified Inorganic Material	49.58
Solidified Organic Material	133.86
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.87E-02
Np-237	5.11E-08
Pu-238	3.72E+01
Pu-239	5.09E-02
Pu-240	2.10E-02
Pu-241	5.36E-01
Pu-242	1.97E-05
Th-229	4.01E-16
Th-230	1.17E-07
Th-232	3.46E-18
U-233	1.17E-12
U-234	1.67E-03
U-235	7.53E-10
U-236	9.34E-09
U-238	4.60E-14

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D027, D028, D029, D043, F002, F004, F005

TRUCON Code(s)

127/227

Waste Stream Description

CH Mixed TRU Homogeneous Solids resulting from liquid absorption at the SRNL.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W027-776A-HET**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU/F listed solvents - Heterogeneous debris from 776A					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - SRS B-25 OP	7.2	0.0	7.2
Box - Steel	40.8	0.0	40.8
SLB2 (5' x 5' x 8) Dir Ld	19.9	0.0	19.9
SWB Dir Ld w/o Liner	5.4	0.0	5.4
Current Form Total	73.3	0.0	73.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SLB2 (5' x 5' x 8) Dir Ld	17.0	0.0	17.0
SWB Dir Ld w/o Liner	54.8	0.0	54.8
Final Form Total	71.8	0.0	71.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	21.64
Aluminum-based Metal/Alloys	1.03
Other Metal/Alloys	2.69
Other Inorganic Materials	10.68
Cellulosics	6.34
Rubber	3.72
Plastics	22.67
Cement	0.00
Solidified Inorganic Material	0.07
Solidified Organic Material	0.07
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.18
Packaging Material, Steel	168.13
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.98E-04
Cs-137	2.06E-02
Np-237	7.99E-10
Pu-238	2.05E-01
Pu-239	5.74E-04
Pu-240	1.87E-04
Pu-241	3.42E-03
Pu-242	1.25E-07
Sr-90	1.41E-02
Th-229	1.29E-17
Th-230	1.31E-09
Th-232	6.04E-20
U-233	2.65E-14
U-234	1.32E-05
U-235	1.19E-11
U-236	1.17E-10
U-238	4.09E-16

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D019, D022, D027, D028, D029, D043, F002, F004, F005

TRUCON Code(s)

125/225, 154

Waste Stream Description

This waste stream is defense related contact handled mixed TRU waste. This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, other job control waste, small HEPAs liquids, sludges and resins may also be found in this waste.

Waste Stream ID: **SR-W027-FB-Pre86-C**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH Mixed TRU - Heterogeneous debris from 221H					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	40.1	0.0	40.1
Box - Steel	2.3	0.0	2.3
SLB2 (5' x 5' x 8) Dir Ld	39.8	0.0	39.8
SWB Dir Ld w/o Liner	7.2	0.0	7.2
Current Form Total	89.4	0.0	89.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	39.3	0.0	39.3
SLB2 (5' x 5' x 8) Dir Ld	34.0	0.0	34.0
SWB Dir Ld w/o Liner	11.3	0.0	11.3
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	86.5	0.0	86.5

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	27.87
Aluminum-based Metal/Alloys	0.29
Other Metal/Alloys	0.36
Other Inorganic Materials	9.40
Cellulosics	9.27
Rubber	9.29
Plastics	64.84
Cement	0.00
Solidified Inorganic Material	0.21
Solidified Organic Material	0.05
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	17.20
Packaging Material, Rubber	0.35
Packaging Material, Steel	168.78
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	1.09E+00
Am-243	1.45E-06
Cm-244	1.46E-03
Cs-137	2.80E-06
Np-237	5.63E-05
Pu-238	3.39E-01
Pu-239	2.74E+00
Pu-240	7.86E-01
Pu-241	3.56E+00
Pu-242	1.44E-04
Sr-90	2.70E-06
Th-229	2.94E-08
Th-230	1.82E-08
Th-232	7.93E-08
U-233	1.34E-05
U-234	9.18E-05
U-235	2.58E-07
U-236	5.82E-07
U-238	8.59E-07

Haz. Waste No(s).

D005, D006, D007, D008, D009, D011, D018, D019, D022, D029, D039, D040, D043, F001, F002, F003, F005, U002, U151

TRUCON Code(s)

125/225, 133/233, 154

Waste Stream Description

This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. Small HEPA filters, sludges, resins, absorbed liquids, and metal equipment is also in present in the waste stream.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W027-HBL-Box**

Appendix A

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH mixed TRU from 221H					**Activity Concentrations Decayed to CY**	2011

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	70.6	0.0	70.6
85-gal Drum Dir Ld w/o Liner	0.7	0.0	0.7
Box - Fiberglass	3.4	0.0	3.4
Box - SRS B-25 OP	18.0	0.0	18.0
Box - SRS Black Box	170.8	0.0	170.8
Box - Steel	46.4	0.0	46.4
Box - Steel SS	28.8	0.0	28.8
SLB2 (5' x 5' x 8) Dir Ld	437.6	0.0	437.6
SWB Dir Ld w/o Liner	239.4	0.0	239.4
Current Form Total	1015.6	0.0	1015.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	70.7	0.0	70.7
SLB2 (5' x 5' x 8) Dir Ld	515.1	0.0	515.1
SWB Dir Ld w/o Liner	491.4	0.0	491.4
Final Form Total	1077.2	0.0	1077.2

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	34.35
Aluminum-based Metal/Alloys	0.01
Other Metal/Alloys	0.01
Other Inorganic Materials	4.05
Cellulosics	48.17
Rubber	1.77
Plastics	30.48
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.19
Packaging Material, Steel	181.65
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	4.56E-03
Am-243	2.03E-10
Cm-244	5.44E-05
Cs-137	3.62E-07
Np-237	4.78E-05
Pu-238	1.94E+00
Pu-239	1.06E-02
Pu-240	3.32E-03
Pu-241	2.06E-02
Pu-242	4.80E-06
Sr-90	3.50E-07
Th-229	4.01E-12
Th-230	8.90E-08
Th-232	1.07E-18
U-233	4.34E-09
U-234	5.22E-04
U-235	5.61E-09
U-236	2.07E-09
U-238	1.56E-14

Haz. Waste No(s).

D006, D007, D008, D009, D011, D019, D022, D029, D043, F002, F005, U133

TRUCON Code(s)

125/225, 154

Waste Stream Description

This waste stream is defense related debris consisting of large equipment and job control waste packaged in large steel boxes

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

APPENDIX B POTENTIAL TRU WASTE PROFILE REPORTS

The following waste profile reports contain information on potential TRU waste streams as of the inventory date, December 31, 2011. These waste streams have been placed in the potential category for various reasons as stated in section 4.0 of this report, if available.

The TRU waste sites that have reported potential TRU waste streams are:

AW Material and Fuels Complex
BL Babcock and Wilcox Nuclear Energy Services
IN Idaho National Laboratory
LA Los Alamos National Laboratory
RL Hanford (Richland) Site
RP Hanford (River Protection) Site
SR Savannah River Site
WV West Valley Demonstration Project

Waste Stream ID: **AW-IN-TRA-BE-01**

Appendix B

Waste Profile Report

Site	Material and Fuels Complex	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Uncategorized Metal Waste			**Inventory Date**	12/31/2011
Stream Name	TRA Beryllium Blocks					**Activity Concentrations as of CY**	2001

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Beryllium Reflector Block	9.0	10.8	19.8
Shim Control Cylinder	6.2	5.4	11.5
Current Form Total	15.2	16.2	31.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid - Dir Ld	15.1	16.0	31.2
Final Form Total	15.1	16.0	31.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	429.85
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.00
Packaging Material, Steel	560.67
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.90E-02
Cs-137	6.12E+00
Pu-238	2.96E-02
Pu-239	5.91E-03
Pu-240	1.54E-02
Pu-241	1.97E+00
Pu-242	3.24E-04
Sr-90	1.80E+00
U-233	2.15E-05
U-234	5.51E-06
U-238	1.88E-06

No Hazardous Waste Numbers Provided

TRUCON Code(s)

317

Waste Stream Description

This waste stream consists of beryllium reflector blocks and outer shim control cylinders (OSCCs) removed from the Advanced Test Reactor (ATR) at INL.

Waste Stream ID: **AW-W018**

Appendix B

Waste Profile Report

Site	Material and Fuels Complex	**Summary Category**	X7000	**Defense Determination**	Pending Determination	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Prohibited Waste			**Inventory Date**	12/31/2011
Stream Name	SODIUM - TRU					**Activity Concentrations as of CY**	1996

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Liner - RSWF	2.6	0.0	2.6
Current Form Total	2.6	0.0	2.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid - Dir Ld	2.7	0.0	2.7
Final Form Total	2.7	0.0	2.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2361.27
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	295.19
Other Inorganic Materials	147.59
Cellulosics	147.59
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.00
Packaging Material, Steel	560.67
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.43E-03
Cs-137	5.81E+02
Np-237	2.39E-05
Pu-238	1.08E-01
Pu-239	2.39E+01
Pu-240	1.24E+01
Sr-90	5.43E+02
U-235	2.10E-03
U-238	1.49E-03

Haz. Waste No(s).

D001, D003

TRUCON Code(s)

317

Waste Stream Description

Sodium was used as a primary and secondary coolant for the EBR-II reactor. Waste sodium metal is a hazardous constituent (D001/D003) of some of the TRU waste stored at the ANL-W Radioactive Scrap and Waste Facility (RSWF). The waste was generated during maintenance and operational activities. The sodium typically coats waste metal equipment, experiments, and components removed during reactor operations and maintenance activities or is contained in blanket elements. This waste will require treatment (EPA technology code DEACT) to remove sodium from the TRU waste prior to disposal at WIPP. Final waste form has not been determined yet, but the sodium will be removed from the waste. Once removed, the resulting waste may not be considered TRU, especially in the case of sodium-bonded blanket fuels.

Waste Stream ID: **AW-W019**

Appendix B

Waste Profile Report

Site	Material and Fuels Complex	**Summary Category**	X7000	**Defense Determination**	Pending Determination	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Prohibited Waste			**Inventory Date**	12/31/2011
Stream Name	SODIUM POTASSIUM -NaK- TRU					**Activity Concentrations as of CY**	1996

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Liner - RSWF	0.3	0.0	0.3
Current Form Total	0.3	0.0	0.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid - Dir Ld	0.9	0.0	0.9
Final Form Total	0.9	0.0	0.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	847.04
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	116.15
Other Inorganic Materials	58.07
Cellulosics	58.07
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.00
Packaging Material, Steel	560.67
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Cs-137	4.02E+02
Pu-239	1.43E-01
Pu-240	5.48E-02
Sr-90	3.93E+02
U-235	2.37E-04
U-238	1.47E-04

Haz. Waste No(s).

D003

TRUCON Code(s)

317

Waste Stream Description

Sodium potassium alloy (NaK) was used as a coolant for some components of the EBR-II Reactor. Waste NaK metal is a hazardous constituent (D003) of some transuranic wastes stored at the ANL-W Radioactive Scrap and Waste Facility (RSWF). The remote-handled NaK waste at RSWF is contained in stainless steel capsules or tubing and placed inside carbon steel waste cans which then are placed in stainless steel outer cans. The entire package is then stored in RSWF storage liners (carbon steel soil storage vaults). The NaK was generated during maintenance and operational activities. NaK waste is in canisters with TRU waste metal pieces and rods from reactor experiments. This waste will require treatment (EPA technology code DEACT) to remove NaK from the TRU waste prior to disposal at WIPP. Final waste form has not been determined yet.

Waste Stream ID: **BL-Parks**

Appendix B

Waste Profile Report

Site	Babcock and Wilcox Nuclear Energy Services	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Parks Township TRU Waste					**Activity Concentrations as of CY**	2000

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	4.0	0.0	4.0
Box - Steel	5.7	0.0	5.7
Current Form Total	9.6	0.0	9.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	4.0	0.0	4.0
SWB Dir Ld w/o Liner	5.7	0.0	5.7
Final Form Total	9.6	0.0	9.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.35
Packaging Material, Steel	144.13
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.99E+00
Cs-137	4.11E-03
Pu-238	3.44E+00
Pu-239	1.82E+01
Pu-240	6.85E+00
Pu-241	1.83E+02
Pu-242	4.04E-03
U-234	3.08E-05
U-235	1.40E-06
U-238	2.79E-06

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

10.05 m3 of waste from Parks Township ROD 63FR3629, 65FR82985, 69FR39446 amended 27 February 2008 Point of Contact William Spurgeon (Any reference to 45m3, Matt Hutmaker, B&W is not related to BL-Parks)

Waste Stream ID: **BL-Parks-A**

Appendix B

Waste Profile Report

Site	Babcock and Wilcox Nuclear Energy Services	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	RH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Parks Township TRU Waste					**Activity Concentrations as of CY**	2000

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Box - Misc	0.2	0.0	0.2
Current Form Total	0.4	0.0	0.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.35E-01
Pu-239	6.29E+00

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

10.05 m3 of waste from Parks Township ROD 63FR3629, 65FR82985, 69FR39446 amended 27 February 2008 Point of Contact William Spurgeon (Any reference to 45m3, Matt Hutmaker, B&W is not related to BL-Parks)

Waste Stream ID: **IN-JH826CH**

Appendix B
Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	J.C. Haynes Waste					**Activity Concentrations as of CY**	1985

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Misc	3.2	0.0	3.2
Current Form Total	3.2	0.0	3.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.8	0.0	0.8
Final Form Total	0.8	0.0	0.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.27E+01

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

Am-241 contaminated debris waste

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-SBW-01A**

Appendix B

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	SBW Treatment - Steam Reforming - Carbonate Waste Form					**Activity Concentrations as of CY**	2006

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Tank(s)	3520.0	0.0	3520.0
Current Form Total	3520.0	0.0	3520.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid - Dir Ld	599.0	0.0	599.0
Final Form Total	599.0	0.0	599.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	1334.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.00
Packaging Material, Steel	560.67
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.27E-01
Am-243	2.85E-04
Cm-244	2.02E-03
Cs-137	2.90E+02
Np-237	4.03E-03
Pu-238	6.22E+00
Pu-239	6.75E-01
Pu-240	2.50E-01
Pu-241	2.54E+00
Pu-242	1.29E-04
Sr-90	1.90E+02
U-233	5.64E-05
U-234	8.98E-03
U-235	2.20E-04
U-238	2.16E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, F001, F002, F005, U134

No TRUCON Codes Provided

Waste Stream Description

The liquid SBW would be transferred from the storage tanks to the steam reforming process over a 1.0-year period. The steam reforming process is a fluidized bed reactor that converts the metals dissolved in the nitric acid into a dry granular powder. The fluidized bed operates at temperature between 600 and 1000 degrees centigrade. The carbonate waste form would be removed from the fluidized bed and transferred to the canning facility and placed by 90% loading in to 72-B canisters (direct loaded). The carbonate waste form would be RH-TRU waste, dried to 1% moisture, and would generate approximately 673 canisters with a surface dose rate <100 Rem/hr.

Waste Stream ID: **IN-SBW-01B**

Appendix B

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	SBW Treatment - Steam Reforming Process - Debris					**Activity Concentrations as of CY**	2010

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid - Dir Ld	0.0	89.0	89.0
Current Form Total	0.0	89.0	89.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid - Dir Ld	0.0	89.0	89.0
Final Form Total	0.0	89.0	89.0

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	700.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	2.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.00
Packaging Material, Steel	560.67
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	**Typical Concentration (Ci/m^3)**
Am-241	5.27E-03
Am-243	2.85E-06
Cm-244	2.02E-05
Cs-137	2.90E+00
Np-237	4.03E-05
Pu-238	6.22E-02
Pu-239	6.75E-03
Pu-240	2.50E-03
Pu-241	2.54E-02
Pu-242	1.29E-06
Sr-90	1.90E+00
U-233	5.64E-07
U-234	8.98E-05
U-235	2.20E-06
U-238	2.16E-06

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, F001, F002, F005, U134

No TRUCON Codes Provided

Waste Stream Description

The debris from the steam reforming process would include spent HEPA filters and other failed equipment.

Waste Stream ID: **IN-W139**

Appendix B

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Discarding Excess/Expired Materials	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Mexican Americium Waste					**Activity Concentrations as of CY**	1986

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.8	0.0	0.8
Current Form Total	0.8	0.0	0.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.8	0.0	0.8
Final Form Total	0.8	0.0	0.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.50E+00

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream consists of Americium contaminated debris waste.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-W269**

Appendix B

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Laboratory Waste					**Activity Concentrations as of CY**	1989

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	24.1	0.0	24.1
Current Form Total	24.1	0.0	24.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	24.1	0.0	24.1
Final Form Total	24.1	0.0	24.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	6.79E+00
Pu-238	7.93E+00
Pu-239	6.97E+01
Pu-240	7.22E+00
Pu-241	2.65E-01
Pu-242	2.46E-05
U-235	1.21E-02
U-238	7.44E-05

Haz. Waste No(s).

D006, D007, D008, D011

No TRUCON Codes Provided

Waste Stream Description

This waste stream, generated at the ANL-W, may include fluxwire, fission counters, glassware, vials, miscellaneous waste from gloveboxes, aluminum foil and capsules, ion exchange resins, plutonium sources, and uranium pellets. Waste may also contain <50% by volume analytical samples and pellets dissolved and absorbed in Oil-Dri.

Waste Stream ID: **IN-W322**

Appendix B

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Unknown	**Handling**	CH
Source Cat.	Other/Multiple Sources	**Waste Matrix Code Group**	Uncategorized Metal Waste			**Inventory Date**	12/31/2011
Stream Name	Actinide Neutron Sources					**Activity Concentrations as of CY**	1989

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.1	0.0	2.1
Current Form Total	2.1	0.0	2.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	5.7	0.0	5.7
Final Form Total	5.7	0.0	5.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	139.10
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-239	4.83E+00
Pu-240	1.00E+00
U-235	1.31E-04

Haz. Waste No(s).

D008

No TRUCON Codes Provided

Waste Stream Description

This waste stream was generated at the INEL. These wastes include actinide neutron sources, a radium needle, small vials of fuel, and metal containers of experimental fuel capsules.

Waste Stream ID: **IN-W338**

Appendix B

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ANL-W ACL Cold-Line Absorbed Liquid and Debris					**Activity Concentrations as of CY**	1989

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.2	0.0	1.2
Current Form Total	1.2	0.0	1.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	1.2	0.0	1.2
Final Form Total	1.2	0.0	1.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-239	4.67E-01
U-235	1.17E-04

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream was generated at ANL-W, includes solidified liquids, miscellaneous hardware, and polyethylene.

Waste Stream ID: **IN-W339**

Appendix B

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	ANL-W FMF EFL: Zr-U-Pu Fuel Casting					**Activity Concentrations as of CY**	1989

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	10.2	0.0	10.2
Current Form Total	10.2	0.0	10.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	10.2	0.0	10.2
Final Form Total	10.2	0.0	10.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-239	9.20E+00
Pu-240	3.76E-02
U-235	6.94E-04

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream was generated at ANL-W. It consists of solid zirconium, uranium, and plutonium fuel casting metal alloy wastes. The waste is a solid with small amounts of glass powder from broken glass molds. The waste is created when the metal is heated in a crucible and then pressurized into the glass molds. The glass molds are broken to remove the fuel pins, and the remaining molds, crucibles, and residues constitute the waste.

Waste Stream ID: **IN-W342R**

Appendix B

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S9000	**Defense Determination**	Unknown	**Handling**	RH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Unknown			**Inventory Date**	12/31/2011
Stream Name	Miscellaneous Radionuclide Sources					**Activity Concentrations as of CY**	1989

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Current Form Total	0.4	0.0	0.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	158.69
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	3.51E+00
Pu-239	3.04E-02

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream generated at the INEL, is believed to contain radionuclide sources (e.g., Pu-239, Cf-252 and Am-241) from calibration units across the INL site.

Waste Stream ID: **IN-W350**

Appendix B

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S9000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Unknown			**Inventory Date**	12/31/2011
Stream Name	Special Source Material (UNK)					**Activity Concentrations as of CY**	1989

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-239	5.74E+01
Pu-240	1.76E+02

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

There is no descriptive or constituent information available for this waste, generated at ANL-E.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **IN-W359R**

Appendix B

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	RH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Uncategorized Metal Waste			**Inventory Date**	12/31/2011
Stream Name	Neutron Sources					**Activity Concentrations as of CY**	1989

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.6	0.0	0.6
Current Form Total	0.6	0.0	0.6

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.6	0.0	0.6
Final Form Total	0.6	0.0	0.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-238	2.01E+02

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream generated by Bettis Atomic Laboratory consists of two Pu-238-Be sources and one Pu-238-Li source.

Waste Stream ID: **IN-W360**

Appendix B

Waste Profile Report

Site	Idaho National Laboratory	**Summary Category**	S9000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Prohibited Waste			**Inventory Date**	12/31/2011
Stream Name	Miscellaneous Sources					**Activity Concentrations as of CY**	1989

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	52.51
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	16.30
Packaging Material, Rubber	0.44
Packaging Material, Steel	211.11
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Pu-238	1.35E-01
Pu-239	3.83E+00
Pu-240	8.71E-01
Pu-241	2.31E+01
Pu-242	6.26E-05

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

The waste stream generated by Bettis Atomic Laboratory consists of two sources.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-OS-00-04**

Appendix B

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Discarding Excess/Expired Materials	**Waste Matrix Code Group**	Uncategorized Metal Waste			**Inventory Date**	12/31/2011
Stream Name	Metal debris from Off-Site Source Recovery (OSR) project					**Activity Concentrations as of CY**	N/A

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal POC - 12" w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal POC - 12" w/ Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	135.10
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	528.85
Packaging Material, Lead	0.00

No Final Form Radionuclides Provided

Haz. Waste No(s).

D006, D008

TRUCON Code(s)

120/220

Waste Stream Description

Manufactured sealed sources in metal containers which are placed inside metal POCs that are then packaged into 55-gallon drums.

Waste Stream ID: **LA-TA-00-04**

Appendix B

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	Absorbed Liquid Waste					**Activity Concentrations as of CY**	2007

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Current Form Total	0.2	0.0	0.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	2.40
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.88
Cellulosics	0.00
Rubber	0.00
Plastics	3.76
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	19.13
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.07E-03
Pu-238	1.28E-03
Pu-239	4.35E-02
Pu-240	1.02E-02
Pu-241	1.53E-01
Pu-242	5.86E-07

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D021, D022, D035, D038, D039, D040, F001, F002, F003, F005, U003, U044, U080, U196, U213

TRUCON Code(s)

112/212

Waste Stream Description

Inorganic particulate waste generated during TA-55 R&D/fabrication and associated recovery, facility and equipment maintenance, D&D, waste repackaging, and below-grade retrieval operations.

Waste Stream ID: **LA-TA-03-17**

Appendix B

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Hepa Filters					**Activity Concentrations as of CY**	N/A

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Crate	19.2	0.0	19.2
Current Form Total	19.2	0.0	19.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	18.9	0.0	18.9
Final Form Total	18.9	0.0	18.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	11.96
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	3.91
Other Inorganic Materials	18.97
Cellulosics	15.28
Rubber	1.55
Plastics	44.87
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.30
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

No Final Form Radionuclides Provided

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

Hepa Filters

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-03-21**

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Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Metals and Miscellaneous Equipment Debris					**Activity Concentrations as of CY**	N/A

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Crate	93.4	0.0	93.4
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Current Form Total	95.3	0.0	95.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	94.5	0.0	94.5
Final Form Total	94.5	0.0	94.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	32.72
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	10.70
Other Inorganic Materials	51.91
Cellulosics	41.81
Rubber	4.24
Plastics	122.76
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.82
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

No Final Form Radionuclides Provided

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225, 154

Waste Stream Description

Metals and Miscellaneous Equipment Debris

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-03-23**

Appendix B

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Hepa Filters					**Activity Concentrations as of CY**	N/A

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Crate	66.4	0.0	66.4
Current Form Total	66.4	0.0	66.4

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	66.2	0.0	66.2
Final Form Total	66.2	0.0	66.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	10.95
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	3.58
Other Inorganic Materials	17.37
Cellulosics	13.99
Rubber	1.42
Plastics	41.08
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.27
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

No Final Form Radionuclides Provided

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

Hepa Filters

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-03-33**

Appendix B

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Source Information Not Compiled	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Combustibles and noncombustibles					**Activity Concentrations as of CY**	N/A

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
30-gal Drum	0.1	0.0	0.1
Current Form Total	0.1	0.0	0.1

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Final Form Total	0.2	0.0	0.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	16.16
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	5.29
Other Inorganic Materials	25.63
Cellulosics	20.65
Rubber	2.09
Plastics	60.62
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.41
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

No Final Form Radionuclides Provided

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

Special items (precious metals) requiring tracking by CST-7

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-21-11**

Appendix B

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	NonCombustible Building Debris					**Activity Concentrations as of CY**	N/A

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Crate	15.9	0.0	15.9
Other	2.1	0.0	2.1
Current Form Total	18.0	0.0	18.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	17.0	0.0	17.0
Final Form Total	17.0	0.0	17.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	41.02
Aluminum-based Metal/Alloys	15.64
Other Metal/Alloys	31.44
Other Inorganic Materials	8.94
Cellulosics	26.65
Rubber	20.59
Plastics	15.32
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

No Final Form Radionuclides Provided

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

NonCombustible Building Debris

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-50-12**

Appendix B

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Metal					**Activity Concentrations as of CY**	N/A

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
Box - Crate	8.1	0.0	8.1
SWB Dir Ld w/ Liner	2.4	0.0	2.4
Current Form Total	10.7	0.0	10.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
SWB Dir Ld w/ Liner	9.5	0.0	9.5
Final Form Total	9.7	0.0	9.7

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	119.93
Aluminum-based Metal/Alloys	43.66
Other Metal/Alloys	44.31
Other Inorganic Materials	4.87
Cellulosics	8.97
Rubber	8.27
Plastics	9.06
Cement	0.00
Solidified Inorganic Material	2.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.97
Packaging Material, Rubber	0.20
Packaging Material, Steel	152.95
Packaging Material, Lead	0.00

No Final Form Radionuclides Provided

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225, 154

Waste Stream Description

Metal

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **LA-TA-50-15**

Appendix B

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Heterogeneous Debris					**Activity Concentrations as of CY**	1987

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Other	7.7	0.0	7.7
Current Form Total	7.7	0.0	7.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	7.6	0.0	7.6
Final Form Total	7.6	0.0	7.6

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	235.51
Aluminum-based Metal/Alloys	85.73
Other Metal/Alloys	87.01
Other Inorganic Materials	9.56
Cellulosics	17.61
Rubber	16.24
Plastics	17.80
Cement	0.00
Solidified Inorganic Material	3.93
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.86E-02
Cs-137	1.94E+04
Pu-238	1.21E-02
Pu-239	4.13E-01
Pu-240	9.66E-02
Pu-241	1.46E+00
Pu-242	5.56E-06
Sr-90	1.37E+04
U-234	8.85E-07
U-235	1.53E-08

Haz. Waste No(s).

D008

TRUCON Code(s)

125/225, 154

Waste Stream Description

Mixed heterogeneous combustible and non-combustible debris from the TA-50-01 RLWTF, TA-50-37 CAI, and TA-50-69 WCRR Facility generated during facility and equipment maintenance, decontamination and decommissioning (D&D), and waste repackaging activities.

Waste Stream ID: **LA-TA-50-20**

Appendix B

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Plutonium contaminated soil (non-mixed)					**Activity Concentrations as of CY**	N/A

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.2	0.0	0.2
85-gal Drum w/ 1 - 55-gal Drum w/ Liner	0.3	0.0	0.3
Current Form Total	0.5	0.0	0.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Final Form Total	0.4	0.0	0.4

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.07
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.07
Cement	0.00
Solidified Inorganic Material	0.22
Solidified Organic Material	0.00
Soils	741.39
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	37.07
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

No Final Form Radionuclides Provided

No Hazardous Waste Numbers Provided

TRUCON Code(s)

111/211

Waste Stream Description

Plutonium Contaminated Soils contaminated with transuranic material as a result of facility and equipment operations and maintenance.

Waste Stream ID: **LA-TRU-Empty**

Appendix B

Waste Profile Report

Site	Los Alamos National Laboratory	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Empty containers					**Activity Concentrations as of CY**	2009

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner (LANL)	0.8	0.0	0.8
85-gal Drum w/ 1 - 55-gal Drum w/ Liner (LANL)	101.4	0.0	101.4
Current Form Total	102.3	0.0	102.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	32.1	0.0	32.1
Final Form Total	32.1	0.0	32.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.23E-01
Am-243	4.37E-05
Cs-137	5.46E-08
Np-237	3.96E-06
Pu-238	3.31E-01
Pu-239	1.87E-01
Pu-240	4.56E-02
Pu-241	4.13E-01
Pu-242	4.63E-10
Sr-90	5.46E-08
Th-229	8.06E-08
U-234	5.27E-05
U-235	2.68E-08
U-238	5.08E-08

No Hazardous Waste Numbers Provided

TRUCON Code(s)

116/216, 117/217, 123/223, 125/225, 154

Waste Stream Description

Empty containers identified as TRU resulting from repackaging/remediation of debris waste streams

Waste Stream ID: **RL300-11**

Appendix B

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	300 Area TRU RH Non-Mixed Debris					**Activity Concentrations as of CY**	2001

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Misc	5.7	0.0	5.7
Current Form Total	5.7	0.0	5.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	7.5	0.0	7.5
Final Form Total	7.5	0.0	7.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	87.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	666.12
Cellulosics	21.75
Rubber	0.00
Plastics	5.44
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.35E-01
Am-243	3.33E-01
Cs-137	5.32E+05
Np-237	2.32E-06
Pu-238	8.20E-01
Pu-239	3.22E-01
Pu-240	1.23E-01
Pu-241	5.42E+00
Pu-242	2.17E-04
Sr-90	3.85E+05
Th-232	1.25E-05
U-234	4.64E-05
U-235	7.08E-07
U-236	1.72E-06
U-238	1.25E-05

No Hazardous Waste Numbers Provided

TRUCON Code(s)

325

Waste Stream Description

Typically, drums contain both combustible and noncombustible waste items. Combustible waste may include wood, plastics, paper, and rags. Noncombustible waste items may include metals, glass, concrete, and absorbed liquids. If present, boxes typically contain larger waste items (e.g., whole or sectioned glove boxes, ducting, and process vessels). Both drums and boxes may be used for disposal of high-efficiency particulate air filters.

Waste Stream ID: **RLCH2-08**

Appendix B

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	Tank Farms TRU RH Mixed Debris					**Activity Concentrations as of CY**	2001

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Uncontained	0.0	279.1	279.1
Current Form Total	1.9	279.1	281.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	2.5	279.6	282.0
Final Form Total	2.5	279.6	282.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	3.09
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	374.77
Other Inorganic Materials	7.39
Cellulosics	0.00
Rubber	46.03
Plastics	12.79
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.97E-02
Cs-137	4.45E+00
Pu-238	7.73E-04
Pu-239	4.45E-02
Pu-240	8.61E-03
Sr-90	2.04E+02
U-235	1.74E-05
U-238	4.05E-04

Haz. Waste No(s).

D030, D032, F001, F002, F003, F004, F005

TRUCON Code(s)

325

Waste Stream Description

RH waste- Equipment removed from waste tanks (instrument trees, pumps, circulators, agitators, heaters, sluicers, steam coils, air lances, cameras). The waste stream ranges from contaminated clothing to process equipment contaminated with RCRA constituents.

Waste Stream ID: **RLPFP-10**

Appendix B

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S4000	**Defense Determination**	Defense-Related	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Contaminated Soil/Debris Waste			**Inventory Date**	12/31/2011
Stream Name	PFP RH-TRU Contaminated Soil					**Activity Concentrations as of CY**	2010

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Uncontained	0.0	23.0	23.0
Current Form Total	0.0	23.0	23.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/ Liner	0.0	23.1	23.1
Final Form Total	0.0	23.1	23.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	45.67
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	9.96E-01
Am-243	9.96E-01
Pu-238	9.96E-01
Pu-239	9.96E-01
Pu-240	9.96E-01
Pu-241	9.96E-01
Pu-242	9.96E-01

No Hazardous Waste Numbers Provided

TRUCON Code(s)

311

Waste Stream Description

Soil remediation wastes in PFP Zone.

Waste Stream ID: **RLPRC-01**

Appendix B

Waste Profile Report

Site	Hanford (Richland) Site	**Summary Category**	S5000	**Defense Determination**	Unknown	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CUPRC TRU Mixed Debris					**Activity Concentrations as of CY**	1987

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Current Form Total	1.9	0.0	1.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/ Liner	1.9	0.0	1.9
Final Form Total	1.9	0.0	1.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	46.45
Other Inorganic Materials	661.59
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.20
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.89E-02
Pu-238	1.99E-02
Pu-239	1.82E-01
Pu-240	4.65E-02
Pu-241	1.28E+00
Pu-242	3.11E-06
Th-232	5.50E-05
U-234	6.24E-07
U-235	2.82E-08
U-238	6.06E-07

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

The waste is generated from R&D/R&D Laboratory Waste activities at the CEER University Laboratory.

Waste Stream ID: **RP-TFC001**

Appendix B

Waste Profile Report

Site	Hanford (River Protection) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Bismuth Phosphate Process TRU Solids					**Activity Concentrations as of CY**	2004

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Tank(s)	1200.0	0.0	1200.0
Current Form Total	1200.0	0.0	1200.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	438.7	0.0	438.7
Final Form Total	438.7	0.0	438.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	1.60
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.37E-02
Cs-137	6.11E-01
Np-237	1.22E-05
Pu-238	6.60E-03
Pu-239	5.16E-01
Pu-240	6.23E-02
Pu-241	1.89E-01
Pu-242	3.08E-06
Sr-90	7.98E+00
U-233	1.10E-09
U-234	1.68E-03
U-235	5.42E-05
U-236	1.62E-05
U-238	1.24E-03

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D028, D029, D030, D033, D034, D035, D036, D038, D039, D040, D041, D043, F001, F002, F003, F004, F005

No TRUCON Codes Provided

Waste Stream Description

Solidified aqueous waste slurry

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RP-W754**

Appendix B

Waste Profile Report

Site	Hanford (River Protection) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	224 Waste					**Activity Concentrations as of CY**	2004

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Tank(s)	1079.0	0.0	1079.0
Current Form Total	1079.0	0.0	1079.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	323.2	0.0	323.2
Final Form Total	323.2	0.0	323.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	1.60
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.20E-01
Cs-137	1.66E-01
Np-237	1.62E-06
Pu-238	1.11E-02
Pu-239	1.55E+00
Pu-240	1.29E-01
Pu-241	2.16E-01
Pu-242	4.91E-06
Sr-90	3.36E+00
U-233	1.24E-10
U-234	1.79E-04
U-235	7.25E-06
U-236	1.75E-06
U-238	1.64E-04

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D028, D029, D030, D033, D034, D035, D036, D038, D039, D040, D041, D043, F001, F002, F003, F004, F005

No TRUCON Codes Provided

Waste Stream Description

Solidified aqueous waste slurry.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **RP-W755**

Appendix B
Waste Profile Report

Site	Hanford (River Protection) Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	Bismuth Phosphate Process TRU Solids					**Activity Concentrations as of CY**	2004

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Tank(s)	3090.0	0.0	3090.0
Current Form Total	3090.0	0.0	3090.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	793.5	0.0	793.5
Final Form Total	793.5	0.0	793.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	1.60
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.41E-01
Cs-137	3.32E-01
Np-237	8.04E-05
Pu-238	2.97E-03
Pu-239	5.40E-01
Pu-240	4.38E-02
Pu-241	6.82E-02
Pu-242	5.51E-07
Sr-90	1.20E+01
U-233	3.11E-09
U-234	3.61E-03
U-235	1.60E-04
U-236	2.90E-05
U-238	3.67E-03

Haz. Waste No(s).

D004, D005, D006, D007, D008, D009, D010, D011, D018, D019, D022, D028, D029, D030, D033, D034, D035, D036, D038, D039, D040, D041, D043, F001, F002, F003, F004, F005

No TRUCON Codes Provided

Waste Stream Description

Solidified aqueous waste slurry

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-T001-WSB-1**

Appendix B

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S3000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Materials Production/Recovery Effluents	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	N/A					**Activity Concentrations as of CY**	2015

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.0	4556.2	4556.2
Current Form Total	0.0	4556.2	4556.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.0	4512.8	4512.8
Final Form Total	0.0	4512.8	4512.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	2.99E+02
Pu-238	6.77E-03
Pu-239	4.44E-02
Pu-240	1.69E-02
Pu-241	8.17E+00
U-234	1.32E-03
U-235	4.25E-05
U-236	6.83E-07
U-238	3.84E-07

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225

Waste Stream Description

This waste stream is defense related, contact handled TRU and is a neutralized aqueous stream solidified in an inorganic matrix.

Waste Stream ID: **SR-W027-773A-HET-CLAS**

Appendix B

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	R&D/R&D Laboratory Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH TRU - Sensitive waste from 773A					**Activity Concentrations as of CY**	1990

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	0.4	0.0	0.4
Box - Steel	10.1	0.0	10.1
SWB Dir Ld w/o Liner	5.4	0.0	5.4
Current Form Total	15.9	0.0	15.9

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/o Liner	17.0	0.0	17.0
SWB w/ 4 - 55-gal Drums w/ Liners	1.9	0.0	1.9
Final Form Total	18.9	0.0	18.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	162.00
Aluminum-based Metal/Alloys	7.74
Other Metal/Alloys	20.12
Other Inorganic Materials	79.97
Cellulosics	47.46
Rubber	27.86
Plastics	169.74
Cement	0.00
Solidified Inorganic Material	0.52
Solidified Organic Material	0.52
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	1.63
Packaging Material, Rubber	0.22
Packaging Material, Steel	159.21
Packaging Material, Lead	0.00

No Final Form Radionuclides Provided

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

This waste stream is defense related, contact handled TRU waste and is composed of metal equipment and debris

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **SR-W027-UNK**

Appendix B

Waste Profile Report

Site	Savannah River Site	**Summary Category**	S5000	**Defense Determination**	Defense-Related	**Handling**	CH
Source Cat.	Source Unknown	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	SRS "Generating Source Unknown" TRU Waste					**Activity Concentrations as of CY**	N/A

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	2.5	0.0	2.5
Box - Concrete	9.5	0.0	9.5
Box - SRS B-25 OP	3.6	0.0	3.6
Box - Steel	20.6	0.0	20.6
Current Form Total	36.2	0.0	36.2

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	2.5	0.0	2.5
SWB Dir Ld w/o Liner	34.0	0.0	34.0
Final Form Total	36.5	0.0	36.5

Waste Material Parameters

Material Parameter	**Average Density (kg/m^3)**
Iron-based Metal/Alloys	168.13
Aluminum-based Metal/Alloys	8.03
Other Metal/Alloys	20.88
Other Inorganic Materials	82.99
Cellulosics	49.26
Rubber	28.91
Plastics	176.16
Cement	0.00
Solidified Inorganic Material	0.54
Solidified Organic Material	0.54
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.22
Packaging Material, Steel	151.89
Packaging Material, Lead	0.00

No Final Form Radionuclides Provided

No Hazardous Waste Numbers Provided

TRUCON Code(s)

125/225, 154

Waste Stream Description

This waste stream consists of legacy plutonium contaminated debris from SRS facilities. The unique identification for these waste containers has been lost. Thus, knowledge of the generation source that would allow the waste to be placed in the proper waste stream is not known at this time. Some waste may be remote handled.

Waste Stream ID: **WV-M010a**

Appendix B

Waste Profile Report

Site	West Valley Demonstration Project	**Summary Category**	S3000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Solidified Organics			**Inventory Date**	12/31/2011
Stream Name	TRU Spent Absorbents CH					**Activity Concentrations as of CY**	2008

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Misc	17.5	0.0	17.5
Current Form Total	17.5	0.0	17.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
SWB Dir Ld w/o Liner	9.5	0.0	9.5
Final Form Total	9.5	0.0	9.5

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	249.74
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.19
Packaging Material, Steel	153.44
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	5.61E-02
Am-243	3.15E-03
Cs-137	8.09E-03
Np-237	4.88E-07
Pu-238	1.83E-02
Pu-239	2.28E-02
Pu-240	1.74E-02
Pu-241	2.44E-01
Pu-242	4.83E-04
Sr-90	7.11E-03
Th-230	4.10E-06
Th-232	2.87E-04
U-233	1.84E-04
U-234	8.79E-05
U-235	2.26E-05
U-236	6.79E-05
U-238	1.09E-04

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream consists of spent absorbents (not cement) generated from site operations. The media absorbed is an organic liquid for this waste stream. This does not contain hazardous waste.

Waste Stream ID: **WV-T004**

Appendix B

Waste Profile Report

Site	West Valley Demonstration Project	**Summary Category**	S3000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Solidified Inorganics			**Inventory Date**	12/31/2011
Stream Name	TRU Liquids					**Activity Concentrations as of CY**	2004

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/ Liner	3.3	0.0	3.3
Current Form Total	3.3	0.0	3.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	3.3	0.0	3.3
Final Form Total	3.3	0.0	3.3

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	0.00
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	1000.60
Solidified Inorganic Material	250.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.42E-01
Am-243	1.08E-02
Cm-244	1.50E-02
Cs-137	2.27E-05
Pu-238	2.74E-01
Pu-239	1.08E-01
Pu-240	8.27E-02
Pu-241	3.45E+00
Pu-242	3.02E-04
Sr-90	2.63E-04
Th-230	1.52E-07
Th-232	2.34E-09
U-233	1.00E-04
U-234	4.71E-05
U-235	5.58E-06
U-236	1.67E-05
U-238	4.17E-05

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream consists of liquid waste with associated fissile material generated from previous decontamination and decommissioning activities.

Waste Stream ID: **WV-T006a**

Appendix B

Waste Profile Report

Site	West Valley Demonstration Project	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH TRU General Waste					**Activity Concentrations as of CY**	2006

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	93.2	0.0	93.2
Box - Misc	189.6	0.0	189.6
Uncontained	0.0	175.0	175.0
Current Form Total	282.8	175.0	457.8

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	95.3	36.8	132.1
SWB Dir Ld w/o Liner	51.0	141.8	192.8
Final Form Total	146.3	178.6	324.9

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	277.61
Other Inorganic Materials	555.22
Cellulosics	0.00
Rubber	111.04
Plastics	166.57
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.34
Packaging Material, Steel	144.22
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	4.82E+00
Am-243	3.65E-01
Cm-244	5.10E-01
Cs-137	8.79E-03
Pu-238	9.29E+00
Pu-239	3.66E+00
Pu-240	2.80E+00
Pu-241	1.17E+02
Pu-242	1.03E-02
Sr-90	1.02E-01
Th-230	5.89E-05
Th-232	9.05E-07
U-233	2.93E-04
U-234	1.38E-04
U-235	1.63E-05
U-236	4.90E-05
U-238	1.22E-04

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream consists of radiologically contaminated solid waste generated from various site activities. The specific contents include but are not limited to Anti-C clothing, hoses, glovebags, tools, pre-filters, HEPA filters, Roughing filters, other filters, sweeping compound, glove boxes, tools, evaporators, dissolver tanks, condensers, piping DAW, plastic bags, bottles, and cell floor debris etc.

Waste Stream ID: **WV-T006b**

Appendix B

Waste Profile Report

Site	West Valley Demonstration Project	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU General Waste					**Activity Concentrations as of CY**	2004

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	75.9	0.0	75.9
Box - Misc	424.8	0.0	424.8
Uncontained	0.0	88.0	88.0
Current Form Total	500.7	88.0	588.7

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	308.9	46.2	355.1
Final Form Total	308.9	46.2	355.1

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	204.93
Other Inorganic Materials	409.87
Cellulosics	0.00
Rubber	81.97
Plastics	122.96
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.59E+00
Cm-244	2.98E-01
Cs-137	1.04E+02
Np-237	2.24E-02
Pu-238	2.80E+00
Pu-239	2.17E+00
Pu-240	1.65E+00
Pu-241	4.87E+01
Sr-90	1.22E+02
Th-232	3.44E-04
U-233	1.31E-02
U-234	6.27E-03
U-235	1.19E-03
U-236	3.58E-03
U-238	4.06E-03

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream consists of radiologically contaminated solid waste generated from various site activities. The specific contents include but are not limited to Anti-C clothing, hoses, glovebags, tools, pre-filters, HEPA filters, Roughing filters, other filters, sweeping compound, glove boxes, tools, evaporators, dissolver tanks, condensers, piping DAW, plastic bags, bottles, and cell floor debris etc.

Waste Stream ID: **WV-T017b**

Appendix B

Waste Profile Report

Site	West Valley Demonstration Project	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU Spent Filter Media					**Activity Concentrations as of CY**	2008

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Box - Misc	39.3	0.0	39.3
Current Form Total	39.3	0.0	39.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	23.7	0.0	23.7
Final Form Total	23.7	0.0	23.7

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	356.36
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	8.18E-02
Cs-137	3.06E+01
Np-237	1.12E-04
Pu-238	2.56E-02
Pu-239	4.92E-02
Pu-240	3.75E-02
Pu-241	4.59E-01
Sr-90	3.58E-01
Th-230	3.03E-05
Th-232	3.79E-05
U-235	1.39E-04
U-236	4.19E-04
U-238	2.19E-04

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

This waste stream consists of spent filter media generated from filtration of the Fuel Receiving & Storage pool where radiologically contaminated equipment was stored.

Waste Stream ID: **WV-W024a**

Appendix B

Waste Profile Report

Site	West Valley Demonstration Project	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	CH TRU Mixed Waste					**Activity Concentrations as of CY**	2006

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	2.7	0.0	2.7
Box - Misc	53.8	0.0	53.8
Current Form Total	56.5	0.0	56.5

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	2.7	0.0	2.7
SWB Dir Ld w/o Liner	26.5	0.0	26.5
Final Form Total	29.2	0.0	29.2

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	250.31
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.23
Packaging Material, Steel	151.34
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	1.42E-01
Am-243	1.08E-02
Cm-244	1.51E-02
Cs-137	2.27E-05
Pu-238	2.74E-01
Pu-239	1.08E-01
Pu-240	8.28E-02
Pu-241	3.46E+00
Pu-242	3.03E-04
Sr-90	2.63E-04
Th-230	1.52E-07
Th-232	2.34E-09
U-233	1.00E-04
U-234	4.72E-05
U-235	5.58E-06
U-236	1.68E-05
U-238	4.18E-05

Haz. Waste No(s).

D006, D007, D008, D009, D010

No TRUCON Codes Provided

Waste Stream Description

Contains hazardous constituents from D&D activities and Laboratory Waste generated onsite in solid forms such as filters, vacuum cans, glove box debris, piping, hoses, pumps, anti C clothing, bags, wipes, and floor debris. If any liquids are found, then the liquid would be solidified and not expected to be TRU.

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

Waste Stream ID: **WV-W024b**

Appendix B

Waste Profile Report

Site	West Valley Demonstration Project	**Summary Category**	S5000	**Defense Determination**	Pending Determination	**Handling**	RH
Source Cat.	Remediation/D&D Waste	**Waste Matrix Code Group**	Heterogeneous Debris Waste			**Inventory Date**	12/31/2011
Stream Name	RH TRU Mixed Waste					**Activity Concentrations as of CY**	2004

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	20.2	0.0	20.2
Box - Misc	131.1	0.0	131.1
Current Form Total	151.3	0.0	151.3

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
RH Can w/ Remov Lid w/ 3 - 55-gal w/o Liner	94.8	0.0	94.8
Final Form Total	94.8	0.0	94.8

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	356.62
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	8.70
Packaging Material, Rubber	0.57
Packaging Material, Steel	931.09
Packaging Material, Lead	0.00

Final Form Radionuclides

Isotope	Typical Concentration (Ci/m^3)
Am-241	7.29E+01
Am-243	4.44E+00
Cm-244	9.01E-01
Cs-137	3.13E+02
Np-237	6.66E-02
Pu-238	1.04E+01
Pu-239	7.93E+01
Pu-240	6.02E+01
Pu-241	4.02E+02
Pu-242	2.00E-01
Sr-90	3.76E+02
Th-229	3.81E-03
Th-230	1.40E-03
Th-232	1.01E-03
U-233	1.68E-01
U-234	7.93E-02
U-235	1.33E-02
U-236	4.12E-02
U-238	4.12E-02

Haz. Waste No(s).

D006, D007, D008, D009, D010

No TRUCON Codes Provided

Waste Stream Description

Contains hazardous constituents from D&D activities and Laboratory Waste generated onsite in solid forms such as filters, vacuum cans, glove box debris, piping, hoses, pumps, anti C clothing, bags, wipes, and floor debris. If any liquids are found, then the liquid would be solidified and not expected to be TRU.

Waste Stream ID: **WV-Z001**

Appendix B

Waste Profile Report

Site	West Valley Demonstration Project	**Summary Category**	S9000	**Defense Determination**	Pending Determination	**Handling**	CH
Source Cat.	Facility/Equipment Operation and Maintenance Waste	**Waste Matrix Code Group**	Prohibited Waste			**Inventory Date**	12/31/2011
Stream Name	West Valley Buried TRU Waste					**Activity Concentrations as of CY**	N/A

Waste Volume Detail (m^3)

Current Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
Uncontained	0.0	1353.0	1353.0
Current Form Total	0.0	1353.0	1353.0

Final Form Volumes			
Container Type	**Stored**	**Proj.**	**Total**
55-gal Drum Dir Ld w/o Liner	0.0	1353.0	1353.0
Final Form Total	0.0	1353.0	1353.0

Waste Material Parameters

Material Parameter	Average Density (kg/m^3)
Iron-based Metal/Alloys	0.00
Aluminum-based Metal/Alloys	0.00
Other Metal/Alloys	0.00
Other Inorganic Materials	249.99
Cellulosics	0.00
Rubber	0.00
Plastics	0.00
Cement	0.00
Solidified Inorganic Material	0.00
Solidified Organic Material	0.00
Soils	0.00
Vitrified	0.00
Packaging Material, Cellulosics	0.00
Packaging Material, Plastic	0.00
Packaging Material, Rubber	0.57
Packaging Material, Steel	130.77
Packaging Material, Lead	0.00

No Final Form Radionuclides Provided

No Hazardous Waste Numbers Provided

No TRUCON Codes Provided

Waste Stream Description

Debris waste buried on-site during original plant processing operations

Comprehensive Inventory Database ver. ***2.01*** *Data ver.* ***D.11.00***

NOTE: Actual numerical values have been rounded for presentation purposes

APPENDIX C HISTORIC CROSSWALK OF WASTE STREAMS

From one release of the ATWIR report to the next, waste streams may undergo reorganization by the TRU waste sites. Waste streams may be renamed, divided, consolidated, created, or removed from the inventory altogether (i.e., shipped to WIPP or reclassified as LLW). This appendix contains a crosswalk that maps current ATWIR-2012 TRU waste site waste streams to the ATWIR-2011 TRU waste site waste streams. This appendix does not include any emplaced waste at the WIPP.

Table C-1 displays the correlation of each ATWIR-2012 waste stream to its respective ATWIR-2011 waste stream(s). Waste streams that are newly reported in the ATWIR-2012 and that do not map to a previous waste stream from ATWIR-2011 are indicated as "*New Waste Stream*."

Table C-2 shows the inverse of Table C-1. Table C-2 displays the correlation of each ATWIR-2011 waste stream to its respective ATWIR-2012 waste stream(s). Waste streams that were previously reported in the ATWIR-2011 and that do not map to a current ATWIR-2012 waste stream are indicated as "*Deleted Waste Stream*" along with a reason for the deletion, if available.

Site Code and Site Name:

AE Argonne National Laboratory - East
AW Material and Fuels Complex
BL Babcock and Wilcox Nuclear Energy Services
BT Bettis Atomic Power Laboratory
IN Idaho National Laboratory
KA Knolls Atomic Power Laboratory - Schenectady
KN Knolls Atomic Power Laboratory - Nuclear Fuel Services
LA Los Alamos National Laboratory
LB Lawrence Berkeley National Laboratory
LL Lawrence Livermore National Laboratory
MC U.S. Army Materiel Command
ND Nuclear Radiation Development Site
NT Nevada National Security Site
OR Oak Ridge National Laboratory
PA Paducah Gaseous Diffusion Plant
RL Hanford (Richland) Site
RP Hanford (River Protection) Site
SA Sandia National Laboratories
SR Savannah River Site
WV West Valley Demonstration Project

Table C-1. Crosswalk of ATWIR-2012 to ATWIR-2011 Waste Streams

Site Code	ATWIR-2012 Waste Streams	ATWIR-2011 Waste Streams
AE	AE-T001	AE-T001
AE	AE-T003	AE-T003
AE	AE-T009	AE-T009
AW	AW-5410N	*New Waste Stream*
AW	AW-5649N	*New Waste Stream*
AW	AW-5882N	*New Waste Stream*
AW	AW-IN-TRA-BE-01	AW-IN-TRA-BE-01
AW	AW-N027.531	AW-N027.531
AW	AW-T031.1322	AW-T031.1322
AW	AW-T033.1325	AW-T033.1325
AW	AW-W018	AW-W018
AW	AW-W019	AW-W019
AW	AW-W020.13	AW-W020.13
BL	BL-Parks	BL-Parks
BL	BL-Parks-A	BL-Parks-A
BT	BT-T001	BT-T001
IN	IN-AE-AGHC-02	IN-AE-AGHC-02
IN	IN-AE-AGHC-02T	IN-AE-AGHC-02
IN	IN-AECHDM-PK	AE-T001
IN	IN-BN004	IN-BN004
IN	IN-BN050	IN-BN050
IN	IN-BN090	IN-BN090
IN	IN-BN095	IN-BN095
IN	IN-BN203	IN-BN203
IN	IN-BN204	IN-BN204
IN	IN-BN222	IN-BN222
IN	IN-BN290	IN-BN290
IN	IN-BN311	IN-BN311
IN	IN-BN375	IN-BN375
IN	IN-BN409	IN-BN409
IN	IN-BN421	IN-BN421
IN	IN-BN425	IN-BN425
IN	IN-BN430	IN-BN430
IN	IN-BN431	IN-BN431
IN	IN-BN432	IN-BN432, IN-W317R
IN	IN-BN510	IN-BN510
IN	IN-BN510.1	IN-BN510.1, IN-W169R, IN-W197R, IN-W198R, IN-W208R, IN-W243R, IN-W245R, IN-W247R, IN-W252R, IN-W254R, IN-W294R, IN-W296R, IN-W298R, IN-W364R, IN-W365R

Table C-1. Crosswalk of ATWIR-2012 to ATWIR-2011 Waste Streams
Continued

Site Code	ATWIR-2012 Waste Streams	ATWIR-2011 Waste Streams
IN	IN-BN600	*New Waste Stream*
IN	IN-BN806	IN-BN806
IN	IN-BN811	IN-BN811
IN	IN-BN817	IN-BN817
IN	IN-BN823	IN-BN823
IN	IN-BN835	IN-BN835
IN	IN-BN836	IN-BN836
IN	IN-BN842	IN-BN842
IN	IN-BN976	IN-BN976
IN	IN-BN978	IN-BN978
IN	IN-BNINW216	IN-BNINW216, IN-W216R, IN-W228R
IN	IN-BNINW218	IN-BNINW218
IN	IN-ID-BTO-030	IN-ID-BTO-030
IN	IN-ID-EBR-S5000	IN-ID-EBR-S5000
IN	IN-ID-INL-152	IN-ID-INL-152
IN	IN-ID-INL-152M	IN-ID-INL-152M
IN	IN-ID-MFC-S5400	*New Waste Stream*
IN	IN-ID-MFC-SOLID	IN-ID-MFC-SOLID
IN	IN-ID-RF-S3114	IN-ID-RF-S3114
IN	IN-ID-RF-S3150-A	IN-ID-RF-S3150-A
IN	IN-ID-RF-S5126	IN-ID-RF-S5126
IN	IN-ID-RF-S5300-A	IN-ID-RF-S5300-A
IN	IN-ID-SA-T001	IN-ID-SA-T001
IN	IN-ID-SDA-Debris	IN-ID-SDA-Debris
IN	IN-ID-SDA-Sludge	IN-ID-SDA-Sludge
IN	IN-ID-SDA-Soil	IN-ID-SDA-Soil
IN	IN-ID-SNL-HCF-S5400	IN-ID-SNL-HCF-S5400
IN	IN-JH826CH	*New Waste Stream*
IN	IN-MFC-S5490	IN-MFC-S5490
IN	IN-NRF-SPC	IN-NRF-SPC
IN	IN-NRF-SPC-103	IN-NRF-SPC-103
IN	IN-SBW-01A	IN-SBW-01A
IN	IN-SBW-01B	IN-SBW-01B
IN	IN-W139	*New Waste Stream*
IN	IN-W170	IN-W170
IN	IN-W171	IN-W171
IN	IN-W259	IN-W259
IN	IN-W269	IN-W269
IN	IN-W283	IN-W283, IN-W283R
IN	IN-W287	IN-W287
IN	IN-W322	IN-W322

Table C-1. Crosswalk of ATWIR-2012 to ATWIR-2011 Waste Streams
Continued

Site Code	ATWIR-2012 Waste Streams	ATWIR-2011 Waste Streams
IN	IN-W323	IN-W323
IN	IN-W337	IN-W337
IN	IN-W338	IN-W338
IN	IN-W339	IN-W339
IN	IN-W342R	IN-W342R
IN	IN-W345	IN-W345
IN	IN-W347	IN-W347
IN	IN-W350	IN-W350
IN	IN-W351	IN-W351
IN	IN-W358	IN-W358
IN	IN-W359R	IN-W359R
IN	IN-W360	IN-W360R
KA	KA-T001	KA-T001
KA	KA-W016	KA-W016
KN	KN-B234TRU	KN-B234TRU
LA	LA-CIN01.001	LA-CIN01.001
LA	LA-CIN02.001	LA-CIN02.001, LA-TA-50-18
LA	LA-CIN03.001	LA-CIN03.001
LA	LA-LAMHD02238	*New Waste Stream*
LA	LA-LAMHD04001	*New Waste Stream*
LA	LA-LAMIN04S	LA-LAMIN04S
LA	LA-LAMSG04001	*New Waste Stream*
LA	LA-LANHD01	LA-LANHD01
LA	LA-LANHD02238	LA-LANHD02238
LA	LA-LANIN03NC	LA-LANIN03NC
LA	LA-MHD01.001	LA-MHD01.001, LA-TA-55-19, LA-TA-55-30
LA	LA-MHD03.001	LA-MHD03.001, LA-TA-03-40, LA-TA-03-42
LA	LA-MHD04.001	LA-MHD04.001
LA	LA-MHD05-ITRI.001	LA-MHD05-ITRI.001
LA	LA-MHD08.001	LA-MHD08.001
LA	LA-MHD09.001	LA-MHD09.001
LA	LA-MIN02-V.001	LA-MIN02-V.001
LA	LA-MIN03-NC.001	LA-MIN03-NC.001
LA	LA-MIN04-S.001	LA-MHD01.001, LA-MIN04-S.001
LA	LA-MSG04.001	LA-MSG04.001
LA	LA-OS-00-01.001	LA-OS-00-01.001
LA	LA-OS-00-04	*New Waste Stream*
LA	LA-TA-00-01	LA-TA-00-01
LA	LA-TA-00-03	LA-TA-00-03
LA	LA-TA-00-04	LA-TA-00-04
LA	LA-TA-03-01	LA-TA-03-01

Table C-1. Crosswalk of ATWIR-2012 to ATWIR-2011 Waste Streams
Continued

Site Code	ATWIR-2012 Waste Streams	ATWIR-2011 Waste Streams
LA	LA-TA-03-09	*New Waste Stream*
LA	LA-TA-03-10	LA-TA-03-10
LA	LA-TA-03-12	LA-TA-03-12
LA	LA-TA-03-14	LA-TA-03-14
LA	LA-TA-03-17	LA-TA-03-17
LA	LA-TA-03-21	LA-TA-03-21
LA	LA-TA-03-23	LA-TA-03-23
LA	LA-TA-03-27	LA-TA-03-27
LA	LA-TA-03-28	LA-TA-03-28
LA	LA-TA-03-30	LA-TA-03-30
LA	LA-TA-03-33	LA-TA-03-33
LA	LA-TA-03-34	LA-TA-03-34
LA	LA-TA-03-42	LA-TA-03-42
LA	LA-TA-21-01	*New Waste Stream*
LA	LA-TA-21-05	LA-TA-21-05
LA	LA-TA-21-06	LA-TA-21-06
LA	LA-TA-21-07	LA-TA-21-07
LA	LA-TA-21-08	LA-TA-21-08
LA	LA-TA-21-09	LA-TA-21-09
LA	LA-TA-21-11	LA-TA-21-11
LA	LA-TA-21-12	LA-TA-21-12
LA	LA-TA-21-13	LA-TA-21-13
LA	LA-TA-21-15	LA-TA-21-15
LA	LA-TA-21-16	LA-TA-21-16
LA	LA-TA-21-17	LA-TA-21-17
LA	LA-TA-50-12	LA-TA-50-12
LA	LA-TA-50-15	LA-TA-50-15
LA	LA-TA-50-18	LA-TA-50-18
LA	LA-TA-50-19	LA-TA-50-19
LA	LA-TA-50-20	LA-TA-50-20
LA	LA-TA-55-14	*New Waste Stream*
LA	LA-TA-55-19	LA-TA-55-19
LA	LA-TA-55-21	LA-TA-55-21
LA	LA-TA-55-30	LA-TA-55-30
LA	LA-TA-55-32	LA-TA-55-32
LA	LA-TA-55-38	LA-TA-55-38
LA	LA-TRU-Empty	LA-TRU-Empty
LB	LB-T001	LB-T001
LB	LB-T002	LB-T002
LL	LL-M001	LL-M001
LL	LL-T004	LL-T004

Table C-1. Crosswalk of ATWIR-2012 to ATWIR-2011 Waste Streams
Continued

Site Code	ATWIR-2012 Waste Streams	ATWIR-2011 Waste Streams
LL	LL-W018-S5100	LL-W018-S5100
LL	LL-W018-SS	LL-W018-SS
LL	LL-W019	LL-W019
ND	ND-T001	ND-T001
ND	ND-T002	ND-T002
NT	NT-JAS-01	NT-JAS-01
NT	NT-W021	NT-W021
OR	OR-CHEM-CH-HET	OR-CHEM-CH-HET
OR	OR-GENR-CH-HET	OR-GENR-CH-HET
OR	OR-GENR-RH-HET	OR-GENR-RH-HET
OR	OR-ISTP-CH-HET	OR-ISTP-CH-HET
OR	OR-ISTP-RH-HET	OR-ISTP-RH-HET
OR	OR-NBL-CH-HET	OR-NBL-CH-HET
OR	OR-NFS-CH-HET	OR-NFS-CH-HET
OR	OR-NFS-CH-HOM	OR-NFS-CH-HOM
OR	OR-NFS-CH-SOIL	OR-NFS-CH-SOIL
OR	OR-PGDP-CH-HET	OR-PGDP-CH-HET
OR	OR-RADP-CH-HET	OR-RADP-CH-HET
OR	OR-RADP-CH-SOILS	OR-RADP-CH-SOILS
OR	OR-RADP-RH-HET	OR-RADP-RH-HET
OR	OR-REDC-CH-HET	OR-REDC-CH-HET
OR	OR-REDC-RH-HET	OR-REDC-RH-HET
OR	OR-RF-CH-HET	OR-RF-CH-HET
OR	OR-RF-CH-HOM	OR-RF-CH-HOM
OR	OR-RF-RH-HET	OR-RF-RH-HET
OR	OR-SWSA-CH-HET	OR-TBD-CH-HET
OR	OR-SWSA-CH-SOIL	OR-RADP-CH-SOILS
OR	OR-TBD-CH-HET	OR-TBD-CH-HET
OR	OR-TBD-RH-HET	OR-TBD-RH-HET
OR	OR-W203	OR-W203
OR	OR-W213-RH-SOILS	OR-W213-RH-SOILS
OR	OR-WSTR-CH-HET	OR-WSTR-CH-HET
OR	OR-Y12-CH-HET	OR-Y12-CH-HET
RL	RL105-01	RL105-01
RL	RL105-03	RL105-03
RL	RL105-08	RL105-08
RL	RL105-09	RL105-09
RL	RL200-01	RL200-01
RL	RL200-02	RL200-02, RLPFP-02
RL	RL201-03	RL201-03
RL	RL202S-01	RL202S-01

Table C-1. Crosswalk of ATWIR-2012 to ATWIR-2011 Waste Streams
Continued

Site Code	ATWIR-2012 Waste Streams	ATWIR-2011 Waste Streams
RL	RL209E-01	RL209E-01
RL	RL209E-08	RL209E-08
RL	RL216Z-02	RL216Z-02
RL	RL221T-01	RL221T-01
RL	RL221U-03	RL221U-01
RL	RL221U-09	RL221U-09
RL	RL222S-01	RL222S-01
RL	RL222S-08	RL222S-08
RL	RL231Z-01	RL231Z-01
RL	RL231Z-03	RL231Z-03
RL	RL233S-01	RL233S-01
RL	RL233S-03	RL233S-03
RL	RL300-01	RL300-01
RL	RL300-03	RL300-03
RL	RL300-08	RL300-08
RL	RL300-11	RL300-11
RL	RL308-01	RL308-01
RL	RL308-03	RL308-01
RL	RL308-08	RL308-08
RL	RL325-01	RL325-01
RL	RL325-03	RL325-03
RL	RL325-08	RL325-08
RL	RL618-01	RL618-01
RL	RL618-08	RL618-08
RL	RLALE-02	RL325-02
RL	RLARG-01	RLARG-01
RL	RLBART-08	RLBART-08
RL	RLBAT-01	RLBAT-01
RL	RLBAT-08	RLBAT-08
RL	RLBET-08	RLBET-08
RL	RLBW-01	RLBW-01
RL	RLBW-03	RLBW-03
RL	RLBW-08	RLBW-08
RL	RLCFF-01	RLCFF-01
RL	RLCFF-03	RLCFF-03
RL	RLCH2-01	RLCH2-01
RL	RLCH2-08	RLCH2-08
RL	RLESG-01	RLESG-01
RL	RLESG-03	RLESG-01
RL	RLESG-08	RLESG-08
RL	RLEXX-01	RLEXX-01

Table C-1. Crosswalk of ATWIR-2012 to ATWIR-2011 Waste Streams
Continued

Site Code	ATWIR-2012 Waste Streams	ATWIR-2011 Waste Streams
RL	RLFFTF-01	RLFFTF-01
RL	RLFFTF-08	RLFFTF-08
RL	RLGEV-01	RLGEV-01
RL	RLGEV-03	RLGEV-03
RL	RLGEV-08	RLGEV-08
RL	RLHAN-01	RLHAN-01
RL	RLHAN-08	RLHAN-08
RL	RLIAEA-03	RLIAEA-01
RL	RLMLB-08	RLMLB-08
RL	RLMLL-01	RLMLL-01
RL	RLP11-01	*New Waste Stream*
RL	RLPFP-01	RLPFP-01
RL	RLPFP-03	RLPFP-03
RL	RLPFP-04	RLPFP-04
RL	RLPFP-08	RLPFP-08
RL	RLPFP-10	RLPFP-10
RL	RLPRC-01	RLPRC-01
RL	RLPURX-01	RLPURX-01
RL	RLPURX-08	RLPURX-08
RL	RLRFET-01	RLRFET-01
RL	RLSAN-01	RLSAN-01
RL	RLSWO-01	RLSWO-01, RLSWO-08
RL	RLWAR-01	RLWAR-01
RL	RLWAR-03	RLWAR-03
RL	RLWTP-08	RLWTP-08
RP	RP-TFC001	RP-TFC001
RP	RP-W754	RP-W754
RP	RP-W755	RP-W755
SA	SA-W135	SA-W135
SA	SA-W136	SA-W136
SA	SA-W137	*New Waste Stream*
SA	SA-W138M	*New Waste Stream*
SR	SR-221H-PuOx	*New Waste Stream*
SR	SR-AGNS-HET	SR-AGNS-HET
SR	SR-AGNS-HOM	SR-AGNS-HOM
SR	SR-BCLDP-HET	SR-BCLDP-HET
SR	SR-BCLDP.003.001	*New Waste Stream*
SR	SR-BCLDP.004.004	*New Waste Stream*
SR	SR-KAC-HET	SR-KAC-HET
SR	SR-LA-PAD1	SR-LA-PAD1
SR	SR-MD-HET	SR-MD-HET

Table C-1. Crosswalk of ATWIR-2012 to ATWIR-2011 Waste Streams
Continued

Site Code	ATWIR-2012 Waste Streams	ATWIR-2011 Waste Streams
SR	SR-MD-HOM-C	SR-MD-HOM-C
SR	SR-MD-PAD1	SR-MD-PAD1
SR	SR-MD-SOIL	SR-MD-SOIL
SR	SR-NIST-HET	SR-NIST-HET
SR	SR-RH-221H.01	SR-RH-221H.01
SR	SR-RH-221H.02	SR-RH-221H.02
SR	SR-RH-235F.01	SR-RH-235F.01
SR	SR-RH-772F.01	SR-RH-772F.01
SR	SR-RH-773A.01	SR-RH-773A.01
SR	SR-RH-FBL.01	SR-RH-FBL.01
SR	SR-RH-MNDPAD1.01	SR-RH-MNDPAD1.01
SR	SR-RH-SDD.01	SR-RH-SDD.01
SR	SR-RH-SWD.01	SR-RH-SWD.01
SR	SR-SDD-HET-A	SR-SDD-HET-A
SR	SR-SDD-HET-B	SR-SDD-HET-B
SR	SR-SDD-HOM-A	SR-SDD-HOM-A
SR	SR-SDD-HOM-B	SR-SDD-HOM-B, SR-SDD-HOM-C
SR	SR-SWMF-HET-A	SR-SWMF-HET-A
SR	SR-SWMF-HET-B	SR-W027-643G-HET
SR	SR-SWMF-SOIL	SR-SWMF-SOIL
SR	SR-T001-WSB-1	SR-T001-WSB-1
SR	SR-W026-221F-HEPA	SR-W026-221F-HEPA
SR	SR-W026-221F-HET	SR-W026-221F-HET
SR	SR-W026-221F-HET-A	SR-W026-221F-HET-A
SR	SR-W026-221F-HOM	SR-W026-221F-HOM
SR	SR-W026-772F-HET	SR-W026-772F-HET
SR	SR-W026-DWPF-HET	SR-W026-DWPF-HET
SR	SR-W026-MFFF-1	SR-W026-MFFF-1
SR	SR-W026-WSB-2	SR-W026-WSB-2
SR	SR-W027-221F-HET-A	SR-W027-221F-HET-A, SR-W027-221F-HET-C-D, SR-W027-221F-HET-E
SR	SR-W027-221H-HEPA	SR-W027-221H-HEPA
SR	SR-W027-221H-HET	SR-W027-221H-HET
SR	SR-W027-221H-HET-C	SR-W027-221H-HET-B, SR-W027-221H-HET-C
SR	SR-W027-221H-HOM	SR-W027-221H-HOM
SR	SR-W027-235F-HEPA	SR-W027-235F-HEPA
SR	SR-W027-235F-HET	SR-W027-235F-HET
SR	SR-W027-235F-HOM	SR-W027-235F-HOM
SR	SR-W027-235F/221H-HET	SR-HBL-235F-HET

Table C-1. Crosswalk of ATWIR-2012 to ATWIR-2011 Waste Streams
Continued

Site Code	ATWIR-2012 Waste Streams	ATWIR-2011 Waste Streams
SR	SR-W027-321-322M-HET	SR-W027-321-322M-HET
SR	SR-W027-321M-HOM	SR-W027-321-322M-HET
SR	SR-W027-773A-HET	SR-W027-773A-HEPA, SR-W027-773A-HET
SR	SR-W027-773A-HET-CLAS	SR-W027-773A-HET-CLAS
SR	SR-W027-773A-HOM	*New Waste Stream*
SR	SR-W027-776A-HET	SR-W027-776A-HET
SR	SR-W027-FB-Pre86-C	SR-W027-FB-Pre86-C
SR	SR-W027-HBL-Box	SR-W027-HBL-Box
SR	SR-W027-UNK	SR-W027-UNK
WV	WV-M010a	WV-M010a
WV	WV-T004	WV-T004
WV	WV-T006a	WV-T006a
WV	WV-T006b	WV-T006b
WV	WV-T017b	WV-T017b
WV	WV-W024a	WV-W024a
WV	WV-W024b	WV-W024b
WV	WV-Z001	WV-Z001

Data Source: CID Data Version D.11.00 LANL-CO 2012. Note: This table contains data for WIPP-bound and potential waste streams only; it does not include data for emplaced waste streams**.**

Table C-2. Crosswalk of ATWIR-2011 to ATWIR-2012 Waste Streams

Site Code	ATWIR-2011 Waste Streams	ATWIR-2012 Waste Streams
AE	AE-T001	AE-T001, IN-AECHDM-PK
AE	AE-T003	AE-T003
AE	AE-T009	AE-T009
AW	AW-IN-TRA-BE-01	AW-IN-TRA-BE-01
AW	AW-N027.531	AW-N027.531
AW	AW-T031.1322	AW-T031.1322
AW	AW-T033.1325	AW-T033.1325
AW	AW-W018	AW-W018
AW	AW-W019	AW-W019
AW	AW-W020.13	AW-W020.13
BL	BL-Parks	BL-Parks
BL	BL-Parks-A	BL-Parks-A
BT	BT-T001	BT-T001
IN	IN-AE-AGHC-02	IN-AE-AGHC-02, IN-AE-AGHC-02T
IN	IN-BN004	IN-BN004
IN	IN-BN005	*Deleted Waste Stream – Determined to be Mixed Low-Level Waste*
IN	IN-BN050	IN-BN050
IN	IN-BN090	IN-BN090
IN	IN-BN095	IN-BN095
IN	IN-BN203	IN-BN203
IN	IN-BN204	IN-BN204
IN	IN-BN222	IN-BN222
IN	IN-BN290	IN-BN290
IN	IN-BN311	IN-BN311
IN	IN-BN375	IN-BN375
IN	IN-BN409	IN-BN409
IN	IN-BN421	IN-BN421
IN	IN-BN425	IN-BN425
IN	IN-BN430	IN-BN430
IN	IN-BN431	IN-BN431
IN	IN-BN432	IN-BN432
IN	IN-BN510	IN-BN510
IN	IN-BN510.1	IN-BN510.1
IN	IN-BN806	IN-BN806
IN	IN-BN811	IN-BN811
IN	IN-BN817	IN-BN817
IN	IN-BN823	IN-BN823
IN	IN-BN835	IN-BN835
IN	IN-BN836	IN-BN836

Table C-2. Crosswalk of ATWIR-2011 to ATWIR-2012 Waste Streams
Continued

Site Code	ATWIR-2011 Waste Streams	ATWIR-2012 Waste Streams
IN	IN-BN842	IN-BN842
IN	IN-BN976	IN-BN976
IN	IN-BN978	IN-BN978
IN	IN-BNINW216	IN-BNINW216
IN	IN-BNINW218	IN-BNINW218
IN	IN-ID-BTO-030	IN-ID-BTO-030
IN	IN-ID-EBR-S5000	IN-ID-EBR-S5000
IN	IN-ID-INL-152	IN-ID-INL-152
IN	IN-ID-INL-152M	IN-ID-INL-152M
IN	IN-ID-MFC-SOLID	IN-ID-MFC-SOLID
IN	IN-ID-RF-S3114	IN-ID-RF-S3114
IN	IN-ID-RF-S3150-A	IN-ID-RF-S3150-A
IN	IN-ID-RF-S5100-A	*Deleted Waste Stream – Shipped to WIPP.*
IN	IN-ID-RF-S5126	IN-ID-RF-S5126
IN	IN-ID-RF-S5300-A	IN-ID-RF-S5300-A
IN	IN-ID-RTC-S5000	*Deleted Waste Stream - Determined to be LLW or MLLW*
IN	IN-ID-SA-T001	IN-ID-SA-T001
IN	IN-ID-SDA-Debris	IN-ID-SDA-Debris
IN	IN-ID-SDA-Sludge	IN-ID-SDA-Sludge
IN	IN-ID-SDA-Soil	IN-ID-SDA-Soil
IN	IN-ID-SNL-HCF-S5400	IN-ID-SNL-HCF-S5400
IN	IN-INTEC-SFS-01	*Deleted Waste Stream - Shipped to WIPP*
IN	IN-LL-M001-S5400	*Deleted Waste Stream - Shipped to WIPP*
IN	IN-LL-T004-S3141	*Deleted Waste Stream - Shipped to WIPP*
IN	IN-LL-W019-S3900	*Deleted Waste Stream - Shipped to WIPP*
IN	IN-MFC-S5490	IN-MFC-S5490
IN	IN-NRF-153	*Deleted Waste Stream - Shipped to WIPP*
IN	IN-NRF-SPC	IN-NRF-SPC
IN	IN-NRF-SPC-103	IN-NRF-SPC-103
IN	IN-SBW-01A	IN-SBW-01A
IN	IN-SBW-01B	IN-SBW-01B
IN	IN-TRA-150	*Deleted Waste Stream - Determined to be LLW or MLLW*
IN	IN-W169R	IN-BN510.1
IN	IN-W170	IN-W170
IN	IN-W171	IN-W171
IN	IN-W197R	IN-BN510.1
IN	IN-W198R	IN-BN510.1
IN	IN-W208R	IN-BN510.1
IN	IN-W216R	IN-BNINW216
IN	IN-W228R	IN-BNINW216
IN	IN-W243R	IN-BN510.1

Table C-2. Crosswalk of ATWIR-2011 to ATWIR-2012 Waste Streams
Continued

Site Code	ATWIR-2011 Waste Streams	ATWIR-2012 Waste Streams
IN	IN-W245R	IN-BN510.1
IN	IN-W247R	IN-BN510.1
IN	IN-W252R	IN-BN510.1
IN	IN-W254R	IN-BN510.1
IN	IN-W259	IN-W259
IN	IN-W269	IN-W269
IN	IN-W283	IN-W283
IN	IN-W283R	IN-W283
IN	IN-W287	IN-W287
IN	IN-W294R	IN-BN510.1
IN	IN-W296R	IN-BN510.1
IN	IN-W298R	IN-BN510.1
IN	IN-W317R	IN-BN432
IN	IN-W322	IN-W322
IN	IN-W323	IN-W323
IN	IN-W337	IN-W337
IN	IN-W338	IN-W338
IN	IN-W339	IN-W339
IN	IN-W342R	IN-W342R
IN	IN-W345	IN-W345
IN	IN-W347	IN-W347
IN	IN-W350	IN-W350
IN	IN-W351	IN-W351
IN	IN-W358	IN-W358
IN	IN-W359R	IN-W359R
IN	IN-W360R	IN-W360
IN	IN-W364R	IN-BN510.1
IN	IN-W365R	IN-BN510.1
KA	KA-T001	KA-T001
KA	KA-W016	KA-W016
KN	KN-B234TRU	KN-B234TRU
KN	KN-B234TRU_SS	*Deleted Waste Stream – Change in process – will not be generated*
LA	LA-CIN01.001	LA-CIN01.001
LA	LA-CIN02.001	LA-CIN02.001
LA	LA-CIN03.001	LA-CIN03.001
LA	LA-LAMIN04S	LA-LAMIN04S
LA	LA-LANHD01	LA-LANHD01
LA	LA-LANHD02238	LA-LANHD02238
LA	LA-LANIN03NC	LA-LANIN03NC
LA	LA-MHD01.001	LA-MHD01.001, LA-MIN04-S.001

Table C-2. Crosswalk of ATWIR-2011 to ATWIR-2012 Waste Streams
Continued

Site Code	ATWIR-2011 Waste Streams	ATWIR-2012 Waste Streams
LA	LA-MHD02-PTX.001	*Deleted Waste Stream - Shipped to WIPP*
LA	LA-MHD03.001	LA-MHD03.001
LA	LA-MHD04.001	LA-MHD04.001
LA	LA-MHD05-ITRI.001	LA-MHD05-ITRI.001
LA	LA-MHD08.001	LA-MHD08.001
LA	LA-MHD09.001	LA-MHD09.001
LA	LA-MIN02-V.001	LA-MIN02-V.001
LA	LA-MIN03-NC.001	LA-MIN03-NC.001
LA	LA-MIN04-S.001	LA-MIN04-S.001
LA	LA-MSG04.001	LA-MSG04.001
LA	LA-OS-00-01.001	LA-OS-00-01.001
LA	LA-OS-00-03	*Deleted Waste Stream - Shipped to WIPP*
LA	LA-TA-00-01	LA-TA-00-01
LA	LA-TA-00-03	LA-TA-00-03
LA	LA-TA-00-04	LA-TA-00-04
LA	LA-TA-03-01	LA-TA-03-01
LA	LA-TA-03-10	LA-TA-03-10
LA	LA-TA-03-12	LA-TA-03-12
LA	LA-TA-03-14	LA-TA-03-14
LA	LA-TA-03-17	LA-TA-03-17
LA	LA-TA-03-21	LA-TA-03-21
LA	LA-TA-03-23	LA-TA-03-23
LA	LA-TA-03-27	LA-TA-03-27
LA	LA-TA-03-28	LA-TA-03-28
LA	LA-TA-03-30	LA-TA-03-30
LA	LA-TA-03-33	LA-TA-03-33
LA	LA-TA-03-34	LA-TA-03-34
LA	LA-TA-03-40	LA-MHD03.001
LA	LA-TA-03-42	LA-MHD03.001, LA-TA-03-42
LA	LA-TA-21-05	LA-TA-21-05
LA	LA-TA-21-06	LA-TA-21-06
LA	LA-TA-21-07	LA-TA-21-07
LA	LA-TA-21-08	LA-TA-21-08
LA	LA-TA-21-09	LA-TA-21-09
LA	LA-TA-21-11	LA-TA-21-11
LA	LA-TA-21-12	LA-TA-21-12
LA	LA-TA-21-13	LA-TA-21-13
LA	LA-TA-21-15	LA-TA-21-15
LA	LA-TA-21-16	LA-TA-21-16
LA	LA-TA-21-17	LA-TA-21-17
LA	LA-TA-50-12	LA-TA-50-12

Table C-2. Crosswalk of ATWIR-2011 to ATWIR-2012 Waste Streams
Continued

Site Code	ATWIR-2011 Waste Streams	ATWIR-2012 Waste Streams
LA	LA-TA-50-15	LA-TA-50-15
LA	LA-TA-50-18	LA-CIN02.001, LA-TA-50-18
LA	LA-TA-50-19	LA-TA-50-19
LA	LA-TA-50-20	LA-TA-50-20
LA	LA-TA-55-19	LA-MHD01.001, LA-TA-55-19
LA	LA-TA-55-21	LA-TA-55-21
LA	LA-TA-55-30	LA-MHD01.001, LA-TA-55-30
LA	LA-TA-55-32	LA-TA-55-32
LA	LA-TA-55-38	LA-TA-55-38
LA	LA-TRU-Empty	LA-TRU-Empty
LB	LB-T001	LB-T001
LB	LB-T002	LB-T002
LB	LB-T003	*Deleted Waste Stream - Shipped to WIPP*
LB	LB-T004	*Deleted Waste Stream - Shipped to WIPP*
LL	LL-M001	LL-M001
LL	LL-T004	LL-T004
LL	LL-W018-S5100	LL-W018-S5100
LL	LL-W018-SS	LL-W018-SS
LL	LL-W019	LL-W019
MC	MC-W001	*Deleted Waste Stream – Disposed by Joint Munitions Command*
ND	ND-T001	ND-T001
ND	ND-T002	ND-T002
NT	NT-JAS-01	NT-JAS-01
NT	NT-W021	NT-W021
OR	OR-CHEM-CH-HET	OR-CHEM-CH-HET
OR	OR-GENR-CH-HET	OR-GENR-CH-HET
OR	OR-GENR-RH-HET	OR-GENR-RH-HET
OR	OR-ISTP-CH-HET	OR-ISTP-CH-HET
OR	OR-ISTP-RH-HET	OR-ISTP-RH-HET
OR	OR-NBL-CH-HET	OR-NBL-CH-HET
OR	OR-NFS-CH-HET	OR-NFS-CH-HET
OR	OR-NFS-CH-HOM	OR-NFS-CH-HOM
OR	OR-NFS-CH-SOIL	OR-NFS-CH-SOIL
OR	OR-PGDP-CH-HET	OR-PGDP-CH-HET
OR	OR-RADP-CH-HET	OR-RADP-CH-HET
OR	OR-RADP-CH-SOILS	OR-RADP-CH-SOILS, OR-SWSA-CH-SOIL
OR	OR-RADP-RH-HET	OR-RADP-RH-HET
OR	OR-REDC-CH-HET	OR-REDC-CH-HET
OR	OR-REDC-RH-HET	OR-REDC-RH-HET
OR	OR-RF-CH-HET	OR-RF-CH-HET

Table C-2. Crosswalk of ATWIR-2011 to ATWIR-2012 Waste Streams
Continued

Site Code	ATWIR-2011 Waste Streams	ATWIR-2012 Waste Streams
OR	OR-RF-CH-HOM	OR-RF-CH-HOM
OR	OR-RF-RH-HET	OR-RF-RH-HET
OR	OR-TBD-CH-HET	OR-SWSA-CH-HET, OR-TBD-CH-HET
OR	OR-TBD-RH-HET	OR-TBD-RH-HET
OR	OR-W203	OR-W203
OR	OR-W213-RH-SOILS	OR-W213-RH-SOILS
OR	OR-WSTR-CH-HET	OR-WSTR-CH-HET
OR	OR-Y12-CH-HET	OR-Y12-CH-HET
PA	PA-A015	*Deleted Waste Stream - Determined to be LLW*
PA	PA-W014	*Deleted Waste Stream - Determined to be LLW*
RL	RL105-01	RL105-01
RL	RL105-03	RL105-03
RL	RL105-08	RL105-08
RL	RL105-09	RL105-09
RL	RL200-01	RL200-01
RL	RL200-02	RL200-02
RL	RL201-03	RL201-03
RL	RL202S-01	RL202S-01
RL	RL209E-01	RL209E-01
RL	RL209E-08	RL209E-08
RL	RL216Z-02	RL216Z-02
RL	RL221T-01	RL221T-01
RL	RL221U-01	RL221U-03
RL	RL221U-09	RL221U-09
RL	RL222S-01	RL222S-01
RL	RL222S-08	RL222S-08
RL	RL231Z-01	RL231Z-01
RL	RL231Z-03	RL231Z-03
RL	RL233S-01	RL233S-01
RL	RL233S-03	RL233S-03
RL	RL300-01	RL300-01
RL	RL300-03	RL300-03
RL	RL300-08	RL300-08
RL	RL300-11	RL300-11
RL	RL308-01	RL308-01, RL308-03
RL	RL308-08	RL308-08
RL	RL325-01	RL325-01
RL	RL325-02	RLALE-02
RL	RL325-03	RL325-03
RL	RL325-08	RL325-08
RL	RL618-01	RL618-01

Table C-2. Crosswalk of ATWIR-2011 to ATWIR-2012 Waste Streams
Continued

Site Code	ATWIR-2011 Waste Streams	ATWIR-2012 Waste Streams
RL	RL618-08	RL618-08
RL	RLARG-01	RLARG-01
RL	RLBART-08	RLBART-08
RL	RLBAT-01	RLBAT-01
RL	RLBAT-08	RLBAT-08
RL	RLBET-08	RLBET-08
RL	RLBW-01	RLBW-01
RL	RLBW-03	RLBW-03
RL	RLBW-08	RLBW-08
RL	RLCFF-01	RLCFF-01
RL	RLCFF-03	RLCFF-03
RL	RLCH2-01	RLCH2-01
RL	RLCH2-08	RLCH2-08
RL	RLESG-01	RLESG-01, RLESG-03
RL	RLESG-08	RLESG-08
RL	RLEXX-01	RLEXX-01
RL	RLFFTF-01	RLFFTF-01
RL	RLFFTF-08	RLFFTF-08
RL	RLGEV-01	RLGEV-01
RL	RLGEV-03	RLGEV-03
RL	RLGEV-08	RLGEV-08
RL	RLHAN-01	RLHAN-01
RL	RLHAN-08	RLHAN-08
RL	RLIAEA-01	RLIAEA-03
RL	RLMLB-08	RLMLB-08
RL	RLMLL-01	RLMLL-01
RL	RLPFP-01	RLPFP-01
RL	RLPFP-02	RL200-02
RL	RLPFP-03	RLPFP-03
RL	RLPFP-04	RLPFP-04
RL	RLPFP-08	RLPFP-08
RL	RLPFP-10	RLPFP-10
RL	RLPRC-01	RLPRC-01
RL	RLPURX-01	RLPURX-01
RL	RLPURX-08	RLPURX-08
RL	RLRFET-01	RLRFET-01
RL	RLSAN-01	RLSAN-01
RL	RLSWO-01	RLSWO-01
RL	RLSWO-08	RLSWO-01
RL	RLWAR-01	RLWAR-01
RL	RLWAR-03	RLWAR-03

Table C-2. Crosswalk of ATWIR-2011 to ATWIR-2012 Waste Streams
Continued

Site Code	ATWIR-2011 Waste Streams	ATWIR-2012 Waste Streams
RL	RLWTP-08	RLWTP-08
RP	RP-TFC001	RP-TFC001
RP	RP-W754	RP-W754
RP	RP-W755	RP-W755
SA	SA-T001	*Deleted Waste Stream - Shipped to INL, then to WIPP*
SA	SA-W134	*Deleted Waste Stream - Shipped to INL, then to WIPP*
SA	SA-W134M	*Deleted Waste Stream - Shipped to INL, then to WIPP*
SA	SA-W135	SA-W135
SA	SA-W136	SA-W136
SR	SR-AGNS-HET	SR-AGNS-HET
SR	SR-AGNS-HOM	SR-AGNS-HOM
SR	SR-BCLDP-HET	SR-BCLDP-HET
SR	SR-HBL-235F-HET	SR-W027-235F/221H-HET
SR	SR-KAC-HET	SR-KAC-HET
SR	SR-LA-PAD1	SR-LA-PAD1
SR	SR-MD-HET	SR-MD-HET
SR	SR-MD-HOM-A	*Deleted Waste Stream – Shipped to WIPP*
SR	SR-MD-HOM-C	SR-MD-HOM-C
SR	SR-MD-PAD1	SR-MD-PAD1
SR	SR-MD-SOIL	SR-MD-SOIL
SR	SR-NIST-HET	SR-NIST-HET
SR	SR-RH-221H.01	SR-RH-221H.01
SR	SR-RH-221H.02	SR-RH-221H.02
SR	SR-RH-235F.01	SR-RH-235F.01
SR	SR-RH-772F.01	SR-RH-772F.01
SR	SR-RH-773A.01	SR-RH-773A.01
SR	SR-RH-FBL.01	SR-RH-FBL.01
SR	SR-RH-FTF.01	*Deleted Waste Stream - Determined to be LLW*
SR	SR-RH-MNDPAD1.01	SR-RH-MNDPAD1.01
SR	SR-RH-SDD.01	SR-RH-SDD.01
SR	SR-RH-SWD.01	SR-RH-SWD.01
SR	SR-RL-BCLDP.002	*Deleted Waste Stream – Shipped to WIPP*
SR	SR-SDD-HET-A	SR-SDD-HET-A
SR	SR-SDD-HET-B	SR-SDD-HET-B
SR	SR-SDD-HOM-A	SR-SDD-HOM-A
SR	SR-SDD-HOM-B	SR-SDD-HOM-B
SR	SR-SDD-HOM-C	SR-SDD-HOM-B
SR	SR-SWMF-HET-A	SR-SWMF-HET-A
SR	SR-SWMF-SOIL	SR-SWMF-SOIL
SR	SR-T001-WSB-1	SR-T001-WSB-1
SR	SR-W026-221F-HEPA	SR-W026-221F-HEPA

Table C-2. Crosswalk of ATWIR-2011 to ATWIR-2012 Waste Streams
Continued

Site Code	ATWIR-2011 Waste Streams	ATWIR-2012 Waste Streams
SR	SR-W026-221F-HET	SR-W026-221F-HET
SR	SR-W026-221F-HET-A	SR-W026-221F-HET-A
SR	SR-W026-221F-HOM	SR-W026-221F-HOM
SR	SR-W026-772F-HET	SR-W026-772F-HET
SR	SR-W026-CIF-HOM	*Deleted Waste Stream - Determined to be LLW*
SR	SR-W026-DWPF-HET	SR-W026-DWPF-HET
SR	SR-W026-MFFF-1	SR-W026-MFFF-1
SR	SR-W026-PDCF-1	*Deleted Waste Stream - Project was cancelled*
SR	SR-W026-WSB-2	SR-W026-WSB-2
SR	SR-W027-221F-HET-A	SR-W027-221F-HET-A
SR	SR-W027-221F-HET-C-D	SR-W027-221F-HET-A
SR	SR-W027-221F-HET-E	SR-W027-221F-HET-A
SR	SR-W027-221H-HEPA	SR-W027-221H-HEPA
SR	SR-W027-221H-HET	SR-W027-221H-HET
SR	SR-W027-221H-HET-B	SR-W027-221H-HET-C
SR	SR-W027-221H-HET-C	SR-W027-221H-HET-C
SR	SR-W027-221H-HOM	SR-W027-221H-HOM
SR	SR-W027-235F-HEPA	SR-W027-235F-HEPA
SR	SR-W027-235F-HET	SR-W027-235F-HET
SR	SR-W027-235F-HOM	SR-W027-235F-HOM
SR	SR-W027-321-322M-HET	SR-W027-321-322M-HET, SR-W027-321M-HOM
SR	SR-W027-643G-HET	SR-SWMF-HET-B
SR	SR-W027-773A-HEPA	SR-W027-773A-HET
SR	SR-W027-773A-HET	SR-W027-773A-HET
SR	SR-W027-773A-HET-CLAS	SR-W027-773A-HET-CLAS
SR	SR-W027-776A-HET	SR-W027-776A-HET
SR	SR-W027-FB-Pre86-C	SR-W027-FB-Pre86-C
SR	SR-W027-HBL-Box	SR-W027-HBL-Box
SR	SR-W027-UNK	SR-W027-UNK
WV	WV-M010a	WV-M010a
WV	WV-T004	WV-T004
WV	WV-T006a	WV-T006a
WV	WV-T006b	WV-T006b
WV	WV-T017b	WV-T017b
WV	WV-W024a	WV-W024a
WV	WV-W024b	WV-W024b
WV	WV-Z001	WV-Z001

Data Source: CID Data Version D.11.00 LANL-CO 2012. Note: This table contains data for WIPP-bound and potential waste streams only; it does not include data for emplaced waste streams.

APPENDIX D DOE POTENTIAL WASTE SCREENING MEMORANDUM

Department of Energy
Carlsbad Field Office
P. O. Box 3090
Carlsbad, New Mexico 88221

March 29, 2010

Mr. Ned Elkins, Manager
Los Alamos National Laboratory - Carlsbad Operations
115 N. Main
Carlsbad, NM 88220

Subject: TRU Waste Inventory Screening Criteria Guidance

Dear Mr. Elkins:

The Department of Energy Carlsbad Field Office (CBFO), in the enclosed memorandum, is providing guidance on the criteria to be used to screen transuranic (TRU) waste streams for exclusion from the Waste Isolation Pilot Plant (WIPP)-bound inventory in upcoming Annual TRU Waste Inventory Reports. This guidance will stay in effect until Los Alamos National Laboratory – Carlsbad Operations is formally notified otherwise by CBFO.

If you have any questions regarding this guidance please notify me at (575) 234-7457.

Sincerely,

Russ Patterson
Compliance Certification Manager

Enclosure

cc: w/enclosure

C. Fesmire, CBFO	*ED
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*ED denotes electronic distribution

INV-1004-01-01-01

CBFO:ORC:RLP:MDA:10-0945:UFC 5822.00

Screening Memorandum
March 17, 2010

This screening memo describes criteria that will be used to screen transuranic (TRU) waste streams for exclusion from the Waste Isolation Pilot Plant (WIPP)-bound inventory. This WIPP-bound waste is used in future performance assessments (PAs) for the Compliance Recertification Application (CRA). This memo does not address high level, low level or commercial waste since they are prohibited for disposal in WIPP. The table below contains screening criteria that will be used to designate Potential waste streams. The table in no way indicates that waste identified as Potential will be excluded from emplacement in WIPP in the future.

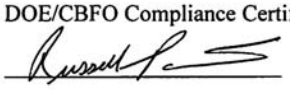
All waste streams collected for each Annual TRU Waste Inventory Report (ATWIR) are categorized within the TRU waste inventory database as WIPP-Bound unless one or more of the screening criteria listed in the table below are encountered. All shipments to WIPP will be subject to the conditions delineated in the WIPP Hazardous Waste Facility Permit Waste Analysis Plan (WAP), WIPP Waste Acceptance Criteria (WAC) and the Transuranic Authorized Methods for Payload Control (TRAMPAC). The table below is intended to be treated as a guide for delineating Potential waste streams that will be reported in the ATWIR in Appendix C and excluded from being reported in Performance Assessment Inventory Report (PAIR) that will be used for future PAs.

Criteria for Categorizing Waste Streams as Potential

Screening Criteria	Comment
TRU Determination Undetermined	Will remain potential until the waste stream has been officially determined to be transuranic. If the waste stream is determined to be non-transuranic then it will be removed from the inventory.
Defense Determination Unknown	Will remain potential until the waste stream has been officially determined to be defense waste. If the waste stream is determined to be non-defense then it will be removed from the inventory.
Regulatory Restrictions • Surface Dose > 1000 R/hr • Activity >23 Ci/L (or 23,000 Ci/m^3) averaged over the volume of the canister • Prohibited hazardous constituents • Summary category groups other then S3000, S4000, S5000 • And other regulatory restrictions	Will remain potential until the waste stream meets all acceptance criteria for WIPP. This may involve: • Repackaging waste stream • Treating waste stream • Removal of restricted items from waste stream • Any other process that would remediate the regulatory restriction
Incomplete Data • Incomplete or missing radionuclide concentrations • Incomplete or missing WMP	Will remain potential until the waste stream reports all required data.

Screening Criteria	Comment
densities • Incomplete or missing final form container information • Unknown waste stream information • Any other incomplete or missing waste stream information that is required for PA	
Directed by DOE to move to Potential	Will remain potential until DOE directs to remove waste stream from potential.

DOE/CBFO Compliance Certification Manager



03/29/10

Russ Patterson

Date

DOE/WIPP-11-3443-2

SEMI-ANNUAL VOC, HYDROGEN, AND METHANE DATA SUMMARY REPORT FOR REPORTING PERIOD July 1, 2011 through December 31, 2011

United States Department of Energy

Waste Isolation Pilot Plant
Carlsbad, New Mexico

WIPP Hazardous Waste Facility Permit
New Mexico Environment Department
Permit Number NM4890139088-TSDF

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LIST OF ABBREVIATIONS, ACRONYMS, AND UNITS

BS	blank spike
BSD	blank spike duplicate
CFR	*Code of Federal Regulations*
CH	contact-handled
COC	concentration of concern
DOE	U.S. Department of Energy
EDD	electronic data deliverable
HWDU	hazardous waste disposal unit (panel)
LCS	laboratory control sample
LCSD	laboratory control sample duplicate
MDL	method detection limit
MRL	method reporting limit
N/A	not applicable
ND	non-detect
NMED	New Mexico Environment Department
ppbv	parts per billion by volume
PPMV	parts per million by volume
QA	quality assurance
QC	quality control
RH	remote-handled
RPD	relative percent difference
TIC	tentatively identified compound
TRU	transuranic
VOC	volatile organic compound
WIPP	Waste Isolation Pilot Plant

1.0 INTRODUCTION

This report is submitted by the U.S. Department of Energy (DOE) Carlsbad Field Office and Washington TRU Solutions LLC (the Permittees) in accordance with Permit Part 4, Permit conditions 4.6.2.2 and 4.6.5.2 of the Waste Isolation Pilot Plant (WIPP) Hazardous Waste Facility Permit NM4890139088-TSDF (Permit). This report documents the Volatile Organic Compound (VOC) Monitoring Program and Hydrogen and Methane Monitoring Program results for the 6-month period of July 1, 2011 through December 31, 2011.

1.1 Monitoring Programs

The VOC Monitoring Program was originally designed to monitor transuranic (TRU) mixed waste-related VOC concentrations in ventilation exhaust air (repository VOC Monitoring). Monitoring for VOCs from within disposal rooms of open/active panels was later incorporated (Disposal Room VOC Monitoring), as well as monitoring of Room 1 within specific filled panels (Ongoing Disposal Room VOC Monitoring). Each program continues to the present time.

The Hydrogen and Methane Monitoring Program was designed to monitor hydrogen and methane concentrations immediately outside and from closed rooms within specific filled panels. This monitoring was implemented for Panel 3 in April 2008 and in May 2009 for Panel 4. Monitoring continues to the present time for Panels 3 and 4.

1.2 Reporting Limits and Qualifier Descriptions

The following definitions apply to this report:

Method detection limit (MDL) – The limit at which concentrations are measured and reported with 99 percent confidence that the analyte concentration is greater than zero.

Method reporting limit (MRL) – The contract-specified limit at which data are required to be reported by the contract analytical laboratory.

Qualifiers (data flags) are used for data in sample analysis data packages and are reflected in reports. These qualifiers are described as follows:

QUALIFIER DESCRIPTIONS

U	Indicates target analyte was analyzed for but not detected above MDL.
J	Estimated value; the target analyte was detected at a concentration below the required MRL but above the MDL.

B This flag is used when the analyte is found in the associated laboratory method blank, as well as in the sample. It indicates possible/probable blank contamination and warns the data user to take appropriate action. This flag must be used for a tentatively identified compound (TIC), as well as for a positively identified target analyte.

R Sample results are unusable due to the quality of the data generated because certain criteria were not met. The analyte may or may not be present in the sample. This qualifier may also be used for data anomalies.

Q Results are useable, but were not associated with analyses that met all quality assurance/quality control (QA/QC) requirements for precision, accuracy, or completeness.

NJ Presumptive evidence of the presence of the material at an estimated quantity. Only used for TICs.

2.0 REPOSITORY VOC MONITORING

Sampling for repository VOC monitoring is presently conducted twice per week at two ambient air sampling locations designated as repository VOC monitoring stations, in accordance with Permit Attachment N, section N-3. The stations are identified as Station VOC-A, sample inlet located in the E-300 drift downstream from the Underground Hazardous Waste Disposal Unit (Underground HWDU) designated as Panel 1, and Station VOC-B, sample inlet located upstream from the most recently activated Underground HWDU. Figure 1 shows an example of the two repository VOC monitoring sample inlet locations and the direction of mine airflow.

The location of Station VOC-A is not expected to change from the present location as waste disposal operations continue. Concentrations found at Station VOC-A represent both the VOCs in the mine air not attributable to disposed TRU mixed waste plus any releases of VOCs from the TRU mixed waste in the repository. As new Underground HWDUs are opened and closed, Station VOC-A will continue to reflect non-waste-emplacement-related VOCs plus TRU mixed waste emissions from the current open/active Underground HWDU(s) and closed/filled Underground HWDUs.

Detections of VOCs for Station VOC-B represent the concentrations in the ventilation air found in the mine before passing through the areas of the repository containing TRU mixed waste. The VOCs detected for this location are considered to be non-waste-emplacement-related concentrations. As TRU mixed waste is placed in new Underground HWDUs, the location of Station VOC-B is changed as needed to sample the ambient air upstream from Underground HWDUs that are receiving TRU mixed waste.

The measured concentrations of Permit-specified target analytes collected at Stations VOC-A and VOC-B are normalized to assess the concentration of VOCs attributable to the TRU mixed waste disposed of at the WIPP facility (i.e., Underground HWDU VOC emission concentration). Section 2.2 describes the normalization process and how running annual average of Underground HWDU VOC emission concentrations are calculated.

For repository VOC monitoring, the target compounds and their respective concentrations of concern (COC), as specified in Permit Part 4, table 4.6.2.3, are shown in table 1. The Permittees are required to notify the Secretary of the New Mexico Environment Department (NMED), as specified in Permit Part 4, Permit condition 4.6.2.3, should individual sample concentration differences between the two stations or the running annual average concentrations exceed the Permit-specified COC, shown in table 1.

Table 1 – Repository VOC Monitoring - Target VOCs, Concentrations of Concern, and MRL

Target Compound	Concentration of Concern (ppbv)	Required MRL (ppbv) Per Permit Attachment N, Table N-2
Carbon Tetrachloride	960	2
Chlorobenzene	220	2
Chloroform	180	2
1,1-Dichloroethylene	100	5
1,2-Dichloroethane	45	2
Methylene Chloride	1930	5
1,1,2,2-Tetrachloroethane	50	2
Toluene	190	5
1,1,1-Trichloroethane	590	5

ppbv = part per billion by volume

2.1 Repository VOC Monitoring Results

The repository VOC monitoring results for this reporting period are discussed in section 2.3 and summarized in table 2. The individual monitoring results, concentration differences, and comparisons to the COC for each sample set collected at Stations VOC-A and VOC-B are provided in attachment 1. Normalization and usage rules for repository VOC monitoring reporting are presented in section 2.2.

2.2 Normalization and Usage Rules for Repository VOC Monitoring Reporting

As applicable, analytical results for Permit specified target analytes are normalized to the typical operating conditions, in accordance with Permit Attachment N section N-3e(1). Target analytes are normalized when not qualified as "U." The normalized concentration of each target VOC detected at Station VOC-B is subtracted from the normalized concentration detected at Station VOC-A in conformity with normalization and usage rules. The resulting concentration represents the Underground HWDU VOC emission concentration and is compared to its COC listed in Permit Part 4, table 4.6.2.3, and shown in table 1.

Results qualified as "U" by the analytical laboratory indicate that the concentrations were not greater than the method detection limit (MDL) and are assigned a value of zero in determinations of concentration differences between Stations VOC-A and VOC-B.

Analytical results qualified as "J" by the analytical laboratory were detected at a concentration greater than the MDL but less than the method reporting limit (MRL) and are considered to be an estimated value. Since these results are below the MRL, they are assigned a value of zero in determinations of concentration differences between Stations VOC-A and VOC-B.

Some values that were qualified by the analytical laboratory with a "J" flag are normalized to values that are above the MRL. The "J" qualifier is still applicable and the normalized concentrations are treated as estimated values. Additionally, some normalized results are not qualified as "J" even though the values are below the MRL. These values were reported by the analytical laboratory as being over the MRL, and then normalized down to a level below the MRL. These results are not treated as estimated values.

For results in which the normalized concentration at Station VOC-B is greater than or equal to Station VOC-A, the concentration difference is set to zero.

The running annual average concentration for each target VOC is determined, in accordance with Permit Attachment N section N-3e(1), by averaging the Underground HWDU VOC emission concentration for each target VOC for each sampling event with concentrations for the previous 12 months. The running annual average concentrations are compared to the COC listed in Permit Part 4, table 4.6.2.3, and shown in table 1.

2.3 Discussion of Repository VOC Monitoring Results

For the reporting period, there were 52 sample sets (104 original samples from Stations VOC-A and VOC-B) analyzed for each of the nine target compounds. The concentration difference for each individual sample set was determined and compared to the COC for each of the nine target compounds and reported in attachment 1. The results for sample number 6530, collected at Station VOC-B on 9/8/2011, was assigned an "R" qualifier (i.e., unusable). Measurable concentrations of carbon tetrachloride and chloroform are normalized to 100.55 ppbv and 7.28 ppbv respectively in the sample but mine ventilation/conditions were not typical on the collection date (i.e., Labor Day outage anomaly) and detections do not represent typical background levels. Therefore, results of all target VOCs in this sample were conservatively assigned a value of zero in this sample set (see shaded sample set in attachment 1). Table 2 and attachment 1 show that none of the 52 individual sample sets showed an exceedance of a COC.

Carbon tetrachloride, 1,1,1-trichloroethane, and chloroform each had running annual average concentrations greater than their individual MRL from sampling at Stations VOC-A and VOC-B. Table 2 shows that during this reporting period, none of these three target VOC averages exceeded their COCs. The running annual averages of the other six target compounds were less than the MRL for each sampling event of the reporting period. Remedial action, as described in Permit Part 4, Permit condition 4.6.2.4, was not required during this reporting period.

Three field duplicate samples were collected at each repository VOC monitoring station, for a total of six field duplicates. These results are reported in attachment 6D and field precision for the VOC Monitoring Program is discussed in section 7.1.

Table 2 – Summary of Repository VOC Monitoring Results

Target Compound	Running Annual Average Concentration Max. Value (ppbv)	Individual Concentration Max. Value (ppbv)	COC (ppbv)	Individual or Running Annual Average COC Exceedances
Carbon Tetrachloride	182.44	336.52	960	0
Chlorobenzene	<MRL	0	220	0
Chloroform	16.86	32.62	180	0
1,1-Dichloroethylene	<MRL	0	100	0
1,2-Dichloroethane	<MRL	0	45	0
Methylene Chloride	<MRL	10.14	1930	0
1,1,2,2-Tetrachloroethane	<MRL	0	50	0
Toluene	<MRL	0	190	0
1,1,1-Trichloroethane	25.66	51.87	590	0

ppbv = part per billion by volume
MRL= method reporting limit (see table 1)
COC= concentration of concern

3.0 DISPOSAL ROOM VOC MONITORING

Collection and analysis of VOC samples from each room containing waste in an active Underground HWDU began on November 20, 2006, and continues to the present time. Sampling frequency is conducted in accordance with Permit Attachment N, section N-3d(2). For this reporting period, the frequency was once every two weeks for all sampling locations excluding Rooms 7 and 6 of Panel 5 where samples were collected on a weekly frequency. Room-based limits and action levels, as specified in Permit Part 4, tables 4.4.1 and 4.6.3.2 respectively, are shown in table 3. Figure 2 shows typical disposal room VOC monitoring sample locations. Sample locations are determined in accordance with Permit Attachment N, section N-3a(2). Results from disposal room VOC monitoring samples are presented in section 3.1 and are compared to the action levels and room-based limits.

The number of disposal room VOC monitoring locations increases as waste emplacement proceeds from room to room. As waste is placed into a room, VOC monitoring in that room commences at the exhaust end of the room. After the room is filled, VOC monitoring begins at a second location in that room at the inlet side. When the next room receives waste, the process is repeated. All rooms within an Underground HWDU that receive waste are actively monitored until waste emplacement in the Underground HWDU is complete. At that point, VOC monitoring in that Underground HWDU will be reduced to Room 1 (i.e., ongoing disposal room VOC monitoring) unless an explosion-isolation wall is installed in the panel.

For process efficiency, generally half of the required disposal room samples are collected each week of the bi-weekly sampling period. For the week of 7/4/2011, samples were scheduled to be collected in Rooms 5, 4, and 1 on a bi-weekly frequency and in Rooms 7 and 6 on a weekly frequency per Permit Part 4, Permit condition 4.6.3.3. Since Rooms 2 and 3 were being collected on a bi-weekly frequency, they were not scheduled to be collected until the week following the closure of Panel 5.

Table 3 – Disposal Room VOC Monitoring Room-Based Limits and Action Levels

Target Compound	Room-based Limits (ppmv)	50% Action Level (ppmv)	95% Action Level (ppmv)
Carbon Tetrachloride	9,625	4,813	9,145
Chlorobenzene	13,000	6,500	12,350
Chloroform	9,930	4,965	9,433
1,1-Dichloroethylene	5,490	2,745	5,215
1,2-Dichloroethane	2,400	1,200	2,280
Methylene Chloride	100,000	50,000	95,000
1,1,2,2-Tetrachloroethane	2,960	1,480	2,812
Toluene	11,000	5,500	10,450
1,1,1-Trichloroethane	33,700	16,850	32,015

ppmv = part per million by volume

3.1 Disposal Room VOC Monitoring Results

During this reporting period, nine original samples (10 total samples) were collected for disposal room VOC monitoring in Panel 5, and 37 original samples (50 total samples) were collected for disposal room VOC monitoring in Panel 6. Original sample results were compared to the levels as shown in table 3 to determine if any action levels or room-based limits were exceeded. Associated data for original samples are reported in attachment 2. The original sample results for Panels 5 and 6 are summarized in tables 4 and 5 respectively. Results for field duplicate samples are reported in attachment 6D and field precision for the VOC Monitoring Program is discussed in section 7.1.

Table 4 – Summary of Disposal Room VOC Monitoring Results for Panel 5

Target Compound	Maximum Detected Value (ppmv)	Location of Maximum Detected Value	No. of Exceedances
Carbon Tetrachloride	6,119	Room 7 Inlet	3*
Chlorobenzene	<MDL	N/A	0
Chloroform	753.5	Room 7 Inlet	0
1,1-Dichloroethylene	<MRL	Room 6 Exhaust	0
1,2-Dichloroethane	<MDL	N/A	0
Methylene Chloride	76.8	Room 7 Inlet	0
1,1,2,2-Tetrachloroethane	<MDL	N/A	0
Toluene	<MRL	Room 1 Exhaust	0
1,1,1-Trichloroethane	232.7	Room 7 Inlet	0

ppmv = part per million by volume
MRL = method reporting limit (contract-specified limit of 0.5 ppmv)
N/A = not applicable
ND= non detect
* = Exceeded 50% action level of 4,813 ppmv

Table 5 – Summary of Disposal Room VOC Monitoring Results for Panel 6

Target Compound	Maximum Detected Value (ppmv)	Location of Maximum Detected Value	No. of Exceedances
Carbon Tetrachloride	298.5	Room 7 Exhaust	0
Chlorobenzene	<MDL	N/A	0
Chloroform	19.6	Room 7 Exhaust	0
1,1-Dichloroethylene	<MDL	N/A	0
1,2-Dichloroethane	<MDL	N/A	0
Methylene Chloride	1.7	Room 7 Exhaust	0
1,1,2,2-Tetrachloroethane	<MDL	N/A	0
Toluene	<MRL	Room 7 Exhaust	0
1,1,1-Trichloroethane	44.4	Room 7 Exhaust	0

ppmv = part per million by volume
MRL = method reporting limit (contract-specified limit of 0.5 ppmv)
MDL = method detection limit
N/A = not applicable

3.2 Discussion of Disposal Room VOC Monitoring Results

During this reporting period, Panel 5 continued to receive waste from similar waste streams as in the previous period. As additional source term accumulated in Panel 5, VOC concentrations increased in closed disposal rooms of Panel 5, as expected. The highest concentration for any compound in any sample was carbon tetrachloride at a maximum value of 6,119 ppmv (table 4). This concentration is greater than 50 percent of the associated room-based limit. Three additional compounds had maximum concentrations above the MRL (0.5 ppmv), but were significantly below the 50 percent action level for each compound. These were methylene chloride detected at 76.8 ppmv, 1,1,1-trichloroethane detected at 233 ppmv, and chloroform detected at 753 ppmv.

Samples collected on 7/5/2011 in Panel 5 Rooms 7E and 7I, and on 7/6/2011 in Panel 5 Room 6I, had concentrations of carbon tetrachloride higher than the 50 percent action level. The data were validated on August 8, 2011 in accordance with Permit Attachment N, section N-5d. No other target compound in Panel 5 and none in Panel 6 exceeded the 50 percent action level.

3.3 Waste Disposal Activities

Waste disposal progress determines which room-based VOC monitoring locations are sampled. As soon as a room receives waste, it is subject to monitoring at one location (exhaust side). When waste disposal activities are complete in the disposal room, the exhaust side continues to be monitored and the inlet side is added to the sampling schedule. On July 1, 2011, active contact-handled (CH) waste emplacement was occurring in Panel 5 Room 1, and active remote-handled (RH) waste emplacement was occurring in Panel 6 Room 7. At this stage, Panel 5 Rooms 7, 6, 5, 4, 3, and 2 had two monitoring locations (exhaust and inlet), while Panel 5 Room 1 and Panel 6 Room 7 each had one monitoring location (exhaust). On December 31, 2011, active CH waste emplacement was occurring in Panel 6 Room 6, and active RH waste emplacement was occurring in Panel 6 Room 5. At this stage, Panel 6 Room 7 had two monitoring locations (exhaust and inlet) and Panel 6 Rooms 6 and 5 had one monitoring location (exhaust).

Required room-based monitoring of Panel 5 ended on 7/7/2011 when waste emplacement ceased and ventilation barriers for Panel 5 Room 1 were emplaced. Ongoing monitoring was not initiated due to the planned installation of an explosion-isolation wall in each access drift of Panel 5. Completion of the explosion-isolation wall in each access drift of Panel 5 occurred on November 1, 2011.

4.0 ONGOING DISPOSAL ROOM VOC MONITORING

After completion of waste emplacement, monitoring for VOCs in Room 1 of Panels 3 through 8 will occur until final panel closure, unless an explosion-isolation wall is installed in the panel per Permit Attachment N, section N-3a(3). During this reporting period, ongoing disposal room VOC monitoring was conducted at the exhaust side of Room 1 in Panels 3 and 4 at a frequency of once per month for a total of six original samples for each panel. A field duplicate sample was collected at the same frequency for each panel. One field duplicate collected in Panel 3 for the month of September was voided before analysis as described in section 7.1.

The original sample results for Panels 3 and 4 are summarized in tables 6 and 7 respectively. Sample results were well below action levels and remedial action was not required as described in Permit Part 4, Permit condition 4.6.3.3. The associated data for original samples are reported in attachment 3. Results for field duplicate samples are reported in attachment 6D and field precision for the VOC Monitoring Program is discussed in section 7.1.

Table 6 – Summary of Ongoing Disposal Room VOC Monitoring Results for Panel 3

Target Compound	Maximum Detected Value (ppmv)	50% Action Level (ppmv)	95% Action Level (ppmv)	Room-based Limits (ppmv)	No. of Exceedances
Carbon Tetrachloride	3.7	4,813	9,145	9,625	0
Chlorobenzene	<MDL	6,500	12,350	13,000	0
Chloroform	<MRL	4,965	9,433	9,930	0
1,1-Dichloroethylene	<MRL	2,745	5,215	5,490	0
1,2-Dichloroethane	<MRL	1,200	2,280	2,400	0
Methylene Chloride	0.8	50,000	95,000	100,000	0
1,1,2,2-Tetrachloroethane	<MDL	1,480	2,812	2,960	0
Toluene	<MRL	5,500	10,450	11,000	0
1,1,1-Trichloroethane	3.1	16,850	32,015	33,700	0

ppmv = part per million by volume
MRL = method reporting limit (contract-specified limit of 0.5 ppmv)
MDL = method detection limit

Table 7 – Summary of Ongoing Disposal Room VOC Monitoring Results for Panel 4

Target Compound	Maximum Detected Value (ppmv)	50% Action Level (ppmv)	95% Action Level (ppmv)	Room-based Limits (ppmv)	No. of Exceedances
Carbon Tetrachloride	766.2	4,813	9,145	9,625	0
Chlorobenzene	<MDL	6,500	12,350	13,000	0
Chloroform	60.5	4,965	9,433	9,930	0
1,1-Dichloroethylene	<MDL	2,745	5,215	5,490	0
1,2-Dichloroethane	<MDL	1,200	2,280	2,400	0
Methylene Chloride	28.7	50,000	95,000	100,000	0
1,1,2,2-Tetrachloroethane	<MDL	1,480	2,812	2,960	0
Toluene	1.6	5,500	10,450	11,000	0
1,1,1-Trichloroethane	145.4	16,850	32,015	33,700	0

ppmv = part per million by volume
MDL = method detection limit

5.0 NON-TARGETS

The Permittees are required to evaluate non-target VOCs (including additional requested analytes and/or TICs) in VOC Monitoring Program compliance samples to determine if the non-targets qualify for addition to the target analyte list(s) as specified by Permit Attachment N, section N-3b. Additional requested analytes are comprised of TICs that previously met the criteria to be added to the target analyte list that have not been assigned a COC or have been added for quantitation for other purposes. The TICs and additional requested analytes that meet the following criteria will be added to or maintained on the target analyte list(s) for repository, disposal room, and ongoing disposal room VOC monitoring, unless the Permittees can justify the exclusion from the target analyte list(s):

1) Listed in Appendix VIII of 40 *Code of Federal Regulations* (CFR) Part 261 (incorporated by reference in 20.4.1.200 of the New Mexico Administrative Code); and

2) Detected in 10 percent or more of the VOC monitoring samples (exclusive of those collected from Station VOC-B).

For the 12-month timeframe from January 1, 2011 to December 31, 2011, non-targets were evaluated in original VOC samples (excluding VOC-B) to determine if they were detected in a minimum of 10 percent of the samples and listed in Appendix VIII of 40 CFR Part 261. After evaluation of non-targets in 247 original VOC samples for the previous reporting period (see Semi-annual VOC, Hydrogen, and Methane Data Summary Report for Reporting Period January 1, 2011 through June 30, 2011) and 110 samples in this report for a total of 357 samples for the 12-month period, it was determined that tetrachloroethylene, trichloroethylene, trichloromonofluoromethane, and chloromethane meet the criteria for addition to the target analyte list(s). These compounds were previously added to the laboratory's target analyte list as additional requested analytes. To gain a better understanding of potential concentrations and associated risk, trichloroethylene, tetrachloroethylene, and benzene were included on the laboratory quantitation list as additional requested analytes starting with samples collected on 1/25/2011. Five other compounds (methyl chloride (chloromethane), trans-1,2-dichloroethylene, 1,2,4-trimethylbenzene, p,m-xylene, and trichloromonofluoromethane) were also included in the laboratory quantitation list as additional requested analytes. These five compounds were added beginning with samples collected on 5/3/2011. None of the added analytes have an associated COC.

The results (not normalized) for these additional requested analytes are reported in attachment 4B and summarized in table 8. The results of TICs are listed in attachment 4A. The TICs reported for Station VOC-A are not normalized in attachment 4A.

Table 8 – Summary of Additional Requested Analytes

Additional Requested Analytes	CAS Number	Maximum Station VOC-A Detected Value (ppbv)	Maximum Disposal Room Detected Value (ppbv)**	Maximum Detection Location
Trichloroethylene	79-01-6	82.48	2,514,306	P5R7I
Tetrachloroethylene	127-18-4	13.2	180,296	P5R5E
Benzene	71-43-2	2.18	12.76 J	P3R1E
Chloromethane	74-87-3	2.13	44,877	P5R7I
trans-1,2-Dichloroethylene	156-60-5	ND	ND	N/A
1,2,4-Trimethylbenzene	95-63-6	0.4 J	1.2 J	P5R1E
p,m-Xylene	106-42-3, 108-38-3	2.88 J	55.08 J	P3R1E
Trichloromonofluoromethane	75-69-4	2.76	16,927	P5R4E

** = includes ongoing disposal room VOC monitoring samples
ppbv = part per billion by volume
ND = non-detect
N/A = not applicable

6.0 HYDROGEN AND METHANE MONITORING

Monitoring of hydrogen and methane within filled panels 3 through 8 is required in accordance with Permit Part 4, Permit condition 4.6.5.1 and Permit Attachment N1. A filled panel is an Underground HWDU that will no longer receive waste for emplacement. Monitoring is required until final panel closure, unless an explosion-isolation wall is installed. Sampling frequency is monthly unless action level 1 (shown in table 9) is exceeded, in which case the sampling frequency would increase to weekly.

Table 9 – Hydrogen and Methane Monitoring Action Levels

Target Compound	Action Level 1 (ppmv)	Action Level 2 (ppmv)
Hydrogen	4,000	8,000
Methane	5,000	10,000

ppmv = part per million by volume

Hydrogen and methane monitoring required by Permit Attachment N1 was implemented in April 2008. This report includes samples collected from July 1, 2011 through December 31, 2011.

Samples were collected at 14 locations in Panel 3 and at 17 locations in Panel 4 for most of the reporting period. Samples were collected in only 16 locations in Panel 4 in the month of December due to Panel 4 Room 6 exhaust sample line loss. The loss of the ability to purge the sample line in the exhaust drift of Panel 4 Room 6 was determined on December 13, 2011. Notification and evaluation of the sample line loss was completed as prescribed in Permit Part 4, Permit condition 4.6.5.5.

Figure 3 illustrates typical hydrogen and methane monitoring locations. A total of 84 original samples (90 total samples) were collected in Panel 3 and 101 original samples

(107 total samples) were collected in Panel 4 from July 1, 2011 through December 31, 2011. One field duplicate collected in Panel 3 for the month of September was voided prior to analysis as described in section 7.2. The maximum detected value for an original sample was 856.32 ppmv for hydrogen. This detection is considerably lower than the action levels (less than 22 percent of action level 1 and less than 11 percent of action level 2). None of the samples yielded methane detections. Associated data for original samples are reported in attachment 5. Original sample results are summarized in tables 10 and 11. Field duplicate sample results are reported in attachment 7 and field precision for the Hydrogen and Methane Monitoring Program is discussed in section7.2. The MRL (contract-specified) for both hydrogen and methane is 150 ppmv. Samples were taken at sub-atmospheric pressure, then a pressure dilution was performed by the analytical lab prior to analysis, resulting in a dilution factor of two and MRLs corrected to 300 ppmv.

Table 10 – Summary of Hydrogen and Methane Monitoring Results for Panel 3

Target Compound	Maximum Detected Value (ppmv)	Location of Maximum Detected Value	Action Level 1 (ppmv)	Action Level 2 (ppmv)	No. of Exceedances
Hydrogen	<MRL	Room 6 Exhaust	4,000	8,000	0
Methane	ND	N/A	5,000	10,000	0

ppmv = part per million by volume
MRL = method reporting limit (contract-specified limit)
N/A = not applicable
ND = non-detect

Table 11 – Summary of Hydrogen and Methane Monitoring Results for Panel 4

Target Compound	Maximum Detected Value (ppmv)	Location of Maximum Detected Value	Action Level 1 (ppmv)	Action Level 2 (ppmv)	No. of Exceedances
Hydrogen	856.32	Room 7 Exhaust	4,000	8,000	0
Methane	ND	N/A	5,000	10,000	0

ppmv = part per million by volume
N/A = not applicable
ND = non-detect

7.0 RESULTS OF PROGRAM OBJECTIVES

The electronic data deliverables (EDDs) submitted by the analytical laboratory are required to be reviewed within five calendar days of receipt. For all samples collected during this reporting period, all EDDs were reviewed within the five calendar day window.

The data package validation is required to be completed within 14 calendar days of receipt for packages that do not include data that exceed concentrations of concern or action levels, and within five calendar days of receipt for packages that do contain data that exceeds concentrations of concern or action levels. During this reporting period, all data were validated within the required time period.

A comprehensive QA/QC program is an integral part of the VOC and hydrogen and methane monitoring effort. A number of QA/QC analyses are performed, including laboratory control samples (LCS), laboratory method blanks, field duplicates, and laboratory duplicate analyses of samples and LCS (i.e., LCS duplicate [LCSD]). The laboratory QA/QC analyses indicate that the laboratory was performing within specifications and was capable of detecting and quantifying the target analytes when they were present. The analytical laboratory used for analyses of compliance monitoring samples during this reporting period performed analyses under an established QA/QC program. Results of QA/QC analyses and completeness for VOCs and hydrogen and methane are discussed in sections 7.1 and 7.2 respectively.

7.1 VOC QA/QC Analyses and Completeness

The QA/QC analyses and completeness results indicate that the VOC data collected during this reporting period met the program objectives and the data are accurate and defensible. The following is a discussion of the results.

Attachment 6A (VOCs – Precision of Laboratory Sample Duplicates) shows that during the reporting period, laboratory sample duplicates met the technical acceptance criterion (≤25 relative percent difference [RPD]) for precision, with the exception of one target analyte in an ongoing disposal room VOC monitoring sample. The sample that contained data that did not meet criterion is flagged and shaded in the data set, as applicable. All other laboratory duplicates met the RPD criteria of ≤25 which is only applicable if one or both values not flagged "U" or "J." The required completeness of valid data (≥95 percent) was maintained; therefore, further action was not required.

Attachment 6B (VOCs – Precision/Accuracy of Laboratory Control Samples) shows that during the reporting period, 100 percent of LCS/LCSD results met the technical acceptance criteria for precision (≤25 RPD) and accuracy (60-140 percent recovery). LCS/LCSD are identified as blank spike/blank spike duplicate (BS/BSD) in the Permit.

Attachment 6C (VOCs – Laboratory Method Blanks) shows that target compound concentrations in each method blank met the contract-specified blank technical acceptance criterion (i.e., all target analytes <0.5 ppbv).

Attachment 6D (VOCs – Field Duplicate Precision) shows the results of field duplicates collected during this reporting period. Six field duplicates were collected at repository VOC monitoring locations, 14 at disposal room VOC monitoring locations, and 12 while conducting the ongoing disposal room VOC monitoring. One field duplicate collected in Panel 3 for ongoing disposal room VOC monitoring for the month of September was voided before analysis. The analytical laboratory notified the Permittees that the sample was received at atmospheric pressure, thus compromising sample integrity. The required field duplicate frequency of 5 percent was maintained; further action was therefore not required. The associated MRLs for repository VOC monitoring are listed in table 1. The associated MRL of each target analyte for disposal room VOC monitoring and ongoing disposal room VOC monitoring is 500 ppbv (0.5 ppmv). The field duplicates met the technical acceptance criterion (≤35 RPD) with the exception of two ongoing disposal room VOC monitoring field duplicate samples. The samples that

contained data that did not meet criterion are flagged and shaded in the data set, as applicable. All other field duplicates met the RPD criteria of ≤35 which is only applicable if one or both values not flagged "U" or "J." The required completeness of valid data (≥95 percent) was maintained; therefore, further action was not required.

Completeness is defined as the percentage of the ratio of the number of valid sample results received (i.e., those that meet data quality objectives) versus the total number of samples collected. Completeness may be affected, for example, by sample loss or destruction during shipping, by laboratory sample handling errors, or by rejection of analytical data during data validation. Field duplicates, with a prescribed frequency of at least 5 percent, are included in the total. The QA objective (i.e., goal) for the program is a completeness of 95 percent or greater. During this reporting period, a total of 110 repository VOC monitoring samples (includes six field duplicates), 60 disposal room VOC monitoring samples (includes 14 field duplicates), and 24 ongoing disposal room VOC monitoring samples (includes 12 field duplicates) were obtained for a total of 194 samples collected. Excluding one field duplicate, the laboratory provided valid results for the samples that were submitted. Two field duplicates and one laboratory duplicate did not meet the technical acceptance criteria. The overall completeness for the reporting period was 98 percent.

7.2 Hydrogen and Methane QA/QC Analyses and Completeness

The QA/QC analyses and completeness results indicate that the hydrogen and methane data collected for this reporting period met the program objectives and the data are accurate and defensible. The following is a discussion of the results.

Attachment 7 shows that during the reporting period, 100 percent of the laboratory sample duplicates met the technical acceptance criterion (≤25 RPD) for precision.

Attachment 7 shows that during the reporting period, 100 percent of the LCS/LCSD results met the technical acceptance criteria for precision (≤25 RPD) and accuracy (70-130 percent recovery).

As shown in attachment 7, all results for both hydrogen and methane met the blank technical acceptance criterion (i.e., ≤ MDL) during this reporting period.

Attachment 7 shows the results of field duplicates collected during this reporting period. Twelve field duplicates were collected while conducting the hydrogen and methane sampling in Panels 3 and 4. One field duplicate collected in Panel 3 for the month of September was voided before analysis. The analytical laboratory notified the Permittees that the sample was received at atmospheric pressure, thus compromising sample integrity. All other field duplicates met the RPD criteria of ≤35 which is only applicable if one or both values not flagged "U" or "J." The required field duplicate frequency of 5 percent was maintained; further action was therefore not required.

Completeness is defined as the percentage of the ratio of the number of valid sample results received (i.e., those which meet data quality objectives) versus the total number of samples collected. Completeness may be affected, for example, by sample loss or

destruction during shipping, by laboratory sample handling errors, or by rejection of analytical data during data validation. Field duplicates, with a prescribed frequency of at least 5 percent, are included in the total. The QA objective (i.e., goal) for the program is a completeness of 95 percent or greater. During this reporting period, a total of 197 samples (includes 12 field duplicates) were collected for hydrogen and methane analysis. Excluding one field duplicate, the laboratory provided valid results for the samples that were submitted. The completeness for the reporting period was 99.5 percent.

8.0 REPORTING OF OTHER NONCOMPLIANCE

Permit Part 1, Permit condition 1.7.14 addresses the reporting of other instances of noncompliance not otherwise required to be reported pursuant to Permit Part 1, Permit conditions 1.7.10. through 1.7.13. Permit condition 1.7.14 requires that this information be reported to the NMED Secretary with the submittal of monitoring reports. Beginning with the Semi-annual VOC Data Summary Report of October 2008, other noncompliance information has been submitted with semi-annual reports due in October. These semi-annual reports will continue to be the means for reporting other noncompliance. The next report of other noncompliance will be included in the Semi-annual VOC, Hydrogen, and Methane Data Summary Report due in October 2012.

Figure 1 – Example of Repository VOC Monitoring Locations and Direction of Mine Airflow (for illustration only)

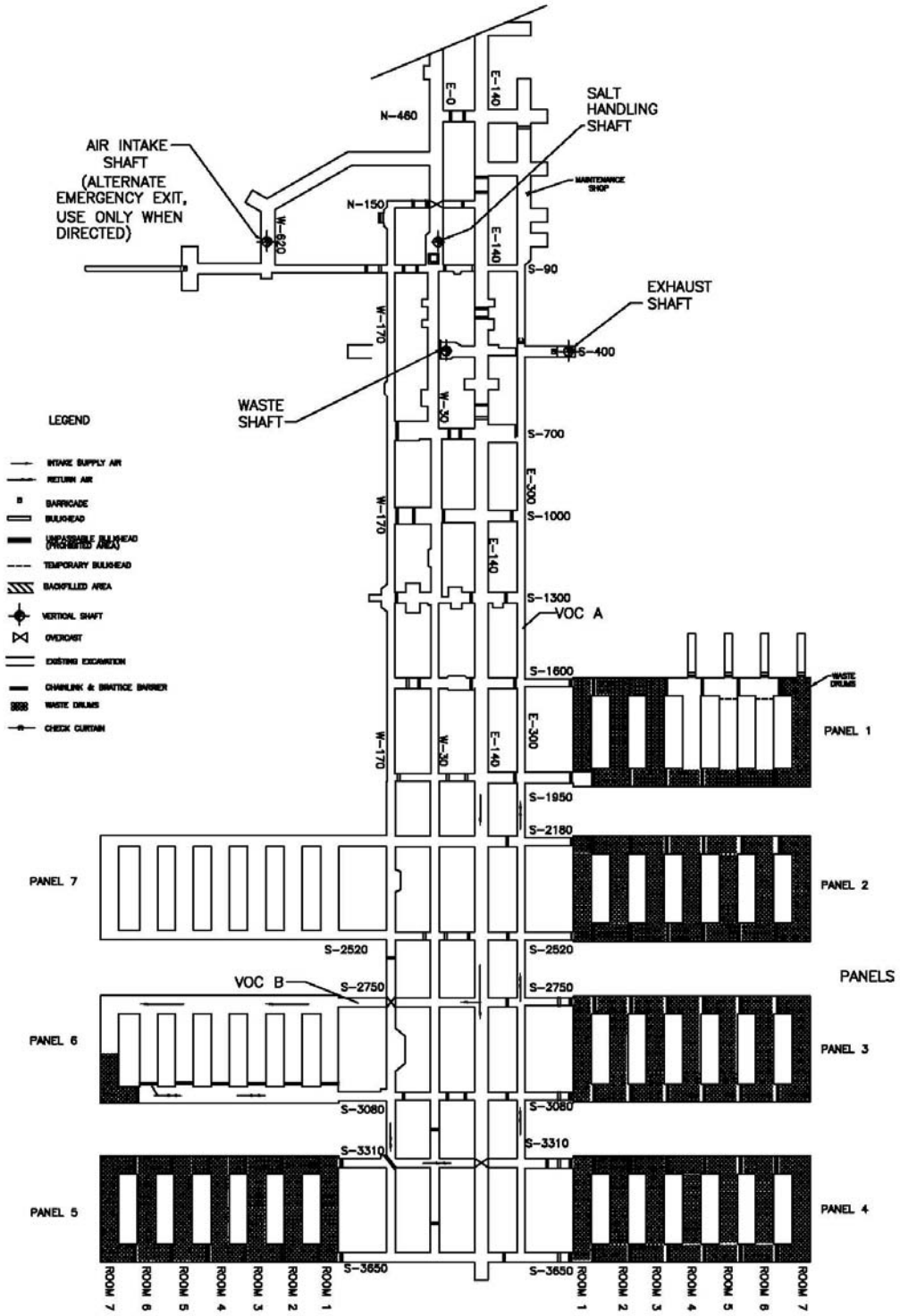


Figure 2 – Typical Disposal Room VOC Monitoring Locations

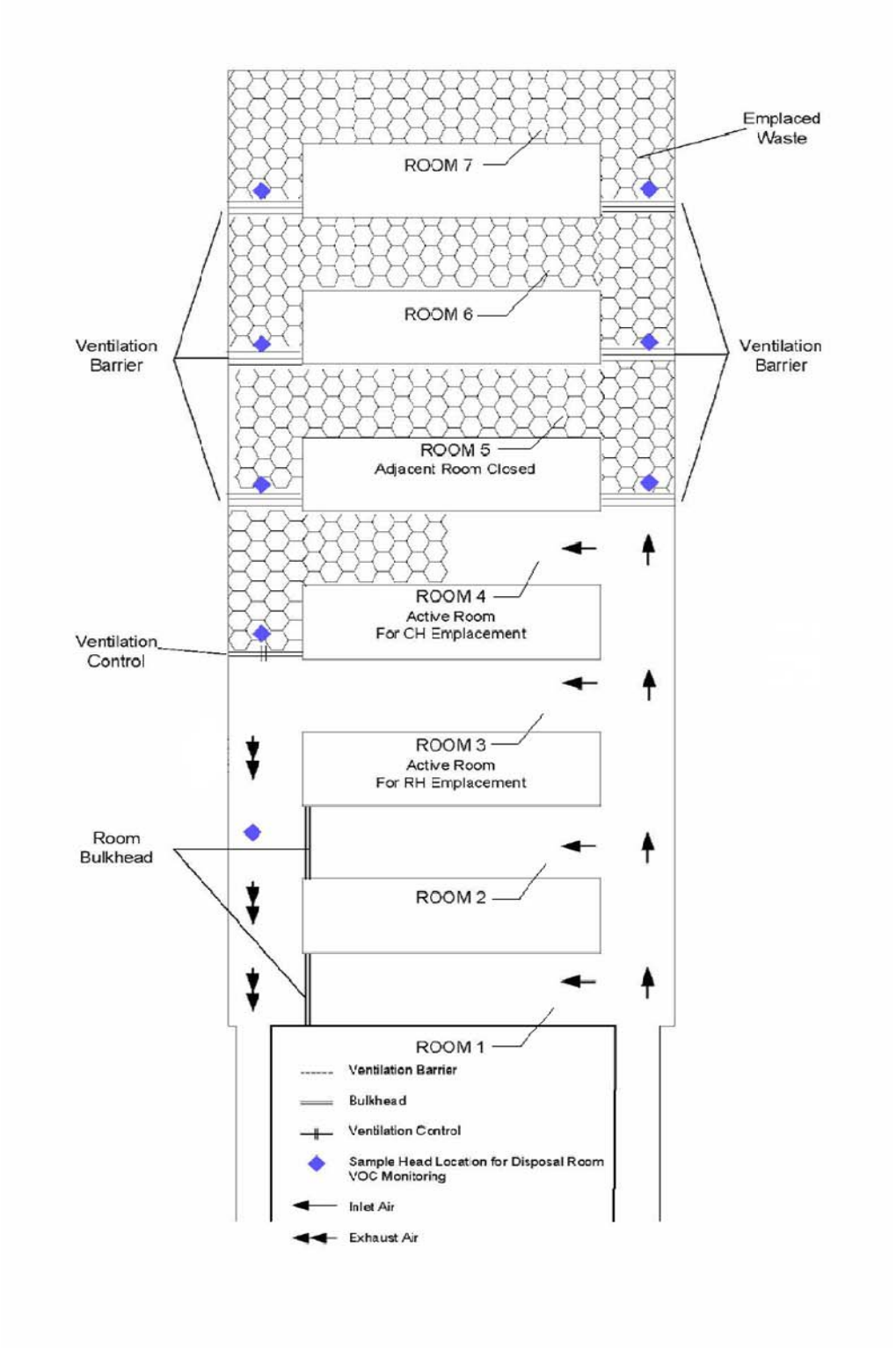
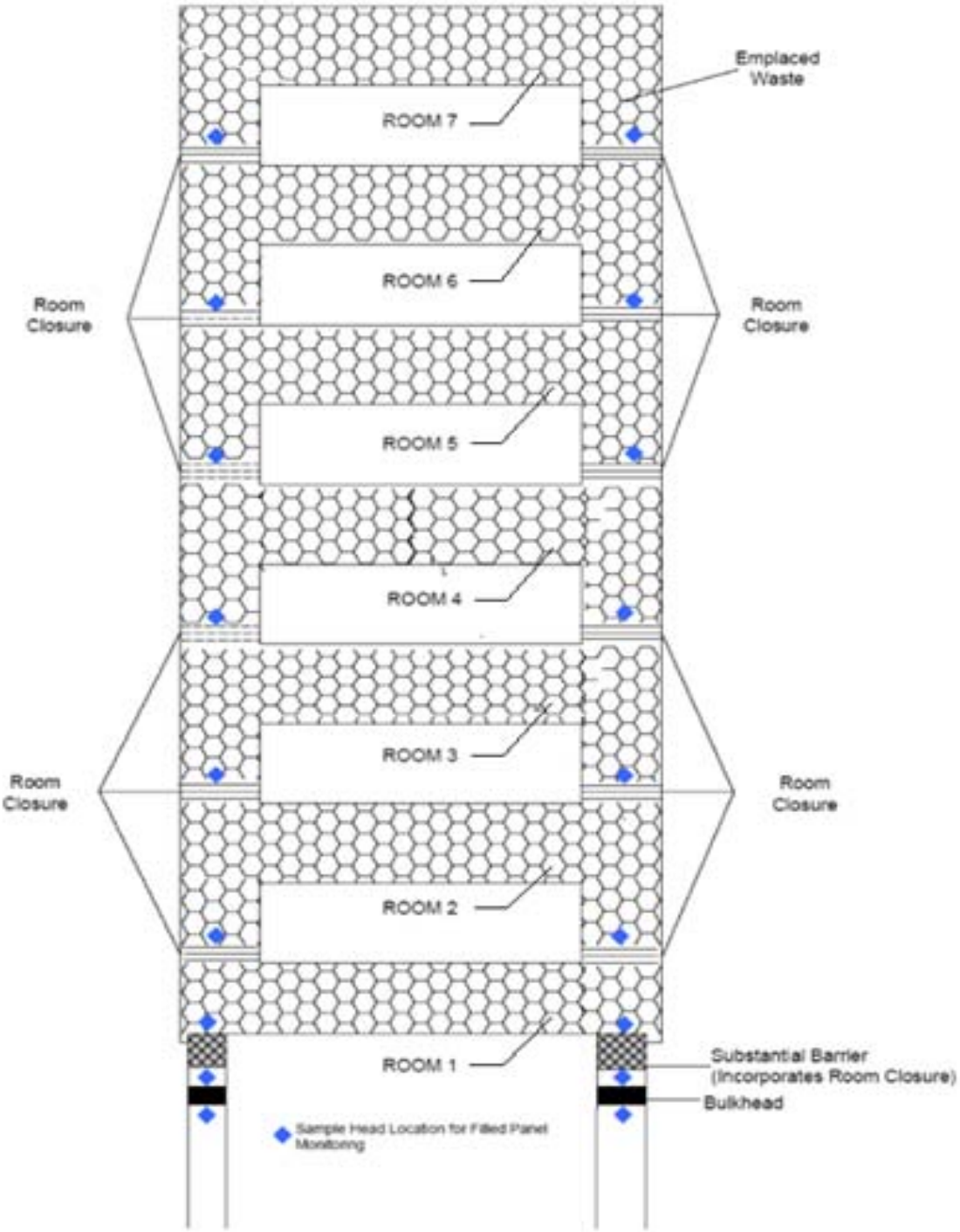


Figure 3 – Typical Hydrogen and Methane Monitoring Locations



Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
7/7/2011	26-Jul-11	1107110_01	6372	26-Jul-11	1107110_02A	6373	1,1,1-Trichloroethane	22.16*	U	22.16	590
7/7/2011	26-Jul-11	1107110_01	6372	26-Jul-11	1107110_02A	6373	1,1,2,2-Tetrachloroethane	U	U	0	50
7/7/2011	26-Jul-11	1107110_01	6372	26-Jul-11	1107110_02A	6373	1,1-Dichloroethylene	U	U	0	100
7/7/2011	26-Jul-11	1107110_01	6372	26-Jul-11	1107110_02A	6373	1,2-Dichloroethane	U	U	0	45
7/7/2011	26-Jul-11	1107110_01	6372	26-Jul-11	1107110_02A	6373	Carbon Tetrachloride	216.93*	0.65* J	216.93	960
7/7/2011	26-Jul-11	1107110_01	6372	26-Jul-11	1107110_02A	6373	Chlorobenzene	U	U	0	220
7/7/2011	26-Jul-11	1107110_01	6372	26-Jul-11	1107110_02A	6373	Chloroform	22.38*	U	22.38	180
7/7/2011	26-Jul-11	1107110_01	6372	26-Jul-11	1107110_02A	6373	Methylene Chloride	6.59* J	0.21* J	0	1930
7/7/2011	26-Jul-11	1107110_01	6372	26-Jul-11	1107110_02A	6373	Toluene	1.23* J	0.38* J	0	190
7/8/2011	26-Jul-11	1107110_03	6374	28-Jul-11	1107110_04	6375	1,1,1-Trichloroethane	21.86*	U	21.86	590
7/8/2011	26-Jul-11	1107110_03	6374	28-Jul-11	1107110_04	6375	1,1,2,2-Tetrachloroethane	U	U	0	50
7/8/2011	26-Jul-11	1107110_03	6374	28-Jul-11	1107110_04	6375	1,1-Dichloroethylene	U	U	0	100
7/8/2011	26-Jul-11	1107110_03	6374	28-Jul-11	1107110_04	6375	1,2-Dichloroethane	U	U	0	45
7/8/2011	26-Jul-11	1107110_03	6374	28-Jul-11	1107110_04	6375	Carbon Tetrachloride	216.05*	0.46* J	216.05	960
7/8/2011	26-Jul-11	1107110_03	6374	28-Jul-11	1107110_04	6375	Chlorobenzene	U	U	0	220
7/8/2011	26-Jul-11	1107110_03	6374	28-Jul-11	1107110_04	6375	Chloroform	23.09*	0.21* J	23.09	180
7/8/2011	26-Jul-11	1107110_03	6374	28-Jul-11	1107110_04	6375	Methylene Chloride	7.14* J	U	0	1930
7/8/2011	26-Jul-11	1107110_03	6374	28-Jul-11	1107110_04	6375	Toluene	1.01* J	0.50* J	0	190
7/12/2011	28-Jul-11	1107140_01	6392	28-Jul-11	1107140_02A	6393	1,1,1-Trichloroethane	17.17*	U	17.17	590
7/12/2011	28-Jul-11	1107140_01	6392	28-Jul-11	1107140_02A	6393	1,1,2,2-Tetrachloroethane	U	U	0	50
7/12/2011	28-Jul-11	1107140_01	6392	28-Jul-11	1107140_02A	6393	1,1-Dichloroethylene	U	U	0	100
7/12/2011	28-Jul-11	1107140_01	6392	28-Jul-11	1107140_02A	6393	1,2-Dichloroethane	U	U	0	45
7/12/2011	28-Jul-11	1107140_01	6392	28-Jul-11	1107140_02A	6393	Carbon Tetrachloride	95.26*	0.65* J	95.26	960
7/12/2011	28-Jul-11	1107140_01	6392	28-Jul-11	1107140_02A	6393	Chlorobenzene	U	U	0	220
7/12/2011	28-Jul-11	1107140_01	6392	28-Jul-11	1107140_02A	6393	Chloroform	9.05*	0.61* J	9.05	180
7/12/2011	28-Jul-11	1107140_01	6392	28-Jul-11	1107140_02A	6393	Methylene Chloride	4.35* J	0.26* J	0	1930
7/12/2011	28-Jul-11	1107140_01	6392	28-Jul-11	1107140_02A	6393	Toluene	1.06* J	0.47* J	0	190
7/13/2011	28-Jul-11	1107140_03	6394	28-Jul-11	1107140_04	6395	1,1,1-Trichloroethane	27.30*	U	27.3	590
7/13/2011	28-Jul-11	1107140_03	6394	28-Jul-11	1107140_04	6395	1,1,2,2-Tetrachloroethane	U	U	0	50
7/13/2011	28-Jul-11	1107140_03	6394	28-Jul-11	1107140_04	6395	1,1-Dichloroethylene	0.45* J	U	0	100
7/13/2011	28-Jul-11	1107140_03	6394	28-Jul-11	1107140_04	6395	1,2-Dichloroethane	U	U	0	45

Laboratory sample duplicate information is reported in attachment 6A.
Field duplicate information is reported in attachment 6D.

Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
7/13/2011	28-Jul-11	1107140_03	6394	28-Jul-11	1107140_04	6395	Carbon Tetrachloride	159.81*	0.25* J	159.81	960
7/13/2011	28-Jul-11	1107140_03	6394	28-Jul-11	1107140_04	6395	Chlorobenzene	U	U	0	220
7/13/2011	28-Jul-11	1107140_03	6394	28-Jul-11	1107140_04	6395	Chloroform	14.92*	U	14.92	180
7/13/2011	28-Jul-11	1107140_03	6394	28-Jul-11	1107140_04	6395	Methylene Chloride	9.63* J	U	0	1930
7/13/2011	28-Jul-11	1107140_03	6394	28-Jul-11	1107140_04	6395	Toluene	1.29* J	0.47* J	0	190
7/19/2011	29-Jul-11	1107210_02	6422	29-Jul-11	1107210_01	6421	1,1,1-Trichloroethane	12.65*	U	12.65	590
7/19/2011	29-Jul-11	1107210_02	6422	29-Jul-11	1107210_01	6421	1,1,2,2-Tetrachloroethane	U	U	0	50
7/19/2011	29-Jul-11	1107210_02	6422	29-Jul-11	1107210_01	6421	1,1-Dichloroethylene	U	U	0	100
7/19/2011	29-Jul-11	1107210_02	6422	29-Jul-11	1107210_01	6421	1,2-Dichloroethane	U	U	0	45
7/19/2011	29-Jul-11	1107210_02	6422	29-Jul-11	1107210_01	6421	Carbon Tetrachloride	72.20*	0.82* J	72.2	960
7/19/2011	29-Jul-11	1107210_02	6422	29-Jul-11	1107210_01	6421	Chlorobenzene	U	U	0	220
7/19/2011	29-Jul-11	1107210_02	6422	29-Jul-11	1107210_01	6421	Chloroform	8.93*	0.35* J	8.93	180
7/19/2011	29-Jul-11	1107210_02	6422	29-Jul-11	1107210_01	6421	Methylene Chloride	3.32* J	0.21* J	0	1930
7/19/2011	29-Jul-11	1107210_02	6422	29-Jul-11	1107210_01	6421	Toluene	1.06* J	0.49* J	0	190
7/20/2011	29-Jul-11	1107210_04	6424	29-Jul-11	1107210_03A	6423	1,1,1-Trichloroethane	25.12*	U	25.12	590
7/20/2011	29-Jul-11	1107210_04	6424	29-Jul-11	1107210_03A	6423	1,1,2,2-Tetrachloroethane	U	U	0	50
7/20/2011	29-Jul-11	1107210_04	6424	29-Jul-11	1107210_03A	6423	1,1-Dichloroethylene	U	U	0	100
7/20/2011	29-Jul-11	1107210_04	6424	29-Jul-11	1107210_03A	6423	1,2-Dichloroethane	U	U	0	45
7/20/2011	29-Jul-11	1107210_04	6424	29-Jul-11	1107210_03A	6423	Carbon Tetrachloride	156.88*	0.90* J	156.88	960
7/20/2011	29-Jul-11	1107210_04	6424	29-Jul-11	1107210_03A	6423	Chlorobenzene	U	U	0	220
7/20/2011	29-Jul-11	1107210_04	6424	29-Jul-11	1107210_03A	6423	Chloroform	14.40*	0.41* J	14.4	180
7/20/2011	29-Jul-11	1107210_04	6424	29-Jul-11	1107210_03A	6423	Methylene Chloride	6.48* J	U	0	1930
7/20/2011	29-Jul-11	1107210_04	6424	29-Jul-11	1107210_03A	6423	Toluene	0.98* J	0.35* J	0	190
7/26/2011	04-Aug-11	1107280_02	6444	04-Aug-11	1107280_01A	6443	1,1,1-Trichloroethane	34.33*	U	34.33	590
7/26/2011	04-Aug-11	1107280_02	6444	04-Aug-11	1107280_01A	6443	1,1,2,2-Tetrachloroethane	U	U	0	50
7/26/2011	04-Aug-11	1107280_02	6444	04-Aug-11	1107280_01A	6443	1,1-Dichloroethylene	U	U	0	100
7/26/2011	04-Aug-11	1107280_02	6444	04-Aug-11	1107280_01A	6443	1,2-Dichloroethane	U	U	0	45
7/26/2011	04-Aug-11	1107280_02	6444	04-Aug-11	1107280_01A	6443	Carbon Tetrachloride	230.31*	0.64* J	230.31	960
7/26/2011	04-Aug-11	1107280_02	6444	04-Aug-11	1107280_01A	6443	Chlorobenzene	U	U	0	220
7/26/2011	04-Aug-11	1107280_02	6444	04-Aug-11	1107280_01A	6443	Chloroform	20.72*	0.20* J	20.72	180
7/26/2011	04-Aug-11	1107280_02	6444	04-Aug-11	1107280_01A	6443	Methylene Chloride	8.88* J	U	0	1930
7/26/2011	04-Aug-11	1107280_02	6444	04-Aug-11	1107280_01A	6443	Toluene	1.08* J	0.28* J	0	190
7/27/2011	04-Aug-11	1107280_04	6446	04-Aug-11	1107280_03	6445	1,1,1-Trichloroethane	33.31*	U	33.31	590
7/27/2011	04-Aug-11	1107280_04	6446	04-Aug-11	1107280_03	6445	1,1,2,2-Tetrachloroethane	U	U	0	50

Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
7/27/2011	04-Aug-11	1107280_04	6446	04-Aug-11	1107280_03	6445	1,1-Dichloroethylene	U	U	0	100
7/27/2011	04-Aug-11	1107280_04	6446	04-Aug-11	1107280_03	6445	1,2-Dichloroethane	U	U	0	45
7/27/2011	04-Aug-11	1107280_04	6446	04-Aug-11	1107280_03	6445	Carbon Tetrachloride	218.28*	1.42* J	218.28	960
7/27/2011	04-Aug-11	1107280_04	6446	04-Aug-11	1107280_03	6445	Chlorobenzene	U	U	0	220
7/27/2011	04-Aug-11	1107280_04	6446	04-Aug-11	1107280_03	6445	Chloroform	19.66*	U	19.66	180
7/27/2011	04-Aug-11	1107280_04	6446	04-Aug-11	1107280_03	6445	Methylene Chloride	8.75* J	U	0	1930
7/27/2011	04-Aug-11	1107280_04	6446	04-Aug-11	1107280_03	6445	Toluene	0.90* J	0.24* J	0	190
8/2/2011	08-Aug-11	1108040_02	6454	08-Aug-11	1108040_01A	6453	1,1,1-Trichloroethane	31.22*	U	31.22	590
8/2/2011	08-Aug-11	1108040_02	6454	08-Aug-11	1108040_01A	6453	1,1,2,2-Tetrachloroethane	U	U	0	50
8/2/2011	08-Aug-11	1108040_02	6454	08-Aug-11	1108040_01A	6453	1,1-Dichloroethylene	U	U	0	100
8/2/2011	08-Aug-11	1108040_02	6454	08-Aug-11	1108040_01A	6453	1,2-Dichloroethane	U	U	0	45
8/2/2011	08-Aug-11	1108040_02	6454	08-Aug-11	1108040_01A	6453	Carbon Tetrachloride	205.51*	0.51* J	205.51	960
8/2/2011	08-Aug-11	1108040_02	6454	08-Aug-11	1108040_01A	6453	Chlorobenzene	U	U	0	220
8/2/2011	08-Aug-11	1108040_02	6454	08-Aug-11	1108040_01A	6453	Chloroform	18.46*	U	18.46	180
8/2/2011	08-Aug-11	1108040_02	6454	08-Aug-11	1108040_01A	6453	Methylene Chloride	7.31* J	0.20* J	0	1930
8/2/2011	08-Aug-11	1108040_02	6454	08-Aug-11	1108040_01A	6453	Toluene	1.02* J	0.36* J	0	190
8/3/2011	08-Aug-11	1108040_06	6458	08-Aug-11	1108040_05	6457	1,1,1-Trichloroethane	29.50*	0.28* J	29.5	590
8/3/2011	08-Aug-11	1108040_06	6458	08-Aug-11	1108040_05	6457	1,1,2,2-Tetrachloroethane	U	U	0	50
8/3/2011	08-Aug-11	1108040_06	6458	08-Aug-11	1108040_05	6457	1,1-Dichloroethylene	U	U	0	100
8/3/2011	08-Aug-11	1108040_06	6458	08-Aug-11	1108040_05	6457	1,2-Dichloroethane	U	U	0	45
8/3/2011	08-Aug-11	1108040_06	6458	08-Aug-11	1108040_05	6457	Carbon Tetrachloride	168.37*	4.97*	163.4	960
8/3/2011	08-Aug-11	1108040_06	6458	08-Aug-11	1108040_05	6457	Chlorobenzene	U	U	0	220
8/3/2011	08-Aug-11	1108040_06	6458	08-Aug-11	1108040_05	6457	Chloroform	14.50*	2.87* J	14.5	180
8/3/2011	08-Aug-11	1108040_06	6458	08-Aug-11	1108040_05	6457	Methylene Chloride	7.28* J	0.27* J	0	1930
8/3/2011	08-Aug-11	1108040_06	6458	08-Aug-11	1108040_05	6457	Toluene	0.96* J	0.50* J	0	190
8/9/2011	25-Aug-11	1108110_01	6462	24-Aug-11	1108110_02A	6463	1,1,1-Trichloroethane	18.14*	U	18.14	590
8/9/2011	25-Aug-11	1108110_01	6462	24-Aug-11	1108110_02A	6463	1,1,2,2-Tetrachloroethane	U	U	0	50
8/9/2011	25-Aug-11	1108110_01	6462	24-Aug-11	1108110_02A	6463	1,1-Dichloroethylene	U	U	0	100
8/9/2011	25-Aug-11	1108110_01	6462	24-Aug-11	1108110_02A	6463	1,2-Dichloroethane	U	U	0	45
8/9/2011	25-Aug-11	1108110_01	6462	24-Aug-11	1108110_02A	6463	Carbon Tetrachloride	113.49*	0.78* J	113.49	960
8/9/2011	25-Aug-11	1108110_01	6462	24-Aug-11	1108110_02A	6463	Chlorobenzene	U	U	0	220
8/9/2011	25-Aug-11	1108110_01	6462	24-Aug-11	1108110_02A	6463	Chloroform	11.18*	0.23* J	11.18	180
8/9/2011	25-Aug-11	1108110_01	6462	24-Aug-11	1108110_02A	6463	Methylene Chloride	4.36* J	U	0	1930
8/9/2011	25-Aug-11	1108110_01	6462	24-Aug-11	1108110_02A	6463	Toluene	1.29* J	0.37* J	0	190
8/10/2011	25-Aug-11	1108110_03	6464	24-Aug-11	1108110_04	6465	1,1,1-Trichloroethane	11.34*	U	11.34	590

Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
8/10/2011	25-Aug-11	1108110_03	6464	24-Aug-11	1108110_04	6465	1,1,2,2-Tetrachloroethane	U	U	0	50
8/10/2011	25-Aug-11	1108110_03	6464	24-Aug-11	1108110_04	6465	1,1-Dichloroethylene	U	U	0	100
8/10/2011	25-Aug-11	1108110_03	6464	24-Aug-11	1108110_04	6465	1,2-Dichloroethane	U	U	0	45
8/10/2011	25-Aug-11	1108110_03	6464	24-Aug-11	1108110_04	6465	Carbon Tetrachloride	69.53*	2.67* J	69.53	960
8/10/2011	25-Aug-11	1108110_03	6464	24-Aug-11	1108110_04	6465	Chlorobenzene	U	U	0	220
8/10/2011	25-Aug-11	1108110_03	6464	24-Aug-11	1108110_04	6465	Chloroform	6.64*	4.52*	2.12	180
8/10/2011	25-Aug-11	1108110_03	6464	24-Aug-11	1108110_04	6465	Methylene Chloride	3.36* J	0.43* J	0	1930
8/10/2011	25-Aug-11	1108110_03	6464	24-Aug-11	1108110_04	6465	Toluene	1.00* J	0.43* J	0	190
8/16/2011	25-Aug-11	1108180_01	6486	25-Aug-11	1108180_02A	6487	1,1,1-Trichloroethane	25.60*	U	25.6	590
8/16/2011	25-Aug-11	1108180_01	6486	25-Aug-11	1108180_02A	6487	1,1,2,2-Tetrachloroethane	U	U	0	50
8/16/2011	25-Aug-11	1108180_01	6486	25-Aug-11	1108180_02A	6487	1,1-Dichloroethylene	U	U	0	100
8/16/2011	25-Aug-11	1108180_01	6486	25-Aug-11	1108180_02A	6487	1,2-Dichloroethane	U	U	0	45
8/16/2011	25-Aug-11	1108180_01	6486	25-Aug-11	1108180_02A	6487	Carbon Tetrachloride	180.86*	1.73* J	180.86	960
8/16/2011	25-Aug-11	1108180_01	6486	25-Aug-11	1108180_02A	6487	Chlorobenzene	U	U	0	220
8/16/2011	25-Aug-11	1108180_01	6486	25-Aug-11	1108180_02A	6487	Chloroform	16.04*	2.81* J	16.04	180
8/16/2011	25-Aug-11	1108180_01	6486	25-Aug-11	1108180_02A	6487	Methylene Chloride	6.54* J	0.27* J	0	1930
8/16/2011	25-Aug-11	1108180_01	6486	25-Aug-11	1108180_02A	6487	Toluene	0.92* J	0.44* J	0	190
8/17/2011	25-Aug-11	1108180_03	6488	25-Aug-11	1108180_04	6489	1,1,1-Trichloroethane	19.52*	U	19.52	590
8/17/2011	25-Aug-11	1108180_03	6488	25-Aug-11	1108180_04	6489	1,1,2,2-Tetrachloroethane	U	U	0	50
8/17/2011	25-Aug-11	1108180_03	6488	25-Aug-11	1108180_04	6489	1,1-Dichloroethylene	U	U	0	100
8/17/2011	25-Aug-11	1108180_03	6488	25-Aug-11	1108180_04	6489	1,2-Dichloroethane	U	U	0	45
8/17/2011	25-Aug-11	1108180_03	6488	25-Aug-11	1108180_04	6489	Carbon Tetrachloride	114.47*	2.79* J	114.47	960
8/17/2011	25-Aug-11	1108180_03	6488	25-Aug-11	1108180_04	6489	Chlorobenzene	U	U	0	220
8/17/2011	25-Aug-11	1108180_03	6488	25-Aug-11	1108180_04	6489	Chloroform	9.58*	1.02* J	9.58	180
8/17/2011	25-Aug-11	1108180_03	6488	25-Aug-11	1108180_04	6489	Methylene Chloride	4.42* J	0.21* J	0	1930
8/17/2011	25-Aug-11	1108180_03	6488	25-Aug-11	1108180_04	6489	Toluene	1.42* J	0.52* J	0	190
8/23/2011	30-Aug-11	1108250_02	6512	30-Aug-11	1108250_01A	6511	1,1,1-Trichloroethane	18.36*	U	18.36	590
8/23/2011	30-Aug-11	1108250_02	6512	30-Aug-11	1108250_01A	6511	1,1,2,2-Tetrachloroethane	U	U	0	50
8/23/2011	30-Aug-11	1108250_02	6512	30-Aug-11	1108250_01A	6511	1,1-Dichloroethylene	U	U	0	100
8/23/2011	30-Aug-11	1108250_02	6512	30-Aug-11	1108250_01A	6511	1,2-Dichloroethane	U	U	0	45
8/23/2011	30-Aug-11	1108250_02	6512	30-Aug-11	1108250_01A	6511	Carbon Tetrachloride	125.09*	0.84* J	125.09	960
8/23/2011	30-Aug-11	1108250_02	6512	30-Aug-11	1108250_01A	6511	Chlorobenzene	U	U	0	220
8/23/2011	30-Aug-11	1108250_02	6512	30-Aug-11	1108250_01A	6511	Chloroform	11.75*	0.41* J	11.75	180
8/23/2011	30-Aug-11	1108250_02	6512	30-Aug-11	1108250_01A	6511	Methylene Chloride	4.38* J	0.19* J	0	1930
8/23/2011	30-Aug-11	1108250_02	6512	30-Aug-11	1108250_01A	6511	Toluene	1.00* J	0.33* J	0	190

Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
8/24/2011	30-Aug-11	1108250_04	6514	30-Aug-11	1108250_03	6513	1,1,1-Trichloroethane	23.04*	U	23.04	590
8/24/2011	30-Aug-11	1108250_04	6514	30-Aug-11	1108250_03	6513	1,1,2,2-Tetrachloroethane	U	U	0	50
8/24/2011	30-Aug-11	1108250_04	6514	30-Aug-11	1108250_03	6513	1,1-Dichloroethylene	U	U	0	100
8/24/2011	30-Aug-11	1108250_04	6514	30-Aug-11	1108250_03	6513	1,2-Dichloroethane	U	U	0	45
8/24/2011	30-Aug-11	1108250_04	6514	30-Aug-11	1108250_03	6513	Carbon Tetrachloride	156.62*	0.33* J	156.62	960
8/24/2011	30-Aug-11	1108250_04	6514	30-Aug-11	1108250_03	6513	Chlorobenzene	U	U	0	220
8/24/2011	30-Aug-11	1108250_04	6514	30-Aug-11	1108250_03	6513	Chloroform	13.60*	U	13.6	180
8/24/2011	30-Aug-11	1108250_04	6514	30-Aug-11	1108250_03	6513	Methylene Chloride	5.61* J	U	0	1930
8/24/2011	30-Aug-11	1108250_04	6514	30-Aug-11	1108250_03	6513	Toluene	0.93* J	0.31* J	0	190
8/30/2011	06-Sep-11	1109010_02	6522	06-Sep-11	1109010_01A	6521	1,1,1-Trichloroethane	27.95*	U	27.95	590
8/30/2011	06-Sep-11	1109010_02	6522	06-Sep-11	1109010_01A	6521	1,1,2,2-Tetrachloroethane	U	U	0	50
8/30/2011	06-Sep-11	1109010_02	6522	06-Sep-11	1109010_01A	6521	1,1-Dichloroethylene	U	U	0	100
8/30/2011	06-Sep-11	1109010_02	6522	06-Sep-11	1109010_01A	6521	1,2-Dichloroethane	U	U	0	45
8/30/2011	06-Sep-11	1109010_02	6522	06-Sep-11	1109010_01A	6521	Carbon Tetrachloride	186.62*	0.59* J	186.62	960
8/30/2011	06-Sep-11	1109010_02	6522	06-Sep-11	1109010_01A	6521	Chlorobenzene	U	U	0	220
8/30/2011	06-Sep-11	1109010_02	6522	06-Sep-11	1109010_01A	6521	Chloroform	16.17*	U	16.17	180
8/30/2011	06-Sep-11	1109010_02	6522	06-Sep-11	1109010_01A	6521	Methylene Chloride	6.13* J	0.19* J	0	1930
8/30/2011	06-Sep-11	1109010_02	6522	06-Sep-11	1109010_01A	6521	Toluene	1.27* J	0.55* J	0	190
8/31/2011	06-Sep-11	1109010_04	6524	06-Sep-11	1109010_03	6523	1,1,1-Trichloroethane	25.43*	U	25.43	590
8/31/2011	06-Sep-11	1109010_04	6524	06-Sep-11	1109010_03	6523	1,1,2,2-Tetrachloroethane	U	U	0	50
8/31/2011	06-Sep-11	1109010_04	6524	06-Sep-11	1109010_03	6523	1,1-Dichloroethylene	U	U	0	100
8/31/2011	06-Sep-11	1109010_04	6524	06-Sep-11	1109010_03	6523	1,2-Dichloroethane	U	U	0	45
8/31/2011	06-Sep-11	1109010_04	6524	06-Sep-11	1109010_03	6523	Carbon Tetrachloride	162.70*	0.34* J	162.7	960
8/31/2011	06-Sep-11	1109010_04	6524	06-Sep-11	1109010_03	6523	Chlorobenzene	U	U	0	220
8/31/2011	06-Sep-11	1109010_04	6524	06-Sep-11	1109010_03	6523	Chloroform	14.08*	U	14.08	180
8/31/2011	06-Sep-11	1109010_04	6524	06-Sep-11	1109010_03	6523	Methylene Chloride	5.82* J	0.23* J	0	1930
8/31/2011	06-Sep-11	1109010_04	6524	06-Sep-11	1109010_03	6523	Toluene	0.96* J	0.30* J	0	190
9/7/2011	13-Sep-11	1109090_01	6528	13-Sep-11	1109090_02A	6529	1,1,1-Trichloroethane	35.02*	0.38* J	35.02	590
9/7/2011	13-Sep-11	1109090_01	6528	13-Sep-11	1109090_02A	6529	1,1,2,2-Tetrachloroethane	U	U	0	50
9/7/2011	13-Sep-11	1109090_01	6528	13-Sep-11	1109090_02A	6529	1,1-Dichloroethylene	1.63* J	U	0	100
9/7/2011	13-Sep-11	1109090_01	6528	13-Sep-11	1109090_02A	6529	1,2-Dichloroethane	U	U	0	45
9/7/2011	13-Sep-11	1109090_01	6528	13-Sep-11	1109090_02A	6529	Carbon Tetrachloride	252.89*	3.42* J	252.89	960
9/7/2011	13-Sep-11	1109090_01	6528	13-Sep-11	1109090_02A	6529	Chlorobenzene	U	U	0	220
9/7/2011	13-Sep-11	1109090_01	6528	13-Sep-11	1109090_02A	6529	Chloroform	20.73*	0.45* J	20.73	180
9/7/2011	13-Sep-11	1109090_01	6528	13-Sep-11	1109090_02A	6529	Methylene Chloride	7.74* J	0.21* J	0	1930

Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
9/7/2011	13-Sep-11	1109090_01	6528	13-Sep-11	1109090_02A	6529	Toluene	1.29* J	0.45* J	0	190
9/8/2011	13-Sep-11	1109090_03	6530(R)	13-Sep-11	1109090_04	6531	1,1,1-Trichloroethane	34.74*	0* R	34.74	590
9/8/2011	13-Sep-11	1109090_03	6530(R)	13-Sep-11	1109090_04	6531	1,1,2,2-Tetrachloroethane	U	0* R	0	50
9/8/2011	13-Sep-11	1109090_03	6530(R)	13-Sep-11	1109090_04	6531	1,1-Dichloroethylene	U	0* R	0	100
9/8/2011	13-Sep-11	1109090_03	6530(R)	13-Sep-11	1109090_04	6531	1,2-Dichloroethane	U	0* R	0	45
9/8/2011	13-Sep-11	1109090_03	6530(R)	13-Sep-11	1109090_04	6531	Carbon Tetrachloride	275.76*	0* R	275.76	960
9/8/2011	13-Sep-11	1109090_03	6530(R)	13-Sep-11	1109090_04	6531	Chlorobenzene	U	0* R	0	220
9/8/2011	13-Sep-11	1109090_03	6530(R)	13-Sep-11	1109090_04	6531	Chloroform	24.49*	0* R	24.49	180
9/8/2011	13-Sep-11	1109090_03	6530(R)	13-Sep-11	1109090_04	6531	Methylene Chloride	8.41* J	0* R	0	1930
9/8/2011	13-Sep-11	1109090_03	6530(R)	13-Sep-11	1109090_04	6531	Toluene	0.99* J	0* R	0	190
9/14/2011	15-Sep-11	1109150_02	6540	15-Sep-11	1109150_01	6539	1,1,1-Trichloroethane	21.18*	U	21.18	590
9/14/2011	15-Sep-11	1109150_02	6540	15-Sep-11	1109150_01	6539	1,1,2,2-Tetrachloroethane	U	U	0	50
9/14/2011	15-Sep-11	1109150_02	6540	15-Sep-11	1109150_01	6539	1,1-Dichloroethylene	U	U	0	100
9/14/2011	15-Sep-11	1109150_02	6540	15-Sep-11	1109150_01	6539	1,2-Dichloroethane	U	U	0	45
9/14/2011	15-Sep-11	1109150_02	6540	15-Sep-11	1109150_01	6539	Carbon Tetrachloride	138.26*	0.37* J	138.26	960
9/14/2011	15-Sep-11	1109150_02	6540	15-Sep-11	1109150_01	6539	Chlorobenzene	U	U	0	220
9/14/2011	15-Sep-11	1109150_02	6540	15-Sep-11	1109150_01	6539	Chloroform	11.03*	U	11.03	180
9/14/2011	15-Sep-11	1109150_02	6540	15-Sep-11	1109150_01	6539	Methylene Chloride	4.48* J	U	0	1930
9/14/2011	15-Sep-11	1109150_02	6540	15-Sep-11	1109150_01	6539	Toluene	0.67* J	0.27* J	0	190
9/14/2011	15-Sep-11	1109150_04	6556	15-Sep-11	1109150_03A	6555	1,1,1-Trichloroethane	26.95*	U	26.95	590
9/14/2011	15-Sep-11	1109150_04	6556	15-Sep-11	1109150_03A	6555	1,1,2,2-Tetrachloroethane	U	U	0	50
9/14/2011	15-Sep-11	1109150_04	6556	15-Sep-11	1109150_03A	6555	1,1-Dichloroethylene	U	U	0	100
9/14/2011	15-Sep-11	1109150_04	6556	15-Sep-11	1109150_03A	6555	1,2-Dichloroethane	U	U	0	45
9/14/2011	15-Sep-11	1109150_04	6556	15-Sep-11	1109150_03A	6555	Carbon Tetrachloride	200.22*	0.19* J	200.22	960
9/14/2011	15-Sep-11	1109150_04	6556	15-Sep-11	1109150_03A	6555	Chlorobenzene	U	U	0	220
9/14/2011	15-Sep-11	1109150_04	6556	15-Sep-11	1109150_03A	6555	Chloroform	17.85*	U	17.85	180
9/14/2011	15-Sep-11	1109150_04	6556	15-Sep-11	1109150_03A	6555	Methylene Chloride	6.08* J	U	0	1930
9/14/2011	15-Sep-11	1109150_04	6556	15-Sep-11	1109150_03A	6555	Toluene	0.86* J	0.40* J	0	190
9/20/2011	27-Sep-11	1109260_01	6564	27-Sep-11	1109260_02A	6565	1,1,1-Trichloroethane	34.36*	U	34.36	590
9/20/2011	27-Sep-11	1109260_01	6564	27-Sep-11	1109260_02A	6565	1,1,2,2-Tetrachloroethane	U	U	0	50
9/20/2011	27-Sep-11	1109260_01	6564	27-Sep-11	1109260_02A	6565	1,1-Dichloroethylene	0.64* J	U	0	100
9/20/2011	27-Sep-11	1109260_01	6564	27-Sep-11	1109260_02A	6565	1,2-Dichloroethane	U	U	0	45
9/20/2011	27-Sep-11	1109260_01	6564	27-Sep-11	1109260_02A	6565	Carbon Tetrachloride	216.42*	0.60* J	216.42	960
9/20/2011	27-Sep-11	1109260_01	6564	27-Sep-11	1109260_02A	6565	Chlorobenzene	U	U	0	220
9/20/2011	27-Sep-11	1109260_01	6564	27-Sep-11	1109260_02A	6565	Chloroform	18.75*	0.29* J	18.75	180

Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
9/20/2011	27-Sep-11	1109260_01	6564	27-Sep-11	1109260_02A	6565	Methylene Chloride	7.39* J	0.27* J	0	1930
9/20/2011	27-Sep-11	1109260_01	6564	27-Sep-11	1109260_02A	6565	Toluene	0.87* J	0.33* J	0	190
9/21/2011	27-Sep-11	1109260_03	6566	27-Sep-11	1109260_04	6567	1,1,1-Trichloroethane	16.92*	U	16.92	590
9/21/2011	27-Sep-11	1109260_03	6566	27-Sep-11	1109260_04	6567	1,1,2,2-Tetrachloroethane	U	U	0	50
9/21/2011	27-Sep-11	1109260_03	6566	27-Sep-11	1109260_04	6567	1,1-Dichloroethylene	U	U	0	100
9/21/2011	27-Sep-11	1109260_03	6566	27-Sep-11	1109260_04	6567	1,2-Dichloroethane	U	U	0	45
9/21/2011	27-Sep-11	1109260_03	6566	27-Sep-11	1109260_04	6567	Carbon Tetrachloride	128.73*	0.19* J	128.73	960
9/21/2011	27-Sep-11	1109260_03	6566	27-Sep-11	1109260_04	6567	Chlorobenzene	U	U	0	220
9/21/2011	27-Sep-11	1109260_03	6566	27-Sep-11	1109260_04	6567	Chloroform	10.20*	U	10.2	180
9/21/2011	27-Sep-11	1109260_03	6566	27-Sep-11	1109260_04	6567	Methylene Chloride	3.28* J	U	0	1930
9/21/2011	27-Sep-11	1109260_03	6566	27-Sep-11	1109260_04	6567	Toluene	0.90* J	0.58* J	0	190
9/27/2011	30-Sep-11	1109290_02	6590	30-Sep-11	1109290_01A	6589	1,1,1-Trichloroethane	14.72*	U	14.72	590
9/27/2011	30-Sep-11	1109290_02	6590	30-Sep-11	1109290_01A	6589	1,1,2,2-Tetrachloroethane	U	U	0	50
9/27/2011	30-Sep-11	1109290_02	6590	30-Sep-11	1109290_01A	6589	1,1-Dichloroethylene	U	U	0	100
9/27/2011	30-Sep-11	1109290_02	6590	30-Sep-11	1109290_01A	6589	1,2-Dichloroethane	U	U	0	45
9/27/2011	30-Sep-11	1109290_02	6590	30-Sep-11	1109290_01A	6589	Carbon Tetrachloride	103.93*	U	103.93	960
9/27/2011	30-Sep-11	1109290_02	6590	30-Sep-11	1109290_01A	6589	Chlorobenzene	U	U	0	220
9/27/2011	30-Sep-11	1109290_02	6590	30-Sep-11	1109290_01A	6589	Chloroform	9.29*	U	9.29	180
9/27/2011	30-Sep-11	1109290_02	6590	30-Sep-11	1109290_01A	6589	Methylene Chloride	3.64* J	U	0	1930
9/27/2011	30-Sep-11	1109290_02	6590	30-Sep-11	1109290_01A	6589	Toluene	1.24* J	1.20* J	0	190
9/28/2011	30-Sep-11	1109290_04	6592	30-Sep-11	1109290_03	6591	1,1,1-Trichloroethane	29.52*	U	29.52	590
9/28/2011	30-Sep-11	1109290_04	6592	30-Sep-11	1109290_03	6591	1,1,2,2-Tetrachloroethane	U	U	0	50
9/28/2011	30-Sep-11	1109290_04	6592	30-Sep-11	1109290_03	6591	1,1-Dichloroethylene	U	U	0	100
9/28/2011	30-Sep-11	1109290_04	6592	30-Sep-11	1109290_03	6591	1,2-Dichloroethane	U	U	0	45
9/28/2011	30-Sep-11	1109290_04	6592	30-Sep-11	1109290_03	6591	Carbon Tetrachloride	226.94*	0.39* J	226.94	960
9/28/2011	30-Sep-11	1109290_04	6592	30-Sep-11	1109290_03	6591	Chlorobenzene	U	U	0	220
9/28/2011	30-Sep-11	1109290_04	6592	30-Sep-11	1109290_03	6591	Chloroform	19.86*	U	19.86	180
9/28/2011	30-Sep-11	1109290_04	6592	30-Sep-11	1109290_03	6591	Methylene Chloride	7.08* J	0.20* J	0	1930
9/28/2011	30-Sep-11	1109290_04	6592	30-Sep-11	1109290_03	6591	Toluene	1.00* J	0.61* J	0	190
10/4/2011	10-Oct-11	1110060_03	6596	10-Oct-11	1110060_01A	6597	1,1,1-Trichloroethane	30.14*	U	30.14	590
10/4/2011	10-Oct-11	1110060_03	6596	10-Oct-11	1110060_01A	6597	1,1,2,2-Tetrachloroethane	U	U	0	50
10/4/2011	10-Oct-11	1110060_03	6596	10-Oct-11	1110060_01A	6597	1,1-Dichloroethylene	U	U	0	100
10/4/2011	10-Oct-11	1110060_03	6596	10-Oct-11	1110060_01A	6597	1,2-Dichloroethane	U	U	0	45
10/4/2011	10-Oct-11	1110060_03	6596	10-Oct-11	1110060_01A	6597	Carbon Tetrachloride	266.24*	0.66* J	266.24	960
10/4/2011	10-Oct-11	1110060_03	6596	10-Oct-11	1110060_01A	6597	Chlorobenzene	U	U	0	220

Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
10/4/2011	10-Oct-11	1110060_03	6596	10-Oct-11	1110060_01A	6597	Chloroform	24.20*	U	24.2	180
10/4/2011	10-Oct-11	1110060_03	6596	10-Oct-11	1110060_01A	6597	Methylene Chloride	7.13* J	0.19* J	0	1930
10/4/2011	10-Oct-11	1110060_03	6596	10-Oct-11	1110060_01A	6597	Toluene	0.91* J	0.30* J	0	190
10/6/2011	10-Oct-11	1110060_05	6610	10-Oct-11	1110060_06	6611	1,1,1-Trichloroethane	15.34*	U	15.34	590
10/6/2011	10-Oct-11	1110060_05	6610	10-Oct-11	1110060_06	6611	1,1,2,2-Tetrachloroethane	U	U	0	50
10/6/2011	10-Oct-11	1110060_05	6610	10-Oct-11	1110060_06	6611	1,1-Dichloroethylene	0.35* J	U	0	100
10/6/2011	10-Oct-11	1110060_05	6610	10-Oct-11	1110060_06	6611	1,2-Dichloroethane	U	U	0	45
10/6/2011	10-Oct-11	1110060_05	6610	10-Oct-11	1110060_06	6611	Carbon Tetrachloride	131.91*	0.82* J	131.91	960
10/6/2011	10-Oct-11	1110060_05	6610	10-Oct-11	1110060_06	6611	Chlorobenzene	U	U	0	220
10/6/2011	10-Oct-11	1110060_05	6610	10-Oct-11	1110060_06	6611	Chloroform	12.59*	0.66* J	12.59	180
10/6/2011	10-Oct-11	1110060_05	6610	10-Oct-11	1110060_06	6611	Methylene Chloride	3.60* J	0.27* J	0	1930
10/6/2011	10-Oct-11	1110060_05	6610	10-Oct-11	1110060_06	6611	Toluene	0.57* J	0.20* J	0	190
10/11/2011	18-Oct-11	1110130_01	6612	18-Oct-11	1110130_02	6613	1,1,1-Trichloroethane	12.54*	U	12.54	590
10/11/2011	18-Oct-11	1110130_01	6612	18-Oct-11	1110130_02	6613	1,1,2,2-Tetrachloroethane	U	U	0	50
10/11/2011	18-Oct-11	1110130_01	6612	18-Oct-11	1110130_02	6613	1,1-Dichloroethylene	0.24* J	U	0	100
10/11/2011	18-Oct-11	1110130_01	6612	18-Oct-11	1110130_02	6613	1,2-Dichloroethane	U	U	0	45
10/11/2011	18-Oct-11	1110130_01	6612	18-Oct-11	1110130_02	6613	Carbon Tetrachloride	99.73*	0.26* J	99.73	960
10/11/2011	18-Oct-11	1110130_01	6612	18-Oct-11	1110130_02	6613	Chlorobenzene	U	U	0	220
10/11/2011	18-Oct-11	1110130_01	6612	18-Oct-11	1110130_02	6613	Chloroform	9.21*	U	9.21	180
10/11/2011	18-Oct-11	1110130_01	6612	18-Oct-11	1110130_02	6613	Methylene Chloride	2.95* J	U	0	1930
10/11/2011	18-Oct-11	1110130_01	6612	18-Oct-11	1110130_02	6613	Toluene	0.45* J	0.28* J	0	190
10/12/2011	18-Oct-11	1110130_03	6614	18-Oct-11	1110130_04A	6615	1,1,1-Trichloroethane	28.45*	U	28.45	590
10/12/2011	18-Oct-11	1110130_03	6614	18-Oct-11	1110130_04A	6615	1,1,2,2-Tetrachloroethane	U	U	0	50
10/12/2011	18-Oct-11	1110130_03	6614	18-Oct-11	1110130_04A	6615	1,1-Dichloroethylene	U	U	0	100
10/12/2011	18-Oct-11	1110130_03	6614	18-Oct-11	1110130_04A	6615	1,2-Dichloroethane	U	U	0	45
10/12/2011	18-Oct-11	1110130_03	6614	18-Oct-11	1110130_04A	6615	Carbon Tetrachloride	206.95*	0.33* J	206.95	960
10/12/2011	18-Oct-11	1110130_03	6614	18-Oct-11	1110130_04A	6615	Chlorobenzene	U	U	0	220
10/12/2011	18-Oct-11	1110130_03	6614	18-Oct-11	1110130_04A	6615	Chloroform	18.99*	0.23* J	18.99	180
10/12/2011	18-Oct-11	1110130_03	6614	18-Oct-11	1110130_04A	6615	Methylene Chloride	6.73* J	0.19* J	0	1930
10/12/2011	18-Oct-11	1110130_03	6614	18-Oct-11	1110130_04A	6615	Toluene	1.37* J	0.76* J	0	190
10/18/2011	26-Oct-11	1110240_02	6640	26-Oct-11	1110240_01A	6639	1,1,1-Trichloroethane	14.01*	U	14.01	590
10/18/2011	26-Oct-11	1110240_02	6640	26-Oct-11	1110240_01A	6639	1,1,2,2-Tetrachloroethane	U	U	0	50
10/18/2011	26-Oct-11	1110240_02	6640	26-Oct-11	1110240_01A	6639	1,1-Dichloroethylene	U	U	0	100
10/18/2011	26-Oct-11	1110240_02	6640	26-Oct-11	1110240_01A	6639	1,2-Dichloroethane	U	U	0	45
10/18/2011	26-Oct-11	1110240_02	6640	26-Oct-11	1110240_01A	6639	Carbon Tetrachloride	102.66*	0.38* J	102.66	960

Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
10/18/2011	26-Oct-11	1110240_02	6640	26-Oct-11	1110240_01A	6639	Chlorobenzene	U	U	0	220
10/18/2011	26-Oct-11	1110240_02	6640	26-Oct-11	1110240_01A	6639	Chloroform	8.56*	0.32* J	8.56	180
10/18/2011	26-Oct-11	1110240_02	6640	26-Oct-11	1110240_01A	6639	Methylene Chloride	2.69* J	0.19* J	0	1930
10/18/2011	26-Oct-11	1110240_02	6640	26-Oct-11	1110240_01A	6639	Toluene	0.78* J	0.42* J	0	190
10/19/2011	26-Oct-11	1110240_04	6642	26-Oct-11	1110240_03	6641	1,1,1-Trichloroethane	19.26*	U	19.26	590
10/19/2011	26-Oct-11	1110240_04	6642	26-Oct-11	1110240_03	6641	1,1,2,2-Tetrachloroethane	U	U	0	50
10/19/2011	26-Oct-11	1110240_04	6642	26-Oct-11	1110240_03	6641	1,1-Dichloroethylene	U	U	0	100
10/19/2011	26-Oct-11	1110240_04	6642	26-Oct-11	1110240_03	6641	1,2-Dichloroethane	U	U	0	45
10/19/2011	26-Oct-11	1110240_04	6642	26-Oct-11	1110240_03	6641	Carbon Tetrachloride	149.45*	0.22* J	149.45	960
10/19/2011	26-Oct-11	1110240_04	6642	26-Oct-11	1110240_03	6641	Chlorobenzene	U	U	0	220
10/19/2011	26-Oct-11	1110240_04	6642	26-Oct-11	1110240_03	6641	Chloroform	12.85*	U	12.85	180
10/19/2011	26-Oct-11	1110240_04	6642	26-Oct-11	1110240_03	6641	Methylene Chloride	4.38* J	0.26* J	0	1930
10/19/2011	26-Oct-11	1110240_04	6642	26-Oct-11	1110240_03	6641	Toluene	0.79* J	0.43* J	0	190
10/25/2011	07-Nov-11	1110270_02	6674	07-Nov-11	1110270_01A	6673	1,1,1-Trichloroethane	31.86*	U	31.86	590
10/25/2011	07-Nov-11	1110270_02	6674	07-Nov-11	1110270_01A	6673	1,1,2,2-Tetrachloroethane	U	U	0	50
10/25/2011	07-Nov-11	1110270_02	6674	07-Nov-11	1110270_01A	6673	1,1-Dichloroethylene	U	U	0	100
10/25/2011	07-Nov-11	1110270_02	6674	07-Nov-11	1110270_01A	6673	1,2-Dichloroethane	U	U	0	45
10/25/2011	07-Nov-11	1110270_02	6674	07-Nov-11	1110270_01A	6673	Carbon Tetrachloride	264.75*	0.55* J	264.75	960
10/25/2011	07-Nov-11	1110270_02	6674	07-Nov-11	1110270_01A	6673	Chlorobenzene	U	U	0	220
10/25/2011	07-Nov-11	1110270_02	6674	07-Nov-11	1110270_01A	6673	Chloroform	25.97*	0.44* J	25.97	180
10/25/2011	07-Nov-11	1110270_02	6674	07-Nov-11	1110270_01A	6673	Methylene Chloride	7.57* J	U	0	1930
10/25/2011	07-Nov-11	1110270_02	6674	07-Nov-11	1110270_01A	6673	Toluene	0.80* J	0.42* J	0	190
10/26/2011	07-Nov-11	1110270_04	6676	07-Nov-11	1110270_03	6675	1,1,1-Trichloroethane	25.38*	U	25.38	590
10/26/2011	07-Nov-11	1110270_04	6676	07-Nov-11	1110270_03	6675	1,1,2,2-Tetrachloroethane	U	U	0	50
10/26/2011	07-Nov-11	1110270_04	6676	07-Nov-11	1110270_03	6675	1,1-Dichloroethylene	U	U	0	100
10/26/2011	07-Nov-11	1110270_04	6676	07-Nov-11	1110270_03	6675	1,2-Dichloroethane	U	U	0	45
10/26/2011	07-Nov-11	1110270_04	6676	07-Nov-11	1110270_03	6675	Carbon Tetrachloride	206.64*	0.92* J	206.64	960
10/26/2011	07-Nov-11	1110270_04	6676	07-Nov-11	1110270_03	6675	Chlorobenzene	U	U	0	220
10/26/2011	07-Nov-11	1110270_04	6676	07-Nov-11	1110270_03	6675	Chloroform	20.36*	0.25* J	20.36	180
10/26/2011	07-Nov-11	1110270_04	6676	07-Nov-11	1110270_03	6675	Methylene Chloride	6.11* J	0.20* J	0	1930
10/26/2011	07-Nov-11	1110270_04	6676	07-Nov-11	1110270_03	6675	Toluene	0.98* J	0.89* J	0	190
11/1/2011	09-Nov-11	1111030_01	6684	09-Nov-11	1111030_02A	6685	1,1,1-Trichloroethane	17.03*	U	17.03	590
11/1/2011	09-Nov-11	1111030_01	6684	09-Nov-11	1111030_02A	6685	1,1,2,2-Tetrachloroethane	U	U	0	50
11/1/2011	09-Nov-11	1111030_01	6684	09-Nov-11	1111030_02A	6685	1,1-Dichloroethylene	0.41* J	U	0	100
11/1/2011	09-Nov-11	1111030_01	6684	09-Nov-11	1111030_02A	6685	1,2-Dichloroethane	U	U	0	45

Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
11/1/2011	09-Nov-11	1111030_01	6684	09-Nov-11	1111030_02A	6685	Carbon Tetrachloride	111.07*	0.21* J	111.07	960
11/1/2011	09-Nov-11	1111030_01	6684	09-Nov-11	1111030_02A	6685	Chlorobenzene	U	U	0	220
11/1/2011	09-Nov-11	1111030_01	6684	09-Nov-11	1111030_02A	6685	Chloroform	9.85*	U	9.85	180
11/1/2011	09-Nov-11	1111030_01	6684	09-Nov-11	1111030_02A	6685	Methylene Chloride	3.72* J	U	0	1930
11/1/2011	09-Nov-11	1111030_01	6684	09-Nov-11	1111030_02A	6685	Toluene	0.76* J	0.27* J	0	190
11/2/2011	09-Nov-11	1111030_03	6686	09-Nov-11	1111030_04	6687	1,1,1-Trichloroethane	15.31*	U	15.31	590
11/2/2011	09-Nov-11	1111030_03	6686	09-Nov-11	1111030_04	6687	1,1,2,2-Tetrachloroethane	U	U	0	50
11/2/2011	09-Nov-11	1111030_03	6686	09-Nov-11	1111030_04	6687	1,1-Dichloroethylene	U	U	0	100
11/2/2011	09-Nov-11	1111030_03	6686	09-Nov-11	1111030_04	6687	1,2-Dichloroethane	U	U	0	45
11/2/2011	09-Nov-11	1111030_03	6686	09-Nov-11	1111030_04	6687	Carbon Tetrachloride	78.50*	U	78.5	960
11/2/2011	09-Nov-11	1111030_03	6686	09-Nov-11	1111030_04	6687	Chlorobenzene	U	U	0	220
11/2/2011	09-Nov-11	1111030_03	6686	09-Nov-11	1111030_04	6687	Chloroform	6.19*	U	6.19	180
11/2/2011	09-Nov-11	1111030_03	6686	09-Nov-11	1111030_04	6687	Methylene Chloride	3.06* J	U	0	1930
11/2/2011	09-Nov-11	1111030_03	6686	09-Nov-11	1111030_04	6687	Toluene	0.78* J	0.41* J	0	190
11/8/2011	15-Nov-11	1111100_02	6712	15-Nov-11	1111100_01A	6711	1,1,1-Trichloroethane	19.53*	U	19.53	590
11/8/2011	15-Nov-11	1111100_02	6712	15-Nov-11	1111100_01A	6711	1,1,2,2-Tetrachloroethane	U	U	0	50
11/8/2011	15-Nov-11	1111100_02	6712	15-Nov-11	1111100_01A	6711	1,1-Dichloroethylene	U	U	0	100
11/8/2011	15-Nov-11	1111100_02	6712	15-Nov-11	1111100_01A	6711	1,2-Dichloroethane	U	U	0	45
11/8/2011	15-Nov-11	1111100_02	6712	15-Nov-11	1111100_01A	6711	Carbon Tetrachloride	96.14*	U	96.14	960
11/8/2011	15-Nov-11	1111100_02	6712	15-Nov-11	1111100_01A	6711	Chlorobenzene	U	U	0	220
11/8/2011	15-Nov-11	1111100_02	6712	15-Nov-11	1111100_01A	6711	Chloroform	7.62*	U	7.62	180
11/8/2011	15-Nov-11	1111100_02	6712	15-Nov-11	1111100_01A	6711	Methylene Chloride	4.06* J	0.16* J	0	1930
11/8/2011	15-Nov-11	1111100_02	6712	15-Nov-11	1111100_01A	6711	Toluene	0.37* J	0.18* J	0	190
11/9/2011	15-Nov-11	1111100_04	6714	15-Nov-11	1111100_03	6713	1,1,1-Trichloroethane	19.11*	U	19.11	590
11/9/2011	15-Nov-11	1111100_04	6714	15-Nov-11	1111100_03	6713	1,1,2,2-Tetrachloroethane	U	U	0	50
11/9/2011	15-Nov-11	1111100_04	6714	15-Nov-11	1111100_03	6713	1,1-Dichloroethylene	U	U	0	100
11/9/2011	15-Nov-11	1111100_04	6714	15-Nov-11	1111100_03	6713	1,2-Dichloroethane	U	U	0	45
11/9/2011	15-Nov-11	1111100_04	6714	15-Nov-11	1111100_03	6713	Carbon Tetrachloride	99.30*	U	99.3	960
11/9/2011	15-Nov-11	1111100_04	6714	15-Nov-11	1111100_03	6713	Chlorobenzene	U	U	0	220
11/9/2011	15-Nov-11	1111100_04	6714	15-Nov-11	1111100_03	6713	Chloroform	8.07*	U	8.07	180
11/9/2011	15-Nov-11	1111100_04	6714	15-Nov-11	1111100_03	6713	Methylene Chloride	3.75* J	U	0	1930
11/9/2011	15-Nov-11	1111100_04	6714	15-Nov-11	1111100_03	6713	Toluene	0.72* J	0.48* J	0	190
11/15/2011	22-Nov-11	1111170_02	6736	22-Nov-11	1111170_01A	6735	1,1,1-Trichloroethane	21.16*	U	21.16	590
11/15/2011	22-Nov-11	1111170_02	6736	22-Nov-11	1111170_01A	6735	1,1,2,2-Tetrachloroethane	U	U	0	50
11/15/2011	22-Nov-11	1111170_02	6736	22-Nov-11	1111170_01A	6735	1,1-Dichloroethylene	U	U	0	100

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Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
11/15/2011	22-Nov-11	1111170_02	6736	22-Nov-11	1111170_01A	6735	1,2-Dichloroethane	U	U	0	45
11/15/2011	22-Nov-11	1111170_02	6736	22-Nov-11	1111170_01A	6735	Carbon Tetrachloride	112.07*	0.18* J	112.07	960
11/15/2011	22-Nov-11	1111170_02	6736	22-Nov-11	1111170_01A	6735	Chlorobenzene	U	U	0	220
11/15/2011	22-Nov-11	1111170_02	6736	22-Nov-11	1111170_01A	6735	Chloroform	9.76*	U	9.76	180
11/15/2011	22-Nov-11	1111170_02	6736	22-Nov-11	1111170_01A	6735	Methylene Chloride	4.48* J	U	0	1930
11/15/2011	22-Nov-11	1111170_02	6736	22-Nov-11	1111170_01A	6735	Toluene	1.58* J	1.52* J	0	190
11/16/2011	22-Nov-11	1111170_04	6738	22-Nov-11	1111170_03	6737	1,1,1-Trichloroethane	19.42*	U	19.42	590
11/16/2011	22-Nov-11	1111170_04	6738	22-Nov-11	1111170_03	6737	1,1,2,2-Tetrachloroethane	U	U	0	50
11/16/2011	22-Nov-11	1111170_04	6738	22-Nov-11	1111170_03	6737	1,1-Dichloroethylene	U	U	0	100
11/16/2011	22-Nov-11	1111170_04	6738	22-Nov-11	1111170_03	6737	1,2-Dichloroethane	U	U	0	45
11/16/2011	22-Nov-11	1111170_04	6738	22-Nov-11	1111170_03	6737	Carbon Tetrachloride	98.69*	0.18* J	98.69	960
11/16/2011	22-Nov-11	1111170_04	6738	22-Nov-11	1111170_03	6737	Chlorobenzene	U	U	0	220
11/16/2011	22-Nov-11	1111170_04	6738	22-Nov-11	1111170_03	6737	Chloroform	8.15*	U	8.15	180
11/16/2011	22-Nov-11	1111170_04	6738	22-Nov-11	1111170_03	6737	Methylene Chloride	4.04* J	U	0	1930
11/16/2011	22-Nov-11	1111170_04	6738	22-Nov-11	1111170_03	6737	Toluene	1.11* J	0.86* J	0	190
11/21/2011	29-Nov-11	1111280_01	6746	29-Nov-11	1111280_02A	6747	1,1,1-Trichloroethane	45.07*	U	45.07	590
11/21/2011	29-Nov-11	1111280_01	6746	29-Nov-11	1111280_02A	6747	1,1,2,2-Tetrachloroethane	U	U	0	50
11/21/2011	29-Nov-11	1111280_01	6746	29-Nov-11	1111280_02A	6747	1,1-Dichloroethylene	0.97* J	U	0	100
11/21/2011	29-Nov-11	1111280_01	6746	29-Nov-11	1111280_02A	6747	1,2-Dichloroethane	U	U	0	45
11/21/2011	29-Nov-11	1111280_01	6746	29-Nov-11	1111280_02A	6747	Carbon Tetrachloride	336.52*	1.11* J	336.52	960
11/21/2011	29-Nov-11	1111280_01	6746	29-Nov-11	1111280_02A	6747	Chlorobenzene	U	U	0	220
11/21/2011	29-Nov-11	1111280_01	6746	29-Nov-11	1111280_02A	6747	Chloroform	32.62*	U	32.62	180
11/21/2011	29-Nov-11	1111280_01	6746	29-Nov-11	1111280_02A	6747	Methylene Chloride	10.14*	0.22* J	10.14	1930
11/21/2011	29-Nov-11	1111280_01	6746	29-Nov-11	1111280_02A	6747	Toluene	1.09* J	0.72* J	0	190
11/22/2011	29-Nov-11	1111280_03	6748	29-Nov-11	1111280_04	6749	1,1,1-Trichloroethane	24.81*	U	24.81	590
11/22/2011	29-Nov-11	1111280_03	6748	29-Nov-11	1111280_04	6749	1,1,2,2-Tetrachloroethane	U	U	0	50
11/22/2011	29-Nov-11	1111280_03	6748	29-Nov-11	1111280_04	6749	1,1-Dichloroethylene	U	U	0	100
11/22/2011	29-Nov-11	1111280_03	6748	29-Nov-11	1111280_04	6749	1,2-Dichloroethane	U	U	0	45
11/22/2011	29-Nov-11	1111280_03	6748	29-Nov-11	1111280_04	6749	Carbon Tetrachloride	131.89*	U	131.89	960
11/22/2011	29-Nov-11	1111280_03	6748	29-Nov-11	1111280_04	6749	Chlorobenzene	U	U	0	220
11/22/2011	29-Nov-11	1111280_03	6748	29-Nov-11	1111280_04	6749	Chloroform	10.65*	U	10.65	180
11/22/2011	29-Nov-11	1111280_03	6748	29-Nov-11	1111280_04	6749	Methylene Chloride	4.65* J	U	0	1930
11/22/2011	29-Nov-11	1111280_03	6748	29-Nov-11	1111280_04	6749	Toluene	0.75* J	0.39* J	0	190
11/29/2011	06-Dec-11	1112010_02	6752	06-Dec-11	1112010_01A	6751	1,1,1-Trichloroethane	26.56*	U	26.56	590
11/29/2011	06-Dec-11	1112010_02	6752	06-Dec-11	1112010_01A	6751	1,1,2,2-Tetrachloroethane	U	U	0	50

Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
11/29/2011	06-Dec-11	1112010_02	6752	06-Dec-11	1112010_01A	6751	1,1-Dichloroethylene	U	U	0	100
11/29/2011	06-Dec-11	1112010_02	6752	06-Dec-11	1112010_01A	6751	1,2-Dichloroethane	U	U	0	45
11/29/2011	06-Dec-11	1112010_02	6752	06-Dec-11	1112010_01A	6751	Carbon Tetrachloride	133.64*	0.14* J	133.64	960
11/29/2011	06-Dec-11	1112010_02	6752	06-Dec-11	1112010_01A	6751	Chlorobenzene	U	U	0	220
11/29/2011	06-Dec-11	1112010_02	6752	06-Dec-11	1112010_01A	6751	Chloroform	10.73*	U	10.73	180
11/29/2011	06-Dec-11	1112010_02	6752	06-Dec-11	1112010_01A	6751	Methylene Chloride	4.03* J	U	0	1930
11/29/2011	06-Dec-11	1112010_02	6752	06-Dec-11	1112010_01A	6751	Toluene	0.86* J	0.64* J	0	190
11/30/2011	06-Dec-11	1112010_04	6754	06-Dec-11	1112010_03	6753	1,1,1-Trichloroethane	49.57*	U	49.57	590
11/30/2011	06-Dec-11	1112010_04	6754	06-Dec-11	1112010_03	6753	1,1,2,2-Tetrachloroethane	U	U	0	50
11/30/2011	06-Dec-11	1112010_04	6754	06-Dec-11	1112010_03	6753	1,1-Dichloroethylene	2.14* J	U	0	100
11/30/2011	06-Dec-11	1112010_04	6754	06-Dec-11	1112010_03	6753	1,2-Dichloroethane	U	U	0	45
11/30/2011	06-Dec-11	1112010_04	6754	06-Dec-11	1112010_03	6753	Carbon Tetrachloride	320.59*	0.28* J	320.59	960
11/30/2011	06-Dec-11	1112010_04	6754	06-Dec-11	1112010_03	6753	Chlorobenzene	U	U	0	220
11/30/2011	06-Dec-11	1112010_04	6754	06-Dec-11	1112010_03	6753	Chloroform	28.81*	U	28.81	180
11/30/2011	06-Dec-11	1112010_04	6754	06-Dec-11	1112010_03	6753	Methylene Chloride	8.35* J	U	0	1930
11/30/2011	06-Dec-11	1112010_04	6754	06-Dec-11	1112010_03	6753	Toluene	0.91* J	0.55* J	0	190
12/6/2011	12-Dec-11	1112080_01	6762	12-Dec-11	1112080_03A	6763	1,1,1-Trichloroethane	24.32*	U	24.32	590
12/6/2011	12-Dec-11	1112080_01	6762	12-Dec-11	1112080_03A	6763	1,1,2,2-Tetrachloroethane	U	U	0	50
12/6/2011	12-Dec-11	1112080_01	6762	12-Dec-11	1112080_03A	6763	1,1-Dichloroethylene	U	U	0	100
12/6/2011	12-Dec-11	1112080_01	6762	12-Dec-11	1112080_03A	6763	1,2-Dichloroethane	U	U	0	45
12/6/2011	12-Dec-11	1112080_01	6762	12-Dec-11	1112080_03A	6763	Carbon Tetrachloride	127.59*	0.13* J	127.59	960
12/6/2011	12-Dec-11	1112080_01	6762	12-Dec-11	1112080_03A	6763	Chlorobenzene	U	U	0	220
12/6/2011	12-Dec-11	1112080_01	6762	12-Dec-11	1112080_03A	6763	Chloroform	9.61*	U	9.61	180
12/6/2011	12-Dec-11	1112080_01	6762	12-Dec-11	1112080_03A	6763	Methylene Chloride	3.46* J	0.14* J	0	1930
12/6/2011	12-Dec-11	1112080_01	6762	12-Dec-11	1112080_03A	6763	Toluene	0.35* J	0.17* J	0	190
12/7/2011	12-Dec-11	1112080_05	6764	12-Dec-11	1112080_06	6765	1,1,1-Trichloroethane	19.78*	U	19.78	590
12/7/2011	12-Dec-11	1112080_05	6764	12-Dec-11	1112080_06	6765	1,1,2,2-Tetrachloroethane	U	U	0	50
12/7/2011	12-Dec-11	1112080_05	6764	12-Dec-11	1112080_06	6765	1,1-Dichloroethylene	U	U	0	100
12/7/2011	12-Dec-11	1112080_05	6764	12-Dec-11	1112080_06	6765	1,2-Dichloroethane	U	U	0	45
12/7/2011	12-Dec-11	1112080_05	6764	12-Dec-11	1112080_06	6765	Carbon Tetrachloride	104.67*	0.12* J	104.67	960
12/7/2011	12-Dec-11	1112080_05	6764	12-Dec-11	1112080_06	6765	Chlorobenzene	U	U	0	220
12/7/2011	12-Dec-11	1112080_05	6764	12-Dec-11	1112080_06	6765	Chloroform	8.68*	U	8.68	180
12/7/2011	12-Dec-11	1112080_05	6764	12-Dec-11	1112080_06	6765	Methylene Chloride	3.38* J	U	0	1930
12/7/2011	12-Dec-11	1112080_05	6764	12-Dec-11	1112080_06	6765	Toluene	0.51* J	0.44* J	0	190
12/13/2011	21-Dec-11	1112150_02	6770	21-Dec-11	1112150_01A	6769	1,1,1-Trichloroethane	28.67*	U	28.67	590

Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
12/13/2011	21-Dec-11	1112150_02	6770	21-Dec-11	1112150_01A	6769	1,1,2,2-Tetrachloroethane	U	U	0	50
12/13/2011	21-Dec-11	1112150_02	6770	21-Dec-11	1112150_01A	6769	1,1-Dichloroethylene	U	U	0	100
12/13/2011	21-Dec-11	1112150_02	6770	21-Dec-11	1112150_01A	6769	1,2-Dichloroethane	U	U	0	45
12/13/2011	21-Dec-11	1112150_02	6770	21-Dec-11	1112150_01A	6769	Carbon Tetrachloride	166.74*	0.14* J	166.74	960
12/13/2011	21-Dec-11	1112150_02	6770	21-Dec-11	1112150_01A	6769	Chlorobenzene	U	U	0	220
12/13/2011	21-Dec-11	1112150_02	6770	21-Dec-11	1112150_01A	6769	Chloroform	14.67*	U	14.67	180
12/13/2011	21-Dec-11	1112150_02	6770	21-Dec-11	1112150_01A	6769	Methylene Chloride	4.81* J	0.13* J	0	1930
12/13/2011	21-Dec-11	1112150_02	6770	21-Dec-11	1112150_01A	6769	Toluene	0.54* J	0.24* J	0	190
12/14/2011	21-Dec-11	1112150_04	6790	21-Dec-11	1112150_03	6789	1,1,1-Trichloroethane	46.91*	U	46.91	590
12/14/2011	21-Dec-11	1112150_04	6790	21-Dec-11	1112150_03	6789	1,1,2,2-Tetrachloroethane	U	U	0	50
12/14/2011	21-Dec-11	1112150_04	6790	21-Dec-11	1112150_03	6789	1,1-Dichloroethylene	U	U	0	100
12/14/2011	21-Dec-11	1112150_04	6790	21-Dec-11	1112150_03	6789	1,2-Dichloroethane	U	U	0	45
12/14/2011	21-Dec-11	1112150_04	6790	21-Dec-11	1112150_03	6789	Carbon Tetrachloride	229.35*	0.32* J	229.35	960
12/14/2011	21-Dec-11	1112150_04	6790	21-Dec-11	1112150_03	6789	Chlorobenzene	U	U	0	220
12/14/2011	21-Dec-11	1112150_04	6790	21-Dec-11	1112150_03	6789	Chloroform	18.30*	0.16* J	18.3	180
12/14/2011	21-Dec-11	1112150_04	6790	21-Dec-11	1112150_03	6789	Methylene Chloride	7.60*	0.19* J	7.6	1930
12/14/2011	21-Dec-11	1112150_04	6790	21-Dec-11	1112150_03	6789	Toluene	0.70* J	0.31* J	0	190
12/19/2011	09-Jan-12	1201030_01	6816	09-Jan-12	1201030_02A	6817	1,1,1-Trichloroethane	51.87*	U	51.87	590
12/19/2011	09-Jan-12	1201030_01	6816	09-Jan-12	1201030_02A	6817	1,1,2,2-Tetrachloroethane	U	U	0	50
12/19/2011	09-Jan-12	1201030_01	6816	09-Jan-12	1201030_02A	6817	1,1-Dichloroethylene	0.96* J	U	0	100
12/19/2011	09-Jan-12	1201030_01	6816	09-Jan-12	1201030_02A	6817	1,2-Dichloroethane	U	U	0	45
12/19/2011	09-Jan-12	1201030_01	6816	09-Jan-12	1201030_02A	6817	Carbon Tetrachloride	316.54*	0.13* J	316.54	960
12/19/2011	09-Jan-12	1201030_01	6816	09-Jan-12	1201030_02A	6817	Chlorobenzene	U	U	0	220
12/19/2011	09-Jan-12	1201030_01	6816	09-Jan-12	1201030_02A	6817	Chloroform	26.85*	0.15* J	26.85	180
12/19/2011	09-Jan-12	1201030_01	6816	09-Jan-12	1201030_02A	6817	Methylene Chloride	8.56*	0.16* J	8.56	1930
12/19/2011	09-Jan-12	1201030_01	6816	09-Jan-12	1201030_02A	6817	Toluene	0.75* J	0.35* J	0	190
12/20/2011	09-Jan-12	1201030_03	6818	09-Jan-12	1201030_04	6819	1,1,1-Trichloroethane	27.43*	U	27.43	590
12/20/2011	09-Jan-12	1201030_03	6818	09-Jan-12	1201030_04	6819	1,1,2,2-Tetrachloroethane	U	U	0	50
12/20/2011	09-Jan-12	1201030_03	6818	09-Jan-12	1201030_04	6819	1,1-Dichloroethylene	U	U	0	100
12/20/2011	09-Jan-12	1201030_03	6818	09-Jan-12	1201030_04	6819	1,2-Dichloroethane	U	U	0	45
12/20/2011	09-Jan-12	1201030_03	6818	09-Jan-12	1201030_04	6819	Carbon Tetrachloride	141.24*	0.12* J	141.24	960
12/20/2011	09-Jan-12	1201030_03	6818	09-Jan-12	1201030_04	6819	Chlorobenzene	U	U	0	220
12/20/2011	09-Jan-12	1201030_03	6818	09-Jan-12	1201030_04	6819	Chloroform	10.53*	U	10.53	180
12/20/2011	09-Jan-12	1201030_03	6818	09-Jan-12	1201030_04	6819	Methylene Chloride	3.93* J	0.13* J	0	1930
12/20/2011	09-Jan-12	1201030_03	6818	09-Jan-12	1201030_04	6819	Toluene	0.45* J	0.19* J	0	190

Attachment 1 – Comparison of Repository VOC Monitoring Concentration Differences and COC

Concentration in ppbv

Sample Date	VOC-B Analysis Date	VOC-B Lab ID	VOC-B Sample ID	VOC-A Analysis Date	VOC-A Lab ID	VOC-A Sample ID	Compound	VOC-A Result	VOC-B Result	Difference	COC
12/28/2011	09-Jan-12	1201030_07	6822	09-Jan-12	1201030_06A	6821	1,1,1-Trichloroethane	38.37*	U	38.37	590
12/28/2011	09-Jan-12	1201030_07	6822	09-Jan-12	1201030_06A	6821	1,1,2,2-Tetrachloroethane	U	U	0	50
12/28/2011	09-Jan-12	1201030_07	6822	09-Jan-12	1201030_06A	6821	1,1-Dichloroethylene	U	U	0	100
12/28/2011	09-Jan-12	1201030_07	6822	09-Jan-12	1201030_06A	6821	1,2-Dichloroethane	U	U	0	45
12/28/2011	09-Jan-12	1201030_07	6822	09-Jan-12	1201030_06A	6821	Carbon Tetrachloride	241.44*	0.09* J	241.44	960
12/28/2011	09-Jan-12	1201030_07	6822	09-Jan-12	1201030_06A	6821	Chlorobenzene	U	U	0	220
12/28/2011	09-Jan-12	1201030_07	6822	09-Jan-12	1201030_06A	6821	Chloroform	19.38*	U	19.38	180
12/28/2011	09-Jan-12	1201030_07	6822	09-Jan-12	1201030_06A	6821	Methylene Chloride	5.96*	0.11* J	5.96	1930
12/28/2011	09-Jan-12	1201030_07	6822	09-Jan-12	1201030_06A	6821	Toluene	0.48* J	0.26* J	0	190
12/29/2011	09-Jan-12	1201030_09	6824	10-Jan-12	1201030_08	6823	1,1,1-Trichloroethane	42.00*	U	42	50
12/29/2011	09-Jan-12	1201030_09	6824	10-Jan-12	1201030_08	6823	1,1,2,2-Tetrachloroethane	U	U	0	100
12/29/2011	09-Jan-12	1201030_09	6824	10-Jan-12	1201030_08	6823	1,1-Dichloroethylene	1.87* J	U	0	45
12/29/2011	09-Jan-12	1201030_09	6824	10-Jan-12	1201030_08	6823	1,2-Dichloroethane	U	U	0	960
12/29/2011	09-Jan-12	1201030_09	6824	10-Jan-12	1201030_08	6823	Carbon Tetrachloride	248.50*	0.10* J	248.5	220
12/29/2011	09-Jan-12	1201030_09	6824	10-Jan-12	1201030_08	6823	Chlorobenzene	U	U	0	180
12/29/2011	09-Jan-12	1201030_09	6824	10-Jan-12	1201030_08	6823	Chloroform	18.01*	U	18.01	1930
12/29/2011	09-Jan-12	1201030_09	6824	10-Jan-12	1201030_08	6823	Methylene Chloride	6.24*	U	6.24	190
12/29/2011	09-Jan-12	1201030_09	6824	10-Jan-12	1201030_08	6823	Toluene	0.53* J	0.35* J	0	50

Notes

J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
* = Normalized concentration.
U = Compound not detected above MDL.
!!! = Concentration exceeds the COC (not applicable in this data set).

Attachment 2 – Disposal Room VOC Monitoring Results

Attachment 2 – Disposal Room VOC Monitoring Results

P5R1E - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 1 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6378	7/5/2011	109.38	J	Carbon Tetrachloride	56-23-5
6378	7/5/2011	ND	U	Chlorobenzene	108-90-7
6378	7/5/2011	15.75	J	Chloroform	67-66-3
6378	7/5/2011	ND	U	1,2-Dichloroethane	107-06-2
6378	7/5/2011	ND	U	1,1-Dichloroethylene	75-35-4
6378	7/5/2011	1.98	J	Methylene Chloride	75-09-2
6378	7/5/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6378	7/5/2011	1.14	J	Toluene	108-88-3
6378	7/5/2011	7.20	J	1,1,1-Trichloroethane	71-55-6

P5R2I - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 2 Inlet

(Not sampled during this reporting period, Panel 5 waste emplacement ceased on 7/7/2011)

Laboratory sample duplicate information is reported in attachment 6A.
Field duplicate information is reported in attachment 6D.

Attachment 2 – Disposal Room VOC Monitoring Results

P5R2E - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 2 Exhaust

(Not sampled during this reporting period, Panel 5 waste emplacement ceased on 7/7/2011)

P5R3I - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 3 Inlet

(Not sampled during this reporting period, Panel 5 waste emplacement ceased on 7/7/2011)

P5R3E - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 3 Exhaust

(Not sampled during this reporting period, Panel 5 waste emplacement ceased on 7/7/2011)

Attachment 2 – Disposal Room VOC Monitoring Results

P5R4I - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 4 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6384	7/7/2011	1995068.88		Carbon Tetrachloride	56-23-5
6384	7/7/2011	ND	U	Chlorobenzene	108-90-7
6384	7/7/2011	257847.30		Chloroform	67-66-3
6384	7/7/2011	ND	U	1,2-Dichloroethane	107-06-2
6384	7/7/2011	ND	U	1,1-Dichloroethylene	75-35-4
6384	7/7/2011	37791.36		Methylene Chloride	75-09-2
6384	7/7/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6384	7/7/2011	U	U	Toluene	108-88-3
6384	7/7/2011	81881.28		1,1,1-Trichloroethane	71-55-6

P5R4E - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 4 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6383	7/7/2011	1866735.72		Carbon Tetrachloride	56-23-5
6383	7/7/2011	ND	U	Chlorobenzene	108-90-7
6383	7/7/2011	236196.00		Chloroform	67-66-3
6383	7/7/2011	ND	U	1,2-Dichloroethane	107-06-2
6383	7/7/2011	ND	U	1,1-Dichloroethylene	75-35-4
6383	7/7/2011	32673.78		Methylene Chloride	75-09-2
6383	7/7/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6383	7/7/2011	U	U	Toluene	108-88-3
6383	7/7/2011	76370.04		1,1,1-Trichloroethane	71-55-6

Attachment 2 – Disposal Room VOC Monitoring Results

P5R5I - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 5 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6380	7/6/2011	3323277.72		Carbon Tetrachloride	56-23-5
6380	7/6/2011	ND	U	Chlorobenzene	108-90-7
6380	7/6/2011	428302.08		Chloroform	67-66-3
6380	7/6/2011	ND	U	1,2-Dichloroethane	107-06-2
6380	7/6/2011	ND	U	1,1-Dichloroethylene	75-35-4
6380	7/6/2011	60623.64		Methylene Chloride	75-09-2
6380	7/6/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6380	7/6/2011	U	U	Toluene	108-88-3
6380	7/6/2011	137781.00		1,1,1-Trichloroethane	71-55-6

P5R5E - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 5 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6379	7/6/2011	4213736.64		Carbon Tetrachloride	56-23-5
6379	7/6/2011	ND	U	Chlorobenzene	108-90-7
6379	7/6/2011	495224.28		Chloroform	67-66-3
6379	7/6/2011	ND	U	1,2-Dichloroethane	107-06-2
6379	7/6/2011	ND	U	1,1-Dichloroethylene	75-35-4
6379	7/6/2011	63772.92		Methylene Chloride	75-09-2
6379	7/6/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6379	7/6/2011	U	U	Toluene	108-88-3
6379	7/6/2011	156676.68		1,1,1-Trichloroethane	71-55-6

Attachment 2 – Disposal Room VOC Monitoring Results

P5R6I - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 6 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6382	7/6/2011	4932953.46		Carbon Tetrachloride	56-23-5
6382	7/6/2011	ND	U	Chlorobenzene	108-90-7
6382	7/6/2011	634186.26		Chloroform	67-66-3
6382	7/6/2011	ND	U	1,2-Dichloroethane	107-06-2
6382	7/6/2011	ND	U	1,1-Dichloroethylene	75-35-4
6382	7/6/2011	67315.86		Methylene Chloride	75-09-2
6382	7/6/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6382	7/6/2011	U	U	Toluene	108-88-3
6382	7/6/2011	196042.68		1,1,1-Trichloroethane	71-55-6

P5R6E - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 6 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6381	7/6/2011	4755806.46		Carbon Tetrachloride	56-23-5
6381	7/6/2011	ND	U	Chlorobenzene	108-90-7
6381	7/6/2011	594032.94		Chloroform	67-66-3
6381	7/6/2011	ND	U	1,2-Dichloroethane	107-06-2
6381	7/6/2011	U	U	1,1-Dichloroethylene	75-35-4
6381	7/6/2011	63772.92		Methylene Chloride	75-09-2
6381	7/6/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6381	7/6/2011	U	U	Toluene	108-88-3
6381	7/6/2011	194861.70		1,1,1-Trichloroethane	71-55-6

Attachment 2 – Disposal Room VOC Monitoring Results

P5R7I - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 7 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6376	7/5/2011	6118657.38		Carbon Tetrachloride	56-23-5
6376	7/5/2011	ND	U	Chlorobenzene	108-90-7
6376	7/5/2011	753465.24		Chloroform	67-66-3
6376	7/5/2011	ND	U	1,2-Dichloroethane	107-06-2
6376	7/5/2011	ND	U	1,1-Dichloroethylene	75-35-4
6376	7/5/2011	76763.70		Methylene Chloride	75-09-2
6376	7/5/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6376	7/5/2011	U	U	Toluene	108-88-3
6376	7/5/2011	232653.06		1,1,1-Trichloroethane	71-55-6

P5R7E - Disposal Room VOC Monitoring Results in ppbv for Panel 5 Room 7 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6377	7/5/2011	4840837.02		Carbon Tetrachloride	56-23-5
6377	7/5/2011	ND	U	Chlorobenzene	108-90-7
6377	7/5/2011	627100.38		Chloroform	67-66-3
6377	7/5/2011	ND	U	1,2-Dichloroethane	107-06-2
6377	7/5/2011	ND	U	1,1-Dichloroethylene	75-35-4
6377	7/5/2011	67315.86		Methylene Chloride	75-09-2
6377	7/5/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6377	7/5/2011	U	U	Toluene	108-88-3
6377	7/5/2011	185413.86		1,1,1-Trichloroethane	71-55-6

Attachment 2 – Disposal Room VOC Monitoring Results

P6R5E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 5 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6664	10/19/2011	85.59	J	Carbon Tetrachloride	56-23-5
6664	10/19/2011	ND	U	Chlorobenzene	108-90-7
6664	10/19/2011	5.43	J	Chloroform	67-66-3
6664	10/19/2011	ND	U	1,2-Dichloroethane	107-06-2
6664	10/19/2011	ND	U	1,1-Dichloroethylene	75-35-4
6664	10/19/2011	0.57	J	Methylene Chloride	75-09-2
6664	10/19/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6664	10/19/2011	0.29	J	Toluene	108-88-3
6664	10/19/2011	11.04	J	1,1,1-Trichloroethane	71-55-6
6677	10/25/2011	90.86	J	Carbon Tetrachloride	56-23-5
6677	10/25/2011	ND	U	Chlorobenzene	108-90-7
6677	10/25/2011	8.13	J	Chloroform	67-66-3
6677	10/25/2011	U	U	1,2-Dichloroethane	107-06-2
6677	10/25/2011	ND	U	1,1-Dichloroethylene	75-35-4
6677	10/25/2011	0.80	J	Methylene Chloride	75-09-2
6677	10/25/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6677	10/25/2011	0.36	J	Toluene	108-88-3
6677	10/25/2011	8.76	J	1,1,1-Trichloroethane	71-55-6
6715	11/8/2011	43.53	J	Carbon Tetrachloride	56-23-5
6715	11/8/2011	ND	U	Chlorobenzene	108-90-7
6715	11/8/2011	3.66	J	Chloroform	67-66-3
6715	11/8/2011	U	U	1,2-Dichloroethane	107-06-2
6715	11/8/2011	ND	U	1,1-Dichloroethylene	75-35-4
6715	11/8/2011	0.36	J	Methylene Chloride	75-09-2
6715	11/8/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5

Attachment 2 – Disposal Room VOC Monitoring Results

P6R5E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 5 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6715	11/8/2011	0.14	J	Toluene	108-88-3
6715	11/8/2011	5.16	J	1,1,1-Trichloroethane	71-55-6
6750	11/22/2011	51.22	J	Carbon Tetrachloride	56-23-5
6750	11/22/2011	ND	U	Chlorobenzene	108-90-7
6750	11/22/2011	4.28	J	Chloroform	67-66-3
6750	11/22/2011	U	U	1,2-Dichloroethane	107-06-2
6750	11/22/2011	U	U	1,1-Dichloroethylene	75-35-4
6750	11/22/2011	0.47	J	Methylene Chloride	75-09-2
6750	11/22/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6750	11/22/2011	0.30	J	Toluene	108-88-3
6750	11/22/2011	6.27	J	1,1,1-Trichloroethane	71-55-6
6766	12/6/2011	111.93	J	Carbon Tetrachloride	56-23-5
6766	12/6/2011	ND	U	Chlorobenzene	108-90-7
6766	12/6/2011	8.22	J	Chloroform	67-66-3
6766	12/6/2011	ND	U	1,2-Dichloroethane	107-06-2
6766	12/6/2011	ND	U	1,1-Dichloroethylene	75-35-4
6766	12/6/2011	0.96	J	Methylene Chloride	75-09-2
6766	12/6/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6766	12/6/2011	U	U	Toluene	108-88-3
6766	12/6/2011	18.09	J	1,1,1-Trichloroethane	71-55-6
6820	12/19/2011	139.44	J	Carbon Tetrachloride	56-23-5
6820	12/19/2011	ND	U	Chlorobenzene	108-90-7
6820	12/19/2011	10.38	J	Chloroform	67-66-3
6820	12/19/2011	ND	U	1,2-Dichloroethane	107-06-2
6820	12/19/2011	ND	U	1,1-Dichloroethylene	75-35-4

Attachment 2 – Disposal Room VOC Monitoring Results

P6R5E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 5 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6820	12/19/2011	0.94	J	Methylene Chloride	75-09-2
6820	12/19/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6820	12/19/2011	0.46	J	Toluene	108-88-3
6820	12/19/2011	24.42	J	1,1,1-Trichloroethane	71-55-6

P6R6E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 6 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6397	7/13/2011	12.34	J	Carbon Tetrachloride	56-23-5
6397	7/13/2011	ND	U	Chlorobenzene	108-90-7
6397	7/13/2011	1.12	J	Chloroform	67-66-3
6397	7/13/2011	ND	U	1,2-Dichloroethane	107-06-2
6397	7/13/2011	ND	U	1,1-Dichloroethylene	75-35-4
6397	7/13/2011	0.14	J	Methylene Chloride	75-09-2
6397	7/13/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6397	7/13/2011	0.28	J	Toluene	108-88-3
6397	7/13/2011	0.96	J	1,1,1-Trichloroethane	71-55-6
6448	7/27/2011	42.03	J	Carbon Tetrachloride	56-23-5
6448	7/27/2011	ND	U	Chlorobenzene	108-90-7
6448	7/27/2011	6.52	J	Chloroform	67-66-3
6448	7/27/2011	U	U	1,2-Dichloroethane	107-06-2
6448	7/27/2011	ND	U	1,1-Dichloroethylene	75-35-4
6448	7/27/2011	0.53	J	Methylene Chloride	75-09-2
6448	7/27/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6448	7/27/2011	0.39	J	Toluene	108-88-3
6448	7/27/2011	2.43	J	1,1,1-Trichloroethane	71-55-6

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P6R6E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 6 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6468	8/10/2011	82.1	J	Carbon Tetrachloride	56-23-5
6468	8/10/2011	ND	U	Chlorobenzene	108-90-7
6468	8/10/2011	7.62	J	Chloroform	67-66-3
6468	8/10/2011	ND	U	1,2-Dichloroethane	107-06-2
6468	8/10/2011	ND	U	1,1-Dichloroethylene	75-35-4
6468	8/10/2011	1.1	J	Methylene Chloride	75-09-2
6468	8/10/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6468	8/10/2011	0.42	J	Toluene	108-88-3
6468	8/10/2011	9.02	J	1,1,1-Trichloroethane	71-55-6
6517	8/24/2011	82.40	J	Carbon Tetrachloride	56-23-5
6517	8/24/2011	ND	U	Chlorobenzene	108-90-7
6517	8/24/2011	6.46	J	Chloroform	67-66-3
6517	8/24/2011	ND	U	1,2-Dichloroethane	107-06-2
6517	8/24/2011	ND	U	1,1-Dichloroethylene	75-35-4
6517	8/24/2011	0.38	J	Methylene Chloride	75-09-2
6517	8/24/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6517	8/24/2011	0.30	J	Toluene	108-88-3
6517	8/24/2011	7.50	J	1,1,1-Trichloroethane	71-55-6
6534	9/8/2011	161.96	J	Carbon Tetrachloride	56-23-5
6534	9/8/2011	ND	U	Chlorobenzene	108-90-7
6534	9/8/2011	12.12	J	Chloroform	67-66-3
6534	9/8/2011	ND	U	1,2-Dichloroethane	107-06-2
6534	9/8/2011	ND	U	1,1-Dichloroethylene	75-35-4
6534	9/8/2011	0.76	J	Methylene Chloride	75-09-2
6534	9/8/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5

Attachment 2 – Disposal Room VOC Monitoring Results

P6R6E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 6 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6534	9/8/2011	U	U	Toluene	108-88-3
6534	9/8/2011	15.12	J	1,1,1-Trichloroethane	71-55-6
6570	9/21/2011	112.86	J	Carbon Tetrachloride	56-23-5
6570	9/21/2011	ND	U	Chlorobenzene	108-90-7
6570	9/21/2011	7.83	J	Chloroform	67-66-3
6570	9/21/2011	ND	U	1,2-Dichloroethane	107-06-2
6570	9/21/2011	ND	U	1,1-Dichloroethylene	75-35-4
6570	9/21/2011	0.63	J	Methylene Chloride	75-09-2
6570	9/21/2011	U	U	1,1,2,2-Tetrachloroethane	79-34-5
6570	9/21/2011	0.36	J	Toluene	108-88-3
6570	9/21/2011	9.24	J	1,1,1-Trichloroethane	71-55-6
6606	10/5/2011	86.97	J	Carbon Tetrachloride	56-23-5
6606	10/5/2011	ND	U	Chlorobenzene	108-90-7
6606	10/5/2011	6.15	J	Chloroform	67-66-3
6606	10/5/2011	U	U	1,2-Dichloroethane	107-06-2
6606	10/5/2011	ND	U	1,1-Dichloroethylene	75-35-4
6606	10/5/2011	0.50	J	Methylene Chloride	75-09-2
6606	10/5/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6606	10/5/2011	0.20	J	Toluene	108-88-3
6606	10/5/2011	7.59	J	1,1,1-Trichloroethane	71-55-6
6645	10/19/2011	73.68	J	Carbon Tetrachloride	56-23-5
6645	10/19/2011	ND	U	Chlorobenzene	108-90-7
6645	10/19/2011	5.22	J	Chloroform	67-66-3
6645	10/19/2011	ND	U	1,2-Dichloroethane	107-06-2
6645	10/19/2011	ND	U	1,1-Dichloroethylene	75-35-4

Attachment 2 – Disposal Room VOC Monitoring Results

P6R6E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 6 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6645	10/19/2011	0.45	J	Methylene Chloride	75-09-2
6645	10/19/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6645	10/19/2011	0.21	J	Toluene	108-88-3
6645	10/19/2011	6.71	J	1,1,1-Trichloroethane	71-55-6
6690	11/2/2011	185.80	J	Carbon Tetrachloride	56-23-5
6690	11/2/2011	ND	U	Chlorobenzene	108-90-7
6690	11/2/2011	12.88	J	Chloroform	67-66-3
6690	11/2/2011	ND	U	1,2-Dichloroethane	107-06-2
6690	11/2/2011	ND	U	1,1-Dichloroethylene	75-35-4
6690	11/2/2011	1.20	J	Methylene Chloride	75-09-2
6690	11/2/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6690	11/2/2011	U	U	Toluene	108-88-3
6690	11/2/2011	24.68	J	1,1,1-Trichloroethane	71-55-6
6742	11/16/2011	2549.34		Carbon Tetrachloride	56-23-5
6742	11/16/2011	ND	U	Chlorobenzene	108-90-7
6742	11/16/2011	178.20	J	Chloroform	67-66-3
6742	11/16/2011	ND	U	1,2-Dichloroethane	107-06-2
6742	11/16/2011	ND	U	1,1-Dichloroethylene	75-35-4
6742	11/16/2011	14.04	J	Methylene Chloride	75-09-2
6742	11/16/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6742	11/16/2011	U	U	Toluene	108-88-3
6742	11/16/2011	325.62	J	1,1,1-Trichloroethane	71-55-6
6757	11/29/2011	1157.76		Carbon Tetrachloride	56-23-5
6757	11/29/2011	ND	U	Chlorobenzene	108-90-7
6757	11/29/2011	69.12	J	Chloroform	67-66-3

Attachment 2 – Disposal Room VOC Monitoring Results

P6R6E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 6 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6757	11/29/2011	ND	U	1,2-Dichloroethane	107-06-2
6757	11/29/2011	ND	U	1,1-Dichloroethylene	75-35-4
6757	11/29/2011	5.94	J	Methylene Chloride	75-09-2
6757	11/29/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6757	11/29/2011	U	U	Toluene	108-88-3
6757	11/29/2011	147.69	J	1,1,1-Trichloroethane	71-55-6
6794	12/14/2011	1775.16		Carbon Tetrachloride	56-23-5
6794	12/14/2011	ND	U	Chlorobenzene	108-90-7
6794	12/14/2011	110.88	J	Chloroform	67-66-3
6794	12/14/2011	ND	U	1,2-Dichloroethane	107-06-2
6794	12/14/2011	ND	U	1,1-Dichloroethylene	75-35-4
6794	12/14/2011	10.08	J	Methylene Chloride	75-09-2
6794	12/14/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6794	12/14/2011	U	U	Toluene	108-88-3
6794	12/14/2011	273.6	J	1,1,1-Trichloroethane	71-55-6
6828	12/29/2011	2012.58		Carbon Tetrachloride	56-23-5
6828	12/29/2011	ND	U	Chlorobenzene	108-90-7
6828	12/29/2011	115.02	J	Chloroform	67-66-3
6828	12/29/2011	ND	U	1,2-Dichloroethane	107-06-2
6828	12/29/2011	ND	U	1,1-Dichloroethylene	75-35-4
6828	12/29/2011	11.07	J	Methylene Chloride	75-09-2
6828	12/29/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6828	12/29/2011	U	U	Toluene	108-88-3
6828	12/29/2011	293.22	J	1,1,1-Trichloroethane	71-55-6

Attachment 2 – Disposal Room VOC Monitoring Results

P6R7I - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 7 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6734	11/8/2011	2919.78		Carbon Tetrachloride	56-23-5
6734	11/8/2011	ND	U	Chlorobenzene	108-90-7
6734	11/8/2011	185.22	J	Chloroform	67-66-3
6734	11/8/2011	ND	U	1,2-Dichloroethane	107-06-2
6734	11/8/2011	U	U	1,1-Dichloroethylene	75-35-4
6734	11/8/2011	30.24	J	Methylene Chloride	75-09-2
6734	11/8/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6734	11/8/2011	U	U	Toluene	108-88-3
6734	11/8/2011	697.14		1,1,1-Trichloroethane	71-55-6
6740	11/15/2011	981.18		Carbon Tetrachloride	56-23-5
6740	11/15/2011	ND	U	Chlorobenzene	108-90-7
6740	11/15/2011	61.83	J	Chloroform	67-66-3
6740	11/15/2011	ND	U	1,2-Dichloroethane	107-06-2
6740	11/15/2011	ND	U	1,1-Dichloroethylene	75-35-4
6740	11/15/2011	8.91	J	Methylene Chloride	75-09-2
6740	11/15/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6740	11/15/2011	U	U	Toluene	108-88-3
6740	11/15/2011	195.75	J	1,1,1-Trichloroethane	71-55-6
6756	11/28/2011	27512.46		Carbon Tetrachloride	56-23-5
6756	11/28/2011	ND	U	Chlorobenzene	108-90-7
6756	11/28/2011	1535.76		Chloroform	67-66-3
6756	11/28/2011	ND	U	1,2-Dichloroethane	107-06-2
6756	11/28/2011	ND	U	1,1-Dichloroethylene	75-35-4
6756	11/28/2011	204.12	J	Methylene Chloride	75-09-2
6756	11/28/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5

Attachment 2 – Disposal Room VOC Monitoring Results

P6R7I - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 7 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6756	11/28/2011	U	U	Toluene	108-88-3
6756	11/28/2011	6186.78		1,1,1-Trichloroethane	71-55-6
6793	12/13/2011	89360.82		Carbon Tetrachloride	56-23-5
6793	12/13/2011	ND	U	Chlorobenzene	108-90-7
6793	12/13/2011	5642.46		Chloroform	67-66-3
6793	12/13/2011	ND	U	1,2-Dichloroethane	107-06-2
6793	12/13/2011	ND	U	1,1-Dichloroethylene	75-35-4
6793	12/13/2011	765.45		Methylene Chloride	75-09-2
6793	12/13/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6793	12/13/2011	U	U	Toluene	108-88-3
6793	12/13/2011	18895.68		1,1,1-Trichloroethane	71-55-6
6834	12/29/2011	110224.80		Carbon Tetrachloride	56-23-5
6834	12/29/2011	ND	U	Chlorobenzene	108-90-7
6834	12/29/2011	6145.47		Chloroform	67-66-3
6834	12/29/2011	ND	U	1,2-Dichloroethane	107-06-2
6834	12/29/2011	ND	U	1,1-Dichloroethylene	75-35-4
6834	12/29/2011	852.93		Methylene Chloride	75-09-2
6834	12/29/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6834	12/29/2011	U	U	Toluene	108-88-3
6834	12/29/2011	27446.85		1,1,1-Trichloroethane	71-55-6

Attachment 2 – Disposal Room VOC Monitoring Results

P6R7E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 7 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6396	7/12/2011	60.57	J	Carbon Tetrachloride	56-23-5
6396	7/12/2011	ND	U	Chlorobenzene	108-90-7
6396	7/12/2011	4.19	J	Chloroform	67-66-3
6396	7/12/2011	ND	U	1,2-Dichloroethane	107-06-2
6396	7/12/2011	ND	U	1,1-Dichloroethylene	75-35-4
6396	7/12/2011	0.20	J	Methylene Chloride	75-09-2
6396	7/12/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6396	7/12/2011	0.18	J	Toluene	108-88-3
6396	7/12/2011	2.73	J	1,1,1-Trichloroethane	71-55-6
6447	7/26/2011	338.58	J	Carbon Tetrachloride	56-23-5
6447	7/26/2011	ND	U	Chlorobenzene	108-90-7
6447	7/26/2011	62.55	J	Chloroform	67-66-3
6447	7/26/2011	ND	U	1,2-Dichloroethane	107-06-2
6447	7/26/2011	ND	U	1,1-Dichloroethylene	75-35-4
6447	7/26/2011	6.39	J	Methylene Chloride	75-09-2
6447	7/26/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6447	7/26/2011	0.99	J	Toluene	108-88-3
6447	7/26/2011	18.36	J	1,1,1-Trichloroethane	71-55-6
6466	8/9/2011	132.16	J	Carbon Tetrachloride	56-23-5
6466	8/9/2011	ND	U	Chlorobenzene	108-90-7
6466	8/9/2011	23.08	J	Chloroform	67-66-3
6466	8/9/2011	ND	U	1,2-Dichloroethane	107-06-2
6466	8/9/2011	ND	U	1,1-Dichloroethylene	75-35-4
6466	8/9/2011	3.04	J	Methylene Chloride	75-09-2

Attachment 2 – Disposal Room VOC Monitoring Results

P6R7E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 7 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6466	8/9/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6466	8/9/2011	0.8	J	Toluene	108-88-3
6466	8/9/2011	12.28	J	1,1,1-Trichloroethane	71-55-6
6515	8/23/2011	147.80	J	Carbon Tetrachloride	56-23-5
6515	8/23/2011	ND	U	Chlorobenzene	108-90-7
6515	8/23/2011	21.12	J	Chloroform	67-66-3
6515	8/23/2011	ND	U	1,2-Dichloroethane	107-06-2
6515	8/23/2011	ND	U	1,1-Dichloroethylene	75-35-4
6515	8/23/2011	1.52	J	Methylene Chloride	75-09-2
6515	8/23/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6515	8/23/2011	0.52	J	Toluene	108-88-3
6515	8/23/2011	9.88	J	1,1,1-Trichloroethane	71-55-6
6532	9/7/2011	1350.72		Carbon Tetrachloride	56-23-5
6532	9/7/2011	ND	U	Chlorobenzene	108-90-7
6532	9/7/2011	84.24	J	Chloroform	67-66-3
6532	9/7/2011	ND	U	1,2-Dichloroethane	107-06-2
6532	9/7/2011	ND	U	1,1-Dichloroethylene	75-35-4
6532	9/7/2011	4.32	J	Methylene Chloride	75-09-2
6532	9/7/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6532	9/7/2011	U	U	Toluene	108-88-3
6532	9/7/2011	104.04	J	1,1,1-Trichloroethane	71-55-6
6568	9/20/2011	157.23	J	Carbon Tetrachloride	56-23-5
6568	9/20/2011	ND	U	Chlorobenzene	108-90-7
6568	9/20/2011	14.01	J	Chloroform	67-66-3
6568	9/20/2011	ND	U	1,2-Dichloroethane	107-06-2

Attachment 2 – Disposal Room VOC Monitoring Results

P6R7E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 7 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6568	9/20/2011	ND	U	1,1-Dichloroethylene	75-35-4
6568	9/20/2011	0.96	J	Methylene Chloride	75-09-2
6568	9/20/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6568	9/20/2011	0.36	J	Toluene	108-88-3
6568	9/20/2011	10.59	J	1,1,1-Trichloroethane	71-55-6
6604	10/4/2011	167.43	J	Carbon Tetrachloride	56-23-5
6604	10/4/2011	ND	U	Chlorobenzene	108-90-7
6604	10/4/2011	14.01	J	Chloroform	67-66-3
6604	10/4/2011	U	U	1,2-Dichloroethane	107-06-2
6604	10/4/2011	ND	U	1,1-Dichloroethylene	75-35-4
6604	10/4/2011	1.14	J	Methylene Chloride	75-09-2
6604	10/4/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6604	10/4/2011	0.30	J	Toluene	108-88-3
6604	10/4/2011	11.64	J	1,1,1-Trichloroethane	71-55-6
6643	10/18/2011	62.10	J	Carbon Tetrachloride	56-23-5
6643	10/18/2011	ND	U	Chlorobenzene	108-90-7
6643	10/18/2011	5.37	J	Chloroform	67-66-3
6643	10/18/2011	U	U	1,2-Dichloroethane	107-06-2
6643	10/18/2011	ND	U	1,1-Dichloroethylene	75-35-4
6643	10/18/2011	0.45	J	Methylene Chloride	75-09-2
6643	10/18/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6643	10/18/2011	0.20	J	Toluene	108-88-3
6643	10/18/2011	4.52	J	1,1,1-Trichloroethane	71-55-6
6688	11/1/2011	16102.80		Carbon Tetrachloride	56-23-5
6688	11/1/2011	ND	U	Chlorobenzene	108-90-7

Attachment 2 – Disposal Room VOC Monitoring Results

P6R7E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 7 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6688	11/1/2011	1047.96		Chloroform	67-66-3
6688	11/1/2011	ND	U	1,2-Dichloroethane	107-06-2
6688	11/1/2011	ND	U	1,1-Dichloroethylene	75-35-4
6688	11/1/2011	97.98	J	Methylene Chloride	75-09-2
6688	11/1/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6688	11/1/2011	U	U	Toluene	108-88-3
6688	11/1/2011	2377.08		1,1,1-Trichloroethane	71-55-6
6739	11/15/2011	260209.26		Carbon Tetrachloride	56-23-5
6739	11/15/2011	ND	U	Chlorobenzene	108-90-7
6739	11/15/2011	17977.14		Chloroform	67-66-3
6739	11/15/2011	ND	U	1,2-Dichloroethane	107-06-2
6739	11/15/2011	ND	U	1,1-Dichloroethylene	75-35-4
6739	11/15/2011	1377.81		Methylene Chloride	75-09-2
6739	11/15/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6739	11/15/2011	U	U	Toluene	108-88-3
6739	11/15/2011	32936.22		1,1,1-Trichloroethane	71-55-6
6755	11/28/2011	252008.01		Carbon Tetrachloride	56-23-5
6755	11/28/2011	ND	U	Chlorobenzene	108-90-7
6755	11/28/2011	15418.35		Chloroform	67-66-3
6755	11/28/2011	ND	U	1,2-Dichloroethane	107-06-2
6755	11/28/2011	ND	U	1,1-Dichloroethylene	75-35-4
6755	11/28/2011	1246.59		Methylene Chloride	75-09-2
6755	11/28/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6755	11/28/2011	U	U	Toluene	108-88-3
6755	11/28/2011	32542.56		1,1,1-Trichloroethane	71-55-6

Attachment 2 – Disposal Room VOC Monitoring Results

P6R7E - Disposal Room VOC Monitoring Results in ppbv for Panel 6 Room 7 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6791	12/13/2011	298459.89		Carbon Tetrachloride	56-23-5
6791	12/13/2011	ND	U	Chlorobenzene	108-90-7
6791	12/13/2011	19617.39		Chloroform	67-66-3
6791	12/13/2011	ND	U	1,2-Dichloroethane	107-06-2
6791	12/13/2011	ND	U	1,1-Dichloroethylene	75-35-4
6791	12/13/2011	1705.86		Methylene Chloride	75-09-2
6791	12/13/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6791	12/13/2011	U	U	Toluene	108-88-3
6791	12/13/2011	44352.36		1,1,1-Trichloroethane	71-55-6
6825	12/28/2011	279367.38		Carbon Tetrachloride	56-23-5
6825	12/28/2011	ND	U	Chlorobenzene	108-90-7
6825	12/28/2011	18064.62		Chloroform	67-66-3
6825	12/28/2011	ND	U	1,2-Dichloroethane	107-06-2
6825	12/28/2011	ND	U	1,1-Dichloroethylene	75-35-4
6825	12/28/2011	1487.16		Methylene Chloride	75-09-2
6825	12/28/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6825	12/28/2011	U	U	Toluene	108-88-3
6825	12/28/2011	42165.36		1,1,1-Trichloroethane	71-55-6

Notes

J =Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
ND = Compound not detected.
U = Compound not detected above MDL.

Attachment 3 – Ongoing Disposal Room VOC Monitoring Results

P3R1E - Ongoing Disposal Room VOC Monitoring Results in ppbv for Panel 3 Room 1 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6433	7/19/2011	1846.26		Carbon Tetrachloride	56-23-5
6433	7/19/2011	ND	U	Chlorobenzene	108-90-7
6433	7/19/2011	52.92	J	Chloroform	67-66-3
6433	7/19/2011	U	U	1,2-Dichloroethane	107-06-2
6433	7/19/2011	15.12	J	1,1-Dichloroethylene	75-35-4
6433	7/19/2011	447.12	J	Methylene Chloride	75-09-2
6433	7/19/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6433	7/19/2011	26.46	J	Toluene	108-88-3
6433	7/19/2011	1574.10		1,1,1-Trichloroethane	71-55-6
6506	8/16/2011	3678.21		Carbon Tetrachloride	56-23-5
6506	8/16/2011	ND	U	Chlorobenzene	108-90-7
6506	8/16/2011	102.06	J	Chloroform	67-66-3
6506	8/16/2011	U	U	1,2-Dichloroethane	107-06-2
6506	8/16/2011	27.54	J	1,1-Dichloroethylene	75-35-4
6506	8/16/2011	795.42		Methylene Chloride	75-09-2
6506	8/16/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6506	8/16/2011	51.03	J	Toluene	108-88-3
6506	8/16/2011	3095.01		1,1,1-Trichloroethane	71-55-6
6584	9/20/2011	2102.76		Carbon Tetrachloride	56-23-5
6584	9/20/2011	ND	U	Chlorobenzene	108-90-7

Laboratory sample duplicate information is reported in attachment 6A.
Field duplicate information is reported in attachment 6D.

Attachment 3 – Ongoing Disposal Room VOC Monitoring Results

P3R1E - Ongoing Disposal Room VOC Monitoring Results in ppbv for Panel 3 Room 1 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6584	9/20/2011	70.74	J	Chloroform	67-66-3
6584	9/20/2011	U	U	1,2-Dichloroethane	107-06-2
6584	9/20/2011	17.82	J	1,1-Dichloroethylene	75-35-4
6584	9/20/2011	445.50	J	Methylene Chloride	75-09-2
6584	9/20/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6584	9/20/2011	31.86	J	Toluene	108-88-3
6584	9/20/2011	1679.40		1,1,1-Trichloroethane	71-55-6
6659	10/18/2011	1576.26		Carbon Tetrachloride	56-23-5
6659	10/18/2011	ND	U	Chlorobenzene	108-90-7
6659	10/18/2011	51.03	J	Chloroform	67-66-3
6659	10/18/2011	3.51	J	1,2-Dichloroethane	107-06-2
6659	10/18/2011	13.50	J	1,1-Dichloroethylene	75-35-4
6659	10/18/2011	303.21	J	Methylene Chloride	75-09-2
6659	10/18/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6659	10/18/2011	22.95	J	Toluene	108-88-3
6659	10/18/2011	1228.23		1,1,1-Trichloroethane	71-55-6
6729	11/8/2011	1206.63		Carbon Tetrachloride	56-23-5
6729	11/8/2011	ND	U	Chlorobenzene	108-90-7
6729	11/8/2011	45.63	J	Chloroform	67-66-3
6729	11/8/2011	U	U	1,2-Dichloroethane	107-06-2
6729	11/8/2011	10.80	J	1,1-Dichloroethylene	75-35-4
6729	11/8/2011	286.74	J	Methylene Chloride	75-09-2
6729	11/8/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5

Attachment 3 – Ongoing Disposal Room VOC Monitoring Results

P3R1E - Ongoing Disposal Room VOC Monitoring Results in ppbv for Panel 3 Room 1 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6729	11/8/2011	21.87	J	Toluene	108-88-3
6729	11/8/2011	1012.77		1,1,1-Trichloroethane	71-55-6
6784	12/6/2011	2715.12		Carbon Tetrachloride	56-23-5
6784	12/6/2011	ND	U	Chlorobenzene	108-90-7
6784	12/6/2011	77.76	J	Chloroform	67-66-3
6784	12/6/2011	U	U	1,2-Dichloroethane	107-06-2
6784	12/6/2011	23.22	J	1,1-Dichloroethylene	75-35-4
6784	12/6/2011	674.46		Methylene Chloride	75-09-2
6784	12/6/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6784	12/6/2011	45.90	J	Toluene	108-88-3
6784	12/6/2011	2504.52		1,1,1-Trichloroethane	71-55-6

Attachment 3 – Ongoing Disposal Room VOC Monitoring Results

P4R1E – Ongoing Disposal Room VOC Monitoring Results in ppbv for Panel 4 Room 1 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6414	7/12/2011	499554.54		Carbon Tetrachloride	56-23-5
6414	7/12/2011	ND	U	Chlorobenzene	108-90-7
6414	7/12/2011	41071.86		Chloroform	67-66-3
6414	7/12/2011	ND	U	1,2-Dichloroethane	107-06-2
6414	7/12/2011	ND	U	1,1-Dichloroethylene	75-35-4
6414	7/12/2011	22832.28		Methylene Chloride	75-09-2
6414	7/12/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6414	7/12/2011	U	U	Toluene	108-88-3
6414	7/12/2011	93034.98		1,1,1-Trichloroethane	71-55-6
6482	8/9/2011	228672.72		Carbon Tetrachloride	56-23-5
6482	8/9/2011	ND	U	Chlorobenzene	108-90-7
6482	8/9/2011	19537.20		Chloroform	67-66-3
6482	8/9/2011	ND	U	1,2-Dichloroethane	107-06-2
6482	8/9/2011	ND	U	1,1-Dichloroethylene	75-35-4
6482	8/9/2011	10555.92		Methylene Chloride	75-09-2
6482	8/9/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6482	8/9/2011	U	U	Toluene	108-88-3
6482	8/9/2011	43506.72		1,1,1-Trichloroethane	71-55-6
6560	9/14/2011	640484.82		Carbon Tetrachloride	56-23-5
6560	9/14/2011	ND	U	Chlorobenzene	108-90-7
6560	9/14/2011	52750.44		Chloroform	67-66-3
6560	9/14/2011	ND	U	1,2-Dichloroethane	107-06-2
6560	9/14/2011	U	U	1,1-Dichloroethylene	75-35-4

Attachment 3 – Ongoing Disposal Room VOC Monitoring Results

P4R1E – Ongoing Disposal Room VOC Monitoring Results in ppbv for Panel 4 Room 1 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6560	9/14/2011	27949.86		Methylene Chloride	75-09-2
6560	9/14/2011	U	U	1,1,2,2-Tetrachloroethane	79-34-5
6560	9/14/2011	1312.20		Toluene	108-88-3
6560	9/14/2011	123478.02		1,1,1-Trichloroethane	71-55-6
6634	10/11/2011	543906.90		Carbon Tetrachloride	56-23-5
6634	10/11/2011	ND	U	Chlorobenzene	108-90-7
6634	10/11/2011	44221.14		Chloroform	67-66-3
6634	10/11/2011	ND	U	1,2-Dichloroethane	107-06-2
6634	10/11/2011	ND	U	1,1-Dichloroethylene	75-35-4
6634	10/11/2011	21782.52		Methylene Chloride	75-09-2
6634	10/11/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6634	10/11/2011	U	U	Toluene	108-88-3
6634	10/11/2011	99464.76		1,1,1-Trichloroethane	71-55-6
6707	11/1/2011	580779.72		Carbon Tetrachloride	56-23-5
6707	11/1/2011	ND	U	Chlorobenzene	108-90-7
6707	11/1/2011	48157.74		Chloroform	67-66-3
6707	11/1/2011	ND	U	1,2-Dichloroethane	107-06-2
6707	11/1/2011	U	U	1,1-Dichloroethylene	75-35-4
6707	11/1/2011	23882.04		Methylene Chloride	75-09-2
6707	11/1/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6707	11/1/2011	1574.64		Toluene	108-88-3
6707	11/1/2011	109043.82		1,1,1-Trichloroethane	71-55-6
6811	12/13/2011	766193.58		Carbon Tetrachloride	56-23-5
6811	12/13/2011	ND	U	Chlorobenzene	108-90-7

Attachment 3 – Ongoing Disposal Room VOC Monitoring Results

P4R1E – Ongoing Disposal Room VOC Monitoring Results in ppbv for Panel 4 Room 1 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6811	12/13/2011	60492.42		Chloroform	67-66-3
6811	12/13/2011	ND	U	1,2-Dichloroethane	107-06-2
6811	12/13/2011	ND	U	1,1-Dichloroethylene	75-35-4
6811	12/13/2011	28605.96		Methylene Chloride	75-09-2
6811	12/13/2011	ND	U	1,1,2,2-Tetrachloroethane	79-34-5
6811	12/13/2011	U	U	Toluene	108-88-3
6811	12/13/2011	145391.76		1,1,1-Trichloroethane	71-55-6

Notes

J =Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
ND = Compound not detected.
U = Compound not detected above MDL.

Attachment 4A – TIC Results

Sample Number	Sample Date	Analysis Date	Estimated Concentration (ppbv)*	Compound Name	CAS Number	Sample Location
6749	11/22/2011	11/29/2011	1.04	2-Butanone	78-93-3	VOC-A
6613	10/11/2011	10/18/2011	1.4393	Benzene, 1,4-dichloro-	106-46-7	VOC-A
6713	11/9/2011	11/15/2011	1.22	Benzene, 1,4-dichloro-	106-46-7	VOC-A
6735	11/15/2011	11/22/2011	2.1	Benzene, 1,4-dichloro-	106-46-7	VOC-A
6737	11/16/2011	11/22/2011	1.65	Benzene, 1,4-dichloro-	106-46-7	VOC-A
6749	11/22/2011	11/29/2011	1.46	Benzene, 1,4-dichloro-	106-46-7	VOC-A
6639	10/18/2011	10/26/2011	1	Carbon disulfide	75-15-0	VOC-A
6421	7/19/2011	7/29/2011	7.64	Cyclotrisiloxane, hexamethyl- ###	541-05-9	VOC-A
6820	12/19/2011	1/9/2012	2.62	Cyclotrisiloxane, hexamethyl- ###	541-05-9	P6R5E
6373	7/7/2011	7/26/2011	5.48	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6375	7/8/2011	7/28/2011	6.12	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6414	7/12/2011	8/4/2011	71908.56	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P4R1E
6393	7/12/2011	7/28/2011	5.775	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6395	7/13/2011	7/28/2011	11.14	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6433	7/19/2011	7/29/2011	583.74	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P3R1E
6421	7/19/2011	7/29/2011	3.79	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6423	7/20/2011	7/29/2011	8.2	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6443	7/26/2011	8/4/2011	10.77	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6445	7/27/2011	8/4/2011	10.86	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6453	8/2/2011	8/8/2011	9.21	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6457	8/3/2011	8/8/2011	8.86	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6482	8/9/2011	8/24/2011	34175.52	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P4R1E
6463	8/9/2011	8/24/2011	5.16	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6465	8/10/2011	8/24/2011	3.4	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6506	8/16/2011	8/25/2011	1180.17	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P3R1E
6487	8/16/2011	8/25/2011	7.86	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6489	8/17/2011	8/25/2011	5.73	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6511	8/23/2011	8/30/2011	4.965	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6513	8/24/2011	8/30/2011	6.6	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6521	8/30/2011	9/6/2011	7.64	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A

Attachment 4A – TIC Results

Sample Number	Sample Date	Analysis Date	Estimated Concentration (ppbv)*	Compound Name	CAS Number	Sample Location
6523	8/31/2011	9/6/2011	7.56	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6529	9/7/2011	9/13/2011	8.32	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6531	9/8/2011	9/13/2011	9.12	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6560	9/14/2011	9/21/2011	97496.46	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P4R1E
6539	9/14/2011	9/15/2011	5.76	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6555	9/14/2011	9/15/2011	7.98	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6584	9/20/2011	9/30/2011	713.34	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P3R1E
6565	9/20/2011	9/27/2011	12.69	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6567	9/21/2011	9/27/2011	3.84	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6589	9/27/2011	9/30/2011	4.575	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6591	9/28/2011	9/30/2011	10.11	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6604	10/4/2011	10/10/2011	9.69	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E
6597	10/4/2011	10/10/2011	9.84	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6606	10/5/2011	10/10/2011	4.935	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E
6611	10/6/2011	10/10/2011	5.55	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6634	10/11/2011	10/18/2011	74270.52	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P4R1E
6613	10/11/2011	10/18/2011	4.1505	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6615	10/12/2011	10/18/2011	7.92	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6659	10/18/2011	10/26/2011	457.38	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P3R1E
6643	10/18/2011	10/26/2011	4.125	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E
6639	10/18/2011	10/26/2011	3.57	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6664	10/19/2011	10/26/2011	11.115	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E
6645	10/19/2011	10/26/2011	4.2	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E
6641	10/19/2011	10/26/2011	6	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6677	10/25/2011	11/7/2011	6.36	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E
6673	10/25/2011	11/7/2011	12.04	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6675	10/26/2011	11/7/2011	8.97	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6707	11/1/2011	11/9/2011	91722.78	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P4R1E
6688	11/1/2011	11/9/2011	2470.8	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E
6685	11/1/2011	11/9/2011	7.515	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6690	11/2/2011	11/9/2011	23.76	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E

Attachment 4A – TIC Results

Sample Number	Sample Date	Analysis Date	Estimated Concentration (ppbv)*	Compound Name	CAS Number	Sample Location
6687	11/2/2011	11/9/2011	7.01	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6729	11/8/2011	11/15/2011	447.39	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P3R1E
6715	11/8/2011	11/15/2011	4.91	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E
6734	11/8/2011	11/15/2011	1191.24	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I
6711	11/8/2011	11/15/2011	9.66	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6713	11/9/2011	11/15/2011	8.96	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6739	11/15/2011	11/22/2011	33264.27	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E
6740	11/15/2011	11/22/2011	315.36	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I
6735	11/15/2011	11/22/2011	9.555	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6742	11/16/2011	11/22/2011	320.22	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E
6737	11/16/2011	11/22/2011	7.75	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6747	11/21/2011	11/29/2011	16.86	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6750	11/22/2011	11/29/2011	5.78	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E
6749	11/22/2011	11/29/2011	10.91	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6755	11/28/2011	12/6/2011	35232.57	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E
6756	11/28/2011	12/6/2011	8952.12	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I
6757	11/29/2011	12/6/2011	149.31	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E
6751	11/29/2011	12/6/2011	10.26	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6753	11/30/2011	12/6/2011	18.72	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6784	12/6/2011	12/12/2011	888.84	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P3R1E
6766	12/6/2011	12/12/2011	135.81	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E
6763	12/6/2011	12/12/2011	24.12	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6765	12/7/2011	12/12/2011	10.74	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6811	12/13/2011	12/21/2011	111274.56	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P4R1E
6791	12/13/2011	12/21/2011	40612.59	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E
6793	12/13/2011	12/21/2011	23772.69	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I
6769	12/13/2011	12/21/2011	14.61	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6794	12/14/2011	12/21/2011	223.56	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E
6789	12/14/2011	12/21/2011	24.21	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6820	12/19/2011	1/9/2012	16.2	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E
6817	12/19/2011	1/9/2012	26.36	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A

Attachment 4A – TIC Results

Sample Number	Sample Date	Analysis Date	Estimated Concentration (ppbv)*	Compound Name	CAS Number	Sample Location
6819	12/20/2011	1/9/2012	14.24	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6825	12/28/2011	1/10/2012	37222.74	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E
6821	12/28/2011	1/9/2012	20.28	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6828	12/29/2011	1/10/2012	251.37	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E
6834	12/29/2011	1/10/2012	33176.79	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I
6823	12/29/2011	1/10/2012	22	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A
6735	11/15/2011	11/22/2011	3.51	Pentane	109-66-0	VOC-A
6737	11/16/2011	11/22/2011	2.88	Pentane	109-66-0	VOC-A
6747	11/21/2011	11/29/2011	5.07	Pentane	109-66-0	VOC-A
6750	11/22/2011	11/29/2011	4.15	Pentane	109-66-0	P6R5E
6393	7/12/2011	7/28/2011	1.695	Styrene	100-42-5	VOC-A
6421	7/19/2011	7/29/2011	2.85	Styrene	100-42-5	VOC-A
6463	8/9/2011	8/24/2011	3.735	Styrene	100-42-5	VOC-A
6465	8/10/2011	8/24/2011	2.86	Styrene	100-42-5	VOC-A
6511	8/23/2011	8/30/2011	3.315	Styrene	100-42-5	VOC-A
6639	10/18/2011	10/26/2011	1.91	Styrene	100-42-5	VOC-A
6749	11/22/2011	11/29/2011	1.7	Styrene	100-42-5	VOC-A
6751	11/29/2011	12/6/2011	2.13	Styrene	100-42-5	VOC-A

TICs associated with column bleed
*All TIC results are qualified as ”NJ.” Description found in section 1.2

Attachment 4B – Additional Requested Analytes

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6378	7/5/2011	7/26/2011	1.2	J	1,2,4-Trimethylbenzene	95-63-6	P5R1E
6377	7/5/2011	7/26/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P5R7E
6376	7/5/2011	7/26/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P5R7I
6379	7/6/2011	7/26/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P5R5E
6380	7/6/2011	7/25/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P5R5I
6381	7/6/2011	7/25/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P5R6E
6382	7/6/2011	7/25/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P5R6I
6383	7/7/2011	7/25/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P5R4E
6384	7/7/2011	7/26/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P5R4I
6373	7/7/2011	7/26/2011	0.4	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6375	7/8/2011	7/28/2011	0.28	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6414	7/12/2011	8/4/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P4R1E
6396	7/12/2011	7/28/2011	0.15	J	1,2,4-Trimethylbenzene	95-63-6	P6R7E
6393	7/12/2011	7/28/2011	0.24	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6397	7/13/2011	7/28/2011	0.18	J	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6395	7/13/2011	7/28/2011	0.16	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6433	7/19/2011	7/29/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P3R1E
6421	7/19/2011	7/29/2011	0.09	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6423	7/20/2011	7/29/2011	0.2	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6447	7/26/2011	8/4/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R7E
6443	7/26/2011	8/4/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6448	7/27/2011	8/4/2011	0.24	J	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6445	7/27/2011	8/4/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6453	8/2/2011	8/8/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6457	8/3/2011	8/8/2011	0.18	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6482	8/9/2011	8/24/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P4R1E
6466	8/9/2011	8/24/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R7E
6463	8/9/2011	8/24/2011	0.195	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6468	8/10/2011	8/24/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6465	8/10/2011	8/24/2011	0.13	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6506	8/16/2011	8/25/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P3R1E
6487	8/16/2011	8/25/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6489	8/17/2011	8/25/2011	0.165	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6515	8/23/2011	8/30/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R7E
6511	8/23/2011	8/30/2011	0.135	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6517	8/24/2011	8/30/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6513	8/24/2011	8/30/2011	0.18	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6521	8/30/2011	9/6/2011	0.22	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6523	8/31/2011	9/6/2011	0.2	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6532	9/7/2011	9/13/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R7E
6529	9/7/2011	9/13/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6534	9/8/2011	9/13/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6531	9/8/2011	9/13/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6560	9/14/2011	9/21/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P4R1E
6539	9/14/2011	9/15/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6555	9/14/2011	9/15/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6584	9/20/2011	9/30/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P3R1E
6568	9/20/2011	9/27/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R7E
6565	9/20/2011	9/27/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6570	9/21/2011	9/27/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6567	9/21/2011	9/27/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6589	9/27/2011	9/30/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6591	9/28/2011	9/30/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6604	10/4/2011	10/10/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R7E
6597	10/4/2011	10/10/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6606	10/5/2011	10/10/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6611	10/6/2011	10/10/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6634	10/11/2011	10/18/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P4R1E
6613	10/11/2011	10/18/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6615	10/12/2011	10/18/2011	0.16	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6659	10/18/2011	10/26/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P3R1E
6643	10/18/2011	10/26/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R7E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6639	10/18/2011	10/26/2011	0.07	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6664	10/19/2011	10/26/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R5E
6645	10/19/2011	10/26/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6641	10/19/2011	10/26/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6677	10/25/2011	11/7/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R5E
6673	10/25/2011	11/7/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6675	10/26/2011	11/7/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6707	11/1/2011	11/9/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P4R1E
6688	11/1/2011	11/9/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R7E
6685	11/1/2011	11/9/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6690	11/2/2011	11/9/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6687	11/2/2011	11/9/2011	0.12	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6729	11/8/2011	11/15/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P3R1E
6715	11/8/2011	11/15/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R5E
6734	11/8/2011	11/15/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R7I
6711	11/8/2011	11/15/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6713	11/9/2011	11/15/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6739	11/15/2011	11/22/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R7E
6740	11/15/2011	11/22/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R7I
6735	11/15/2011	11/22/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6742	11/16/2011	11/22/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6737	11/16/2011	11/22/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6747	11/21/2011	11/29/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6750	11/22/2011	11/29/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R5E
6749	11/22/2011	11/29/2011	0.08	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6755	11/28/2011	12/6/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R7E
6756	11/28/2011	12/6/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R7I
6757	11/29/2011	12/6/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6751	11/29/2011	12/6/2011	0.165	J	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6753	11/30/2011	12/6/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6784	12/6/2011	12/12/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P3R1E
6766	12/6/2011	12/12/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R5E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6763	12/6/2011	12/12/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6765	12/7/2011	12/12/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6811	12/13/2011	12/21/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P4R1E
6791	12/13/2011	12/21/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R7E
6793	12/13/2011	12/21/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R7I
6769	12/13/2011	12/21/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6794	12/14/2011	12/21/2011	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6789	12/14/2011	12/21/2011	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6820	12/19/2011	1/9/2012	U	U	1,2,4-Trimethylbenzene	95-63-6	P6R5E
6817	12/19/2011	1/9/2012	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6819	12/20/2011	1/9/2012	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6825	12/28/2011	1/10/2012	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R7E
6821	12/28/2011	1/9/2012	U	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6828	12/29/2011	1/10/2012	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R6E
6834	12/29/2011	1/10/2012	ND	U	1,2,4-Trimethylbenzene	95-63-6	P6R7I
6823	12/29/2011	1/10/2012	ND	U	1,2,4-Trimethylbenzene	95-63-6	VOC-A
6378	7/5/2011	7/26/2011	0.63	J	Benzene	71-43-2	P5R1E
6377	7/5/2011	7/26/2011	ND	U	Benzene	71-43-2	P5R7E
6376	7/5/2011	7/26/2011	ND	U	Benzene	71-43-2	P5R7I
6380	7/6/2011	7/25/2011	ND	U	Benzene	71-43-2	P5R5I
6379	7/6/2011	7/26/2011	ND	U	Benzene	71-43-2	P5R5E
6381	7/6/2011	7/25/2011	ND	U	Benzene	71-43-2	P5R6E
6382	7/6/2011	7/25/2011	ND	U	Benzene	71-43-2	P5R6I
6383	7/7/2011	7/25/2011	ND	U	Benzene	71-43-2	P5R4E
6384	7/7/2011	7/26/2011	ND	U	Benzene	71-43-2	P5R4I
6373	7/7/2011	7/26/2011	0.36	J	Benzene	71-43-2	VOC-A
6375	7/8/2011	7/28/2011	0.32	J	Benzene	71-43-2	VOC-A
6414	7/12/2011	8/4/2011	ND	U	Benzene	71-43-2	P4R1E
6396	7/12/2011	7/28/2011	0.27	J	Benzene	71-43-2	P6R7E
6393	7/12/2011	7/28/2011	0.54	J	Benzene	71-43-2	VOC-A
6397	7/13/2011	7/28/2011	0.23	J	Benzene	71-43-2	P6R6E
6395	7/13/2011	7/28/2011	0.5	J	Benzene	71-43-2	VOC-A

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Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6433	7/19/2011	7/29/2011	7.02	J	Benzene	71-43-2	P3R1E
6421	7/19/2011	7/29/2011	0.77	J	Benzene	71-43-2	VOC-A
6423	7/20/2011	7/29/2011	0.42	J	Benzene	71-43-2	VOC-A
6447	7/26/2011	8/4/2011	U	U	Benzene	71-43-2	P6R7E
6443	7/26/2011	8/4/2011	0.36	J	Benzene	71-43-2	VOC-A
6448	7/27/2011	8/4/2011	0.24	J	Benzene	71-43-2	P6R6E
6445	7/27/2011	8/4/2011	0.33	J	Benzene	71-43-2	VOC-A
6453	8/2/2011	8/8/2011	0.36	J	Benzene	71-43-2	VOC-A
6457	8/3/2011	8/8/2011	0.52	J	Benzene	71-43-2	VOC-A
6482	8/9/2011	8/24/2011	ND	U	Benzene	71-43-2	P4R1E
6466	8/9/2011	8/24/2011	0.68	J	Benzene	71-43-2	P6R7E
6463	8/9/2011	8/24/2011	2.175		Benzene	71-43-2	VOC-A
6468	8/10/2011	8/24/2011	0.26	J	Benzene	71-43-2	P6R6E
6465	8/10/2011	8/24/2011	0.64	J	Benzene	71-43-2	VOC-A
6506	8/16/2011	8/25/2011	12.96	J	Benzene	71-43-2	P3R1E
6487	8/16/2011	8/25/2011	0.42	J	Benzene	71-43-2	VOC-A
6489	8/17/2011	8/25/2011	0.6	J	Benzene	71-43-2	VOC-A
6515	8/23/2011	8/30/2011	U	U	Benzene	71-43-2	P6R7E
6511	8/23/2011	8/30/2011	0.435	J	Benzene	71-43-2	VOC-A
6517	8/24/2011	8/30/2011	0.26	J	Benzene	71-43-2	P6R6E
6513	8/24/2011	8/30/2011	0.48	J	Benzene	71-43-2	VOC-A
6521	8/30/2011	9/6/2011	0.56	J	Benzene	71-43-2	VOC-A
6523	8/31/2011	9/6/2011	0.4	J	Benzene	71-43-2	VOC-A
6532	9/7/2011	9/13/2011	ND	U	Benzene	71-43-2	P6R7E
6529	9/7/2011	9/13/2011	0.44	J	Benzene	71-43-2	VOC-A
6534	9/8/2011	9/13/2011	0.32	J	Benzene	71-43-2	P6R6E
6531	9/8/2011	9/13/2011	0.32	J	Benzene	71-43-2	VOC-A
6560	9/14/2011	9/21/2011	ND	U	Benzene	71-43-2	P4R1E
6539	9/14/2011	9/15/2011	0.24	J	Benzene	71-43-2	VOC-A
6555	9/14/2011	9/15/2011	0.45	J	Benzene	71-43-2	VOC-A
6584	9/20/2011	9/30/2011	8.1	J	Benzene	71-43-2	P3R1E
6568	9/20/2011	9/27/2011	0.33	J	Benzene	71-43-2	P6R7E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6565	9/20/2011	9/27/2011	0.36	J	Benzene	71-43-2	VOC-A
6570	9/21/2011	9/27/2011	0.42	J	Benzene	71-43-2	P6R6E
6567	9/21/2011	9/27/2011	0.45	J	Benzene	71-43-2	VOC-A
6589	9/27/2011	9/30/2011	0.75	J	Benzene	71-43-2	VOC-A
6591	9/28/2011	9/30/2011	0.48	J	Benzene	71-43-2	VOC-A
6604	10/4/2011	10/10/2011	0.33	J	Benzene	71-43-2	P6R7E
6597	10/4/2011	10/10/2011	0.45	J	Benzene	71-43-2	VOC-A
6606	10/5/2011	10/10/2011	0.18	J	Benzene	71-43-2	P6R6E
6611	10/6/2011	10/10/2011	0.36	J	Benzene	71-43-2	VOC-A
6634	10/11/2011	10/18/2011	ND	U	Benzene	71-43-2	P4R1E
6613	10/11/2011	10/18/2011	0.31	J	Benzene	71-43-2	VOC-A
6615	10/12/2011	10/18/2011	0.78	J	Benzene	71-43-2	VOC-A
6659	10/18/2011	10/26/2011	5.67	J	Benzene	71-43-2	P3R1E
6643	10/18/2011	10/26/2011	0.45	J	Benzene	71-43-2	P6R7E
6639	10/18/2011	10/26/2011	0.41	J	Benzene	71-43-2	VOC-A
6664	10/19/2011	10/26/2011	0.645	J	Benzene	71-43-2	P6R5E
6645	10/19/2011	10/26/2011	0.405	J	Benzene	71-43-2	P6R6E
6641	10/19/2011	10/26/2011	0.48	J	Benzene	71-43-2	VOC-A
6677	10/25/2011	11/7/2011	0.45	J	Benzene	71-43-2	P6R5E
6673	10/25/2011	11/7/2011	0.48	J	Benzene	71-43-2	VOC-A
6675	10/26/2011	11/7/2011	0.66	J	Benzene	71-43-2	VOC-A
6707	11/1/2011	11/9/2011	U	U	Benzene	71-43-2	P4R1E
6688	11/1/2011	11/9/2011	ND	U	Benzene	71-43-2	P6R7E
6685	11/1/2011	11/9/2011	0.36	J	Benzene	71-43-2	VOC-A
6690	11/2/2011	11/9/2011	U	U	Benzene	71-43-2	P6R6E
6687	11/2/2011	11/9/2011	0.57	J	Benzene	71-43-2	VOC-A
6729	11/8/2011	11/15/2011	5.67	J	Benzene	71-43-2	P3R1E
6715	11/8/2011	11/15/2011	0.23	J	Benzene	71-43-2	P6R5E
6734	11/8/2011	11/15/2011	ND	U	Benzene	71-43-2	P6R7I
6711	11/8/2011	11/15/2011	0.345	J	Benzene	71-43-2	VOC-A
6713	11/9/2011	11/15/2011	0.62	J	Benzene	71-43-2	VOC-A
6739	11/15/2011	11/22/2011	ND	U	Benzene	71-43-2	P6R7E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6740	11/15/2011	11/22/2011	ND	U	Benzene	71-43-2	P6R7I
6735	11/15/2011	11/22/2011	0.885	J	Benzene	71-43-2	VOC-A
6742	11/16/2011	11/22/2011	ND	U	Benzene	71-43-2	P6R6E
6737	11/16/2011	11/22/2011	0.85	J	Benzene	71-43-2	VOC-A
6747	11/21/2011	11/29/2011	0.66	J	Benzene	71-43-2	VOC-A
6750	11/22/2011	11/29/2011	0.48	J	Benzene	71-43-2	P6R5E
6749	11/22/2011	11/29/2011	0.44	J	Benzene	71-43-2	VOC-A
6755	11/28/2011	12/6/2011	ND	U	Benzene	71-43-2	P6R7E
6756	11/28/2011	12/6/2011	ND	U	Benzene	71-43-2	P6R7I
6757	11/29/2011	12/6/2011	ND	U	Benzene	71-43-2	P6R6E
6751	11/29/2011	12/6/2011	0.885	J	Benzene	71-43-2	VOC-A
6753	11/30/2011	12/6/2011	0.48	J	Benzene	71-43-2	VOC-A
6784	12/6/2011	12/12/2011	11.88	J	Benzene	71-43-2	P3R1E
6766	12/6/2011	12/12/2011	ND	U	Benzene	71-43-2	P6R5E
6763	12/6/2011	12/12/2011	0.36	J	Benzene	71-43-2	VOC-A
6765	12/7/2011	12/12/2011	0.9	J	Benzene	71-43-2	VOC-A
6811	12/13/2011	12/21/2011	ND	U	Benzene	71-43-2	P4R1E
6791	12/13/2011	12/21/2011	ND	U	Benzene	71-43-2	P6R7E
6793	12/13/2011	12/21/2011	ND	U	Benzene	71-43-2	P6R7I
6769	12/13/2011	12/21/2011	0.51	J	Benzene	71-43-2	VOC-A
6794	12/14/2011	12/21/2011	ND	U	Benzene	71-43-2	P6R6E
6789	12/14/2011	12/21/2011	0.84	J	Benzene	71-43-2	VOC-A
6820	12/19/2011	1/9/2012	0.74	J	Benzene	71-43-2	P6R5E
6817	12/19/2011	1/9/2012	0.64	J	Benzene	71-43-2	VOC-A
6819	12/20/2011	1/9/2012	0.68	J	Benzene	71-43-2	VOC-A
6825	12/28/2011	1/10/2012	ND	U	Benzene	71-43-2	P6R7E
6821	12/28/2011	1/9/2012	0.52	J	Benzene	71-43-2	VOC-A
6828	12/29/2011	1/10/2012	ND	U	Benzene	71-43-2	P6R6E
6834	12/29/2011	1/10/2012	ND	U	Benzene	71-43-2	P6R7I
6823	12/29/2011	1/10/2012	0.6	J	Benzene	71-43-2	VOC-A
6378	7/5/2011	7/26/2011	1.65	J	Chloromethane	74-87-3	P5R1E
6377	7/5/2011	7/26/2011	41334.3		Chloromethane	74-87-3	P5R7E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6376	7/5/2011	7/26/2011	44877.24		Chloromethane	74-87-3	P5R7I
6379	7/6/2011	7/26/2011	29130.84		Chloromethane	74-87-3	P5R5E
6380	7/6/2011	7/25/2011	29130.84		Chloromethane	74-87-3	P5R5I
6381	7/6/2011	7/25/2011	35429.4		Chloromethane	74-87-3	P5R6E
6382	7/6/2011	7/25/2011	41334.3		Chloromethane	74-87-3	P5R6I
6383	7/7/2011	7/25/2011	15746.4		Chloromethane	74-87-3	P5R4E
6384	7/7/2011	7/26/2011	14565.42		Chloromethane	74-87-3	P5R4I
6373	7/7/2011	7/26/2011	1.48	J	Chloromethane	74-87-3	VOC-A
6375	7/8/2011	7/28/2011	1.6	J	Chloromethane	74-87-3	VOC-A
6414	7/12/2011	8/4/2011	2099.52		Chloromethane	74-87-3	P4R1E
6396	7/12/2011	7/28/2011	0.75	J	Chloromethane	74-87-3	P6R7E
6393	7/12/2011	7/28/2011	1.05	J	Chloromethane	74-87-3	VOC-A
6397	7/13/2011	7/28/2011	0.71	J	Chloromethane	74-87-3	P6R6E
6395	7/13/2011	7/28/2011	1.12	J	Chloromethane	74-87-3	VOC-A
6433	7/19/2011	7/29/2011	35.64	J	Chloromethane	74-87-3	P3R1E
6421	7/19/2011	7/29/2011	0.92	J	Chloromethane	74-87-3	VOC-A
6423	7/20/2011	7/29/2011	1.24	J	Chloromethane	74-87-3	VOC-A
6447	7/26/2011	8/4/2011	1.53	J	Chloromethane	74-87-3	P6R7E
6443	7/26/2011	8/4/2011	1.41	J	Chloromethane	74-87-3	VOC-A
6448	7/27/2011	8/4/2011	0.72	J	Chloromethane	74-87-3	P6R6E
6445	7/27/2011	8/4/2011	1.44	J	Chloromethane	74-87-3	VOC-A
6453	8/2/2011	8/8/2011	1.2	J	Chloromethane	74-87-3	VOC-A
6457	8/3/2011	8/8/2011	1.04	J	Chloromethane	74-87-3	VOC-A
6482	8/9/2011	8/24/2011	991.44		Chloromethane	74-87-3	P4R1E
6466	8/9/2011	8/24/2011	1	J	Chloromethane	74-87-3	P6R7E
6463	8/9/2011	8/24/2011	1.155	J	Chloromethane	74-87-3	VOC-A
6468	8/10/2011	8/24/2011	0.92	J	Chloromethane	74-87-3	P6R6E
6465	8/10/2011	8/24/2011	0.97	J	Chloromethane	74-87-3	VOC-A
6506	8/16/2011	8/25/2011	72.9	J	Chloromethane	74-87-3	P3R1E
6487	8/16/2011	8/25/2011	1.32	J	Chloromethane	74-87-3	VOC-A
6489	8/17/2011	8/25/2011	0.96	J	Chloromethane	74-87-3	VOC-A
6515	8/23/2011	8/30/2011	0.8	J	Chloromethane	74-87-3	P6R7E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6511	8/23/2011	8/30/2011	1.005	J	Chloromethane	74-87-3	VOC-A
6517	8/24/2011	8/30/2011	0.78	J	Chloromethane	74-87-3	P6R6E
6513	8/24/2011	8/30/2011	1.18	J	Chloromethane	74-87-3	VOC-A
6521	8/30/2011	9/6/2011	1.12	J	Chloromethane	74-87-3	VOC-A
6523	8/31/2011	9/6/2011	1.08	J	Chloromethane	74-87-3	VOC-A
6532	9/7/2011	9/13/2011	ND	U	Chloromethane	74-87-3	P6R7E
6529	9/7/2011	9/13/2011	1.32	J	Chloromethane	74-87-3	VOC-A
6534	9/8/2011	9/13/2011	0.8	J	Chloromethane	74-87-3	P6R6E
6531	9/8/2011	9/13/2011	1.44	J	Chloromethane	74-87-3	VOC-A
6560	9/14/2011	9/21/2011	3149.28		Chloromethane	74-87-3	P4R1E
6539	9/14/2011	9/15/2011	0.99	J	Chloromethane	74-87-3	VOC-A
6555	9/14/2011	9/15/2011	1.2	J	Chloromethane	74-87-3	VOC-A
6584	9/20/2011	9/30/2011	41.58	J	Chloromethane	74-87-3	P3R1E
6568	9/20/2011	9/27/2011	0.87	J	Chloromethane	74-87-3	P6R7E
6565	9/20/2011	9/27/2011	1.17	J	Chloromethane	74-87-3	VOC-A
6570	9/21/2011	9/27/2011	0.78	J	Chloromethane	74-87-3	P6R6E
6567	9/21/2011	9/27/2011	0.9	J	Chloromethane	74-87-3	VOC-A
6589	9/27/2011	9/30/2011	0.945	J	Chloromethane	74-87-3	VOC-A
6591	9/28/2011	9/30/2011	1.23	J	Chloromethane	74-87-3	VOC-A
6604	10/4/2011	10/10/2011	0.9	J	Chloromethane	74-87-3	P6R7E
6597	10/4/2011	10/10/2011	1.56	J	Chloromethane	74-87-3	VOC-A
6606	10/5/2011	10/10/2011	0.78	J	Chloromethane	74-87-3	P6R6E
6611	10/6/2011	10/10/2011	1.08	J	Chloromethane	74-87-3	VOC-A
6634	10/11/2011	10/18/2011	2099.52		Chloromethane	74-87-3	P4R1E
6613	10/11/2011	10/18/2011	1.02	J	Chloromethane	74-87-3	VOC-A
6615	10/12/2011	10/18/2011	1.26	J	Chloromethane	74-87-3	VOC-A
6659	10/18/2011	10/26/2011	28.89	J	Chloromethane	74-87-3	P3R1E
6643	10/18/2011	10/26/2011	0.84	J	Chloromethane	74-87-3	P6R7E
6639	10/18/2011	10/26/2011	0.7	J	Chloromethane	74-87-3	VOC-A
6664	10/19/2011	10/26/2011	0.765	J	Chloromethane	74-87-3	P6R5E
6645	10/19/2011	10/26/2011	0.675	J	Chloromethane	74-87-3	P6R6E
6641	10/19/2011	10/26/2011	1.005	J	Chloromethane	74-87-3	VOC-A

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6677	10/25/2011	11/7/2011	0.795	J	Chloromethane	74-87-3	P6R5E
6673	10/25/2011	11/7/2011	1.72	J	Chloromethane	74-87-3	VOC-A
6675	10/26/2011	11/7/2011	1.26	J	Chloromethane	74-87-3	VOC-A
6707	11/1/2011	11/9/2011	2099.52		Chloromethane	74-87-3	P4R1E
6688	11/1/2011	11/9/2011	ND	U	Chloromethane	74-87-3	P6R7E
6685	11/1/2011	11/9/2011	0.885	J	Chloromethane	74-87-3	VOC-A
6690	11/2/2011	11/9/2011	0.48	J	Chloromethane	74-87-3	P6R6E
6687	11/2/2011	11/9/2011	0.75	J	Chloromethane	74-87-3	VOC-A
6729	11/8/2011	11/15/2011	30.24	J	Chloromethane	74-87-3	P3R1E
6715	11/8/2011	11/15/2011	0.65	J	Chloromethane	74-87-3	P6R5E
6734	11/8/2011	11/15/2011	6.48	J	Chloromethane	74-87-3	P6R7I
6711	11/8/2011	11/15/2011	0.795	J	Chloromethane	74-87-3	VOC-A
6713	11/9/2011	11/15/2011	0.79	J	Chloromethane	74-87-3	VOC-A
6739	11/15/2011	11/22/2011	ND	U	Chloromethane	74-87-3	P6R7E
6740	11/15/2011	11/22/2011	2.16	J	Chloromethane	74-87-3	P6R7I
6735	11/15/2011	11/22/2011	0.9	J	Chloromethane	74-87-3	VOC-A
6742	11/16/2011	11/22/2011	4.86	J	Chloromethane	74-87-3	P6R6E
6737	11/16/2011	11/22/2011	0.76	J	Chloromethane	74-87-3	VOC-A
6747	11/21/2011	11/29/2011	2.13		Chloromethane	74-87-3	VOC-A
6750	11/22/2011	11/29/2011	0.76	J	Chloromethane	74-87-3	P6R5E
6749	11/22/2011	11/29/2011	0.88	J	Chloromethane	74-87-3	VOC-A
6755	11/28/2011	12/6/2011	ND	U	Chloromethane	74-87-3	P6R7E
6756	11/28/2011	12/6/2011	ND	U	Chloromethane	74-87-3	P6R7I
6757	11/29/2011	12/6/2011	ND	U	Chloromethane	74-87-3	P6R6E
6751	11/29/2011	12/6/2011	0.735	J	Chloromethane	74-87-3	VOC-A
6753	11/30/2011	12/6/2011	1.52	J	Chloromethane	74-87-3	VOC-A
6784	12/6/2011	12/12/2011	58.32	J	Chloromethane	74-87-3	P3R1E
6766	12/6/2011	12/12/2011	0.72	J	Chloromethane	74-87-3	P6R5E
6763	12/6/2011	12/12/2011	0.72	J	Chloromethane	74-87-3	VOC-A
6765	12/7/2011	12/12/2011	0.8	J	Chloromethane	74-87-3	VOC-A
6811	12/13/2011	12/21/2011	3018.06		Chloromethane	74-87-3	P4R1E
6791	12/13/2011	12/21/2011	ND	U	Chloromethane	74-87-3	P6R7E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6793	12/13/2011	12/21/2011	ND	U	Chloromethane	74-87-3	P6R7I
6769	12/13/2011	12/21/2011	1.2	J	Chloromethane	74-87-3	VOC-A
6794	12/14/2011	12/21/2011	ND	U	Chloromethane	74-87-3	P6R6E
6789	12/14/2011	12/21/2011	1.11	J	Chloromethane	74-87-3	VOC-A
6820	12/19/2011	1/9/2012	0.8	J	Chloromethane	74-87-3	P6R5E
6817	12/19/2011	1/9/2012	1.72	J	Chloromethane	74-87-3	VOC-A
6819	12/20/2011	1/9/2012	0.86	J	Chloromethane	74-87-3	VOC-A
6825	12/28/2011	1/10/2012	ND	U	Chloromethane	74-87-3	P6R7E
6821	12/28/2011	1/9/2012	1.64	J	Chloromethane	74-87-3	VOC-A
6828	12/29/2011	1/10/2012	ND	U	Chloromethane	74-87-3	P6R6E
6834	12/29/2011	1/10/2012	ND	U	Chloromethane	74-87-3	P6R7I
6823	12/29/2011	1/10/2012	1.64	J	Chloromethane	74-87-3	VOC-A
6378	7/5/2011	7/26/2011	2.13	J	p,m-Xylene	106-42-3, 108-38-3	P5R1E
6377	7/5/2011	7/26/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P5R7E
6376	7/5/2011	7/26/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P5R7I
6379	7/6/2011	7/26/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P5R5E
6380	7/6/2011	7/25/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P5R5I
6381	7/6/2011	7/25/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P5R6E
6382	7/6/2011	7/25/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P5R6I
6383	7/7/2011	7/25/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P5R4E
6384	7/7/2011	7/26/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P5R4I
6373	7/7/2011	7/26/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6375	7/8/2011	7/28/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6414	7/12/2011	8/4/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P4R1E
6396	7/12/2011	7/28/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E
6393	7/12/2011	7/28/2011	0.345	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6397	7/13/2011	7/28/2011	0.18	J	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6395	7/13/2011	7/28/2011	0.34	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6433	7/19/2011	7/29/2011	30.78	J	p,m-Xylene	106-42-3, 108-38-3	P3R1E
6421	7/19/2011	7/29/2011	0.26	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6423	7/20/2011	7/29/2011	0.34	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6447	7/26/2011	8/4/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6443	7/26/2011	8/4/2011	0.51	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6448	7/27/2011	8/4/2011	0.4	J	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6445	7/27/2011	8/4/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6453	8/2/2011	8/8/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6457	8/3/2011	8/8/2011	0.32	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6482	8/9/2011	8/24/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P4R1E
6466	8/9/2011	8/24/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E
6463	8/9/2011	8/24/2011	0.315	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6468	8/10/2011	8/24/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6465	8/10/2011	8/24/2011	0.25	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6506	8/16/2011	8/25/2011	55.08	J	p,m-Xylene	106-42-3, 108-38-3	P3R1E
6487	8/16/2011	8/25/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6489	8/17/2011	8/25/2011	0.81	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6515	8/23/2011	8/30/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E
6511	8/23/2011	8/30/2011	0.375	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6517	8/24/2011	8/30/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6513	8/24/2011	8/30/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6521	8/30/2011	9/6/2011	0.34	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6523	8/31/2011	9/6/2011	0.38	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6532	9/7/2011	9/13/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E
6529	9/7/2011	9/13/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6534	9/8/2011	9/13/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6531	9/8/2011	9/13/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6560	9/14/2011	9/21/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P4R1E
6539	9/14/2011	9/15/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6555	9/14/2011	9/15/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6584	9/20/2011	9/30/2011	35.64	J	p,m-Xylene	106-42-3, 108-38-3	P3R1E
6568	9/20/2011	9/27/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E
6565	9/20/2011	9/27/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6570	9/21/2011	9/27/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6567	9/21/2011	9/27/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6589	9/27/2011	9/30/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6591	9/28/2011	9/30/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6604	10/4/2011	10/10/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E
6597	10/4/2011	10/10/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6606	10/5/2011	10/10/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6611	10/6/2011	10/10/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6634	10/11/2011	10/18/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P4R1E
6613	10/11/2011	10/18/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6615	10/12/2011	10/18/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6659	10/18/2011	10/26/2011	32.4	J	p,m-Xylene	106-42-3, 108-38-3	P3R1E
6643	10/18/2011	10/26/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E
6639	10/18/2011	10/26/2011	0.23	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6664	10/19/2011	10/26/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R5E
6645	10/19/2011	10/26/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6641	10/19/2011	10/26/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6677	10/25/2011	11/7/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R5E
6673	10/25/2011	11/7/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6675	10/26/2011	11/7/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6707	11/1/2011	11/9/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P4R1E
6688	11/1/2011	11/9/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E
6685	11/1/2011	11/9/2011	0.66	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6690	11/2/2011	11/9/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6687	11/2/2011	11/9/2011	0.26	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6729	11/8/2011	11/15/2011	29.97	J	p,m-Xylene	106-42-3, 108-38-3	P3R1E
6715	11/8/2011	11/15/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R5E
6734	11/8/2011	11/15/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7I
6711	11/8/2011	11/15/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6713	11/9/2011	11/15/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6739	11/15/2011	11/22/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E
6740	11/15/2011	11/22/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7I
6735	11/15/2011	11/22/2011	2.88	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6742	11/16/2011	11/22/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6737	11/16/2011	11/22/2011	0.19	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6747	11/21/2011	11/29/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6750	11/22/2011	11/29/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R5E
6749	11/22/2011	11/29/2011	0.49	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6755	11/28/2011	12/6/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E
6756	11/28/2011	12/6/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7I
6757	11/29/2011	12/6/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6751	11/29/2011	12/6/2011	0.21	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6753	11/30/2011	12/6/2011	0.52	J	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6784	12/6/2011	12/12/2011	49.14	J	p,m-Xylene	106-42-3, 108-38-3	P3R1E
6766	12/6/2011	12/12/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R5E
6763	12/6/2011	12/12/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6765	12/7/2011	12/12/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6811	12/13/2011	12/21/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P4R1E
6791	12/13/2011	12/21/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E
6793	12/13/2011	12/21/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7I
6769	12/13/2011	12/21/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6794	12/14/2011	12/21/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6789	12/14/2011	12/21/2011	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6820	12/19/2011	1/9/2012	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R5E
6817	12/19/2011	1/9/2012	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6819	12/20/2011	1/9/2012	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6825	12/28/2011	1/10/2012	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7E
6821	12/28/2011	1/9/2012	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6828	12/29/2011	1/10/2012	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R6E
6834	12/29/2011	1/10/2012	U	U	p,m-Xylene	106-42-3, 108-38-3	P6R7I
6823	12/29/2011	1/10/2012	U	U	p,m-Xylene	106-42-3, 108-38-3	VOC-A
6378	7/5/2011	7/26/2011	5.79	J	Tetrachloroethylene	127-18-4	P5R1E
6377	7/5/2011	7/26/2011	148803.48		Tetrachloroethylene	127-18-4	P5R7E
6376	7/5/2011	7/26/2011	164156.22		Tetrachloroethylene	127-18-4	P5R7I
6379	7/6/2011	7/26/2011	180296.28		Tetrachloroethylene	127-18-4	P5R5E
6380	7/6/2011	7/25/2011	110224.8		Tetrachloroethylene	127-18-4	P5R5I
6381	7/6/2011	7/25/2011	168880.14		Tetrachloroethylene	127-18-4	P5R6E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6382	7/6/2011	7/25/2011	161794.26		Tetrachloroethylene	127-18-4	P5R6I
6383	7/7/2011	7/25/2011	65347.56		Tetrachloroethylene	127-18-4	P5R4E
6384	7/7/2011	7/26/2011	86605.2		Tetrachloroethylene	127-18-4	P5R4I
6373	7/7/2011	7/26/2011	3.56	J	Tetrachloroethylene	127-18-4	VOC-A
6375	7/8/2011	7/28/2011	3.6	J	Tetrachloroethylene	127-18-4	VOC-A
6414	7/12/2011	8/4/2011	7741.98		Tetrachloroethylene	127-18-4	P4R1E
6396	7/12/2011	7/28/2011	9.555	J	Tetrachloroethylene	127-18-4	P6R7E
6393	7/12/2011	7/28/2011	1.785	J	Tetrachloroethylene	127-18-4	VOC-A
6397	7/13/2011	7/28/2011	2.68	J	Tetrachloroethylene	127-18-4	P6R6E
6395	7/13/2011	7/28/2011	1.96	J	Tetrachloroethylene	127-18-4	VOC-A
6433	7/19/2011	7/29/2011	27.54	J	Tetrachloroethylene	127-18-4	P3R1E
6421	7/19/2011	7/29/2011	1.73	J	Tetrachloroethylene	127-18-4	VOC-A
6423	7/20/2011	7/29/2011	2.26	J	Tetrachloroethylene	127-18-4	VOC-A
6447	7/26/2011	8/4/2011	38.07	J	Tetrachloroethylene	127-18-4	P6R7E
6443	7/26/2011	8/4/2011	2.94	J	Tetrachloroethylene	127-18-4	VOC-A
6448	7/27/2011	8/4/2011	6.74	J	Tetrachloroethylene	127-18-4	P6R6E
6445	7/27/2011	8/4/2011	2.91	J	Tetrachloroethylene	127-18-4	VOC-A
6453	8/2/2011	8/8/2011	3.33	J	Tetrachloroethylene	127-18-4	VOC-A
6457	8/3/2011	8/8/2011	2.54	J	Tetrachloroethylene	127-18-4	VOC-A
6482	8/9/2011	8/24/2011	4199.04		Tetrachloroethylene	127-18-4	P4R1E
6466	8/9/2011	8/24/2011	18.88	J	Tetrachloroethylene	127-18-4	P6R7E
6463	8/9/2011	8/24/2011	2.52	J	Tetrachloroethylene	127-18-4	VOC-A
6468	8/10/2011	8/24/2011	16.38	J	Tetrachloroethylene	127-18-4	P6R6E
6465	8/10/2011	8/24/2011	1.53	J	Tetrachloroethylene	127-18-4	VOC-A
6506	8/16/2011	8/25/2011	53.46	J	Tetrachloroethylene	127-18-4	P3R1E
6487	8/16/2011	8/25/2011	3.36	J	Tetrachloroethylene	127-18-4	VOC-A
6489	8/17/2011	8/25/2011	2.55	J	Tetrachloroethylene	127-18-4	VOC-A
6515	8/23/2011	8/30/2011	17.48	J	Tetrachloroethylene	127-18-4	P6R7E
6511	8/23/2011	8/30/2011	3.48	J	Tetrachloroethylene	127-18-4	VOC-A
6517	8/24/2011	8/30/2011	16.96	J	Tetrachloroethylene	127-18-4	P6R6E
6513	8/24/2011	8/30/2011	3.36	J	Tetrachloroethylene	127-18-4	VOC-A
6521	8/30/2011	9/6/2011	4.72	J	Tetrachloroethylene	127-18-4	VOC-A

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6523	8/31/2011	9/6/2011	3.74	J	Tetrachloroethylene	127-18-4	VOC-A
6532	9/7/2011	9/13/2011	153	J	Tetrachloroethylene	127-18-4	P6R7E
6529	9/7/2011	9/13/2011	6.96		Tetrachloroethylene	127-18-4	VOC-A
6534	9/8/2011	9/13/2011	24.32	J	Tetrachloroethylene	127-18-4	P6R6E
6531	9/8/2011	9/13/2011	6.76		Tetrachloroethylene	127-18-4	VOC-A
6560	9/14/2011	9/21/2011	12072.24		Tetrachloroethylene	127-18-4	P4R1E
6539	9/14/2011	9/15/2011	4.245	J	Tetrachloroethylene	127-18-4	VOC-A
6555	9/14/2011	9/15/2011	4.83	J	Tetrachloroethylene	127-18-4	VOC-A
6584	9/20/2011	9/30/2011	36.72	J	Tetrachloroethylene	127-18-4	P3R1E
6568	9/20/2011	9/27/2011	16.95	J	Tetrachloroethylene	127-18-4	P6R7E
6565	9/20/2011	9/27/2011	3.96	J	Tetrachloroethylene	127-18-4	VOC-A
6570	9/21/2011	9/27/2011	21.72	J	Tetrachloroethylene	127-18-4	P6R6E
6567	9/21/2011	9/27/2011	4.635	J	Tetrachloroethylene	127-18-4	VOC-A
6589	9/27/2011	9/30/2011	3.255	J	Tetrachloroethylene	127-18-4	VOC-A
6591	9/28/2011	9/30/2011	5.52		Tetrachloroethylene	127-18-4	VOC-A
6604	10/4/2011	10/10/2011	18.66	J	Tetrachloroethylene	127-18-4	P6R7E
6597	10/4/2011	10/10/2011	6.54		Tetrachloroethylene	127-18-4	VOC-A
6606	10/5/2011	10/10/2011	16.545	J	Tetrachloroethylene	127-18-4	P6R6E
6611	10/6/2011	10/10/2011	3.78	J	Tetrachloroethylene	127-18-4	VOC-A
6634	10/11/2011	10/18/2011	11022.48		Tetrachloroethylene	127-18-4	P4R1E
6613	10/11/2011	10/18/2011	2.49	J	Tetrachloroethylene	127-18-4	VOC-A
6615	10/12/2011	10/18/2011	5.68		Tetrachloroethylene	127-18-4	VOC-A
6659	10/18/2011	10/26/2011	27.54	J	Tetrachloroethylene	127-18-4	P3R1E
6643	10/18/2011	10/26/2011	7.23	J	Tetrachloroethylene	127-18-4	P6R7E
6639	10/18/2011	10/26/2011	4.49	J	Tetrachloroethylene	127-18-4	VOC-A
6664	10/19/2011	10/26/2011	11.175	J	Tetrachloroethylene	127-18-4	P6R5E
6645	10/19/2011	10/26/2011	13.02	J	Tetrachloroethylene	127-18-4	P6R6E
6641	10/19/2011	10/26/2011	5.055		Tetrachloroethylene	127-18-4	VOC-A
6677	10/25/2011	11/7/2011	15.225	J	Tetrachloroethylene	127-18-4	P6R5E
6673	10/25/2011	11/7/2011	6.6		Tetrachloroethylene	127-18-4	VOC-A
6675	10/26/2011	11/7/2011	4.77	J	Tetrachloroethylene	127-18-4	VOC-A
6707	11/1/2011	11/9/2011	15090.3		Tetrachloroethylene	127-18-4	P4R1E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6688	11/1/2011	11/9/2011	2423.94		Tetrachloroethylene	127-18-4	P6R7E
6685	11/1/2011	11/9/2011	4.215	J	Tetrachloroethylene	127-18-4	VOC-A
6690	11/2/2011	11/9/2011	34.2	J	Tetrachloroethylene	127-18-4	P6R6E
6687	11/2/2011	11/9/2011	3.41	J	Tetrachloroethylene	127-18-4	VOC-A
6729	11/8/2011	11/15/2011	23.49	J	Tetrachloroethylene	127-18-4	P3R1E
6715	11/8/2011	11/15/2011	6.46	J	Tetrachloroethylene	127-18-4	P6R5E
6734	11/8/2011	11/15/2011	370.98	J	Tetrachloroethylene	127-18-4	P6R7I
6711	11/8/2011	11/15/2011	2.1	J	Tetrachloroethylene	127-18-4	VOC-A
6713	11/9/2011	11/15/2011	3.05	J	Tetrachloroethylene	127-18-4	VOC-A
6739	11/15/2011	11/22/2011	38709.9		Tetrachloroethylene	127-18-4	P6R7E
6740	11/15/2011	11/22/2011	120.69	J	Tetrachloroethylene	127-18-4	P6R7I
6735	11/15/2011	11/22/2011	3.375	J	Tetrachloroethylene	127-18-4	VOC-A
6742	11/16/2011	11/22/2011	421.2	J	Tetrachloroethylene	127-18-4	P6R6E
6737	11/16/2011	11/22/2011	2.68	J	Tetrachloroethylene	127-18-4	VOC-A
6747	11/21/2011	11/29/2011	6.6		Tetrachloroethylene	127-18-4	VOC-A
6750	11/22/2011	11/29/2011	10.08	J	Tetrachloroethylene	127-18-4	P6R5E
6749	11/22/2011	11/29/2011	5.01		Tetrachloroethylene	127-18-4	VOC-A
6755	11/28/2011	12/6/2011	32280.12		Tetrachloroethylene	127-18-4	P6R7E
6756	11/28/2011	12/6/2011	3275.64		Tetrachloroethylene	127-18-4	P6R7I
6757	11/29/2011	12/6/2011	185.22	J	Tetrachloroethylene	127-18-4	P6R6E
6751	11/29/2011	12/6/2011	4.785	J	Tetrachloroethylene	127-18-4	VOC-A
6753	11/30/2011	12/6/2011	6.44		Tetrachloroethylene	127-18-4	VOC-A
6784	12/6/2011	12/12/2011	47.52	J	Tetrachloroethylene	127-18-4	P3R1E
6766	12/6/2011	12/12/2011	16.11	J	Tetrachloroethylene	127-18-4	P6R5E
6763	12/6/2011	12/12/2011	6.4		Tetrachloroethylene	127-18-4	VOC-A
6765	12/7/2011	12/12/2011	4.48	J	Tetrachloroethylene	127-18-4	VOC-A
6811	12/13/2011	12/21/2011	13909.32		Tetrachloroethylene	127-18-4	P4R1E
6791	12/13/2011	12/21/2011	41596.74		Tetrachloroethylene	127-18-4	P6R7E
6793	12/13/2011	12/21/2011	9950.85		Tetrachloroethylene	127-18-4	P6R7I
6769	12/13/2011	12/21/2011	6.9		Tetrachloroethylene	127-18-4	VOC-A
6794	12/14/2011	12/21/2011	293.04	J	Tetrachloroethylene	127-18-4	P6R6E
6789	12/14/2011	12/21/2011	6.9		Tetrachloroethylene	127-18-4	VOC-A

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6820	12/19/2011	1/9/2012	26.26	J	Tetrachloroethylene	127-18-4	P6R5E
6817	12/19/2011	1/9/2012	13.2		Tetrachloroethylene	127-18-4	VOC-A
6819	12/20/2011	1/9/2012	8.56		Tetrachloroethylene	127-18-4	VOC-A
6825	12/28/2011	1/10/2012	41465.52		Tetrachloroethylene	127-18-4	P6R7E
6821	12/28/2011	1/9/2012	8.68		Tetrachloroethylene	127-18-4	VOC-A
6828	12/29/2011	1/10/2012	311.04	J	Tetrachloroethylene	127-18-4	P6R6E
6834	12/29/2011	1/10/2012	10781.91		Tetrachloroethylene	127-18-4	P6R7I
6823	12/29/2011	1/10/2012	10.16		Tetrachloroethylene	127-18-4	VOC-A
6378	7/5/2011	7/26/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P5R1E
6377	7/5/2011	7/26/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P5R7E
6376	7/5/2011	7/26/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P5R7I
6379	7/6/2011	7/26/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P5R5E
6380	7/6/2011	7/25/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P5R5I
6381	7/6/2011	7/25/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P5R6E
6382	7/6/2011	7/25/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P5R6I
6383	7/7/2011	7/25/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P5R4E
6384	7/7/2011	7/26/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P5R4I
6373	7/7/2011	7/26/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6375	7/8/2011	7/28/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6414	7/12/2011	8/4/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P4R1E
6396	7/12/2011	7/28/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E
6393	7/12/2011	7/28/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6397	7/13/2011	7/28/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E
6395	7/13/2011	7/28/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6433	7/19/2011	7/29/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P3R1E
6421	7/19/2011	7/29/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6423	7/20/2011	7/29/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6447	7/26/2011	8/4/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E
6443	7/26/2011	8/4/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6448	7/27/2011	8/4/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E
6445	7/27/2011	8/4/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6453	8/2/2011	8/8/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A

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Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6457	8/3/2011	8/8/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6482	8/9/2011	8/24/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P4R1E
6466	8/9/2011	8/24/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E
6463	8/9/2011	8/24/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6468	8/10/2011	8/24/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E
6465	8/10/2011	8/24/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6506	8/16/2011	8/25/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P3R1E
6487	8/16/2011	8/25/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6489	8/17/2011	8/25/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6515	8/23/2011	8/30/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E
6511	8/23/2011	8/30/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6517	8/24/2011	8/30/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E
6513	8/24/2011	8/30/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6521	8/30/2011	9/6/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6523	8/31/2011	9/6/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6532	9/7/2011	9/13/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E
6529	9/7/2011	9/13/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6534	9/8/2011	9/13/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E
6531	9/8/2011	9/13/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6560	9/14/2011	9/21/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P4R1E
6539	9/14/2011	9/15/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6555	9/14/2011	9/15/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6584	9/20/2011	9/30/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P3R1E
6568	9/20/2011	9/27/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E
6565	9/20/2011	9/27/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6570	9/21/2011	9/27/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E
6567	9/21/2011	9/27/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6589	9/27/2011	9/30/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6591	9/28/2011	9/30/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6604	10/4/2011	10/10/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E
6597	10/4/2011	10/10/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6606	10/5/2011	10/10/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E

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Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6611	10/6/2011	10/10/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6634	10/11/2011	10/18/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P4R1E
6613	10/11/2011	10/18/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6615	10/12/2011	10/18/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6659	10/18/2011	10/26/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P3R1E
6643	10/18/2011	10/26/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E
6639	10/18/2011	10/26/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6664	10/19/2011	10/26/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R5E
6645	10/19/2011	10/26/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E
6641	10/19/2011	10/26/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6677	10/25/2011	11/7/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R5E
6673	10/25/2011	11/7/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6675	10/26/2011	11/7/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6707	11/1/2011	11/9/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P4R1E
6688	11/1/2011	11/9/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E
6685	11/1/2011	11/9/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6690	11/2/2011	11/9/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E
6687	11/2/2011	11/9/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6729	11/8/2011	11/15/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P3R1E
6715	11/8/2011	11/15/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R5E
6734	11/8/2011	11/15/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7I
6711	11/8/2011	11/15/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6713	11/9/2011	11/15/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6739	11/15/2011	11/22/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E
6740	11/15/2011	11/22/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7I
6735	11/15/2011	11/22/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6742	11/16/2011	11/22/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E
6737	11/16/2011	11/22/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6747	11/21/2011	11/29/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6750	11/22/2011	11/29/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R5E
6749	11/22/2011	11/29/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6755	11/28/2011	12/6/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6756	11/28/2011	12/6/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7I
6757	11/29/2011	12/6/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E
6751	11/29/2011	12/6/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6753	11/30/2011	12/6/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6784	12/6/2011	12/12/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P3R1E
6766	12/6/2011	12/12/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R5E
6763	12/6/2011	12/12/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6765	12/7/2011	12/12/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6811	12/13/2011	12/21/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P4R1E
6791	12/13/2011	12/21/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E
6793	12/13/2011	12/21/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7I
6769	12/13/2011	12/21/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6794	12/14/2011	12/21/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E
6789	12/14/2011	12/21/2011	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6820	12/19/2011	1/9/2012	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R5E
6817	12/19/2011	1/9/2012	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6819	12/20/2011	1/9/2012	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6825	12/28/2011	1/10/2012	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7E
6821	12/28/2011	1/9/2012	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6828	12/29/2011	1/10/2012	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R6E
6834	12/29/2011	1/10/2012	ND	U	trans-1,2-Dichloroethylene	156-60-5	P6R7I
6823	12/29/2011	1/10/2012	ND	U	trans-1,2-Dichloroethylene	156-60-5	VOC-A
6378	7/5/2011	7/26/2011	49.23	J	Trichloroethylene	79-01-6	P5R1E
6377	7/5/2011	7/26/2011	2002942.08		Trichloroethylene	79-01-6	P5R7E
6376	7/5/2011	7/26/2011	2514306.42		Trichloroethylene	79-01-6	P5R7I
6379	7/6/2011	7/26/2011	1786429.08		Trichloroethylene	79-01-6	P5R5E
6380	7/6/2011	7/25/2011	1387257.84		Trichloroethylene	79-01-6	P5R5I
6381	7/6/2011	7/25/2011	1913187.6		Trichloroethylene	79-01-6	P5R6E
6382	7/6/2011	7/25/2011	1972236.6		Trichloroethylene	79-01-6	P5R6I
6383	7/7/2011	7/25/2011	717642.18		Trichloroethylene	79-01-6	P5R4E
6384	7/7/2011	7/26/2011	871169.58		Trichloroethylene	79-01-6	P5R4I
6373	7/7/2011	7/26/2011	38.36		Trichloroethylene	79-01-6	VOC-A

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6375	7/8/2011	7/28/2011	38		Trichloroethylene	79-01-6	VOC-A
6414	7/12/2011	8/4/2011	130826.34		Trichloroethylene	79-01-6	P4R1E
6396	7/12/2011	7/28/2011	44.1	J	Trichloroethylene	79-01-6	P6R7E
6393	7/12/2011	7/28/2011	17.205		Trichloroethylene	79-01-6	VOC-A
6397	7/13/2011	7/28/2011	10.07	J	Trichloroethylene	79-01-6	P6R6E
6395	7/13/2011	7/28/2011	23.22		Trichloroethylene	79-01-6	VOC-A
6433	7/19/2011	7/29/2011	205.2	J	Trichloroethylene	79-01-6	P3R1E
6421	7/19/2011	7/29/2011	15.26		Trichloroethylene	79-01-6	VOC-A
6423	7/20/2011	7/29/2011	23.5		Trichloroethylene	79-01-6	VOC-A
6447	7/26/2011	8/4/2011	329.49	J	Trichloroethylene	79-01-6	P6R7E
6443	7/26/2011	8/4/2011	33.27		Trichloroethylene	79-01-6	VOC-A
6448	7/27/2011	8/4/2011	40.93	J	Trichloroethylene	79-01-6	P6R6E
6445	7/27/2011	8/4/2011	31.35		Trichloroethylene	79-01-6	VOC-A
6453	8/2/2011	8/8/2011	31.68		Trichloroethylene	79-01-6	VOC-A
6457	8/3/2011	8/8/2011	25.4		Trichloroethylene	79-01-6	VOC-A
6482	8/9/2011	8/24/2011	59719.68		Trichloroethylene	79-01-6	P4R1E
6466	8/9/2011	8/24/2011	127.92	J	Trichloroethylene	79-01-6	P6R7E
6463	8/9/2011	8/24/2011	20.445		Trichloroethylene	79-01-6	VOC-A
6468	8/10/2011	8/24/2011	62.12	J	Trichloroethylene	79-01-6	P6R6E
6465	8/10/2011	8/24/2011	12.68		Trichloroethylene	79-01-6	VOC-A
6506	8/16/2011	8/25/2011	401.76	J	Trichloroethylene	79-01-6	P3R1E
6487	8/16/2011	8/25/2011	29.55		Trichloroethylene	79-01-6	VOC-A
6489	8/17/2011	8/25/2011	20.175		Trichloroethylene	79-01-6	VOC-A
6515	8/23/2011	8/30/2011	104.2	J	Trichloroethylene	79-01-6	P6R7E
6511	8/23/2011	8/30/2011	24.975		Trichloroethylene	79-01-6	VOC-A
6517	8/24/2011	8/30/2011	59.54	J	Trichloroethylene	79-01-6	P6R6E
6513	8/24/2011	8/30/2011	27.32		Trichloroethylene	79-01-6	VOC-A
6521	8/30/2011	9/6/2011	33.42		Trichloroethylene	79-01-6	VOC-A
6523	8/31/2011	9/6/2011	28.24		Trichloroethylene	79-01-6	VOC-A
6532	9/7/2011	9/13/2011	546.12		Trichloroethylene	79-01-6	P6R7E
6529	9/7/2011	9/13/2011	41.24		Trichloroethylene	79-01-6	VOC-A
6534	9/8/2011	9/13/2011	94.64	J	Trichloroethylene	79-01-6	P6R6E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6531	9/8/2011	9/13/2011	44.08		Trichloroethylene	79-01-6	VOC-A
6560	9/14/2011	9/21/2011	173604.06		Trichloroethylene	79-01-6	P4R1E
6539	9/14/2011	9/15/2011	25.32		Trichloroethylene	79-01-6	VOC-A
6555	9/14/2011	9/15/2011	34.2		Trichloroethylene	79-01-6	VOC-A
6584	9/20/2011	9/30/2011	300.78	J	Trichloroethylene	79-01-6	P3R1E
6568	9/20/2011	9/27/2011	89.52	J	Trichloroethylene	79-01-6	P6R7E
6565	9/20/2011	9/27/2011	34.23		Trichloroethylene	79-01-6	VOC-A
6570	9/21/2011	9/27/2011	75.36	J	Trichloroethylene	79-01-6	P6R6E
6567	9/21/2011	9/27/2011	27.12		Trichloroethylene	79-01-6	VOC-A
6589	9/27/2011	9/30/2011	21.315		Trichloroethylene	79-01-6	VOC-A
6591	9/28/2011	9/30/2011	43.14		Trichloroethylene	79-01-6	VOC-A
6604	10/4/2011	10/10/2011	94.71	J	Trichloroethylene	79-01-6	P6R7E
6597	10/4/2011	10/10/2011	52.47		Trichloroethylene	79-01-6	VOC-A
6606	10/5/2011	10/10/2011	57.78	J	Trichloroethylene	79-01-6	P6R6E
6611	10/6/2011	10/10/2011	28.77		Trichloroethylene	79-01-6	VOC-A
6634	10/11/2011	10/18/2011	133319.52		Trichloroethylene	79-01-6	P4R1E
6613	10/11/2011	10/18/2011	18		Trichloroethylene	79-01-6	VOC-A
6615	10/12/2011	10/18/2011	37.9		Trichloroethylene	79-01-6	VOC-A
6659	10/18/2011	10/26/2011	193.05	J	Trichloroethylene	79-01-6	P3R1E
6643	10/18/2011	10/26/2011	30.72	J	Trichloroethylene	79-01-6	P6R7E
6639	10/18/2011	10/26/2011	22.84		Trichloroethylene	79-01-6	VOC-A
6664	10/19/2011	10/26/2011	42.855	J	Trichloroethylene	79-01-6	P6R5E
6645	10/19/2011	10/26/2011	43.5	J	Trichloroethylene	79-01-6	P6R6E
6641	10/19/2011	10/26/2011	28.83		Trichloroethylene	79-01-6	VOC-A
6677	10/25/2011	11/7/2011	61.08	J	Trichloroethylene	79-01-6	P6R5E
6673	10/25/2011	11/7/2011	49.36		Trichloroethylene	79-01-6	VOC-A
6675	10/26/2011	11/7/2011	38.37		Trichloroethylene	79-01-6	VOC-A
6707	11/1/2011	11/9/2011	163368.9		Trichloroethylene	79-01-6	P4R1E
6688	11/1/2011	11/9/2011	9107.88		Trichloroethylene	79-01-6	P6R7E
6685	11/1/2011	11/9/2011	26.955		Trichloroethylene	79-01-6	VOC-A
6690	11/2/2011	11/9/2011	115.56	J	Trichloroethylene	79-01-6	P6R6E
6687	11/2/2011	11/9/2011	18.91		Trichloroethylene	79-01-6	VOC-A

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6729	11/8/2011	11/15/2011	223.56	J	Trichloroethylene	79-01-6	P3R1E
6715	11/8/2011	11/15/2011	25.62	J	Trichloroethylene	79-01-6	P6R5E
6734	11/8/2011	11/15/2011	1483.92		Trichloroethylene	79-01-6	P6R7I
6711	11/8/2011	11/15/2011	19.11		Trichloroethylene	79-01-6	VOC-A
6713	11/9/2011	11/15/2011	22.19		Trichloroethylene	79-01-6	VOC-A
6739	11/15/2011	11/22/2011	159694.74		Trichloroethylene	79-01-6	P6R7E
6740	11/15/2011	11/22/2011	506.79		Trichloroethylene	79-01-6	P6R7I
6735	11/15/2011	11/22/2011	26.025		Trichloroethylene	79-01-6	VOC-A
6742	11/16/2011	11/22/2011	1585.98		Trichloroethylene	79-01-6	P6R6E
6737	11/16/2011	11/22/2011	20.21		Trichloroethylene	79-01-6	VOC-A
6747	11/21/2011	11/29/2011	60.87		Trichloroethylene	79-01-6	VOC-A
6750	11/22/2011	11/29/2011	39.36	J	Trichloroethylene	79-01-6	P6R5E
6749	11/22/2011	11/29/2011	29.49		Trichloroethylene	79-01-6	VOC-A
6755	11/28/2011	12/6/2011	134106.84		Trichloroethylene	79-01-6	P6R7E
6756	11/28/2011	12/6/2011	12713.76		Trichloroethylene	79-01-6	P6R7I
6757	11/29/2011	12/6/2011	653.94		Trichloroethylene	79-01-6	P6R6E
6751	11/29/2011	12/6/2011	28.53		Trichloroethylene	79-01-6	VOC-A
6753	11/30/2011	12/6/2011	53.72		Trichloroethylene	79-01-6	VOC-A
6784	12/6/2011	12/12/2011	311.04	J	Trichloroethylene	79-01-6	P3R1E
6766	12/6/2011	12/12/2011	61.65	J	Trichloroethylene	79-01-6	P6R5E
6763	12/6/2011	12/12/2011	30.96		Trichloroethylene	79-01-6	VOC-A
6765	12/7/2011	12/12/2011	26.54		Trichloroethylene	79-01-6	VOC-A
6811	12/13/2011	12/21/2011	173866.5		Trichloroethylene	79-01-6	P4R1E
6791	12/13/2011	12/21/2011	164549.88		Trichloroethylene	79-01-6	P6R7E
6793	12/13/2011	12/21/2011	41837.31		Trichloroethylene	79-01-6	P6R7I
6769	12/13/2011	12/21/2011	42.99		Trichloroethylene	79-01-6	VOC-A
6794	12/14/2011	12/21/2011	984.6		Trichloroethylene	79-01-6	P6R6E
6789	12/14/2011	12/21/2011	49.77		Trichloroethylene	79-01-6	VOC-A
6820	12/19/2011	1/9/2012	91.76	J	Trichloroethylene	79-01-6	P6R5E
6817	12/19/2011	1/9/2012	82.48		Trichloroethylene	79-01-6	VOC-A
6819	12/20/2011	1/9/2012	41.5		Trichloroethylene	79-01-6	VOC-A
6825	12/28/2011	1/10/2012	155714.4		Trichloroethylene	79-01-6	P6R7E

Attachment 4B – Additional Requested Analytes

Sample Number	Sample Date	Analysis Date	Concentration (ppbv)	Data Flags	Analyte Name	CAS Number	Sample Location
6821	12/28/2011	1/9/2012	64.08		Trichloroethylene	79-01-6	VOC-A
6828	12/29/2011	1/10/2012	1080.27		Trichloroethylene	79-01-6	P6R6E
6834	12/29/2011	1/10/2012	46342.53		Trichloroethylene	79-01-6	P6R7I
6823	12/29/2011	1/10/2012	66.64		Trichloroethylene	79-01-6	VOC-A

Notes
ND = Compound not detected.
J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above MDL.

Attachment 5 – Hydrogen and Methane Results

P3R1E - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 1 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6433	7/19/2011	ND	U	Hydrogen	1333-74-0
6433	7/19/2011	ND	U	Methane	74-82-8
6506	8/16/2011	34.00	J	Hydrogen	1333-74-0
6506	8/16/2011	ND	U	Methane	74-82-8
6584	9/20/2011	ND	U	Hydrogen	1333-74-0
6584	9/20/2011	ND	U	Methane	74-82-8
6659	10/18/2011	ND	U	Hydrogen	1333-74-0
6659	10/18/2011	ND	U	Methane	74-82-8
6729	11/8/2011	ND	U	Hydrogen	1333-74-0
6729	11/8/2011	ND	U	Methane	74-82-8
6784	12/6/2011	ND	U	Hydrogen	1333-74-0
6784	12/6/2011	ND	U	Methane	74-82-8

P3R1I - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 1 Inlet

Sample line determined as obstructed on 7/14/2008.

Laboratory and field duplicate information is reported in attachment 7.

Attachment 5 – Hydrogen and Methane Results

P3R2E - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 2 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6431	7/18/2011	37.94	J	Hydrogen	1333-74-0
6431	7/18/2011	ND	U	Methane	74-82-8
6499	8/15/2011	55.18	J	Hydrogen	1333-74-0
6499	8/15/2011	ND	U	Methane	74-82-8
6577	9/19/2011	33.10	J	Hydrogen	1333-74-0
6577	9/19/2011	ND	U	Methane	74-82-8
6650	10/17/2011	U	U	Hydrogen	1333-74-0
6650	10/17/2011	ND	U	Methane	74-82-8
6722	11/7/2011	U	U	Hydrogen	1333-74-0
6722	11/7/2011	ND	U	Methane	74-82-8
6777	12/5/2011	31.18	J	Hydrogen	1333-74-0
6777	12/5/2011	ND	U	Methane	74-82-8

P3R2I - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 2 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6439	7/19/2011	ND	U	Hydrogen	1333-74-0
6439	7/19/2011	ND	U	Methane	74-82-8
6505	8/16/2011	ND	U	Hydrogen	1333-74-0
6505	8/16/2011	ND	U	Methane	74-82-8
6583	9/20/2011	ND	U	Hydrogen	1333-74-0
6583	9/20/2011	ND	U	Methane	74-82-8
6658	10/18/2011	ND	U	Hydrogen	1333-74-0
6658	10/18/2011	ND	U	Methane	74-82-8
6728	11/8/2011	ND	U	Hydrogen	1333-74-0
6728	11/8/2011	ND	U	Methane	74-82-8
6783	12/6/2011	ND	U	Hydrogen	1333-74-0
6783	12/6/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P3R3E - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 3 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6430	7/18/2011	53.20	J	Hydrogen	1333-74-0
6430	7/18/2011	ND	U	Methane	74-82-8
6498	8/15/2011	50.46	J	Hydrogen	1333-74-0
6498	8/15/2011	ND	U	Methane	74-82-8
6576	9/19/2011	38.60	J	Hydrogen	1333-74-0
6576	9/19/2011	ND	U	Methane	74-82-8
6649	10/17/2011	28.86	J	Hydrogen	1333-74-0
6649	10/17/2011	ND	U	Methane	74-82-8
6721	11/7/2011	U	U	Hydrogen	1333-74-0
6721	11/7/2011	ND	U	Methane	74-82-8
6776	12/5/2011	38.26	J	Hydrogen	1333-74-0
6776	12/5/2011	ND	U	Methane	74-82-8

P3R3I - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 3 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6438	7/19/2011	ND	U	Hydrogen	1333-74-0
6438	7/19/2011	ND	U	Methane	74-82-8
6504	8/16/2011	ND	U	Hydrogen	1333-74-0
6504	8/16/2011	ND	U	Methane	74-82-8
6582	9/20/2011	ND	U	Hydrogen	1333-74-0
6582	9/20/2011	ND	U	Methane	74-82-8
6657	10/18/2011	ND	U	Hydrogen	1333-74-0
6657	10/18/2011	ND	U	Methane	74-82-8
6727	11/8/2011	ND	U	Hydrogen	1333-74-0
6727	11/8/2011	ND	U	Methane	74-82-8
6782	12/6/2011	ND	U	Hydrogen	1333-74-0
6782	12/6/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P3R4E - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 4 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6429	7/18/2011	55.78	J	Hydrogen	1333-74-0
6429	7/18/2011	ND	U	Methane	74-82-8
6497	8/15/2011	66.62	J	Hydrogen	1333-74-0
6497	8/15/2011	ND	U	Methane	74-82-8
6575	9/19/2011	51.62	J	Hydrogen	1333-74-0
6575	9/19/2011	ND	U	Methane	74-82-8
6648	10/17/2011	34.04	J	Hydrogen	1333-74-0
6648	10/17/2011	ND	U	Methane	74-82-8
6720	11/7/2011	30	J	Hydrogen	1333-74-0
6720	11/7/2011	ND	U	Methane	74-82-8
6775	12/5/2011	29.26	J	Hydrogen	1333-74-0
6775	12/5/2011	ND	U	Methane	74-82-8

P3R4I - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 4 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6437	7/19/2011	ND	U	Hydrogen	1333-74-0
6437	7/19/2011	ND	U	Methane	74-82-8
6503	8/16/2011	42.26	J	Hydrogen	1333-74-0
6503	8/16/2011	ND	U	Methane	74-82-8
6581	9/20/2011	ND	U	Hydrogen	1333-74-0
6581	9/20/2011	ND	U	Methane	74-82-8
6656	10/18/2011	ND	U	Hydrogen	1333-74-0
6656	10/18/2011	ND	U	Methane	74-82-8
6726	11/7/2011	ND	U	Hydrogen	1333-74-0
6726	11/7/2011	ND	U	Methane	74-82-8
6781	12/6/2011	ND	U	Hydrogen	1333-74-0
6781	12/6/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P3R5E - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 5 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6428	7/18/2011	50.44	J	Hydrogen	1333-74-0
6428	7/18/2011	ND	U	Methane	74-82-8
6496	8/15/2011	59.04	J	Hydrogen	1333-74-0
6496	8/15/2011	ND	U	Methane	74-82-8
6574	9/19/2011	41.84	J	Hydrogen	1333-74-0
6574	9/19/2011	ND	U	Methane	74-82-8
6647	10/17/2011	U	U	Hydrogen	1333-74-0
6647	10/17/2011	ND	U	Methane	74-82-8
6719	11/7/2011	32.00	J	Hydrogen	1333-74-0
6719	11/7/2011	ND	U	Methane	74-82-8
6774	12/5/2011	44.44	J	Hydrogen	1333-74-0
6774	12/5/2011	ND	U	Methane	74-82-8

P3R5I - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 5 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6436	7/19/2011	ND	U	Hydrogen	1333-74-0
6436	7/19/2011	ND	U	Methane	74-82-8
6502	8/16/2011	49.46	J	Hydrogen	1333-74-0
6502	8/16/2011	ND	U	Methane	74-82-8
6580	9/20/2011	U	U	Hydrogen	1333-74-0
6580	9/20/2011	ND	U	Methane	74-82-8
6651	10/17/2011	U	U	Hydrogen	1333-74-0
6651	10/17/2011	ND	U	Methane	74-82-8
6725	11/7/2011	ND	U	Hydrogen	1333-74-0
6725	11/7/2011	ND	U	Methane	74-82-8
6780	12/5/2011	ND	U	Hydrogen	1333-74-0
6780	12/5/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P3R6E - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 6 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6427	7/18/2011	36.06	J	Hydrogen	1333-74-0
6427	7/18/2011	ND	U	Methane	74-82-8
6495	8/15/2011	76.68	J	Hydrogen	1333-74-0
6495	8/15/2011	ND	U	Methane	74-82-8
6573	9/19/2011	46.88	J	Hydrogen	1333-74-0
6573	9/19/2011	ND	U	Methane	74-82-8
6646	10/17/2011	38.82	J	Hydrogen	1333-74-0
6646	10/17/2011	ND	U	Methane	74-82-8
6718	11/7/2011	32.08	J	Hydrogen	1333-74-0
6718	11/7/2011	ND	U	Methane	74-82-8
6773	12/5/2011	U	U	Hydrogen	1333-74-0
6773	12/5/2011	ND	U	Methane	74-82-8

P3R6I - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 6 Inlet

Sample line determined as obstructed on 9/22/2010.

Attachment 5 – Hydrogen and Methane Results

P3R7E - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 7 Exhaust

Sample line determined as obstructed on 8/30/2010.

P3R7I - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Room 7 Inlet

Sample line determined as obstructed on 7/14/2008.

Attachment 5 – Hydrogen and Methane Results

P3EBW - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Exhaust Bulkhead Waste Side

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6432	7/18/2011	ND	U	Hydrogen	1333-74-0
6432	7/18/2011	ND	U	Methane	74-82-8
6500	8/15/2011	ND	U	Hydrogen	1333-74-0
6500	8/15/2011	ND	U	Methane	74-82-8
6578	9/19/2011	ND	U	Hydrogen	1333-74-0
6578	9/19/2011	ND	U	Methane	74-82-8
6652	10/17/2011	ND	U	Hydrogen	1333-74-0
6652	10/17/2011	ND	U	Methane	74-82-8
6723	11/7/2011	ND	U	Hydrogen	1333-74-0
6723	11/7/2011	ND	U	Methane	74-82-8
6778	12/5/2011	29.60	J	Hydrogen	1333-74-0
6778	12/5/2011	ND	U	Methane	74-82-8

P3EBA - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Exhaust Bulkhead Ambient Side

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6435	7/19/2011	ND	U	Hydrogen	1333-74-0
6435	7/19/2011	ND	U	Methane	74-82-8
6501	8/16/2011	ND	U	Hydrogen	1333-74-0
6501	8/16/2011	ND	U	Methane	74-82-8
6579	9/20/2011	ND	U	Hydrogen	1333-74-0
6579	9/20/2011	ND	U	Methane	74-82-8
6653	10/17/2011	ND	U	Hydrogen	1333-74-0
6653	10/17/2011	ND	U	Methane	74-82-8
6724	11/7/2011	ND	U	Hydrogen	1333-74-0
6724	11/7/2011	ND	U	Methane	74-82-8
6779	12/5/2011	ND	U	Hydrogen	1333-74-0
6779	12/5/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P3IBW - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Inlet Bulkhead Waste Side

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6426	7/18/2011	ND	U	Hydrogen	1333-74-0
6426	7/18/2011	ND	U	Methane	74-82-8
6494	8/15/2011	ND	U	Hydrogen	1333-74-0
6494	8/15/2011	ND	U	Methane	74-82-8
6571	9/19/2011	ND	U	Hydrogen	1333-74-0
6571	9/19/2011	ND	U	Methane	74-82-8
6654	10/18/2011	ND	U	Hydrogen	1333-74-0
6654	10/18/2011	ND	U	Methane	74-82-8
6716	11/7/2011	38.82	J	Hydrogen	1333-74-0
6716	11/7/2011	ND	U	Methane	74-82-8
6771	12/5/2011	ND	U	Hydrogen	1333-74-0
6771	12/5/2011	ND	U	Methane	74-82-8

P3IBA - Hydrogen and Methane Monitoring Results in ppmv for Panel 3 Inlet Bulkhead Ambient Side

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6425	7/18/2011	ND	U	Hydrogen	1333-74-0
6425	7/18/2011	ND	U	Methane	74-82-8
6493	8/15/2011	ND	U	Hydrogen	1333-74-0
6493	8/15/2011	ND	U	Methane	74-82-8
6572	9/19/2011	ND	U	Hydrogen	1333-74-0
6572	9/19/2011	ND	U	Methane	74-82-8
6655	10/18/2011	ND	U	Hydrogen	1333-74-0
6655	10/18/2011	ND	U	Methane	74-82-8
6717	11/7/2011	ND	U	Hydrogen	1333-74-0
6717	11/7/2011	ND	U	Methane	74-82-8
6772	12/5/2011	ND	U	Hydrogen	1333-74-0
6772	12/5/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P4R1E - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 1 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6414	7/12/2011	283.24	J	Hydrogen	1333-74-0
6414	7/12/2011	ND	U	Methane	74-82-8
6482	8/9/2011	143.48	J	Hydrogen	1333-74-0
6482	8/9/2011	ND	U	Methane	74-82-8
6560	9/14/2011	410.04		Hydrogen	1333-74-0
6560	9/14/2011	ND	U	Methane	74-82-8
6634	10/11/2011	305.92		Hydrogen	1333-74-0
6634	10/11/2011	ND	U	Methane	74-82-8
6707	11/1/2011	388.88		Hydrogen	1333-74-0
6707	11/1/2011	ND	U	Methane	74-82-8
6811	12/13/2011	494.32		Hydrogen	1333-74-0
6811	12/13/2011	ND	U	Methane	74-82-8

P4R1I - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 1 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6406	7/11/2011	411.26		Hydrogen	1333-74-0
6406	7/11/2011	ND	U	Methane	74-82-8
6474	8/9/2011	300.02		Hydrogen	1333-74-0
6474	8/9/2011	ND	U	Methane	74-82-8
6550	9/13/2011	429.54		Hydrogen	1333-74-0
6550	9/13/2011	ND	U	Methane	74-82-8
6624	10/10/2011	294.66	J	Hydrogen	1333-74-0
6624	10/10/2011	ND	U	Methane	74-82-8
6697	11/1/2011	365.72		Hydrogen	1333-74-0
6697	11/1/2011	ND	U	Methane	74-82-8
6801	12/12/2011	483.68		Hydrogen	1333-74-0
6801	12/12/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P4R2E - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 2 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6413	7/12/2011	472.86		Hydrogen	1333-74-0
6413	7/12/2011	ND	U	Methane	74-82-8
6481	8/9/2011	416.32		Hydrogen	1333-74-0
6481	8/9/2011	ND	U	Methane	74-82-8
6559	9/14/2011	465.28		Hydrogen	1333-74-0
6559	9/14/2011	ND	U	Methane	74-82-8
6631	10/11/2011	327.84		Hydrogen	1333-74-0
6631	10/11/2011	ND	U	Methane	74-82-8
6704	11/1/2011	426.68		Hydrogen	1333-74-0
6704	11/1/2011	ND	U	Methane	74-82-8
6808	12/13/2011	506.18		Hydrogen	1333-74-0
6808	12/13/2011	ND	U	Methane	74-82-8

P4R2I - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 2 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6405	7/11/2011	460.76		Hydrogen	1333-74-0
6405	7/11/2011	ND	U	Methane	74-82-8
6473	8/9/2011	353.70		Hydrogen	1333-74-0
6473	8/9/2011	ND	U	Methane	74-82-8
6549	9/13/2011	468.10		Hydrogen	1333-74-0
6549	9/13/2011	ND	U	Methane	74-82-8
6623	10/10/2011	332.94		Hydrogen	1333-74-0
6623	10/10/2011	ND	U	Methane	74-82-8
6696	11/1/2011	399.78		Hydrogen	1333-74-0
6696	11/1/2011	ND	U	Methane	74-82-8
6800	12/12/2011	494.62		Hydrogen	1333-74-0
6800	12/12/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P4R3E - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 3 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6412	7/12/2011	635.28		Hydrogen	1333-74-0
6412	7/12/2011	ND	U	Methane	74-82-8
6480	8/9/2011	663.40		Hydrogen	1333-74-0
6480	8/9/2011	ND	U	Methane	74-82-8
6558	9/14/2011	626.82		Hydrogen	1333-74-0
6558	9/14/2011	ND	U	Methane	74-82-8
6630	10/11/2011	628.78		Hydrogen	1333-74-0
6630	10/11/2011	ND	U	Methane	74-82-8
6703	11/1/2011	605.58		Hydrogen	1333-74-0
6703	11/1/2011	ND	U	Methane	74-82-8
6807	12/13/2011	552.70		Hydrogen	1333-74-0
6807	12/13/2011	ND	U	Methane	74-82-8

P4R3I - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 3 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6404	7/11/2011	592.78		Hydrogen	1333-74-0
6404	7/11/2011	ND	U	Methane	74-82-8
6472	8/9/2011	589.06		Hydrogen	1333-74-0
6472	8/9/2011	ND	U	Methane	74-82-8
6548	9/13/2011	586.56		Hydrogen	1333-74-0
6548	9/13/2011	ND	U	Methane	74-82-8
6622	10/10/2011	543.54		Hydrogen	1333-74-0
6622	10/10/2011	ND	U	Methane	74-82-8
6695	11/1/2011	476.68		Hydrogen	1333-74-0
6695	11/1/2011	ND	U	Methane	74-82-8
6799	12/12/2011	538.2		Hydrogen	1333-74-0
6799	12/12/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P4R4E - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 4 Exhaust

Sample line determined as obstructed on 4/7/2011

P4R4I - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 4 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6403	7/11/2011	629.18		Hydrogen	1333-74-0
6403	7/11/2011	ND	U	Methane	74-82-8
6471	8/9/2011	445.40		Hydrogen	1333-74-0
6471	8/9/2011	ND	U	Methane	74-82-8
6547	9/13/2011	428.76		Hydrogen	1333-74-0
6547	9/13/2011	ND	U	Methane	74-82-8
6621	10/10/2011	357.76		Hydrogen	1333-74-0
6621	10/10/2011	ND	U	Methane	74-82-8
6694	11/1/2011	381.34		Hydrogen	1333-74-0
6694	11/1/2011	ND	U	Methane	74-82-8
6798	12/12/2011	552.18		Hydrogen	1333-74-0
6798	12/12/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P4R5E - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 5 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6411	7/12/2011	640.36		Hydrogen	1333-74-0
6411	7/12/2011	ND	U	Methane	74-82-8
6479	8/9/2011	646.18		Hydrogen	1333-74-0
6479	8/9/2011	ND	U	Methane	74-82-8
6557	9/14/2011	671.18		Hydrogen	1333-74-0
6557	9/14/2011	ND	U	Methane	74-82-8
6629	10/11/2011	673.00		Hydrogen	1333-74-0
6629	10/11/2011	ND	U	Methane	74-82-8
6702	11/1/2011	604.10		Hydrogen	1333-74-0
6702	11/1/2011	ND	U	Methane	74-82-8
6806	12/13/2011	558.76		Hydrogen	1333-74-0
6806	12/13/2011	ND	U	Methane	74-82-8

P4R5I - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 5 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6402	7/11/2011	715.64		Hydrogen	1333-74-0
6402	7/11/2011	ND	U	Methane	74-82-8
6470	8/9/2011	631.96		Hydrogen	1333-74-0
6470	8/9/2011	ND	U	Methane	74-82-8
6546	9/13/2011	564.12		Hydrogen	1333-74-0
6546	9/13/2011	ND	U	Methane	74-82-8
6620	10/10/2011	449.38		Hydrogen	1333-74-0
6620	10/10/2011	ND	U	Methane	74-82-8
6693	11/1/2011	421.78		Hydrogen	1333-74-0
6693	11/1/2011	ND	U	Methane	74-82-8
6797	12/12/2011	502.48		Hydrogen	1333-74-0
6797	12/12/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P4R6E - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 6 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6410	7/12/2011	648.56		Hydrogen	1333-74-0
6410	7/12/2011	ND	U	Methane	74-82-8
6478	8/9/2011	692.68		Hydrogen	1333-74-0
6478	8/9/2011	ND	U	Methane	74-82-8
6554	9/14/2011	656.56		Hydrogen	1333-74-0
6554	9/14/2011	ND	U	Methane	74-82-8
6628	10/11/2011	679.30		Hydrogen	1333-74-0
6628	10/11/2011	ND	U	Methane	74-82-8
6701	11/1/2011	661.62		Hydrogen	1333-74-0
6701	11/1/2011	ND	U	Methane	74-82-8
Sample line determined as obstructed on 12/13/2011					

P4R6I - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 6 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6401	7/11/2011	494.48		Hydrogen	1333-74-0
6401	7/11/2011	ND	U	Methane	74-82-8
6469	8/9/2011	397.04		Hydrogen	1333-74-0
6469	8/9/2011	ND	U	Methane	74-82-8
6545	9/13/2011	461.88		Hydrogen	1333-74-0
6545	9/13/2011	ND	U	Methane	74-82-8
6619	10/10/2011	323.52		Hydrogen	1333-74-0
6619	10/10/2011	ND	U	Methane	74-82-8
6692	11/1/2011	370.18		Hydrogen	1333-74-0
6692	11/1/2011	ND	U	Methane	74-82-8
6796	12/12/2011	459.02		Hydrogen	1333-74-0
6796	12/12/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P4R7E - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 7 Exhaust

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6409	7/12/2011	775.72		Hydrogen	1333-74-0
6409	7/12/2011	ND	U	Methane	74-82-8
6477	8/9/2011	837.04		Hydrogen	1333-74-0
6477	8/9/2011	ND	U	Methane	74-82-8
6553	9/14/2011	823.62		Hydrogen	1333-74-0
6553	9/14/2011	ND	U	Methane	74-82-8
6627	10/11/2011	856.32		Hydrogen	1333-74-0
6627	10/11/2011	ND	U	Methane	74-82-8
6700	11/1/2011	793.36		Hydrogen	1333-74-0
6700	11/1/2011	ND	U	Methane	74-82-8
6804	12/12/2011	737.98		Hydrogen	1333-74-0
6804	12/12/2011	ND	U	Methane	74-82-8

P4R7I - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Room 7 Inlet

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6400	7/11/2011	674.94		Hydrogen	1333-74-0
6400	7/11/2011	ND	U	Methane	74-82-8
6461	8/9/2011	507.68		Hydrogen	1333-74-0
6461	8/9/2011	ND	U	Methane	74-82-8
6544	9/13/2011	500.24		Hydrogen	1333-74-0
6544	9/13/2011	ND	U	Methane	74-82-8
6618	10/10/2011	388.58		Hydrogen	1333-74-0
6618	10/10/2011	ND	U	Methane	74-82-8
6691	11/1/2011	425.88		Hydrogen	1333-74-0
6691	11/1/2011	ND	U	Methane	74-82-8
6795	12/12/2011	557.70		Hydrogen	1333-74-0
6795	12/12/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P4EBW - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Exhaust Bulkhead Waste Side

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6416	7/12/2011	68.52	J	Hydrogen	1333-74-0
6416	7/12/2011	ND	U	Methane	74-82-8
6484	8/9/2011	45.78	J	Hydrogen	1333-74-0
6484	8/9/2011	ND	U	Methane	74-82-8
6562	9/14/2011	109.38	J	Hydrogen	1333-74-0
6562	9/14/2011	ND	U	Methane	74-82-8
6632	10/11/2011	51.88	J	Hydrogen	1333-74-0
6632	10/11/2011	ND	U	Methane	74-82-8
6705	11/1/2011	183.10	J	Hydrogen	1333-74-0
6705	11/1/2011	ND	U	Methane	74-82-8
6809	12/13/2011	214.68	J	Hydrogen	1333-74-0
6809	12/13/2011	ND	U	Methane	74-82-8

P4EBA - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Exhaust Bulkhead Ambient Side

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6417	7/12/2011	ND	U	Hydrogen	1333-74-0
6417	7/12/2011	ND	U	Methane	74-82-8
6485	8/9/2011	ND	U	Hydrogen	1333-74-0
6485	8/9/2011	ND	U	Methane	74-82-8
6563	9/14/2011	ND	U	Hydrogen	1333-74-0
6563	9/14/2011	ND	U	Methane	74-82-8
6633	10/11/2011	ND	U	Hydrogen	1333-74-0
6633	10/11/2011	ND	U	Methane	74-82-8
6706	11/1/2011	ND	U	Hydrogen	1333-74-0
6706	11/1/2011	ND	U	Methane	74-82-8
6810	12/13/2011	ND	U	Hydrogen	1333-74-0
6810	12/13/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P4IBW - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Inlet Bulkhead Waste Side

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6407	7/11/2011	263.72	J	Hydrogen	1333-74-0
6407	7/11/2011	ND	U	Methane	74-82-8
6475	8/9/2011	264.52	J	Hydrogen	1333-74-0
6475	8/9/2011	ND	U	Methane	74-82-8
6551	9/13/2011	289.72	J	Hydrogen	1333-74-0
6551	9/13/2011	ND	U	Methane	74-82-8
6625	10/10/2011	229.52	J	Hydrogen	1333-74-0
6625	10/10/2011	ND	U	Methane	74-82-8
6698	11/1/2011	249.70	J	Hydrogen	1333-74-0
6698	11/1/2011	ND	U	Methane	74-82-8
6802	12/12/2011	356.14		Hydrogen	1333-74-0
6802	12/12/2011	ND	U	Methane	74-82-8

Attachment 5 – Hydrogen and Methane Results

P4IBA - Hydrogen and Methane Monitoring Results in ppmv for Panel 4 Inlet Bulkhead Ambient Side

Sample ID	Sample Date	Results	Data Flags	Compound Name	CAS #
6408	7/12/2011	ND	U	Hydrogen	1333-74-0
6408	7/12/2011	ND	U	Methane	74-82-8
6476	8/9/2011	ND	U	Hydrogen	1333-74-0
6476	8/9/2011	ND	U	Methane	74-82-8
6552	9/14/2011	ND	U	Hydrogen	1333-74-0
6552	9/14/2011	ND	U	Methane	74-82-8
6626	10/10/2011	ND	U	Hydrogen	1333-74-0
6626	10/10/2011	ND	U	Methane	74-82-8
6699	11/1/2011	ND	U	Hydrogen	1333-74-0
6699	11/1/2011	ND	U	Methane	74-82-8
6803	12/12/2011	ND	U	Hydrogen	1333-74-0
6803	12/12/2011	ND	U	Methane	74-82-8

Notes

J =Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
ND = Compound not detected
U = Compound not detected above MDL.

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
7/7/2011	7/26/2011	1107110_02A	6373	7/7/2011	7/26/2011	1107110_02A	6373-dup	1,1,1-Trichloroethane	22.16*	21.72*	0.44	2.01
7/7/2011	7/26/2011	1107110_02A	6373	7/7/2011	7/26/2011	1107110_02A	6373-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
7/7/2011	7/26/2011	1107110_02A	6373	7/7/2011	7/26/2011	1107110_02A	6373-dup	1,1-Dichloroethylene	U	U	0	0
7/7/2011	7/26/2011	1107110_02A	6373	7/7/2011	7/26/2011	1107110_02A	6373-dup	1,2-Dichloroethane	U	U	0	0
7/7/2011	7/26/2011	1107110_02A	6373	7/7/2011	7/26/2011	1107110_02A	6373-dup	Carbon Tetrachloride	216.93*	214.75*	2.18	1.01
7/7/2011	7/26/2011	1107110_02A	6373	7/7/2011	7/26/2011	1107110_02A	6373-dup	Chlorobenzene	U	U	0	0
7/7/2011	7/26/2011	1107110_02A	6373	7/7/2011	7/26/2011	1107110_02A	6373-dup	Chloroform	22.38*	22.45*	-0.07	0.31
7/7/2011	7/26/2011	1107110_02A	6373	7/7/2011	7/26/2011	1107110_02A	6373-dup	Methylene Chloride	6.59* J	6.66* J	-0.07	1.06
7/7/2011	7/26/2011	1107110_02A	6373	7/7/2011	7/26/2011	1107110_02A	6373-dup	Toluene	1.23* J	1.08* J	0.15	12.99
7/6/2011	7/25/2011	1107110_09A	6380	7/6/2011	7/25/2011	1107110_09A	6380-dup	1,1,1-Trichloroethane	137781	136206.36	1574.64	1.15
7/6/2011	7/25/2011	1107110_09A	6380	7/6/2011	7/25/2011	1107110_09A	6380-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
7/6/2011	7/25/2011	1107110_09A	6380	7/6/2011	7/25/2011	1107110_09A	6380-dup	1,1-Dichloroethylene	U	U	0	0
7/6/2011	7/25/2011	1107110_09A	6380	7/6/2011	7/25/2011	1107110_09A	6380-dup	1,2-Dichloroethane	U	U	0	0
7/6/2011	7/25/2011	1107110_09A	6380	7/6/2011	7/25/2011	1107110_09A	6380-dup	Carbon Tetrachloride	3323277.7	3425629.3	-102351.6	3.03
7/6/2011	7/25/2011	1107110_09A	6380	7/6/2011	7/25/2011	1107110_09A	6380-dup	Chlorobenzene	U	U	0	0
7/6/2011	7/25/2011	1107110_09A	6380	7/6/2011	7/25/2011	1107110_09A	6380-dup	Chloroform	428302.08	435387.96	-7085.88	1.64
7/6/2011	7/25/2011	1107110_09A	6380	7/6/2011	7/25/2011	1107110_09A	6380-dup	Methylene Chloride	60623.64	58261.68	2361.96	3.97
7/6/2011	7/25/2011	1107110_09A	6380	7/6/2011	7/25/2011	1107110_09A	6380-dup	Toluene	U	U	0	0
7/12/2011	7/28/2011	1107140_02A	6393	7/12/2011	7/28/2011	1107140_02A	6393-dup	1,1,1-Trichloroethane	17.17*	16.81*	0.36	2.12
7/12/2011	7/28/2011	1107140_02A	6393	7/12/2011	7/28/2011	1107140_02A	6393-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
7/12/2011	7/28/2011	1107140_02A	6393	7/12/2011	7/28/2011	1107140_02A	6393-dup	1,1-Dichloroethylene	U	U	0	0
7/12/2011	7/28/2011	1107140_02A	6393	7/12/2011	7/28/2011	1107140_02A	6393-dup	1,2-Dichloroethane	U	U	0	0
7/12/2011	7/28/2011	1107140_02A	6393	7/12/2011	7/28/2011	1107140_02A	6393-dup	Carbon Tetrachloride	95.26*	93.69*	1.57	1.66
7/12/2011	7/28/2011	1107140_02A	6393	7/12/2011	7/28/2011	1107140_02A	6393-dup	Chlorobenzene	U	U	0	0
7/12/2011	7/28/2011	1107140_02A	6393	7/12/2011	7/28/2011	1107140_02A	6393-dup	Chloroform	9.05*	8.85*	0.2	2.23
7/12/2011	7/28/2011	1107140_02A	6393	7/12/2011	7/28/2011	1107140_02A	6393-dup	Methylene Chloride	4.35* J	4.24* J	0.11	2.56
7/12/2011	7/28/2011	1107140_02A	6393	7/12/2011	7/28/2011	1107140_02A	6393-dup	Toluene	1.06* J	1.04* J	0.02	1.9
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_22A	6414-dup	1,1,1-Trichloroethane	93034.98	90410.58	2624.4	2.86
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_22A	6414-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_22A	6414-dup	1,1-Dichloroethylene	U	U	0	0
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_22A	6414-dup	1,2-Dichloroethane	U	U	0	0
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_22A	6414-dup	Carbon Tetrachloride	499554.54	478165.68	21388.86	4.38
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_22A	6414-dup	Chlorobenzene	U	U	0	0
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_22A	6414-dup	Chloroform	41071.86	39759.66	1312.2	3.25
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_22A	6414-dup	Methylene Chloride	22832.28	22176.18	656.1	2.92

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_22A	6414-dup	Toluene	U	U	0	0
7/20/2011	7/29/2011	1107210_03A	6423	7/20/2011	7/29/2011	1107210_03A	6423-dup	1,1,1-Trichloroethane	25.12*	24.82*	0.3	1.2
7/20/2011	7/29/2011	1107210_03A	6423	7/20/2011	7/29/2011	1107210_03A	6423-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
7/20/2011	7/29/2011	1107210_03A	6423	7/20/2011	7/29/2011	1107210_03A	6423-dup	1,1-Dichloroethylene	U	U	0	0
7/20/2011	7/29/2011	1107210_03A	6423	7/20/2011	7/29/2011	1107210_03A	6423-dup	1,2-Dichloroethane	U	U	0	0
7/20/2011	7/29/2011	1107210_03A	6423	7/20/2011	7/29/2011	1107210_03A	6423-dup	Carbon Tetrachloride	156.88*	155.71*	1.17	0.75
7/20/2011	7/29/2011	1107210_03A	6423	7/20/2011	7/29/2011	1107210_03A	6423-dup	Chlorobenzene	U	U	0	0
7/20/2011	7/29/2011	1107210_03A	6423	7/20/2011	7/29/2011	1107210_03A	6423-dup	Chloroform	14.40*	14.40*	0	0
7/20/2011	7/29/2011	1107210_03A	6423	7/20/2011	7/29/2011	1107210_03A	6423-dup	Methylene Chloride	6.48* J	6.03* J	0.45	7.19
7/20/2011	7/29/2011	1107210_03A	6423	7/20/2011	7/29/2011	1107210_03A	6423-dup	Toluene	0.98* J	0.94* J	0.04	4.17
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_13A	6433-dup	Carbon Tetrachloride	1846.26	1858.14	-11.88	0.64
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_13A	6433-dup	Chlorobenzene	U	U	0	0
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_13A	6433-dup	Chloroform	52.92 J	51.3 J	1.62	3.11
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_13A	6433-dup	1,2-Dichloroethane	U	U	0	0
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_13A	6433-dup	1,1-Dichloroethylene	15.12 J	14.58 J	0.54	3.64
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_13A	6433-dup	Methylene Chloride	447.12 J	439.56 J	7.56	1.71
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_13A	6433-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_13A	6433-dup	Toluene	26.46 J	25.38 J	1.08	4.17
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_13A	6433-dup	1,1,1-Trichloroethane	1574.1	1579.5	-5.4	0.34
7/26/2011	8/4/2011	1107280_01A	6443	7/26/2011	8/4/2011	1107280_01A	6443-dup	Carbon Tetrachloride	230.31*	224.96*	5.35	2.35
7/26/2011	8/4/2011	1107280_01A	6443	7/26/2011	8/4/2011	1107280_01A	6443-dup	Chlorobenzene	U	U	0	0
7/26/2011	8/4/2011	1107280_01A	6443	7/26/2011	8/4/2011	1107280_01A	6443-dup	Chloroform	20.72*	21.35*	-0.63	3
7/26/2011	8/4/2011	1107280_01A	6443	7/26/2011	8/4/2011	1107280_01A	6443-dup	1,2-Dichloroethane	U	U	0	0
7/26/2011	8/4/2011	1107280_01A	6443	7/26/2011	8/4/2011	1107280_01A	6443-dup	1,1-Dichloroethylene	U	U	0	0
7/26/2011	8/4/2011	1107280_01A	6443	7/26/2011	8/4/2011	1107280_01A	6443-dup	Methylene Chloride	8.88* J	8.82* J	0.06	0.68
7/26/2011	8/4/2011	1107280_01A	6443	7/26/2011	8/4/2011	1107280_01A	6443-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
7/26/2011	8/4/2011	1107280_01A	6443	7/26/2011	8/4/2011	1107280_01A	6443-dup	Toluene	1.08* J	1.08* J	0	0
7/26/2011	8/4/2011	1107280_01A	6443	7/26/2011	8/4/2011	1107280_01A	6443-dup	1,1,1-Trichloroethane	34.33*	33.76*	0.57	1.67
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_01A	6453-dup	Carbon Tetrachloride	205.51*	196.07*	9.44	4.7
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_01A	6453-dup	Chlorobenzene	U	U	0	0
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_01A	6453-dup	Chloroform	18.46*	17.72*	0.74	4.09
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_01A	6453-dup	1,2-Dichloroethane	U	U	0	0
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_01A	6453-dup	1,1-Dichloroethylene	U	U	0	0
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_01A	6453-dup	Methylene Chloride	7.31* J	7.49* J	-0.18	2.43
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_01A	6453-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_01A	6453-dup	Toluene	1.02* J	0.97* J	0.05	5.03

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_01A	6453-dup	1,1,1-Trichloroethane	31.22*	29.84*	1.38	4.52
8/9/2011	8/24/2011	1108110_02A	6463	8/9/2011	8/24/2011	1108110_02A	6463-dup	Carbon Tetrachloride	113.49*	113.40*	0.09	0.08
8/9/2011	8/24/2011	1108110_02A	6463	8/9/2011	8/24/2011	1108110_02A	6463-dup	Chlorobenzene	U	U	0	0
8/9/2011	8/24/2011	1108110_02A	6463	8/9/2011	8/24/2011	1108110_02A	6463-dup	Chloroform	11.18*	10.97*	0.21	1.9
8/9/2011	8/24/2011	1108110_02A	6463	8/9/2011	8/24/2011	1108110_02A	6463-dup	1,2-Dichloroethane	U	U	0	0
8/9/2011	8/24/2011	1108110_02A	6463	8/9/2011	8/24/2011	1108110_02A	6463-dup	1,1-Dichloroethylene	U	U	0	0
8/9/2011	8/24/2011	1108110_02A	6463	8/9/2011	8/24/2011	1108110_02A	6463-dup	Methylene Chloride	4.36* J	4.33* J	0.03	0.69
8/9/2011	8/24/2011	1108110_02A	6463	8/9/2011	8/24/2011	1108110_02A	6463-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
8/9/2011	8/24/2011	1108110_02A	6463	8/9/2011	8/24/2011	1108110_02A	6463-dup	Toluene	1.29* J	1.29* J	0	0
8/9/2011	8/24/2011	1108110_02A	6463	8/9/2011	8/24/2011	1108110_02A	6463-dup	1,1,1-Trichloroethane	18.14*	17.97*	0.17	0.94
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_08A	6482-dup	Carbon Tetrachloride	228672.72	225231.84	3440.88	1.52
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_08A	6482-dup	Chlorobenzene	U	U	0	0
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_08A	6482-dup	Chloroform	19537.2	19187.28	349.92	1.81
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_08A	6482-dup	1,2-Dichloroethane	U	U	0	0
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_08A	6482-dup	1,1-Dichloroethylene	U	U	0	0
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_08A	6482-dup	Methylene Chloride	10555.92	10439.28	116.64	1.11
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_08A	6482-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_08A	6482-dup	Toluene	U	U	0	0
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_08A	6482-dup	1,1,1-Trichloroethane	43506.72	42398.64	1108.08	2.58
8/16/2011	8/25/2011	1108180_02A	6487	8/16/2011	8/25/2011	1108180_02A	6487-dup	Carbon Tetrachloride	180.86*	179.12*	1.74	0.97
8/16/2011	8/25/2011	1108180_02A	6487	8/16/2011	8/25/2011	1108180_02A	6487-dup	Chlorobenzene	U	U	0	0
8/16/2011	8/25/2011	1108180_02A	6487	8/16/2011	8/25/2011	1108180_02A	6487-dup	Chloroform	16.04*	16.91*	-0.87	5.28
8/16/2011	8/25/2011	1108180_02A	6487	8/16/2011	8/25/2011	1108180_02A	6487-dup	1,2-Dichloroethane	U	U	0	0
8/16/2011	8/25/2011	1108180_02A	6487	8/16/2011	8/25/2011	1108180_02A	6487-dup	1,1-Dichloroethylene	U	U	0	0
8/16/2011	8/25/2011	1108180_02A	6487	8/16/2011	8/25/2011	1108180_02A	6487-dup	Methylene Chloride	6.54* J	6.43* J	0.11	1.7
8/16/2011	8/25/2011	1108180_02A	6487	8/16/2011	8/25/2011	1108180_02A	6487-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
8/16/2011	8/25/2011	1108180_02A	6487	8/16/2011	8/25/2011	1108180_02A	6487-dup	Toluene	0.92* J	1.04* J	-0.12	12.24
8/16/2011	8/25/2011	1108180_02A	6487	8/16/2011	8/25/2011	1108180_02A	6487-dup	1,1,1-Trichloroethane	25.60*	25.60*	0	0
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_18A	6506-dup	Carbon Tetrachloride	3678.21	3777.03	-98.82	2.65
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_18A	6506-dup	Chlorobenzene	U	U	0	0
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_18A	6506-dup	Chloroform	102.06 J	105.3 J	-3.24	3.13
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_18A	6506-dup	1,2-Dichloroethane	U	U	0	0
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_18A	6506-dup	1,1-Dichloroethylene	27.54 J	26.73 J	0.81	2.99
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_18A	6506-dup	Methylene Chloride	795.42	817.29	-21.87	2.71
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_18A	6506-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_18A	6506-dup	Toluene	51.03 J	57.51 J	-6.48	11.94

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_18A	6506-dup	1,1,1-Trichloroethane	3095.01	3178.44	-83.43	2.66
8/23/2011	8/30/2011	1108250_01A	6511	8/23/2011	8/30/2011	1108250_01A	6511-dup	Carbon Tetrachloride	125.09*	126.10*	-1.01	0.8
8/23/2011	8/30/2011	1108250_01A	6511	8/23/2011	8/30/2011	1108250_01A	6511-dup	Chlorobenzene	U	U	0	0
8/23/2011	8/30/2011	1108250_01A	6511	8/23/2011	8/30/2011	1108250_01A	6511-dup	Chloroform	11.75*	11.46*	0.29	2.5
8/23/2011	8/30/2011	1108250_01A	6511	8/23/2011	8/30/2011	1108250_01A	6511-dup	1,2-Dichloroethane	U	U	0	0
8/23/2011	8/30/2011	1108250_01A	6511	8/23/2011	8/30/2011	1108250_01A	6511-dup	1,1-Dichloroethylene	U	U	0	0
8/23/2011	8/30/2011	1108250_01A	6511	8/23/2011	8/30/2011	1108250_01A	6511-dup	Methylene Chloride	4.38* J	4.29* J	0.09	2.08
8/23/2011	8/30/2011	1108250_01A	6511	8/23/2011	8/30/2011	1108250_01A	6511-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
8/23/2011	8/30/2011	1108250_01A	6511	8/23/2011	8/30/2011	1108250_01A	6511-dup	Toluene	1.00* J	0.97* J	0.03	3.05
8/23/2011	8/30/2011	1108250_01A	6511	8/23/2011	8/30/2011	1108250_01A	6511-dup	1,1,1-Trichloroethane	18.36*	18.30*	0.06	0.33
8/30/2011	9/6/2011	1109010_01A	6521	8/30/2011	9/6/2011	1109010_01A	6521-dup	Carbon Tetrachloride	186.62*	193.95*	-7.33	3.85
8/30/2011	9/6/2011	1109010_01A	6521	8/30/2011	9/6/2011	1109010_01A	6521-dup	Chlorobenzene	U	U	0	0
8/30/2011	9/6/2011	1109010_01A	6521	8/30/2011	9/6/2011	1109010_01A	6521-dup	Chloroform	16.17*	16.95*	-0.78	4.71
8/30/2011	9/6/2011	1109010_01A	6521	8/30/2011	9/6/2011	1109010_01A	6521-dup	1,2-Dichloroethane	U	U	0	0
8/30/2011	9/6/2011	1109010_01A	6521	8/30/2011	9/6/2011	1109010_01A	6521-dup	1,1-Dichloroethylene	U	U	0	0
8/30/2011	9/6/2011	1109010_01A	6521	8/30/2011	9/6/2011	1109010_01A	6521-dup	Methylene Chloride	6.13* J	6.48* J	-0.35	5.55
8/30/2011	9/6/2011	1109010_01A	6521	8/30/2011	9/6/2011	1109010_01A	6521-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
8/30/2011	9/6/2011	1109010_01A	6521	8/30/2011	9/6/2011	1109010_01A	6521-dup	Toluene	1.27* J	1.23* J	0.04	3.2
8/30/2011	9/6/2011	1109010_01A	6521	8/30/2011	9/6/2011	1109010_01A	6521-dup	1,1,1-Trichloroethane	27.95*	28.57*	-0.62	2.19
9/7/2011	9/13/2011	1109090_02A	6529	9/7/2011	9/13/2011	1109090_02A	6529-dup	Carbon Tetrachloride	252.89*	245.57*	7.32	2.94
9/7/2011	9/13/2011	1109090_02A	6529	9/7/2011	9/13/2011	1109090_02A	6529-dup	Chlorobenzene	U	U	0	0
9/7/2011	9/13/2011	1109090_02A	6529	9/7/2011	9/13/2011	1109090_02A	6529-dup	Chloroform	20.73*	20.13*	0.6	2.94
9/7/2011	9/13/2011	1109090_02A	6529	9/7/2011	9/13/2011	1109090_02A	6529-dup	1,2-Dichloroethane	U	U	0	0
9/7/2011	9/13/2011	1109090_02A	6529	9/7/2011	9/13/2011	1109090_02A	6529-dup	1,1-Dichloroethylene	1.63* J	1.54* J	0.09	5.68
9/7/2011	9/13/2011	1109090_02A	6529	9/7/2011	9/13/2011	1109090_02A	6529-dup	Methylene Chloride	7.74* J	7.31* J	0.43	5.71
9/7/2011	9/13/2011	1109090_02A	6529	9/7/2011	9/13/2011	1109090_02A	6529-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
9/7/2011	9/13/2011	1109090_02A	6529	9/7/2011	9/13/2011	1109090_02A	6529-dup	Toluene	1.29* J	1.11* J	0.18	15
9/7/2011	9/13/2011	1109090_02A	6529	9/7/2011	9/13/2011	1109090_02A	6529-dup	1,1,1-Trichloroethane	35.02*	33.21*	1.81	5.31
9/14/2011	9/15/2011	1109150_03A	6555	9/14/2011	9/15/2011	1109150_03A	6555-dup	Carbon Tetrachloride	200.22*	203.12*	-2.9	1.44
9/14/2011	9/15/2011	1109150_03A	6555	9/14/2011	9/15/2011	1109150_03A	6555-dup	Chlorobenzene	U	U	0	0
9/14/2011	9/15/2011	1109150_03A	6555	9/14/2011	9/15/2011	1109150_03A	6555-dup	Chloroform	17.85*	17.21*	0.64	3.65
9/14/2011	9/15/2011	1109150_03A	6555	9/14/2011	9/15/2011	1109150_03A	6555-dup	1,2-Dichloroethane	U	U	0	0
9/14/2011	9/15/2011	1109150_03A	6555	9/14/2011	9/15/2011	1109150_03A	6555-dup	1,1-Dichloroethylene	U	U	0	0
9/14/2011	9/15/2011	1109150_03A	6555	9/14/2011	9/15/2011	1109150_03A	6555-dup	Methylene Chloride	6.08* J	5.91* J	0.17	2.84
9/14/2011	9/15/2011	1109150_03A	6555	9/14/2011	9/15/2011	1109150_03A	6555-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
9/14/2011	9/15/2011	1109150_03A	6555	9/14/2011	9/15/2011	1109150_03A	6555-dup	Toluene	0.86* J	0.75* J	0.11	13.66

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
9/14/2011	9/15/2011	1109150_03A	6555	9/14/2011	9/15/2011	1109150_03A	6555-dup	1,1,1-Trichloroethane	26.95*	27.24*	-0.29	1.07
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_19A	6560-dup	Carbon Tetrachloride	640484.82	663317.1	-22832.28	3.5
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_19A	6560-dup	Chlorobenzene	U	U	0	0
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_19A	6560-dup	Chloroform	52750.44	53668.98	-918.54	1.73
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_19A	6560-dup	1,2-Dichloroethane	U	U	0	0
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_19A	6560-dup	1,1-Dichloroethylene	U	U	0	0
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_19A	6560-dup	Methylene Chloride	27949.86	28605.96	-656.1	2.32
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_19A	6560-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_19A	6560-dup	Toluene	1312.2	1312.2	0	0
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_19A	6560-dup	1,1,1-Trichloroethane	123478.02	127414.62	-3936.6	3.14
9/20/2011	9/27/2011	1109260_02A	6565	9/20/2011	9/27/2011	1109260_02A	6565-dup	Carbon Tetrachloride	216.42*	217.00*	-0.58	0.27
9/20/2011	9/27/2011	1109260_02A	6565	9/20/2011	9/27/2011	1109260_02A	6565-dup	Chlorobenzene	U	U	0	0
9/20/2011	9/27/2011	1109260_02A	6565	9/20/2011	9/27/2011	1109260_02A	6565-dup	Chloroform	18.75*	18.92*	-0.17	0.9
9/20/2011	9/27/2011	1109260_02A	6565	9/20/2011	9/27/2011	1109260_02A	6565-dup	1,2-Dichloroethane	U	U	0	0
9/20/2011	9/27/2011	1109260_02A	6565	9/20/2011	9/27/2011	1109260_02A	6565-dup	1,1-Dichloroethylene	0.64* J	0.58* J	0.06	9.84
9/20/2011	9/27/2011	1109260_02A	6565	9/20/2011	9/27/2011	1109260_02A	6565-dup	Methylene Chloride	7.39* J	7.45* J	-0.06	0.81
9/20/2011	9/27/2011	1109260_02A	6565	9/20/2011	9/27/2011	1109260_02A	6565-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
9/20/2011	9/27/2011	1109260_02A	6565	9/20/2011	9/27/2011	1109260_02A	6565-dup	Toluene	0.87* J	0.75* J	0.12	14.81
9/20/2011	9/27/2011	1109260_02A	6565	9/20/2011	9/27/2011	1109260_02A	6565-dup	1,1,1-Trichloroethane	34.36*	34.07*	0.29	0.85
9/20/2011	9/30/2011	1109260_21A	6584	9/20/2011	9/30/2011	1109260_21A	6584-dup	Carbon Tetrachloride	2102.76	1866.78	235.98	11.89
9/20/2011	9/30/2011	1109260_21A	6584	9/20/2011	9/30/2011	1109260_21A	6584-dup	Chlorobenzene	U	U	0	0
9/20/2011	9/30/2011	1109260_21A	6584	9/20/2011	9/30/2011	1109260_21A	6584-dup	Chloroform	70.74 J	62.1 J	8.64	13.01
9/20/2011	9/30/2011	1109260_21A	6584	9/20/2011	9/30/2011	1109260_21A	6584-dup	1,2-Dichloroethane	U	U	0	0
9/20/2011	9/30/2011	1109260_21A	6584	9/20/2011	9/30/2011	1109260_21A	6584-dup	1,1-Dichloroethylene	17.82 J	15.12 J	2.7	16.39
9/20/2011	9/30/2011	1109260_21A	6584	9/20/2011	9/30/2011	1109260_21A	6584-dup	Methylene Chloride	445.5 J	408.78 J	36.72	8.6
9/20/2011	9/30/2011	1109260_21A	6584	9/20/2011	9/30/2011	1109260_21A	6584-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
9/20/2011	9/30/2011	1109260_21A	6584	9/20/2011	9/30/2011	1109260_21A	6584-dup	Toluene	31.86 J	28.08 J	3.78	12.61
9/20/2011	9/30/2011	1109260_21A	6584	9/20/2011	9/30/2011	1109260_21A	6584-dup	1,1,1-Trichloroethane	1679.4	1502.28	177.12	11.13
9/27/2011	9/30/2011	1109290_01A	6589	9/27/2011	9/30/2011	1109290_01A	6589-dup	Carbon Tetrachloride	103.93*	103.42*	0.51	0.49
9/27/2011	9/30/2011	1109290_01A	6589	9/27/2011	9/30/2011	1109290_01A	6589-dup	Chlorobenzene	U	U	0	0
9/27/2011	9/30/2011	1109290_01A	6589	9/27/2011	9/30/2011	1109290_01A	6589-dup	Chloroform	9.29*	9.15*	0.14	1.52
9/27/2011	9/30/2011	1109290_01A	6589	9/27/2011	9/30/2011	1109290_01A	6589-dup	1,2-Dichloroethane	U	U	0	0
9/27/2011	9/30/2011	1109290_01A	6589	9/27/2011	9/30/2011	1109290_01A	6589-dup	1,1-Dichloroethylene	U	U	0	0
9/27/2011	9/30/2011	1109290_01A	6589	9/27/2011	9/30/2011	1109290_01A	6589-dup	Methylene Chloride	3.64* J	3.58* J	0.06	1.66
9/27/2011	9/30/2011	1109290_01A	6589	9/27/2011	9/30/2011	1109290_01A	6589-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
9/27/2011	9/30/2011	1109290_01A	6589	9/27/2011	9/30/2011	1109290_01A	6589-dup	Toluene	1.24* J	1.18* J	0.06	4.96

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
9/27/2011	9/30/2011	1109290_01A	6589	9/27/2011	9/30/2011	1109290_01A	6589-dup	1,1,1-Trichloroethane	14.72*	14.61*	0.11	0.75
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_01A	6597-dup	Carbon Tetrachloride	266.24*	264.64*	1.6	0.6
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_01A	6597-dup	Chlorobenzene	U	U	0	0
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_01A	6597-dup	Chloroform	24.20*	24.38*	-0.18	0.74
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_01A	6597-dup	1,2-Dichloroethane	U	U	0	0
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_01A	6597-dup	1,1-Dichloroethylene	U	U	0	0
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_01A	6597-dup	Methylene Chloride	7.13* J	7.30* J	-0.17	2.36
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_01A	6597-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_01A	6597-dup	Toluene	0.91* J	0.97* J	-0.06	6.38
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_01A	6597-dup	1,1,1-Trichloroethane	30.14*	30.03*	0.11	0.37
10/12/2011	10/18/2011	1110130_04A	6615	10/12/2011	10/18/2011	1110130_04A	6615-dup	Carbon Tetrachloride	206.95*	206.55*	0.4	0.19
10/12/2011	10/18/2011	1110130_04A	6615	10/12/2011	10/18/2011	1110130_04A	6615-dup	Chlorobenzene	U	U	0	0
10/12/2011	10/18/2011	1110130_04A	6615	10/12/2011	10/18/2011	1110130_04A	6615-dup	Chloroform	18.99*	18.83*	0.16	0.85
10/12/2011	10/18/2011	1110130_04A	6615	10/12/2011	10/18/2011	1110130_04A	6615-dup	1,2-Dichloroethane	U	U	0	0
10/12/2011	10/18/2011	1110130_04A	6615	10/12/2011	10/18/2011	1110130_04A	6615-dup	1,1-Dichloroethylene	U	U	0	0
10/12/2011	10/18/2011	1110130_04A	6615	10/12/2011	10/18/2011	1110130_04A	6615-dup	Methylene Chloride	6.73* J	6.50* J	0.23	3.48
10/12/2011	10/18/2011	1110130_04A	6615	10/12/2011	10/18/2011	1110130_04A	6615-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
10/12/2011	10/18/2011	1110130_04A	6615	10/12/2011	10/18/2011	1110130_04A	6615-dup	Toluene	1.37* J	1.26* J	0.11	8.37
10/12/2011	10/18/2011	1110130_04A	6615	10/12/2011	10/18/2011	1110130_04A	6615-dup	1,1,1-Trichloroethane	28.45*	28.29*	0.16	0.56
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_21A	6634-dup	Carbon Tetrachloride	543906.9	550205.46	-6298.56	1.15
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_21A	6634-dup	Chlorobenzene	U	U	0	0
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_21A	6634-dup	Chloroform	44221.14	45008.46	-787.32	1.76
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_21A	6634-dup	1,2-Dichloroethane	U	U	0	0
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_21A	6634-dup	1,1-Dichloroethylene	U	U	0	0
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_21A	6634-dup	Methylene Chloride	21782.52	22569.84	-787.32	3.55
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_21A	6634-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_21A	6634-dup	Toluene	U	U	0	0
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_21A	6634-dup	1,1,1-Trichloroethane	99464.76	102089.16	-2624.4	2.6
10/18/2011	10/26/2011	1110240_01A	6639	10/18/2011	10/26/2011	1110240_01A	6639-dup	Carbon Tetrachloride	102.66*	108.34*	-5.68	5.38
10/18/2011	10/26/2011	1110240_01A	6639	10/18/2011	10/26/2011	1110240_01A	6639-dup	Chlorobenzene	U	U	0	0
10/18/2011	10/26/2011	1110240_01A	6639	10/18/2011	10/26/2011	1110240_01A	6639-dup	Chloroform	8.56*	9.16*	-0.6	6.77
10/18/2011	10/26/2011	1110240_01A	6639	10/18/2011	10/26/2011	1110240_01A	6639-dup	1,2-Dichloroethane	U	U	0	0
10/18/2011	10/26/2011	1110240_01A	6639	10/18/2011	10/26/2011	1110240_01A	6639-dup	1,1-Dichloroethylene	U	U	0	0
10/18/2011	10/26/2011	1110240_01A	6639	10/18/2011	10/26/2011	1110240_01A	6639-dup	Methylene Chloride	2.69* J	3.00* J	-0.31	10.9
10/18/2011	10/26/2011	1110240_01A	6639	10/18/2011	10/26/2011	1110240_01A	6639-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
10/18/2011	10/26/2011	1110240_01A	6639	10/18/2011	10/26/2011	1110240_01A	6639-dup	Toluene	0.78* J	0.84* J	-0.06	7.41

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
10/18/2011	10/26/2011	1110240_01A	6639	10/18/2011	10/26/2011	1110240_01A	6639-dup	1,1,1-Trichloroethane	14.01*	14.70*	-0.69	4.81
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_22A	6659-dup	Carbon Tetrachloride	1576.26	1524.69	51.57	3.33
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_22A	6659-dup	Chlorobenzene	U	U	0	0
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_22A	6659-dup	Chloroform	51.03 J	49.14 J	1.89	3.77
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_22A	6659-dup	1,2-Dichloroethane	3.51 J	U	3.51	200
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_22A	6659-dup	1,1-Dichloroethylene	13.5 J	13.77 J	-0.27	1.98
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_22A	6659-dup	Methylene Chloride	303.21 J	290.52 J	12.69	4.27
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_22A	6659-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_22A	6659-dup	Toluene	22.95 J	23.22 J	-0.27	1.17
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_22A	6659-dup	1,1,1-Trichloroethane	1228.23	1198.26	29.97	2.47
10/25/2011	11/7/2011	1110270_01A	6673	10/25/2011	11/7/2011	1110270_01A	6673-dup	Carbon Tetrachloride	264.75*	268.87*	-4.12	1.54
10/25/2011	11/7/2011	1110270_01A	6673	10/25/2011	11/7/2011	1110270_01A	6673-dup	Chlorobenzene	U	U	0	0
10/25/2011	11/7/2011	1110270_01A	6673	10/25/2011	11/7/2011	1110270_01A	6673-dup	Chloroform	25.97*	26.78*	-0.81	3.07
10/25/2011	11/7/2011	1110270_01A	6673	10/25/2011	11/7/2011	1110270_01A	6673-dup	1,2-Dichloroethane	U	U	0	0
10/25/2011	11/7/2011	1110270_01A	6673	10/25/2011	11/7/2011	1110270_01A	6673-dup	1,1-Dichloroethylene	U	U	0	0
10/25/2011	11/7/2011	1110270_01A	6673	10/25/2011	11/7/2011	1110270_01A	6673-dup	Methylene Chloride	7.57* J	7.50* J	0.07	0.93
10/25/2011	11/7/2011	1110270_01A	6673	10/25/2011	11/7/2011	1110270_01A	6673-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
10/25/2011	11/7/2011	1110270_01A	6673	10/25/2011	11/7/2011	1110270_01A	6673-dup	Toluene	0.80* J	0.73* J	0.07	9.15
10/25/2011	11/7/2011	1110270_01A	6673	10/25/2011	11/7/2011	1110270_01A	6673-dup	1,1,1-Trichloroethane	31.86*	32.15*	-0.29	0.91
10/21/2011	11/8/2011	1110270_10A	6669	10/21/2011	11/8/2011	1110270_10A	6669-dup	Carbon Tetrachloride	79606.8	84175.2	-4568.4	5.58
10/21/2011	11/8/2011	1110270_10A	6669	10/21/2011	11/8/2011	1110270_10A	6669-dup	Chlorobenzene	U	U	0	0
10/21/2011	11/8/2011	1110270_10A	6669	10/21/2011	11/8/2011	1110270_10A	6669-dup	Chloroform	6492.96	6940.08	-447.12	6.66
10/21/2011	11/8/2011	1110270_10A	6669	10/21/2011	11/8/2011	1110270_10A	6669-dup	1,2-Dichloroethane	U	U	0	0
10/21/2011	11/8/2011	1110270_10A	6669	10/21/2011	11/8/2011	1110270_10A	6669-dup	1,1-Dichloroethylene	U	U	0	0
10/21/2011	11/8/2011	1110270_10A	6669	10/21/2011	11/8/2011	1110270_10A	6669-dup	Methylene Chloride	991.44	1049.76	-58.32	5.71
10/21/2011	11/8/2011	1110270_10A	6669	10/21/2011	11/8/2011	1110270_10A	6669-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
10/21/2011	11/8/2011	1110270_10A	6669	10/21/2011	11/8/2011	1110270_10A	6669-dup	Toluene	U	U	0	0
10/21/2011	11/8/2011	1110270_10A	6669	10/21/2011	11/8/2011	1110270_10A	6669-dup	1,1,1-Trichloroethane	15182.64	16018.56	-835.92	5.36
11/1/2011	11/9/2011	1111030_02A	6685	11/1/2011	11/9/2011	1111030_02A	6685-dup	Carbon Tetrachloride	111.07*	111.78*	-0.71	0.64
11/1/2011	11/9/2011	1111030_02A	6685	11/1/2011	11/9/2011	1111030_02A	6685-dup	Chlorobenzene	U	U	0	0
11/1/2011	11/9/2011	1111030_02A	6685	11/1/2011	11/9/2011	1111030_02A	6685-dup	Chloroform	9.85*	10.13*	-0.28	2.8
11/1/2011	11/9/2011	1111030_02A	6685	11/1/2011	11/9/2011	1111030_02A	6685-dup	1,2-Dichloroethane	U	U	0	0
11/1/2011	11/9/2011	1111030_02A	6685	11/1/2011	11/9/2011	1111030_02A	6685-dup	1,1-Dichloroethylene	0.41* J	0.41* J	0	0
11/1/2011	11/9/2011	1111030_02A	6685	11/1/2011	11/9/2011	1111030_02A	6685-dup	Methylene Chloride	3.72* J	3.69* J	0.03	0.81
11/1/2011	11/9/2011	1111030_02A	6685	11/1/2011	11/9/2011	1111030_02A	6685-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
11/1/2011	11/9/2011	1111030_02A	6685	11/1/2011	11/9/2011	1111030_02A	6685-dup	Toluene	0.76* J	0.78* J	-0.02	2.6

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
11/1/2011	11/9/2011	1111030_02A	6685	11/1/2011	11/9/2011	1111030_02A	6685-dup	1,1,1-Trichloroethane	17.03*	17.35*	-0.32	1.86
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_24A	6707-dup	Carbon Tetrachloride	580779.72	567920.16	12859.56	2.24
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_24A	6707-dup	Chlorobenzene	U	U	0	0
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_24A	6707-dup	Chloroform	48157.74	48288.96	-131.22	0.27
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_24A	6707-dup	1,2-Dichloroethane	U	U	0	0
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_24A	6707-dup	1,1-Dichloroethylene	U	U	0	0
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_24A	6707-dup	Methylene Chloride	23882.04	23750.82	131.22	0.55
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_24A	6707-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_24A	6707-dup	Toluene	1574.64	1180.98	393.66	28.57Q
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_24A	6707-dup	1,1,1-Trichloroethane	109043.82	105894.54	3149.28	2.93
11/8/2011	11/15/2011	1111100_01A	6711	11/8/2011	11/15/2011	1111100_01A	6711-dup	Carbon Tetrachloride	96.14*	88.91*	7.23	7.81
11/8/2011	11/15/2011	1111100_01A	6711	11/8/2011	11/15/2011	1111100_01A	6711-dup	Chlorobenzene	U	U	0	0
11/8/2011	11/15/2011	1111100_01A	6711	11/8/2011	11/15/2011	1111100_01A	6711-dup	Chloroform	7.62*	7.42*	0.2	2.66
11/8/2011	11/15/2011	1111100_01A	6711	11/8/2011	11/15/2011	1111100_01A	6711-dup	1,2-Dichloroethane	U	U	0	0
11/8/2011	11/15/2011	1111100_01A	6711	11/8/2011	11/15/2011	1111100_01A	6711-dup	1,1-Dichloroethylene	U	U	0	0
11/8/2011	11/15/2011	1111100_01A	6711	11/8/2011	11/15/2011	1111100_01A	6711-dup	Methylene Chloride	4.06* J	3.94* J	0.12	3
11/8/2011	11/15/2011	1111100_01A	6711	11/8/2011	11/15/2011	1111100_01A	6711-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
11/8/2011	11/15/2011	1111100_01A	6711	11/8/2011	11/15/2011	1111100_01A	6711-dup	Toluene	0.37* J	0.44* J	-0.07	17.28
11/8/2011	11/15/2011	1111100_01A	6711	11/8/2011	11/15/2011	1111100_01A	6711-dup	1,1,1-Trichloroethane	19.53*	18.10*	1.43	7.6
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_20A	6729-dup	Carbon Tetrachloride	1206.63	1179.63	27	2.26
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_20A	6729-dup	Chlorobenzene	U	U	0	0
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_20A	6729-dup	Chloroform	45.63 J	45.36 J	0.27	0.59
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_20A	6729-dup	1,2-Dichloroethane	U	U	0	0
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_20A	6729-dup	1,1-Dichloroethylene	10.8 J	11.34 J	-0.54	4.88
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_20A	6729-dup	Methylene Chloride	286.74 J	290.25 J	-3.51	1.22
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_20A	6729-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_20A	6729-dup	Toluene	21.87 J	22.95 J	-1.08	4.82
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_20A	6729-dup	1,1,1-Trichloroethane	1012.77	990.09	22.68	2.26
11/15/2011	11/22/2011	1111170_01A	6735	11/15/2011	11/22/2011	1111170_01A	6735-dup	Carbon Tetrachloride	112.07*	111.15*	0.92	0.82
11/15/2011	11/22/2011	1111170_01A	6735	11/15/2011	11/22/2011	1111170_01A	6735-dup	Chlorobenzene	U	U	0	0
11/15/2011	11/22/2011	1111170_01A	6735	11/15/2011	11/22/2011	1111170_01A	6735-dup	Chloroform	9.76*	9.59*	0.17	1.76
11/15/2011	11/22/2011	1111170_01A	6735	11/15/2011	11/22/2011	1111170_01A	6735-dup	1,2-Dichloroethane	U	U	0	0
11/15/2011	11/22/2011	1111170_01A	6735	11/15/2011	11/22/2011	1111170_01A	6735-dup	1,1-Dichloroethylene	U	U	0	0
11/15/2011	11/22/2011	1111170_01A	6735	11/15/2011	11/22/2011	1111170_01A	6735-dup	Methylene Chloride	4.48* J	4.21* J	0.27	6.21
11/15/2011	11/22/2011	1111170_01A	6735	11/15/2011	11/22/2011	1111170_01A	6735-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
11/15/2011	11/22/2011	1111170_01A	6735	11/15/2011	11/22/2011	1111170_01A	6735-dup	Toluene	1.58* J	1.58* J	0	0

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
11/15/2011	11/22/2011	1111170_01A	6735	11/15/2011	11/22/2011	1111170_01A	6735-dup	1,1,1-Trichloroethane	21.16*	20.69*	0.47	2.25
11/21/2011	11/29/2011	1111280_02A	6747	11/21/2011	11/29/2011	1111280_02A	6747-dup	Carbon Tetrachloride	336.52*	321.58*	14.94	4.54
11/21/2011	11/29/2011	1111280_02A	6747	11/21/2011	11/29/2011	1111280_02A	6747-dup	Chlorobenzene	U	U	0	0
11/21/2011	11/29/2011	1111280_02A	6747	11/21/2011	11/29/2011	1111280_02A	6747-dup	Chloroform	32.62*	31.46*	1.16	3.62
11/21/2011	11/29/2011	1111280_02A	6747	11/21/2011	11/29/2011	1111280_02A	6747-dup	1,2-Dichloroethane	U	U	0	0
11/21/2011	11/29/2011	1111280_02A	6747	11/21/2011	11/29/2011	1111280_02A	6747-dup	1,1-Dichloroethylene	0.97* J	0.66* J	0.31	38.04
11/21/2011	11/29/2011	1111280_02A	6747	11/21/2011	11/29/2011	1111280_02A	6747-dup	Methylene Chloride	10.14*	9.59* J	0.55	5.58
11/21/2011	11/29/2011	1111280_02A	6747	11/21/2011	11/29/2011	1111280_02A	6747-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
11/21/2011	11/29/2011	1111280_02A	6747	11/21/2011	11/29/2011	1111280_02A	6747-dup	Toluene	1.09* J	1.21* J	-0.12	10.43
11/21/2011	11/29/2011	1111280_02A	6747	11/21/2011	11/29/2011	1111280_02A	6747-dup	1,1,1-Trichloroethane	45.07*	43.91*	1.16	2.61
11/29/2011	12/6/2011	1112010_01A	6751	11/29/2011	12/6/2011	1112010_01A	6751-dup	Carbon Tetrachloride	133.64*	136.09*	-2.45	1.82
11/29/2011	12/6/2011	1112010_01A	6751	11/29/2011	12/6/2011	1112010_01A	6751-dup	Chlorobenzene	U	U	0	0
11/29/2011	12/6/2011	1112010_01A	6751	11/29/2011	12/6/2011	1112010_01A	6751-dup	Chloroform	10.73*	11.03*	-0.3	2.76
11/29/2011	12/6/2011	1112010_01A	6751	11/29/2011	12/6/2011	1112010_01A	6751-dup	1,2-Dichloroethane	U	U	0	0
11/29/2011	12/6/2011	1112010_01A	6751	11/29/2011	12/6/2011	1112010_01A	6751-dup	1,1-Dichloroethylene	U	U	0	0
11/29/2011	12/6/2011	1112010_01A	6751	11/29/2011	12/6/2011	1112010_01A	6751-dup	Methylene Chloride	4.03* J	3.95* J	0.08	2.01
11/29/2011	12/6/2011	1112010_01A	6751	11/29/2011	12/6/2011	1112010_01A	6751-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
11/29/2011	12/6/2011	1112010_01A	6751	11/29/2011	12/6/2011	1112010_01A	6751-dup	Toluene	0.86* J	0.80* J	0.06	7.23
11/29/2011	12/6/2011	1112010_01A	6751	11/29/2011	12/6/2011	1112010_01A	6751-dup	1,1,1-Trichloroethane	26.56*	26.72*	-0.16	0.6
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_03A	6763-dup	Carbon Tetrachloride	127.59*	128.90*	-1.31	1.02
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_03A	6763-dup	Chlorobenzene	U	U	0	0
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_03A	6763-dup	Chloroform	9.61*	9.73*	-0.12	1.24
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_03A	6763-dup	1,2-Dichloroethane	U	U	0	0
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_03A	6763-dup	1,1-Dichloroethylene	U	U	0	0
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_03A	6763-dup	Methylene Chloride	3.46* J	3.49* J	-0.03	0.86
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_03A	6763-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_03A	6763-dup	Toluene	0.35* J	0.35* J	0	0
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_03A	6763-dup	1,1,1-Trichloroethane	24.32*	24.64*	-0.32	1.31
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_21A	6784-dup	Carbon Tetrachloride	2715.12	2654.1	61.02	2.27
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_21A	6784-dup	Chlorobenzene	U	U	0	0
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_21A	6784-dup	Chloroform	77.76 J	76.14 J	1.62	2.11
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_21A	6784-dup	1,2-Dichloroethane	U	U	0	0
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_21A	6784-dup	1,1-Dichloroethylene	23.22 J	22.14 J	1.08	4.76
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_21A	6784-dup	Methylene Chloride	674.46	662.58	11.88	1.78
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_21A	6784-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_21A	6784-dup	Toluene	45.9 J	41.58 J	4.32	9.88

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_21A	6784-dup	1,1,1-Trichloroethane	2504.52	2444.58	59.94	2.42
12/13/2011	12/21/2011	1112150_01A	6769	12/13/2011	12/21/2011	1112150_01A	6769-dup	Carbon Tetrachloride	166.74*	173.00*	-6.26	3.69
12/13/2011	12/21/2011	1112150_01A	6769	12/13/2011	12/21/2011	1112150_01A	6769-dup	Chlorobenzene	U	U	0	0
12/13/2011	12/21/2011	1112150_01A	6769	12/13/2011	12/21/2011	1112150_01A	6769-dup	Chloroform	14.67*	15.41*	-0.74	4.92
12/13/2011	12/21/2011	1112150_01A	6769	12/13/2011	12/21/2011	1112150_01A	6769-dup	1,2-Dichloroethane	U	U	0	0
12/13/2011	12/21/2011	1112150_01A	6769	12/13/2011	12/21/2011	1112150_01A	6769-dup	1,1-Dichloroethylene	U	U	0	0
12/13/2011	12/21/2011	1112150_01A	6769	12/13/2011	12/21/2011	1112150_01A	6769-dup	Methylene Chloride	4.81* J	5.04* J	-0.23	4.67
12/13/2011	12/21/2011	1112150_01A	6769	12/13/2011	12/21/2011	1112150_01A	6769-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
12/13/2011	12/21/2011	1112150_01A	6769	12/13/2011	12/21/2011	1112150_01A	6769-dup	Toluene	0.54* J	0.54* J	0	0
12/13/2011	12/21/2011	1112150_01A	6769	12/13/2011	12/21/2011	1112150_01A	6769-dup	1,1,1-Trichloroethane	28.67*	29.73*	-1.06	3.63
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_24A	6811-dup	Carbon Tetrachloride	766193.58	796505.4	-30311.82	3.88
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_24A	6811-dup	Chlorobenzene	U	U	0	0
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_24A	6811-dup	Chloroform	60492.42	62723.16	-2230.74	3.62
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_24A	6811-dup	1,2-Dichloroethane	U	U	0	0
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_24A	6811-dup	1,1-Dichloroethylene	U	U	0	0
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_24A	6811-dup	Methylene Chloride	28605.96	29786.94	-1180.98	4.04
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_24A	6811-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_24A	6811-dup	Toluene	1049.76U	1180.98	-131.22	11.76
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_24A	6811-dup	1,1,1-Trichloroethane	145391.76	149065.92	-3674.16	2.5
12/19/2011	1/9/2012	1201030_02A	6817	12/19/2011	1/9/2012	1201030_02A	6817-dup	Carbon Tetrachloride	316.54*	295.87*	20.67	6.75
12/19/2011	1/9/2012	1201030_02A	6817	12/19/2011	1/9/2012	1201030_02A	6817-dup	Chlorobenzene	U	U	0	0
12/19/2011	1/9/2012	1201030_02A	6817	12/19/2011	1/9/2012	1201030_02A	6817-dup	Chloroform	26.85*	25.12*	1.73	6.66
12/19/2011	1/9/2012	1201030_02A	6817	12/19/2011	1/9/2012	1201030_02A	6817-dup	1,2-Dichloroethane	U	U	0	0
12/19/2011	1/9/2012	1201030_02A	6817	12/19/2011	1/9/2012	1201030_02A	6817-dup	1,1-Dichloroethylene	0.96* J	0.91* J	0.05	5.35
12/19/2011	1/9/2012	1201030_02A	6817	12/19/2011	1/9/2012	1201030_02A	6817-dup	Methylene Chloride	8.56*	7.80*	0.76	9.29
12/19/2011	1/9/2012	1201030_02A	6817	12/19/2011	1/9/2012	1201030_02A	6817-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
12/19/2011	1/9/2012	1201030_02A	6817	12/19/2011	1/9/2012	1201030_02A	6817-dup	Toluene	0.75* J	0.70* J	0.05	6.9
12/19/2011	1/9/2012	1201030_02A	6817	12/19/2011	1/9/2012	1201030_02A	6817-dup	1,1,1-Trichloroethane	51.87*	47.77*	4.1	8.23
12/28/2011	1/9/2012	1201030_06A	6821	12/28/2011	1/9/2012	1201030_06A	6821-dup	Carbon Tetrachloride	241.44*	252.75*	-11.31	4.58
12/28/2011	1/9/2012	1201030_06A	6821	12/28/2011	1/9/2012	1201030_06A	6821-dup	Chlorobenzene	U	U	0	0
12/28/2011	1/9/2012	1201030_06A	6821	12/28/2011	1/9/2012	1201030_06A	6821-dup	Chloroform	19.38*	19.73*	-0.35	1.79
12/28/2011	1/9/2012	1201030_06A	6821	12/28/2011	1/9/2012	1201030_06A	6821-dup	1,2-Dichloroethane	U	U	0	0
12/28/2011	1/9/2012	1201030_06A	6821	12/28/2011	1/9/2012	1201030_06A	6821-dup	1,1-Dichloroethylene	U	U	0	0
12/28/2011	1/9/2012	1201030_06A	6821	12/28/2011	1/9/2012	1201030_06A	6821-dup	Methylene Chloride	5.96*	6.18*	-0.22	3.62

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
12/28/2011	1/9/2012	1201030_06A	6821	12/28/2011	1/9/2012	1201030_06A	6821-dup	1,1,2,2-Tetrachloroethane	U	U	0	0
12/28/2011	1/9/2012	1201030_06A	6821	12/28/2011	1/9/2012	1201030_06A	6821-dup	Toluene	0.48* J	0.44* J	0.04	8.7
12/28/2011	1/9/2012	1201030_06A	6821	12/28/2011	1/9/2012	1201030_06A	6821-dup	1,1,1-Trichloroethane	38.37*	40.57*	-2.2	5.57

Notes

J =Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U =Compound analyzed for, but not detected above the MDL.
*= Normalized target VOC concentration.
= Technical acceptance criterion for duplicate analysis of a sample is ≤25 RPD which is only applicable if one or both values not flagged "U" or "J."

Relative Percent Difference (RPD)
RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS, LCSD listed as percent recovery

LCS Analytical Date	LCS Lab ID	LCS Sample ID	LCSD Analysis Date	LCSD Lab ID	LCSD Sample ID	Compound	LCS	LCSD	Difference	RPD
25-Jul-11	1107110_21A	LCS	25-Jul-11	1107110_21AA	LCSD	1,1,1-Trichloroethane	86.42	87.44	-1.02	1.17
25-Jul-11	1107110_21A	LCS	25-Jul-11	1107110_21AA	LCSD	1,1,2,2-Tetrachloroethane	89.9	87.91	1.99	2.24
25-Jul-11	1107110_21A	LCS	25-Jul-11	1107110_21AA	LCSD	1,1-Dichloroethylene	87.48	89.06	-1.58	1.79
25-Jul-11	1107110_21A	LCS	25-Jul-11	1107110_21AA	LCSD	1,2-Dichloroethane	84.72	84.09	0.63	0.75
25-Jul-11	1107110_21A	LCS	25-Jul-11	1107110_21AA	LCSD	Carbon Tetrachloride	91.46	90.65	0.81	0.89
25-Jul-11	1107110_21A	LCS	25-Jul-11	1107110_21AA	LCSD	Chlorobenzene	83.09	83.49	-0.40	0.48
25-Jul-11	1107110_21A	LCS	25-Jul-11	1107110_21AA	LCSD	Chloroform	85.74	85.85	-0.11	0.13
25-Jul-11	1107110_21A	LCS	25-Jul-11	1107110_21AA	LCSD	Methylene Chloride	87.62	88.73	-1.11	1.26
25-Jul-11	1107110_21A	LCS	25-Jul-11	1107110_21AA	LCSD	Toluene	83.28	84.05	-0.77	0.92
26-Jul-11	1107110_24A	LCS	26-Jul-11	1107110_24AA	LCSD	1,1,1-Trichloroethane	95.05	85.69	9.36	10.36
26-Jul-11	1107110_24A	LCS	26-Jul-11	1107110_24AA	LCSD	1,1,2,2-Tetrachloroethane	95.54	87.97	7.57	8.25
26-Jul-11	1107110_24A	LCS	26-Jul-11	1107110_24AA	LCSD	1,1-Dichloroethylene	100.11	86.77	13.34	14.28
26-Jul-11	1107110_24A	LCS	26-Jul-11	1107110_24AA	LCSD	1,2-Dichloroethane	92.92	84.07	8.85	10.00
26-Jul-11	1107110_24A	LCS	26-Jul-11	1107110_24AA	LCSD	Carbon Tetrachloride	98.6	88.28	10.32	11.04
26-Jul-11	1107110_24A	LCS	26-Jul-11	1107110_24AA	LCSD	Chlorobenzene	89.15	84.67	4.48	5.15
26-Jul-11	1107110_24A	LCS	26-Jul-11	1107110_24AA	LCSD	Chloroform	94.79	85.91	8.88	9.83
26-Jul-11	1107110_24A	LCS	26-Jul-11	1107110_24AA	LCSD	Methylene Chloride	96.22	85.79	10.43	11.46
26-Jul-11	1107110_24A	LCS	26-Jul-11	1107110_24AA	LCSD	Toluene	89.25	86.06	3.19	3.64
28-Jul-11	1107110_27A	LCS	28-Jul-11	1107110_27AA	LCSD	1,1,1-Trichloroethane	85.15	84.63	0.52	0.61
28-Jul-11	1107110_27A	LCS	28-Jul-11	1107110_27AA	LCSD	1,1,2,2-Tetrachloroethane	94.81	95.24	-0.43	0.45
28-Jul-11	1107110_27A	LCS	28-Jul-11	1107110_27AA	LCSD	1,1-Dichloroethylene	88.95	89.45	-0.50	0.56
28-Jul-11	1107110_27A	LCS	28-Jul-11	1107110_27AA	LCSD	1,2-Dichloroethane	81.35	81.29	0.06	0.07
28-Jul-11	1107110_27A	LCS	28-Jul-11	1107110_27AA	LCSD	Carbon Tetrachloride	90.79	89.47	1.32	1.46
28-Jul-11	1107110_27A	LCS	28-Jul-11	1107110_27AA	LCSD	Chlorobenzene	82.01	84.52	-2.51	3.01
28-Jul-11	1107110_27A	LCS	28-Jul-11	1107110_27AA	LCSD	Chloroform	85.79	84.07	1.72	2.03
28-Jul-11	1107110_27A	LCS	28-Jul-11	1107110_27AA	LCSD	Methylene Chloride	88.07	89.4	-1.33	1.50
28-Jul-11	1107110_27A	LCS	28-Jul-11	1107110_27AA	LCSD	Toluene	83.3	86.49	-3.19	3.76
28-Jul-11	1107140_28A	LCS	28-Jul-11	1107140_28AA	LCSD	1,1,1-Trichloroethane	85.15	84.63	0.52	0.61
28-Jul-11	1107140_28A	LCS	28-Jul-11	1107140_28AA	LCSD	1,1,2,2-Tetrachloroethane	94.81	95.24	-0.43	0.45
28-Jul-11	1107140_28A	LCS	28-Jul-11	1107140_28AA	LCSD	1,1-Dichloroethylene	88.95	89.45	-0.50	0.56
28-Jul-11	1107140_28A	LCS	28-Jul-11	1107140_28AA	LCSD	1,2-Dichloroethane	81.35	81.29	0.06	0.07
28-Jul-11	1107140_28A	LCS	28-Jul-11	1107140_28AA	LCSD	Carbon Tetrachloride	90.79	89.47	1.32	1.46
28-Jul-11	1107140_28A	LCS	28-Jul-11	1107140_28AA	LCSD	Chlorobenzene	82.01	84.52	-2.51	3.01

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS, LCSD listed as percent recovery

LCS Analytical Date	LCS Lab ID	LCS Sample ID	LCSD Analysis Date	LCSD Lab ID	LCSD Sample ID	Compound	LCS	LCSD	Difference	RPD
28-Jul-11	1107140_28A	LCS	28-Jul-11	1107140_28AA	LCSD	Chloroform	85.79	84.07	1.72	2.03
28-Jul-11	1107140_28A	LCS	28-Jul-11	1107140_28AA	LCSD	Methylene Chloride	88.07	89.4	-1.33	1.50
28-Jul-11	1107140_28A	LCS	28-Jul-11	1107140_28AA	LCSD	Toluene	83.3	86.49	-3.19	3.76
29-Jul-11	1107210_22A	LCS	29-Jul-11	1107210_22AA	LCSD	1,1,1-Trichloroethane	85.19	83.98	1.21	1.43
29-Jul-11	1107210_22A	LCS	29-Jul-11	1107210_22AA	LCSD	1,1,2,2-Tetrachloroethane	97.33	88.13	9.20	9.92
29-Jul-11	1107210_22A	LCS	29-Jul-11	1107210_22AA	LCSD	1,1-Dichloroethylene	91.2	89.87	1.33	1.47
29-Jul-11	1107210_22A	LCS	29-Jul-11	1107210_22AA	LCSD	1,2-Dichloroethane	81.44	79.73	1.71	2.12
29-Jul-11	1107210_22A	LCS	29-Jul-11	1107210_22AA	LCSD	Carbon Tetrachloride	91.64	87.91	3.73	4.15
29-Jul-11	1107210_22A	LCS	29-Jul-11	1107210_22AA	LCSD	Chlorobenzene	84.23	82.28	1.95	2.34
29-Jul-11	1107210_22A	LCS	29-Jul-11	1107210_22AA	LCSD	Chloroform	85.7	83.04	2.66	3.15
29-Jul-11	1107210_22A	LCS	29-Jul-11	1107210_22AA	LCSD	Methylene Chloride	90.82	87.8	3.02	3.38
29-Jul-11	1107210_22A	LCS	29-Jul-11	1107210_22AA	LCSD	Toluene	87.16	82.1	5.06	5.98
04-Aug-11	1107140_31A	LCS	04-Aug-11	1107140_31AA	LCSD	1,1,1-Trichloroethane	91.13	95.11	-3.98	4.27
04-Aug-11	1107140_31A	LCS	04-Aug-11	1107140_31AA	LCSD	1,1,2,2-Tetrachloroethane	97.89	101.44	-3.55	3.56
04-Aug-11	1107140_31A	LCS	04-Aug-11	1107140_31AA	LCSD	1,1-Dichloroethylene	94.24	100.19	-5.95	6.12
04-Aug-11	1107140_31A	LCS	04-Aug-11	1107140_31AA	LCSD	1,2-Dichloroethane	89.82	95.67	-5.85	6.31
04-Aug-11	1107140_31A	LCS	04-Aug-11	1107140_31AA	LCSD	Carbon Tetrachloride	95.89	98.5	-2.61	2.69
04-Aug-11	1107140_31A	LCS	04-Aug-11	1107140_31AA	LCSD	Chlorobenzene	89.88	94.13	-4.25	4.62
04-Aug-11	1107140_31A	LCS	04-Aug-11	1107140_31AA	LCSD	Chloroform	91.4	96.24	-4.84	5.16
04-Aug-11	1107140_31A	LCS	04-Aug-11	1107140_31AA	LCSD	Methylene Chloride	95.52	99.96	-4.44	4.54
04-Aug-11	1107140_31A	LCS	04-Aug-11	1107140_31AA	LCSD	Toluene	90.1	96.33	-6.23	6.68
04-Aug-11	1107280_10A	LCS	04-Aug-11	1107280_10AA	LCSD	1,1,1-Trichloroethane	91.13	95.11	-3.98	4.27
04-Aug-11	1107280_10A	LCS	04-Aug-11	1107280_10AA	LCSD	1,1,2,2-Tetrachloroethane	97.89	101.44	-3.55	3.56
04-Aug-11	1107280_10A	LCS	04-Aug-11	1107280_10AA	LCSD	1,1-Dichloroethylene	94.24	100.19	-5.95	6.12
04-Aug-11	1107280_10A	LCS	04-Aug-11	1107280_10AA	LCSD	1,2-Dichloroethane	89.82	95.67	-5.85	6.31
04-Aug-11	1107280_10A	LCS	04-Aug-11	1107280_10AA	LCSD	Carbon Tetrachloride	95.89	98.50	-2.61	2.69
04-Aug-11	1107280_10A	LCS	04-Aug-11	1107280_10AA	LCSD	Chlorobenzene	89.88	94.13	-4.25	4.62
04-Aug-11	1107280_10A	LCS	04-Aug-11	1107280_10AA	LCSD	Chloroform	91.40	96.24	-4.83	5.15
04-Aug-11	1107280_10A	LCS	04-Aug-11	1107280_10AA	LCSD	Methylene Chloride	95.52	99.96	-4.44	4.55
04-Aug-11	1107280_10A	LCS	04-Aug-11	1107280_10AA	LCSD	Toluene	90.10	96.33	-6.24	6.69
08-Aug-11	1108040_09A	LCS	08-Aug-11	1108040_09AA	LCSD	1,1,1-Trichloroethane	88.35	89.84	-1.49	1.67
08-Aug-11	1108040_09A	LCS	08-Aug-11	1108040_09AA	LCSD	1,1,2,2-Tetrachloroethane	98.32	96.63	1.70	1.74
08-Aug-11	1108040_09A	LCS	08-Aug-11	1108040_09AA	LCSD	1,1-Dichloroethylene	90.71	95.68	-4.97	5.33
08-Aug-11	1108040_09A	LCS	08-Aug-11	1108040_09AA	LCSD	1,2-Dichloroethane	88.07	89.16	-1.09	1.23
08-Aug-11	1108040_09A	LCS	08-Aug-11	1108040_09AA	LCSD	Carbon Tetrachloride	93.18	93.38	-0.20	0.22

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS, LCSD listed as percent recovery

LCS Analytical Date	LCS Lab ID	LCS Sample ID	LCSD Analysis Date	LCSD Lab ID	LCSD Sample ID	Compound	LCS	LCSD	Difference	RPD
08-Aug-11	1108040_09A	LCS	08-Aug-11	1108040_09AA	LCSD	Chlorobenzene	88.24	89.00	-0.75	0.85
08-Aug-11	1108040_09A	LCS	08-Aug-11	1108040_09AA	LCSD	Chloroform	89.67	89.57	0.10	0.12
08-Aug-11	1108040_09A	LCS	08-Aug-11	1108040_09AA	LCSD	Methylene Chloride	92.34	94.70	-2.36	2.52
08-Aug-11	1108040_09A	LCS	08-Aug-11	1108040_09AA	LCSD	Toluene	88.88	90.12	-1.24	1.38
24-Aug-11	1108110_39A	LCS	24-Aug-11	1108110_39AA	LCSD	1,1,1-Trichloroethane	90.70	83.08	7.62	8.77
24-Aug-11	1108110_39A	LCS	24-Aug-11	1108110_39AA	LCSD	1,1,2,2-Tetrachloroethane	97.87	88.29	9.58	10.29
24-Aug-11	1108110_39A	LCS	24-Aug-11	1108110_39AA	LCSD	1,1-Dichloroethylene	90.28	83.82	6.46	7.42
24-Aug-11	1108110_39A	LCS	24-Aug-11	1108110_39AA	LCSD	1,2-Dichloroethane	89.98	82.20	7.78	9.04
24-Aug-11	1108110_39A	LCS	24-Aug-11	1108110_39AA	LCSD	Carbon Tetrachloride	94.78	86.06	8.72	9.64
24-Aug-11	1108110_39A	LCS	24-Aug-11	1108110_39AA	LCSD	Chlorobenzene	94.30	86.56	7.74	8.56
24-Aug-11	1108110_39A	LCS	24-Aug-11	1108110_39AA	LCSD	Chloroform	92.49	84.78	7.71	8.70
24-Aug-11	1108110_39A	LCS	24-Aug-11	1108110_39AA	LCSD	Methylene Chloride	91.39	84.38	7.00	7.97
24-Aug-11	1108110_39A	LCS	24-Aug-11	1108110_39AA	LCSD	Toluene	96.88	88.97	7.91	8.52
25-Aug-11	1108110_42A	LCS	25-Aug-11	1108110_42AA	LCSD	1,1,1-Trichloroethane	87.85	85.22	2.63	3.04
25-Aug-11	1108110_42A	LCS	25-Aug-11	1108110_42AA	LCSD	1,1,2,2-Tetrachloroethane	101.71	95.77	5.94	6.02
25-Aug-11	1108110_42A	LCS	25-Aug-11	1108110_42AA	LCSD	1,1-Dichloroethylene	84.02	88.72	-4.69	5.43
25-Aug-11	1108110_42A	LCS	25-Aug-11	1108110_42AA	LCSD	1,2-Dichloroethane	86.60	84.82	1.78	2.08
25-Aug-11	1108110_42A	LCS	25-Aug-11	1108110_42AA	LCSD	Carbon Tetrachloride	93.52	89.57	3.96	4.32
25-Aug-11	1108110_42A	LCS	25-Aug-11	1108110_42AA	LCSD	Chlorobenzene	95.39	91.11	4.29	4.60
25-Aug-11	1108110_42A	LCS	25-Aug-11	1108110_42AA	LCSD	Chloroform	88.84	87.67	1.16	1.32
25-Aug-11	1108110_42A	LCS	25-Aug-11	1108110_42AA	LCSD	Methylene Chloride	87.74	90.57	-2.83	3.17
25-Aug-11	1108110_42A	LCS	25-Aug-11	1108110_42AA	LCSD	Toluene	95.81	91.75	4.06	4.33
25-Aug-11	1108180_22A	LCS	25-Aug-11	1108180_22AA	LCSD	1,1,1-Trichloroethane	87.85	85.22	2.63	3.04
25-Aug-11	1108180_22A	LCS	25-Aug-11	1108180_22AA	LCSD	1,1,2,2-Tetrachloroethane	101.71	95.77	5.94	6.02
25-Aug-11	1108180_22A	LCS	25-Aug-11	1108180_22AA	LCSD	1,1-Dichloroethylene	84.02	88.72	-4.69	5.43
25-Aug-11	1108180_22A	LCS	25-Aug-11	1108180_22AA	LCSD	1,2-Dichloroethane	86.60	84.82	1.78	2.08
25-Aug-11	1108180_22A	LCS	25-Aug-11	1108180_22AA	LCSD	Carbon Tetrachloride	93.52	89.57	3.96	4.32
25-Aug-11	1108180_22A	LCS	25-Aug-11	1108180_22AA	LCSD	Chlorobenzene	95.39	91.11	4.29	4.60
25-Aug-11	1108180_22A	LCS	25-Aug-11	1108180_22AA	LCSD	Chloroform	88.84	87.67	1.16	1.32
25-Aug-11	1108180_22A	LCS	25-Aug-11	1108180_22AA	LCSD	Methylene Chloride	87.74	90.57	-2.83	3.17
25-Aug-11	1108180_22A	LCS	25-Aug-11	1108180_22AA	LCSD	Toluene	95.81	91.75	4.06	4.33
25-Aug-11	1108180_25A	LCS	25-Aug-11	1108180_25AA	LCSD	1,1,1-Trichloroethane	84.72	80.85	3.87	4.67
25-Aug-11	1108180_25A	LCS	25-Aug-11	1108180_25AA	LCSD	1,1,2,2-Tetrachloroethane	101.44	88.12	13.32	14.05
25-Aug-11	1108180_25A	LCS	25-Aug-11	1108180_25AA	LCSD	1,1-Dichloroethylene	82.46	82.74	-0.28	0.34
25-Aug-11	1108180_25A	LCS	25-Aug-11	1108180_25AA	LCSD	Carbon Tetrachloride	91.00	84.35	6.65	7.59

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS, LCSD listed as percent recovery

LCS Analytical Date	LCS Lab ID	LCS Sample ID	LCSD Analysis Date	LCSD Lab ID	LCSD Sample ID	Compound	LCS	LCSD	Difference	RPD
25-Aug-11	1108180_25A	LCS	25-Aug-11	1108180_25AA	LCSD	1,2-Dichloroethane	86.15	75.96	10.19	12.57
25-Aug-11	1108180_25A	LCS	25-Aug-11	1108180_25AA	LCSD	Chlorobenzene	93.83	83.35	10.49	11.84
25-Aug-11	1108180_25A	LCS	25-Aug-11	1108180_25AA	LCSD	Chloroform	85.94	80.08	5.86	7.06
25-Aug-11	1108180_25A	LCS	25-Aug-11	1108180_25AA	LCSD	Methylene Chloride	85.71	83.24	2.47	2.92
25-Aug-11	1108180_25A	LCS	25-Aug-11	1108180_25AA	LCSD	Toluene	94.17	82.88	11.30	12.76
30-Aug-11	1108250_10A	LCS	30-Aug-11	1108250_10AA	LCSD	1,1,1-Trichloroethane	91.63	90.21	1.41	1.56
30-Aug-11	1108250_10A	LCS	30-Aug-11	1108250_10AA	LCSD	1,1,2,2-Tetrachloroethane	98.73	92.98	5.75	6.00
30-Aug-11	1108250_10A	LCS	30-Aug-11	1108250_10AA	LCSD	1,1-Dichloroethylene	87.58	90.84	-3.26	3.65
30-Aug-11	1108250_10A	LCS	30-Aug-11	1108250_10AA	LCSD	1,2-Dichloroethane	88.82	85.54	3.28	3.77
30-Aug-11	1108250_10A	LCS	30-Aug-11	1108250_10AA	LCSD	Carbon Tetrachloride	96.84	93.66	3.18	3.34
30-Aug-11	1108250_10A	LCS	30-Aug-11	1108250_10AA	LCSD	Chlorobenzene	95.63	92.63	3.00	3.19
30-Aug-11	1108250_10A	LCS	30-Aug-11	1108250_10AA	LCSD	Chloroform	93.33	89.94	3.39	3.70
30-Aug-11	1108250_10A	LCS	30-Aug-11	1108250_10AA	LCSD	Methylene Chloride	92.54	91.76	0.78	0.84
30-Aug-11	1108250_10A	LCS	30-Aug-11	1108250_10AA	LCSD	Toluene	97.81	94.57	3.24	3.37
06-Sep-11	1109010_07A	LCS	06-Sep-11	1109010_07AA	LCSD	1,1,1-Trichloroethane	92.10	88.12	3.98	4.42
06-Sep-11	1109010_07A	LCS	06-Sep-11	1109010_07AA	LCSD	1,1,2,2-Tetrachloroethane	100.15	93.45	6.71	6.93
06-Sep-11	1109010_07A	LCS	06-Sep-11	1109010_07AA	LCSD	1,1-Dichloroethylene	93.08	91.98	1.10	1.18
06-Sep-11	1109010_07A	LCS	06-Sep-11	1109010_07AA	LCSD	1,2-Dichloroethane	87.76	85.82	1.95	2.24
06-Sep-11	1109010_07A	LCS	06-Sep-11	1109010_07AA	LCSD	Carbon Tetrachloride	97.08	91.02	6.06	6.44
06-Sep-11	1109010_07A	LCS	06-Sep-11	1109010_07AA	LCSD	Chlorobenzene	97.84	93.40	4.45	4.65
06-Sep-11	1109010_07A	LCS	06-Sep-11	1109010_07AA	LCSD	Chloroform	93.43	90.20	3.22	3.51
06-Sep-11	1109010_07A	LCS	06-Sep-11	1109010_07AA	LCSD	Methylene Chloride	94.55	92.22	2.33	2.50
06-Sep-11	1109010_07A	LCS	06-Sep-11	1109010_07AA	LCSD	Toluene	99.90	96.15	3.76	3.84
13-Sep-11	1109090_10A	LCS	13-Sep-11	1109090_10AA	LCSD	1,1,1-Trichloroethane	86.73	81.53	5.20	6.18
13-Sep-11	1109090_10A	LCS	13-Sep-11	1109090_10AA	LCSD	1,1,2,2-Tetrachloroethane	92.06	83.08	8.98	10.25
13-Sep-11	1109090_10A	LCS	13-Sep-11	1109090_10AA	LCSD	1,1-Dichloroethylene	86.52	85.61	0.91	1.05
13-Sep-11	1109090_10A	LCS	13-Sep-11	1109090_10AA	LCSD	1,2-Dichloroethane	82.29	76.49	5.80	7.30
13-Sep-11	1109090_10A	LCS	13-Sep-11	1109090_10AA	LCSD	Carbon Tetrachloride	91.58	85.2	6.38	7.22
13-Sep-11	1109090_10A	LCS	13-Sep-11	1109090_10AA	LCSD	Chlorobenzene	89.69	83.53	6.16	7.12
13-Sep-11	1109090_10A	LCS	13-Sep-11	1109090_10AA	LCSD	Chloroform	87.80	82.65	5.14	6.03
13-Sep-11	1109090_10A	LCS	13-Sep-11	1109090_10AA	LCSD	Methylene Chloride	89.36	84.45	4.91	5.65
13-Sep-11	1109090_10A	LCS	13-Sep-11	1109090_10AA	LCSD	Toluene	90.92	84.79	6.13	6.97
15-Sep-11	1109150_25A	LCS	15-Sep-11	1109150_25AA	LCSD	1,1,1-Trichloroethane	90.47	87.69	2.78	3.13
15-Sep-11	1109150_25A	LCS	15-Sep-11	1109150_25AA	LCSD	1,1,2,2-Tetrachloroethane	98.19	92.16	6.03	6.34
15-Sep-11	1109150_25A	LCS	15-Sep-11	1109150_25AA	LCSD	1,1-Dichloroethylene	90.43	89.94	0.49	0.54

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS, LCSD listed as percent recovery

LCS Analytical Date	LCS Lab ID	LCS Sample ID	LCSD Analysis Date	LCSD Lab ID	LCSD Sample ID	Compound	LCS	LCSD	Difference	RPD
15-Sep-11	1109150_25A	LCS	15-Sep-11	1109150_25AA	LCSD	1,2-Dichloroethane	85.93	82.83	3.10	3.68
15-Sep-11	1109150_25A	LCS	15-Sep-11	1109150_25AA	LCSD	Carbon Tetrachloride	95.96	91.6	4.36	4.65
15-Sep-11	1109150_25A	LCS	15-Sep-11	1109150_25AA	LCSD	Chlorobenzene	95.74	91.35	4.39	4.69
15-Sep-11	1109150_25A	LCS	15-Sep-11	1109150_25AA	LCSD	Chloroform	90.92	88.00	2.92	3.26
15-Sep-11	1109150_25A	LCS	15-Sep-11	1109150_25AA	LCSD	Methylene Chloride	91.12	89.44	1.68	1.86
15-Sep-11	1109150_25A	LCS	15-Sep-11	1109150_25AA	LCSD	Toluene	97.16	92.39	4.77	5.03
21-Sep-11	1109150_28A	LCS	21-Sep-11	1109150_28AA	LCSD	1,1,1-Trichloroethane	88.73	83.90	4.82	5.59
21-Sep-11	1109150_28A	LCS	21-Sep-11	1109150_28AA	LCSD	1,1,2,2-Tetrachloroethane	101.29	90.75	10.54	10.98
21-Sep-11	1109150_28A	LCS	21-Sep-11	1109150_28AA	LCSD	1,1-Dichloroethylene	84.56	85.88	-1.32	1.55
21-Sep-11	1109150_28A	LCS	21-Sep-11	1109150_28AA	LCSD	1,2-Dichloroethane	82.52	78.69	3.83	4.76
21-Sep-11	1109150_28A	LCS	21-Sep-11	1109150_28AA	LCSD	Carbon Tetrachloride	94.68	88.16	6.52	7.13
21-Sep-11	1109150_28A	LCS	21-Sep-11	1109150_28AA	LCSD	Chlorobenzene	97.40	90.17	7.23	7.71
21-Sep-11	1109150_28A	LCS	21-Sep-11	1109150_28AA	LCSD	Chloroform	88.90	83.73	5.16	5.98
21-Sep-11	1109150_28A	LCS	21-Sep-11	1109150_28AA	LCSD	Methylene Chloride	88.61	85.53	3.08	3.54
21-Sep-11	1109150_28A	LCS	21-Sep-11	1109150_28AA	LCSD	Toluene	99.62	91.53	8.09	8.47
27-Sep-11	1109260_25A	LCS	27-Sep-11	1109260_25AA	LCSD	1,1,1-Trichloroethane	91.08	88.65	2.43	2.71
27-Sep-11	1109260_25A	LCS	27-Sep-11	1109260_25AA	LCSD	1,1,2,2-Tetrachloroethane	99.31	94.72	4.59	4.73
27-Sep-11	1109260_25A	LCS	27-Sep-11	1109260_25AA	LCSD	1,1-Dichloroethylene	88.77	88.47	0.30	0.34
27-Sep-11	1109260_25A	LCS	27-Sep-11	1109260_25AA	LCSD	1,2-Dichloroethane	86.71	84.12	2.58	3.02
27-Sep-11	1109260_25A	LCS	27-Sep-11	1109260_25AA	LCSD	Carbon Tetrachloride	96.76	93.44	3.32	3.49
27-Sep-11	1109260_25A	LCS	27-Sep-11	1109260_25AA	LCSD	Chlorobenzene	97.92	95.25	2.67	2.77
27-Sep-11	1109260_25A	LCS	27-Sep-11	1109260_25AA	LCSD	Chloroform	91.94	88.92	3.02	3.34
27-Sep-11	1109260_25A	LCS	27-Sep-11	1109260_25AA	LCSD	Methylene Chloride	91.58	89.42	2.16	2.38
27-Sep-11	1109260_25A	LCS	27-Sep-11	1109260_25AA	LCSD	Toluene	99.96	97.90	2.06	2.08
30-Sep-11	1109260_28A	LCS	30-Sep-11	1109260_28AA	LCSD	1,1,1-Trichloroethane	91.85	83.43	8.42	9.61
30-Sep-11	1109260_28A	LCS	30-Sep-11	1109260_28AA	LCSD	1,1,2,2-Tetrachloroethane	105.40	93.64	11.76	11.82
30-Sep-11	1109260_28A	LCS	30-Sep-11	1109260_28AA	LCSD	1,1-Dichloroethylene	85.15	83.57	1.58	1.87
30-Sep-11	1109260_28A	LCS	30-Sep-11	1109260_28AA	LCSD	1,2-Dichloroethane	86.57	77.78	8.79	10.70
30-Sep-11	1109260_28A	LCS	30-Sep-11	1109260_28AA	LCSD	Carbon Tetrachloride	98.05	87.51	10.54	11.36
30-Sep-11	1109260_28A	LCS	30-Sep-11	1109260_28AA	LCSD	Chlorobenzene	99.35	90.42	8.94	9.42
30-Sep-11	1109260_28A	LCS	30-Sep-11	1109260_28AA	LCSD	Chloroform	91.89	83.71	8.17	9.31
30-Sep-11	1109260_28A	LCS	30-Sep-11	1109260_28AA	LCSD	Methylene Chloride	89.41	84.27	5.13	5.91
30-Sep-11	1109260_28A	LCS	30-Sep-11	1109260_28AA	LCSD	Toluene	99.89	91.21	8.67	9.08
30-Sep-11	1109290_07A	LCS	30-Sep-11	1109290_07AA	LCSD	1,1,1-Trichloroethane	91.85	83.43	8.42	9.61
30-Sep-11	1109290_07A	LCS	30-Sep-11	1109290_07AA	LCSD	1,1,2,2-Tetrachloroethane	105.40	93.64	11.76	11.82

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS, LCSD listed as percent recovery

LCS Analytical Date	LCS Lab ID	LCS Sample ID	LCSD Analysis Date	LCSD Lab ID	LCSD Sample ID	Compound	LCS	LCSD	Difference	RPD
30-Sep-11	1109290_07A	LCS	30-Sep-11	1109290_07AA	LCSD	1,1-Dichloroethylene	85.15	83.57	1.58	1.87
30-Sep-11	1109290_07A	LCS	30-Sep-11	1109290_07AA	LCSD	1,2-Dichloroethane	86.57	77.78	8.79	10.70
30-Sep-11	1109290_07A	LCS	30-Sep-11	1109290_07AA	LCSD	Carbon Tetrachloride	98.05	87.51	10.54	11.36
30-Sep-11	1109290_07A	LCS	30-Sep-11	1109290_07AA	LCSD	Chlorobenzene	99.35	90.42	8.94	9.42
30-Sep-11	1109290_07A	LCS	30-Sep-11	1109290_07AA	LCSD	Chloroform	91.89	83.71	8.17	9.31
30-Sep-11	1109290_07A	LCS	30-Sep-11	1109290_07AA	LCSD	Methylene Chloride	89.41	84.27	5.13	5.91
30-Sep-11	1109290_07A	LCS	30-Sep-11	1109290_07AA	LCSD	Toluene	99.89	91.21	8.67	9.08
10-Oct-11	1110060_12A	LCS	10-Oct-11	1110060_12AA	LCSD	1,1,1-Trichloroethane	94.33	84.52	9.81	10.96
10-Oct-11	1110060_12A	LCS	10-Oct-11	1110060_12AA	LCSD	1,1,2,2-Tetrachloroethane	108.24	95.79	12.45	12.21
10-Oct-11	1110060_12A	LCS	10-Oct-11	1110060_12AA	LCSD	1,1-Dichloroethylene	93.20	82.82	10.38	11.79
10-Oct-11	1110060_12A	LCS	10-Oct-11	1110060_12AA	LCSD	1,2-Dichloroethane	86.59	75.65	10.94	13.48
10-Oct-11	1110060_12A	LCS	10-Oct-11	1110060_12AA	LCSD	Chlorobenzene	103.15	92.73	10.42	10.64
10-Oct-11	1110060_12A	LCS	10-Oct-11	1110060_12AA	LCSD	Chloroform	95.17	84.36	10.81	12.04
10-Oct-11	1110060_12A	LCS	10-Oct-11	1110060_12AA	LCSD	Methylene Chloride	94.89	84.29	10.59	11.83
10-Oct-11	1110060_12A	LCS	10-Oct-11	1110060_12AA	LCSD	Toluene	105.64	95.03	10.61	10.57
18-Oct-11	1110130_25A	LCS	18-Oct-11	1110130_25AA	LCSD	1,1,1-Trichloroethane	91.15	85.98	5.17	5.83
18-Oct-11	1110130_25A	LCS	18-Oct-11	1110130_25AA	LCSD	1,1,2,2-Tetrachloroethane	104.58	94.66	9.92	9.96
18-Oct-11	1110130_25A	LCS	18-Oct-11	1110130_25AA	LCSD	1,1-Dichloroethylene	93.68	90.56	3.12	3.39
18-Oct-11	1110130_25A	LCS	18-Oct-11	1110130_25AA	LCSD	1,2-Dichloroethane	90.33	83.54	6.78	7.80
18-Oct-11	1110130_25A	LCS	18-Oct-11	1110130_25AA	LCSD	Carbon Tetrachloride	96.74	89.90	6.84	7.33
18-Oct-11	1110130_25A	LCS	18-Oct-11	1110130_25AA	LCSD	Chlorobenzene	95.31	89.62	5.69	6.16
18-Oct-11	1110130_25A	LCS	18-Oct-11	1110130_25AA	LCSD	Chloroform	93.33	88.30	5.03	5.54
18-Oct-11	1110130_25A	LCS	18-Oct-11	1110130_25AA	LCSD	Methylene Chloride	91.61	88.47	3.14	3.49
18-Oct-11	1110130_25A	LCS	18-Oct-11	1110130_25AA	LCSD	Toluene	97.78	91.12	6.66	7.05
26-Oct-11	1110240_26A	LCS	26-Oct-11	1110240_26AA	LCSD	1,1,1-Trichloroethane	87.62	87.93	-0.31	0.36
26-Oct-11	1110240_26A	LCS	26-Oct-11	1110240_26AA	LCSD	1,1,2,2-Tetrachloroethane	92.85	94.29	-1.44	1.54
26-Oct-11	1110240_26A	LCS	26-Oct-11	1110240_26AA	LCSD	1,1-Dichloroethylene	90.00	89.32	0.68	0.75
26-Oct-11	1110240_26A	LCS	26-Oct-11	1110240_26AA	LCSD	1,2-Dichloroethane	85.46	85.44	0.02	0.02
26-Oct-11	1110240_26A	LCS	26-Oct-11	1110240_26AA	LCSD	Carbon Tetrachloride	93.14	91.93	1.21	1.31
26-Oct-11	1110240_26A	LCS	26-Oct-11	1110240_26AA	LCSD	Chlorobenzene	86.24	88.90	-2.66	3.03
26-Oct-11	1110240_26A	LCS	26-Oct-11	1110240_26AA	LCSD	Chloroform	87.91	88.28	-0.37	0.41
26-Oct-11	1110240_26A	LCS	26-Oct-11	1110240_26AA	LCSD	Methylene Chloride	86.97	87.09	-0.11	0.13
26-Oct-11	1110240_26A	LCS	26-Oct-11	1110240_26AA	LCSD	Toluene	87.59	90.97	-3.38	3.78
07-Nov-11	1110270_16A	LCS	07-Nov-11	1110270_16AA	LCSD	1,1,1-Trichloroethane	83.90	81.02	2.87	3.49
07-Nov-11	1110270_16A	LCS	07-Nov-11	1110270_16AA	LCSD	1,1,2,2-Tetrachloroethane	95.44	92.36	3.08	3.28

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS, LCSD listed as percent recovery

LCS Analytical Date	LCS Lab ID	LCS Sample ID	LCSD Analysis Date	LCSD Lab ID	LCSD Sample ID	Compound	LCS	LCSD	Difference	RPD
07-Nov-11	1110270_16A	LCS	07-Nov-11	1110270_16AA	LCSD	1,1-Dichloroethylene	86.17	87.95	-1.78	2.05
07-Nov-11	1110270_16A	LCS	07-Nov-11	1110270_16AA	LCSD	1,2-Dichloroethane	83.33	79.57	3.75	4.61
07-Nov-11	1110270_16A	LCS	07-Nov-11	1110270_16AA	LCSD	Carbon Tetrachloride	87.41	83.88	3.53	4.13
07-Nov-11	1110270_16A	LCS	07-Nov-11	1110270_16AA	LCSD	Chlorobenzene	91.55	89.33	2.22	2.46
07-Nov-11	1110270_16A	LCS	07-Nov-11	1110270_16AA	LCSD	Chloroform	89.18	85.98	3.20	3.65
07-Nov-11	1110270_16A	LCS	07-Nov-11	1110270_16AA	LCSD	Methylene Chloride	86.00	84.93	1.06	1.24
07-Nov-11	1110270_16A	LCS	07-Nov-11	1110270_16AA	LCSD	Toluene	93.85	90.61	3.24	3.51
07-Nov-11	1110270_19A	LCS	07-Nov-11	1110270_19AA	LCSD	1,1,1-Trichloroethane	79.02	78.33	0.69	0.88
07-Nov-11	1110270_19A	LCS	07-Nov-11	1110270_19AA	LCSD	1,1,2,2-Tetrachloroethane	93.13	91.61	1.53	1.65
07-Nov-11	1110270_19A	LCS	07-Nov-11	1110270_19AA	LCSD	1,1-Dichloroethylene	78.92	82.07	-3.15	3.91
07-Nov-11	1110270_19A	LCS	07-Nov-11	1110270_19AA	LCSD	1,2-Dichloroethane	73.25	74.33	-1.08	1.47
07-Nov-11	1110270_19A	LCS	07-Nov-11	1110270_19AA	LCSD	Carbon Tetrachloride	83.37	81.16	2.21	2.68
07-Nov-11	1110270_19A	LCS	07-Nov-11	1110270_19AA	LCSD	Chlorobenzene	90.27	89.54	0.73	0.81
07-Nov-11	1110270_19A	LCS	07-Nov-11	1110270_19AA	LCSD	Chloroform	81.84	83.87	-2.03	2.45
07-Nov-11	1110270_19A	LCS	07-Nov-11	1110270_19AA	LCSD	Methylene Chloride	77.97	82.28	-4.31	5.38
07-Nov-11	1110270_19A	LCS	07-Nov-11	1110270_19AA	LCSD	Toluene	91.61	92.34	-0.73	0.79
09-Nov-11	1111030_28A	LCS	09-Nov-11	1111030_28AA	LCSD	1,1,1-Trichloroethane	81.00	77.93	3.07	3.86
09-Nov-11	1111030_28A	LCS	09-Nov-11	1111030_28AA	LCSD	1,1,2,2-Tetrachloroethane	96.92	91.16	5.76	6.13
09-Nov-11	1111030_28A	LCS	09-Nov-11	1111030_28AA	LCSD	1,1-Dichloroethylene	82.64	81.14	1.50	1.83
09-Nov-11	1111030_28A	LCS	09-Nov-11	1111030_28AA	LCSD	1,2-Dichloroethane	76.48	73.11	3.37	4.50
09-Nov-11	1111030_28A	LCS	09-Nov-11	1111030_28AA	LCSD	Carbon Tetrachloride	85.20	81.69	3.51	4.21
09-Nov-11	1111030_28A	LCS	09-Nov-11	1111030_28AA	LCSD	Chlorobenzene	93.87	90.17	3.70	4.02
09-Nov-11	1111030_28A	LCS	09-Nov-11	1111030_28AA	LCSD	Chloroform	85.14	81.58	3.57	4.28
09-Nov-11	1111030_28A	LCS	09-Nov-11	1111030_28AA	LCSD	Methylene Chloride	82.17	80.58	1.59	1.95
09-Nov-11	1111030_28A	LCS	09-Nov-11	1111030_28AA	LCSD	Toluene	98.03	93.81	4.21	4.39
15-Nov-11	1111100_24A	LCS	15-Nov-11	1111100_24AA	LCSD	1,1,1-Trichloroethane	77.38	79.53	-2.15	2.73
15-Nov-11	1111100_24A	LCS	15-Nov-11	1111100_24AA	LCSD	1,1,2,2-Tetrachloroethane	90.89	93.48	-2.59	2.81
15-Nov-11	1111100_24A	LCS	15-Nov-11	1111100_24AA	LCSD	1,1-Dichloroethylene	79.96	81.65	-1.69	2.09
15-Nov-11	1111100_24A	LCS	15-Nov-11	1111100_24AA	LCSD	1,2-Dichloroethane	70.00	72.88	-2.88	4.03
15-Nov-11	1111100_24A	LCS	15-Nov-11	1111100_24AA	LCSD	Carbon Tetrachloride	80.92	82.51	-1.59	1.94
15-Nov-11	1111100_24A	LCS	15-Nov-11	1111100_24AA	LCSD	Chlorobenzene	89.92	93.22	-3.30	3.60
15-Nov-11	1111100_24A	LCS	15-Nov-11	1111100_24AA	LCSD	Chloroform	80.66	82.46	-1.80	2.21
15-Nov-11	1111100_24A	LCS	15-Nov-11	1111100_24AA	LCSD	Methylene Chloride	78.12	80.10	-1.97	2.49
15-Nov-11	1111100_24A	LCS	15-Nov-11	1111100_24AA	LCSD	Toluene	92.82	96.67	-3.85	4.06
22-Nov-11	1111170_11A	LCS	22-Nov-11	1111170_11AA	LCSD	1,1,1-Trichloroethane	72.87	73.82	-0.94	1.29

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS, LCSD listed as percent recovery

LCS Analytical Date	LCS Lab ID	LCS Sample ID	LCSD Analysis Date	LCSD Lab ID	LCSD Sample ID	Compound	LCS	LCSD	Difference	RPD
22-Nov-11	1111170_11A	LCS	22-Nov-11	1111170_11AA	LCSD	1,1,2,2-Tetrachloroethane	88.94	90.15	-1.22	1.36
22-Nov-11	1111170_11A	LCS	22-Nov-11	1111170_11AA	LCSD	1,1-Dichloroethylene	77.12	78.86	-1.75	2.24
22-Nov-11	1111170_11A	LCS	22-Nov-11	1111170_11AA	LCSD	1,2-Dichloroethane	67.27	69.15	-1.88	2.75
22-Nov-11	1111170_11A	LCS	22-Nov-11	1111170_11AA	LCSD	Carbon Tetrachloride	75.72	75.86	-0.14	0.19
22-Nov-11	1111170_11A	LCS	22-Nov-11	1111170_11AA	LCSD	Chlorobenzene	88.62	88.98	-0.36	0.41
22-Nov-11	1111170_11A	LCS	22-Nov-11	1111170_11AA	LCSD	Chloroform	78.46	79.18	-0.72	0.91
22-Nov-11	1111170_11A	LCS	22-Nov-11	1111170_11AA	LCSD	Methylene Chloride	76.92	77.52	-0.60	0.78
22-Nov-11	1111170_11A	LCS	22-Nov-11	1111170_11AA	LCSD	Toluene	92.24	94.60	-2.36	2.52
29-Nov-11	1111280_08A	LCS	29-Nov-11	1111280_08AA	LCSD	1,1,1-Trichloroethane	72.38	75.01	-2.63	3.56
29-Nov-11	1111280_08A	LCS	29-Nov-11	1111280_08AA	LCSD	1,1,2,2-Tetrachloroethane	86.28	89.55	-3.27	3.72
29-Nov-11	1111280_08A	LCS	29-Nov-11	1111280_08AA	LCSD	1,1-Dichloroethylene	77.24	82.55	-5.31	6.64
29-Nov-11	1111280_08A	LCS	29-Nov-11	1111280_08AA	LCSD	1,2-Dichloroethane	66.73	71.44	-4.70	6.81
29-Nov-11	1111280_08A	LCS	29-Nov-11	1111280_08AA	LCSD	Carbon Tetrachloride	75.71	77.96	-2.25	2.93
29-Nov-11	1111280_08A	LCS	29-Nov-11	1111280_08AA	LCSD	Chlorobenzene	88.17	91.23	-3.06	3.41
29-Nov-11	1111280_08A	LCS	29-Nov-11	1111280_08AA	LCSD	Chloroform	77.69	80.96	-3.27	4.12
29-Nov-11	1111280_08A	LCS	29-Nov-11	1111280_08AA	LCSD	Methylene Chloride	77.38	81.24	-3.86	4.86
29-Nov-11	1111280_08A	LCS	29-Nov-11	1111280_08AA	LCSD	Toluene	92.20	95.83	-3.63	3.86
06-Dec-11	1112010_11A	LCS	06-Dec-11	1112010_11AA	LCSD	1,1,1-Trichloroethane	77.49	77.23	0.26	0.34
06-Dec-11	1112010_11A	LCS	06-Dec-11	1112010_11AA	LCSD	1,1,2,2-Tetrachloroethane	71.30	68.74	2.56	3.65
06-Dec-11	1112010_11A	LCS	06-Dec-11	1112010_11AA	LCSD	1,1-Dichloroethylene	74.52	76.12	-1.60	2.13
06-Dec-11	1112010_11A	LCS	06-Dec-11	1112010_11AA	LCSD	1,2-Dichloroethane	74.04	73.11	0.93	1.26
06-Dec-11	1112010_11A	LCS	06-Dec-11	1112010_11AA	LCSD	Carbon Tetrachloride	80.92	79.14	1.78	2.22
06-Dec-11	1112010_11A	LCS	06-Dec-11	1112010_11AA	LCSD	Chlorobenzene	78.73	76.20	2.53	3.27
06-Dec-11	1112010_11A	LCS	06-Dec-11	1112010_11AA	LCSD	Chloroform	75.90	75.88	0.02	0.03
06-Dec-11	1112010_11A	LCS	06-Dec-11	1112010_11AA	LCSD	Methylene Chloride	74.04	74.90	-0.87	1.16
06-Dec-11	1112010_11A	LCS	06-Dec-11	1112010_11AA	LCSD	Toluene	82.75	79.88	2.87	3.52
12-Dec-11	1112080_25A	LCS	12-Dec-11	1112080_25AA	LCSD	1,1,1-Trichloroethane	86.29	87.17	-0.88	1.02
12-Dec-11	1112080_25A	LCS	12-Dec-11	1112080_25AA	LCSD	1,1,2,2-Tetrachloroethane	83.64	82.87	0.77	0.92
12-Dec-11	1112080_25A	LCS	12-Dec-11	1112080_25AA	LCSD	1,1-Dichloroethylene	83.80	90.00	-6.20	7.13
12-Dec-11	1112080_25A	LCS	12-Dec-11	1112080_25AA	LCSD	1,2-Dichloroethane	83.58	86.36	-2.78	3.27
12-Dec-11	1112080_25A	LCS	12-Dec-11	1112080_25AA	LCSD	Carbon Tetrachloride	87.73	87.93	-0.20	0.23
12-Dec-11	1112080_25A	LCS	12-Dec-11	1112080_25AA	LCSD	Chlorobenzene	83.65	85.59	-1.95	2.30
12-Dec-11	1112080_25A	LCS	12-Dec-11	1112080_25AA	LCSD	Chloroform	84.00	87.19	-3.19	3.72
12-Dec-11	1112080_25A	LCS	12-Dec-11	1112080_25AA	LCSD	Methylene Chloride	83.96	88.90	-4.94	5.72
12-Dec-11	1112080_25A	LCS	12-Dec-11	1112080_25AA	LCSD	Toluene	82.83	86.06	-3.24	3.83

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS, LCSD listed as percent recovery

LCS Analytical Date	LCS Lab ID	LCS Sample ID	LCSD Analysis Date	LCSD Lab ID	LCSD Sample ID	Compound	LCS	LCSD	Difference	RPD
21-Dec-11	1112150_28A	LCS	21-Dec-11	1112150_28AA	LCSD	1,1,1-Trichloroethane	84.97	83.53	1.44	1.71
21-Dec-11	1112150_28A	LCS	21-Dec-11	1112150_28AA	LCSD	1,1,2,2-Tetrachloroethane	83.50	81.95	1.56	1.88
21-Dec-11	1112150_28A	LCS	21-Dec-11	1112150_28AA	LCSD	1,1-Dichloroethylene	81.60	85.14	-3.53	4.24
21-Dec-11	1112150_28A	LCS	21-Dec-11	1112150_28AA	LCSD	1,2-Dichloroethane	81.42	80.39	1.02	1.27
21-Dec-11	1112150_28A	LCS	21-Dec-11	1112150_28AA	LCSD	Carbon Tetrachloride	85.77	81.86	3.91	4.66
21-Dec-11	1112150_28A	LCS	21-Dec-11	1112150_28AA	LCSD	Chlorobenzene	85.54	86.02	-0.49	0.57
21-Dec-11	1112150_28A	LCS	21-Dec-11	1112150_28AA	LCSD	Chloroform	84.42	83.71	0.71	0.84
21-Dec-11	1112150_28A	LCS	21-Dec-11	1112150_28AA	LCSD	Methylene Chloride	84.37	85.16	-0.79	0.93
21-Dec-11	1112150_28A	LCS	21-Dec-11	1112150_28AA	LCSD	Toluene	85.15	86.90	-1.75	2.04
09-Jan-12	1201030_16A	LCS	09-Jan-12	1201030_16AA	LCSD	1,1,1-Trichloroethane	106.80	93.75	13.05	13.01
09-Jan-12	1201030_16A	LCS	09-Jan-12	1201030_16AA	LCSD	1,1,2,2-Tetrachloroethane	103.53	88.43	15.11	15.74
09-Jan-12	1201030_16A	LCS	09-Jan-12	1201030_16AA	LCSD	1,1-Dichloroethylene	98.14	91.92	6.21	6.54
09-Jan-12	1201030_16A	LCS	09-Jan-12	1201030_16AA	LCSD	1,2-Dichloroethane	103.13	88.56	14.57	15.20
09-Jan-12	1201030_16A	LCS	09-Jan-12	1201030_16AA	LCSD	Carbon Tetrachloride	106.35	91.49	14.86	15.02
09-Jan-12	1201030_16A	LCS	09-Jan-12	1201030_16AA	LCSD	Chlorobenzene	105.19	93.57	11.62	11.69
09-Jan-12	1201030_16A	LCS	09-Jan-12	1201030_16AA	LCSD	Chloroform	105.35	93.84	11.50	11.55
09-Jan-12	1201030_16A	LCS	09-Jan-12	1201030_16AA	LCSD	Methylene Chloride	100.56	92.78	7.77	8.04
09-Jan-12	1201030_16A	LCS	09-Jan-12	1201030_16AA	LCSD	Toluene	103.90	94.92	8.97	9.03
09-Jan-12	1201030_19A	LCS	09-Jan-12	1201030_19AA	LCSD	1,1,1-Trichloroethane	94.32	83.69	10.63	11.94
09-Jan-12	1201030_19A	LCS	09-Jan-12	1201030_19AA	LCSD	1,1,2,2-Tetrachloroethane	97.83	83.47	14.36	15.84
09-Jan-12	1201030_19A	LCS	09-Jan-12	1201030_19AA	LCSD	1,1-Dichloroethylene	80.77	81.47	-0.70	0.86
09-Jan-12	1201030_19A	LCS	09-Jan-12	1201030_19AA	LCSD	1,2-Dichloroethane	89.25	79.90	9.35	11.05
09-Jan-12	1201030_19A	LCS	09-Jan-12	1201030_19AA	LCSD	Carbon Tetrachloride	94.88	81.93	12.95	14.65
09-Jan-12	1201030_19A	LCS	09-Jan-12	1201030_19AA	LCSD	Chlorobenzene	96.65	87.11	9.54	10.39
09-Jan-12	1201030_19A	LCS	09-Jan-12	1201030_19AA	LCSD	Chloroform	90.75	83.27	7.48	8.60
09-Jan-12	1201030_19A	LCS	09-Jan-12	1201030_19AA	LCSD	Methylene Chloride	84.36	82.30	2.05	2.46
09-Jan-12	1201030_19A	LCS	09-Jan-12	1201030_19AA	LCSD	Toluene	94.09	87.97	6.12	6.73

Relative Percent Difference (RPD)

RPD = ABS(A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6C – VOCs – Laboratory Method Blanks

Concentrations in ppbv

Analysis Date	Lab ID	Sample ID	111TA	1122T	11DCE	12DCA	CCL4	CHBNZ	CHFRM	DCM	C7H8
25-Jul-11	1107110_20	VBLK	U	U	U	U	U	U	U	U	U
26-Jul-11	1107110_23	VBLK	U	U	U	U	U	U	U	U	U
28-Jul-11	1107110_26	VBLK	U	U	U	U	U	U	U	U	U
28-Jul-11	1107140_27	VBLK	U	U	U	U	U	U	U	U	U
29-Jul-11	1107210_21	VBLK	U	U	U	U	U	U	U	U	U
04-Aug-11	1107140_30	VBLK	U	U	U	U	U	U	U	U	U
04-Aug-11	1107280_09	VBLK	U	U	U	U	U	U	U	U	U
08-Aug-11	1108040_08	VBLK	U	U	U	U	U	U	U	U	U
24-Aug-11	1108110_38	VBLK	U	U	U	U	U	U	U	U	U
24-Aug-11	1108180_21	VBLK	U	U	U	U	U	U	U	U	U
25-Aug-11	1108180_24	VBLK	U	U	U	U	U	U	U	U	U
30-Aug-11	1108250_09	VBLK	U	U	U	U	U	U	U	U	U
06-Sep-11	1109010_06	VBLK	U	0.1J	U	U	U	U	U	U	U
13-Sep-11	1109090_09	VBLK	U	0.11J	U	U	U	U	U	U	U
15-Sep-11	1109150_24	VBLK	U	0.1J	U	U	U	U	U	U	U
21-Sep-11	1109150_27	VBLK	U	U	U	U	U	U	U	U	U
27-Sep-11	1109260_24	VBLK	U	U	U	U	U	U	U	U	U
30-Sep-11	1109260_27	VBLK	U	U	U	U	U	U	U	U	U
30-Sep-11	1109290_06	VBLK	U	U	U	U	U	U	U	U	U
10-Oct-11	1110060_11	VBLK	U	U	U	U	U	U	U	U	U
18-Oct-11	1110130_24	VBLK	U	U	U	U	U	U	U	U	U
26-Oct-11	1110240_25	VBLK	U	0.1J	U	U	U	U	U	U	U
07-Nov-11	1110270_15	VBLK	U	0.1J	U	U	U	U	U	U	U
09-Nov-11	1111030_27	VBLK	U	0.08J	U	U	U	U	U	U	U
15-Nov-11	1111100_23	VBLK	U	0.08J	U	U	U	U	U	U	U
22-Nov-11	1111170_10	VBLK	U	0.08J	U	U	U	U	U	U	U
29-Nov-11	1111280_07	VBLK	U	0.09J	U	U	U	U	U	U	U
06-Dec-11	1112010_10	VBLK	U	U	U	U	U	U	U	U	U

Attachment 6C – VOCs – Laboratory Method Blanks

Concentrations in ppbv

Analysis Date	Lab ID	Sample ID	111TA	1122T	11DCE	12DCA	CCL4	CHBNZ	CHFRM	DCM	C7H8
12-Dec-11	1112080_24	VBLK	U	0.1J	U	U	U	U	U	U	U
21-Dec-11	1112150_27	VBLK	U	0.11J	U	U	U	U	U	U	U
09-Jan-12	1201030_15	VBLK	U	U	U	U	U	U	U	U	U

Legend

111TA = 1,1,1-Trichloroethane
1122T = 1,1,2,2-Tetrachloroethane
11DCE = 1,1-Dichloroethylene
12DCA = 1,2-Dichloroethane
CCL4 = Carbon tetrachloride
CHBNZ = Chlorobenzene
CHFRM = Chloroform
DCM = Methylene chloride
C7H8 = Toluene

Data Flags

J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound analyzed for, but not detected above the MDL

Attachment 6D – VOCs – Field Duplicate Precision

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
7/7/2011	7/26/2011	1107110_13	6384	7/7/2011	7/26/2011	1107110_14	6385	1,1,1-Trichloroethane	81881.28	74008.08	7873.2	10.1
7/7/2011	7/26/2011	1107110_13	6384	7/7/2011	7/26/2011	1107110_14	6385	1,1,2,2-	U	U	0	0
7/7/2011	7/26/2011	1107110_13	6384	7/7/2011	7/26/2011	1107110_14	6385	1,1-Dichloroethylene	U	U	0	0
7/7/2011	7/26/2011	1107110_13	6384	7/7/2011	7/26/2011	1107110_14	6385	1,2-Dichloroethane	U	U	0	0
7/7/2011	7/26/2011	1107110_13	6384	7/7/2011	7/26/2011	1107110_14	6385	Carbon Tetrachloride	1995068.88	1819890.18	175178.7	9.18
7/7/2011	7/26/2011	1107110_13	6384	7/7/2011	7/26/2011	1107110_14	6385	Chlorobenzene	U	U	0	0
7/7/2011	7/26/2011	1107110_13	6384	7/7/2011	7/26/2011	1107110_14	6385	Chloroform	257847.3	234227.7	23619.6	9.6
7/7/2011	7/26/2011	1107110_13	6384	7/7/2011	7/26/2011	1107110_14	6385	Methylene Chloride	37791.36	33067.44	4723.92	13.33
7/7/2011	7/26/2011	1107110_13	6384	7/7/2011	7/26/2011	1107110_14	6385	Toluene	U	U	0	0
7/12/2011	7/28/2011	1107140_05	6396	7/12/2011	7/28/2011	1107140_06	6399	1,1,1-Trichloroethane	2.73 J	2.81 J	-0.08	2.89
7/12/2011	7/28/2011	1107140_05	6396	7/12/2011	7/28/2011	1107140_06	6399	1,1,2,2-	U	U	0	0
7/12/2011	7/28/2011	1107140_05	6396	7/12/2011	7/28/2011	1107140_06	6399	1,1-Dichloroethylene	U	U	0	0
7/12/2011	7/28/2011	1107140_05	6396	7/12/2011	7/28/2011	1107140_06	6399	1,2-Dichloroethane	U	U	0	0
7/12/2011	7/28/2011	1107140_05	6396	7/12/2011	7/28/2011	1107140_06	6399	Carbon Tetrachloride	60.57 J	60.26 J	0.31	0.51
7/12/2011	7/28/2011	1107140_05	6396	7/12/2011	7/28/2011	1107140_06	6399	Chlorobenzene	U	U	0	0
7/12/2011	7/28/2011	1107140_05	6396	7/12/2011	7/28/2011	1107140_06	6399	Chloroform	4.19 J	4.25 J	-0.06	1.42
7/12/2011	7/28/2011	1107140_05	6396	7/12/2011	7/28/2011	1107140_06	6399	Methylene Chloride	0.2 J	0.21 J	-0.01	4.88
7/12/2011	7/28/2011	1107140_05	6396	7/12/2011	7/28/2011	1107140_06	6399	Toluene	0.18 J	0.2 J	-0.02	10.53
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_23	6415	1,1,1-Trichloroethane	93034.98	89623.26	3411.72	3.74
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_23	6415	1,1,2,2-Tetrachloroethane	U	U	0	0
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_23	6415	1,1-Dichloroethylene	U	U	0	0
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_23	6415	1,2-Dichloroethane	U	U	0	0
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_23	6415	Carbon Tetrachloride	499554.54	467536.86	32017.68	6.62
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_23	6415	Chlorobenzene	U	U	0	0
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_23	6415	Chloroform	41071.86	40022.1	1049.76	2.59
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_23	6415	Methylene Chloride	22832.28	22963.5	-131.22	0.57
7/12/2011	8/4/2011	1107140_22A	6414	7/12/2011	8/4/2011	1107140_23	6415	Toluene	U	U	0	0
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_14	6434	1,1,1-Trichloroethane	1574.1	1598.94	-24.84	1.57
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_14	6434	1,1,2,2-Tetrachloroethane	U	U	0	0
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_14	6434	1,1-Dichloroethylene	15.12 J	15.12 J	0	0
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_14	6434	1,2-Dichloroethane	U	U	0	0
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_14	6434	Carbon Tetrachloride	1846.26	1879.74	-33.48	1.8
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_14	6434	Chlorobenzene	U	U	0	0

Relative Percent Difference (RPD)
RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6D – VOCs – Field Duplicate Precision

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_14	6434	Chloroform	52.92 J	55.62 J	-2.7	4.98
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_14	6434	Methylene Chloride	447.12 J	455.76 J	-8.64	1.91
7/19/2011	7/29/2011	1107210_13A	6433	7/19/2011	7/29/2011	1107210_14	6434	Toluene	26.46 J	25.38 J	1.08	4.17
7/26/2011	8/4/2011	1107280_05	6447	7/26/2011	8/4/2011	1107280_06	6449	1,1,1-Trichloroethane	18.36 J	7.59 J	10.77	83.01
7/26/2011	8/4/2011	1107280_05	6447	7/26/2011	8/4/2011	1107280_06	6449	1,1,2,2-Tetrachloroethane	U	U	0	0
7/26/2011	8/4/2011	1107280_05	6447	7/26/2011	8/4/2011	1107280_06	6449	1,1-Dichloroethylene	U	U	0	0
7/26/2011	8/4/2011	1107280_05	6447	7/26/2011	8/4/2011	1107280_06	6449	1,2-Dichloroethane	U	U	0	0
7/26/2011	8/4/2011	1107280_05	6447	7/26/2011	8/4/2011	1107280_06	6449	Carbon Tetrachloride	338.58 J	133.08 J	205.5	87.14
7/26/2011	8/4/2011	1107280_05	6447	7/26/2011	8/4/2011	1107280_06	6449	Chlorobenzene	U	U	0	0
7/26/2011	8/4/2011	1107280_05	6447	7/26/2011	8/4/2011	1107280_06	6449	Chloroform	62.55 J	23.34 J	39.21	91.3
7/26/2011	8/4/2011	1107280_05	6447	7/26/2011	8/4/2011	1107280_06	6449	Methylene Chloride	6.39 J	2.16 J	4.23	98.95
7/26/2011	8/4/2011	1107280_05	6447	7/26/2011	8/4/2011	1107280_06	6449	Toluene	0.99 J	0.57 J	0.42	53.85
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_03	6455	1,1,1-Trichloroethane	31.22*	33.22*	-2	6.21
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_03	6455	1,1,2,2-Tetrachloroethane	U	U	0	0
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_03	6455	1,1-Dichloroethylene	U	U	0	0
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_03	6455	1,2-Dichloroethane	U	U	0	0
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_03	6455	Carbon Tetrachloride	205.51*	219.12*	-13.61	6.41
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_03	6455	Chlorobenzene	U	U	0	0
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_03	6455	Chloroform	18.46*	19.61*	-1.15	6.04
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_03	6455	Methylene Chloride	7.31* J	7.83* J	-0.52	6.87
8/2/2011	8/8/2011	1108040_01A	6453	8/2/2011	8/8/2011	1108040_03	6455	Toluene	1.02* J	0.97* J	0.05	5.03
8/2/2011	8/8/2011	1108040_02	6454	8/2/2011	8/8/2011	1108040_04	6456	1,1,1-Trichloroethane	U	U	0	0
8/2/2011	8/8/2011	1108040_02	6454	8/2/2011	8/8/2011	1108040_04	6456	1,1,2,2-Tetrachloroethane	U	U	0	0
8/2/2011	8/8/2011	1108040_02	6454	8/2/2011	8/8/2011	1108040_04	6456	1,1-Dichloroethylene	U	U	0	0
8/2/2011	8/8/2011	1108040_02	6454	8/2/2011	8/8/2011	1108040_04	6456	1,2-Dichloroethane	U	U	0	0
8/2/2011	8/8/2011	1108040_02	6454	8/2/2011	8/8/2011	1108040_04	6456	Carbon Tetrachloride	0.51* J	0.74* J	-0.23	36.8
8/2/2011	8/8/2011	1108040_02	6454	8/2/2011	8/8/2011	1108040_04	6456	Chlorobenzene	U	U	0	0
8/2/2011	8/8/2011	1108040_02	6454	8/2/2011	8/8/2011	1108040_04	6456	Chloroform	U	0.32* J	-0.32	200
8/2/2011	8/8/2011	1108040_02	6454	8/2/2011	8/8/2011	1108040_04	6456	Methylene Chloride	0.20* J	0.19* J	0.01	5.13
8/2/2011	8/8/2011	1108040_02	6454	8/2/2011	8/8/2011	1108040_04	6456	Toluene	0.36* J	0.34* J	0.02	5.71
8/9/2011	8/24/2011	1108110_05	6466	8/9/2011	8/24/2011	1108110_06	6467	1,1,1-Trichloroethane	12.28 J	12.12 J	0.16	1.31
8/9/2011	8/24/2011	1108110_05	6466	8/9/2011	8/24/2011	1108110_06	6467	1,1,2,2-Tetrachloroethane	U	U	0	0
8/9/2011	8/24/2011	1108110_05	6466	8/9/2011	8/24/2011	1108110_06	6467	1,1-Dichloroethylene	U	U	0	0
8/9/2011	8/24/2011	1108110_05	6466	8/9/2011	8/24/2011	1108110_06	6467	1,2-Dichloroethane	U	U	0	0

Relative Percent Difference (RPD)
RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6D – VOCs – Field Duplicate Precision

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
8/9/2011	8/24/2011	1108110_05	6466	8/9/2011	8/24/2011	1108110_06	6467	Carbon Tetrachloride	132.16 J	166.08 J	-33.92	22.75
8/9/2011	8/24/2011	1108110_05	6466	8/9/2011	8/24/2011	1108110_06	6467	Chlorobenzene	U	U	0	0
8/9/2011	8/24/2011	1108110_05	6466	8/9/2011	8/24/2011	1108110_06	6467	Chloroform	23.08 J	27.88 J	-4.8	18.84
8/9/2011	8/24/2011	1108110_05	6466	8/9/2011	8/24/2011	1108110_06	6467	Methylene Chloride	3.04 J	3.16 J	-0.12	3.87
8/9/2011	8/24/2011	1108110_05	6466	8/9/2011	8/24/2011	1108110_06	6467	Toluene	0.8 J	0.72 J	0.08	10.53
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_09	6483(Q)	1,1,1-Trichloroethane	43506.72	1563.84	41942.88	186.12
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_09	6483	1,1,2,2-Tetrachloroethane	U	U	0	0
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_09	6483	1,1-Dichloroethylene	U	U	0	0
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_09	6483	1,2-Dichloroethane	U	U	0	0
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_09	6483(Q)	Carbon Tetrachloride	228672.72	8432.64	220240.08	185.77
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_09	6483	Chlorobenzene	U	U	0	0
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_09	6483(Q)	Chloroform	19537.2	684.72	18852.48	186.46
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_09	6483(Q)	Methylene Chloride	10555.92	386.64 J	10169.28	185.87
8/9/2011	8/24/2011	1108110_08A	6482	8/9/2011	8/25/2011	1108110_09	6483	Toluene	U	U	0	0
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_19	6507	1,1,1-Trichloroethane	3095.01	2944.35	150.66	4.99
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_19	6507	1,1,2,2-Tetrachloroethane	U	U	0	0
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_19	6507	1,1-Dichloroethylene	27.54 J	25.92 J	1.62	6.06
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_19	6507	1,2-Dichloroethane	U	U	0	0
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_19	6507	Carbon Tetrachloride	3678.21	3478.95	199.26	5.57
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_19	6507	Chlorobenzene	U	U	0	0
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_19	6507	Chloroform	102.06 J	99.63 J	2.43	2.41
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_19	6507	Methylene Chloride	795.42	754.11	41.31	5.33
8/16/2011	8/25/2011	1108180_18A	6506	8/16/2011	8/25/2011	1108180_19	6507	Toluene	51.03 J	52.65 J	-1.62	3.13
8/23/2011	8/30/2011	1108250_05	6515	8/23/2011	8/30/2011	1108250_06	6516	1,1,1-Trichloroethane	9.88 J	5.9 J	3.98	50.44
8/23/2011	8/30/2011	1108250_05	6515	8/23/2011	8/30/2011	1108250_06	6516	1,1,2,2-Tetrachloroethane	U	U	0	0
8/23/2011	8/30/2011	1108250_05	6515	8/23/2011	8/30/2011	1108250_06	6516	1,1-Dichloroethylene	U	U	0	0
8/23/2011	8/30/2011	1108250_05	6515	8/23/2011	8/30/2011	1108250_06	6516	1,2-Dichloroethane	U	U	0	0
8/23/2011	8/30/2011	1108250_05	6515	8/23/2011	8/30/2011	1108250_06	6516	Carbon Tetrachloride	147.8 J	80.92 J	66.88	58.48
8/23/2011	8/30/2011	1108250_05	6515	8/23/2011	8/30/2011	1108250_06	6516	Chlorobenzene	U	U	0	0
8/23/2011	8/30/2011	1108250_05	6515	8/23/2011	8/30/2011	1108250_06	6516	Chloroform	21.12 J	10.9 J	10.22	63.84
8/23/2011	8/30/2011	1108250_05	6515	8/23/2011	8/30/2011	1108250_06	6516	Methylene Chloride	1.52 J	0.72 J	0.8	71.43
8/23/2011	8/30/2011	1108250_05	6515	8/23/2011	8/30/2011	1108250_06	6516	Toluene	0.52 J	0.36 J	0.16	36.36
9/7/2011	9/13/2011	1109090_05	6532	9/7/2011	9/13/2011	1109090_06	6533	1,1,1-Trichloroethane	104.04 J	101.52 J	2.52	2.45
9/7/2011	9/13/2011	1109090_05	6532	9/7/2011	9/13/2011	1109090_06	6533	1,1,2,2-Tetrachloroethane	U	U	0	0

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Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
9/7/2011	9/13/2011	1109090_05	6532	9/7/2011	9/13/2011	1109090_06	6533	1,1-Dichloroethylene	U	U	0	0
9/7/2011	9/13/2011	1109090_05	6532	9/7/2011	9/13/2011	1109090_06	6533	1,2-Dichloroethane	U	U	0	0
9/7/2011	9/13/2011	1109090_05	6532	9/7/2011	9/13/2011	1109090_06	6533	Carbon Tetrachloride	1350.72	1305	45.72	3.44
9/7/2011	9/13/2011	1109090_05	6532	9/7/2011	9/13/2011	1109090_06	6533	Chlorobenzene	U	U	0	0
9/7/2011	9/13/2011	1109090_05	6532	9/7/2011	9/13/2011	1109090_06	6533	Chloroform	84.24 J	77.76 J	6.48	8
9/7/2011	9/13/2011	1109090_05	6532	9/7/2011	9/13/2011	1109090_06	6533	Methylene Chloride	4.32 J	U	4.32	200
9/7/2011	9/13/2011	1109090_05	6532	9/7/2011	9/13/2011	1109090_06	6533	Toluene	U	U	0	0
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_20	6561	1,1,1-Trichloroethane	123478.02	125708.76	-2230.74	1.79
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_20	6561	1,1,2,2-Tetrachloroethane	U	U	0	0
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_20	6561	1,1-Dichloroethylene	U	U	0	0
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_20	6561	1,2-Dichloroethane	U	U	0	0
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_20	6561	Carbon Tetrachloride	640484.82	663973.2	-23488.38	3.6
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_20	6561	Chlorobenzene	U	U	0	0
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_20	6561	Chloroform	52750.44	54193.86	-1443.42	2.7
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_20	6561	Methylene Chloride	27949.86	28343.52	-393.66	1.4
9/14/2011	9/21/2011	1109150_19A	6560	9/14/2011	9/21/2011	1109150_20	6561	Toluene	1312.2	1180.98	131.22	10.53
9/20/2011	9/27/2011	1109260_05	6568	9/20/2011	9/27/2011	1109260_06	6569	1,1,1-Trichloroethane	10.59 J	7.74 J	2.85	31.1
9/20/2011	9/27/2011	1109260_05	6568	9/20/2011	9/27/2011	1109260_06	6569	1,1,2,2-Tetrachloroethane	U	U	0	0
9/20/2011	9/27/2011	1109260_05	6568	9/20/2011	9/27/2011	1109260_06	6569	1,1-Dichloroethylene	U	U	0	0
9/20/2011	9/27/2011	1109260_05	6568	9/20/2011	9/27/2011	1109260_06	6569	1,2-Dichloroethane	U	U	0	0
9/20/2011	9/27/2011	1109260_05	6568	9/20/2011	9/27/2011	1109260_06	6569	Carbon Tetrachloride	157.23 J	112.9 J	44.33	32.82
9/20/2011	9/27/2011	1109260_05	6568	9/20/2011	9/27/2011	1109260_06	6569	Chlorobenzene	U	U	0	0
9/20/2011	9/27/2011	1109260_05	6568	9/20/2011	9/27/2011	1109260_06	6569	Chloroform	14.01 J	8.84 J	5.17	45.25
9/20/2011	9/27/2011	1109260_05	6568	9/20/2011	9/27/2011	1109260_06	6569	Methylene Chloride	0.96 J	0.52 J	0.44	59.46
9/20/2011	9/27/2011	1109260_05	6568	9/20/2011	9/27/2011	1109260_06	6569	Toluene	0.36 J	0.26 J	0.1	32.26
10/4/2011	10/10/2011	1110060_03	6596	10/4/2011	10/10/2011	1110060_04	6598	1,1,1-Trichloroethane	U	U	0	0
10/4/2011	10/10/2011	1110060_03	6596	10/4/2011	10/10/2011	1110060_04	6598	1,1,2,2-	U	U	0	0
10/4/2011	10/10/2011	1110060_03	6596	10/4/2011	10/10/2011	1110060_04	6598	1,1-Dichloroethylene	U	U	0	0
10/4/2011	10/10/2011	1110060_03	6596	10/4/2011	10/10/2011	1110060_04	6598	1,2-Dichloroethane	U	U	0	0
10/4/2011	10/10/2011	1110060_03	6596	10/4/2011	10/10/2011	1110060_04	6598	Carbon Tetrachloride	0.66* J	0.62* J	0.04	6.25
10/4/2011	10/10/2011	1110060_03	6596	10/4/2011	10/10/2011	1110060_04	6598	Chlorobenzene	U	U	0	0
10/4/2011	10/10/2011	1110060_03	6596	10/4/2011	10/10/2011	1110060_04	6598	Chloroform	U	U	0	0
10/4/2011	10/10/2011	1110060_03	6596	10/4/2011	10/10/2011	1110060_04	6598	Methylene Chloride	0.19* J	0.19* J	0	0
10/4/2011	10/10/2011	1110060_03	6596	10/4/2011	10/10/2011	1110060_04	6598	Toluene	0.30* J	0.24* J	0.06	22.22

Relative Percent Difference (RPD)
RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6D – VOCs – Field Duplicate Precision

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_02	6599	1,1,1-Trichloroethane	30.14*	31.28*	-1.14	3.71
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_02	6599	1,1,2,2-Tetrachloroethane	U	U	0	0
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_02	6599	1,1-Dichloroethylene	U	U	0	0
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_02	6599	1,2-Dichloroethane	U	U	0	0
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_02	6599	Carbon Tetrachloride	266.24*	279.09*	-12.85	4.71
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_02	6599	Chlorobenzene	U	U	0	0
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_02	6599	Chloroform	24.20*	25.40*	-1.2	4.84
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_02	6599	Methylene Chloride	7.13* J	7.36* J	-0.23	3.17
10/4/2011	10/10/2011	1110060_01A	6597	10/4/2011	10/10/2011	1110060_02	6599	Toluene	0.91* J	0.91* J	0	0
10/4/2011	10/10/2011	1110060_07	6604	10/4/2011	10/10/2011	1110060_08	6605	1,1,1-Trichloroethane	11.64 J	9.06 J	2.58	24.93
10/4/2011	10/10/2011	1110060_07	6604	10/4/2011	10/10/2011	1110060_08	6605	1,1,2,2-Tetrachloroethane	U	U	0	0
10/4/2011	10/10/2011	1110060_07	6604	10/4/2011	10/10/2011	1110060_08	6605	1,1-Dichloroethylene	U	U	0	0
10/4/2011	10/10/2011	1110060_07	6604	10/4/2011	10/10/2011	1110060_08	6605	1,2-Dichloroethane	U	U	0	0
10/4/2011	10/10/2011	1110060_07	6604	10/4/2011	10/10/2011	1110060_08	6605	Carbon Tetrachloride	167.43 J	123.6 J	43.83	30.12
10/4/2011	10/10/2011	1110060_07	6604	10/4/2011	10/10/2011	1110060_08	6605	Chlorobenzene	U	U	0	0
10/4/2011	10/10/2011	1110060_07	6604	10/4/2011	10/10/2011	1110060_08	6605	Chloroform	14.01 J	8.94 J	5.07	44.18
10/4/2011	10/10/2011	1110060_07	6604	10/4/2011	10/10/2011	1110060_08	6605	Methylene Chloride	1.14 J	0.87 J	0.27	26.87
10/4/2011	10/10/2011	1110060_07	6604	10/4/2011	10/10/2011	1110060_08	6605	Toluene	0.3 J	U	0.3	200
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_22	6635	1,1,1-Trichloroethane	99464.76	93166.2	6298.56	6.54
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_22	6635	1,1,2,2-Tetrachloroethane	U	U	0	0
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_22	6635	1,1-Dichloroethylene	U	U	0	0
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_22	6635	1,2-Dichloroethane	U	U	0	0
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_22	6635	Carbon Tetrachloride	543906.9	501654.06	42252.84	8.08
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_22	6635	Chlorobenzene	U	U	0	0
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_22	6635	Chloroform	44221.14	40415.76	3805.38	8.99
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_22	6635	Methylene Chloride	21782.52	20207.88	1574.64	7.5
10/11/2011	10/18/2011	1110130_21A	6634	10/11/2011	10/18/2011	1110130_22	6635	Toluene	U	U	0	0
10/18/2011	10/26/2011	1110240_05	6643	10/18/2011	10/26/2011	1110240_06	6644	1,1,1-Trichloroethane	4.515 J	3.75 J	0.76	18.39
10/18/2011	10/26/2011	1110240_05	6643	10/18/2011	10/26/2011	1110240_06	6644	1,1,2,2-Tetrachloroethane	U	U	0	0
10/18/2011	10/26/2011	1110240_05	6643	10/18/2011	10/26/2011	1110240_06	6644	1,1-Dichloroethylene	U	U	0	0
10/18/2011	10/26/2011	1110240_05	6643	10/18/2011	10/26/2011	1110240_06	6644	1,2-Dichloroethane	U	U	0	0
10/18/2011	10/26/2011	1110240_05	6643	10/18/2011	10/26/2011	1110240_06	6644	Carbon Tetrachloride	62.1 J	49.005 J	13.09	23.56
10/18/2011	10/26/2011	1110240_05	6643	10/18/2011	10/26/2011	1110240_06	6644	Chlorobenzene	U	U	0	0
10/18/2011	10/26/2011	1110240_05	6643	10/18/2011	10/26/2011	1110240_06	6644	Chloroform	5.37 J	4.005 J	1.36	29.01

Relative Percent Difference (RPD)
RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6D – VOCs – Field Duplicate Precision

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
10/18/2011	10/26/2011	1110240_05	6643	10/18/2011	10/26/2011	1110240_06	6644	Methylene Chloride	0.45 J	0.525 J	-0.07	14.36
10/18/2011	10/26/2011	1110240_05	6643	10/18/2011	10/26/2011	1110240_06	6644	Toluene	0.195 J	0.165 J	0.03	16.67
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_23	6660	1,1,1-Trichloroethane	1228.23	1217.43	10.8	0.88
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_23	6660	1,1,2,2-Tetrachloroethane	U	U	0	0
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_23	6660	1,1-Dichloroethylene	13.5 J	15.12 J	-1.62	11.32
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_23	6660	1,2-Dichloroethane	3.51 J	3.51 J	0	0
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_23	6660	Carbon Tetrachloride	1576.26	1559.25	17.01	1.08
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_23	6660	Chlorobenzene	U	U	0	0
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_23	6660	Chloroform	51.03 J	52.65 J	-1.62	3.13
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_23	6660	Methylene Chloride	303.21 J	312.12 J	-8.91	2.9
10/18/2011	10/26/2011	1110240_22A	6659	10/18/2011	10/27/2011	1110240_23	6660	Toluene	22.95 J	25.92 J	-2.97	12.15
11/1/2011	11/9/2011	1111030_05	6688	11/1/2011	11/9/2011	1111030_06	6689	1,1,1-Trichloroethane	2377.08	2428.2	-51.12	2.13
11/1/2011	11/9/2011	1111030_05	6688	11/1/2011	11/9/2011	1111030_06	6689	1,1,2,2-Tetrachloroethane	U	U	0	0
11/1/2011	11/9/2011	1111030_05	6688	11/1/2011	11/9/2011	1111030_06	6689	1,1-Dichloroethylene	U	U	0	0
11/1/2011	11/9/2011	1111030_05	6688	11/1/2011	11/9/2011	1111030_06	6689	1,2-Dichloroethane	U	U	0	0
11/1/2011	11/9/2011	1111030_05	6688	11/1/2011	11/9/2011	1111030_06	6689	Carbon Tetrachloride	16102.8	16409.52	-306.72	1.89
11/1/2011	11/9/2011	1111030_05	6688	11/1/2011	11/9/2011	1111030_06	6689	Chlorobenzene	U	U	0	0
11/1/2011	11/9/2011	1111030_05	6688	11/1/2011	11/9/2011	1111030_06	6689	Chloroform	1047.96	1094.82	-46.86	4.37
11/1/2011	11/9/2011	1111030_05	6688	11/1/2011	11/9/2011	1111030_06	6689	Methylene Chloride	97.98 J	106.5 J	-8.52	8.33
11/1/2011	11/9/2011	1111030_05	6688	11/1/2011	11/9/2011	1111030_06	6689	Toluene	U	U	0	0
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_25	6708	1,1,1-Trichloroethane	109043.82	105107.22	3936.6	3.68
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_25	6708	1,1,2,2-Tetrachloroethane	U	U	0	0
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_25	6708	1,1-Dichloroethylene	U	U	0	0
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_25	6708	1,2-Dichloroethane	U	U	0	0
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_25	6708	Carbon Tetrachloride	580779.72	555060.6	25719.12	4.53
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_25	6708	Chlorobenzene	U	U	0	0
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_25	6708	Chloroform	48157.74	47239.2	918.54	1.93
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_25	6708	Methylene Chloride	23882.04	22963.5	918.54	3.92
11/1/2011	11/9/2011	1111030_24A	6707	11/1/2011	11/9/2011	1111030_25	6708	Toluene	1574.64	1180.98	393.66	28.57
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_21	6730	1,1,1-Trichloroethane	1012.77	878.04	134.73	14.25
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_21	6730	1,1,2,2-Tetrachloroethane	U	U	0	0
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_21	6730	1,1-Dichloroethylene	10.8 J	9.99 J	0.81	7.79
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_21	6730	1,2-Dichloroethane	U	U	0	0
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_21	6730	Carbon Tetrachloride	1206.63	1044.9	161.73	14.37

Relative Percent Difference (RPD)
RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6D – VOCs – Field Duplicate Precision

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_21	6730	Chlorobenzene	U	U	0	0
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_21	6730	Chloroform	45.63 J	40.77 J	4.86	11.25
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_21	6730	Methylene Chloride	286.74 J	257.85 J	28.89	10.61
11/8/2011	11/15/2011	1111100_20A	6729	11/8/2011	11/15/2011	1111100_21	6730	Toluene	21.87 J	19.44 J	2.43	11.76
11/15/2011	11/22/2011	1111170_06	6740	11/15/2011	11/22/2011	1111170_07	6741	1,1,1-Trichloroethane	195.75 J	216.54 J	-20.79	10.09
11/15/2011	11/22/2011	1111170_06	6740	11/15/2011	11/22/2011	1111170_07	6741	1,1,2,2-Tetrachloroethane	U	U	0	0
11/15/2011	11/22/2011	1111170_06	6740	11/15/2011	11/22/2011	1111170_07	6741	1,1-Dichloroethylene	U	U	0	0
11/15/2011	11/22/2011	1111170_06	6740	11/15/2011	11/22/2011	1111170_07	6741	1,2-Dichloroethane	U	U	0	0
11/15/2011	11/22/2011	1111170_06	6740	11/15/2011	11/22/2011	1111170_07	6741	Carbon Tetrachloride	981.18	1097.55	-116.37	11.2
11/15/2011	11/22/2011	1111170_06	6740	11/15/2011	11/22/2011	1111170_07	6741	Chlorobenzene	U	U	0	0
11/15/2011	11/22/2011	1111170_06	6740	11/15/2011	11/22/2011	1111170_07	6741	Chloroform	61.83 J	69.12 J	-7.29	11.13
11/15/2011	11/22/2011	1111170_06	6740	11/15/2011	11/22/2011	1111170_07	6741	Methylene Chloride	8.91 J	9.18 J	-0.27	2.99
11/15/2011	11/22/2011	1111170_06	6740	11/15/2011	11/22/2011	1111170_07	6741	Toluene	U	U	0	0
11/29/2011	12/6/2011	1112010_07	6757	11/29/2011	12/6/2011	1112010_08	6758	1,1,1-Trichloroethane	147.69 J	69.75 J	77.94	71.69
11/29/2011	12/6/2011	1112010_07	6757	11/29/2011	12/6/2011	1112010_08	6758	1,1,2,2-Tetrachloroethane	U	U	0	0
11/29/2011	12/6/2011	1112010_07	6757	11/29/2011	12/6/2011	1112010_08	6758	1,1-Dichloroethylene	U	U	0	0
11/29/2011	12/6/2011	1112010_07	6757	11/29/2011	12/6/2011	1112010_08	6758	1,2-Dichloroethane	U	U	0	0
11/29/2011	12/6/2011	1112010_07	6757	11/29/2011	12/6/2011	1112010_08	6758(Q)	Carbon Tetrachloride	1157.76	482.4 J	675.36	82.35
11/29/2011	12/6/2011	1112010_07	6757	11/29/2011	12/6/2011	1112010_08	6758	Chlorobenzene	U	U	0	0
11/29/2011	12/6/2011	1112010_07	6757	11/29/2011	12/6/2011	1112010_08	6758	Chloroform	69.12 J	31.05 J	38.07	76.01
11/29/2011	12/6/2011	1112010_07	6757	11/29/2011	12/6/2011	1112010_08	6758	Methylene Chloride	5.94 J	2.43 J	3.51	83.87
11/29/2011	12/6/2011	1112010_07	6757	11/29/2011	12/6/2011	1112010_08	6758	Toluene	U	U	0	0
12/6/2011	12/12/2011	1112080_01	6762	12/6/2011	12/12/2011	1112080_02	6768	1,1,1-Trichloroethane	U	U	0	0
12/6/2011	12/12/2011	1112080_01	6762	12/6/2011	12/12/2011	1112080_02	6768	1,1,2,2-	U	U	0	0
12/6/2011	12/12/2011	1112080_01	6762	12/6/2011	12/12/2011	1112080_02	6768	1,1-Dichloroethylene	U	U	0	0
12/6/2011	12/12/2011	1112080_01	6762	12/6/2011	12/12/2011	1112080_02	6768	1,2-Dichloroethane	U	U	0	0
12/6/2011	12/12/2011	1112080_01	6762	12/6/2011	12/12/2011	1112080_02	6768	Carbon Tetrachloride	0.13* J	0.13* J	0	0
12/6/2011	12/12/2011	1112080_01	6762	12/6/2011	12/12/2011	1112080_02	6768	Chlorobenzene	U	U	0	0
12/6/2011	12/12/2011	1112080_01	6762	12/6/2011	12/12/2011	1112080_02	6768	Chloroform	U	U	0	0
12/6/2011	12/12/2011	1112080_01	6762	12/6/2011	12/12/2011	1112080_02	6768	Methylene Chloride	0.14* J	U	0	0
12/6/2011	12/12/2011	1112080_01	6762	12/6/2011	12/12/2011	1112080_02	6768	Toluene	0.17* J	0.14* J	0.03	19.35
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_04	6767	1,1,1-Trichloroethane	24.32*	25.44*	-1.12	4.5
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_04	6767	1,1,2,2-	U	U	0	0
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_04	6767	1,1-Dichloroethylene	U	U	0	0

Relative Percent Difference (RPD)
RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6D – VOCs – Field Duplicate Precision

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_04	6767	1,2-Dichloroethane	U	U	0	0
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_04	6767	Carbon Tetrachloride	127.59*	133.19*	-5.6	4.29
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_04	6767	Chlorobenzene	U	U	0	0
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_04	6767	Chloroform	9.61*	10.14*	-0.53	5.37
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_04	6767	Methylene Chloride	3.46* J	3.55* J	-0.09	2.57
12/6/2011	12/12/2011	1112080_03A	6763	12/6/2011	12/12/2011	1112080_04	6767	Toluene	0.35* J	0.35* J	0	0
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_22	6785	1,1,1-Trichloroethane	2504.52	2461.32	43.2	1.74
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_22	6785	1,1,2,2-Tetrachloroethane	U	U	0	0
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_22	6785	1,1-Dichloroethylene	23.22 J	23.76 J	-0.54	2.3
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_22	6785	1,2-Dichloroethane	U	U	0	0
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_22	6785	Carbon Tetrachloride	2715.12	2678.94	36.18	1.34
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_22	6785	Chlorobenzene	U	U	0	0
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_22	6785	Chloroform	77.76 J	78.84 J	-1.08	1.38
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_22	6785	Methylene Chloride	674.46	671.76	2.7	0.4
12/6/2011	12/12/2011	1112080_21A	6784	12/6/2011	12/12/2011	1112080_22	6785	Toluene	45.9 J	42.66 J	3.24	7.32
12/13/2011	12/21/2011	1112150_05	6791	12/13/2011	12/21/2011	1112150_06	6792	1,1,1-Trichloroethane	44352.36	43630.65	721.71	1.64
12/13/2011	12/21/2011	1112150_05	6791	12/13/2011	12/21/2011	1112150_06	6792	1,1,2,2-Tetrachloroethane	U	U	0	0
12/13/2011	12/21/2011	1112150_05	6791	12/13/2011	12/21/2011	1112150_06	6792	1,1-Dichloroethylene	U	U	0	0
12/13/2011	12/21/2011	1112150_05	6791	12/13/2011	12/21/2011	1112150_06	6792	1,2-Dichloroethane	U	U	0	0
12/13/2011	12/21/2011	1112150_05	6791	12/13/2011	12/21/2011	1112150_06	6792	Carbon Tetrachloride	298459.89	299444.04	-984.15	0.33
12/13/2011	12/21/2011	1112150_05	6791	12/13/2011	12/21/2011	1112150_06	6792	Chlorobenzene	U	U	0	0
12/13/2011	12/21/2011	1112150_05	6791	12/13/2011	12/21/2011	1112150_06	6792	Chloroform	19617.39	19617.39	0	0
12/13/2011	12/21/2011	1112150_05	6791	12/13/2011	12/21/2011	1112150_06	6792	Methylene Chloride	1705.86	1837.08	-131.22	7.41
12/13/2011	12/21/2011	1112150_05	6791	12/13/2011	12/21/2011	1112150_06	6792	Toluene	U	U	0	0
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_25	6812	1,1,1-Trichloroethane	145391.76	156414.24	-11022.48	7.3
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_25	6812	1,1,2,2-Tetrachloroethane	U	U	0	0
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_25	6812	1,1-Dichloroethylene	U	U	0	0
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_25	6812	1,2-Dichloroethane	U	U	0	0
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_25	6812	Carbon Tetrachloride	766193.58	814482.54	-48288.96	6.11
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_25	6812	Chlorobenzene	U	U	0	0
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_25	6812	Chloroform	60492.42	65085.12	-4592.7	7.31
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_25	6812	Methylene Chloride	28605.96	31361.58	-2755.62	9.19
12/13/2011	12/21/2011	1112150_24A	6811	12/13/2011	12/21/2011	1112150_25	6812	Toluene	1049.76U	1180.98	-131.22	11.76
12/29/2011	1/10/2012	1201030_11	6834	12/29/2011	1/10/2012	1201030_12	6835	1,1,1-Trichloroethane	27446.85	26484.57	962.28	3.57

Relative Percent Difference (RPD)
RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 6D – VOCs – Field Duplicate Precision

Concentrations in ppbv

Original Sample Date	Original Analysis Date	Original Lab ID	Original Sample ID	Duplicate Sample Date	Duplicate Analysis Date	Duplicate Lab ID	Duplicate Sample ID	Compound	Original	Duplicate	Difference	RPD#
12/29/2011	1/10/2012	1201030_11	6834	12/29/2011	1/10/2012	1201030_12	6835	1,1,2,2-Tetrachloroethane	U	U	0	0
12/29/2011	1/10/2012	1201030_11	6834	12/29/2011	1/10/2012	1201030_12	6835	1,1-Dichloroethylene	U	U	0	0
12/29/2011	1/10/2012	1201030_11	6834	12/29/2011	1/10/2012	1201030_12	6835	1,2-Dichloroethane	U	U	0	0
12/29/2011	1/10/2012	1201030_11	6834	12/29/2011	1/10/2012	1201030_12	6835	Carbon Tetrachloride	110224.8	105216.57	5008.23	4.65
12/29/2011	1/10/2012	1201030_11	6834	12/29/2011	1/10/2012	1201030_12	6835	Chlorobenzene	U	U	0	0
12/29/2011	1/10/2012	1201030_11	6834	12/29/2011	1/10/2012	1201030_12	6835	Chloroform	6145.47	6014.25	131.22	2.16
12/29/2011	1/10/2012	1201030_11	6834	12/29/2011	1/10/2012	1201030_12	6835	Methylene Chloride	852.93	809.19	43.74	5.26
12/29/2011	1/10/2012	1201030_11	6834	12/29/2011	1/10/2012	1201030_12	6835	Toluene	U	U	0	0

Notes

J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound analyzed for, but not detected above the MDL.
* = Normalized target VOC concentration.
# = Technical acceptance criterion for field duplicates is ≤35 RPD which is only applicable if one or both values not flagged "U" or "J."

Relative Percent Difference (RPD)
RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 7 – QA/QC Results for Hydrogen and Methane Monitoring of Panels 3 and 4

Results in ppmv

PANEL 3

LCS/LCSD	% Recovery LCS		% Recovery LCSD		RPD#	
Sample Month	Hydrogen	Methane	Hydrogen	Methane	Hydrogen	Methane
July	104.77 103.88	108.76 101.49	100.66 104.67	98.04 103.05	**4.00** **0.76**	**10.37** **1.53**
August	101.57	97.24	97.53	96.04	**4.06**	**1.24**
September	101.70	105.06	93.75	95.66	**8.14**	**9.37**
October	100.88	97.59	100.49	96.64	**0.39**	**0.98**
November	100.16	103.13	101.45	98.56	**1.28**	**4.53**
December	107.27	107.21	106.53	100.64	**0.69**	**6.32**

Lab Duplicate	Sample Results		Duplicate Results		RPD#	
Sample Month	Hydrogen	Methane	Hydrogen	Methane	Hydrogen	Methane
July (1)	50.44 J	U	43.34 J	U	**15.14**	**0**
July (2)	36.06 J	U	44.28 J	U	**20.46**	**0**
August	U	U	U	U	**0**	**0**
September	46.88 J	U	45.16 J	U	**3.74**	**0**
October	34.04 J	U	42.34 J	U	**21.73**	**0**
November	32.08 J	U	31.14 J	U	**2.97**	**0**
December	U	U	U	U	**0**	**0**

Method Blank Results		
Sample Month	Hydrogen	Methane
July (1)	**U**	**U**
July (2)	**U**	**U**
August	**U**	**U**
September	**U**	**U**
October	**U**	**U**
November	**U**	**U**
December	**U**	**U**

Field Duplicate	Sample Results		Duplicate Results		RPD#	
Sample Month	Hydrogen	Methane	Hydrogen	Methane	Hydrogen	Methane
July	U	U	U	U	**0**	**0**
August	34.00 J	U	41.26 J	U	**19.29**	**0**
September	Field	Duplicate	Voided			
October	U	U	U	U	**0**	**0**
November	U	U	U	U	**0**	**0**
December	U	U	U	U	**0**	**0**

= technical acceptance criterion is ≤25 RPD for LCS/LCSD and lab duplicate and ≤35 RPD for field duplicate which is only applicable if one or both values not flagged "U" or "J."

Relative Percent Difference (RPD)
RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

Attachment 7 – QA/QC Results for Hydrogen and Methane Monitoring of Panels 3 and 4

Results in ppmv

PANEL 4

LCS/LCSD	% Recovery LCS		% Recovery LCSD		RPD#	
Sample Month	Hydrogen	Methane	Hydrogen	Methane	Hydrogen	Methane
July	98.68	111.32	101.80	104.51	**3.11**	**6.31**
August	103.17	96.88	102.58	100.92	**0.57**	**4.08**
September	97.92	103.08	96.94	100.80	**1.01**	**2.24**
October	101.00	101.23	102.95	95.76	**1.91**	**5.55**
November	101.91	99.61	102.55	101.60	**0.63**	**1.98**
December	103.52	102.89	105.07	107.92	**1.49**	**4.77**

Lab Duplicate	Sample Results		Duplicate Results		RPD#	
Sample Month	Hydrogen	Methane	Hydrogen	Methane	Hydrogen	Methane
July	674.94	U	690.58	U	**2.29**	**0**
August	507.68	U	488.02	U	**3.95**	**0**
September	500.24	U	471.62	U	**5.89**	**0**
October	388.58	U	399.36	U	**2.74**	**0**
November	425.88	U	422.48	U	**0.80**	**0**
December	557.70	U	542.74	U	**2.72**	**0**

Method Blank Results		
Sample Month	Hydrogen	Methane
July	**U**	**U**
August	**U**	**U**
September	**U**	**U**
October	**U**	**U**
November	**U**	**U**
December	**U**	**U**

Field Duplicate	Sample Results		Duplicate Results		RPD#	
Sample Month	Hydrogen	Methane	Hydrogen	Methane	Hydrogen	Methane
July	283.24 J	U	325.74	U	**13.96**	**0**
August	143.48 J	U	U	U	**200.00**	**0**
September	410.04	U	412.10	U	**0.50**	**0**
October	305.92	U	268.94 J	U	**12.87**	**0**
November	388.88	U	363.44	U	**6.76**	**0**
December	494.32	U	466.76	U	**5.74**	**0**

= technical acceptance criterion is ≤25 RPD for LCS/LCSD and lab duplicate and ≤35 RPD for field duplicate which is only applicable if one or both values not flagged "U" or "J."

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS=absolute value of a number

DOE/WIPP-12-3492-1, Rev. 0

SEMI-ANNUAL VOC, HYDROGEN, AND METHANE DATA SUMMARY REPORT FOR REPORTING PERIOD January 1, 2012 through June 30, 2012

United States Department of Energy

Waste Isolation Pilot Plant
Carlsbad, New Mexico

WIPP Hazardous Waste Facility Permit
New Mexico Environment Department
Permit Number NM4890139088-TSDF

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LIST OF ABBREVIATIONS, ACRONYMS, AND UNITS

BS	blank spike
BSD	blank spike duplicate
CFR	Code of Federal Regulations
CH	contact-handled
COC	concentration of concern
DOE	U.S. Department of Energy
EDD	electronic data deliverable
HWDU	hazardous waste disposal unit (panel)
IRIS	Integrated Risk Information System
LCS	laboratory control sample
LCSD	laboratory control sample duplicate
MDL	method detection limit
MRL	method reporting limit
N/A	not applicable
NMED	New Mexico Environment Department
ppbv	parts per billion by volume
ppmv	parts per million by volume
QA	quality assurance
QC	quality control
RCRA	Resource Conservation and Recovery Act
RH	remote-handled
RPD	relative percent difference
TIC	tentatively identified compound
TRU	transuranic
VOC	volatile organic compound
WIPP	Waste Isolation Pilot Plant

1.0 INTRODUCTION

This report is submitted by the U.S. Department of Energy (DOE) Carlsbad Field Office and Nuclear Waste Partnership LLC (the Permittees) in accordance with Permit Part 4, Permit conditions 4.6.2.2 and 4.6.5.2 of the Waste Isolation Pilot Plant (WIPP) Hazardous Waste Facility Permit NM4890139088-TSDF (Permit). This report documents the Volatile Organic Compound (VOC) Monitoring Program and Hydrogen and Methane Monitoring Program results for the 6-month period of January 1, 2012 through June 30, 2012.

1.1 Monitoring Programs

The VOC Monitoring Program was originally designed to monitor transuranic (TRU) mixed waste-related VOC concentrations in ventilation exhaust air (Repository VOC Monitoring). Monitoring for VOCs from within disposal rooms of open/active panels was later incorporated (Disposal Room VOC Monitoring), as well as monitoring of Room 1 within specific filled panels (Ongoing Disposal Room VOC Monitoring). Each program continues to the present time.

The Hydrogen and Methane Monitoring Program was designed to monitor hydrogen and methane concentrations in Panels 3 through 8 as specified in Permit Part 4.6.5 and Permit Attachment N1. This monitoring was implemented for Panel 3 in April 2008 and in May 2009 for Panel 4. Monitoring continues to the present time for Panels 3 and 4.

1.2 Reporting Limits and Qualifier Descriptions

The following terms apply to this report:

Method detection limit (MDL) – The MDL is the limit at which concentrations are measured and reported with 99 percent confidence that the analyte concentration is greater than zero. For target VOCs and additional requested analytes, MDLs were within 0.03 – 0.19 ppbv. Hydrogen and methane MDLs for this reporting period were 14.4 ppmv and 17.45 ppmv, respectively.

Method reporting limit (MRL) – The MRL is the lowest concentration that can be reliably measured and is determined by the analytical laboratory. For this reporting period, the analytical laboratory determination for MRLs is the nominal concentration of the lowest standard used for calibration. For target VOCs and additional requested analytes, the MRL is one ppbv with the exception of one additional requested analyte (i.e., p,m-xylene at two ppbv). The MRL for hydrogen and methane is 50 ppmv. These values are the MRLs for samples not requiring dilutions. The analytical methods allow for adjusting the MRLs to compensate for dilutions, therefore the MRL for carbon tetrachloride is corrected to 100 ppbv for a VOC sample diluted by a factor of 100. The MRL for p,m-xylene is corrected to 200 ppbv for a VOC sample diluted by a factor of 100. The MRLs obtained by the laboratory met the requirements as specified in Permit Attachment N, table N-2, and shown in table 1.

Table 1 – VOC Monitoring Program - Target VOCs and Required MRLs

Target Compound	Required Repository MRL (ppbv)	Required Disposal Room MRL (ppbv)
Carbon Tetrachloride	2	500
Chlorobenzene	2	500
Chloroform	2	500
1,1-Dichloroethylene	5	500
1,2-Dichloroethane	2	500
Methylene Chloride	5	500
1,1,2,2-Tetrachloroethane	2	500
Toluene	5	500
1,1,1-Trichloroethane	5	500

ppbv = parts per billion by volume
MRL = maximum method reporting limit for undiluted samples

Qualifiers (data flags) are used for data in sample analysis data packages and are reflected in reports. These qualifiers are described as follows:

QUALIFIER DESCRIPTIONS

U Indicates target analyte was analyzed for but not detected above MDL.

J Estimated value; the target analyte was detected at a concentration below the MRL but above the MDL.

B This flag is used when the analyte is found in the associated laboratory method blank, as well as in the sample. It indicates possible/probable blank contamination and warns the data user to take appropriate action. This flag must be used for a tentatively identified compound (TIC) as well as for a positively identified target analyte.

R Sample results are unusable due to the quality of the data generated because certain criteria were not met. The analyte may or may not be present in the sample. This qualifier may also be used for data anomalies.

Q Results are useable, but were not associated with analyses that met all quality assurance/quality control (QA/QC) requirements for precision, accuracy, or completeness.

NJ Presumptive evidence of the presence of the material at an estimated quantity. Only used for TICs.

2.0 REPOSITORY VOC MONITORING

Sampling for repository VOC monitoring is conducted twice per week at two ambient air sampling locations designated as repository VOC monitoring stations, in accordance with Permit Attachment N, section N-3. The stations are identified as Station VOC-A, sample inlet located in the E-300 drift downstream from the Underground Hazardous Waste Disposal Unit (Underground HWDU) designated as Panel 1, and Station VOC-B, sample inlet located upstream from the most recently activated Underground HWDU.

The location of Station VOC-A is not expected to change from the present location as waste disposal operations continue. Concentrations found at Station VOC-A represent both the VOCs in the mine air not attributable to disposed TRU mixed waste plus any releases of VOCs from the TRU mixed waste in the repository. As new Underground HWDUs are opened and closed, Station VOC-A will continue to reflect non-waste-emplacement-related VOCs plus TRU mixed waste emissions from the current open/active Underground HWDUs and closed/filled Underground HWDUs.

Detections of VOCs for Station VOC-B represent the concentrations in the ventilation air found in the mine before passing through the areas of the repository containing TRU mixed waste. The VOCs detected for this location are considered to be non-waste-emplacement-related concentrations. As TRU mixed waste is placed in new Underground HWDUs, the location of Station VOC-B is changed as needed to sample the ambient air upstream from Underground HWDUs that are receiving TRU mixed waste.

The measured concentrations of Permit-specified target analytes collected at Stations VOC-A and VOC-B are normalized to assess the concentration of VOCs attributable to the TRU mixed waste disposed of at the WIPP facility (i.e., Underground HWDU VOC emission concentration). Section 2.2 describes the normalization process and how running annual average of Underground HWDU VOC emission concentrations are calculated.

For repository VOC monitoring, the target compounds and their respective concentrations of concern (COC), as specified in Permit Part 4, table 4.6.2.3, are shown in table 2. The Permittees are required to notify the Secretary of the New Mexico Environment Department (NMED), as specified in Permit Part 4, Permit condition 4.6.2.3, should emission concentrations between the two stations or the running annual average concentrations exceed the Permit-specified COC.

2.1 Repository VOC Monitoring Results

The repository VOC monitoring results for this reporting period are discussed in section 2.3 and summarized in table 2. The individual monitoring results for original samples, emission concentrations, and comparisons to the COC for each sample set collected at Stations VOC-A and VOC-B are provided in attachment 1.

2.2 Normalization and Usage Rules for Repository VOC Monitoring Reporting

Analytical results not qualified as "U" are normalized to the typical operating conditions, in accordance with Permit Attachment N, section N-3e(1). The normalized concentration of each target VOC detected at Station VOC-B is subtracted from the normalized concentration detected at Station VOC-A and the difference is the Underground HWDU VOC emission concentration. The resulting concentration for each target analyte is compared to its COC listed in the WIPP Resource Conservation and Recovery Act (RCRA) Permit Part 4, table 4.6.2.3.

Results qualified as "U" indicate that the laboratory's quantitative results were not greater than the MDL and are assigned a value of zero for determination of emission concentrations.

Analytical results qualified as "J" indicate that the laboratory's quantitative results were at a concentration greater than the MDL but less than the laboratory's MRL. Results qualified as "J" are normalized but are considered to be estimated values and are assigned a value of zero for determination of emission concentrations.

When the normalized concentration at Station VOC-A is less than Station VOC-B, the emission concentration is reported as zero.

The running annual average concentration for each target VOC is determined, in accordance with Permit Attachment N section N-3e(1), by averaging the Underground HWDU VOC emission concentration for each target VOC for each sampling event with concentrations for the previous 12 months. The running annual average concentrations are compared to the COC listed in Permit Part 4, table 4.6.2.3, and shown in table 2.

2.3 Discussion of Repository VOC Monitoring Results

For the reporting period, there were 52 sample sets (104 original samples from Stations VOC-A and VOC-B) analyzed for each of the nine target compounds. The emission concentration for each individual sample set was determined and compared to the COC for each of the nine target compounds and reported in attachment 1. The results for sample numbers 7176 and 7252, collected at Station VOC-B on 5/8/2012 and 6/6/2012, respectively, were assigned an "R" qualifier (i.e., rejected). Measurable concentrations of carbon tetrachloride and chloroform were detected but do not represent typical background levels. Therefore, results of all target VOCs in these samples were conservatively assigned a value of zero (see shaded sample sets in attachment 1). Table 2 and attachment 1 show that none of the 52 individual sample sets showed an exceedance of a COC.

Table 2 also shows that during this reporting period, none of the target VOC running annual averages exceeded the COC. Remedial action, as described in Permit Part 4, Permit condition 4.6.2.4, was not required during this reporting period.

Three field duplicate samples were collected at each repository VOC monitoring station, for a total of six field duplicates. Normalized results are reported in attachment 6D and field precision for the VOC Monitoring Program is discussed in section 7.1.

Table 2 – Summary of Repository VOC Monitoring Results

Target Compound	Running Annual Average Max. Value (ppbv)	Emission Concentration Max. Value (ppbv)	COC (ppbv)	No. of Exceedances
Carbon Tetrachloride	187.66	461.70	960	0
Chlorobenzene	0	0	220	0
Chloroform	16.18	38.43	180	0
1,1-Dichloroethylene	0	0	100	0
1,2-Dichloroethane	0	0	45	0
Methylene Chloride	3.01	14.45	1930	0
1,1,2,2-Tetrachloroethane	0	0	50	0
Toluene	0	0	190	0
1,1,1-Trichloroethane	30.53	72.52	590	0

ppbv = parts per billion by volume
COC = concentration of concern

3.0 DISPOSAL ROOM VOC MONITORING

Collection and analysis of VOC samples from each room containing waste in an active Underground HWDU began on November 20, 2006, and continues to the present time. Sampling frequency is conducted in accordance with Permit Attachment N, section N-3d(2). For this reporting period, the frequency was once every two weeks for all sampling locations. Room-based limits and action levels, as specified in Permit Part 4, tables 4.4.1 and 4.6.3.2 respectively, are shown in table 3. Sample locations are determined in accordance with Permit Attachment N, section N-3a(2). Results from disposal room VOC monitoring samples are presented in section 3.1 and are compared to the action levels and room-based limits.

The number of disposal room VOC monitoring locations increases as waste emplacement proceeds from room to room. As waste is placed into a room, VOC monitoring in that room commences at the exhaust end of the room. After the room is filled, VOC monitoring begins at a second location in that room at the inlet side. When the next room receives waste, the process is repeated. All rooms within an Underground HWDU that receive waste are actively monitored until waste emplacement in the Underground HWDU is complete. At that point, VOC monitoring in that Underground HWDU will be reduced to Room 1 (i.e., ongoing disposal room VOC monitoring) unless an explosion-isolation wall is installed in the panel. Sample location data are identified by the source panel number, room number, and intake (I) or exhaust (E) function. For example, the Panel 6 Room 7 exhaust location is P6R7E.

3.1 Disposal Room VOC Monitoring Results

During this reporting period, 69 original samples (95 total samples) were collected for disposal room VOC monitoring in Panel 6. Original sample results were compared to the levels as shown in table 3 to determine if any action levels or room-based limits were exceeded. Associated data for original samples are reported in attachment 2.

The original sample results for Panel 6 are summarized in table 3. Results for field duplicate samples are reported in attachment 6D and field precision for the VOC Monitoring Program is discussed in section 7.1.

Table 3 – Summary of Disposal Room VOC Monitoring Results

Target Compound	Maximum Detected Value (ppmv)	Location of Maximum Detected Value	50% Action Level (ppmv)	95% Action Level (ppmv)	Room-based Limits (ppmv)	No. of Exceedances
Panel 6						
Carbon Tetrachloride	535	P6R7E	4,813	9,145	9,625	0
Chlorobenzene	<MDL	N/A	6,500	12,350	13,000	0
Chloroform	29	P6R7E	4,965	9,433	9,930	0
1,1-Dichloroethylene	<MDL	N/A	2,745	5,215	5,490	0
1,2-Dichloroethane	<MDL	N/A	1,200	2,280	2,400	0
Methylene Chloride	3.1 J	P6R7I	50,000	95,000	100,000	0
1,1,2,2-Tetrachloroethane	<MDL	N/A	1,480	2,812	2,960	0
Toluene	0.05 J	P6R6E	5,500	10,450	11,000	0
1,1,1-Trichloroethane	79	P6R7E	16,850	32,015	33,700	0

ppmv = parts per million by volume
MDL = method detection limit
J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL)
N/A = not applicable

3.2 Discussion of Disposal Room VOC Monitoring Results

During this reporting period, only Panel 6 received TRU waste. The highest concentration for any compound in any sample was carbon tetrachloride at a maximum value of 535 ppmv (table 3). All maximum concentrations were significantly below the 50 percent action level for each compound. All data were validated in accordance with Permit Attachment N, section N-5d.

3.3 Waste Disposal Activities

Waste disposal progress determines which room-based VOC monitoring locations are sampled. As soon as a room receives waste, it is subject to monitoring at one location (exhaust side). When waste disposal activities are complete in the disposal room, the exhaust side continues to be monitored and the inlet side is added to the sampling schedule. On January 1, 2012, active contact-handled (CH) waste emplacement was occurring in Panel 6 Room 6, and active remote-handled (RH) waste emplacement was occurring in Panel 6 Room 5. At this stage, Panel 6 Room 7 had two monitoring locations (exhaust and inlet), while Panel 6 Rooms 6 and 5 each had one monitoring location (exhaust). On June 30, 2012, active CH waste emplacement was occurring in Panel 6 Room 5, and active RH waste emplacement was occurring in Panel 6 Room 4. At this stage, Panel 6 Rooms 7 and 6 had two monitoring locations (exhaust and inlet) and Panel 6 Rooms 5 and 4 had one monitoring location (exhaust).

4.0 ONGOING DISPOSAL ROOM VOC MONITORING

After completion of waste emplacement, monitoring for VOCs in Room 1 of Panels 3 through 8 will occur until final panel closure, unless an explosion-isolation wall is installed in the panel per Permit Attachment N, section N-3a(3). This ongoing disposal room VOC monitoring was conducted in Panels 3 and 4 during this reporting period. Panel 5 is a filled panel that does not require monitoring since an explosion-isolation wall is installed, Panel 6 is the current active panel, and Panels 7 and 8 are not yet available for TRU waste disposal. Monitoring was conducted at the exhaust side of Room 1 in Panels 3 and 4 at a frequency of once per month for a total of six original samples for each panel. A field duplicate sample was collected at the same frequency for each panel. Sample location data are identified by the source panel number, room number, and intake (I) or exhaust (E) function. For example, the Panel 3 Room 1 exhaust location is P3R1E.

The original sample results for Panels 3 and 4 are summarized in table 4. Sample results were well below action levels and remedial action was not required as described in Permit Part 4, Permit condition 4.6.3.3. The associated data for original samples are reported in attachment 3. Results for field duplicate samples are reported in attachment 6D and field precision for the VOC Monitoring Program is discussed in section 7.1.

Table 4 – Summary of Ongoing Disposal Room VOC Monitoring Results

Target Compound	Maximum Detected Value (ppmv)	50% Action Level (ppmv)	95% Action Level (ppmv)	Room-based Limits (ppmv)	No. of Exceedances
Panel 3					
Carbon Tetrachloride	4.9	4,813	9,145	9,625	0
Chlorobenzene	<MDL	6,500	12,350	13,000	0
Chloroform	0.15	4,965	9,433	9,930	0
1,1-Dichloroethylene	0.05 J	2,745	5,215	5,490	0
1,2-Dichloroethane	0.01 J	1,200	2,280	2,400	0
Methylene Chloride	1.3	50,000	95,000	100,000	0
1,1,2,2-Tetrachloroethane	<MDL	1,480	2,812	2,960	0
Toluene	0.09	5,500	10,450	11,000	0
1,1,1-Trichloroethane	4.5	16,850	32,015	33,700	0
Panel 4					
Carbon Tetrachloride	887	4,813	9,145	9,625	0
Chlorobenzene	<MDL	6,500	12,350	13,000	0
Chloroform	67	4,965	9,433	9,930	0
1,1-Dichloroethylene	<MDL	2,745	5,215	5,490	0
1,2-Dichloroethane	<MDL	1,200	2,280	2,400	0
Methylene Chloride	31	50,000	95,000	100,000	0
1,1,2,2-Tetrachloroethane	<MDL	1,480	2,812	2,960	0
Toluene	1.4 J	5,500	10,450	11,000	0
1,1,1-Trichloroethane	160	16,850	32,015	33,700	0

ppmv = parts per million by volume
MDL = method detection limit
J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL)

5.0 NON-TARGETS

The Permittees are required to evaluate non-target VOCs (including additional requested analytes and/or TICs) in VOC Monitoring Program compliance samples to determine if the non-targets qualify for addition to the target analyte list(s) as specified by Permit Attachment N, section N-3b. Additional requested analytes are comprised of TICs that previously met the criteria to be added to the target analyte list that have not been assigned a COC or have been added for quantitation for other purposes. The TICs and additional requested analytes that meet the following criteria will be added to or maintained on the target analyte list(s) for repository, disposal room, and ongoing disposal room VOC monitoring, unless the Permittees can justify the exclusion from the target analyte list(s):

1) Listed in Appendix VIII of 40 *Code of Federal Regulations* (CFR) Part 261 (incorporated by reference in 20.4.1.200 of the New Mexico Administrative Code); and

2) Detected in 10 percent or more of the VOC monitoring samples (exclusive of those collected from Station VOC-B).

For the 12-month timeframe from July 1, 2011 to June 30, 2012, non-targets were evaluated in original VOC samples (excluding VOC-B) to determine if they were detected in a minimum of 10 percent of the samples and listed in Appendix VIII of 40 CFR Part 261. After evaluation of non-targets in 110 original VOC samples for the previous reporting period (see Semi-annual VOC, Hydrogen, and Methane Data Summary Report for Reporting Period July 1, 2011 through December 31, 2011) and 133 samples in this report for a total of 243 samples for the 12-month period, it was determined that 1,1,2-trichloro-1,2,2-trifluoroethane, tetrachloroethylene, trichloroethylene, and trichloromonofluoromethane meet the criteria for addition to the target analyte list(s). Excluding 1,1,2-trichloro-1,2,2-trifluoroethane, these compounds were previously added to the laboratory's target analyte list as additional requested analytes.

A facility emission rate (source term) for VOCs present in TRU mixed waste is modeled from measured concentrations in the waste. The relative contribution of each VOC to overall risk is calculated from the source term using a concentration/toxicity screening procedure. The revised risk criteria indicate 1,1,2-trichloro-1,2,2-trifluoroethane and tetrachloroethylene contribute less than one percent of the risk and are detected in HWDU emissions at low concentrations, therefore these two compounds are being excluded from the laboratory's target analyte list. Trichloromonofluoromethane was not on the list of VOCs that were analyzed in waste headspace volumes from 1999 to 2010 and therefore a concentration/toxicity screen has not been performed for this compound. The HWDU emission concentration running annual average, as of 6/30/2012, is less than 0.5 ppbv. In addition, the U.S. Environmental Protection Agency Integrated Risk Information System (IRIS) database does not indicate any specific risk factor for cancer and non-cancer effects; therefore this compound is being excluded from the laboratory's target analyte list. Trichloroethylene is being retained on the

laboratory's target analyte list as an additional requested analyte since it is a qualifying compound and there is no justification for exclusion at this time.

To gain a better understanding of potential concentrations and associated risk, trichloroethylene, tetrachloroethylene, and benzene were included on the laboratory quantitation list as additional requested analytes starting with samples collected on 1/25/2011. Five other compounds (methyl chloride (chloromethane), trans-1,2-dichloroethylene, 1,2,4-trimethylbenzene, p,m-xylene, and trichloromonofluoromethane) were also included in the laboratory quantitation list as additional requested analytes. These five compounds were added beginning with samples collected on 5/3/2011. None of the added analytes have an associated COC.

The results for these additional requested analytes in original samples are reported in attachment 4 and summarized in table 5. The results for TICs in original samples are also listed in attachment 4. The additional requested analytes and TICs reported in attachment 4 are not normalized.

Table 5 – Summary of Additional Requested Analytes

Additional Requested Analytes	CAS Number	Maximum Station VOC-A Detected Value (ppbv)	Maximum Disposal Room Detected Value (ppbv)*	Maximum Disposal Room Detection Location
Trichloroethylene	79-01-6	95.58	253,604.52	P6R7E
Tetrachloroethylene	127-18-4	12.92	68,168.79	P6R7E
Benzene	71-43-2	1.18	22.32 J	P3R1E
Chloromethane	74-87-3	3.24 J	2,799.36 J	P4R1E
trans-1,2-Dichloroethylene	156-60-5	< MDL	< MDL	N/A
1,2,4-Trimethylbenzene	95-63-6	0.20 J	0.25 J	P6R5E
p,m-Xylene	106-42-3, 108-38-3	1.58 J	124.20 J	P3R1E
Trichloromonofluoromethane	75-69-4	4.59 J	4,024.08 J	P4R1E

ppbv = parts per billion by volume
MDL = method detection limit
J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL)
N/A = not applicable
* Includes ongoing disposal room VOC monitoring samples

6.0 HYDROGEN AND METHANE MONITORING

Monitoring of hydrogen and methane within filled Panels 3 through 8 is required in accordance with Permit Part 4, Permit condition 4.6.5.1 and Permit Attachment N1. A filled panel is an Underground HWDU that will no longer receive waste for emplacement. Monitoring is required until final panel closure, unless an explosion-isolation wall is installed. Sampling frequency is monthly unless action level 1 (shown in table 6) is exceeded, in which case the sampling frequency would increase to weekly.

Hydrogen and methane monitoring required by Permit Attachment N1 was implemented in April 2008. Two sample head locations for each monitored room of a panel correspond to intake and exhaust locations. Bulkheads separate Room 1 from the main access drift and the bulkhead areas also contains sampling points on both sides (waste [W] and accessible [A]). Sample data are identified by the source panel number, room number or "B" for bulkhead, and intake (I) or exhaust (E) function. For example, the Panel 3 Room 7 exhaust location is P3R7E. Similarly, Panel 3 Exhaust Bulkhead's Waste side is coded P3EBW. This report only includes samples collected at 14 locations in Panel 3 and at 16 locations in Panel 4 from January 1, 2012 through June 30, 2012.

The sample locations determined to have unusable sampling lines are as follows:

- P3R7I and P3R1I on July 14, 2008
- P3R7E on August 30, 2010
- P3R6I on September 22, 2010
- P4R4E on April 7, 2011
- P4R6E on December 13, 2011
- P4R5E on August 14, 2012 (not impactive to results for this reporting period)

The P3IBW sampling line was determined to be unusable on April 21, 2010, and was replaced and sampling resumed on May 25, 2010. Panel 5 is a filled panel that does not require monitoring since an explosion-isolation wall is installed, Panel 6 is the current active panel, and Panels 7 and 8 are not yet available for TRU waste disposal.

A total of 84 original samples (90 total samples) were collected in Panel 3, and 96 original samples (102 total samples) were collected in Panel 4 from January 1, 2012 through June 30, 2012. Samples were collected using sub-atmospheric sampling methods; thus, a pressure dilution was performed by the analytical lab prior to analysis. The maximum detected value for an original sample was 759.70 ppmv for hydrogen. This detection is considerably lower than the action levels (less than 19 percent of action level 1 and less than 9.5 percent of action level 2). None of the samples yielded methane detections thus flagged with a “U” qualifier. Associated data for original samples are reported in attachment 5. Original sample results are summarized in table 6. Field duplicate sample results are reported in attachment 7 and field precision for the Hydrogen and Methane Monitoring Program is discussed in section 7.2.

Table 6 – Summary of Hydrogen and Methane Monitoring Results

Target Compound	Maximum Detected Value (ppmv)	Location of Maximum Detected Value	Action Level 1 (ppmv)	Action Level 2 (ppmv)	No. of Exceedances
Panel 3					
Hydrogen	60.96 J	P3R2E	4,000	8,000	0
Methane	< MDL	N/A	5,000	10,000	0
Panel 4					
Hydrogen	759.70	P4R7E	4,000	8,000	0
Methane	< MDL	N/A	5,000	10,000	0

ppmv = parts per million by volume
MDL = method detection limit
J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL)
N/A = not applicable

7.0 RESULTS OF PROGRAM OBJECTIVES

The electronic data deliverables (EDDs) submitted by the analytical laboratory are required to be reviewed within five calendar days of receipt. For all samples collected during this reporting period, all EDDs were reviewed within the five calendar day window.

The data package validation is required to be completed within 14 calendar days of receipt for packages that do not include data that exceed concentrations of concern or action levels, and within five calendar days of receipt for packages that do contain data that exceeds concentrations of concern or action levels. During this reporting period, all data were validated within the required time period.

A comprehensive QA/QC program is an integral part of the VOC and hydrogen and methane monitoring effort. A number of QA/QC analyses are performed, including laboratory control samples (LCS), laboratory method blanks, field duplicates, and laboratory duplicate analyses of samples and LCS (i.e., LCS duplicate [LCSD]). The laboratory QA/QC analyses indicate that the laboratory was performing within specifications and was capable of detecting and quantifying the target analytes when they were present. The analytical laboratory used for analyses of compliance monitoring samples during this reporting period performed analyses under an established QA/QC program. Results of QA/QC analyses and completeness for VOCs and hydrogen and methane are discussed in sections 7.1 and 7.2 respectively.

7.1 VOC QA/QC Analyses and Completeness

The QA/QC analyses and completeness results indicate that the VOC data collected during this reporting period met the program objectives and the data are accurate and defensible. The following is a discussion of the results.

Attachment 6A (VOCs – Precision of Laboratory Sample Duplicates) shows that during the reporting period, laboratory sample duplicates met the technical acceptance

criterion (≤25 relative percent difference [RPD]) for precision, which is only applicable if one or both values are not flagged "U" or "J."

Attachment 6B (VOCs – Precision/Accuracy of Laboratory Control Samples) shows that during the reporting period, 100 percent of LCS/LCSD results met the technical acceptance criteria for precision (≤25 RPD) and accuracy (60-140 percent recovery). LCS/LCSD are identified as blank spike/blank spike duplicate (BS/BSD) in the Permit.

Attachment 6C (VOCs – Laboratory Method Blanks) shows that target compound concentrations in each method blank met the contract-specified blank technical acceptance criterion (i.e., all target analytes <0.5 ppbv).

Attachment 6D (VOCs – Field Duplicate Precision) shows the results of field duplicates collected during this reporting period. Six field duplicates were collected at repository VOC monitoring locations, 26 at disposal room VOC monitoring locations, and 12 while conducting the ongoing disposal room VOC monitoring. The field duplicates met the technical acceptance criterion (≤35 RPD) with the exception of four disposal room VOC monitoring field duplicate samples. The sample sets that contained data that did not meet criterion are shaded in attachment 6D. A “Q” flag appears next to the sample ID for the VOCs that did not meet the criterion. All other field duplicates met the RPD criteria of ≤35, which is only applicable if one or both values are not flagged "U" or "J." The required completeness of valid data (≥95 percent) was maintained; therefore, further action was not required.

Completeness is defined as the percentage of the ratio of the number of valid sample results received (i.e., those that meet data quality objectives) versus the total number of samples collected. Completeness may be affected, for example, by sample loss or destruction during shipping, by laboratory sample handling errors, or by rejection of analytical data during data validation. Field duplicates, with a prescribed frequency of at least 5 percent, are included in the total. The QA objective (i.e., goal) for the program is a completeness of 95 percent or greater. During this reporting period, a total of 110 repository VOC monitoring samples (includes six field duplicates), 95 disposal room VOC monitoring samples (includes 26 field duplicates), and 24 ongoing disposal room VOC monitoring samples (includes 12 field duplicates) were obtained for a total of 229 samples collected. Four field duplicates did not meet the technical acceptance criteria. The overall completeness for the reporting period was 98 percent.

7.2 Hydrogen and Methane QA/QC Analyses and Completeness

The QA/QC analyses and completeness results indicate that the hydrogen and methane data collected for this reporting period met the program objectives and the data are accurate and defensible. The following is a discussion of the results.

Attachment 7 shows that during the reporting period:

- 100 percent of the LCS/LCSD results met the technical acceptance criteria for precision (≤25 RPD) and accuracy (70-130 percent recovery).

- All results for both hydrogen and methane met the blank technical acceptance criterion (i.e., ≤ MDL).

- 100 percent of the laboratory sample duplicates met the technical acceptance criterion (≤25 RPD) for precision.

- All 12 field duplicates met the RPD criteria of ≤35, which is only applicable if one or both values are not flagged "U" or "J."

Completeness is defined as the percentage of the ratio of the number of valid sample results received (i.e., those which meet data quality objectives) versus the total number of samples collected. Completeness may be affected, for example, by sample loss or destruction during shipping, by laboratory sample handling errors, or by rejection of analytical data during data validation. Field duplicates, with a prescribed frequency of at least 5 percent, are included in the total. The QA objective (i.e., goal) for the program is a completeness of 95 percent or greater. During this reporting period, a total of 192 samples (includes 12 field duplicates) were collected for hydrogen and methane analysis. The laboratory provided valid results for all the samples that were submitted. The completeness for the reporting period was 100 percent.

8.0 REPORTING OF OTHER NONCOMPLIANCE

Permit Part 1, Permit condition 1.7.14 addresses the reporting of other instances of noncompliance not otherwise required to be reported pursuant to Permit Part 1, Permit conditions 1.7.10 through 1.7.13. Permit condition 1.7.14 requires that this information be reported to the NMED Secretary annually in October with the submittal of monitoring reports. Beginning with the Semi-annual VOC Data Summary Report of October 2008, other noncompliance information has been submitted with semi-annual reports due in October. These semi-annual reports will continue to be the means for reporting other noncompliance. During the period from July 1, 2011 to June 30, 2012, no other known noncompliances that have not previously been reported in accordance with specific permit conditions have occurred.

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
1/3/2012	6833	1/11/2012	9	6832	1/11/2012	1	1,1,1-Trichloroethane	63.82*	U	63.82	590
1/3/2012	6833	1/11/2012	9	6832	1/11/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
1/3/2012	6833	1/11/2012	9	6832	1/11/2012	1	1,1-Dichloroethylene	3.99* J	U	0	100
1/3/2012	6833	1/11/2012	9	6832	1/11/2012	1	1,2-Dichloroethane	U	U	0	45
1/3/2012	6833	1/11/2012	9	6832	1/11/2012	1	Carbon Tetrachloride	454.68*	U	454.68	960
1/3/2012	6833	1/11/2012	9	6832	1/11/2012	1	Chlorobenzene	U	U	0	220
1/3/2012	6833	1/11/2012	9	6832	1/11/2012	1	Chloroform	38.43*	U	38.43	180
1/3/2012	6833	1/11/2012	9	6832	1/11/2012	1	Methylene Chloride	10.81* J	0.13* J	0	1930
1/3/2012	6833	1/11/2012	9	6832	1/11/2012	1	Toluene	U	0.50* J	0	190
1/4/2012	6839	1/11/2012	2	6838	1/11/2012	1	1,1,1-Trichloroethane	26.86*	U	26.86	590
1/4/2012	6839	1/11/2012	2	6838	1/11/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
1/4/2012	6839	1/11/2012	2	6838	1/11/2012	1	1,1-Dichloroethylene	U	U	0	100
1/4/2012	6839	1/11/2012	2	6838	1/11/2012	1	1,2-Dichloroethane	U	U	0	45
1/4/2012	6839	1/11/2012	2	6838	1/11/2012	1	Carbon Tetrachloride	128.75*	U	128.75	960
1/4/2012	6839	1/11/2012	2	6838	1/11/2012	1	Chlorobenzene	U	U	0	220
1/4/2012	6839	1/11/2012	2	6838	1/11/2012	1	Chloroform	9.52*	U	9.52	180
1/4/2012	6839	1/11/2012	2	6838	1/11/2012	1	Methylene Chloride	4.09*	U	4.09	1930
1/4/2012	6839	1/11/2012	2	6838	1/11/2012	1	Toluene	0.62* J	0.44* J	0	190
1/10/2012	6843	1/18/2012	2	6844	1/18/2012	1	1,1,1-Trichloroethane	25.37*	U	25.37	590
1/10/2012	6843	1/18/2012	2	6844	1/18/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
1/10/2012	6843	1/18/2012	2	6844	1/18/2012	1	1,1-Dichloroethylene	0.53* J	U	0	100
1/10/2012	6843	1/18/2012	2	6844	1/18/2012	1	1,2-Dichloroethane	U	U	0	45
1/10/2012	6843	1/18/2012	2	6844	1/18/2012	1	Carbon Tetrachloride	140.47*	0.11* J	140.47	960
1/10/2012	6843	1/18/2012	2	6844	1/18/2012	1	Chlorobenzene	U	U	0	220
1/10/2012	6843	1/18/2012	2	6844	1/18/2012	1	Chloroform	11.05*	U	11.05	180
1/10/2012	6843	1/18/2012	2	6844	1/18/2012	1	Methylene Chloride	3.98*	U	3.98	1930
1/10/2012	6843	1/18/2012	2	6844	1/18/2012	1	Toluene	0.66* J	0.65* J	0	190
1/11/2012	6845	1/18/2012	4	6846	1/18/2012	1	1,1,1-Trichloroethane	42.61*	U	42.61	590
1/11/2012	6845	1/18/2012	4	6846	1/18/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
1/11/2012	6845	1/18/2012	4	6846	1/18/2012	1	1,1-Dichloroethylene	1.04* J	U	0	100
1/11/2012	6845	1/18/2012	4	6846	1/18/2012	1	1,2-Dichloroethane	U	U	0	45
1/11/2012	6845	1/18/2012	4	6846	1/18/2012	1	Carbon Tetrachloride	272.10*	0.13* J	272.1	960
1/11/2012	6845	1/18/2012	4	6846	1/18/2012	1	Chlorobenzene	U	U	0	220
1/11/2012	6845	1/18/2012	4	6846	1/18/2012	1	Chloroform	22.40*	U	22.4	180
1/11/2012	6845	1/18/2012	4	6846	1/18/2012	1	Methylene Chloride	6.87*	U	6.87	1930
1/11/2012	6845	1/18/2012	4	6846	1/18/2012	1	Toluene	0.62* J	0.32* J	0	190

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
1/17/2012	6871	1/25/2012	2	6872	1/25/2012	1	1,1,1-Trichloroethane	30.90*	U	30.9	590
1/17/2012	6871	1/25/2012	2	6872	1/25/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
1/17/2012	6871	1/25/2012	2	6872	1/25/2012	1	1,1-Dichloroethylene	U	U	0	100
1/17/2012	6871	1/25/2012	2	6872	1/25/2012	1	1,2-Dichloroethane	U	U	0	45
1/17/2012	6871	1/25/2012	2	6872	1/25/2012	1	Carbon Tetrachloride	152.67*	0.18* J	152.67	960
1/17/2012	6871	1/25/2012	2	6872	1/25/2012	1	Chlorobenzene	U	U	0	220
1/17/2012	6871	1/25/2012	2	6872	1/25/2012	1	Chloroform	9.89*	U	9.89	180
1/17/2012	6871	1/25/2012	2	6872	1/25/2012	1	Methylene Chloride	3.48*	0.14* J	3.48	1930
1/17/2012	6871	1/25/2012	2	6872	1/25/2012	1	Toluene	0.40* J	0.24* J	0	190
1/18/2012	6873	1/25/2012	4	6874	1/25/2012	1	1,1,1-Trichloroethane	45.43*	U	45.43	590
1/18/2012	6873	1/25/2012	4	6874	1/25/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
1/18/2012	6873	1/25/2012	4	6874	1/25/2012	1	1,1-Dichloroethylene	U	U	0	100
1/18/2012	6873	1/25/2012	4	6874	1/25/2012	1	1,2-Dichloroethane	U	U	0	45
1/18/2012	6873	1/25/2012	4	6874	1/25/2012	1	Carbon Tetrachloride	284.50*	0.14* J	284.5	960
1/18/2012	6873	1/25/2012	4	6874	1/25/2012	1	Chlorobenzene	U	U	0	220
1/18/2012	6873	1/25/2012	4	6874	1/25/2012	1	Chloroform	24.48*	U	24.48	180
1/18/2012	6873	1/25/2012	4	6874	1/25/2012	1	Methylene Chloride	7.29*	U	7.29	1930
1/18/2012	6873	1/25/2012	4	6874	1/25/2012	1	Toluene	0.52* J	0.39* J	0	190
1/24/2012	6899	2/1/2012	3	6900	2/1/2012	1	1,1,1-Trichloroethane	38.17*	U	38.17	590
1/24/2012	6899	2/1/2012	3	6900	2/1/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
1/24/2012	6899	2/1/2012	3	6900	2/1/2012	1	1,1-Dichloroethylene	1.74* J	U	0	100
1/24/2012	6899	2/1/2012	3	6900	2/1/2012	1	1,2-Dichloroethane	U	U	0	45
1/24/2012	6899	2/1/2012	3	6900	2/1/2012	1	Carbon Tetrachloride	229.41*	0.22* J	229.41	960
1/24/2012	6899	2/1/2012	3	6900	2/1/2012	1	Chlorobenzene	U	U	0	220
1/24/2012	6899	2/1/2012	3	6900	2/1/2012	1	Chloroform	19.21*	U	19.21	180
1/24/2012	6899	2/1/2012	3	6900	2/1/2012	1	Methylene Chloride	7.42*	0.16* J	7.42	1930
1/24/2012	6899	2/1/2012	3	6900	2/1/2012	1	Toluene	0.58* J	0.38* J	0	190
1/25/2012	6901	2/1/2012	3	6902	2/1/2012	1	1,1,1-Trichloroethane	36.08*	U	36.08	590
1/25/2012	6901	2/1/2012	3	6902	2/1/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
1/25/2012	6901	2/1/2012	3	6902	2/1/2012	1	1,1-Dichloroethylene	U	U	0	100
1/25/2012	6901	2/1/2012	3	6902	2/1/2012	1	1,2-Dichloroethane	U	U	0	45
1/25/2012	6901	2/1/2012	3	6902	2/1/2012	1	Carbon Tetrachloride	166.27*	0.13* J	166.27	960
1/25/2012	6901	2/1/2012	3	6902	2/1/2012	1	Chlorobenzene	U	U	0	220
1/25/2012	6901	2/1/2012	3	6902	2/1/2012	1	Chloroform	12.53*	U	12.53	180
1/25/2012	6901	2/1/2012	3	6902	2/1/2012	1	Methylene Chloride	6.71*	U	6.71	1930
1/25/2012	6901	2/1/2012	3	6902	2/1/2012	1	Toluene	0.85* J	0.41* J	0	190

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
1/31/2012	6911	2/6/2012	1	6910	2/6/2012	1	1,1,1-Trichloroethane	15.50*	U	15.5	590
1/31/2012	6911	2/6/2012	1	6910	2/6/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
1/31/2012	6911	2/6/2012	1	6910	2/6/2012	1	1,1-Dichloroethylene	U	U	0	100
1/31/2012	6911	2/6/2012	1	6910	2/6/2012	1	1,2-Dichloroethane	U	U	0	45
1/31/2012	6911	2/6/2012	1	6910	2/6/2012	1	Carbon Tetrachloride	74.62*	0.15* J	74.62	960
1/31/2012	6911	2/6/2012	1	6910	2/6/2012	1	Chlorobenzene	U	U	0	220
1/31/2012	6911	2/6/2012	1	6910	2/6/2012	1	Chloroform	5.26*	U	5.26	180
1/31/2012	6911	2/6/2012	1	6910	2/6/2012	1	Methylene Chloride	2.36*	0.14* J	2.36	1930
1/31/2012	6911	2/6/2012	1	6910	2/6/2012	1	Toluene	0.43* J	0.39* J	0	190
2/1/2012	6913	2/6/2012	3	6912	2/6/2012	1	1,1,1-Trichloroethane	40.64*	U	40.64	590
2/1/2012	6913	2/6/2012	3	6912	2/6/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
2/1/2012	6913	2/6/2012	3	6912	2/6/2012	1	1,1-Dichloroethylene	U	U	0	100
2/1/2012	6913	2/6/2012	3	6912	2/6/2012	1	1,2-Dichloroethane	U	U	0	45
2/1/2012	6913	2/6/2012	3	6912	2/6/2012	1	Carbon Tetrachloride	204.93*	0.13* J	204.93	960
2/1/2012	6913	2/6/2012	3	6912	2/6/2012	1	Chlorobenzene	U	U	0	220
2/1/2012	6913	2/6/2012	3	6912	2/6/2012	1	Chloroform	15.30*	U	15.3	180
2/1/2012	6913	2/6/2012	3	6912	2/6/2012	1	Methylene Chloride	7.44*	U	7.44	1930
2/1/2012	6913	2/6/2012	3	6912	2/6/2012	1	Toluene	0.73* J	0.80* J	0	190
2/7/2012	6923	2/14/2012	1.5	6922	2/14/2012	1	1,1,1-Trichloroethane	18.72*	U	18.72	590
2/7/2012	6923	2/14/2012	1.5	6922	2/14/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
2/7/2012	6923	2/14/2012	1.5	6922	2/14/2012	1	1,1-Dichloroethylene	U	U	0	100
2/7/2012	6923	2/14/2012	1.5	6922	2/14/2012	1	1,2-Dichloroethane	U	U	0	45
2/7/2012	6923	2/14/2012	1.5	6922	2/14/2012	1	Carbon Tetrachloride	105.55*	U	105.55	960
2/7/2012	6923	2/14/2012	1.5	6922	2/14/2012	1	Chlorobenzene	U	U	0	220
2/7/2012	6923	2/14/2012	1.5	6922	2/14/2012	1	Chloroform	9.06*	U	9.06	180
2/7/2012	6923	2/14/2012	1.5	6922	2/14/2012	1	Methylene Chloride	3.50*	0.15* J	3.5	1930
2/7/2012	6923	2/14/2012	1.5	6922	2/14/2012	1	Toluene	0.56* J	0.53* J	0	190
2/8/2012	6925	2/14/2012	1.5	6924	2/14/2012	1	1,1,1-Trichloroethane	16.99*	U	16.99	590
2/8/2012	6925	2/14/2012	1.5	6924	2/14/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
2/8/2012	6925	2/14/2012	1.5	6924	2/14/2012	1	1,1-Dichloroethylene	U	U	0	100
2/8/2012	6925	2/14/2012	1.5	6924	2/14/2012	1	1,2-Dichloroethane	U	U	0	45
2/8/2012	6925	2/14/2012	1.5	6924	2/14/2012	1	Carbon Tetrachloride	92.31*	0.14* J	92.31	960
2/8/2012	6925	2/14/2012	1.5	6924	2/14/2012	1	Chlorobenzene	U	U	0	220
2/8/2012	6925	2/14/2012	1.5	6924	2/14/2012	1	Chloroform	7.27*	U	7.27	180
2/8/2012	6925	2/14/2012	1.5	6924	2/14/2012	1	Methylene Chloride	2.98*	0.16* J	2.98	1930
2/8/2012	6925	2/14/2012	1.5	6924	2/14/2012	1	Toluene	0.39* J	0.23* J	0	190

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
2/15/2012	6953	2/23/2012	2	6952	2/23/2012	1	1,1,1-Trichloroethane	29.81*	U	29.81	590
2/15/2012	6953	2/23/2012	2	6952	2/23/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
2/15/2012	6953	2/23/2012	2	6952	2/23/2012	1	1,1-Dichloroethylene	U	U	0	100
2/15/2012	6953	2/23/2012	2	6952	2/23/2012	1	1,2-Dichloroethane	U	U	0	45
2/15/2012	6953	2/23/2012	2	6952	2/23/2012	1	Carbon Tetrachloride	148.02*	0.18* J	148.02	960
2/15/2012	6953	2/23/2012	2	6952	2/23/2012	1	Chlorobenzene	U	U	0	220
2/15/2012	6953	2/23/2012	2	6952	2/23/2012	1	Chloroform	10.22*	U	10.22	180
2/15/2012	6953	2/23/2012	2	6952	2/23/2012	1	Methylene Chloride	4.28*	U	4.28	1930
2/15/2012	6953	2/23/2012	2	6952	2/23/2012	1	Toluene	0.48* J	0.39* J	0	190
2/16/2012	6951	2/23/2012	1	6950	2/23/2012	1	1,1,1-Trichloroethane	15.39*	U	15.39	590
2/16/2012	6951	2/23/2012	1	6950	2/23/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
2/16/2012	6951	2/23/2012	1	6950	2/23/2012	1	1,1-Dichloroethylene	U	U	0	100
2/16/2012	6951	2/23/2012	1	6950	2/23/2012	1	1,2-Dichloroethane	U	U	0	45
2/16/2012	6951	2/23/2012	1	6950	2/23/2012	1	Carbon Tetrachloride	76.36*	0.17* J	76.36	960
2/16/2012	6951	2/23/2012	1	6950	2/23/2012	1	Chlorobenzene	U	U	0	220
2/16/2012	6951	2/23/2012	1	6950	2/23/2012	1	Chloroform	5.93*	U	5.93	180
2/16/2012	6951	2/23/2012	1	6950	2/23/2012	1	Methylene Chloride	2.56*	0.18* J	2.56	1930
2/16/2012	6951	2/23/2012	1	6950	2/23/2012	1	Toluene	0.57* J	0.40* J	0	190
2/21/2012	6977	2/28/2012	4	6978	2/28/2012	1	1,1,1-Trichloroethane	51.06*	U	51.06	590
2/21/2012	6977	2/28/2012	4	6978	2/28/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
2/21/2012	6977	2/28/2012	4	6978	2/28/2012	1	1,1-Dichloroethylene	U	U	0	100
2/21/2012	6977	2/28/2012	4	6978	2/28/2012	1	1,2-Dichloroethane	U	U	0	45
2/21/2012	6977	2/28/2012	4	6978	2/28/2012	1	Carbon Tetrachloride	291.71*	0.25* J	291.71	960
2/21/2012	6977	2/28/2012	4	6978	2/28/2012	1	Chlorobenzene	U	U	0	220
2/21/2012	6977	2/28/2012	4	6978	2/28/2012	1	Chloroform	21.81*	0.19* J	21.81	180
2/21/2012	6977	2/28/2012	4	6978	2/28/2012	1	Methylene Chloride	8.77*	0.25* J	8.77	1930
2/21/2012	6977	2/28/2012	4	6978	2/28/2012	1	Toluene	0.58* J	0.53* J	0	190
2/22/2012	6979	2/28/2012	4	6980	2/28/2012	1	1,1,1-Trichloroethane	62.18*	U	62.18	590
2/22/2012	6979	2/28/2012	4	6980	2/28/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
2/22/2012	6979	2/28/2012	4	6980	2/28/2012	1	1,1-Dichloroethylene	0.63* J	U	0	100
2/22/2012	6979	2/28/2012	4	6980	2/28/2012	1	1,2-Dichloroethane	U	U	0	45
2/22/2012	6979	2/28/2012	4	6980	2/28/2012	1	Carbon Tetrachloride	425.35*	0.23* J	425.35	960
2/22/2012	6979	2/28/2012	4	6980	2/28/2012	1	Chlorobenzene	U	U	0	220
2/22/2012	6979	2/28/2012	4	6980	2/28/2012	1	Chloroform	33.36*	0.34* J	33.36	180
2/22/2012	6979	2/28/2012	4	6980	2/28/2012	1	Methylene Chloride	10.72*	0.34* J	10.72	1930
2/22/2012	6979	2/28/2012	4	6980	2/28/2012	1	Toluene	0.94* J	0.36* J	0	190

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
2/28/2012	6989	3/1/2012	3	6988	3/1/2012	1	1,1,1-Trichloroethane	47.84*	U	47.84	590
2/28/2012	6989	3/1/2012	3	6988	3/1/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
2/28/2012	6989	3/1/2012	3	6988	3/1/2012	1	1,1-Dichloroethylene	0.82* J	U	0	100
2/28/2012	6989	3/1/2012	3	6988	3/1/2012	1	1,2-Dichloroethane	U	U	0	45
2/28/2012	6989	3/1/2012	3	6988	3/1/2012	1	Carbon Tetrachloride	271.03*	0.22* J	271.03	960
2/28/2012	6989	3/1/2012	3	6988	3/1/2012	1	Chlorobenzene	U	U	0	220
2/28/2012	6989	3/1/2012	3	6988	3/1/2012	1	Chloroform	22.69*	U	22.69	180
2/28/2012	6989	3/1/2012	3	6988	3/1/2012	1	Methylene Chloride	9.82*	U	9.82	1930
2/28/2012	6989	3/1/2012	3	6988	3/1/2012	1	Toluene	0.82* J	0.48* J	0	190
2/29/2012	6991	3/1/2012	2	6990	3/1/2012	1	1,1,1-Trichloroethane	27.72*	U	27.72	590
2/29/2012	6991	3/1/2012	2	6990	3/1/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
2/29/2012	6991	3/1/2012	2	6990	3/1/2012	1	1,1-Dichloroethylene	U	U	0	100
2/29/2012	6991	3/1/2012	2	6990	3/1/2012	1	1,2-Dichloroethane	U	U	0	45
2/29/2012	6991	3/1/2012	2	6990	3/1/2012	1	Carbon Tetrachloride	155.07*	0.16* J	155.07	960
2/29/2012	6991	3/1/2012	2	6990	3/1/2012	1	Chlorobenzene	U	U	0	220
2/29/2012	6991	3/1/2012	2	6990	3/1/2012	1	Chloroform	11.87*	U	11.87	180
2/29/2012	6991	3/1/2012	2	6990	3/1/2012	1	Methylene Chloride	4.28*	U	4.28	1930
2/29/2012	6991	3/1/2012	2	6990	3/1/2012	1	Toluene	0.48* J	0.27* J	0	190
3/6/2012	6999	3/13/2012	4	6998	3/13/2012	1	1,1,1-Trichloroethane	56.79*	U	56.79	590
3/6/2012	6999	3/13/2012	4	6998	3/13/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
3/6/2012	6999	3/13/2012	4	6998	3/13/2012	1	1,1-Dichloroethylene	1.86* J	U	0	100
3/6/2012	6999	3/13/2012	4	6998	3/13/2012	1	1,2-Dichloroethane	U	U	0	45
3/6/2012	6999	3/13/2012	4	6998	3/13/2012	1	Carbon Tetrachloride	370.32*	0.28* J	370.32	960
3/6/2012	6999	3/13/2012	4	6998	3/13/2012	1	Chlorobenzene	U	U	0	220
3/6/2012	6999	3/13/2012	4	6998	3/13/2012	1	Chloroform	32.06*	U	32.06	180
3/6/2012	6999	3/13/2012	4	6998	3/13/2012	1	Methylene Chloride	10.19*	0.21* J	10.19	1930
3/6/2012	6999	3/13/2012	4	6998	3/13/2012	1	Toluene	0.66* J	0.3* J	0	190
3/7/2012	7001	3/13/2012	2	7000	3/13/2012	1	1,1,1-Trichloroethane	30.84*	U	30.84	590
3/7/2012	7001	3/13/2012	2	7000	3/13/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
3/7/2012	7001	3/13/2012	2	7000	3/13/2012	1	1,1-Dichloroethylene	U	U	0	100
3/7/2012	7001	3/13/2012	2	7000	3/13/2012	1	1,2-Dichloroethane	U	U	0	45
3/7/2012	7001	3/13/2012	2	7000	3/13/2012	1	Carbon Tetrachloride	154.52*	0.22* J	154.52	960
3/7/2012	7001	3/13/2012	2	7000	3/13/2012	1	Chlorobenzene	U	U	0	220
3/7/2012	7001	3/13/2012	2	7000	3/13/2012	1	Chloroform	11.76*	U	11.76	180
3/7/2012	7001	3/13/2012	2	7000	3/13/2012	1	Methylene Chloride	5.02*	0.16* J	5.02	1930
3/7/2012	7001	3/13/2012	2	7000	3/13/2012	1	Toluene	0.52* J	0.59* J	0	190

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
3/13/2012	7025	3/21/2012	2	7024	3/21/2012	1	1,1,1-Trichloroethane	26.77*	U	26.77	590
3/13/2012	7025	3/21/2012	2	7024	3/21/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
3/13/2012	7025	3/21/2012	2	7024	3/21/2012	1	1,1-Dichloroethylene	U	U	0	100
3/13/2012	7025	3/21/2012	2	7024	3/21/2012	1	1,2-Dichloroethane	U	U	0	45
3/13/2012	7025	3/21/2012	2	7024	3/21/2012	1	Carbon Tetrachloride	149.03*	0.24* J	149.03	960
3/13/2012	7025	3/21/2012	2	7024	3/21/2012	1	Chlorobenzene	U	U	0	220
3/13/2012	7025	3/21/2012	2	7024	3/21/2012	1	Chloroform	11.55*	U	11.55	180
3/13/2012	7025	3/21/2012	2	7024	3/21/2012	1	Methylene Chloride	4.67*	0.18* J	4.67	1930
3/13/2012	7025	3/21/2012	2	7024	3/21/2012	1	Toluene	0.61* J	0.61* J	0	190
3/14/2012	7027	3/21/2012	9	7026	3/21/2012	1	1,1,1-Trichloroethane	72.52*	U	72.52	590
3/14/2012	7027	3/21/2012	9	7026	3/21/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
3/14/2012	7027	3/21/2012	9	7026	3/21/2012	1	1,1-Dichloroethylene	U	U	0	100
3/14/2012	7027	3/21/2012	9	7026	3/21/2012	1	1,2-Dichloroethane	U	U	0	45
3/14/2012	7027	3/21/2012	9	7026	3/21/2012	1	Carbon Tetrachloride	461.70*	0.49* J	461.7	960
3/14/2012	7027	3/21/2012	9	7026	3/21/2012	1	Chlorobenzene	U	U	0	220
3/14/2012	7027	3/21/2012	9	7026	3/21/2012	1	Chloroform	38.08*	U	38.08	180
3/14/2012	7027	3/21/2012	9	7026	3/21/2012	1	Methylene Chloride	14.45*	0.16* J	14.45	1930
3/14/2012	7027	3/21/2012	9	7026	3/21/2012	1	Toluene	U	0.26* J	0	190
3/20/2012	7055	4/2/2012	3	7054	4/2/2012	1	1,1,1-Trichloroethane	24.32*	U	24.32	590
3/20/2012	7055	4/2/2012	3	7054	4/2/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
3/20/2012	7055	4/2/2012	3	7054	4/2/2012	1	1,1-Dichloroethylene	U	U	0	100
3/20/2012	7055	4/2/2012	3	7054	4/2/2012	1	1,2-Dichloroethane	U	U	0	45
3/20/2012	7055	4/2/2012	3	7054	4/2/2012	1	Carbon Tetrachloride	137.04*	U	137.04	960
3/20/2012	7055	4/2/2012	3	7054	4/2/2012	1	Chlorobenzene	U	U	0	220
3/20/2012	7055	4/2/2012	3	7054	4/2/2012	1	Chloroform	10.11*	U	10.11	180
3/20/2012	7055	4/2/2012	3	7054	4/2/2012	1	Methylene Chloride	4.24* J	U	0	1930
3/20/2012	7055	4/2/2012	3	7054	4/2/2012	1	Toluene	0.58* J	0.18* J	0	190
3/21/2012	7057	4/2/2012	3	7056	4/2/2012	1	1,1,1-Trichloroethane	29.37*	U	29.37	590
3/21/2012	7057	4/2/2012	3	7056	4/2/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
3/21/2012	7057	4/2/2012	3	7056	4/2/2012	1	1,1-Dichloroethylene	U	U	0	100
3/21/2012	7057	4/2/2012	3	7056	4/2/2012	1	1,2-Dichloroethane	U	U	0	45
3/21/2012	7057	4/2/2012	3	7056	4/2/2012	1	Carbon Tetrachloride	168.27*	0.13* J	168.27	960
3/21/2012	7057	4/2/2012	3	7056	4/2/2012	1	Chlorobenzene	U	U	0	220
3/21/2012	7057	4/2/2012	3	7056	4/2/2012	1	Chloroform	12.39*	U	12.39	180
3/21/2012	7057	4/2/2012	3	7056	4/2/2012	1	Methylene Chloride	4.99*	U	4.99	1930
3/21/2012	7057	4/2/2012	3	7056	4/2/2012	1	Toluene	0.55* J	0.32* J	0	190

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
3/28/2012	7063	4/11/2012	4	7062	4/11/2012	1	1,1,1-Trichloroethane	45.84*	U	45.84	590
3/28/2012	7063	4/11/2012	4	7062	4/11/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
3/28/2012	7063	4/11/2012	4	7062	4/11/2012	1	1,1-Dichloroethylene	U	U	0	100
3/28/2012	7063	4/11/2012	4	7062	4/11/2012	1	1,2-Dichloroethane	U	U	0	45
3/28/2012	7063	4/11/2012	4	7062	4/11/2012	1	Carbon Tetrachloride	234.09*	0.40* J	234.09	960
3/28/2012	7063	4/11/2012	4	7062	4/11/2012	1	Chlorobenzene	U	U	0	220
3/28/2012	7063	4/11/2012	4	7062	4/11/2012	1	Chloroform	19.62*	U	19.62	180
3/28/2012	7063	4/11/2012	4	7062	4/11/2012	1	Methylene Chloride	8.22*	U	8.22	1930
3/28/2012	7063	4/11/2012	4	7062	4/11/2012	1	Toluene	0.84* J	0.51* J	0	190
3/30/2012	7065	4/11/2012	2	7064	4/11/2012	1	1,1,1-Trichloroethane	25.19*	U	25.19	590
3/30/2012	7065	4/11/2012	2	7064	4/11/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
3/30/2012	7065	4/11/2012	2	7064	4/11/2012	1	1,1-Dichloroethylene	U	U	0	100
3/30/2012	7065	4/11/2012	2	7064	4/11/2012	1	1,2-Dichloroethane	U	U	0	45
3/30/2012	7065	4/11/2012	2	7064	4/11/2012	1	Carbon Tetrachloride	134.45*	0.12* J	134.45	960
3/30/2012	7065	4/11/2012	2	7064	4/11/2012	1	Chlorobenzene	U	U	0	220
3/30/2012	7065	4/11/2012	2	7064	4/11/2012	1	Chloroform	10.68*	U	10.68	180
3/30/2012	7065	4/11/2012	2	7064	4/11/2012	1	Methylene Chloride	3.95*	U	3.95	1930
3/30/2012	7065	4/11/2012	2	7064	4/11/2012	1	Toluene	0.67* J	0.35* J	0	190
4/3/2012	7073	4/12/2012	2	7072	4/12/2012	1	1,1,1-Trichloroethane	32.22*	U	32.22	590
4/3/2012	7073	4/12/2012	2	7072	4/12/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
4/3/2012	7073	4/12/2012	2	7072	4/12/2012	1	1,1-Dichloroethylene	U	U	0	100
4/3/2012	7073	4/12/2012	2	7072	4/12/2012	1	1,2-Dichloroethane	U	U	0	45
4/3/2012	7073	4/12/2012	2	7072	4/12/2012	1	Carbon Tetrachloride	167.15*	0.16* J	167.15	960
4/3/2012	7073	4/12/2012	2	7072	4/12/2012	1	Chlorobenzene	U	U	0	220
4/3/2012	7073	4/12/2012	2	7072	4/12/2012	1	Chloroform	13.28*	U	13.28	180
4/3/2012	7073	4/12/2012	2	7072	4/12/2012	1	Methylene Chloride	5.01*	U	5.01	1930
4/3/2012	7073	4/12/2012	2	7072	4/12/2012	1	Toluene	0.76* J	0.43* J	0	190
4/4/2012	7077	4/12/2012	3	7076	4/12/2012	1	1,1,1-Trichloroethane	33.12*	U	33.12	590
4/4/2012	7077	4/12/2012	3	7076	4/12/2012	1	1,1,2,2-Tetrachloroethane	U	0.29* J	0	50
4/4/2012	7077	4/12/2012	3	7076	4/12/2012	1	1,1-Dichloroethylene	U	U	0	100
4/4/2012	7077	4/12/2012	3	7076	4/12/2012	1	1,2-Dichloroethane	U	U	0	45
4/4/2012	7077	4/12/2012	3	7076	4/12/2012	1	Carbon Tetrachloride	187.90*	0.11* J	187.9	960
4/4/2012	7077	4/12/2012	3	7076	4/12/2012	1	Chlorobenzene	U	U	0	220
4/4/2012	7077	4/12/2012	3	7076	4/12/2012	1	Chloroform	15.60*	U	15.6	180
4/4/2012	7077	4/12/2012	3	7076	4/12/2012	1	Methylene Chloride	5.02*	U	5.02	1930
4/4/2012	7077	4/12/2012	3	7076	4/12/2012	1	Toluene	0.84* J	0.63* J	0	190

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
4/10/2012	7097	4/13/2012	3	7098	4/13/2012	1	1,1,1-Trichloroethane	39.30*	U	39.3	590
4/10/2012	7097	4/13/2012	3	7098	4/13/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
4/10/2012	7097	4/13/2012	3	7098	4/13/2012	1	1,1-Dichloroethylene	U	U	0	100
4/10/2012	7097	4/13/2012	3	7098	4/13/2012	1	1,2-Dichloroethane	U	U	0	45
4/10/2012	7097	4/13/2012	3	7098	4/13/2012	1	Carbon Tetrachloride	209.15*	0.32* J	209.15	960
4/10/2012	7097	4/13/2012	3	7098	4/13/2012	1	Chlorobenzene	U	U	0	220
4/10/2012	7097	4/13/2012	3	7098	4/13/2012	1	Chloroform	16.80*	U	16.8	180
4/10/2012	7097	4/13/2012	3	7098	4/13/2012	1	Methylene Chloride	5.57*	U	5.57	1930
4/10/2012	7097	4/13/2012	3	7098	4/13/2012	1	Toluene	0.69* J	0.34* J	0	190
4/11/2012	7099	4/13/2012	4	7100	4/13/2012	1	1,1,1-Trichloroethane	44.82*	U	44.82	590
4/11/2012	7099	4/13/2012	4	7100	4/13/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
4/11/2012	7099	4/13/2012	4	7100	4/13/2012	1	1,1-Dichloroethylene	U	U	0	100
4/11/2012	7099	4/13/2012	4	7100	4/13/2012	1	1,2-Dichloroethane	U	U	0	45
4/11/2012	7099	4/13/2012	4	7100	4/13/2012	1	Carbon Tetrachloride	274.59*	0.37* J	274.59	960
4/11/2012	7099	4/13/2012	4	7100	4/13/2012	1	Chlorobenzene	U	U	0	220
4/11/2012	7099	4/13/2012	4	7100	4/13/2012	1	Chloroform	23.80*	U	23.8	180
4/11/2012	7099	4/13/2012	4	7100	4/13/2012	1	Methylene Chloride	6.45*	U	6.45	1930
4/11/2012	7099	4/13/2012	4	7100	4/13/2012	1	Toluene	0.87* J	0.78* J	0	190
4/17/2012	7127	4/25/2012	2	7128	4/25/2012	1	1,1,1-Trichloroethane	24.66*	U	24.66	590
4/17/2012	7127	4/25/2012	2	7128	4/25/2012	1	1,1,2,2-Tetrachloroethane	0.61* J	U	0	50
4/17/2012	7127	4/25/2012	2	7128	4/25/2012	1	1,1-Dichloroethylene	U	U	0	100
4/17/2012	7127	4/25/2012	2	7128	4/25/2012	1	1,2-Dichloroethane	U	U	0	45
4/17/2012	7127	4/25/2012	2	7128	4/25/2012	1	Carbon Tetrachloride	125.64*	0.28* J	125.64	960
4/17/2012	7127	4/25/2012	2	7128	4/25/2012	1	Chlorobenzene	U	U	0	220
4/17/2012	7127	4/25/2012	2	7128	4/25/2012	1	Chloroform	9.31*	U	9.31	180
4/17/2012	7127	4/25/2012	2	7128	4/25/2012	1	Methylene Chloride	3.74*	U	3.74	1930
4/17/2012	7127	4/25/2012	2	7128	4/25/2012	1	Toluene	0.53* J	0.28* J	0	190
4/18/2012	7129	4/25/2012	3	7130	4/25/2012	1	1,1,1-Trichloroethane	31.56*	U	31.56	590
4/18/2012	7129	4/25/2012	3	7130	4/25/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
4/18/2012	7129	4/25/2012	3	7130	4/25/2012	1	1,1-Dichloroethylene	U	U	0	100
4/18/2012	7129	4/25/2012	3	7130	4/25/2012	1	1,2-Dichloroethane	U	U	0	45
4/18/2012	7129	4/25/2012	3	7130	4/25/2012	1	Carbon Tetrachloride	178.45*	0.23* J	178.45	960
4/18/2012	7129	4/25/2012	3	7130	4/25/2012	1	Chlorobenzene	U	U	0	220
4/18/2012	7129	4/25/2012	3	7130	4/25/2012	1	Chloroform	14.89*	U	14.89	180
4/18/2012	7129	4/25/2012	3	7130	4/25/2012	1	Methylene Chloride	5.00*	U	5	1930
4/18/2012	7129	4/25/2012	3	7130	4/25/2012	1	Toluene	0.53* J	0.21* J	0	190

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
4/24/2012	7135	4/27/2012	4	7136	4/27/2012	1	1,1,1-Trichloroethane	37.77*	U	37.77	590
4/24/2012	7135	4/27/2012	4	7136	4/27/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
4/24/2012	7135	4/27/2012	4	7136	4/27/2012	1	1,1-Dichloroethylene	U	U	0	100
4/24/2012	7135	4/27/2012	4	7136	4/27/2012	1	1,2-Dichloroethane	U	U	0	45
4/24/2012	7135	4/27/2012	4	7136	4/27/2012	1	Carbon Tetrachloride	206.41*	0.46* J	206.41	960
4/24/2012	7135	4/27/2012	4	7136	4/27/2012	1	Chlorobenzene	U	U	0	220
4/24/2012	7135	4/27/2012	4	7136	4/27/2012	1	Chloroform	16.69*	U	16.69	180
4/24/2012	7135	4/27/2012	4	7136	4/27/2012	1	Methylene Chloride	6.62*	U	6.62	1930
4/24/2012	7135	4/27/2012	4	7136	4/27/2012	1	Toluene	0.71* J	0.27* J	0	190
4/25/2012	7137	4/27/2012	3	7138	4/27/2012	1	1,1,1-Trichloroethane	24.26*	U	24.26	590
4/25/2012	7137	4/27/2012	3	7138	4/27/2012	1	1,1,2,2-Tetrachloroethane	U	0.15* J	0	50
4/25/2012	7137	4/27/2012	3	7138	4/27/2012	1	1,1-Dichloroethylene	U	U	0	100
4/25/2012	7137	4/27/2012	3	7138	4/27/2012	1	1,2-Dichloroethane	U	U	0	45
4/25/2012	7137	4/27/2012	3	7138	4/27/2012	1	Carbon Tetrachloride	140.23*	0.23* J	140.23	960
4/25/2012	7137	4/27/2012	3	7138	4/27/2012	1	Chlorobenzene	U	U	0	220
4/25/2012	7137	4/27/2012	3	7138	4/27/2012	1	Chloroform	10.77*	U	10.77	180
4/25/2012	7137	4/27/2012	3	7138	4/27/2012	1	Methylene Chloride	4.00* J	U	0	1930
4/25/2012	7137	4/27/2012	3	7138	4/27/2012	1	Toluene	0.49* J	0.30* J	0	190
5/1/2012	7145	5/10/2012	3	7146	5/10/2012	1	1,1,1-Trichloroethane	28.05*	U	28.05	590
5/1/2012	7145	5/10/2012	3	7146	5/10/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
5/1/2012	7145	5/10/2012	3	7146	5/10/2012	1	1,1-Dichloroethylene	U	U	0	100
5/1/2012	7145	5/10/2012	3	7146	5/10/2012	1	1,2-Dichloroethane	U	U	0	45
5/1/2012	7145	5/10/2012	3	7146	5/10/2012	1	Carbon Tetrachloride	140.09*	0.27* J	140.09	960
5/1/2012	7145	5/10/2012	3	7146	5/10/2012	1	Chlorobenzene	U	U	0	220
5/1/2012	7145	5/10/2012	3	7146	5/10/2012	1	Chloroform	11.60*	U	11.6	180
5/1/2012	7145	5/10/2012	3	7146	5/10/2012	1	Methylene Chloride	4.65*	0.12* J	4.65	1930
5/1/2012	7145	5/10/2012	3	7146	5/10/2012	1	Toluene	0.94* J	0.48* J	0	190
5/2/2012	7147	5/10/2012	3	7148	5/10/2012	1	1,1,1-Trichloroethane	22.07*	U	22.07	590
5/2/2012	7147	5/10/2012	3	7148	5/10/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
5/2/2012	7147	5/10/2012	3	7148	5/10/2012	1	1,1-Dichloroethylene	U	U	0	100
5/2/2012	7147	5/10/2012	3	7148	5/10/2012	1	1,2-Dichloroethane	U	U	0	45
5/2/2012	7147	5/10/2012	3	7148	5/10/2012	1	Carbon Tetrachloride	115.40*	0.19* J	115.4	960
5/2/2012	7147	5/10/2012	3	7148	5/10/2012	1	Chlorobenzene	U	U	0	220
5/2/2012	7147	5/10/2012	3	7148	5/10/2012	1	Chloroform	9.05*	U	9.05	180
5/2/2012	7147	5/10/2012	3	7148	5/10/2012	1	Methylene Chloride	3.68*	0.14* J	3.68	1930
5/2/2012	7147	5/10/2012	3	7148	5/10/2012	1	Toluene	0.78* J	0.39* J	0	190

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Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
5/8/2012	7175	5/15/2012	4	7176	5/15/2012	1	1,1,1-Trichloroethane	38.58*	0* R	38.58	590
5/8/2012	7175	5/15/2012	4	7176	5/15/2012	1	1,1,2,2-Tetrachloroethane	U	0* R	0	50
5/8/2012	7175	5/15/2012	4	7176	5/15/2012	1	1,1-Dichloroethylene	U	0* R	0	100
5/8/2012	7175	5/15/2012	4	7176	5/15/2012	1	1,2-Dichloroethane	U	0* R	0	45
5/8/2012	7175	5/15/2012	4	7176	5/15/2012	1	Carbon Tetrachloride	312.48*	0* R	312.48	960
5/8/2012	7175	5/15/2012	4	7176	5/15/2012	1	Chlorobenzene	U	0* R	0	220
5/8/2012	7175	5/15/2012	4	7176	5/15/2012	1	Chloroform	32.97*	0* R	32.97	180
5/8/2012	7175	5/15/2012	4	7176	5/15/2012	1	Methylene Chloride	7.95*	0* R	7.95	1930
5/8/2012	7175	5/15/2012	4	7176	5/15/2012	1	Toluene	0.99* J	0* R	0	190
5/9/2012	7177	5/15/2012	3	7178	5/15/2012	1	1,1,1-Trichloroethane	53.62*	U	53.62	590
5/9/2012	7177	5/15/2012	3	7178	5/15/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
5/9/2012	7177	5/15/2012	3	7178	5/15/2012	1	1,1-Dichloroethylene	U	U	0	100
5/9/2012	7177	5/15/2012	3	7178	5/15/2012	1	1,2-Dichloroethane	U	U	0	45
5/9/2012	7177	5/15/2012	3	7178	5/15/2012	1	Carbon Tetrachloride	271.62*	0.18* J	271.62	960
5/9/2012	7177	5/15/2012	3	7178	5/15/2012	1	Chlorobenzene	U	U	0	220
5/9/2012	7177	5/15/2012	3	7178	5/15/2012	1	Chloroform	20.22*	U	20.22	180
5/9/2012	7177	5/15/2012	3	7178	5/15/2012	1	Methylene Chloride	8.85*	0.15* J	8.85	1930
5/9/2012	7177	5/15/2012	3	7178	5/15/2012	1	Toluene	0.94* J	0.3* J	0	190
5/15/2012	7199	5/23/2012	2	7200	5/23/2012	1	1,1,1-Trichloroethane	32.69*	U	32.69	590
5/15/2012	7199	5/23/2012	2	7200	5/23/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
5/15/2012	7199	5/23/2012	2	7200	5/23/2012	1	1,1-Dichloroethylene	U	U	0	100
5/15/2012	7199	5/23/2012	2	7200	5/23/2012	1	1,2-Dichloroethane	U	U	0	45
5/15/2012	7199	5/23/2012	2	7200	5/23/2012	1	Carbon Tetrachloride	162.61*	U	162.61	960
5/15/2012	7199	5/23/2012	2	7200	5/23/2012	1	Chlorobenzene	U	U	0	220
5/15/2012	7199	5/23/2012	2	7200	5/23/2012	1	Chloroform	11.78*	U	11.78	180
5/15/2012	7199	5/23/2012	2	7200	5/23/2012	1	Methylene Chloride	4.80*	0.15* J	4.8	1930
5/15/2012	7199	5/23/2012	2	7200	5/23/2012	1	Toluene	1.20* J	0.67* J	0	190
5/16/2012	7201	5/23/2012	2	7202	5/23/2012	1	1,1,1-Trichloroethane	30.16*	U	30.16	590
5/16/2012	7201	5/23/2012	2	7202	5/23/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
5/16/2012	7201	5/23/2012	2	7202	5/23/2012	1	1,1-Dichloroethylene	U	U	0	100
5/16/2012	7201	5/23/2012	2	7202	5/23/2012	1	1,2-Dichloroethane	U	U	0	45
5/16/2012	7201	5/23/2012	2	7202	5/23/2012	1	Carbon Tetrachloride	156.94*	0.15* J	156.94	960
5/16/2012	7201	5/23/2012	2	7202	5/23/2012	1	Chlorobenzene	U	U	0	220
5/16/2012	7201	5/23/2012	2	7202	5/23/2012	1	Chloroform	11.51*	U	11.51	180
5/16/2012	7201	5/23/2012	2	7202	5/23/2012	1	Methylene Chloride	4.76*	0.15* J	4.76	1930
5/16/2012	7201	5/23/2012	2	7202	5/23/2012	1	Toluene	1.24* J	0.60* J	0	190

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
5/22/2012	7211	5/24/2012	4	7212	5/24/2012	1	1,1,1-Trichloroethane	44.44*	U	44.44	590
5/22/2012	7211	5/24/2012	4	7212	5/24/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
5/22/2012	7211	5/24/2012	4	7212	5/24/2012	1	1,1-Dichloroethylene	U	U	0	100
5/22/2012	7211	5/24/2012	4	7212	5/24/2012	1	1,2-Dichloroethane	U	U	0	45
5/22/2012	7211	5/24/2012	4	7212	5/24/2012	1	Carbon Tetrachloride	300.15*	0.27* J	300.15	960
5/22/2012	7211	5/24/2012	4	7212	5/24/2012	1	Chlorobenzene	U	U	0	220
5/22/2012	7211	5/24/2012	4	7212	5/24/2012	1	Chloroform	24.84*	U	24.84	180
5/22/2012	7211	5/24/2012	4	7212	5/24/2012	1	Methylene Chloride	6.65*	0.14* J	6.65	1930
5/22/2012	7211	5/24/2012	4	7212	5/24/2012	1	Toluene	0.88* J	0.47* J	0	190
5/23/2012	7213	5/24/2012	4	7214	5/24/2012	1	1,1,1-Trichloroethane	39.84*	U	39.84	590
5/23/2012	7213	5/24/2012	4	7214	5/24/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
5/23/2012	7213	5/24/2012	4	7214	5/24/2012	1	1,1-Dichloroethylene	0.63* J	U	0	100
5/23/2012	7213	5/24/2012	4	7214	5/24/2012	1	1,2-Dichloroethane	U	U	0	45
5/23/2012	7213	5/24/2012	4	7214	5/24/2012	1	Carbon Tetrachloride	237.11*	0.40* J	237.11	960
5/23/2012	7213	5/24/2012	4	7214	5/24/2012	1	Chlorobenzene	U	U	0	220
5/23/2012	7213	5/24/2012	4	7214	5/24/2012	1	Chloroform	18.56*	U	18.56	180
5/23/2012	7213	5/24/2012	4	7214	5/24/2012	1	Methylene Chloride	6.18*	0.15* J	6.18	1930
5/23/2012	7213	5/24/2012	4	7214	5/24/2012	1	Toluene	0.69* J	0.36* J	0	190
5/29/2012	7223	6/5/2012	1	7222	6/5/2012	1	1,1,1-Trichloroethane	42.35*	U	42.35	590
5/29/2012	7223	6/5/2012	1	7222	6/5/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
5/29/2012	7223	6/5/2012	1	7222	6/5/2012	1	1,1-Dichloroethylene	U	U	0	100
5/29/2012	7223	6/5/2012	1	7222	6/5/2012	1	1,2-Dichloroethane	U	U	0	45
5/29/2012	7223	6/5/2012	1	7222	6/5/2012	1	Carbon Tetrachloride	203.15*	0.28* J	203.15	960
5/29/2012	7223	6/5/2012	1	7222	6/5/2012	1	Chlorobenzene	U	U	0	220
5/29/2012	7223	6/5/2012	1	7222	6/5/2012	1	Chloroform	16.47*	U	16.47	180
5/29/2012	7223	6/5/2012	1	7222	6/5/2012	1	Methylene Chloride	7.41*	0.31* J	7.41	1930
5/29/2012	7223	6/5/2012	1	7222	6/5/2012	1	Toluene	2.84* J	1.98* J	0	190
5/30/2012	7225	6/5/2012	2	7224	6/5/2012	1	1,1,1-Trichloroethane	47.58*	U	47.58	590
5/30/2012	7225	6/5/2012	2	7224	6/5/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
5/30/2012	7225	6/5/2012	2	7224	6/5/2012	1	1,1-Dichloroethylene	U	U	0	100
5/30/2012	7225	6/5/2012	2	7224	6/5/2012	1	1,2-Dichloroethane	U	U	0	45
5/30/2012	7225	6/5/2012	2	7224	6/5/2012	1	Carbon Tetrachloride	278.61*	0.26* J	278.61	960
5/30/2012	7225	6/5/2012	2	7224	6/5/2012	1	Chlorobenzene	U	U	0	220
5/30/2012	7225	6/5/2012	2	7224	6/5/2012	1	Chloroform	22.71*	U	22.71	180
5/30/2012	7225	6/5/2012	2	7224	6/5/2012	1	Methylene Chloride	7.80*	0.19* J	7.8	1930
5/30/2012	7225	6/5/2012	2	7224	6/5/2012	1	Toluene	1.69* J	3.88*	-3.88	190

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
6/5/2012	7249	6/7/2012	2	7248	6/7/2012	1	1,1,1-Trichloroethane	34.85*	U	34.85	590
6/5/2012	7249	6/7/2012	2	7248	6/7/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
6/5/2012	7249	6/7/2012	2	7248	6/7/2012	1	1,1-Dichloroethylene	U	U	0	100
6/5/2012	7249	6/7/2012	2	7248	6/7/2012	1	1,2-Dichloroethane	U	U	0	45
6/5/2012	7249	6/7/2012	2	7248	6/7/2012	1	Carbon Tetrachloride	190.77*	0.13* J	190.77	960
6/5/2012	7249	6/7/2012	2	7248	6/7/2012	1	Chlorobenzene	U	U	0	220
6/5/2012	7249	6/7/2012	2	7248	6/7/2012	1	Chloroform	14.36*	U	14.36	180
6/5/2012	7249	6/7/2012	2	7248	6/7/2012	1	Methylene Chloride	5.09*	U	5.09	1930
6/5/2012	7249	6/7/2012	2	7248	6/7/2012	1	Toluene	1.05* J	0.55* J	0	190
6/6/2012	7253	6/7/2012	3	7252	6/7/2012	1	1,1,1-Trichloroethane	39.62*	0* R	39.62	590
6/6/2012	7253	6/7/2012	3	7252	6/7/2012	1	1,1,2,2-Tetrachloroethane	U	0* R	0	50
6/6/2012	7253	6/7/2012	3	7252	6/7/2012	1	1,1-Dichloroethylene	U	0* R	0	100
6/6/2012	7253	6/7/2012	3	7252	6/7/2012	1	1,2-Dichloroethane	U	0* R	0	45
6/6/2012	7253	6/7/2012	3	7252	6/7/2012	1	Carbon Tetrachloride	246.73*	0* R	246.73	960
6/6/2012	7253	6/7/2012	3	7252	6/7/2012	1	Chlorobenzene	U	0* R	0	220
6/6/2012	7253	6/7/2012	3	7252	6/7/2012	1	Chloroform	19.63*	0* R	19.63	180
6/6/2012	7253	6/7/2012	3	7252	6/7/2012	1	Methylene Chloride	6.13*	0* R	6.13	1930
6/6/2012	7253	6/7/2012	3	7252	6/7/2012	1	Toluene	0.83* J	0* R	0	190
6/12/2012	7279	6/21/2012	2	7278	6/21/2012	1	1,1,1-Trichloroethane	37.76*	U	37.76	590
6/12/2012	7279	6/21/2012	2	7278	6/21/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
6/12/2012	7279	6/21/2012	2	7278	6/21/2012	1	1,1-Dichloroethylene	U	U	0	100
6/12/2012	7279	6/21/2012	2	7278	6/21/2012	1	1,2-Dichloroethane	U	U	0	45
6/12/2012	7279	6/21/2012	2	7278	6/21/2012	1	Carbon Tetrachloride	204.79*	0.58* J	204.79	960
6/12/2012	7279	6/21/2012	2	7278	6/21/2012	1	Chlorobenzene	U	U	0	220
6/12/2012	7279	6/21/2012	2	7278	6/21/2012	1	Chloroform	13.51*	U	13.51	180
6/12/2012	7279	6/21/2012	2	7278	6/21/2012	1	Methylene Chloride	5.41*	0.17* J	5.41	1930
6/12/2012	7279	6/21/2012	2	7278	6/21/2012	1	Toluene	1.05* J	0.46* J	0	190
6/13/2012	7281	6/21/2012	2	7280	6/21/2012	1	1,1,1-Trichloroethane	36.90*	U	36.9	590
6/13/2012	7281	6/21/2012	2	7280	6/21/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
6/13/2012	7281	6/21/2012	2	7280	6/21/2012	1	1,1-Dichloroethylene	U	U	0	100
6/13/2012	7281	6/21/2012	2	7280	6/21/2012	1	1,2-Dichloroethane	U	U	0	45
6/13/2012	7281	6/21/2012	2	7280	6/21/2012	1	Carbon Tetrachloride	207.49*	0.54* J	207.49	960
6/13/2012	7281	6/21/2012	2	7280	6/21/2012	1	Chlorobenzene	U	U	0	220
6/13/2012	7281	6/21/2012	2	7280	6/21/2012	1	Chloroform	13.18*	U	13.18	180
6/13/2012	7281	6/21/2012	2	7280	6/21/2012	1	Methylene Chloride	5.05*	0.14* J	5.05	1930
6/13/2012	7281	6/21/2012	2	7280	6/21/2012	1	Toluene	0.82* J	0.32* J	0	190

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Sample Date (A and B)	VOC-A Sample ID	VOC-A Analysis Date	VOC-A MRL (ppbv)	VOC-B Sample ID	VOC-B Analysis Date	VOC-B MRL (ppbv)	Compound	VOC-A (ppbv)	VOC-B (ppbv)	VOC Emission[1]	COC (ppbv)
6/19/2012	7287	6/25/2012	2	7288	6/25/2012	1	1,1,1-Trichloroethane	18.27*	U	18.27	590
6/19/2012	7287	6/25/2012	2	7288	6/25/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
6/19/2012	7287	6/25/2012	2	7288	6/25/2012	1	1,1-Dichloroethylene	U	U	0	100
6/19/2012	7287	6/25/2012	2	7288	6/25/2012	1	1,2-Dichloroethane	U	U	0	45
6/19/2012	7287	6/25/2012	2	7288	6/25/2012	1	Carbon Tetrachloride	94.31*	0.16* J	94.31	960
6/19/2012	7287	6/25/2012	2	7288	6/25/2012	1	Chlorobenzene	U	U	0	220
6/19/2012	7287	6/25/2012	2	7288	6/25/2012	1	Chloroform	6.21*	U	6.21	180
6/19/2012	7287	6/25/2012	2	7288	6/25/2012	1	Methylene Chloride	2.62*	0.12* J	2.62	1930
6/19/2012	7287	6/25/2012	2	7288	6/25/2012	1	Toluene	0.56* J	0.45* J	0	190
6/20/2012	7289	6/25/2012	1.5	7290	6/25/2012	1	1,1,1-Trichloroethane	20.12*	U	20.12	590
6/20/2012	7289	6/25/2012	1.5	7290	6/25/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
6/20/2012	7289	6/25/2012	1.5	7290	6/25/2012	1	1,1-Dichloroethylene	0.24* J	U	0	100
6/20/2012	7289	6/25/2012	1.5	7290	6/25/2012	1	1,2-Dichloroethane	U	U	0	45
6/20/2012	7289	6/25/2012	1.5	7290	6/25/2012	1	Carbon Tetrachloride	102.63*	0.34* J	102.63	960
6/20/2012	7289	6/25/2012	1.5	7290	6/25/2012	1	Chlorobenzene	U	U	0	220
6/20/2012	7289	6/25/2012	1.5	7290	6/25/2012	1	Chloroform	6.35*	U	6.35	180
6/20/2012	7289	6/25/2012	1.5	7290	6/25/2012	1	Methylene Chloride	2.84*	U	2.84	1930
6/20/2012	7289	6/25/2012	1.5	7290	6/25/2012	1	Toluene	0.66* J	0.21* J	0	190
6/26/2012	7305	7/9/2012	1.5	7302	7/9/2012	1	1,1,1-Trichloroethane	18.30*	U	18.3	590
6/26/2012	7305	7/9/2012	1.5	7302	7/9/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
6/26/2012	7305	7/9/2012	1.5	7302	7/9/2012	1	1,1-Dichloroethylene	U	U	0	100
6/26/2012	7305	7/9/2012	1.5	7302	7/9/2012	1	1,2-Dichloroethane	U	U	0	45
6/26/2012	7305	7/9/2012	1.5	7302	7/9/2012	1	Carbon Tetrachloride	94.65*	0.70* J	94.65	960
6/26/2012	7305	7/9/2012	1.5	7302	7/9/2012	1	Chlorobenzene	U	U	0	220
6/26/2012	7305	7/9/2012	1.5	7302	7/9/2012	1	Chloroform	7.33*	0.14* J	7.33	180
6/26/2012	7305	7/9/2012	1.5	7302	7/9/2012	1	Methylene Chloride	2.66*	U	2.66	1930
6/26/2012	7305	7/9/2012	1.5	7302	7/9/2012	1	Toluene	0.76* J	0.59* J	0	190
6/27/2012	7303	7/9/2012	2	7304	7/9/2012	1	1,1,1-Trichloroethane	19.58*	U	19.58	590
6/27/2012	7303	7/9/2012	2	7304	7/9/2012	1	1,1,2,2-Tetrachloroethane	U	U	0	50
6/27/2012	7303	7/9/2012	2	7304	7/9/2012	1	1,1-Dichloroethylene	U	U	0	100
6/27/2012	7303	7/9/2012	2	7304	7/9/2012	1	1,2-Dichloroethane	U	U	0	45
6/27/2012	7303	7/9/2012	2	7304	7/9/2012	1	Carbon Tetrachloride	103.86*	0.34* J	103.86	960
6/27/2012	7303	7/9/2012	2	7304	7/9/2012	1	Chlorobenzene	U	U	0	220
6/27/2012	7303	7/9/2012	2	7304	7/9/2012	1	Chloroform	7.39*	U	7.39	180
6/27/2012	7303	7/9/2012	2	7304	7/9/2012	1	Methylene Chloride	2.75*	U	2.75	1930
6/27/2012	7303	7/9/2012	2	7304	7/9/2012	1	Toluene	0.60* J	0.40* J	0	190

Attachment 1 – Comparison of the Underground HWDU VOC Emission Concentration and COC - Repository VOC Monitoring

Notes:
J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above MDL.
* Normalized concentration.
!!! Concentration exceeds the COC (not applicable in this data set).
[1] Analytical results not qualified as "U" are normalized to the typical operating conditions, in accordance with Permit Attachment N, section N-3e(1). The normalized concentration of each target VOC detected at Station VOC-B is subtracted from the normalized concentration detected at Station VOC-A and represents the Underground HWDU VOC emission concentration. The resulting concentration for each target analyte is compared to its COC listed in the WIPP RCRA Permit Part 4, table 4.6.2.3. Results qualified as "U" indicate that the laboratory's quantitative results were not greater than the method detection limit (MDL) and are assigned a value of zero for determination of emission concentrations. Analytical results qualified as "J" indicate that the laboratory's quantitative results were at a concentration greater than the MDL but less than the laboratory's method reporting limit (MRL). Results qualified as "J" are normalized but are considered to be estimated values and are assigned a value of zero for determination of emission concentrations. When the normalized concentration at Station VOC-A is less than Station VOC-B, the emission concentration is reported as zero.

Attachment 2 – Disposal Room VOC Monitoring Results

Panel 6 - Disposal Room VOC Monitoring Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R4E	6877	1/17/2012	1/25/2012	1,1,1-Trichloroethane	6	40.14
P6R4E	6877	1/17/2012	1/25/2012	1,1,2,2-Tetrachloroethane	6	U
P6R4E	6877	1/17/2012	1/25/2012	1,1-Dichloroethylene	6	U
P6R4E	6877	1/17/2012	1/25/2012	1,2-Dichloroethane	6	U
P6R4E	6877	1/17/2012	1/25/2012	Carbon Tetrachloride	6	240.12
P6R4E	6877	1/17/2012	1/25/2012	Chlorobenzene	6	U
P6R4E	6877	1/17/2012	1/25/2012	Chloroform	6	14.82
P6R4E	6877	1/17/2012	1/25/2012	Methylene Chloride	6	1.56 J
P6R4E	6877	1/17/2012	1/25/2012	Toluene	6	U
P6R4E	6918	1/31/2012	2/6/2012	1,1,1-Trichloroethane	2	18.44
P6R4E	6918	1/31/2012	2/6/2012	1,1,2,2-Tetrachloroethane	2	U
P6R4E	6918	1/31/2012	2/6/2012	1,1-Dichloroethylene	2	U
P6R4E	6918	1/31/2012	2/6/2012	1,2-Dichloroethane	2	U
P6R4E	6918	1/31/2012	2/6/2012	Carbon Tetrachloride	2	105.52
P6R4E	6918	1/31/2012	2/6/2012	Chlorobenzene	2	U
P6R4E	6918	1/31/2012	2/6/2012	Chloroform	2	6.80
P6R4E	6918	1/31/2012	2/6/2012	Methylene Chloride	2	0.76 J
P6R4E	6918	1/31/2012	2/6/2012	Toluene	2	0.30 J
P6R4E	6958	2/14/2012	2/23/2012	1,1,1-Trichloroethane	9	47.43
P6R4E	6958	2/14/2012	2/23/2012	1,1,2,2-Tetrachloroethane	9	U
P6R4E	6958	2/14/2012	2/23/2012	1,1-Dichloroethylene	9	U
P6R4E	6958	2/14/2012	2/23/2012	1,2-Dichloroethane	9	U
P6R4E	6958	2/14/2012	2/23/2012	Carbon Tetrachloride	9	259.11
P6R4E	6958	2/14/2012	2/23/2012	Chlorobenzene	9	U

Attachment 2 – Disposal Room VOC Monitoring Results

Panel 6 - Disposal Room VOC Monitoring Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R4E	6958	2/14/2012	2/23/2012	Chloroform	9	15.21
P6R4E	6958	2/14/2012	2/23/2012	Methylene Chloride	9	2.16 J
P6R4E	6958	2/14/2012	2/23/2012	Toluene	9	U
P6R4E	6994	2/28/2012	3/1/2012	1,1,1-Trichloroethane	2	21.36
P6R4E	6994	2/28/2012	3/1/2012	1,1,2,2-Tetrachloroethane	2	U
P6R4E	6994	2/28/2012	3/1/2012	1,1-Dichloroethylene	2	U
P6R4E	6994	2/28/2012	3/1/2012	1,2-Dichloroethane	2	U
P6R4E	6994	2/28/2012	3/1/2012	Carbon Tetrachloride	2	108.62
P6R4E	6994	2/28/2012	3/1/2012	Chlorobenzene	2	U
P6R4E	6994	2/28/2012	3/1/2012	Chloroform	2	6.76
P6R4E	6994	2/28/2012	3/1/2012	Methylene Chloride	2	0.72 J
P6R4E	6994	2/28/2012	3/1/2012	Toluene	2	0.30 J
P6R4E	7030	3/12/2012	3/21/2012	1,1,1-Trichloroethane	1.5	13.88
P6R4E	7030	3/12/2012	3/21/2012	1,1,2,2-Tetrachloroethane	1.5	U
P6R4E	7030	3/12/2012	3/21/2012	1,1-Dichloroethylene	1.5	U
P6R4E	7030	3/12/2012	3/21/2012	1,2-Dichloroethane	1.5	U
P6R4E	7030	3/12/2012	3/21/2012	Carbon Tetrachloride	1.5	81.14
P6R4E	7030	3/12/2012	3/21/2012	Chlorobenzene	1.5	U
P6R4E	7030	3/12/2012	3/21/2012	Chloroform	1.5	5.00
P6R4E	7030	3/12/2012	3/21/2012	Methylene Chloride	1.5	0.54 J
P6R4E	7030	3/12/2012	3/21/2012	Toluene	1.5	0.21 J
P6R4E	7068	3/29/2012	4/11/2012	1,1,1-Trichloroethane	4	33.60
P6R4E	7068	3/29/2012	4/11/2012	1,1,2,2-Tetrachloroethane	4	U
P6R4E	7068	3/29/2012	4/11/2012	1,1-Dichloroethylene	4	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R4E	7068	3/29/2012	4/11/2012	1,2-Dichloroethane	4	U
P6R4E	7068	3/29/2012	4/11/2012	Carbon Tetrachloride	4	173.08
P6R4E	7068	3/29/2012	4/11/2012	Chlorobenzene	4	U
P6R4E	7068	3/29/2012	4/11/2012	Chloroform	4	11.84
P6R4E	7068	3/29/2012	4/11/2012	Methylene Chloride	4	2.24 J
P6R4E	7068	3/29/2012	4/11/2012	Toluene	4	0.44 J
P6R4E	7103	4/11/2012	4/13/2012	1,1,1-Trichloroethane	1	0.76 J
P6R4E	7103	4/11/2012	4/13/2012	1,1,2,2-Tetrachloroethane	1	U
P6R4E	7103	4/11/2012	4/13/2012	1,1-Dichloroethylene	1	U
P6R4E	7103	4/11/2012	4/13/2012	1,2-Dichloroethane	1	U
P6R4E	7103	4/11/2012	4/13/2012	Carbon Tetrachloride	1	3.75
P6R4E	7103	4/11/2012	4/13/2012	Chlorobenzene	1	U
P6R4E	7103	4/11/2012	4/13/2012	Chloroform	1	0.61 J
P6R4E	7103	4/11/2012	4/13/2012	Methylene Chloride	1	0.26 J
P6R4E	7103	4/11/2012	4/13/2012	Toluene	1	0.15 J
P6R4E	7141	4/24/2012	4/27/2012	1,1,1-Trichloroethane	1.5	13.38
P6R4E	7141	4/24/2012	4/27/2012	1,1,2,2-Tetrachloroethane	1.5	U
P6R4E	7141	4/24/2012	4/27/2012	1,1-Dichloroethylene	1.5	U
P6R4E	7141	4/24/2012	4/27/2012	1,2-Dichloroethane	1.5	U
P6R4E	7141	4/24/2012	4/27/2012	Carbon Tetrachloride	1.5	57.96
P6R4E	7141	4/24/2012	4/27/2012	Chlorobenzene	1.5	U
P6R4E	7141	4/24/2012	4/27/2012	Chloroform	1.5	3.87
P6R4E	7141	4/24/2012	4/27/2012	Methylene Chloride	1.5	0.47 J
P6R4E	7141	4/24/2012	4/27/2012	Toluene	1.5	0.26 J

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R4E	7180	5/8/2012	5/15/2012	1,1,1-Trichloroethane	1.5	24.83
P6R4E	7180	5/8/2012	5/15/2012	1,1,2,2-Tetrachloroethane	1.5	U
P6R4E	7180	5/8/2012	5/15/2012	1,1-Dichloroethylene	1.5	U
P6R4E	7180	5/8/2012	5/15/2012	1,2-Dichloroethane	1.5	U
P6R4E	7180	5/8/2012	5/15/2012	Carbon Tetrachloride	1.5	64.19
P6R4E	7180	5/8/2012	5/15/2012	Chlorobenzene	1.5	U
P6R4E	7180	5/8/2012	5/15/2012	Chloroform	1.5	4.31
P6R4E	7180	5/8/2012	5/15/2012	Methylene Chloride	1.5	0.95 J
P6R4E	7180	5/8/2012	5/15/2012	Toluene	1.5	0.65 J
P6R4E	7217	5/22/2012	5/24/2012	1,1,1-Trichloroethane	1	10.25
P6R4E	7217	5/22/2012	5/24/2012	1,1,2,2-Tetrachloroethane	1	U
P6R4E	7217	5/22/2012	5/24/2012	1,1-Dichloroethylene	1	U
P6R4E	7217	5/22/2012	5/24/2012	1,2-Dichloroethane	1	U
P6R4E	7217	5/22/2012	5/24/2012	Carbon Tetrachloride	1	42.61
P6R4E	7217	5/22/2012	5/24/2012	Chlorobenzene	1	U
P6R4E	7217	5/22/2012	5/24/2012	Chloroform	1	2.86
P6R4E	7217	5/22/2012	5/24/2012	Methylene Chloride	1	0.47 J
P6R4E	7217	5/22/2012	5/24/2012	Toluene	1	0.23 J
P6R4E	7255	6/5/2012	6/7/2012	1,1,1-Trichloroethane	2	21.36
P6R4E	7255	6/5/2012	6/7/2012	1,1,2,2-Tetrachloroethane	2	U
P6R4E	7255	6/5/2012	6/7/2012	1,1-Dichloroethylene	2	U
P6R4E	7255	6/5/2012	6/7/2012	1,2-Dichloroethane	2	U
P6R4E	7255	6/5/2012	6/7/2012	Carbon Tetrachloride	2	111.40
P6R4E	7255	6/5/2012	6/7/2012	Chlorobenzene	2	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R4E	7255	6/5/2012	6/7/2012	Chloroform	2	6.78
P6R4E	7255	6/5/2012	6/7/2012	Methylene Chloride	2	0.86 J
P6R4E	7255	6/5/2012	6/7/2012	Toluene	2	0.40 J
P6R4E	7293	6/19/2012	6/25/2012	1,1,1-Trichloroethane	2	15.04
P6R4E	7293	6/19/2012	6/25/2012	1,1,2,2-Tetrachloroethane	2	U
P6R4E	7293	6/19/2012	6/25/2012	1,1-Dichloroethylene	2	U
P6R4E	7293	6/19/2012	6/25/2012	1,2-Dichloroethane	2	U
P6R4E	7293	6/19/2012	6/25/2012	Carbon Tetrachloride	2	78.14
P6R4E	7293	6/19/2012	6/25/2012	Chlorobenzene	2	U
P6R4E	7293	6/19/2012	6/25/2012	Chloroform	2	4.58
P6R4E	7293	6/19/2012	6/25/2012	Methylene Chloride	2	0.64 J
P6R4E	7293	6/19/2012	6/25/2012	Toluene	2	U
P6R5E	6836	1/3/2012	1/11/2012	1,1,1-Trichloroethane	3	29.46
P6R5E	6836	1/3/2012	1/11/2012	1,1,2,2-Tetrachloroethane	3	U
P6R5E	6836	1/3/2012	1/11/2012	1,1-Dichloroethylene	3	U
P6R5E	6836	1/3/2012	1/11/2012	1,2-Dichloroethane	3	U
P6R5E	6836	1/3/2012	1/11/2012	Carbon Tetrachloride	3	125.70
P6R5E	6836	1/3/2012	1/11/2012	Chlorobenzene	3	U
P6R5E	6836	1/3/2012	1/11/2012	Chloroform	3	8.19
P6R5E	6836	1/3/2012	1/11/2012	Methylene Chloride	3	0.90 J
P6R5E	6836	1/3/2012	1/11/2012	Toluene	3	0.45 J
P6R5E	6875	1/16/2012	1/25/2012	1,1,1-Trichloroethane	6	48.72
P6R5E	6875	1/16/2012	1/25/2012	1,1,2,2-Tetrachloroethane	6	U
P6R5E	6875	1/16/2012	1/25/2012	1,1-Dichloroethylene	6	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R5E	6875	1/16/2012	1/25/2012	1,2-Dichloroethane	6	U
P6R5E	6875	1/16/2012	1/25/2012	Carbon Tetrachloride	6	271.74
P6R5E	6875	1/16/2012	1/25/2012	Chlorobenzene	6	U
P6R5E	6875	1/16/2012	1/25/2012	Chloroform	6	17.22
P6R5E	6875	1/16/2012	1/25/2012	Methylene Chloride	6	1.68 J
P6R5E	6875	1/16/2012	1/25/2012	Toluene	6	U
P6R5E	6916	1/30/2012	2/6/2012	1,1,1-Trichloroethane	4	46.56
P6R5E	6916	1/30/2012	2/6/2012	1,1,2,2-Tetrachloroethane	4	U
P6R5E	6916	1/30/2012	2/6/2012	1,1-Dichloroethylene	4	U
P6R5E	6916	1/30/2012	2/6/2012	1,2-Dichloroethane	4	U
P6R5E	6916	1/30/2012	2/6/2012	Carbon Tetrachloride	4	197.16
P6R5E	6916	1/30/2012	2/6/2012	Chlorobenzene	4	U
P6R5E	6916	1/30/2012	2/6/2012	Chloroform	4	12.36
P6R5E	6916	1/30/2012	2/6/2012	Methylene Chloride	4	1.16 J
P6R5E	6916	1/30/2012	2/6/2012	Toluene	4	0.40 J
P6R5E	6956	2/13/2012	2/23/2012	1,1,1-Trichloroethane	9	50.13
P6R5E	6956	2/13/2012	2/23/2012	1,1,2,2-Tetrachloroethane	9	U
P6R5E	6956	2/13/2012	2/23/2012	1,1-Dichloroethylene	9	U
P6R5E	6956	2/13/2012	2/23/2012	1,2-Dichloroethane	9	U
P6R5E	6956	2/13/2012	2/23/2012	Carbon Tetrachloride	9	266.13
P6R5E	6956	2/13/2012	2/23/2012	Chlorobenzene	9	U
P6R5E	6956	2/13/2012	2/23/2012	Chloroform	9	16.38
P6R5E	6956	2/13/2012	2/23/2012	Methylene Chloride	9	1.89 J
P6R5E	6956	2/13/2012	2/23/2012	Toluene	9	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R5E	6992	2/27/2012	3/1/2012	1,1,1-Trichloroethane	3	38.34
P6R5E	6992	2/27/2012	3/1/2012	1,1,2,2-Tetrachloroethane	3	U
P6R5E	6992	2/27/2012	3/1/2012	1,1-Dichloroethylene	3	U
P6R5E	6992	2/27/2012	3/1/2012	1,2-Dichloroethane	3	U
P6R5E	6992	2/27/2012	3/1/2012	Carbon Tetrachloride	3	129.12
P6R5E	6992	2/27/2012	3/1/2012	Chlorobenzene	3	U
P6R5E	6992	2/27/2012	3/1/2012	Chloroform	3	7.95
P6R5E	6992	2/27/2012	3/1/2012	Methylene Chloride	3	1.14 J
P6R5E	6992	2/27/2012	3/1/2012	Toluene	3	0.51 J
P6R5E	7028	3/12/2012	3/21/2012	1,1,1-Trichloroethane	1.5	16.68
P6R5E	7028	3/12/2012	3/21/2012	1,1,2,2-Tetrachloroethane	1.5	U
P6R5E	7028	3/12/2012	3/21/2012	1,1-Dichloroethylene	1.5	U
P6R5E	7028	3/12/2012	3/21/2012	1,2-Dichloroethane	1.5	U
P6R5E	7028	3/12/2012	3/21/2012	Carbon Tetrachloride	1.5	71.78
P6R5E	7028	3/12/2012	3/21/2012	Chlorobenzene	1.5	U
P6R5E	7028	3/12/2012	3/21/2012	Chloroform	1.5	4.97
P6R5E	7028	3/12/2012	3/21/2012	Methylene Chloride	1.5	0.68 J
P6R5E	7028	3/12/2012	3/21/2012	Toluene	1.5	0.33 J
P6R5E	7066	3/28/2012	4/11/2012	1,1,1-Trichloroethane	4	28.44
P6R5E	7066	3/28/2012	4/11/2012	1,1,2,2-Tetrachloroethane	4	U
P6R5E	7066	3/28/2012	4/11/2012	1,1-Dichloroethylene	4	U
P6R5E	7066	3/28/2012	4/11/2012	1,2-Dichloroethane	4	U
P6R5E	7066	3/28/2012	4/11/2012	Carbon Tetrachloride	4	152.80
P6R5E	7066	3/28/2012	4/11/2012	Chlorobenzene	4	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R5E	7066	3/28/2012	4/11/2012	Chloroform	4	10.88
P6R5E	7066	3/28/2012	4/11/2012	Methylene Chloride	4	1.40 J
P6R5E	7066	3/28/2012	4/11/2012	Toluene	4	0.40 J
P6R5E	7101	4/10/2012	4/13/2012	1,1,1-Trichloroethane	3	18.63
P6R5E	7101	4/10/2012	4/13/2012	1,1,2,2-Tetrachloroethane	3	U
P6R5E	7101	4/10/2012	4/13/2012	1,1-Dichloroethylene	3	U
P6R5E	7101	4/10/2012	4/13/2012	1,2-Dichloroethane	3	U
P6R5E	7101	4/10/2012	4/13/2012	Carbon Tetrachloride	3	103.38
P6R5E	7101	4/10/2012	4/13/2012	Chlorobenzene	3	U
P6R5E	7101	4/10/2012	4/13/2012	Chloroform	3	7.53
P6R5E	7101	4/10/2012	4/13/2012	Methylene Chloride	3	0.90 J
P6R5E	7101	4/10/2012	4/13/2012	Toluene	3	0.42 J
P6R5E	7139	4/23/2012	4/27/2012	1,1,1-Trichloroethane	1	7.60
P6R5E	7139	4/23/2012	4/27/2012	1,1,2,2-Tetrachloroethane	1	U
P6R5E	7139	4/23/2012	4/27/2012	1,1-Dichloroethylene	1	U
P6R5E	7139	4/23/2012	4/27/2012	1,2-Dichloroethane	1	U
P6R5E	7139	4/23/2012	4/27/2012	Carbon Tetrachloride	1	30.78
P6R5E	7139	4/23/2012	4/27/2012	Chlorobenzene	1	U
P6R5E	7139	4/23/2012	4/27/2012	Chloroform	1	2.38
P6R5E	7139	4/23/2012	4/27/2012	Methylene Chloride	1	0.36 J
P6R5E	7139	4/23/2012	4/27/2012	Toluene	1	0.46 J
P6R5E	7179	5/7/2012	5/15/2012	1,1,1-Trichloroethane	1.5	35.37
P6R5E	7179	5/7/2012	5/15/2012	1,1,2,2-Tetrachloroethane	1.5	U
P6R5E	7179	5/7/2012	5/15/2012	1,1-Dichloroethylene	1.5	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R5E	7179	5/7/2012	5/15/2012	1,2-Dichloroethane	1.5	U
P6R5E	7179	5/7/2012	5/15/2012	Carbon Tetrachloride	1.5	79.44
P6R5E	7179	5/7/2012	5/15/2012	Chlorobenzene	1.5	U
P6R5E	7179	5/7/2012	5/15/2012	Chloroform	1.5	6.44
P6R5E	7179	5/7/2012	5/15/2012	Methylene Chloride	1.5	1.14 J
P6R5E	7179	5/7/2012	5/15/2012	Toluene	1.5	0.93 J
P6R5E	7215	5/21/2012	5/24/2012	1,1,1-Trichloroethane	1	10.48
P6R5E	7215	5/21/2012	5/24/2012	1,1,2,2-Tetrachloroethane	1	U
P6R5E	7215	5/21/2012	5/24/2012	1,1-Dichloroethylene	1	U
P6R5E	7215	5/21/2012	5/24/2012	1,2-Dichloroethane	1	U
P6R5E	7215	5/21/2012	5/24/2012	Carbon Tetrachloride	1	22.08
P6R5E	7215	5/21/2012	5/24/2012	Chlorobenzene	1	U
P6R5E	7215	5/21/2012	5/24/2012	Chloroform	1	2.07
P6R5E	7215	5/21/2012	5/24/2012	Methylene Chloride	1	0.48 J
P6R5E	7215	5/21/2012	5/24/2012	Toluene	1	0.29 J
P6R5E	7254	6/4/2012	6/7/2012	1,1,1-Trichloroethane	1.5	32.22
P6R5E	7254	6/4/2012	6/7/2012	1,1,2,2-Tetrachloroethane	1.5	U
P6R5E	7254	6/4/2012	6/7/2012	1,1-Dichloroethylene	1.5	U
P6R5E	7254	6/4/2012	6/7/2012	1,2-Dichloroethane	1.5	U
P6R5E	7254	6/4/2012	6/7/2012	Carbon Tetrachloride	1.5	74.97
P6R5E	7254	6/4/2012	6/7/2012	Chlorobenzene	1.5	U
P6R5E	7254	6/4/2012	6/7/2012	Chloroform	1.5	5.82
P6R5E	7254	6/4/2012	6/7/2012	Methylene Chloride	1.5	0.95 J
P6R5E	7254	6/4/2012	6/7/2012	Toluene	1.5	0.63 J

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R5E	7291	6/18/2012	6/25/2012	1,1,1-Trichloroethane	3	46.41
P6R5E	7291	6/18/2012	6/25/2012	1,1,2,2-Tetrachloroethane	3	U
P6R5E	7291	6/18/2012	6/25/2012	1,1-Dichloroethylene	3	U
P6R5E	7291	6/18/2012	6/25/2012	1,2-Dichloroethane	3	U
P6R5E	7291	6/18/2012	6/25/2012	Carbon Tetrachloride	3	104.76
P6R5E	7291	6/18/2012	6/25/2012	Chlorobenzene	3	U
P6R5E	7291	6/18/2012	6/25/2012	Chloroform	3	7.05
P6R5E	7291	6/18/2012	6/25/2012	Methylene Chloride	3	1.11 J
P6R5E	7291	6/18/2012	6/25/2012	Toluene	3	0.51 J
P6R6E	6849	1/11/2012	1/19/2012	1,1,1-Trichloroethane	27	244.62
P6R6E	6849	1/11/2012	1/19/2012	1,1,2,2-Tetrachloroethane	27	U
P6R6E	6849	1/11/2012	1/19/2012	1,1-Dichloroethylene	27	U
P6R6E	6849	1/11/2012	1/19/2012	1,2-Dichloroethane	27	U
P6R6E	6849	1/11/2012	1/19/2012	Carbon Tetrachloride	27	1,480.68
P6R6E	6849	1/11/2012	1/19/2012	Chlorobenzene	27	U
P6R6E	6849	1/11/2012	1/19/2012	Chloroform	27	87.75
P6R6E	6849	1/11/2012	1/19/2012	Methylene Chloride	27	8.64 J
P6R6E	6849	1/11/2012	1/19/2012	Toluene	27	U
P6R6E	6906	1/24/2012	2/1/2012	1,1,1-Trichloroethane	27	444.15
P6R6E	6906	1/24/2012	2/1/2012	1,1,2,2-Tetrachloroethane	27	U
P6R6E	6906	1/24/2012	2/1/2012	1,1-Dichloroethylene	27	U
P6R6E	6906	1/24/2012	2/1/2012	1,2-Dichloroethane	27	U
P6R6E	6906	1/24/2012	2/1/2012	Carbon Tetrachloride	27	1,518.21
P6R6E	6906	1/24/2012	2/1/2012	Chlorobenzene	27	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R6E	6906	1/24/2012	2/1/2012	Chloroform	27	79.38
P6R6E	6906	1/24/2012	2/1/2012	Methylene Chloride	27	7.02 J
P6R6E	6906	1/24/2012	2/1/2012	Toluene	27	U
P6R6E	6929	2/7/2012	2/14/2012	1,1,1-Trichloroethane	27	238.95
P6R6E	6929	2/7/2012	2/14/2012	1,1,2,2-Tetrachloroethane	27	U
P6R6E	6929	2/7/2012	2/14/2012	1,1-Dichloroethylene	27	U
P6R6E	6929	2/7/2012	2/14/2012	1,2-Dichloroethane	27	U
P6R6E	6929	2/7/2012	2/14/2012	Carbon Tetrachloride	27	1,578.42
P6R6E	6929	2/7/2012	2/14/2012	Chlorobenzene	27	U
P6R6E	6929	2/7/2012	2/14/2012	Chloroform	27	93.96
P6R6E	6929	2/7/2012	2/14/2012	Methylene Chloride	27	7.83 J
P6R6E	6929	2/7/2012	2/14/2012	Toluene	27	U
P6R6E	6983	2/22/2012	2/28/2012	1,1,1-Trichloroethane	12	96.96
P6R6E	6983	2/22/2012	2/28/2012	1,1,2,2-Tetrachloroethane	12	U
P6R6E	6983	2/22/2012	2/28/2012	1,1-Dichloroethylene	12	U
P6R6E	6983	2/22/2012	2/28/2012	1,2-Dichloroethane	12	U
P6R6E	6983	2/22/2012	2/28/2012	Carbon Tetrachloride	12	587.28
P6R6E	6983	2/22/2012	2/28/2012	Chlorobenzene	12	U
P6R6E	6983	2/22/2012	2/28/2012	Chloroform	12	34.32
P6R6E	6983	2/22/2012	2/28/2012	Methylene Chloride	12	3.72 J
P6R6E	6983	2/22/2012	2/28/2012	Toluene	12	U
P6R6E	7005	3/6/2012	3/13/2012	1,1,1-Trichloroethane	27	155.52
P6R6E	7005	3/6/2012	3/13/2012	1,1,2,2-Tetrachloroethane	27	U
P6R6E	7005	3/6/2012	3/13/2012	1,1-Dichloroethylene	27	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R6E	7005	3/6/2012	3/13/2012	1,2-Dichloroethane	27	U
P6R6E	7005	3/6/2012	3/13/2012	Carbon Tetrachloride	27	943.11
P6R6E	7005	3/6/2012	3/13/2012	Chlorobenzene	27	U
P6R6E	7005	3/6/2012	3/13/2012	Chloroform	27	57.51
P6R6E	7005	3/6/2012	3/13/2012	Methylene Chloride	27	5.67 J
P6R6E	7005	3/6/2012	3/13/2012	Toluene	27	U
P6R6E	7061	3/20/2012	4/2/2012	1,1,1-Trichloroethane	9	68.22
P6R6E	7061	3/20/2012	4/2/2012	1,1,2,2-Tetrachloroethane	9	U
P6R6E	7061	3/20/2012	4/2/2012	1,1-Dichloroethylene	9	U
P6R6E	7061	3/20/2012	4/2/2012	1,2-Dichloroethane	9	U
P6R6E	7061	3/20/2012	4/2/2012	Carbon Tetrachloride	9	404.55
P6R6E	7061	3/20/2012	4/2/2012	Chlorobenzene	9	U
P6R6E	7061	3/20/2012	4/2/2012	Chloroform	9	21.60
P6R6E	7061	3/20/2012	4/2/2012	Methylene Chloride	9	2.61 J
P6R6E	7061	3/20/2012	4/2/2012	Toluene	9	U
P6R6E	7080	4/4/2012	4/12/2012	1,1,1-Trichloroethane	18	108.54
P6R6E	7080	4/4/2012	4/12/2012	1,1,2,2-Tetrachloroethane	18	U
P6R6E	7080	4/4/2012	4/12/2012	1,1-Dichloroethylene	18	U
P6R6E	7080	4/4/2012	4/12/2012	1,2-Dichloroethane	18	U
P6R6E	7080	4/4/2012	4/12/2012	Carbon Tetrachloride	18	658.98
P6R6E	7080	4/4/2012	4/12/2012	Chlorobenzene	18	U
P6R6E	7080	4/4/2012	4/12/2012	Chloroform	18	41.94
P6R6E	7080	4/4/2012	4/12/2012	Methylene Chloride	18	4.32 J
P6R6E	7080	4/4/2012	4/12/2012	Toluene	18	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R6E	7134	4/17/2012	4/25/2012	1,1,1-Trichloroethane	18	93.78
P6R6E	7134	4/17/2012	4/25/2012	1,1,2,2-Tetrachloroethane	18	U
P6R6E	7134	4/17/2012	4/25/2012	1,1-Dichloroethylene	18	U
P6R6E	7134	4/17/2012	4/25/2012	1,2-Dichloroethane	18	U
P6R6E	7134	4/17/2012	4/25/2012	Carbon Tetrachloride	18	601.74
P6R6E	7134	4/17/2012	4/25/2012	Chlorobenzene	18	U
P6R6E	7134	4/17/2012	4/25/2012	Chloroform	18	37.80
P6R6E	7134	4/17/2012	4/25/2012	Methylene Chloride	18	U
P6R6E	7134	4/17/2012	4/25/2012	Toluene	18	U
P6R6E	7153	5/2/2012	5/10/2012	1,1,1-Trichloroethane	324	3,035.88
P6R6E	7153	5/2/2012	5/10/2012	1,1,2,2-Tetrachloroethane	324	U
P6R6E	7153	5/2/2012	5/10/2012	1,1-Dichloroethylene	324	U
P6R6E	7153	5/2/2012	5/10/2012	1,2-Dichloroethane	324	U
P6R6E	7153	5/2/2012	5/10/2012	Carbon Tetrachloride	324	10,387.44
P6R6E	7153	5/2/2012	5/10/2012	Chlorobenzene	324	U
P6R6E	7153	5/2/2012	5/10/2012	Chloroform	324	719.28
P6R6E	7153	5/2/2012	5/10/2012	Methylene Chloride	324	106.92 J
P6R6E	7153	5/2/2012	5/10/2012	Toluene	324	51.84 J
P6R6E	7206	5/15/2012	5/23/2012	1,1,1-Trichloroethane	81	1,233.63
P6R6E	7206	5/15/2012	5/23/2012	1,1,2,2-Tetrachloroethane	81	U
P6R6E	7206	5/15/2012	5/23/2012	1,1-Dichloroethylene	81	U
P6R6E	7206	5/15/2012	5/23/2012	1,2-Dichloroethane	81	U
P6R6E	7206	5/15/2012	5/23/2012	Carbon Tetrachloride	81	3,819.96
P6R6E	7206	5/15/2012	5/23/2012	Chlorobenzene	81	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R6E	7206	5/15/2012	5/23/2012	Chloroform	81	226.80
P6R6E	7206	5/15/2012	5/23/2012	Methylene Chloride	81	27.54 J
P6R6E	7206	5/15/2012	5/23/2012	Toluene	81	10.53 J
P6R6E	7230	5/30/2012	6/5/2012	1,1,1-Trichloroethane	162	3,886.38
P6R6E	7230	5/30/2012	6/5/2012	1,1,2,2-Tetrachloroethane	162	U
P6R6E	7230	5/30/2012	6/5/2012	1,1-Dichloroethylene	162	U
P6R6E	7230	5/30/2012	6/5/2012	1,2-Dichloroethane	162	U
P6R6E	7230	5/30/2012	6/5/2012	Carbon Tetrachloride	162	11,790.36
P6R6E	7230	5/30/2012	6/5/2012	Chlorobenzene	162	U
P6R6E	7230	5/30/2012	6/5/2012	Chloroform	162	784.08
P6R6E	7230	5/30/2012	6/5/2012	Methylene Chloride	162	95.58 J
P6R6E	7230	5/30/2012	6/5/2012	Toluene	162	37.26 J
P6R6E	7285	6/12/2012	6/21/2012	1,1,1-Trichloroethane	324	3,602.88
P6R6E	7285	6/12/2012	6/21/2012	1,1,2,2-Tetrachloroethane	324	U
P6R6E	7285	6/12/2012	6/21/2012	1,1-Dichloroethylene	324	U
P6R6E	7285	6/12/2012	6/21/2012	1,2-Dichloroethane	324	U
P6R6E	7285	6/12/2012	6/21/2012	Carbon Tetrachloride	324	17,670.96
P6R6E	7285	6/12/2012	6/21/2012	Chlorobenzene	324	U
P6R6E	7285	6/12/2012	6/21/2012	Chloroform	324	1,033.56
P6R6E	7285	6/12/2012	6/21/2012	Methylene Chloride	324	142.56 J
P6R6E	7285	6/12/2012	6/21/2012	Toluene	324	35.64 J
P6R6E	7309	6/26/2012	7/9/2012	1,1,1-Trichloroethane	121.5	2,111.67
P6R6E	7309	6/26/2012	7/9/2012	1,1,2,2-Tetrachloroethane	121.5	U
P6R6E	7309	6/26/2012	7/9/2012	1,1-Dichloroethylene	121.5	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R6E	7309	6/26/2012	7/9/2012	1,2-Dichloroethane	121.5	U
P6R6E	7309	6/26/2012	7/9/2012	Carbon Tetrachloride	121.5	8,526.87
P6R6E	7309	6/26/2012	7/9/2012	Chlorobenzene	121.5	U
P6R6E	7309	6/26/2012	7/9/2012	Chloroform	121.5	533.39
P6R6E	7309	6/26/2012	7/9/2012	Methylene Chloride	121.5	74.12 J
P6R6E	7309	6/26/2012	7/9/2012	Toluene	121.5	20.66 J
P6R6I	7152	5/2/2012	5/10/2012	1,1,1-Trichloroethane	81	819.72
P6R6I	7152	5/2/2012	5/10/2012	1,1,2,2-Tetrachloroethane	81	U
P6R6I	7152	5/2/2012	5/10/2012	1,1-Dichloroethylene	81	U
P6R6I	7152	5/2/2012	5/10/2012	1,2-Dichloroethane	81	U
P6R6I	7152	5/2/2012	5/10/2012	Carbon Tetrachloride	81	2,787.21
P6R6I	7152	5/2/2012	5/10/2012	Chlorobenzene	81	U
P6R6I	7152	5/2/2012	5/10/2012	Chloroform	81	147.42
P6R6I	7152	5/2/2012	5/10/2012	Methylene Chloride	81	38.88 J
P6R6I	7152	5/2/2012	5/10/2012	Toluene	81	14.58 J
P6R6I	7205	5/15/2012	5/23/2012	1,1,1-Trichloroethane	54	1,110.78
P6R6I	7205	5/15/2012	5/23/2012	1,1,2,2-Tetrachloroethane	54	U
P6R6I	7205	5/15/2012	5/23/2012	1,1-Dichloroethylene	54	U
P6R6I	7205	5/15/2012	5/23/2012	1,2-Dichloroethane	54	U
P6R6I	7205	5/15/2012	5/23/2012	Carbon Tetrachloride	54	3,709.26
P6R6I	7205	5/15/2012	5/23/2012	Chlorobenzene	54	U
P6R6I	7205	5/15/2012	5/23/2012	Chloroform	54	199.26
P6R6I	7205	5/15/2012	5/23/2012	Methylene Chloride	54	42.66 J
P6R6I	7205	5/15/2012	5/23/2012	Toluene	54	11.88 J

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R6I	7228	5/30/2012	6/5/2012	1,1,1-Trichloroethane	40.5	983.75
P6R6I	7228	5/30/2012	6/5/2012	1,1,2,2-Tetrachloroethane	40.5	U
P6R6I	7228	5/30/2012	6/5/2012	1,1-Dichloroethylene	40.5	U
P6R6I	7228	5/30/2012	6/5/2012	1,2-Dichloroethane	40.5	U
P6R6I	7228	5/30/2012	6/5/2012	Carbon Tetrachloride	40.5	2,605.37
P6R6I	7228	5/30/2012	6/5/2012	Chlorobenzene	40.5	U
P6R6I	7228	5/30/2012	6/5/2012	Chloroform	40.5	127.58
P6R6I	7228	5/30/2012	6/5/2012	Methylene Chloride	40.5	34.02 J
P6R6I	7228	5/30/2012	6/5/2012	Toluene	40.5	6.89 J
P6R6I	7286	6/12/2012	6/21/2012	1,1,1-Trichloroethane	108	954.72
P6R6I	7286	6/12/2012	6/21/2012	1,1,2,2-Tetrachloroethane	108	U
P6R6I	7286	6/12/2012	6/21/2012	1,1-Dichloroethylene	108	U
P6R6I	7286	6/12/2012	6/21/2012	1,2-Dichloroethane	108	U
P6R6I	7286	6/12/2012	6/21/2012	Carbon Tetrachloride	108	4,595.40
P6R6I	7286	6/12/2012	6/21/2012	Chlorobenzene	108	U
P6R6I	7286	6/12/2012	6/21/2012	Chloroform	108	209.52
P6R6I	7286	6/12/2012	6/21/2012	Methylene Chloride	108	41.04 J
P6R6I	7286	6/12/2012	6/21/2012	Toluene	108	U
P6R6I	7310	6/26/2012	7/9/2012	1,1,1-Trichloroethane	27	345.33
P6R6I	7310	6/26/2012	7/9/2012	1,1,2,2-Tetrachloroethane	27	U
P6R6I	7310	6/26/2012	7/9/2012	1,1-Dichloroethylene	27	U
P6R6I	7310	6/26/2012	7/9/2012	1,2-Dichloroethane	27	U
P6R6I	7310	6/26/2012	7/9/2012	Carbon Tetrachloride	27	1,376.73
P6R6I	7310	6/26/2012	7/9/2012	Chlorobenzene	27	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R6I	7310	6/26/2012	7/9/2012	Chloroform	27	70.47
P6R6I	7310	6/26/2012	7/9/2012	Methylene Chloride	27	9.18 J
P6R6I	7310	6/26/2012	7/9/2012	Toluene	27	U
P6R7E	6847	1/10/2012	1/19/2012	1,1,1-Trichloroethane	6561	43,696.26
P6R7E	6847	1/10/2012	1/19/2012	1,1,2,2-Tetrachloroethane	6561	U
P6R7E	6847	1/10/2012	1/19/2012	1,1-Dichloroethylene	6561	U
P6R7E	6847	1/10/2012	1/19/2012	1,2-Dichloroethane	6561	U
P6R7E	6847	1/10/2012	1/19/2012	Carbon Tetrachloride	6561	272,609.55
P6R7E	6847	1/10/2012	1/19/2012	Chlorobenzene	6561	U
P6R7E	6847	1/10/2012	1/19/2012	Chloroform	6561	17,452.26
P6R7E	6847	1/10/2012	1/19/2012	Methylene Chloride	6561	1,705.86 J
P6R7E	6847	1/10/2012	1/19/2012	Toluene	6561	U
P6R7E	6903	1/23/2012	2/1/2012	1,1,1-Trichloroethane	2916	22,948.92
P6R7E	6903	1/23/2012	2/1/2012	1,1,2,2-Tetrachloroethane	2916	U
P6R7E	6903	1/23/2012	2/1/2012	1,1-Dichloroethylene	2916	U
P6R7E	6903	1/23/2012	2/1/2012	1,2-Dichloroethane	2916	U
P6R7E	6903	1/23/2012	2/1/2012	Carbon Tetrachloride	2916	150,261.48
P6R7E	6903	1/23/2012	2/1/2012	Chlorobenzene	2916	U
P6R7E	6903	1/23/2012	2/1/2012	Chloroform	2916	9,156.24
P6R7E	6903	1/23/2012	2/1/2012	Methylene Chloride	2916	787.32 J
P6R7E	6903	1/23/2012	2/1/2012	Toluene	2916	U
P6R7E	6928	2/6/2012	2/14/2012	1,1,1-Trichloroethane	4374	31,667.76
P6R7E	6928	2/6/2012	2/14/2012	1,1,2,2-Tetrachloroethane	4374	U
P6R7E	6928	2/6/2012	2/14/2012	1,1-Dichloroethylene	4374	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R7E	6928	2/6/2012	2/14/2012	1,2-Dichloroethane	4374	U
P6R7E	6928	2/6/2012	2/14/2012	Carbon Tetrachloride	4374	218,350.08
P6R7E	6928	2/6/2012	2/14/2012	Chlorobenzene	4374	U
P6R7E	6928	2/6/2012	2/14/2012	Chloroform	4374	13,734.36
P6R7E	6928	2/6/2012	2/14/2012	Methylene Chloride	4374	1,180.98 J
P6R7E	6928	2/6/2012	2/14/2012	Toluene	4374	U
P6R7E	6981	2/21/2012	2/28/2012	1,1,1-Trichloroethane	2817	22,176.18
P6R7E	6981	2/21/2012	2/28/2012	1,1,2,2-Tetrachloroethane	2817	U
P6R7E	6981	2/21/2012	2/28/2012	1,1-Dichloroethylene	2817	U
P6R7E	6981	2/21/2012	2/28/2012	1,2-Dichloroethane	2817	U
P6R7E	6981	2/21/2012	2/28/2012	Carbon Tetrachloride	2817	141,017.76
P6R7E	6981	2/21/2012	2/28/2012	Chlorobenzene	2817	U
P6R7E	6981	2/21/2012	2/28/2012	Chloroform	2817	8,573.04
P6R7E	6981	2/21/2012	2/28/2012	Methylene Chloride	2817	809.19 J
P6R7E	6981	2/21/2012	2/28/2012	Toluene	2817	U
P6R7E	7002	3/5/2012	3/13/2012	1,1,1-Trichloroethane	2187	19,354.95
P6R7E	7002	3/5/2012	3/13/2012	1,1,2,2-Tetrachloroethane	2187	U
P6R7E	7002	3/5/2012	3/13/2012	1,1-Dichloroethylene	2187	U
P6R7E	7002	3/5/2012	3/13/2012	1,2-Dichloroethane	2187	U
P6R7E	7002	3/5/2012	3/13/2012	Carbon Tetrachloride	2187	122,034.60
P6R7E	7002	3/5/2012	3/13/2012	Chlorobenzene	2187	U
P6R7E	7002	3/5/2012	3/13/2012	Chloroform	2187	7,370.19
P6R7E	7002	3/5/2012	3/13/2012	Methylene Chloride	2187	699.84 J
P6R7E	7002	3/5/2012	3/13/2012	Toluene	2187	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R7E	7060	3/19/2012	4/2/2012	1,1,1-Trichloroethane	2916	21,607.56
P6R7E	7060	3/19/2012	4/2/2012	1,1,2,2-Tetrachloroethane	2916	U
P6R7E	7060	3/19/2012	4/2/2012	1,1-Dichloroethylene	2916	U
P6R7E	7060	3/19/2012	4/2/2012	1,2-Dichloroethane	2916	U
P6R7E	7060	3/19/2012	4/2/2012	Carbon Tetrachloride	2916	131,919.84
P6R7E	7060	3/19/2012	4/2/2012	Chlorobenzene	2916	U
P6R7E	7060	3/19/2012	4/2/2012	Chloroform	2916	7,581.60
P6R7E	7060	3/19/2012	4/2/2012	Methylene Chloride	2916	787.32 J
P6R7E	7060	3/19/2012	4/2/2012	Toluene	2916	U
P6R7E	7079	4/3/2012	4/12/2012	1,1,1-Trichloroethane	2187	12,159.72
P6R7E	7079	4/3/2012	4/12/2012	1,1,2,2-Tetrachloroethane	2187	U
P6R7E	7079	4/3/2012	4/12/2012	1,1-Dichloroethylene	2187	U
P6R7E	7079	4/3/2012	4/12/2012	1,2-Dichloroethane	2187	U
P6R7E	7079	4/3/2012	4/12/2012	Carbon Tetrachloride	2187	81,312.66
P6R7E	7079	4/3/2012	4/12/2012	Chlorobenzene	2187	U
P6R7E	7079	4/3/2012	4/12/2012	Chloroform	2187	5,030.10
P6R7E	7079	4/3/2012	4/12/2012	Methylene Chloride	2187	481.14 J
P6R7E	7079	4/3/2012	4/12/2012	Toluene	2187	U
P6R7E	7131	4/16/2012	4/25/2012	1,1,1-Trichloroethane	1458	10,191.42
P6R7E	7131	4/16/2012	4/25/2012	1,1,2,2-Tetrachloroethane	1458	U
P6R7E	7131	4/16/2012	4/25/2012	1,1-Dichloroethylene	1458	U
P6R7E	7131	4/16/2012	4/25/2012	1,2-Dichloroethane	1458	U
P6R7E	7131	4/16/2012	4/25/2012	Carbon Tetrachloride	1458	67,272.12
P6R7E	7131	4/16/2012	4/25/2012	Chlorobenzene	1458	U

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Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R7E	7131	4/16/2012	4/25/2012	Chloroform	1458	4,038.66
P6R7E	7131	4/16/2012	4/25/2012	Methylene Chloride	1458	393.66 J
P6R7E	7131	4/16/2012	4/25/2012	Toluene	1458	U
P6R7E	7149	5/1/2012	5/10/2012	1,1,1-Trichloroethane	6561	35,626.23
P6R7E	7149	5/1/2012	5/10/2012	1,1,2,2-Tetrachloroethane	6561	U
P6R7E	7149	5/1/2012	5/10/2012	1,1-Dichloroethylene	6561	U
P6R7E	7149	5/1/2012	5/10/2012	1,2-Dichloroethane	6561	U
P6R7E	7149	5/1/2012	5/10/2012	Carbon Tetrachloride	6561	213,363.72
P6R7E	7149	5/1/2012	5/10/2012	Chlorobenzene	6561	U
P6R7E	7149	5/1/2012	5/10/2012	Chloroform	6561	13,646.88
P6R7E	7149	5/1/2012	5/10/2012	Methylene Chloride	6561	1,312.20 J
P6R7E	7149	5/1/2012	5/10/2012	Toluene	6561	U
P6R7E	7203	5/14/2012	5/23/2012	1,1,1-Trichloroethane	4374	45,008.46
P6R7E	7203	5/14/2012	5/23/2012	1,1,2,2-Tetrachloroethane	4374	U
P6R7E	7203	5/14/2012	5/23/2012	1,1-Dichloroethylene	4374	U
P6R7E	7203	5/14/2012	5/23/2012	1,2-Dichloroethane	4374	U
P6R7E	7203	5/14/2012	5/23/2012	Carbon Tetrachloride	4374	269,569.62
P6R7E	7203	5/14/2012	5/23/2012	Chlorobenzene	4374	U
P6R7E	7203	5/14/2012	5/23/2012	Chloroform	4374	16,796.16
P6R7E	7203	5/14/2012	5/23/2012	Methylene Chloride	4374	1,662.12 J
P6R7E	7203	5/14/2012	5/23/2012	Toluene	4374	U
P6R7E	7227	5/29/2012	6/5/2012	1,1,1-Trichloroethane	4374	41,990.40
P6R7E	7227	5/29/2012	6/5/2012	1,1,2,2-Tetrachloroethane	4374	U
P6R7E	7227	5/29/2012	6/5/2012	1,1-Dichloroethylene	4374	U

Attachment 2 – Disposal Room VOC Monitoring Results

Panel 6 - Disposal Room VOC Monitoring Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R7E	7227	5/29/2012	6/5/2012	1,2-Dichloroethane	4374	U
P6R7E	7227	5/29/2012	6/5/2012	Carbon Tetrachloride	4374	249,011.82
P6R7E	7227	5/29/2012	6/5/2012	Chlorobenzene	4374	U
P6R7E	7227	5/29/2012	6/5/2012	Chloroform	4374	15,571.44
P6R7E	7227	5/29/2012	6/5/2012	Methylene Chloride	4374	1,574.64 J
P6R7E	7227	5/29/2012	6/5/2012	Toluene	4374	U
P6R7E	7283	6/11/2012	6/21/2012	1,1,1-Trichloroethane	8748	79,081.92
P6R7E	7283	6/11/2012	6/21/2012	1,1,2,2-Tetrachloroethane	8748	U
P6R7E	7283	6/11/2012	6/21/2012	1,1-Dichloroethylene	8748	U
P6R7E	7283	6/11/2012	6/21/2012	1,2-Dichloroethane	8748	U
P6R7E	7283	6/11/2012	6/21/2012	Carbon Tetrachloride	8748	534,940.20
P6R7E	7283	6/11/2012	6/21/2012	Chlorobenzene	8748	U
P6R7E	7283	6/11/2012	6/21/2012	Chloroform	8748	28,518.48
P6R7E	7283	6/11/2012	6/21/2012	Methylene Chloride	8748	3,061.80 J
P6R7E	7283	6/11/2012	6/21/2012	Toluene	8748	U
P6R7E	7308	6/25/2012	7/9/2012	1,1,1-Trichloroethane	6561	61,870.23
P6R7E	7308	6/25/2012	7/9/2012	1,1,2,2-Tetrachloroethane	6561	U
P6R7E	7308	6/25/2012	7/9/2012	1,1-Dichloroethylene	6561	U
P6R7E	7308	6/25/2012	7/9/2012	1,2-Dichloroethane	6561	U
P6R7E	7308	6/25/2012	7/9/2012	Carbon Tetrachloride	6561	436,962.60
P6R7E	7308	6/25/2012	7/9/2012	Chlorobenzene	6561	U
P6R7E	7308	6/25/2012	7/9/2012	Chloroform	6561	23,750.82
P6R7E	7308	6/25/2012	7/9/2012	Methylene Chloride	6561	2,230.74 J
P6R7E	7308	6/25/2012	7/9/2012	Toluene	6561	U

Attachment 2 – Disposal Room VOC Monitoring Results

Panel 6 - Disposal Room VOC Monitoring Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R7I	6848	1/10/2012	1/19/2012	1,1,1-Trichloroethane	1458	16,679.52
P6R7I	6848	1/10/2012	1/19/2012	1,1,2,2-Tetrachloroethane	1458	U
P6R7I	6848	1/10/2012	1/19/2012	1,1-Dichloroethylene	1458	U
P6R7I	6848	1/10/2012	1/19/2012	1,2-Dichloroethane	1458	U
P6R7I	6848	1/10/2012	1/19/2012	Carbon Tetrachloride	1458	73,629.00
P6R7I	6848	1/10/2012	1/19/2012	Chlorobenzene	1458	U
P6R7I	6848	1/10/2012	1/19/2012	Chloroform	1458	4,432.32
P6R7I	6848	1/10/2012	1/19/2012	Methylene Chloride	1458	626.94 J
P6R7I	6848	1/10/2012	1/19/2012	Toluene	1458	U
P6R7I	6905	1/23/2012	2/1/2012	1,1,1-Trichloroethane	972	14,521.68
P6R7I	6905	1/23/2012	2/1/2012	1,1,2,2-Tetrachloroethane	972	U
P6R7I	6905	1/23/2012	2/1/2012	1,1-Dichloroethylene	972	U
P6R7I	6905	1/23/2012	2/1/2012	1,2-Dichloroethane	972	U
P6R7I	6905	1/23/2012	2/1/2012	Carbon Tetrachloride	972	53,391.96
P6R7I	6905	1/23/2012	2/1/2012	Chlorobenzene	972	U
P6R7I	6905	1/23/2012	2/1/2012	Chloroform	972	2,925.72
P6R7I	6905	1/23/2012	2/1/2012	Methylene Chloride	972	447.12 J
P6R7I	6905	1/23/2012	2/1/2012	Toluene	972	U
P6R7I	6926	2/6/2012	2/14/2012	1,1,1-Trichloroethane	2916	40,065.84
P6R7I	6926	2/6/2012	2/14/2012	1,1,2,2-Tetrachloroethane	2916	U
P6R7I	6926	2/6/2012	2/14/2012	1,1-Dichloroethylene	2916	U
P6R7I	6926	2/6/2012	2/14/2012	1,2-Dichloroethane	2916	U
P6R7I	6926	2/6/2012	2/14/2012	Carbon Tetrachloride	2916	166,620.24
P6R7I	6926	2/6/2012	2/14/2012	Chlorobenzene	2916	U

Attachment 2 – Disposal Room VOC Monitoring Results

Panel 6 - Disposal Room VOC Monitoring Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R7I	6926	2/6/2012	2/14/2012	Chloroform	2916	9,127.08
P6R7I	6926	2/6/2012	2/14/2012	Methylene Chloride	2916	1,224.72 J
P6R7I	6926	2/6/2012	2/14/2012	Toluene	2916	U
P6R7I	6982	2/21/2012	2/28/2012	1,1,1-Trichloroethane	324	5,582.52
P6R7I	6982	2/21/2012	2/28/2012	1,1,2,2-Tetrachloroethane	324	U
P6R7I	6982	2/21/2012	2/28/2012	1,1-Dichloroethylene	324	U
P6R7I	6982	2/21/2012	2/28/2012	1,2-Dichloroethane	324	U
P6R7I	6982	2/21/2012	2/28/2012	Carbon Tetrachloride	324	19,747.80
P6R7I	6982	2/21/2012	2/28/2012	Chlorobenzene	324	U
P6R7I	6982	2/21/2012	2/28/2012	Chloroform	324	1,114.56
P6R7I	6982	2/21/2012	2/28/2012	Methylene Chloride	324	178.20 J
P6R7I	6982	2/21/2012	2/28/2012	Toluene	324	U
P6R7I	7004	3/5/2012	3/13/2012	1,1,1-Trichloroethane	729	10,862.10
P6R7I	7004	3/5/2012	3/13/2012	1,1,2,2-Tetrachloroethane	729	U
P6R7I	7004	3/5/2012	3/13/2012	1,1-Dichloroethylene	729	U
P6R7I	7004	3/5/2012	3/13/2012	1,2-Dichloroethane	729	U
P6R7I	7004	3/5/2012	3/13/2012	Carbon Tetrachloride	729	30,967.92
P6R7I	7004	3/5/2012	3/13/2012	Chlorobenzene	729	U
P6R7I	7004	3/5/2012	3/13/2012	Chloroform	729	1,567.35
P6R7I	7004	3/5/2012	3/13/2012	Methylene Chloride	729	277.02 J
P6R7I	7004	3/5/2012	3/13/2012	Toluene	729	U
P6R7I	7058	3/19/2012	4/2/2012	1,1,1-Trichloroethane	486	6,949.80
P6R7I	7058	3/19/2012	4/2/2012	1,1,2,2-Tetrachloroethane	486	U
P6R7I	7058	3/19/2012	4/2/2012	1,1-Dichloroethylene	486	U

Attachment 2 – Disposal Room VOC Monitoring Results

Panel 6 - Disposal Room VOC Monitoring Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R7I	7058	3/19/2012	4/2/2012	1,2-Dichloroethane	486	U
P6R7I	7058	3/19/2012	4/2/2012	Carbon Tetrachloride	486	22,409.46
P6R7I	7058	3/19/2012	4/2/2012	Chlorobenzene	486	U
P6R7I	7058	3/19/2012	4/2/2012	Chloroform	486	1,098.36
P6R7I	7058	3/19/2012	4/2/2012	Methylene Chloride	486	184.68 J
P6R7I	7058	3/19/2012	4/2/2012	Toluene	486	U
P6R7I	7078	4/3/2012	4/12/2012	1,1,1-Trichloroethane	121.5	1,804.28
P6R7I	7078	4/3/2012	4/12/2012	1,1,2,2-Tetrachloroethane	121.5	U
P6R7I	7078	4/3/2012	4/12/2012	1,1-Dichloroethylene	121.5	U
P6R7I	7078	4/3/2012	4/12/2012	1,2-Dichloroethane	121.5	U
P6R7I	7078	4/3/2012	4/12/2012	Carbon Tetrachloride	121.5	5,363.01
P6R7I	7078	4/3/2012	4/12/2012	Chlorobenzene	121.5	U
P6R7I	7078	4/3/2012	4/12/2012	Chloroform	121.5	273.38
P6R7I	7078	4/3/2012	4/12/2012	Methylene Chloride	121.5	43.74 J
P6R7I	7078	4/3/2012	4/12/2012	Toluene	121.5	U
P6R7I	7133	4/16/2012	4/25/2012	1,1,1-Trichloroethane	162	2,901.42
P6R7I	7133	4/16/2012	4/25/2012	1,1,2,2-Tetrachloroethane	162	U
P6R7I	7133	4/16/2012	4/25/2012	1,1-Dichloroethylene	162	U
P6R7I	7133	4/16/2012	4/25/2012	1,2-Dichloroethane	162	U
P6R7I	7133	4/16/2012	4/25/2012	Carbon Tetrachloride	162	7,826.22
P6R7I	7133	4/16/2012	4/25/2012	Chlorobenzene	162	U
P6R7I	7133	4/16/2012	4/25/2012	Chloroform	162	393.66
P6R7I	7133	4/16/2012	4/25/2012	Methylene Chloride	162	48.60 J
P6R7I	7133	4/16/2012	4/25/2012	Toluene	162	U

Attachment 2 – Disposal Room VOC Monitoring Results

Panel 6 - Disposal Room VOC Monitoring Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R7I	7150	5/1/2012	5/10/2012	1,1,1-Trichloroethane	6561	43,302.60
P6R7I	7150	5/1/2012	5/10/2012	1,1,2,2-Tetrachloroethane	6561	U
P6R7I	7150	5/1/2012	5/10/2012	1,1-Dichloroethylene	6561	U
P6R7I	7150	5/1/2012	5/10/2012	1,2-Dichloroethane	6561	U
P6R7I	7150	5/1/2012	5/10/2012	Carbon Tetrachloride	6561	189,875.34
P6R7I	7150	5/1/2012	5/10/2012	Chlorobenzene	6561	U
P6R7I	7150	5/1/2012	5/10/2012	Chloroform	6561	11,284.92
P6R7I	7150	5/1/2012	5/10/2012	Methylene Chloride	6561	1,705.86 J
P6R7I	7150	5/1/2012	5/10/2012	Toluene	6561	U
P6R7I	7204	5/14/2012	5/23/2012	1,1,1-Trichloroethane	4374	54,762.48
P6R7I	7204	5/14/2012	5/23/2012	1,1,2,2-Tetrachloroethane	4374	U
P6R7I	7204	5/14/2012	5/23/2012	1,1-Dichloroethylene	4374	U
P6R7I	7204	5/14/2012	5/23/2012	1,2-Dichloroethane	4374	U
P6R7I	7204	5/14/2012	5/23/2012	Carbon Tetrachloride	4374	246,649.86
P6R7I	7204	5/14/2012	5/23/2012	Chlorobenzene	4374	U
P6R7I	7204	5/14/2012	5/23/2012	Chloroform	4374	14,390.46
P6R7I	7204	5/14/2012	5/23/2012	Methylene Chloride	4374	2,012.04 J
P6R7I	7204	5/14/2012	5/23/2012	Toluene	4374	U
P6R7I	7226	5/29/2012	6/5/2012	1,1,1-Trichloroethane	3280.5	41,531.13
P6R7I	7226	5/29/2012	6/5/2012	1,1,2,2-Tetrachloroethane	3280.5	U
P6R7I	7226	5/29/2012	6/5/2012	1,1-Dichloroethylene	3280.5	U
P6R7I	7226	5/29/2012	6/5/2012	1,2-Dichloroethane	3280.5	U
P6R7I	7226	5/29/2012	6/5/2012	Carbon Tetrachloride	3280.5	200,930.63
P6R7I	7226	5/29/2012	6/5/2012	Chlorobenzene	3280.5	U

Attachment 2 – Disposal Room VOC Monitoring Results

Panel 6 - Disposal Room VOC Monitoring Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P6R7I	7226	5/29/2012	6/5/2012	Chloroform	3280.5	11,809.80
P6R7I	7226	5/29/2012	6/5/2012	Methylene Chloride	3280.5	1,640.25 J
P6R7I	7226	5/29/2012	6/5/2012	Toluene	3280.5	U
P6R7I	7282	6/11/2012	6/21/2012	1,1,1-Trichloroethane	8748	77,419.80
P6R7I	7282	6/11/2012	6/21/2012	1,1,2,2-Tetrachloroethane	8748	U
P6R7I	7282	6/11/2012	6/21/2012	1,1-Dichloroethylene	8748	U
P6R7I	7282	6/11/2012	6/21/2012	1,2-Dichloroethane	8748	U
P6R7I	7282	6/11/2012	6/21/2012	Carbon Tetrachloride	8748	450,696.96
P6R7I	7282	6/11/2012	6/21/2012	Chlorobenzene	8748	U
P6R7I	7282	6/11/2012	6/21/2012	Chloroform	8748	22,657.32
P6R7I	7282	6/11/2012	6/21/2012	Methylene Chloride	8748	3,149.28 J
P6R7I	7282	6/11/2012	6/21/2012	Toluene	8748	U
P6R7I	7306	6/25/2012	7/9/2012	1,1,1-Trichloroethane	8748	58,611.60
P6R7I	7306	6/25/2012	7/9/2012	1,1,2,2-Tetrachloroethane	8748	U
P6R7I	7306	6/25/2012	7/9/2012	1,1-Dichloroethylene	8748	U
P6R7I	7306	6/25/2012	7/9/2012	1,2-Dichloroethane	8748	U
P6R7I	7306	6/25/2012	7/9/2012	Carbon Tetrachloride	8748	362,954.52
P6R7I	7306	6/25/2012	7/9/2012	Chlorobenzene	8748	U
P6R7I	7306	6/25/2012	7/9/2012	Chloroform	8748	17,670.96
P6R7I	7306	6/25/2012	7/9/2012	Methylene Chloride	8748	2,536.92 J
P6R7I	7306	6/25/2012	7/9/2012	Toluene	8748	U

Notes:

J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above the MDL.

Attachment 3 – Ongoing Disposal Room VOC Monitoring Results

P3R1E – Ongoing Disposal Room VOC Monitoring Results for Panel 3 Room 1 Exhaust

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P3R1E	6869	1/10/2012	1/19/2012	1,1,1-Trichloroethane	72	4,248.72
P3R1E	6869	1/10/2012	1/19/2012	1,1,2,2-Tetrachloroethane	72	U
P3R1E	6869	1/10/2012	1/19/2012	1,1-Dichloroethylene	72	54.00 J
P3R1E	6869	1/10/2012	1/19/2012	1,2-Dichloroethane	72	10.08 J
P3R1E	6869	1/10/2012	1/19/2012	Carbon Tetrachloride	72	4,372.56
P3R1E	6869	1/10/2012	1/19/2012	Chlorobenzene	72	U
P3R1E	6869	1/10/2012	1/19/2012	Chloroform	72	131.76
P3R1E	6869	1/10/2012	1/19/2012	Methylene Chloride	72	1,207.44
P3R1E	6869	1/10/2012	1/19/2012	Toluene	72	87.84
P3R1E	6972	2/16/2012	2/28/2012	1,1,1-Trichloroethane	24	1,098.24
P3R1E	6972	2/16/2012	2/28/2012	1,1,2,2-Tetrachloroethane	24	U
P3R1E	6972	2/16/2012	2/28/2012	1,1-Dichloroethylene	24	8.64 J
P3R1E	6972	2/16/2012	2/28/2012	1,2-Dichloroethane	24	2.88 J
P3R1E	6972	2/16/2012	2/28/2012	Carbon Tetrachloride	24	1,273.68
P3R1E	6972	2/16/2012	2/28/2012	Chlorobenzene	24	U
P3R1E	6972	2/16/2012	2/28/2012	Chloroform	24	41.04
P3R1E	6972	2/16/2012	2/28/2012	Methylene Chloride	24	288.24
P3R1E	6972	2/16/2012	2/28/2012	Toluene	24	18.24 J
P3R1E	7022	3/6/2012	3/13/2012	1,1,1-Trichloroethane	108	4,485.24
P3R1E	7022	3/6/2012	3/13/2012	1,1,2,2-Tetrachloroethane	108	U
P3R1E	7022	3/6/2012	3/13/2012	1,1-Dichloroethylene	108	33.48 J
P3R1E	7022	3/6/2012	3/13/2012	1,2-Dichloroethane	108	U
P3R1E	7022	3/6/2012	3/13/2012	Carbon Tetrachloride	108	4,943.16

Attachment 3 – Ongoing Disposal Room VOC Monitoring Results

P3R1E – Ongoing Disposal Room VOC Monitoring Results for Panel 3 Room 1 Exhaust

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P3R1E	7022	3/6/2012	3/13/2012	Chlorobenzene	108	U
P3R1E	7022	3/6/2012	3/13/2012	Chloroform	108	147.96
P3R1E	7022	3/6/2012	3/13/2012	Methylene Chloride	108	1,286.28
P3R1E	7022	3/6/2012	3/13/2012	Toluene	108	57.24 J
P3R1E	7095	4/3/2012	4/11/2012	1,1,1-Trichloroethane	72	2,154.96
P3R1E	7095	4/3/2012	4/11/2012	1,1,2,2-Tetrachloroethane	72	U
P3R1E	7095	4/3/2012	4/11/2012	1,1-Dichloroethylene	72	16.56 J
P3R1E	7095	4/3/2012	4/11/2012	1,2-Dichloroethane	72	U
P3R1E	7095	4/3/2012	4/11/2012	Carbon Tetrachloride	72	2,601.36
P3R1E	7095	4/3/2012	4/11/2012	Chlorobenzene	72	U
P3R1E	7095	4/3/2012	4/11/2012	Chloroform	72	82.08
P3R1E	7095	4/3/2012	4/11/2012	Methylene Chloride	72	580.32
P3R1E	7095	4/3/2012	4/11/2012	Toluene	72	32.40 J
P3R1E	7173	5/1/2012	5/11/2012	1,1,1-Trichloroethane	108	2,960.28
P3R1E	7173	5/1/2012	5/11/2012	1,1,2,2-Tetrachloroethane	108	U
P3R1E	7173	5/1/2012	5/11/2012	1,1-Dichloroethylene	108	36.72 J
P3R1E	7173	5/1/2012	5/11/2012	1,2-Dichloroethane	108	U
P3R1E	7173	5/1/2012	5/11/2012	Carbon Tetrachloride	108	3,410.64
P3R1E	7173	5/1/2012	5/11/2012	Chlorobenzene	108	U
P3R1E	7173	5/1/2012	5/11/2012	Chloroform	108	106.92 J
P3R1E	7173	5/1/2012	5/11/2012	Methylene Chloride	108	825.12
P3R1E	7173	5/1/2012	5/11/2012	Toluene	108	95.04 J
P3R1E	7246	6/5/2012	6/18/2012	1,1,1-Trichloroethane	72	2,698.56

Attachment 3 – Ongoing Disposal Room VOC Monitoring Results

P3R1E – Ongoing Disposal Room VOC Monitoring Results for Panel 3 Room 1 Exhaust

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P3R1E	7246	6/5/2012	6/18/2012	1,1,2,2-Tetrachloroethane	72	U
P3R1E	7246	6/5/2012	6/18/2012	1,1-Dichloroethylene	72	28.08 J
P3R1E	7246	6/5/2012	6/18/2012	1,2-Dichloroethane	72	U
P3R1E	7246	6/5/2012	6/18/2012	Carbon Tetrachloride	72	3,501.36
P3R1E	7246	6/5/2012	6/18/2012	Chlorobenzene	72	U
P3R1E	7246	6/5/2012	6/18/2012	Chloroform	72	85.68
P3R1E	7246	6/5/2012	6/18/2012	Methylene Chloride	72	606.96
P3R1E	7246	6/5/2012	6/18/2012	Toluene	72	55.44 J

Notes:

J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above the MDL.

Attachment 3 – Ongoing Disposal Room VOC Monitoring Results

P4R1E – Ongoing Disposal Room VOC Monitoring Results for Panel 4 Room 1 Exhaust

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P4R1E	6897	1/17/2012	1/25/2012	1,1,1-Trichloroethane	17496	160,263.36
P4R1E	6897	1/17/2012	1/25/2012	1,1,2,2-Tetrachloroethane	17496	U
P4R1E	6897	1/17/2012	1/25/2012	1,1-Dichloroethylene	17496	U
P4R1E	6897	1/17/2012	1/25/2012	1,2-Dichloroethane	17496	U
P4R1E	6897	1/17/2012	1/25/2012	Carbon Tetrachloride	17496	884,422.80
P4R1E	6897	1/17/2012	1/25/2012	Chlorobenzene	17496	U
P4R1E	6897	1/17/2012	1/25/2012	Chloroform	17496	66,484.80
P4R1E	6897	1/17/2012	1/25/2012	Methylene Chloride	17496	30,268.08
P4R1E	6897	1/17/2012	1/25/2012	Toluene	17496	U
P4R1E	6948	2/7/2012	2/14/2012	1,1,1-Trichloroethane	13122	136,600.02
P4R1E	6948	2/7/2012	2/14/2012	1,1,2,2-Tetrachloroethane	13122	U
P4R1E	6948	2/7/2012	2/14/2012	1,1-Dichloroethylene	13122	U
P4R1E	6948	2/7/2012	2/14/2012	1,2-Dichloroethane	13122	U
P4R1E	6948	2/7/2012	2/14/2012	Carbon Tetrachloride	13122	760,419.90
P4R1E	6948	2/7/2012	2/14/2012	Chlorobenzene	13122	U
P4R1E	6948	2/7/2012	2/14/2012	Chloroform	13122	58,655.34
P4R1E	6948	2/7/2012	2/14/2012	Methylene Chloride	13122	26,375.22
P4R1E	6948	2/7/2012	2/14/2012	Toluene	13122	U
P4R1E	7049	3/13/2012	3/21/2012	1,1,1-Trichloroethane	13122	158,251.32
P4R1E	7049	3/13/2012	3/21/2012	1,1,2,2-Tetrachloroethane	13122	U
P4R1E	7049	3/13/2012	3/21/2012	1,1-Dichloroethylene	13122	U
P4R1E	7049	3/13/2012	3/21/2012	1,2-Dichloroethane	13122	U
P4R1E	7049	3/13/2012	3/21/2012	Carbon Tetrachloride	13122	886,522.32

Attachment 3 – Ongoing Disposal Room VOC Monitoring Results

P4R1E – Ongoing Disposal Room VOC Monitoring Results for Panel 4 Room 1 Exhaust

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P4R1E	7049	3/13/2012	3/21/2012	Chlorobenzene	13122	U
P4R1E	7049	3/13/2012	3/21/2012	Chloroform	13122	67,053.42
P4R1E	7049	3/13/2012	3/21/2012	Methylene Chloride	13122	31,099.14
P4R1E	7049	3/13/2012	3/21/2012	Toluene	13122	1,180.98 J
P4R1E	7119	4/10/2012	4/24/2012	1,1,1-Trichloroethane	13122	110,880.90
P4R1E	7119	4/10/2012	4/24/2012	1,1,2,2-Tetrachloroethane	13122	U
P4R1E	7119	4/10/2012	4/24/2012	1,1-Dichloroethylene	13122	U
P4R1E	7119	4/10/2012	4/24/2012	1,2-Dichloroethane	13122	U
P4R1E	7119	4/10/2012	4/24/2012	Carbon Tetrachloride	13122	605,973.96
P4R1E	7119	4/10/2012	4/24/2012	Chlorobenzene	13122	U
P4R1E	7119	4/10/2012	4/24/2012	Chloroform	13122	47,501.64
P4R1E	7119	4/10/2012	4/24/2012	Methylene Chloride	13122	21,388.86
P4R1E	7119	4/10/2012	4/24/2012	Toluene	13122	U
P4R1E	7197	5/9/2012	5/18/2012	1,1,1-Trichloroethane	8748	82,056.24
P4R1E	7197	5/9/2012	5/18/2012	1,1,2,2-Tetrachloroethane	8748	U
P4R1E	7197	5/9/2012	5/18/2012	1,1-Dichloroethylene	8748	U
P4R1E	7197	5/9/2012	5/18/2012	1,2-Dichloroethane	8748	U
P4R1E	7197	5/9/2012	5/18/2012	Carbon Tetrachloride	8748	448,684.92
P4R1E	7197	5/9/2012	5/18/2012	Chlorobenzene	8748	U
P4R1E	7197	5/9/2012	5/18/2012	Chloroform	8748	36,479.16
P4R1E	7197	5/9/2012	5/18/2012	Methylene Chloride	8748	16,358.76
P4R1E	7197	5/9/2012	5/18/2012	Toluene	8748	1,399.68 J
P4R1E	7276	6/11/2012	6/25/2012	1,1,1-Trichloroethane	8748	84,418.20

Attachment 3 – Ongoing Disposal Room VOC Monitoring Results

P4R1E – Ongoing Disposal Room VOC Monitoring Results for Panel 4 Room 1 Exhaust

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppbv)	Concentration (ppbv)
P4R1E	7276	6/11/2012	6/25/2012	1,1,2,2-Tetrachloroethane	8748	U
P4R1E	7276	6/11/2012	6/25/2012	1,1-Dichloroethylene	8748	U
P4R1E	7276	6/11/2012	6/25/2012	1,2-Dichloroethane	8748	U
P4R1E	7276	6/11/2012	6/25/2012	Carbon Tetrachloride	8748	546,487.56
P4R1E	7276	6/11/2012	6/25/2012	Chlorobenzene	8748	U
P4R1E	7276	6/11/2012	6/25/2012	Chloroform	8748	35,866.80
P4R1E	7276	6/11/2012	6/25/2012	Methylene Chloride	8748	16,096.32
P4R1E	7276	6/11/2012	6/25/2012	Toluene	8748	787.32 J

Notes:

J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above the MDL.

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Benzene, 1,4-dichloro-	106-46-7	VOC-A	6911	1/31/2012	2/6/2012		1.24 NJ
Benzene, 1,4-dichloro-	106-46-7	VOC-A	6951	2/16/2012	2/23/2012		1.19 NJ
Benzene, 1,4-dichloro-	106-46-7	VOC-A	6989	2/28/2012	3/1/2012		3.90 NJ
Benzene, 1,4-dichloro-	106-46-7	P6R4E	6994	2/28/2012	3/1/2012		3.40 NJ
Benzene, 1,4-dichloro-	106-46-7	P6R4E	7180	5/8/2012	5/15/2012		2.28 NJ
Benzene, 1,4-dichloro-	106-46-7	P6R5E	6992	2/27/2012	3/1/2012		191.61 NJ
Tetrachloroethylene *	127-18-4	VOC-A	6833	1/3/2012	1/11/2012	9	12.33
Tetrachloroethylene *	127-18-4	VOC-A	6839	1/4/2012	1/11/2012	2	6.52
Tetrachloroethylene *	127-18-4	VOC-A	6843	1/10/2012	1/18/2012	2	6.00
Tetrachloroethylene *	127-18-4	VOC-A	6845	1/11/2012	1/18/2012	4	8.88
Tetrachloroethylene *	127-18-4	VOC-A	6871	1/17/2012	1/25/2012	2	10.64
Tetrachloroethylene *	127-18-4	VOC-A	6873	1/18/2012	1/25/2012	4	10.16
Tetrachloroethylene *	127-18-4	VOC-A	6899	1/24/2012	2/1/2012	3	4.32
Tetrachloroethylene *	127-18-4	VOC-A	6901	1/25/2012	2/1/2012	3	5.28
Tetrachloroethylene *	127-18-4	VOC-A	6911	1/31/2012	2/6/2012	1	4.26
Tetrachloroethylene *	127-18-4	VOC-A	6913	2/1/2012	2/6/2012	3	4.20
Tetrachloroethylene *	127-18-4	VOC-A	6923	2/7/2012	2/14/2012	1.5	3.45
Tetrachloroethylene *	127-18-4	VOC-A	6925	2/8/2012	2/14/2012	1.5	3.84
Tetrachloroethylene *	127-18-4	VOC-A	6953	2/15/2012	2/23/2012	2	6.90
Tetrachloroethylene *	127-18-4	VOC-A	6951	2/16/2012	2/23/2012	1	3.97
Tetrachloroethylene *	127-18-4	VOC-A	6977	2/21/2012	2/28/2012	4	6.72
Tetrachloroethylene *	127-18-4	VOC-A	6979	2/22/2012	2/28/2012	4	10.56
Tetrachloroethylene *	127-18-4	VOC-A	6989	2/28/2012	3/1/2012	3	6.90
Tetrachloroethylene *	127-18-4	VOC-A	6991	2/29/2012	3/1/2012	2	6.04
Tetrachloroethylene *	127-18-4	VOC-A	6999	3/6/2012	3/13/2012	4	8.88
Tetrachloroethylene *	127-18-4	VOC-A	7001	3/7/2012	3/13/2012	2	6.50
Tetrachloroethylene *	127-18-4	VOC-A	7025	3/13/2012	3/21/2012	2	6.36
Tetrachloroethylene *	127-18-4	VOC-A	7027	3/14/2012	3/21/2012	9	12.33
Tetrachloroethylene *	127-18-4	VOC-A	7055	3/20/2012	4/2/2012	3	5.52
Tetrachloroethylene *	127-18-4	VOC-A	7057	3/21/2012	4/2/2012	3	6.36

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Tetrachloroethylene *	127-18-4	VOC-A	7063	3/28/2012	4/11/2012	4	6.88
Tetrachloroethylene *	127-18-4	VOC-A	7065	3/30/2012	4/11/2012	2	6.26
Tetrachloroethylene *	127-18-4	VOC-A	7073	4/3/2012	4/12/2012	2	8.36
Tetrachloroethylene *	127-18-4	VOC-A	7077	4/4/2012	4/12/2012	3	8.88
Tetrachloroethylene *	127-18-4	VOC-A	7097	4/10/2012	4/13/2012	3	10.17
Tetrachloroethylene *	127-18-4	VOC-A	7099	4/11/2012	4/13/2012	4	12.92
Tetrachloroethylene *	127-18-4	VOC-A	7127	4/17/2012	4/25/2012	2	7.24
Tetrachloroethylene *	127-18-4	VOC-A	7129	4/18/2012	4/25/2012	3	7.68
Tetrachloroethylene *	127-18-4	VOC-A	7135	4/24/2012	4/27/2012	4	5.32
Tetrachloroethylene *	127-18-4	VOC-A	7137	4/25/2012	4/27/2012	3	3.87
Tetrachloroethylene *	127-18-4	VOC-A	7145	5/1/2012	5/10/2012	3	7.35
Tetrachloroethylene *	127-18-4	VOC-A	7147	5/2/2012	5/10/2012	3	6.90
Tetrachloroethylene *	127-18-4	VOC-A	7175	5/8/2012	5/15/2012	4	7.20
Tetrachloroethylene *	127-18-4	VOC-A	7177	5/9/2012	5/15/2012	3	8.64
Tetrachloroethylene *	127-18-4	VOC-A	7199	5/15/2012	5/23/2012	2	7.20
Tetrachloroethylene *	127-18-4	VOC-A	7201	5/16/2012	5/23/2012	2	6.96
Tetrachloroethylene *	127-18-4	VOC-A	7211	5/22/2012	5/24/2012	4	11.52
Tetrachloroethylene *	127-18-4	VOC-A	7213	5/23/2012	5/24/2012	4	8.72
Tetrachloroethylene *	127-18-4	VOC-A	7223	5/29/2012	6/5/2012	1	3.87
Tetrachloroethylene *	127-18-4	VOC-A	7225	5/30/2012	6/5/2012	2	8.40
Tetrachloroethylene *	127-18-4	VOC-A	7249	6/5/2012	6/7/2012	2	9.50
Tetrachloroethylene *	127-18-4	VOC-A	7253	6/6/2012	6/7/2012	3	9.18
Tetrachloroethylene *	127-18-4	VOC-A	7279	6/12/2012	6/21/2012	2	5.58
Tetrachloroethylene *	127-18-4	VOC-A	7281	6/13/2012	6/21/2012	2	7.08
Tetrachloroethylene *	127-18-4	VOC-A	7287	6/19/2012	6/25/2012	2	5.46
Tetrachloroethylene *	127-18-4	VOC-A	7289	6/20/2012	6/25/2012	1.5	5.13
Tetrachloroethylene *	127-18-4	VOC-A	7305	6/26/2012	7/9/2012	1.5	5.09
Tetrachloroethylene *	127-18-4	VOC-A	7303	6/27/2012	7/9/2012	2	5.12
Tetrachloroethylene *	127-18-4	P3R1E	6869	1/10/2012	1/19/2012	72	92.88
Tetrachloroethylene *	127-18-4	P3R1E	6972	2/16/2012	2/28/2012	24	28.56

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Tetrachloroethylene *	127-18-4	P3R1E	7022	3/6/2012	3/13/2012	108	75.60 J
Tetrachloroethylene *	127-18-4	P3R1E	7095	4/3/2012	4/11/2012	72	53.28 J
Tetrachloroethylene *	127-18-4	P3R1E	7173	5/1/2012	5/11/2012	108	97.20 J
Tetrachloroethylene *	127-18-4	P3R1E	7246	6/5/2012	6/18/2012	72	78.48
Tetrachloroethylene *	127-18-4	P4R1E	6897	1/17/2012	1/25/2012	17496	14,346.72 J
Tetrachloroethylene *	127-18-4	P4R1E	6948	2/7/2012	2/14/2012	13122	13,122.00
Tetrachloroethylene *	127-18-4	P4R1E	7049	3/13/2012	3/21/2012	13122	15,090.30
Tetrachloroethylene *	127-18-4	P4R1E	7119	4/10/2012	4/24/2012	13122	15,483.96
Tetrachloroethylene *	127-18-4	P4R1E	7197	5/9/2012	5/18/2012	8748	15,921.36
Tetrachloroethylene *	127-18-4	P4R1E	7276	6/11/2012	6/25/2012	8748	11,372.40
Tetrachloroethylene *	127-18-4	P6R4E	6877	1/17/2012	1/25/2012	6	32.46
Tetrachloroethylene *	127-18-4	P6R4E	6918	1/31/2012	2/6/2012	2	17.86
Tetrachloroethylene *	127-18-4	P6R4E	6958	2/14/2012	2/23/2012	9	33.30
Tetrachloroethylene *	127-18-4	P6R4E	6994	2/28/2012	3/1/2012	2	17.40
Tetrachloroethylene *	127-18-4	P6R4E	7030	3/12/2012	3/21/2012	1.5	13.56
Tetrachloroethylene *	127-18-4	P6R4E	7068	3/29/2012	4/11/2012	4	32.64
Tetrachloroethylene *	127-18-4	P6R4E	7103	4/11/2012	4/13/2012	1	1.80
Tetrachloroethylene *	127-18-4	P6R4E	7141	4/24/2012	4/27/2012	1.5	11.57
Tetrachloroethylene *	127-18-4	P6R4E	7180	5/8/2012	5/15/2012	1.5	12.45
Tetrachloroethylene *	127-18-4	P6R4E	7217	5/22/2012	5/24/2012	1	9.05
Tetrachloroethylene *	127-18-4	P6R4E	7255	6/5/2012	6/7/2012	2	21.96
Tetrachloroethylene *	127-18-4	P6R4E	7293	6/19/2012	6/25/2012	2	11.94
Tetrachloroethylene *	127-18-4	P6R5E	6836	1/3/2012	1/11/2012	3	19.56
Tetrachloroethylene *	127-18-4	P6R5E	6875	1/16/2012	1/25/2012	6	38.28
Tetrachloroethylene *	127-18-4	P6R5E	6916	1/30/2012	2/6/2012	4	33.36
Tetrachloroethylene *	127-18-4	P6R5E	6956	2/13/2012	2/23/2012	9	35.73
Tetrachloroethylene *	127-18-4	P6R5E	6992	2/27/2012	3/1/2012	3	20.22
Tetrachloroethylene *	127-18-4	P6R5E	7028	3/12/2012	3/21/2012	1.5	16.11
Tetrachloroethylene *	127-18-4	P6R5E	7066	3/28/2012	4/11/2012	4	30.72
Tetrachloroethylene *	127-18-4	P6R5E	7101	4/10/2012	4/13/2012	3	21.39

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Tetrachloroethylene *	127-18-4	P6R5E	7139	4/23/2012	4/27/2012	1	7.73
Tetrachloroethylene *	127-18-4	P6R5E	7179	5/7/2012	5/15/2012	1.5	28.02
Tetrachloroethylene *	127-18-4	P6R5E	7215	5/21/2012	5/24/2012	1	9.54
Tetrachloroethylene *	127-18-4	P6R5E	7254	6/4/2012	6/7/2012	1.5	29.00
Tetrachloroethylene *	127-18-4	P6R5E	7291	6/18/2012	6/25/2012	3	26.73
Tetrachloroethylene *	127-18-4	P6R6E	6849	1/11/2012	1/19/2012	27	236.79
Tetrachloroethylene *	127-18-4	P6R6E	6906	1/24/2012	2/1/2012	27	223.29
Tetrachloroethylene *	127-18-4	P6R6E	6929	2/7/2012	2/14/2012	27	265.95
Tetrachloroethylene *	127-18-4	P6R6E	6983	2/22/2012	2/28/2012	12	105.00
Tetrachloroethylene *	127-18-4	P6R6E	7005	3/6/2012	3/13/2012	27	164.16
Tetrachloroethylene *	127-18-4	P6R6E	7061	3/20/2012	4/2/2012	9	82.71
Tetrachloroethylene *	127-18-4	P6R6E	7080	4/4/2012	4/12/2012	18	126.90
Tetrachloroethylene *	127-18-4	P6R6E	7134	4/17/2012	4/25/2012	18	134.10
Tetrachloroethylene *	127-18-4	P6R6E	7153	5/2/2012	5/10/2012	324	2,588.76
Tetrachloroethylene *	127-18-4	P6R6E	7206	5/15/2012	5/23/2012	81	802.71
Tetrachloroethylene *	127-18-4	P6R6E	7230	5/30/2012	6/5/2012	162	3,021.30
Tetrachloroethylene *	127-18-4	P6R6E	7285	6/12/2012	6/21/2012	324	3,460.32
Tetrachloroethylene *	127-18-4	P6R6E	7309	6/26/2012	7/9/2012	121.5	1,865.03
Tetrachloroethylene *	127-18-4	P6R6I	7152	5/2/2012	5/10/2012	81	383.94
Tetrachloroethylene *	127-18-4	P6R6I	7205	5/15/2012	5/23/2012	54	537.84
Tetrachloroethylene *	127-18-4	P6R6I	7228	5/30/2012	6/5/2012	40.5	292.01
Tetrachloroethylene *	127-18-4	P6R6I	7286	6/12/2012	6/21/2012	108	507.60
Tetrachloroethylene *	127-18-4	P6R6I	7310	6/26/2012	7/9/2012	27	319.68
Tetrachloroethylene *	127-18-4	P6R7E	6847	1/10/2012	1/19/2012	6561	39,300.39
Tetrachloroethylene *	127-18-4	P6R7E	6903	1/23/2012	2/1/2012	2916	24,144.48
Tetrachloroethylene *	127-18-4	P6R7E	6928	2/6/2012	2/14/2012	4374	32,280.12
Tetrachloroethylene *	127-18-4	P6R7E	6981	2/21/2012	2/28/2012	2817	24,166.35
Tetrachloroethylene *	127-18-4	P6R7E	7002	3/5/2012	3/13/2012	2187	18,830.07
Tetrachloroethylene *	127-18-4	P6R7E	7060	3/19/2012	4/2/2012	2916	19,683.00
Tetrachloroethylene *	127-18-4	P6R7E	7079	4/3/2012	4/12/2012	2187	11,700.45

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Tetrachloroethylene *	127-18-4	P6R7E	7131	4/16/2012	4/25/2012	1458	12,436.74
Tetrachloroethylene *	127-18-4	P6R7E	7149	5/1/2012	5/10/2012	6561	39,103.56
Tetrachloroethylene *	127-18-4	P6R7E	7203	5/14/2012	5/23/2012	4374	43,827.48
Tetrachloroethylene *	127-18-4	P6R7E	7227	5/29/2012	6/5/2012	4374	44,439.84
Tetrachloroethylene *	127-18-4	P6R7E	7283	6/11/2012	6/21/2012	8748	65,784.96
Tetrachloroethylene *	127-18-4	P6R7E	7308	6/25/2012	7/9/2012	6561	68,168.79
Tetrachloroethylene *	127-18-4	P6R7I	6848	1/10/2012	1/19/2012	1458	8,077.32
Tetrachloroethylene *	127-18-4	P6R7I	6905	1/23/2012	2/1/2012	972	5,822.28
Tetrachloroethylene *	127-18-4	P6R7I	6926	2/6/2012	2/14/2012	2916	15,629.76
Tetrachloroethylene *	127-18-4	P6R7I	6982	2/21/2012	2/28/2012	324	2,660.04
Tetrachloroethylene *	127-18-4	P6R7I	7004	3/5/2012	3/13/2012	729	2,784.78
Tetrachloroethylene *	127-18-4	P6R7I	7058	3/19/2012	4/2/2012	486	2,677.86
Tetrachloroethylene *	127-18-4	P6R7I	7078	4/3/2012	4/12/2012	121.5	809.19
Tetrachloroethylene *	127-18-4	P6R7I	7133	4/16/2012	4/25/2012	162	1,168.02
Tetrachloroethylene *	127-18-4	P6R7I	7150	5/1/2012	5/10/2012	6561	24,210.09
Tetrachloroethylene *	127-18-4	P6R7I	7204	5/14/2012	5/23/2012	4374	30,530.52
Tetrachloroethylene *	127-18-4	P6R7I	7226	5/29/2012	6/5/2012	3280.5	28,081.08
Tetrachloroethylene *	127-18-4	P6R7I	7282	6/11/2012	6/21/2012	8748	43,914.96
Tetrachloroethylene *	127-18-4	P6R7I	7306	6/25/2012	7/9/2012	8748	41,115.60
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6833	1/3/2012	1/11/2012	9	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6839	1/4/2012	1/11/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6843	1/10/2012	1/18/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6845	1/11/2012	1/18/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6871	1/17/2012	1/25/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6873	1/18/2012	1/25/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6899	1/24/2012	2/1/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6901	1/25/2012	2/1/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6911	1/31/2012	2/6/2012	1	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6913	2/1/2012	2/6/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6923	2/7/2012	2/14/2012	1.5	U

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6925	2/8/2012	2/14/2012	1.5	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6953	2/15/2012	2/23/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6951	2/16/2012	2/23/2012	1	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6977	2/21/2012	2/28/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6979	2/22/2012	2/28/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6989	2/28/2012	3/1/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6991	2/29/2012	3/1/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	6999	3/6/2012	3/13/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7001	3/7/2012	3/13/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7025	3/13/2012	3/21/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7027	3/14/2012	3/21/2012	9	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7055	3/20/2012	4/2/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7057	3/21/2012	4/2/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7063	3/28/2012	4/11/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7065	3/30/2012	4/11/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7073	4/3/2012	4/12/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7077	4/4/2012	4/12/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7097	4/10/2012	4/13/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7099	4/11/2012	4/13/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7127	4/17/2012	4/25/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7129	4/18/2012	4/25/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7135	4/24/2012	4/27/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7137	4/25/2012	4/27/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7145	5/1/2012	5/10/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7147	5/2/2012	5/10/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7175	5/8/2012	5/15/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7177	5/9/2012	5/15/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7199	5/15/2012	5/23/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7201	5/16/2012	5/23/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7211	5/22/2012	5/24/2012	4	U

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7213	5/23/2012	5/24/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7223	5/29/2012	6/5/2012	1	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7225	5/30/2012	6/5/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7249	6/5/2012	6/7/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7253	6/6/2012	6/7/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7279	6/12/2012	6/21/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7281	6/13/2012	6/21/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7287	6/19/2012	6/25/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7289	6/20/2012	6/25/2012	1.5	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7305	6/26/2012	7/9/2012	1.5	U
trans-1,2-Dichloroethylene *	156-60-5	VOC-A	7303	6/27/2012	7/9/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	P3R1E	6869	1/10/2012	1/19/2012	72	U
trans-1,2-Dichloroethylene *	156-60-5	P3R1E	6972	2/16/2012	2/28/2012	24	U
trans-1,2-Dichloroethylene *	156-60-5	P3R1E	7022	3/6/2012	3/13/2012	108	U
trans-1,2-Dichloroethylene *	156-60-5	P3R1E	7095	4/3/2012	4/11/2012	72	U
trans-1,2-Dichloroethylene *	156-60-5	P3R1E	7173	5/1/2012	5/11/2012	108	U
trans-1,2-Dichloroethylene *	156-60-5	P3R1E	7246	6/5/2012	6/18/2012	72	U
trans-1,2-Dichloroethylene *	156-60-5	P4R1E	6897	1/17/2012	1/25/2012	17496	U
trans-1,2-Dichloroethylene *	156-60-5	P4R1E	6948	2/7/2012	2/14/2012	13122	U
trans-1,2-Dichloroethylene *	156-60-5	P4R1E	7049	3/13/2012	3/21/2012	13122	U
trans-1,2-Dichloroethylene *	156-60-5	P4R1E	7119	4/10/2012	4/24/2012	13122	U
trans-1,2-Dichloroethylene *	156-60-5	P4R1E	7197	5/9/2012	5/18/2012	8748	U
trans-1,2-Dichloroethylene *	156-60-5	P4R1E	7276	6/11/2012	6/25/2012	8748	U
trans-1,2-Dichloroethylene *	156-60-5	P6R4E	6877	1/17/2012	1/25/2012	6	U
trans-1,2-Dichloroethylene *	156-60-5	P6R4E	6918	1/31/2012	2/6/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	P6R4E	6958	2/14/2012	2/23/2012	9	U
trans-1,2-Dichloroethylene *	156-60-5	P6R4E	6994	2/28/2012	3/1/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	P6R4E	7030	3/12/2012	3/21/2012	1.5	U
trans-1,2-Dichloroethylene *	156-60-5	P6R4E	7068	3/29/2012	4/11/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	P6R4E	7103	4/11/2012	4/13/2012	1	U

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
trans-1,2-Dichloroethylene *	156-60-5	P6R4E	7141	4/24/2012	4/27/2012	1.5	U
trans-1,2-Dichloroethylene *	156-60-5	P6R4E	7180	5/8/2012	5/15/2012	1.5	U
trans-1,2-Dichloroethylene *	156-60-5	P6R4E	7217	5/22/2012	5/24/2012	1	U
trans-1,2-Dichloroethylene *	156-60-5	P6R4E	7255	6/5/2012	6/7/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	P6R4E	7293	6/19/2012	6/25/2012	2	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	6836	1/3/2012	1/11/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	6875	1/16/2012	1/25/2012	6	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	6916	1/30/2012	2/6/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	6956	2/13/2012	2/23/2012	9	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	6992	2/27/2012	3/1/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	7028	3/12/2012	3/21/2012	1.5	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	7066	3/28/2012	4/11/2012	4	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	7101	4/10/2012	4/13/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	7139	4/23/2012	4/27/2012	1	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	7179	5/7/2012	5/15/2012	1.5	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	7215	5/21/2012	5/24/2012	1	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	7254	6/4/2012	6/7/2012	1.5	U
trans-1,2-Dichloroethylene *	156-60-5	P6R5E	7291	6/18/2012	6/25/2012	3	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	6849	1/11/2012	1/19/2012	27	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	6906	1/24/2012	2/1/2012	27	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	6929	2/7/2012	2/14/2012	27	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	6983	2/22/2012	2/28/2012	12	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	7005	3/6/2012	3/13/2012	27	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	7061	3/20/2012	4/2/2012	9	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	7080	4/4/2012	4/12/2012	18	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	7134	4/17/2012	4/25/2012	18	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	7153	5/2/2012	5/10/2012	324	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	7206	5/15/2012	5/23/2012	81	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	7230	5/30/2012	6/5/2012	162	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	7285	6/12/2012	6/21/2012	324	U

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
trans-1,2-Dichloroethylene *	156-60-5	P6R6E	7309	6/26/2012	7/9/2012	121.5	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6I	7152	5/2/2012	5/10/2012	81	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6I	7205	5/15/2012	5/23/2012	54	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6I	7228	5/30/2012	6/5/2012	40.5	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6I	7286	6/12/2012	6/21/2012	108	U
trans-1,2-Dichloroethylene *	156-60-5	P6R6I	7310	6/26/2012	7/9/2012	27	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	6847	1/10/2012	1/19/2012	6561	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	6903	1/23/2012	2/1/2012	2916	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	6928	2/6/2012	2/14/2012	4374	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	6981	2/21/2012	2/28/2012	2817	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	7002	3/5/2012	3/13/2012	2187	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	7060	3/19/2012	4/2/2012	2916	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	7079	4/3/2012	4/12/2012	2187	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	7131	4/16/2012	4/25/2012	1458	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	7149	5/1/2012	5/10/2012	6561	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	7203	5/14/2012	5/23/2012	4374	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	7227	5/29/2012	6/5/2012	4374	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	7283	6/11/2012	6/21/2012	8748	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7E	7308	6/25/2012	7/9/2012	6561	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	6848	1/10/2012	1/19/2012	1458	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	6905	1/23/2012	2/1/2012	972	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	6926	2/6/2012	2/14/2012	2916	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	6982	2/21/2012	2/28/2012	324	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	7004	3/5/2012	3/13/2012	729	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	7058	3/19/2012	4/2/2012	486	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	7078	4/3/2012	4/12/2012	121.5	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	7133	4/16/2012	4/25/2012	162	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	7150	5/1/2012	5/10/2012	6561	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	7204	5/14/2012	5/23/2012	4374	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	7226	5/29/2012	6/5/2012	3280.5	U

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	7282	6/11/2012	6/21/2012	8748	U
trans-1,2-Dichloroethylene *	156-60-5	P6R7I	7306	6/25/2012	7/9/2012	8748	U
Benzene *	71-43-2	VOC-A	6833	1/3/2012	1/11/2012	9	0.72 J
Benzene *	71-43-2	VOC-A	6839	1/4/2012	1/11/2012	2	0.70 J
Benzene *	71-43-2	VOC-A	6843	1/10/2012	1/18/2012	2	0.80 J
Benzene *	71-43-2	VOC-A	6845	1/11/2012	1/18/2012	4	0.56 J
Benzene *	71-43-2	VOC-A	6871	1/17/2012	1/25/2012	2	0.34 J
Benzene *	71-43-2	VOC-A	6873	1/18/2012	1/25/2012	4	0.44 J
Benzene *	71-43-2	VOC-A	6899	1/24/2012	2/1/2012	3	0.39 J
Benzene *	71-43-2	VOC-A	6901	1/25/2012	2/1/2012	3	0.63 J
Benzene *	71-43-2	VOC-A	6911	1/31/2012	2/6/2012	1	0.40 J
Benzene *	71-43-2	VOC-A	6913	2/1/2012	2/6/2012	3	0.72 J
Benzene *	71-43-2	VOC-A	6923	2/7/2012	2/14/2012	1.5	0.45 J
Benzene *	71-43-2	VOC-A	6925	2/8/2012	2/14/2012	1.5	0.42 J
Benzene *	71-43-2	VOC-A	6953	2/15/2012	2/23/2012	2	0.44 J
Benzene *	71-43-2	VOC-A	6951	2/16/2012	2/23/2012	1	0.37 J
Benzene *	71-43-2	VOC-A	6977	2/21/2012	2/28/2012	4	0.48 J
Benzene *	71-43-2	VOC-A	6979	2/22/2012	2/28/2012	4	0.36 J
Benzene *	71-43-2	VOC-A	6989	2/28/2012	3/1/2012	3	0.45 J
Benzene *	71-43-2	VOC-A	6991	2/29/2012	3/1/2012	2	0.44 J
Benzene *	71-43-2	VOC-A	6999	3/6/2012	3/13/2012	4	0.40 J
Benzene *	71-43-2	VOC-A	7001	3/7/2012	3/13/2012	2	0.40 J
Benzene *	71-43-2	VOC-A	7025	3/13/2012	3/21/2012	2	0.44 J
Benzene *	71-43-2	VOC-A	7027	3/14/2012	3/21/2012	9	U
Benzene *	71-43-2	VOC-A	7055	3/20/2012	4/2/2012	3	0.33 J
Benzene *	71-43-2	VOC-A	7057	3/21/2012	4/2/2012	3	0.39 J
Benzene *	71-43-2	VOC-A	7063	3/28/2012	4/11/2012	4	U
Benzene *	71-43-2	VOC-A	7065	3/30/2012	4/11/2012	2	0.54 J
Benzene *	71-43-2	VOC-A	7073	4/3/2012	4/12/2012	2	0.48 J
Benzene *	71-43-2	VOC-A	7077	4/4/2012	4/12/2012	3	0.60 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Benzene *	71-43-2	VOC-A	7097	4/10/2012	4/13/2012	3	0.42 J
Benzene *	71-43-2	VOC-A	7099	4/11/2012	4/13/2012	4	U
Benzene *	71-43-2	VOC-A	7127	4/17/2012	4/25/2012	2	0.42 J
Benzene *	71-43-2	VOC-A	7129	4/18/2012	4/25/2012	3	0.36 J
Benzene *	71-43-2	VOC-A	7135	4/24/2012	4/27/2012	4	U
Benzene *	71-43-2	VOC-A	7137	4/25/2012	4/27/2012	3	U
Benzene *	71-43-2	VOC-A	7145	5/1/2012	5/10/2012	3	0.63 J
Benzene *	71-43-2	VOC-A	7147	5/2/2012	5/10/2012	3	0.54 J
Benzene *	71-43-2	VOC-A	7175	5/8/2012	5/15/2012	4	0.32 J
Benzene *	71-43-2	VOC-A	7177	5/9/2012	5/15/2012	3	0.33 J
Benzene *	71-43-2	VOC-A	7199	5/15/2012	5/23/2012	2	0.88 J
Benzene *	71-43-2	VOC-A	7201	5/16/2012	5/23/2012	2	0.60 J
Benzene *	71-43-2	VOC-A	7211	5/22/2012	5/24/2012	4	0.52 J
Benzene *	71-43-2	VOC-A	7213	5/23/2012	5/24/2012	4	0.44 J
Benzene *	71-43-2	VOC-A	7223	5/29/2012	6/5/2012	1	1.18
Benzene *	71-43-2	VOC-A	7225	5/30/2012	6/5/2012	2	0.64 J
Benzene *	71-43-2	VOC-A	7249	6/5/2012	6/7/2012	2	0.72 J
Benzene *	71-43-2	VOC-A	7253	6/6/2012	6/7/2012	3	0.48 J
Benzene *	71-43-2	VOC-A	7279	6/12/2012	6/21/2012	2	0.56 J
Benzene *	71-43-2	VOC-A	7281	6/13/2012	6/21/2012	2	0.46 J
Benzene *	71-43-2	VOC-A	7287	6/19/2012	6/25/2012	2	0.34 J
Benzene *	71-43-2	VOC-A	7289	6/20/2012	6/25/2012	1.5	0.35 J
Benzene *	71-43-2	VOC-A	7305	6/26/2012	7/9/2012	1.5	0.42 J
Benzene *	71-43-2	VOC-A	7303	6/27/2012	7/9/2012	2	0.46 J
Benzene *	71-43-2	P3R1E	6869	1/10/2012	1/19/2012	72	22.32 J
Benzene *	71-43-2	P3R1E	6972	2/16/2012	2/28/2012	24	4.80 J
Benzene *	71-43-2	P3R1E	7022	3/6/2012	3/13/2012	108	17.28 J
Benzene *	71-43-2	P3R1E	7095	4/3/2012	4/11/2012	72	8.64 J
Benzene *	71-43-2	P3R1E	7173	5/1/2012	5/11/2012	108	21.60 J
Benzene *	71-43-2	P3R1E	7246	6/5/2012	6/18/2012	72	12.96 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Benzene *	71-43-2	P4R1E	6897	1/17/2012	1/25/2012	17496	U
Benzene *	71-43-2	P4R1E	6948	2/7/2012	2/14/2012	13122	U
Benzene *	71-43-2	P4R1E	7049	3/13/2012	3/21/2012	13122	U
Benzene *	71-43-2	P4R1E	7119	4/10/2012	4/24/2012	13122	U
Benzene *	71-43-2	P4R1E	7197	5/9/2012	5/18/2012	8748	U
Benzene *	71-43-2	P4R1E	7276	6/11/2012	6/25/2012	8748	U
Benzene *	71-43-2	P6R4E	6877	1/17/2012	1/25/2012	6	U
Benzene *	71-43-2	P6R4E	6918	1/31/2012	2/6/2012	2	0.38 J
Benzene *	71-43-2	P6R4E	6958	2/14/2012	2/23/2012	9	U
Benzene *	71-43-2	P6R4E	6994	2/28/2012	3/1/2012	2	0.46 J
Benzene *	71-43-2	P6R4E	7030	3/12/2012	3/21/2012	1.5	0.30 J
Benzene *	71-43-2	P6R4E	7068	3/29/2012	4/11/2012	4	U
Benzene *	71-43-2	P6R4E	7103	4/11/2012	4/13/2012	1	0.36 J
Benzene *	71-43-2	P6R4E	7141	4/24/2012	4/27/2012	1.5	0.27 J
Benzene *	71-43-2	P6R4E	7180	5/8/2012	5/15/2012	1.5	0.24 J
Benzene *	71-43-2	P6R4E	7217	5/22/2012	5/24/2012	1	0.21 J
Benzene *	71-43-2	P6R4E	7255	6/5/2012	6/7/2012	2	0.40 J
Benzene *	71-43-2	P6R4E	7293	6/19/2012	6/25/2012	2	U
Benzene *	71-43-2	P6R5E	6836	1/3/2012	1/11/2012	3	0.90 J
Benzene *	71-43-2	P6R5E	6875	1/16/2012	1/25/2012	6	U
Benzene *	71-43-2	P6R5E	6916	1/30/2012	2/6/2012	4	0.48 J
Benzene *	71-43-2	P6R5E	6956	2/13/2012	2/23/2012	9	U
Benzene *	71-43-2	P6R5E	6992	2/27/2012	3/1/2012	3	1.14 J
Benzene *	71-43-2	P6R5E	7028	3/12/2012	3/21/2012	1.5	0.45 J
Benzene *	71-43-2	P6R5E	7066	3/28/2012	4/11/2012	4	U
Benzene *	71-43-2	P6R5E	7101	4/10/2012	4/13/2012	3	0.45 J
Benzene *	71-43-2	P6R5E	7139	4/23/2012	4/27/2012	1	1.46
Benzene *	71-43-2	P6R5E	7179	5/7/2012	5/15/2012	1.5	0.83 J
Benzene *	71-43-2	P6R5E	7215	5/21/2012	5/24/2012	1	0.42 J
Benzene *	71-43-2	P6R5E	7254	6/4/2012	6/7/2012	1.5	0.51 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Benzene *	71-43-2	P6R5E	7291	6/18/2012	6/25/2012	3	0.54 J
Benzene *	71-43-2	P6R6E	6849	1/11/2012	1/19/2012	27	U
Benzene *	71-43-2	P6R6E	6906	1/24/2012	2/1/2012	27	U
Benzene *	71-43-2	P6R6E	6929	2/7/2012	2/14/2012	27	U
Benzene *	71-43-2	P6R6E	6983	2/22/2012	2/28/2012	12	U
Benzene *	71-43-2	P6R6E	7005	3/6/2012	3/13/2012	27	U
Benzene *	71-43-2	P6R6E	7061	3/20/2012	4/2/2012	9	U
Benzene *	71-43-2	P6R6E	7080	4/4/2012	4/12/2012	18	U
Benzene *	71-43-2	P6R6E	7134	4/17/2012	4/25/2012	18	U
Benzene *	71-43-2	P6R6E	7153	5/2/2012	5/10/2012	324	U
Benzene *	71-43-2	P6R6E	7206	5/15/2012	5/23/2012	81	U
Benzene *	71-43-2	P6R6E	7230	5/30/2012	6/5/2012	162	U
Benzene *	71-43-2	P6R6E	7285	6/12/2012	6/21/2012	324	U
Benzene *	71-43-2	P6R6E	7309	6/26/2012	7/9/2012	121.5	U
Benzene *	71-43-2	P6R6I	7152	5/2/2012	5/10/2012	81	U
Benzene *	71-43-2	P6R6I	7205	5/15/2012	5/23/2012	54	U
Benzene *	71-43-2	P6R6I	7228	5/30/2012	6/5/2012	40.5	U
Benzene *	71-43-2	P6R6I	7286	6/12/2012	6/21/2012	108	U
Benzene *	71-43-2	P6R6I	7310	6/26/2012	7/9/2012	27	U
Benzene *	71-43-2	P6R7E	6847	1/10/2012	1/19/2012	6561	U
Benzene *	71-43-2	P6R7E	6903	1/23/2012	2/1/2012	2916	U
Benzene *	71-43-2	P6R7E	6928	2/6/2012	2/14/2012	4374	U
Benzene *	71-43-2	P6R7E	6981	2/21/2012	2/28/2012	2817	U
Benzene *	71-43-2	P6R7E	7002	3/5/2012	3/13/2012	2187	U
Benzene *	71-43-2	P6R7E	7060	3/19/2012	4/2/2012	2916	U
Benzene *	71-43-2	P6R7E	7079	4/3/2012	4/12/2012	2187	U
Benzene *	71-43-2	P6R7E	7131	4/16/2012	4/25/2012	1458	U
Benzene *	71-43-2	P6R7E	7149	5/1/2012	5/10/2012	6561	U
Benzene *	71-43-2	P6R7E	7203	5/14/2012	5/23/2012	4374	U
Benzene *	71-43-2	P6R7E	7227	5/29/2012	6/5/2012	4374	U

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Benzene *	71-43-2	P6R7E	7283	6/11/2012	6/21/2012	8748	U
Benzene *	71-43-2	P6R7E	7308	6/25/2012	7/9/2012	6561	U
Benzene *	71-43-2	P6R7I	6848	1/10/2012	1/19/2012	1458	U
Benzene *	71-43-2	P6R7I	6905	1/23/2012	2/1/2012	972	U
Benzene *	71-43-2	P6R7I	6926	2/6/2012	2/14/2012	2916	U
Benzene *	71-43-2	P6R7I	6982	2/21/2012	2/28/2012	324	U
Benzene *	71-43-2	P6R7I	7004	3/5/2012	3/13/2012	729	U
Benzene *	71-43-2	P6R7I	7058	3/19/2012	4/2/2012	486	U
Benzene *	71-43-2	P6R7I	7078	4/3/2012	4/12/2012	121.5	U
Benzene *	71-43-2	P6R7I	7133	4/16/2012	4/25/2012	162	U
Benzene *	71-43-2	P6R7I	7150	5/1/2012	5/10/2012	6561	U
Benzene *	71-43-2	P6R7I	7204	5/14/2012	5/23/2012	4374	U
Benzene *	71-43-2	P6R7I	7226	5/29/2012	6/5/2012	3280.5	U
Benzene *	71-43-2	P6R7I	7282	6/11/2012	6/21/2012	8748	U
Benzene *	71-43-2	P6R7I	7306	6/25/2012	7/9/2012	8748	U
Chloromethane *	74-87-3	VOC-A	6833	1/3/2012	1/11/2012	9	3.24 J
Chloromethane *	74-87-3	VOC-A	6839	1/4/2012	1/11/2012	2	0.80 J
Chloromethane *	74-87-3	VOC-A	6843	1/10/2012	1/18/2012	2	1.02 J
Chloromethane *	74-87-3	VOC-A	6845	1/11/2012	1/18/2012	4	1.88 J
Chloromethane *	74-87-3	VOC-A	6871	1/17/2012	1/25/2012	2	0.68 J
Chloromethane *	74-87-3	VOC-A	6873	1/18/2012	1/25/2012	4	1.48 J
Chloromethane *	74-87-3	VOC-A	6899	1/24/2012	2/1/2012	3	1.47 J
Chloromethane *	74-87-3	VOC-A	6901	1/25/2012	2/1/2012	3	1.32 J
Chloromethane *	74-87-3	VOC-A	6911	1/31/2012	2/6/2012	1	0.73 J
Chloromethane *	74-87-3	VOC-A	6913	2/1/2012	2/6/2012	3	0.99 J
Chloromethane *	74-87-3	VOC-A	6923	2/7/2012	2/14/2012	1.5	0.92 J
Chloromethane *	74-87-3	VOC-A	6925	2/8/2012	2/14/2012	1.5	0.83 J
Chloromethane *	74-87-3	VOC-A	6953	2/15/2012	2/23/2012	2	0.90 J
Chloromethane *	74-87-3	VOC-A	6951	2/16/2012	2/23/2012	1	1.41
Chloromethane *	74-87-3	VOC-A	6977	2/21/2012	2/28/2012	4	1.32 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Chloromethane *	74-87-3	VOC-A	6979	2/22/2012	2/28/2012	4	1.96 J
Chloromethane *	74-87-3	VOC-A	6989	2/28/2012	3/1/2012	3	1.38 J
Chloromethane *	74-87-3	VOC-A	6991	2/29/2012	3/1/2012	2	1.10 J
Chloromethane *	74-87-3	VOC-A	6999	3/6/2012	3/13/2012	4	2.00 J
Chloromethane *	74-87-3	VOC-A	7001	3/7/2012	3/13/2012	2	1.08 J
Chloromethane *	74-87-3	VOC-A	7025	3/13/2012	3/21/2012	2	1.20 J
Chloromethane *	74-87-3	VOC-A	7027	3/14/2012	3/21/2012	9	2.61 J
Chloromethane *	74-87-3	VOC-A	7055	3/20/2012	4/2/2012	3	0.78 J
Chloromethane *	74-87-3	VOC-A	7057	3/21/2012	4/2/2012	3	0.93 J
Chloromethane *	74-87-3	VOC-A	7063	3/28/2012	4/11/2012	4	1.20 J
Chloromethane *	74-87-3	VOC-A	7065	3/30/2012	4/11/2012	2	0.94 J
Chloromethane *	74-87-3	VOC-A	7073	4/3/2012	4/12/2012	2	0.92 J
Chloromethane *	74-87-3	VOC-A	7077	4/4/2012	4/12/2012	3	1.05 J
Chloromethane *	74-87-3	VOC-A	7097	4/10/2012	4/13/2012	3	1.20 J
Chloromethane *	74-87-3	VOC-A	7099	4/11/2012	4/13/2012	4	1.64 J
Chloromethane *	74-87-3	VOC-A	7127	4/17/2012	4/25/2012	2	0.86 J
Chloromethane *	74-87-3	VOC-A	7129	4/18/2012	4/25/2012	3	1.14 J
Chloromethane *	74-87-3	VOC-A	7135	4/24/2012	4/27/2012	4	1.20 J
Chloromethane *	74-87-3	VOC-A	7137	4/25/2012	4/27/2012	3	0.87 J
Chloromethane *	74-87-3	VOC-A	7145	5/1/2012	5/10/2012	3	1.02 J
Chloromethane *	74-87-3	VOC-A	7147	5/2/2012	5/10/2012	3	0.99 J
Chloromethane *	74-87-3	VOC-A	7175	5/8/2012	5/15/2012	4	1.76 J
Chloromethane *	74-87-3	VOC-A	7177	5/9/2012	5/15/2012	3	0.90 J
Chloromethane *	74-87-3	VOC-A	7199	5/15/2012	5/23/2012	2	0.74 J
Chloromethane *	74-87-3	VOC-A	7201	5/16/2012	5/23/2012	2	0.84 J
Chloromethane *	74-87-3	VOC-A	7211	5/22/2012	5/24/2012	4	1.52 J
Chloromethane *	74-87-3	VOC-A	7213	5/23/2012	5/24/2012	4	1.16 J
Chloromethane *	74-87-3	VOC-A	7223	5/29/2012	6/5/2012	1	0.84 J
Chloromethane *	74-87-3	VOC-A	7225	5/30/2012	6/5/2012	2	1.14 J
Chloromethane *	74-87-3	VOC-A	7249	6/5/2012	6/7/2012	2	0.94 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Chloromethane *	74-87-3	VOC-A	7253	6/6/2012	6/7/2012	3	1.32 J
Chloromethane *	74-87-3	VOC-A	7279	6/12/2012	6/21/2012	2	1.20 J
Chloromethane *	74-87-3	VOC-A	7281	6/13/2012	6/21/2012	2	1.20 J
Chloromethane *	74-87-3	VOC-A	7287	6/19/2012	6/25/2012	2	0.96 J
Chloromethane *	74-87-3	VOC-A	7289	6/20/2012	6/25/2012	1.5	0.93 J
Chloromethane *	74-87-3	VOC-A	7305	6/26/2012	7/9/2012	1.5	0.81 J
Chloromethane *	74-87-3	VOC-A	7303	6/27/2012	7/9/2012	2	0.88 J
Chloromethane *	74-87-3	P3R1E	6869	1/10/2012	1/19/2012	72	123.12
Chloromethane *	74-87-3	P3R1E	6972	2/16/2012	2/28/2012	24	26.40
Chloromethane *	74-87-3	P3R1E	7022	3/6/2012	3/13/2012	108	112.32
Chloromethane *	74-87-3	P3R1E	7095	4/3/2012	4/11/2012	72	57.60 J
Chloromethane *	74-87-3	P3R1E	7173	5/1/2012	5/11/2012	108	75.60 J
Chloromethane *	74-87-3	P3R1E	7246	6/5/2012	6/18/2012	72	51.84 J
Chloromethane *	74-87-3	P4R1E	6897	1/17/2012	1/25/2012	17496	2,799.36 J
Chloromethane *	74-87-3	P4R1E	6948	2/7/2012	2/14/2012	13122	2,361.96 J
Chloromethane *	74-87-3	P4R1E	7049	3/13/2012	3/21/2012	13122	2,493.18 J
Chloromethane *	74-87-3	P4R1E	7119	4/10/2012	4/24/2012	13122	U
Chloromethane *	74-87-3	P4R1E	7197	5/9/2012	5/18/2012	8748	1,312.20 J
Chloromethane *	74-87-3	P4R1E	7276	6/11/2012	6/25/2012	8748	1,224.72 J
Chloromethane *	74-87-3	P6R4E	6877	1/17/2012	1/25/2012	6	U
Chloromethane *	74-87-3	P6R4E	6918	1/31/2012	2/6/2012	2	0.72 J
Chloromethane *	74-87-3	P6R4E	6958	2/14/2012	2/23/2012	9	1.08 J
Chloromethane *	74-87-3	P6R4E	6994	2/28/2012	3/1/2012	2	0.68 J
Chloromethane *	74-87-3	P6R4E	7030	3/12/2012	3/21/2012	1.5	0.74 J
Chloromethane *	74-87-3	P6R4E	7068	3/29/2012	4/11/2012	4	0.80 J
Chloromethane *	74-87-3	P6R4E	7103	4/11/2012	4/13/2012	1	0.60 J
Chloromethane *	74-87-3	P6R4E	7141	4/24/2012	4/27/2012	1.5	0.72 J
Chloromethane *	74-87-3	P6R4E	7180	5/8/2012	5/15/2012	1.5	0.75 J
Chloromethane *	74-87-3	P6R4E	7217	5/22/2012	5/24/2012	1	0.63 J
Chloromethane *	74-87-3	P6R4E	7255	6/5/2012	6/7/2012	2	0.64 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Chloromethane *	74-87-3	P6R4E	7293	6/19/2012	6/25/2012	2	0.36 J
Chloromethane *	74-87-3	P6R5E	6836	1/3/2012	1/11/2012	3	0.81 J
Chloromethane *	74-87-3	P6R5E	6875	1/16/2012	1/25/2012	6	U
Chloromethane *	74-87-3	P6R5E	6916	1/30/2012	2/6/2012	4	0.96 J
Chloromethane *	74-87-3	P6R5E	6956	2/13/2012	2/23/2012	9	0.99 J
Chloromethane *	74-87-3	P6R5E	6992	2/27/2012	3/1/2012	3	0.87 J
Chloromethane *	74-87-3	P6R5E	7028	3/12/2012	3/21/2012	1.5	0.71 J
Chloromethane *	74-87-3	P6R5E	7066	3/28/2012	4/11/2012	4	U
Chloromethane *	74-87-3	P6R5E	7101	4/10/2012	4/13/2012	3	0.69 J
Chloromethane *	74-87-3	P6R5E	7139	4/23/2012	4/27/2012	1	0.60 J
Chloromethane *	74-87-3	P6R5E	7179	5/7/2012	5/15/2012	1.5	0.77 J
Chloromethane *	74-87-3	P6R5E	7215	5/21/2012	5/24/2012	1	0.63 J
Chloromethane *	74-87-3	P6R5E	7254	6/4/2012	6/7/2012	1.5	0.78 J
Chloromethane *	74-87-3	P6R5E	7291	6/18/2012	6/25/2012	3	0.87 J
Chloromethane *	74-87-3	P6R6E	6849	1/11/2012	1/19/2012	27	U
Chloromethane *	74-87-3	P6R6E	6906	1/24/2012	2/1/2012	27	2.70 J
Chloromethane *	74-87-3	P6R6E	6929	2/7/2012	2/14/2012	27	U
Chloromethane *	74-87-3	P6R6E	6983	2/22/2012	2/28/2012	12	U
Chloromethane *	74-87-3	P6R6E	7005	3/6/2012	3/13/2012	27	2.16 J
Chloromethane *	74-87-3	P6R6E	7061	3/20/2012	4/2/2012	9	0.99 J
Chloromethane *	74-87-3	P6R6E	7080	4/4/2012	4/12/2012	18	U
Chloromethane *	74-87-3	P6R6E	7134	4/17/2012	4/25/2012	18	U
Chloromethane *	74-87-3	P6R6E	7153	5/2/2012	5/10/2012	324	U
Chloromethane *	74-87-3	P6R6E	7206	5/15/2012	5/23/2012	81	6.48 J
Chloromethane *	74-87-3	P6R6E	7230	5/30/2012	6/5/2012	162	22.68 J
Chloromethane *	74-87-3	P6R6E	7285	6/12/2012	6/21/2012	324	38.88 J
Chloromethane *	74-87-3	P6R6E	7309	6/26/2012	7/9/2012	121.5	U
Chloromethane *	74-87-3	P6R6I	7152	5/2/2012	5/10/2012	81	6.48 J
Chloromethane *	74-87-3	P6R6I	7205	5/15/2012	5/23/2012	54	5.94 J
Chloromethane *	74-87-3	P6R6I	7228	5/30/2012	6/5/2012	40.5	5.27 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Chloromethane *	74-87-3	P6R6I	7286	6/12/2012	6/21/2012	108	U
Chloromethane *	74-87-3	P6R6I	7310	6/26/2012	7/9/2012	27	U
Chloromethane *	74-87-3	P6R7E	6847	1/10/2012	1/19/2012	6561	U
Chloromethane *	74-87-3	P6R7E	6903	1/23/2012	2/1/2012	2916	U
Chloromethane *	74-87-3	P6R7E	6928	2/6/2012	2/14/2012	4374	U
Chloromethane *	74-87-3	P6R7E	6981	2/21/2012	2/28/2012	2817	U
Chloromethane *	74-87-3	P6R7E	7002	3/5/2012	3/13/2012	2187	U
Chloromethane *	74-87-3	P6R7E	7060	3/19/2012	4/2/2012	2916	U
Chloromethane *	74-87-3	P6R7E	7079	4/3/2012	4/12/2012	2187	U
Chloromethane *	74-87-3	P6R7E	7131	4/16/2012	4/25/2012	1458	U
Chloromethane *	74-87-3	P6R7E	7149	5/1/2012	5/10/2012	6561	U
Chloromethane *	74-87-3	P6R7E	7203	5/14/2012	5/23/2012	4374	393.66 J
Chloromethane *	74-87-3	P6R7E	7227	5/29/2012	6/5/2012	4374	U
Chloromethane *	74-87-3	P6R7E	7283	6/11/2012	6/21/2012	8748	699.84 J
Chloromethane *	74-87-3	P6R7E	7308	6/25/2012	7/9/2012	6561	U
Chloromethane *	74-87-3	P6R7I	6848	1/10/2012	1/19/2012	1458	U
Chloromethane *	74-87-3	P6R7I	6905	1/23/2012	2/1/2012	972	U
Chloromethane *	74-87-3	P6R7I	6926	2/6/2012	2/14/2012	2916	U
Chloromethane *	74-87-3	P6R7I	6982	2/21/2012	2/28/2012	324	U
Chloromethane *	74-87-3	P6R7I	7004	3/5/2012	3/13/2012	729	U
Chloromethane *	74-87-3	P6R7I	7058	3/19/2012	4/2/2012	486	U
Chloromethane *	74-87-3	P6R7I	7078	4/3/2012	4/12/2012	121.5	U
Chloromethane *	74-87-3	P6R7I	7133	4/16/2012	4/25/2012	162	U
Chloromethane *	74-87-3	P6R7I	7150	5/1/2012	5/10/2012	6561	U
Chloromethane *	74-87-3	P6R7I	7204	5/14/2012	5/23/2012	4374	U
Chloromethane *	74-87-3	P6R7I	7226	5/29/2012	6/5/2012	3280.5	U
Chloromethane *	74-87-3	P6R7I	7282	6/11/2012	6/21/2012	8748	U
Chloromethane *	74-87-3	P6R7I	7306	6/25/2012	7/9/2012	8748	U
Trichloromonofluoromethane *	75-69-4	VOC-A	6833	1/3/2012	1/11/2012	9	4.59 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6839	1/4/2012	1/11/2012	2	0.82 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Trichloromonofluoromethane *	75-69-4	VOC-A	6843	1/10/2012	1/18/2012	2	1.28 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6845	1/11/2012	1/18/2012	4	2.60 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6871	1/17/2012	1/25/2012	2	0.72 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6873	1/18/2012	1/25/2012	4	1.92 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6899	1/24/2012	2/1/2012	3	1.77 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6901	1/25/2012	2/1/2012	3	1.38 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6911	1/31/2012	2/6/2012	1	0.70 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6913	2/1/2012	2/6/2012	3	1.26 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6923	2/7/2012	2/14/2012	1.5	0.95 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6925	2/8/2012	2/14/2012	1.5	0.86 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6953	2/15/2012	2/23/2012	2	0.82 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6951	2/16/2012	2/23/2012	1	0.62 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6977	2/21/2012	2/28/2012	4	1.44 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6979	2/22/2012	2/28/2012	4	2.56 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6989	2/28/2012	3/1/2012	3	1.62 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6991	2/29/2012	3/1/2012	2	1.06 J
Trichloromonofluoromethane *	75-69-4	VOC-A	6999	3/6/2012	3/13/2012	4	2.68 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7001	3/7/2012	3/13/2012	2	1.12 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7025	3/13/2012	3/21/2012	2	1.20 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7027	3/14/2012	3/21/2012	9	3.69 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7055	3/20/2012	4/2/2012	3	1.02 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7057	3/21/2012	4/2/2012	3	1.11 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7063	3/28/2012	4/11/2012	4	0.84 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7065	3/30/2012	4/11/2012	2	0.60 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7073	4/3/2012	4/12/2012	2	0.62 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7077	4/4/2012	4/12/2012	3	0.81 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7097	4/10/2012	4/13/2012	3	0.87 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7099	4/11/2012	4/13/2012	4	1.48 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7127	4/17/2012	4/25/2012	2	0.52 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7129	4/18/2012	4/25/2012	3	0.99 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Trichloromonofluoromethane *	75-69-4	VOC-A	7135	4/24/2012	4/27/2012	4	0.92 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7137	4/25/2012	4/27/2012	3	0.66 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7145	5/1/2012	5/10/2012	3	0.72 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7147	5/2/2012	5/10/2012	3	0.60 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7175	5/8/2012	5/15/2012	4	1.60 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7177	5/9/2012	5/15/2012	3	0.78 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7199	5/15/2012	5/23/2012	2	0.50 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7201	5/16/2012	5/23/2012	2	0.58 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7211	5/22/2012	5/24/2012	4	1.40 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7213	5/23/2012	5/24/2012	4	1.00 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7223	5/29/2012	6/5/2012	1	0.51 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7225	5/30/2012	6/5/2012	2	0.82 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7249	6/5/2012	6/7/2012	2	0.70 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7253	6/6/2012	6/7/2012	3	0.99 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7279	6/12/2012	6/21/2012	2	0.86 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7281	6/13/2012	6/21/2012	2	0.90 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7287	6/19/2012	6/25/2012	2	0.64 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7289	6/20/2012	6/25/2012	1.5	0.63 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7305	6/26/2012	7/9/2012	1.5	0.56 J
Trichloromonofluoromethane *	75-69-4	VOC-A	7303	6/27/2012	7/9/2012	2	0.58 J
Trichloromonofluoromethane *	75-69-4	P3R1E	6869	1/10/2012	1/19/2012	72	70.56 J
Trichloromonofluoromethane *	75-69-4	P3R1E	6972	2/16/2012	2/28/2012	24	19.92 J
Trichloromonofluoromethane *	75-69-4	P3R1E	7022	3/6/2012	3/13/2012	108	87.48 J
Trichloromonofluoromethane *	75-69-4	P3R1E	7095	4/3/2012	4/11/2012	72	36.72 J
Trichloromonofluoromethane *	75-69-4	P3R1E	7173	5/1/2012	5/11/2012	108	51.84 J
Trichloromonofluoromethane *	75-69-4	P3R1E	7246	6/5/2012	6/18/2012	72	46.80 J
Trichloromonofluoromethane *	75-69-4	P4R1E	6897	1/17/2012	1/25/2012	17496	4,024.08 J
Trichloromonofluoromethane *	75-69-4	P4R1E	6948	2/7/2012	2/14/2012	13122	3,149.28 J
Trichloromonofluoromethane *	75-69-4	P4R1E	7049	3/13/2012	3/21/2012	13122	3,411.72 J
Trichloromonofluoromethane *	75-69-4	P4R1E	7119	4/10/2012	4/24/2012	13122	2,493.18 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Trichloromonofluoromethane *	75-69-4	P4R1E	7197	5/9/2012	5/18/2012	8748	1,749.60 J
Trichloromonofluoromethane *	75-69-4	P4R1E	7276	6/11/2012	6/25/2012	8748	2,099.52 J
Trichloromonofluoromethane *	75-69-4	P6R4E	6877	1/17/2012	1/25/2012	6	0.90 J
Trichloromonofluoromethane *	75-69-4	P6R4E	6918	1/31/2012	2/6/2012	2	0.72 J
Trichloromonofluoromethane *	75-69-4	P6R4E	6958	2/14/2012	2/23/2012	9	1.35 J
Trichloromonofluoromethane *	75-69-4	P6R4E	6994	2/28/2012	3/1/2012	2	0.62 J
Trichloromonofluoromethane *	75-69-4	P6R4E	7030	3/12/2012	3/21/2012	1.5	0.57 J
Trichloromonofluoromethane *	75-69-4	P6R4E	7068	3/29/2012	4/11/2012	4	0.64 J
Trichloromonofluoromethane *	75-69-4	P6R4E	7103	4/11/2012	4/13/2012	1	0.24 J
Trichloromonofluoromethane *	75-69-4	P6R4E	7141	4/24/2012	4/27/2012	1.5	0.33 J
Trichloromonofluoromethane *	75-69-4	P6R4E	7180	5/8/2012	5/15/2012	1.5	0.50 J
Trichloromonofluoromethane *	75-69-4	P6R4E	7217	5/22/2012	5/24/2012	1	0.37 J
Trichloromonofluoromethane *	75-69-4	P6R4E	7255	6/5/2012	6/7/2012	2	0.40 J
Trichloromonofluoromethane *	75-69-4	P6R4E	7293	6/19/2012	6/25/2012	2	0.36 J
Trichloromonofluoromethane *	75-69-4	P6R5E	6836	1/3/2012	1/11/2012	3	0.69 J
Trichloromonofluoromethane *	75-69-4	P6R5E	6875	1/16/2012	1/25/2012	6	0.96 J
Trichloromonofluoromethane *	75-69-4	P6R5E	6916	1/30/2012	2/6/2012	4	1.08 J
Trichloromonofluoromethane *	75-69-4	P6R5E	6956	2/13/2012	2/23/2012	9	1.17 J
Trichloromonofluoromethane *	75-69-4	P6R5E	6992	2/27/2012	3/1/2012	3	0.75 J
Trichloromonofluoromethane *	75-69-4	P6R5E	7028	3/12/2012	3/21/2012	1.5	0.60 J
Trichloromonofluoromethane *	75-69-4	P6R5E	7066	3/28/2012	4/11/2012	4	U
Trichloromonofluoromethane *	75-69-4	P6R5E	7101	4/10/2012	4/13/2012	3	U
Trichloromonofluoromethane *	75-69-4	P6R5E	7139	4/23/2012	4/27/2012	1	0.32 J
Trichloromonofluoromethane *	75-69-4	P6R5E	7179	5/7/2012	5/15/2012	1.5	0.45 J
Trichloromonofluoromethane *	75-69-4	P6R5E	7215	5/21/2012	5/24/2012	1	0.31 J
Trichloromonofluoromethane *	75-69-4	P6R5E	7254	6/4/2012	6/7/2012	1.5	0.48 J
Trichloromonofluoromethane *	75-69-4	P6R5E	7291	6/18/2012	6/25/2012	3	1.89 J
Trichloromonofluoromethane *	75-69-4	P6R6E	6849	1/11/2012	1/19/2012	27	4.59 J
Trichloromonofluoromethane *	75-69-4	P6R6E	6906	1/24/2012	2/1/2012	27	4.59 J
Trichloromonofluoromethane *	75-69-4	P6R6E	6929	2/7/2012	2/14/2012	27	4.59 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Trichloromonofluoromethane *	75-69-4	P6R6E	6983	2/22/2012	2/28/2012	12	1.92 J
Trichloromonofluoromethane *	75-69-4	P6R6E	7005	3/6/2012	3/13/2012	27	2.97 J
Trichloromonofluoromethane *	75-69-4	P6R6E	7061	3/20/2012	4/2/2012	9	1.53 J
Trichloromonofluoromethane *	75-69-4	P6R6E	7080	4/4/2012	4/12/2012	18	U
Trichloromonofluoromethane *	75-69-4	P6R6E	7134	4/17/2012	4/25/2012	18	U
Trichloromonofluoromethane *	75-69-4	P6R6E	7153	5/2/2012	5/10/2012	324	U
Trichloromonofluoromethane *	75-69-4	P6R6E	7206	5/15/2012	5/23/2012	81	U
Trichloromonofluoromethane *	75-69-4	P6R6E	7230	5/30/2012	6/5/2012	162	29.16 J
Trichloromonofluoromethane *	75-69-4	P6R6E	7285	6/12/2012	6/21/2012	324	35.64 J
Trichloromonofluoromethane *	75-69-4	P6R6E	7309	6/26/2012	7/9/2012	121.5	U
Trichloromonofluoromethane *	75-69-4	P6R6I	7152	5/2/2012	5/10/2012	81	U
Trichloromonofluoromethane *	75-69-4	P6R6I	7205	5/15/2012	5/23/2012	54	8.64 J
Trichloromonofluoromethane *	75-69-4	P6R6I	7228	5/30/2012	6/5/2012	40.5	4.86 J
Trichloromonofluoromethane *	75-69-4	P6R6I	7286	6/12/2012	6/21/2012	108	14.04 J
Trichloromonofluoromethane *	75-69-4	P6R6I	7310	6/26/2012	7/9/2012	27	U
Trichloromonofluoromethane *	75-69-4	P6R7E	6847	1/10/2012	1/19/2012	6561	U
Trichloromonofluoromethane *	75-69-4	P6R7E	6903	1/23/2012	2/1/2012	2916	320.76 J
Trichloromonofluoromethane *	75-69-4	P6R7E	6928	2/6/2012	2/14/2012	4374	437.40 J
Trichloromonofluoromethane *	75-69-4	P6R7E	6981	2/21/2012	2/28/2012	2817	284.31 J
Trichloromonofluoromethane *	75-69-4	P6R7E	7002	3/5/2012	3/13/2012	2187	240.57 J
Trichloromonofluoromethane *	75-69-4	P6R7E	7060	3/19/2012	4/2/2012	2916	320.76 J
Trichloromonofluoromethane *	75-69-4	P6R7E	7079	4/3/2012	4/12/2012	2187	U
Trichloromonofluoromethane *	75-69-4	P6R7E	7131	4/16/2012	4/25/2012	1458	U
Trichloromonofluoromethane *	75-69-4	P6R7E	7149	5/1/2012	5/10/2012	6561	U
Trichloromonofluoromethane *	75-69-4	P6R7E	7203	5/14/2012	5/23/2012	4374	656.10 J
Trichloromonofluoromethane *	75-69-4	P6R7E	7227	5/29/2012	6/5/2012	4374	568.62 J
Trichloromonofluoromethane *	75-69-4	P6R7E	7283	6/11/2012	6/21/2012	8748	1,224.72 J
Trichloromonofluoromethane *	75-69-4	P6R7E	7308	6/25/2012	7/9/2012	6561	U
Trichloromonofluoromethane *	75-69-4	P6R7I	6848	1/10/2012	1/19/2012	1458	291.60 J
Trichloromonofluoromethane *	75-69-4	P6R7I	6905	1/23/2012	2/1/2012	972	291.60 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Trichloromonofluoromethane *	75-69-4	P6R7I	6926	2/6/2012	2/14/2012	2916	729.00 J
Trichloromonofluoromethane *	75-69-4	P6R7I	6982	2/21/2012	2/28/2012	324	110.16 J
Trichloromonofluoromethane *	75-69-4	P6R7I	7004	3/5/2012	3/13/2012	729	225.99 J
Trichloromonofluoromethane *	75-69-4	P6R7I	7058	3/19/2012	4/2/2012	486	150.66 J
Trichloromonofluoromethane *	75-69-4	P6R7I	7078	4/3/2012	4/12/2012	121.5	42.53 J
Trichloromonofluoromethane *	75-69-4	P6R7I	7133	4/16/2012	4/25/2012	162	64.80 J
Trichloromonofluoromethane *	75-69-4	P6R7I	7150	5/1/2012	5/10/2012	6561	721.71 J
Trichloromonofluoromethane *	75-69-4	P6R7I	7204	5/14/2012	5/23/2012	4374	962.28 J
Trichloromonofluoromethane *	75-69-4	P6R7I	7226	5/29/2012	6/5/2012	3280.5	721.71 J
Trichloromonofluoromethane *	75-69-4	P6R7I	7282	6/11/2012	6/21/2012	8748	1,399.68 J
Trichloromonofluoromethane *	75-69-4	P6R7I	7306	6/25/2012	7/9/2012	8748	U
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6833	1/3/2012	1/11/2012		32.13 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6839	1/4/2012	1/11/2012		13.26 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6843	1/10/2012	1/18/2012		11.92 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6845	1/11/2012	1/18/2012		20.28 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6871	1/17/2012	1/25/2012		15.54 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6873	1/18/2012	1/25/2012		20.60 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6899	1/24/2012	2/1/2012		15.57 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6901	1/25/2012	2/1/2012		12.84 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6911	1/31/2012	2/6/2012		6.35 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6913	2/1/2012	2/6/2012		17.61 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6923	2/7/2012	2/14/2012		6.93 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6925	2/8/2012	2/14/2012		7.29 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6953	2/15/2012	2/23/2012		11.50 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6951	2/16/2012	2/23/2012		5.53 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6977	2/21/2012	2/28/2012		20.36 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6979	2/22/2012	2/28/2012		24.52 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6989	2/28/2012	3/1/2012		19.62 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6991	2/29/2012	3/1/2012		11.30 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	6999	3/6/2012	3/13/2012		21.28 NJ

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7001	3/7/2012	3/13/2012		12.62 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7025	3/13/2012	3/21/2012		9.44 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7027	3/14/2012	3/21/2012		34.29 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7055	3/20/2012	4/2/2012		9.87 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7057	3/21/2012	4/2/2012		11.85 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7063	3/28/2012	4/11/2012		19.96 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7065	3/30/2012	4/11/2012		10.00 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7073	4/3/2012	4/12/2012		11.80 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7077	4/4/2012	4/12/2012		12.90 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7097	4/10/2012	4/13/2012		17.40 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7099	4/11/2012	4/13/2012		20.76 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7127	4/17/2012	4/25/2012		10.50 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7129	4/18/2012	4/25/2012		13.62 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7135	4/24/2012	4/27/2012		16.04 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7137	4/25/2012	4/27/2012		9.42 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7145	5/1/2012	5/10/2012		14.01 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7147	5/2/2012	5/10/2012		10.23 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7175	5/8/2012	5/15/2012		12.72 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7177	5/9/2012	5/15/2012		19.17 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7199	5/15/2012	5/23/2012		10.40 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7201	5/16/2012	5/23/2012		9.74 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7211	5/22/2012	5/24/2012		14.76 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7213	5/23/2012	5/24/2012		14.48 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7223	5/29/2012	6/5/2012		6.00 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7225	5/30/2012	6/5/2012		12.18 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7249	6/5/2012	6/7/2012		13.04 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7253	6/6/2012	6/7/2012		14.01 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7279	6/12/2012	6/21/2012		10.76 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7281	6/13/2012	6/21/2012		10.16 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7287	6/19/2012	6/25/2012		6.60 NJ

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7289	6/20/2012	6/25/2012		6.44 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7305	6/26/2012	7/9/2012		7.34 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	VOC-A	7303	6/27/2012	7/9/2012		7.82 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P3R1E	6869	1/10/2012	1/19/2012		1,519.92 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P3R1E	6972	2/16/2012	2/28/2012		384.48 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P3R1E	7022	3/6/2012	3/13/2012		1,644.84 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P3R1E	7095	4/3/2012	4/11/2012		805.68 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P3R1E	7173	5/1/2012	5/11/2012		1,087.56 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P3R1E	7246	6/5/2012	6/18/2012		929.52 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P4R1E	6897	1/17/2012	1/25/2012		120,897.36 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P4R1E	6948	2/7/2012	2/14/2012		102,220.38 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P4R1E	7049	3/13/2012	3/21/2012		111,012.12 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P4R1E	7119	4/10/2012	4/24/2012		78,600.78 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P4R1E	7197	5/9/2012	5/18/2012		52,400.52 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P4R1E	7276	6/11/2012	6/25/2012		46,101.96 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R4E	6877	1/17/2012	1/25/2012		34.50 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R4E	6918	1/31/2012	2/6/2012		13.50 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R4E	6958	2/14/2012	2/23/2012		40.59 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R4E	6994	2/28/2012	3/1/2012		13.58 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R4E	7030	3/12/2012	3/21/2012		7.32 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R4E	7068	3/29/2012	4/11/2012		22.32 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R4E	7141	4/24/2012	4/27/2012		6.48 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R4E	7180	5/8/2012	5/15/2012		13.23 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R4E	7217	5/22/2012	5/24/2012		5.24 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R4E	7255	6/5/2012	6/7/2012		10.88 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R4E	7293	6/19/2012	6/25/2012		6.72 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	6836	1/3/2012	1/11/2012		20.58 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	6875	1/16/2012	1/25/2012		35.76 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	6916	1/30/2012	2/6/2012		30.88 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	6956	2/13/2012	2/23/2012		36.27 NJ

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	6992	2/27/2012	3/1/2012		23.61 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	7028	3/12/2012	3/21/2012		8.85 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	7066	3/28/2012	4/11/2012		16.72 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	7101	4/10/2012	4/13/2012		10.11 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	7139	4/23/2012	4/27/2012		4.12 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	7179	5/7/2012	5/15/2012		14.70 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	7215	5/21/2012	5/24/2012		3.81 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	7254	6/4/2012	6/7/2012		12.86 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R5E	7291	6/18/2012	6/25/2012		17.07 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	6849	1/11/2012	1/19/2012		194.94 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	6906	1/24/2012	2/1/2012		244.08 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	6929	2/7/2012	2/14/2012		158.22 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	6983	2/22/2012	2/28/2012		73.92 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	7005	3/6/2012	3/13/2012		103.14 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	7061	3/20/2012	4/2/2012		45.09 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	7080	4/4/2012	4/12/2012		77.76 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	7134	4/17/2012	4/25/2012		56.88 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	7153	5/2/2012	5/10/2012		1,519.56 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	7206	5/15/2012	5/23/2012		546.75 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	7230	5/30/2012	6/5/2012		1,731.78 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	7285	6/12/2012	6/21/2012		1,513.08 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6E	7309	6/26/2012	7/9/2012		1,059.48 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6I	7152	5/2/2012	5/10/2012		511.92 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6I	7205	5/15/2012	5/23/2012		635.58 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6I	7228	5/30/2012	6/5/2012		533.79 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6I	7286	6/12/2012	6/21/2012		552.96 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R6I	7310	6/26/2012	7/9/2012		181.44 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	6847	1/10/2012	1/19/2012		38,119.41 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	6903	1/23/2012	2/1/2012		18,545.76 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	6928	2/6/2012	2/14/2012		23,138.46 NJ

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	6981	2/21/2012	2/28/2012		17,496.00 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	7002	3/5/2012	3/13/2012		14,062.41 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	7060	3/19/2012	4/2/2012		16,796.16 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	7079	4/3/2012	4/12/2012		9,557.19 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	7131	4/16/2012	4/25/2012		7,202.52 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	7149	5/1/2012	5/10/2012		22,241.79 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	7203	5/14/2012	5/23/2012		27,599.94 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	7227	5/29/2012	6/5/2012		25,150.50 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	7283	6/11/2012	6/21/2012		43,302.60 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7E	7308	6/25/2012	7/9/2012		44,024.31 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	6848	1/10/2012	1/19/2012		19,128.96 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	6905	1/23/2012	2/1/2012		16,786.44 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	6926	2/6/2012	2/14/2012		42,748.56 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	6982	2/21/2012	2/28/2012		5,780.16 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	7004	3/5/2012	3/13/2012		11,139.12 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	7058	3/19/2012	4/2/2012		7,178.22 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	7078	4/3/2012	4/12/2012		1,759.32 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	7133	4/16/2012	4/25/2012		2,502.90 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	7150	5/1/2012	5/10/2012		37,266.48 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	7204	5/14/2012	5/23/2012		42,690.24 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	7226	5/29/2012	6/5/2012		31,361.58 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	7282	6/11/2012	6/21/2012		51,088.32 NJ
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-	76-13-1	P6R7I	7306	6/25/2012	7/9/2012		50,563.44 NJ
Propane, 1,2-dichloro-	78-87-5	P3R1E	7173	5/1/2012	5/11/2012		133.92 NJ
Propane, 1,2-dichloro-	78-87-5	P3R1E	7246	6/5/2012	6/18/2012		84.24 NJ
2-Butanone	78-93-3	P6R5E	7179	5/7/2012	5/15/2012		1.97 NJ
Trichloroethylene *	79-01-6	VOC-A	6833	1/3/2012	1/11/2012	9	95.58
Trichloroethylene *	79-01-6	VOC-A	6839	1/4/2012	1/11/2012	2	33.20
Trichloroethylene *	79-01-6	VOC-A	6843	1/10/2012	1/18/2012	2	34.94
Trichloroethylene *	79-01-6	VOC-A	6845	1/11/2012	1/18/2012	4	62.48

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Trichloroethylene *	79-01-6	VOC-A	6871	1/17/2012	1/25/2012	2	44.14
Trichloroethylene *	79-01-6	VOC-A	6873	1/18/2012	1/25/2012	4	60.24
Trichloroethylene *	79-01-6	VOC-A	6899	1/24/2012	2/1/2012	3	36.09
Trichloroethylene *	79-01-6	VOC-A	6901	1/25/2012	2/1/2012	3	32.97
Trichloroethylene *	79-01-6	VOC-A	6911	1/31/2012	2/6/2012	1	19.28
Trichloroethylene *	79-01-6	VOC-A	6913	2/1/2012	2/6/2012	3	33.30
Trichloroethylene *	79-01-6	VOC-A	6923	2/7/2012	2/14/2012	1.5	21.51
Trichloroethylene *	79-01-6	VOC-A	6925	2/8/2012	2/14/2012	1.5	21.20
Trichloroethylene *	79-01-6	VOC-A	6953	2/15/2012	2/23/2012	2	32.14
Trichloroethylene *	79-01-6	VOC-A	6951	2/16/2012	2/23/2012	1	18.41
Trichloroethylene *	79-01-6	VOC-A	6977	2/21/2012	2/28/2012	4	48.00
Trichloroethylene *	79-01-6	VOC-A	6979	2/22/2012	2/28/2012	4	79.48
Trichloroethylene *	79-01-6	VOC-A	6989	2/28/2012	3/1/2012	3	47.79
Trichloroethylene *	79-01-6	VOC-A	6991	2/29/2012	3/1/2012	2	33.68
Trichloroethylene *	79-01-6	VOC-A	6999	3/6/2012	3/13/2012	4	64.16
Trichloroethylene *	79-01-6	VOC-A	7001	3/7/2012	3/13/2012	2	34.28
Trichloroethylene *	79-01-6	VOC-A	7025	3/13/2012	3/21/2012	2	32.28
Trichloroethylene *	79-01-6	VOC-A	7027	3/14/2012	3/21/2012	9	94.14
Trichloroethylene *	79-01-6	VOC-A	7055	3/20/2012	4/2/2012	3	27.18
Trichloroethylene *	79-01-6	VOC-A	7057	3/21/2012	4/2/2012	3	32.49
Trichloroethylene *	79-01-6	VOC-A	7063	3/28/2012	4/11/2012	4	43.96
Trichloroethylene *	79-01-6	VOC-A	7065	3/30/2012	4/11/2012	2	31.96
Trichloroethylene *	79-01-6	VOC-A	7073	4/3/2012	4/12/2012	2	38.22
Trichloroethylene *	79-01-6	VOC-A	7077	4/4/2012	4/12/2012	3	45.75
Trichloroethylene *	79-01-6	VOC-A	7097	4/10/2012	4/13/2012	3	52.68
Trichloroethylene *	79-01-6	VOC-A	7099	4/11/2012	4/13/2012	4	74.40
Trichloroethylene *	79-01-6	VOC-A	7127	4/17/2012	4/25/2012	2	35.22
Trichloroethylene *	79-01-6	VOC-A	7129	4/18/2012	4/25/2012	3	45.03
Trichloroethylene *	79-01-6	VOC-A	7135	4/24/2012	4/27/2012	4	41.40
Trichloroethylene *	79-01-6	VOC-A	7137	4/25/2012	4/27/2012	3	29.46

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Trichloroethylene *	79-01-6	VOC-A	7145	5/1/2012	5/10/2012	3	38.79
Trichloroethylene *	79-01-6	VOC-A	7147	5/2/2012	5/10/2012	3	36.48
Trichloroethylene *	79-01-6	VOC-A	7175	5/8/2012	5/15/2012	4	57.60
Trichloroethylene *	79-01-6	VOC-A	7177	5/9/2012	5/15/2012	3	52.23
Trichloroethylene *	79-01-6	VOC-A	7199	5/15/2012	5/23/2012	2	35.82
Trichloroethylene *	79-01-6	VOC-A	7201	5/16/2012	5/23/2012	2	37.10
Trichloroethylene *	79-01-6	VOC-A	7211	5/22/2012	5/24/2012	4	69.72
Trichloroethylene *	79-01-6	VOC-A	7213	5/23/2012	5/24/2012	4	52.48
Trichloroethylene *	79-01-6	VOC-A	7223	5/29/2012	6/5/2012	1	22.27
Trichloroethylene *	79-01-6	VOC-A	7225	5/30/2012	6/5/2012	2	50.32
Trichloroethylene *	79-01-6	VOC-A	7249	6/5/2012	6/7/2012	2	49.48
Trichloroethylene *	79-01-6	VOC-A	7253	6/6/2012	6/7/2012	3	56.04
Trichloroethylene *	79-01-6	VOC-A	7279	6/12/2012	6/21/2012	2	32.32
Trichloroethylene *	79-01-6	VOC-A	7281	6/13/2012	6/21/2012	2	41.56
Trichloroethylene *	79-01-6	VOC-A	7287	6/19/2012	6/25/2012	2	24.56
Trichloroethylene *	79-01-6	VOC-A	7289	6/20/2012	6/25/2012	1.5	24.39
Trichloroethylene *	79-01-6	VOC-A	7305	6/26/2012	7/9/2012	1.5	24.29
Trichloroethylene *	79-01-6	VOC-A	7303	6/27/2012	7/9/2012	2	25.74
Trichloroethylene *	79-01-6	P3R1E	6869	1/10/2012	1/19/2012	72	550.08
Trichloroethylene *	79-01-6	P3R1E	6972	2/16/2012	2/28/2012	24	172.80
Trichloroethylene *	79-01-6	P3R1E	7022	3/6/2012	3/13/2012	108	563.76
Trichloroethylene *	79-01-6	P3R1E	7095	4/3/2012	4/11/2012	72	326.88
Trichloroethylene *	79-01-6	P3R1E	7173	5/1/2012	5/11/2012	108	503.28
Trichloroethylene *	79-01-6	P3R1E	7246	6/5/2012	6/18/2012	72	395.28
Trichloroethylene *	79-01-6	P4R1E	6897	1/17/2012	1/25/2012	17496	181,783.44
Trichloroethylene *	79-01-6	P4R1E	6948	2/7/2012	2/14/2012	13122	170,323.56
Trichloroethylene *	79-01-6	P4R1E	7049	3/13/2012	3/21/2012	13122	190,793.88
Trichloroethylene *	79-01-6	P4R1E	7119	4/10/2012	4/24/2012	13122	150,640.56
Trichloroethylene *	79-01-6	P4R1E	7197	5/9/2012	5/18/2012	8748	131,307.48
Trichloroethylene *	79-01-6	P4R1E	7276	6/11/2012	6/25/2012	8748	118,447.92

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Trichloroethylene *	79-01-6	P6R4E	6877	1/17/2012	1/25/2012	6	116.70
Trichloroethylene *	79-01-6	P6R4E	6918	1/31/2012	2/6/2012	2	59.78
Trichloroethylene *	79-01-6	P6R4E	6958	2/14/2012	2/23/2012	9	122.85
Trichloroethylene *	79-01-6	P6R4E	6994	2/28/2012	3/1/2012	2	60.38
Trichloroethylene *	79-01-6	P6R4E	7030	3/12/2012	3/21/2012	1.5	44.96
Trichloroethylene *	79-01-6	P6R4E	7068	3/29/2012	4/11/2012	4	108.16
Trichloroethylene *	79-01-6	P6R4E	7103	4/11/2012	4/13/2012	1	7.09
Trichloroethylene *	79-01-6	P6R4E	7141	4/24/2012	4/27/2012	1.5	34.80
Trichloroethylene *	79-01-6	P6R4E	7180	5/8/2012	5/15/2012	1.5	35.84
Trichloroethylene *	79-01-6	P6R4E	7217	5/22/2012	5/24/2012	1	29.25
Trichloroethylene *	79-01-6	P6R4E	7255	6/5/2012	6/7/2012	2	68.90
Trichloroethylene *	79-01-6	P6R4E	7293	6/19/2012	6/25/2012	2	40.12
Trichloroethylene *	79-01-6	P6R5E	6836	1/3/2012	1/11/2012	3	66.36
Trichloroethylene *	79-01-6	P6R5E	6875	1/16/2012	1/25/2012	6	137.82
Trichloroethylene *	79-01-6	P6R5E	6916	1/30/2012	2/6/2012	4	105.00
Trichloroethylene *	79-01-6	P6R5E	6956	2/13/2012	2/23/2012	9	129.87
Trichloroethylene *	79-01-6	P6R5E	6992	2/27/2012	3/1/2012	3	64.92
Trichloroethylene *	79-01-6	P6R5E	7028	3/12/2012	3/21/2012	1.5	48.23
Trichloroethylene *	79-01-6	P6R5E	7066	3/28/2012	4/11/2012	4	97.44
Trichloroethylene *	79-01-6	P6R5E	7101	4/10/2012	4/13/2012	3	67.20
Trichloroethylene *	79-01-6	P6R5E	7139	4/23/2012	4/27/2012	1	21.64
Trichloroethylene *	79-01-6	P6R5E	7179	5/7/2012	5/15/2012	1.5	61.88
Trichloroethylene *	79-01-6	P6R5E	7215	5/21/2012	5/24/2012	1	23.62
Trichloroethylene *	79-01-6	P6R5E	7254	6/4/2012	6/7/2012	1.5	64.02
Trichloroethylene *	79-01-6	P6R5E	7291	6/18/2012	6/25/2012	3	69.75
Trichloroethylene *	79-01-6	P6R6E	6849	1/11/2012	1/19/2012	27	764.91
Trichloroethylene *	79-01-6	P6R6E	6906	1/24/2012	2/1/2012	27	702.54
Trichloroethylene *	79-01-6	P6R6E	6929	2/7/2012	2/14/2012	27	888.57
Trichloroethylene *	79-01-6	P6R6E	6983	2/22/2012	2/28/2012	12	320.40
Trichloroethylene *	79-01-6	P6R6E	7005	3/6/2012	3/13/2012	27	507.33

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Trichloroethylene *	79-01-6	P6R6E	7061	3/20/2012	4/2/2012	9	222.75
Trichloroethylene *	79-01-6	P6R6E	7080	4/4/2012	4/12/2012	18	369.90
Trichloroethylene *	79-01-6	P6R6E	7134	4/17/2012	4/25/2012	18	375.66
Trichloroethylene *	79-01-6	P6R6E	7153	5/2/2012	5/10/2012	324	6,778.08
Trichloroethylene *	79-01-6	P6R6E	7206	5/15/2012	5/23/2012	81	2,097.09
Trichloroethylene *	79-01-6	P6R6E	7230	5/30/2012	6/5/2012	162	7,455.24
Trichloroethylene *	79-01-6	P6R6E	7285	6/12/2012	6/21/2012	324	9,781.56
Trichloroethylene *	79-01-6	P6R6E	7309	6/26/2012	7/9/2012	121.5	4,983.93
Trichloroethylene *	79-01-6	P6R6I	7152	5/2/2012	5/10/2012	81	1,241.73
Trichloroethylene *	79-01-6	P6R6I	7205	5/15/2012	5/23/2012	54	1,671.84
Trichloroethylene *	79-01-6	P6R6I	7228	5/30/2012	6/5/2012	40.5	1,013.31
Trichloroethylene *	79-01-6	P6R6I	7286	6/12/2012	6/21/2012	108	1,709.64
Trichloroethylene *	79-01-6	P6R6I	7310	6/26/2012	7/9/2012	27	651.24
Trichloroethylene *	79-01-6	P6R7E	6847	1/10/2012	1/19/2012	6561	143,161.02
Trichloroethylene *	79-01-6	P6R7E	6903	1/23/2012	2/1/2012	2916	85,584.60
Trichloroethylene *	79-01-6	P6R7E	6928	2/6/2012	2/14/2012	4374	121,247.28
Trichloroethylene *	79-01-6	P6R7E	6981	2/21/2012	2/28/2012	2817	79,912.98
Trichloroethylene *	79-01-6	P6R7E	7002	3/5/2012	3/13/2012	2187	67,250.25
Trichloroethylene *	79-01-6	P6R7E	7060	3/19/2012	4/2/2012	2916	67,505.40
Trichloroethylene *	79-01-6	P6R7E	7079	4/3/2012	4/12/2012	2187	44,155.53
Trichloroethylene *	79-01-6	P6R7E	7131	4/16/2012	4/25/2012	1458	39,540.96
Trichloroethylene *	79-01-6	P6R7E	7149	5/1/2012	5/10/2012	6561	127,873.89
Trichloroethylene *	79-01-6	P6R7E	7203	5/14/2012	5/23/2012	4374	153,614.88
Trichloroethylene *	79-01-6	P6R7E	7227	5/29/2012	6/5/2012	4374	148,016.16
Trichloroethylene *	79-01-6	P6R7E	7283	6/11/2012	6/21/2012	8748	253,604.52
Trichloroethylene *	79-01-6	P6R7E	7308	6/25/2012	7/9/2012	6561	211,067.37
Trichloroethylene *	79-01-6	P6R7I	6848	1/10/2012	1/19/2012	1458	32,484.24
Trichloroethylene *	79-01-6	P6R7I	6905	1/23/2012	2/1/2012	972	23,211.36
Trichloroethylene *	79-01-6	P6R7I	6926	2/6/2012	2/14/2012	2916	68,934.24
Trichloroethylene *	79-01-6	P6R7I	6982	2/21/2012	2/28/2012	324	9,276.12

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Trichloroethylene *	79-01-6	P6R7I	7004	3/5/2012	3/13/2012	729	11,212.02
Trichloroethylene *	79-01-6	P6R7I	7058	3/19/2012	4/2/2012	486	9,073.62
Trichloroethylene *	79-01-6	P6R7I	7078	4/3/2012	4/12/2012	121.5	2,447.01
Trichloroethylene *	79-01-6	P6R7I	7133	4/16/2012	4/25/2012	162	3,533.22
Trichloroethylene *	79-01-6	P6R7I	7150	5/1/2012	5/10/2012	6561	93,363.03
Trichloroethylene *	79-01-6	P6R7I	7204	5/14/2012	5/23/2012	4374	118,797.84
Trichloroethylene *	79-01-6	P6R7I	7226	5/29/2012	6/5/2012	3280.5	103,073.31
Trichloroethylene *	79-01-6	P6R7I	7282	6/11/2012	6/21/2012	8748	182,920.68
Trichloroethylene *	79-01-6	P6R7I	7306	6/25/2012	7/9/2012	8748	160,963.20

VOC non-target results for compounds not appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Styrene	100-42-5	VOC-A	6925	2/8/2012	2/14/2012		1.76 NJ
Styrene	100-42-5	VOC-A	7281	6/13/2012	6/21/2012		2.50 NJ
Styrene	100-42-5	P6R4E	7180	5/8/2012	5/15/2012		1.86 NJ
Styrene	100-42-5	P6R5E	6836	1/3/2012	1/11/2012		4.38 NJ
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6833	1/3/2012	1/11/2012	18	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6839	1/4/2012	1/11/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6843	1/10/2012	1/18/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6845	1/11/2012	1/18/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6871	1/17/2012	1/25/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6873	1/18/2012	1/25/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6899	1/24/2012	2/1/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6901	1/25/2012	2/1/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6911	1/31/2012	2/6/2012	2	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6913	2/1/2012	2/6/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6923	2/7/2012	2/14/2012	3	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6925	2/8/2012	2/14/2012	3	U

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds not appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6953	2/15/2012	2/23/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6951	2/16/2012	2/23/2012	2	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6977	2/21/2012	2/28/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6979	2/22/2012	2/28/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6989	2/28/2012	3/1/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6991	2/29/2012	3/1/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	6999	3/6/2012	3/13/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7001	3/7/2012	3/13/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7025	3/13/2012	3/21/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7027	3/14/2012	3/21/2012	18	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7055	3/20/2012	4/2/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7057	3/21/2012	4/2/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7063	3/28/2012	4/11/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7065	3/30/2012	4/11/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7073	4/3/2012	4/12/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7077	4/4/2012	4/12/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7097	4/10/2012	4/13/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7099	4/11/2012	4/13/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7127	4/17/2012	4/25/2012	4	0.26 J
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7129	4/18/2012	4/25/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7135	4/24/2012	4/27/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7137	4/25/2012	4/27/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7145	5/1/2012	5/10/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7147	5/2/2012	5/10/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7175	5/8/2012	5/15/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7177	5/9/2012	5/15/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7199	5/15/2012	5/23/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7201	5/16/2012	5/23/2012	4	1.58 J
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7211	5/22/2012	5/24/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7213	5/23/2012	5/24/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7223	5/29/2012	6/5/2012	2	0.31 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds not appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7225	5/30/2012	6/5/2012	4	0.50 J
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7249	6/5/2012	6/7/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7253	6/6/2012	6/7/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7279	6/12/2012	6/21/2012	4	0.32 J
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7281	6/13/2012	6/21/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7287	6/19/2012	6/25/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7289	6/20/2012	6/25/2012	3	0.42 J
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7305	6/26/2012	7/9/2012	3	0.29 J
p,m-Xylene *	106-42-3, 108-38-3	VOC-A	7303	6/27/2012	7/9/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	P3R1E	6869	1/10/2012	1/19/2012	144	93.60 J
p,m-Xylene *	106-42-3, 108-38-3	P3R1E	6972	2/16/2012	2/28/2012	48	21.60 J
p,m-Xylene *	106-42-3, 108-38-3	P3R1E	7022	3/6/2012	3/13/2012	216	57.24 J
p,m-Xylene *	106-42-3, 108-38-3	P3R1E	7095	4/3/2012	4/11/2012	144	37.44 J
p,m-Xylene *	106-42-3, 108-38-3	P3R1E	7173	5/1/2012	5/11/2012	216	124.20 J
p,m-Xylene *	106-42-3, 108-38-3	P3R1E	7246	6/5/2012	6/18/2012	144	74.16 J
p,m-Xylene *	106-42-3, 108-38-3	P4R1E	6897	1/17/2012	1/25/2012	34992	U
p,m-Xylene *	106-42-3, 108-38-3	P4R1E	6948	2/7/2012	2/14/2012	26244	U
p,m-Xylene *	106-42-3, 108-38-3	P4R1E	7049	3/13/2012	3/21/2012	26244	U
p,m-Xylene *	106-42-3, 108-38-3	P4R1E	7119	4/10/2012	4/24/2012	26244	U
p,m-Xylene *	106-42-3, 108-38-3	P4R1E	7197	5/9/2012	5/18/2012	17496	U
p,m-Xylene *	106-42-3, 108-38-3	P4R1E	7276	6/11/2012	6/25/2012	17496	U
p,m-Xylene *	106-42-3, 108-38-3	P6R4E	6877	1/17/2012	1/25/2012	12	U
p,m-Xylene *	106-42-3, 108-38-3	P6R4E	6918	1/31/2012	2/6/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	P6R4E	6958	2/14/2012	2/23/2012	18	U
p,m-Xylene *	106-42-3, 108-38-3	P6R4E	6994	2/28/2012	3/1/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	P6R4E	7030	3/12/2012	3/21/2012	3	U
p,m-Xylene *	106-42-3, 108-38-3	P6R4E	7068	3/29/2012	4/11/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	P6R4E	7103	4/11/2012	4/13/2012	2	U
p,m-Xylene *	106-42-3, 108-38-3	P6R4E	7141	4/24/2012	4/27/2012	3	U
p,m-Xylene *	106-42-3, 108-38-3	P6R4E	7180	5/8/2012	5/15/2012	3	0.32 J
p,m-Xylene *	106-42-3, 108-38-3	P6R4E	7217	5/22/2012	5/24/2012	2	U

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds not appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
p,m-Xylene *	106-42-3, 108-38-3	P6R4E	7255	6/5/2012	6/7/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	P6R4E	7293	6/19/2012	6/25/2012	4	U
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	6836	1/3/2012	1/11/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	6875	1/16/2012	1/25/2012	12	U
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	6916	1/30/2012	2/6/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	6956	2/13/2012	2/23/2012	18	U
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	6992	2/27/2012	3/1/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	7028	3/12/2012	3/21/2012	3	U
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	7066	3/28/2012	4/11/2012	8	U
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	7101	4/10/2012	4/13/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	7139	4/23/2012	4/27/2012	2	0.22 J
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	7179	5/7/2012	5/15/2012	3	1.10 J
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	7215	5/21/2012	5/24/2012	2	0.17 J
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	7254	6/4/2012	6/7/2012	3	0.27 J
p,m-Xylene *	106-42-3, 108-38-3	P6R5E	7291	6/18/2012	6/25/2012	6	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	6849	1/11/2012	1/19/2012	54	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	6906	1/24/2012	2/1/2012	54	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	6929	2/7/2012	2/14/2012	54	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	6983	2/22/2012	2/28/2012	24	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	7005	3/6/2012	3/13/2012	54	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	7061	3/20/2012	4/2/2012	18	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	7080	4/4/2012	4/12/2012	36	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	7134	4/17/2012	4/25/2012	36	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	7153	5/2/2012	5/10/2012	648	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	7206	5/15/2012	5/23/2012	162	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	7230	5/30/2012	6/5/2012	324	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	7285	6/12/2012	6/21/2012	648	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6E	7309	6/26/2012	7/9/2012	243	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6I	7152	5/2/2012	5/10/2012	162	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6I	7205	5/15/2012	5/23/2012	108	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6I	7228	5/30/2012	6/5/2012	81	U

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds not appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
p,m-Xylene *	106-42-3, 108-38-3	P6R6I	7286	6/12/2012	6/21/2012	216	U
p,m-Xylene *	106-42-3, 108-38-3	P6R6I	7310	6/26/2012	7/9/2012	54	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	6847	1/10/2012	1/19/2012	13122	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	6903	1/23/2012	2/1/2012	5832	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	6928	2/6/2012	2/14/2012	8748	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	6981	2/21/2012	2/28/2012	5634	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	7002	3/5/2012	3/13/2012	4374	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	7060	3/19/2012	4/2/2012	5832	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	7079	4/3/2012	4/12/2012	4374	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	7131	4/16/2012	4/25/2012	2916	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	7149	5/1/2012	5/10/2012	13122	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	7203	5/14/2012	5/23/2012	8748	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	7227	5/29/2012	6/5/2012	8748	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	7283	6/11/2012	6/21/2012	17496	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7E	7308	6/25/2012	7/9/2012	13122	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	6848	1/10/2012	1/19/2012	2916	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	6905	1/23/2012	2/1/2012	1944	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	6926	2/6/2012	2/14/2012	5832	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	6982	2/21/2012	2/28/2012	648	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	7004	3/5/2012	3/13/2012	1458	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	7058	3/19/2012	4/2/2012	972	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	7078	4/3/2012	4/12/2012	243	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	7133	4/16/2012	4/25/2012	324	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	7150	5/1/2012	5/10/2012	13122	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	7204	5/14/2012	5/23/2012	8748	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	7226	5/29/2012	6/5/2012	6561	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	7282	6/11/2012	6/21/2012	17496	U
p,m-Xylene *	106-42-3, 108-38-3	P6R7I	7306	6/25/2012	7/9/2012	17496	U
Butane	106-97-8	VOC-A	7145	5/1/2012	5/10/2012		7.20 NJ
Butane	106-97-8	VOC-A	7147	5/2/2012	5/10/2012		4.32 NJ
Butane	106-97-8	VOC-A	7199	5/15/2012	5/23/2012		9.12 NJ

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds not appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Butane	106-97-8	VOC-A	7201	5/16/2012	5/23/2012		9.18 NJ
Butane	106-97-8	VOC-A	7211	5/22/2012	5/24/2012		4.52 NJ
Butane	106-97-8	VOC-A	7213	5/23/2012	5/24/2012		4.56 NJ
Butane	106-97-8	VOC-A	7223	5/29/2012	6/5/2012		6.90 NJ
Butane	106-97-8	VOC-A	7225	5/30/2012	6/5/2012		8.90 NJ
Butane	106-97-8	P6R4E	7217	5/22/2012	5/24/2012		2.10 NJ
Butane	106-97-8	P6R5E	7215	5/21/2012	5/24/2012		2.65 NJ
Pentane, 2-methyl-	107-83-5	VOC-A	7223	5/29/2012	6/5/2012		1.14 NJ
Pentane	109-66-0	VOC-A	7145	5/1/2012	5/10/2012		3.18 NJ
Pentane	109-66-0	VOC-A	7199	5/15/2012	5/23/2012		4.04 NJ
Pentane	109-66-0	VOC-A	7223	5/29/2012	6/5/2012		3.56 NJ
Pentane	109-66-0	VOC-A	7225	5/30/2012	6/5/2012		4.20 NJ
Pentane	109-66-0	VOC-A	7249	6/5/2012	6/7/2012		2.58 NJ
Pentane	109-66-0	VOC-A	7279	6/12/2012	6/21/2012		2.22 NJ
Pentane	109-66-0	P6R4E	7217	5/22/2012	5/24/2012		1.06 NJ
Pentane	109-66-0	P6R5E	7215	5/21/2012	5/24/2012		1.05 NJ
Propene	115-07-1	P6R5E	7139	4/23/2012	4/27/2012		1.26 NJ
† Cyclotrisiloxane, hexamethyl-	541-05-9	P6R4E	7141	4/24/2012	4/27/2012		2.10 NJ
† Cyclotetrasiloxane, octamethyl-	556-67-2	P6R5E	7139	4/23/2012	4/27/2012		1.26 NJ
† Cyclotetrasiloxane, octamethyl-	556-67-2	P6R5E	7179	5/7/2012	5/15/2012		2.19 NJ
† Cyclotetrasiloxane, octamethyl-	556-67-2	P6R5E	7215	5/21/2012	5/24/2012		1.29 NJ
Acetone	67-64-1	VOC-A	6843	1/10/2012	1/18/2012		3.22 NJ
Acetone	67-64-1	VOC-A	6901	1/25/2012	2/1/2012		3.51 NJ
Acetone	67-64-1	VOC-A	6951	2/16/2012	2/23/2012		3.60 NJ
Acetone	67-64-1	VOC-A	7001	3/7/2012	3/13/2012		5.06 NJ
Acetone	67-64-1	VOC-A	7201	5/16/2012	5/23/2012		6.18 NJ
Acetone	67-64-1	VOC-A	7223	5/29/2012	6/5/2012		1.47 NJ
Acetone	67-64-1	VOC-A	7279	6/12/2012	6/21/2012		3.02 NJ
Acetone	67-64-1	VOC-A	7287	6/19/2012	6/25/2012		3.46 NJ
Acetone	67-64-1	VOC-A	7289	6/20/2012	6/25/2012		4.25 NJ
Acetone	67-64-1	P3R1E	6869	1/10/2012	1/19/2012		212.40 NJ

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds not appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
Acetone	67-64-1	P3R1E	6972	2/16/2012	2/28/2012		72.72 NJ
Acetone	67-64-1	P3R1E	7173	5/1/2012	5/11/2012		133.92 NJ
Acetone	67-64-1	P3R1E	7246	6/5/2012	6/18/2012		97.20 NJ
Acetone	67-64-1	P6R4E	6994	2/28/2012	3/1/2012		2.60 NJ
Acetone	67-64-1	P6R4E	7103	4/11/2012	4/13/2012		1.34 NJ
Acetone	67-64-1	P6R4E	7180	5/8/2012	5/15/2012		2.46 NJ
Acetone	67-64-1	P6R4E	7217	5/22/2012	5/24/2012		2.01 NJ
Acetone	67-64-1	P6R4E	7255	6/5/2012	6/7/2012		2.18 NJ
Acetone	67-64-1	P6R5E	7179	5/7/2012	5/15/2012		4.59 NJ
Acetone	67-64-1	P6R5E	7215	5/21/2012	5/24/2012		2.47 NJ
Acetone	67-64-1	P6R5E	7254	6/4/2012	6/7/2012		2.24 NJ
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6833	1/3/2012	1/11/2012	9	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6839	1/4/2012	1/11/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6843	1/10/2012	1/18/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6845	1/11/2012	1/18/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6871	1/17/2012	1/25/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6873	1/18/2012	1/25/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6899	1/24/2012	2/1/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6901	1/25/2012	2/1/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6911	1/31/2012	2/6/2012	1	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6913	2/1/2012	2/6/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6923	2/7/2012	2/14/2012	1.5	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6925	2/8/2012	2/14/2012	1.5	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6953	2/15/2012	2/23/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6951	2/16/2012	2/23/2012	1	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6977	2/21/2012	2/28/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6979	2/22/2012	2/28/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6989	2/28/2012	3/1/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6991	2/29/2012	3/1/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	6999	3/6/2012	3/13/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7001	3/7/2012	3/13/2012	2	U

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds not appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7025	3/13/2012	3/21/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7027	3/14/2012	3/21/2012	9	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7055	3/20/2012	4/2/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7057	3/21/2012	4/2/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7063	3/28/2012	4/11/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7065	3/30/2012	4/11/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7073	4/3/2012	4/12/2012	2	0.06 J
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7077	4/4/2012	4/12/2012	3	0.09 J
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7097	4/10/2012	4/13/2012	3	0.09 J
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7099	4/11/2012	4/13/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7127	4/17/2012	4/25/2012	2	0.20 J
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7129	4/18/2012	4/25/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7135	4/24/2012	4/27/2012	4	0.12 J
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7137	4/25/2012	4/27/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7145	5/1/2012	5/10/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7147	5/2/2012	5/10/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7175	5/8/2012	5/15/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7177	5/9/2012	5/15/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7199	5/15/2012	5/23/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7201	5/16/2012	5/23/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7211	5/22/2012	5/24/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7213	5/23/2012	5/24/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7223	5/29/2012	6/5/2012	1	0.08 J
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7225	5/30/2012	6/5/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7249	6/5/2012	6/7/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7253	6/6/2012	6/7/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7279	6/12/2012	6/21/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7281	6/13/2012	6/21/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7287	6/19/2012	6/25/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7289	6/20/2012	6/25/2012	1.5	U
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7305	6/26/2012	7/9/2012	1.5	0.06 J

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds not appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
1,2,4-Trimethylbenzene *	95-63-6	VOC-A	7303	6/27/2012	7/9/2012	2	0.06 J
1,2,4-Trimethylbenzene *	95-63-6	P3R1E	6869	1/10/2012	1/19/2012	72	U
1,2,4-Trimethylbenzene *	95-63-6	P3R1E	6972	2/16/2012	2/28/2012	24	U
1,2,4-Trimethylbenzene *	95-63-6	P3R1E	7022	3/6/2012	3/13/2012	108	U
1,2,4-Trimethylbenzene *	95-63-6	P3R1E	7095	4/3/2012	4/11/2012	72	U
1,2,4-Trimethylbenzene *	95-63-6	P3R1E	7173	5/1/2012	5/11/2012	108	U
1,2,4-Trimethylbenzene *	95-63-6	P3R1E	7246	6/5/2012	6/18/2012	72	U
1,2,4-Trimethylbenzene *	95-63-6	P4R1E	6897	1/17/2012	1/25/2012	17496	U
1,2,4-Trimethylbenzene *	95-63-6	P4R1E	6948	2/7/2012	2/14/2012	13122	U
1,2,4-Trimethylbenzene *	95-63-6	P4R1E	7049	3/13/2012	3/21/2012	13122	U
1,2,4-Trimethylbenzene *	95-63-6	P4R1E	7119	4/10/2012	4/24/2012	13122	U
1,2,4-Trimethylbenzene *	95-63-6	P4R1E	7197	5/9/2012	5/18/2012	8748	U
1,2,4-Trimethylbenzene *	95-63-6	P4R1E	7276	6/11/2012	6/25/2012	8748	U
1,2,4-Trimethylbenzene *	95-63-6	P6R4E	6877	1/17/2012	1/25/2012	6	U
1,2,4-Trimethylbenzene *	95-63-6	P6R4E	6918	1/31/2012	2/6/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	P6R4E	6958	2/14/2012	2/23/2012	9	U
1,2,4-Trimethylbenzene *	95-63-6	P6R4E	6994	2/28/2012	3/1/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	P6R4E	7030	3/12/2012	3/21/2012	1.5	U
1,2,4-Trimethylbenzene *	95-63-6	P6R4E	7068	3/29/2012	4/11/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	P6R4E	7103	4/11/2012	4/13/2012	1	U
1,2,4-Trimethylbenzene *	95-63-6	P6R4E	7141	4/24/2012	4/27/2012	1.5	U
1,2,4-Trimethylbenzene *	95-63-6	P6R4E	7180	5/8/2012	5/15/2012	1.5	U
1,2,4-Trimethylbenzene *	95-63-6	P6R4E	7217	5/22/2012	5/24/2012	1	U
1,2,4-Trimethylbenzene *	95-63-6	P6R4E	7255	6/5/2012	6/7/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	P6R4E	7293	6/19/2012	6/25/2012	2	U
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	6836	1/3/2012	1/11/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	6875	1/16/2012	1/25/2012	6	U
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	6916	1/30/2012	2/6/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	6956	2/13/2012	2/23/2012	9	U
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	6992	2/27/2012	3/1/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	7028	3/12/2012	3/21/2012	1.5	U

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds not appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	7066	3/28/2012	4/11/2012	4	U
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	7101	4/10/2012	4/13/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	7139	4/23/2012	4/27/2012	1	0.25 J
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	7179	5/7/2012	5/15/2012	1.5	0.15 J
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	7215	5/21/2012	5/24/2012	1	U
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	7254	6/4/2012	6/7/2012	1.5	U
1,2,4-Trimethylbenzene *	95-63-6	P6R5E	7291	6/18/2012	6/25/2012	3	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	6849	1/11/2012	1/19/2012	27	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	6906	1/24/2012	2/1/2012	27	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	6929	2/7/2012	2/14/2012	27	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	6983	2/22/2012	2/28/2012	12	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	7005	3/6/2012	3/13/2012	27	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	7061	3/20/2012	4/2/2012	9	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	7080	4/4/2012	4/12/2012	18	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	7134	4/17/2012	4/25/2012	18	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	7153	5/2/2012	5/10/2012	324	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	7206	5/15/2012	5/23/2012	81	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	7230	5/30/2012	6/5/2012	162	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	7285	6/12/2012	6/21/2012	324	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6E	7309	6/26/2012	7/9/2012	121.5	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6I	7152	5/2/2012	5/10/2012	81	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6I	7205	5/15/2012	5/23/2012	54	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6I	7228	5/30/2012	6/5/2012	40.5	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6I	7286	6/12/2012	6/21/2012	108	U
1,2,4-Trimethylbenzene *	95-63-6	P6R6I	7310	6/26/2012	7/9/2012	27	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	6847	1/10/2012	1/19/2012	6561	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	6903	1/23/2012	2/1/2012	2916	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	6928	2/6/2012	2/14/2012	4374	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	6981	2/21/2012	2/28/2012	2817	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	7002	3/5/2012	3/13/2012	2187	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	7060	3/19/2012	4/2/2012	2916	U

Attachment 4 – VOC Non-Target Results (TICs and Additional Requested Analytes)

VOC non-target results for compounds not appearing in Appendix VIII of 40 CFR Part 261

Compound Name	CAS #	Location	Sample ID	Sample Date	Analysis Date	MRL (ppbv)	Concentration (ppbv)
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	7079	4/3/2012	4/12/2012	2187	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	7131	4/16/2012	4/25/2012	1458	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	7149	5/1/2012	5/10/2012	6561	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	7203	5/14/2012	5/23/2012	4374	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	7227	5/29/2012	6/5/2012	4374	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	7283	6/11/2012	6/21/2012	8748	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7E	7308	6/25/2012	7/9/2012	6561	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	6848	1/10/2012	1/19/2012	1458	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	6905	1/23/2012	2/1/2012	972	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	6926	2/6/2012	2/14/2012	2916	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	6982	2/21/2012	2/28/2012	324	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	7004	3/5/2012	3/13/2012	729	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	7058	3/19/2012	4/2/2012	486	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	7078	4/3/2012	4/12/2012	121.5	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	7133	4/16/2012	4/25/2012	162	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	7150	5/1/2012	5/10/2012	6561	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	7204	5/14/2012	5/23/2012	4374	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	7226	5/29/2012	6/5/2012	3280.5	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	7282	6/11/2012	6/21/2012	8748	U
1,2,4-Trimethylbenzene *	95-63-6	P6R7I	7306	6/25/2012	7/9/2012	8748	U

Notes:
J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above the MDL.
NJ = Estimated value; only used for TICs. A value will not appear in the MRL column for TICs.
* Denotes additional requested analyte.
† Compounds associated with column bleed

Panel 3 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P3EBA	6864	1/10/2012	1/13/2012	Hydrogen	100	U
P3EBA	6864	1/10/2012	1/13/2012	Methane	100	U
P3EBA	6967	2/16/2012	2/22/2012	Hydrogen	100	U
P3EBA	6967	2/16/2012	2/22/2012	Methane	100	U
P3EBA	7017	3/6/2012	3/9/2012	Hydrogen	100	U
P3EBA	7017	3/6/2012	3/9/2012	Methane	100	U
P3EBA	7090	4/3/2012	4/9/2012	Hydrogen	100	U
P3EBA	7090	4/3/2012	4/9/2012	Methane	100	U
P3EBA	7168	5/1/2012	5/4/2012	Hydrogen	100	U
P3EBA	7168	5/1/2012	5/4/2012	Methane	100	U
P3EBA	7241	6/5/2012	6/8/2012	Hydrogen	100	U
P3EBA	7241	6/5/2012	6/8/2012	Methane	100	U
P3EBW	6863	1/9/2012	1/13/2012	Hydrogen	100	51.46 J
P3EBW	6863	1/9/2012	1/13/2012	Methane	100	U
P3EBW	6966	2/16/2012	2/22/2012	Hydrogen	100	U
P3EBW	6966	2/16/2012	2/22/2012	Methane	100	U
P3EBW	7016	3/6/2012	3/9/2012	Hydrogen	100	U
P3EBW	7016	3/6/2012	3/9/2012	Methane	100	U
P3EBW	7089	4/2/2012	4/9/2012	Hydrogen	100	U
P3EBW	7089	4/2/2012	4/9/2012	Methane	100	U
P3EBW	7167	5/1/2012	5/4/2012	Hydrogen	100	U
P3EBW	7167	5/1/2012	5/4/2012	Methane	100	U
P3EBW	7240	6/4/2012	6/8/2012	Hydrogen	100	U
P3EBW	7240	6/4/2012	6/8/2012	Methane	100	U
P3IBA	6856	1/9/2012	1/13/2012	Hydrogen	100	U
P3IBA	6856	1/9/2012	1/13/2012	Methane	100	U
P3IBA	6960	2/16/2012	2/22/2012	Hydrogen	100	U
P3IBA	6960	2/16/2012	2/22/2012	Methane	100	U
P3IBA	7010	3/6/2012	3/9/2012	Hydrogen	100	U
P3IBA	7010	3/6/2012	3/9/2012	Methane	100	U
P3IBA	7082	4/2/2012	4/9/2012	Hydrogen	100	U

Attachment 5 – Hydrogen and Methane Results

Panel 3 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P3IBA	7082	4/2/2012	4/9/2012	Methane	100	U
P3IBA	7160	5/1/2012	5/4/2012	Hydrogen	100	U
P3IBA	7160	5/1/2012	5/4/2012	Methane	100	U
P3IBA	7233	6/4/2012	6/8/2012	Hydrogen	100	U
P3IBA	7233	6/4/2012	6/8/2012	Methane	100	U
P3IBW	6857	1/9/2012	1/13/2012	Hydrogen	100	U
P3IBW	6857	1/9/2012	1/13/2012	Methane	100	U
P3IBW	6959	2/16/2012	2/22/2012	Hydrogen	100	U
P3IBW	6959	2/16/2012	2/22/2012	Methane	100	U
P3IBW	7009	3/6/2012	3/9/2012	Hydrogen	100	U
P3IBW	7009	3/6/2012	3/9/2012	Methane	100	U
P3IBW	7083	4/2/2012	4/9/2012	Hydrogen	100	U
P3IBW	7083	4/2/2012	4/9/2012	Methane	100	U
P3IBW	7161	5/1/2012	5/4/2012	Hydrogen	100	U
P3IBW	7161	5/1/2012	5/4/2012	Methane	100	U
P3IBW	7234	6/4/2012	6/8/2012	Hydrogen	100	U
P3IBW	7234	6/4/2012	6/8/2012	Methane	100	U
P3R1E	6869	1/10/2012	1/13/2012	Hydrogen	100	50.88 J
P3R1E	6869	1/10/2012	1/13/2012	Methane	100	U
P3R1E	6972	2/16/2012	2/22/2012	Hydrogen	100	U
P3R1E	6972	2/16/2012	2/22/2012	Methane	100	U
P3R1E	7022	3/6/2012	3/9/2012	Hydrogen	100	32.80 J
P3R1E	7022	3/6/2012	3/9/2012	Methane	100	U
P3R1E	7095	4/3/2012	4/9/2012	Hydrogen	100	U
P3R1E	7095	4/3/2012	4/9/2012	Methane	100	U
P3R1E	7173	5/1/2012	5/4/2012	Hydrogen	100	31.26 J
P3R1E	7173	5/1/2012	5/4/2012	Methane	100	U
P3R1E	7246	6/5/2012	6/8/2012	Hydrogen	100	U
P3R1E	7246	6/5/2012	6/8/2012	Methane	100	U
P3R2E	6862	1/9/2012	1/13/2012	Hydrogen	100	60.96 J
P3R2E	6862	1/9/2012	1/13/2012	Methane	100	U
P3R2E	6965	2/16/2012	2/22/2012	Hydrogen	100	U

Panel 3 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P3R2E	6965	2/16/2012	2/22/2012	Methane	100	U
P3R2E	7015	3/6/2012	3/9/2012	Hydrogen	100	40.78 J
P3R2E	7015	3/6/2012	3/9/2012	Methane	100	U
P3R2E	7088	4/2/2012	4/9/2012	Hydrogen	100	35.32 J
P3R2E	7088	4/2/2012	4/9/2012	Methane	100	U
P3R2E	7166	5/1/2012	5/4/2012	Hydrogen	100	U
P3R2E	7166	5/1/2012	5/4/2012	Methane	100	U
P3R2E	7239	6/4/2012	6/8/2012	Hydrogen	100	36.96 J
P3R2E	7239	6/4/2012	6/8/2012	Methane	100	U
P3R2I	6868	1/10/2012	1/13/2012	Hydrogen	100	U
P3R2I	6868	1/10/2012	1/13/2012	Methane	100	U
P3R2I	6971	2/16/2012	2/22/2012	Hydrogen	100	U
P3R2I	6971	2/16/2012	2/22/2012	Methane	100	U
P3R2I	7021	3/6/2012	3/9/2012	Hydrogen	100	U
P3R2I	7021	3/6/2012	3/9/2012	Methane	100	U
P3R2I	7094	4/3/2012	4/9/2012	Hydrogen	100	U
P3R2I	7094	4/3/2012	4/9/2012	Methane	100	U
P3R2I	7172	5/1/2012	5/4/2012	Hydrogen	100	U
P3R2I	7172	5/1/2012	5/4/2012	Methane	100	U
P3R2I	7245	6/5/2012	6/8/2012	Hydrogen	100	U
P3R2I	7245	6/5/2012	6/8/2012	Methane	100	U
P3R3E	6861	1/9/2012	1/13/2012	Hydrogen	100	53.60 J
P3R3E	6861	1/9/2012	1/13/2012	Methane	100	U
P3R3E	6964	2/16/2012	2/22/2012	Hydrogen	100	U
P3R3E	6964	2/16/2012	2/22/2012	Methane	100	U
P3R3E	7014	3/6/2012	3/9/2012	Hydrogen	100	32.26 J
P3R3E	7014	3/6/2012	3/9/2012	Methane	100	U
P3R3E	7087	4/2/2012	4/9/2012	Hydrogen	100	U
P3R3E	7087	4/2/2012	4/9/2012	Methane	100	U
P3R3E	7165	5/1/2012	5/4/2012	Hydrogen	100	U
P3R3E	7165	5/1/2012	5/4/2012	Methane	100	U
P3R3E	7238	6/4/2012	6/8/2012	Hydrogen	100	U

Attachment 5 – Hydrogen and Methane Results

Panel 3 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P3R3E	7238	6/4/2012	6/8/2012	Methane	100	U
P3R3I	6867	1/10/2012	1/13/2012	Hydrogen	100	U
P3R3I	6867	1/10/2012	1/13/2012	Methane	100	U
P3R3I	6970	2/16/2012	2/22/2012	Hydrogen	100	U
P3R3I	6970	2/16/2012	2/22/2012	Methane	100	U
P3R3I	7020	3/6/2012	3/9/2012	Hydrogen	100	U
P3R3I	7020	3/6/2012	3/9/2012	Methane	100	U
P3R3I	7093	4/3/2012	4/9/2012	Hydrogen	100	U
P3R3I	7093	4/3/2012	4/9/2012	Methane	100	U
P3R3I	7171	5/1/2012	5/4/2012	Hydrogen	100	U
P3R3I	7171	5/1/2012	5/4/2012	Methane	100	U
P3R3I	7244	6/5/2012	6/8/2012	Hydrogen	100	U
P3R3I	7244	6/5/2012	6/8/2012	Methane	100	U
P3R4E	6860	1/9/2012	1/13/2012	Hydrogen	100	58.28 J
P3R4E	6860	1/9/2012	1/13/2012	Methane	100	U
P3R4E	6963	2/16/2012	2/22/2012	Hydrogen	100	U
P3R4E	6963	2/16/2012	2/22/2012	Methane	100	U
P3R4E	7013	3/6/2012	3/9/2012	Hydrogen	100	42.20 J
P3R4E	7013	3/6/2012	3/9/2012	Methane	100	U
P3R4E	7086	4/2/2012	4/9/2012	Hydrogen	100	33.40 J
P3R4E	7086	4/2/2012	4/9/2012	Methane	100	U
P3R4E	7164	5/1/2012	5/4/2012	Hydrogen	100	U
P3R4E	7164	5/1/2012	5/4/2012	Methane	100	U
P3R4E	7237	6/4/2012	6/8/2012	Hydrogen	100	41.10 J
P3R4E	7237	6/4/2012	6/8/2012	Methane	100	U
P3R4I	6866	1/10/2012	1/13/2012	Hydrogen	100	U
P3R4I	6866	1/10/2012	1/13/2012	Methane	100	U
P3R4I	6969	2/16/2012	2/22/2012	Hydrogen	100	U
P3R4I	6969	2/16/2012	2/22/2012	Methane	100	U
P3R4I	7019	3/6/2012	3/9/2012	Hydrogen	100	U
P3R4I	7019	3/6/2012	3/9/2012	Methane	100	U
P3R4I	7092	4/3/2012	4/9/2012	Hydrogen	100	U

Panel 3 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P3R4I	7092	4/3/2012	4/9/2012	Methane	100	U
P3R4I	7170	5/1/2012	5/4/2012	Hydrogen	100	U
P3R4I	7170	5/1/2012	5/4/2012	Methane	100	U
P3R4I	7243	6/5/2012	6/8/2012	Hydrogen	100	U
P3R4I	7243	6/5/2012	6/8/2012	Methane	100	U
P3R5E	6859	1/9/2012	1/13/2012	Hydrogen	100	51.44 J
P3R5E	6859	1/9/2012	1/13/2012	Methane	100	U
P3R5E	6962	2/16/2012	2/22/2012	Hydrogen	100	U
P3R5E	6962	2/16/2012	2/22/2012	Methane	100	U
P3R5E	7012	3/6/2012	3/9/2012	Hydrogen	100	52.86 J
P3R5E	7012	3/6/2012	3/9/2012	Methane	100	U
P3R5E	7085	4/2/2012	4/9/2012	Hydrogen	100	43.68 J
P3R5E	7085	4/2/2012	4/9/2012	Methane	100	U
P3R5E	7163	5/1/2012	5/4/2012	Hydrogen	100	48.28 J
P3R5E	7163	5/1/2012	5/4/2012	Methane	100	U
P3R5E	7236	6/4/2012	6/8/2012	Hydrogen	100	U
P3R5E	7236	6/4/2012	6/8/2012	Methane	100	U
P3R5I	6865	1/10/2012	1/13/2012	Hydrogen	100	U
P3R5I	6865	1/10/2012	1/13/2012	Methane	100	U
P3R5I	6968	2/16/2012	2/22/2012	Hydrogen	100	U
P3R5I	6968	2/16/2012	2/22/2012	Methane	100	U
P3R5I	7018	3/6/2012	3/9/2012	Hydrogen	100	U
P3R5I	7018	3/6/2012	3/9/2012	Methane	100	U
P3R5I	7091	4/3/2012	4/9/2012	Hydrogen	100	U
P3R5I	7091	4/3/2012	4/9/2012	Methane	100	U
P3R5I	7169	5/1/2012	5/4/2012	Hydrogen	100	U
P3R5I	7169	5/1/2012	5/4/2012	Methane	100	U
P3R5I	7242	6/5/2012	6/8/2012	Hydrogen	100	U
P3R5I	7242	6/5/2012	6/8/2012	Methane	100	U
P3R6E	6858	1/9/2012	1/13/2012	Hydrogen	100	52.82 J
P3R6E	6858	1/9/2012	1/13/2012	Methane	100	U
P3R6E	6961	2/16/2012	2/22/2012	Hydrogen	100	34.02 J

Attachment 5 – Hydrogen and Methane Results

Panel 3 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P3R6E	6961	2/16/2012	2/22/2012	Methane	100	U
P3R6E	7011	3/6/2012	3/9/2012	Hydrogen	100	45.38 J
P3R6E	7011	3/6/2012	3/9/2012	Methane	100	U
P3R6E	7084	4/2/2012	4/9/2012	Hydrogen	100	29.00 J
P3R6E	7084	4/2/2012	4/9/2012	Methane	100	U
P3R6E	7162	5/1/2012	5/4/2012	Hydrogen	100	32.72 J
P3R6E	7162	5/1/2012	5/4/2012	Methane	100	U
P3R6E	7235	6/4/2012	6/8/2012	Hydrogen	100	34.30 J
P3R6E	7235	6/4/2012	6/8/2012	Methane	100	U

Notes:

J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above the MDL.

Panel 3 sample lines determined as obstructed: (1) P3R1I on July 14, 2008
(2) P3R6I on September 22, 2010
(3) P3R7E on August 30, 2010
(4) P3R7I on July 14, 2008

Attachment 5 – Hydrogen and Methane Results

Panel 4 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P4EBA	6896	1/17/2012	1/23/2012	Hydrogen	100	U
P4EBA	6896	1/17/2012	1/23/2012	Methane	100	U
P4EBA	6947	2/7/2012	2/10/2012	Hydrogen	100	U
P4EBA	6947	2/7/2012	2/10/2012	Methane	100	U
P4EBA	7048	3/13/2012	3/16/2012	Hydrogen	100	U
P4EBA	7048	3/13/2012	3/16/2012	Methane	100	U
P4EBA	7118	4/10/2012	4/13/2012	Hydrogen	100	U
P4EBA	7118	4/10/2012	4/13/2012	Methane	100	U
P4EBA	7196	5/9/2012	5/15/2012	Hydrogen	100	U
P4EBA	7196	5/9/2012	5/15/2012	Methane	100	U
P4EBA	7275	6/11/2012	6/18/2012	Hydrogen	100	U
P4EBA	7275	6/11/2012	6/18/2012	Methane	100	U
P4EBW	6895	1/17/2012	1/23/2012	Hydrogen	100	152.46
P4EBW	6895	1/17/2012	1/23/2012	Methane	100	U
P4EBW	6946	2/7/2012	2/10/2012	Hydrogen	100	126.92
P4EBW	6946	2/7/2012	2/10/2012	Methane	100	U
P4EBW	7047	3/13/2012	3/16/2012	Hydrogen	100	169.86
P4EBW	7047	3/13/2012	3/16/2012	Methane	100	U
P4EBW	7117	4/10/2012	4/13/2012	Hydrogen	100	158.14
P4EBW	7117	4/10/2012	4/13/2012	Methane	100	U
P4EBW	7195	5/9/2012	5/15/2012	Hydrogen	100	274.44
P4EBW	7195	5/9/2012	5/15/2012	Methane	100	U
P4EBW	7274	6/11/2012	6/18/2012	Hydrogen	100	181.18
P4EBW	7274	6/11/2012	6/18/2012	Methane	100	U
P4IBA	6889	1/17/2012	1/23/2012	Hydrogen	100	U
P4IBA	6889	1/17/2012	1/23/2012	Methane	100	U
P4IBA	6941	2/7/2012	2/10/2012	Hydrogen	100	U
P4IBA	6941	2/7/2012	2/10/2012	Methane	100	U
P4IBA	7042	3/13/2012	3/16/2012	Hydrogen	100	U
P4IBA	7042	3/13/2012	3/16/2012	Methane	100	U
P4IBA	7112	4/10/2012	4/13/2012	Hydrogen	100	U

Attachment 5 – Hydrogen and Methane Results

Panel 4 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P4IBA	7112	4/10/2012	4/13/2012	Methane	100	U
P4IBA	7190	5/8/2012	5/15/2012	Hydrogen	100	U
P4IBA	7190	5/8/2012	5/15/2012	Methane	100	U
P4IBA	7269	6/11/2012	6/18/2012	Hydrogen	100	U
P4IBA	7269	6/11/2012	6/18/2012	Methane	100	U
P4IBW	6888	1/17/2012	1/23/2012	Hydrogen	100	310.84
P4IBW	6888	1/17/2012	1/23/2012	Methane	100	U
P4IBW	6940	2/7/2012	2/10/2012	Hydrogen	100	318.06
P4IBW	6940	2/7/2012	2/10/2012	Methane	100	U
P4IBW	7041	3/13/2012	3/16/2012	Hydrogen	100	226.60
P4IBW	7041	3/13/2012	3/16/2012	Methane	100	U
P4IBW	7111	4/10/2012	4/13/2012	Hydrogen	100	51.64 J
P4IBW	7111	4/10/2012	4/13/2012	Methane	100	U
P4IBW	7189	5/8/2012	5/15/2012	Hydrogen	100	95.04 J
P4IBW	7189	5/8/2012	5/15/2012	Methane	100	U
P4IBW	7268	6/11/2012	6/18/2012	Hydrogen	100	77.72 J
P4IBW	7268	6/11/2012	6/18/2012	Methane	100	U
P4R1E	6897	1/17/2012	1/23/2012	Hydrogen	100	501.80
P4R1E	6897	1/17/2012	1/23/2012	Methane	100	U
P4R1E	6948	2/7/2012	2/10/2012	Hydrogen	100	414.88
P4R1E	6948	2/7/2012	2/10/2012	Methane	100	U
P4R1E	7049	3/13/2012	3/16/2012	Hydrogen	100	376.52
P4R1E	7049	3/13/2012	3/16/2012	Methane	100	U
P4R1E	7119	4/10/2012	4/13/2012	Hydrogen	100	322.28
P4R1E	7119	4/10/2012	4/13/2012	Methane	100	U
P4R1E	7197	5/9/2012	5/15/2012	Hydrogen	100	278.46
P4R1E	7197	5/9/2012	5/15/2012	Methane	100	U
P4R1E	7276	6/11/2012	6/18/2012	Hydrogen	100	219.08
P4R1E	7276	6/11/2012	6/18/2012	Methane	100	U
P4R1I	6887	1/17/2012	1/23/2012	Hydrogen	100	505.60
P4R1I	6887	1/17/2012	1/23/2012	Methane	100	U

Attachment 5 – Hydrogen and Methane Results

Panel 4 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P4R1I	6939	2/7/2012	2/10/2012	Hydrogen	100	412.76
P4R1I	6939	2/7/2012	2/10/2012	Methane	100	U
P4R1I	7040	3/13/2012	3/16/2012	Hydrogen	100	362.80
P4R1I	7040	3/13/2012	3/16/2012	Methane	100	U
P4R1I	7110	4/10/2012	4/13/2012	Hydrogen	100	192.06
P4R1I	7110	4/10/2012	4/13/2012	Methane	100	U
P4R1I	7188	5/8/2012	5/15/2012	Hydrogen	100	191.24
P4R1I	7188	5/8/2012	5/15/2012	Methane	100	U
P4R1I	7267	6/11/2012	6/18/2012	Hydrogen	100	134.02
P4R1I	7267	6/11/2012	6/18/2012	Methane	100	U
P4R2E	6894	1/17/2012	1/23/2012	Hydrogen	100	552.66
P4R2E	6894	1/17/2012	1/23/2012	Methane	100	U
P4R2E	6945	2/7/2012	2/10/2012	Hydrogen	100	432.98
P4R2E	6945	2/7/2012	2/10/2012	Methane	100	U
P4R2E	7046	3/13/2012	3/16/2012	Hydrogen	100	424.60
P4R2E	7046	3/13/2012	3/16/2012	Methane	100	U
P4R2E	7116	4/10/2012	4/13/2012	Hydrogen	100	348.22
P4R2E	7116	4/10/2012	4/13/2012	Methane	100	U
P4R2E	7194	5/9/2012	5/15/2012	Hydrogen	100	259.10
P4R2E	7194	5/9/2012	5/15/2012	Methane	100	U
P4R2E	7273	6/11/2012	6/18/2012	Hydrogen	100	249.62
P4R2E	7273	6/11/2012	6/18/2012	Methane	100	U
P4R2I	6886	1/17/2012	1/23/2012	Hydrogen	100	486.72
P4R2I	6886	1/17/2012	1/23/2012	Methane	100	U
P4R2I	6938	2/7/2012	2/10/2012	Hydrogen	100	375.26
P4R2I	6938	2/7/2012	2/10/2012	Methane	100	U
P4R2I	7039	3/13/2012	3/16/2012	Hydrogen	100	344.34
P4R2I	7039	3/13/2012	3/16/2012	Methane	100	U
P4R2I	7109	4/10/2012	4/13/2012	Hydrogen	100	209.40
P4R2I	7109	4/10/2012	4/13/2012	Methane	100	U
P4R2I	7187	5/8/2012	5/15/2012	Hydrogen	100	217.40

Attachment 5 – Hydrogen and Methane Results

Panel 4 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P4R2I	7187	5/8/2012	5/15/2012	Methane	100	U
P4R2I	7266	6/11/2012	6/18/2012	Hydrogen	100	146.80
P4R2I	7266	6/11/2012	6/18/2012	Methane	100	U
P4R3E	6893	1/17/2012	1/23/2012	Hydrogen	100	590.80
P4R3E	6893	1/17/2012	1/23/2012	Methane	100	U
P4R3E	6944	2/7/2012	2/10/2012	Hydrogen	100	533.58
P4R3E	6944	2/7/2012	2/10/2012	Methane	100	U
P4R3E	7045	3/13/2012	3/16/2012	Hydrogen	100	524.88
P4R3E	7045	3/13/2012	3/16/2012	Methane	100	U
P4R3E	7115	4/10/2012	4/13/2012	Hydrogen	100	407.36
P4R3E	7115	4/10/2012	4/13/2012	Methane	100	U
P4R3E	7193	5/9/2012	5/15/2012	Hydrogen	100	353.58
P4R3E	7193	5/9/2012	5/15/2012	Methane	100	U
P4R3E	7272	6/11/2012	6/18/2012	Hydrogen	100	322.22
P4R3E	7272	6/11/2012	6/18/2012	Methane	100	U
P4R3I	6885	1/17/2012	1/23/2012	Hydrogen	100	557.32
P4R3I	6885	1/17/2012	1/23/2012	Methane	100	U
P4R3I	6937	2/7/2012	2/10/2012	Hydrogen	100	489.38
P4R3I	6937	2/7/2012	2/10/2012	Methane	100	U
P4R3I	7038	3/13/2012	3/16/2012	Hydrogen	100	446.26
P4R3I	7038	3/13/2012	3/16/2012	Methane	100	U
P4R3I	7108	4/10/2012	4/13/2012	Hydrogen	100	403.18
P4R3I	7108	4/10/2012	4/13/2012	Methane	100	U
P4R3I	7186	5/8/2012	5/15/2012	Hydrogen	100	322.48
P4R3I	7186	5/8/2012	5/15/2012	Methane	100	U
P4R3I	7265	6/11/2012	6/18/2012	Hydrogen	100	251.78
P4R3I	7265	6/11/2012	6/18/2012	Methane	100	U
P4R4I	6884	1/17/2012	1/23/2012	Hydrogen	100	550.82
P4R4I	6884	1/17/2012	1/23/2012	Methane	100	U
P4R4I	6936	2/7/2012	2/10/2012	Hydrogen	100	457.42
P4R4I	6936	2/7/2012	2/10/2012	Methane	100	U

Attachment 5 – Hydrogen and Methane Results

Panel 4 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P4R4I	7037	3/13/2012	3/16/2012	Hydrogen	100	389.74
P4R4I	7037	3/13/2012	3/16/2012	Methane	100	U
P4R4I	7107	4/10/2012	4/13/2012	Hydrogen	100	312.08
P4R4I	7107	4/10/2012	4/13/2012	Methane	100	U
P4R4I	7185	5/8/2012	5/15/2012	Hydrogen	100	290.96
P4R4I	7185	5/8/2012	5/15/2012	Methane	100	U
P4R4I	7264	6/11/2012	6/18/2012	Hydrogen	100	282.70
P4R4I	7264	6/11/2012	6/18/2012	Methane	100	U
P4R5E	6892	1/17/2012	1/23/2012	Hydrogen	100	648.78
P4R5E	6892	1/17/2012	1/23/2012	Methane	100	U
P4R5E	6943	2/7/2012	2/10/2012	Hydrogen	100	606.14
P4R5E	6943	2/7/2012	2/10/2012	Methane	100	U
P4R5E	7044	3/13/2012	3/16/2012	Hydrogen	100	533.38
P4R5E	7044	3/13/2012	3/16/2012	Methane	100	U
P4R5E	7114	4/10/2012	4/13/2012	Hydrogen	100	484.22
P4R5E	7114	4/10/2012	4/13/2012	Methane	100	U
P4R5E	7192	5/9/2012	5/15/2012	Hydrogen	100	425.66
P4R5E	7192	5/9/2012	5/15/2012	Methane	100	U
P4R5E	7271	6/11/2012	6/18/2012	Hydrogen	100	337.64
P4R5E	7271	6/11/2012	6/18/2012	Methane	100	U
P4R5I	6883	1/17/2012	1/23/2012	Hydrogen	100	517.00
P4R5I	6883	1/17/2012	1/23/2012	Methane	100	U
P4R5I	6935	2/7/2012	2/10/2012	Hydrogen	100	442.04
P4R5I	6935	2/7/2012	2/10/2012	Methane	100	U
P4R5I	7036	3/13/2012	3/16/2012	Hydrogen	100	421.60
P4R5I	7036	3/13/2012	3/16/2012	Methane	100	U
P4R5I	7106	4/10/2012	4/13/2012	Hydrogen	100	312.30
P4R5I	7106	4/10/2012	4/13/2012	Methane	100	U
P4R5I	7184	5/8/2012	5/15/2012	Hydrogen	100	279.52
P4R5I	7184	5/8/2012	5/15/2012	Methane	100	U
P4R5I	7263	6/11/2012	6/18/2012	Hydrogen	100	258.10

Attachment 5 – Hydrogen and Methane Results

Panel 4 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P4R5I	7263	6/11/2012	6/18/2012	Methane	100	U
P4R6I	6882	1/17/2012	1/23/2012	Hydrogen	100	496.08
P4R6I	6882	1/17/2012	1/23/2012	Methane	100	U
P4R6I	6934	2/7/2012	2/10/2012	Hydrogen	100	382.54
P4R6I	6934	2/7/2012	2/10/2012	Methane	100	U
P4R6I	7035	3/13/2012	3/16/2012	Hydrogen	100	376.90
P4R6I	7035	3/13/2012	3/16/2012	Methane	100	U
P4R6I	7105	4/10/2012	4/13/2012	Hydrogen	100	143.80
P4R6I	7105	4/10/2012	4/13/2012	Methane	100	U
P4R6I	7183	5/8/2012	5/15/2012	Hydrogen	100	239.76
P4R6I	7183	5/8/2012	5/15/2012	Methane	100	U
P4R6I	7262	6/11/2012	6/18/2012	Hydrogen	100	131.74
P4R6I	7262	6/11/2012	6/18/2012	Methane	100	U
P4R7E	6890	1/17/2012	1/23/2012	Hydrogen	100	759.70
P4R7E	6890	1/17/2012	1/23/2012	Methane	100	U
P4R7E	6942	2/7/2012	2/10/2012	Hydrogen	100	735.92
P4R7E	6942	2/7/2012	2/10/2012	Methane	100	U
P4R7E	7043	3/13/2012	3/16/2012	Hydrogen	100	669.68
P4R7E	7043	3/13/2012	3/16/2012	Methane	100	U
P4R7E	7113	4/10/2012	4/13/2012	Hydrogen	100	635.18
P4R7E	7113	4/10/2012	4/13/2012	Methane	100	U
P4R7E	7191	5/9/2012	5/15/2012	Hydrogen	100	530.68
P4R7E	7191	5/9/2012	5/15/2012	Methane	100	U
P4R7E	7270	6/11/2012	6/18/2012	Hydrogen	100	466.46
P4R7E	7270	6/11/2012	6/18/2012	Methane	100	U
P4R7I	6881	1/17/2012	1/23/2012	Hydrogen	100	529.76
P4R7I	6881	1/17/2012	1/23/2012	Methane	100	U
P4R7I	6933	2/7/2012	2/10/2012	Hydrogen	100	435.94
P4R7I	6933	2/7/2012	2/10/2012	Methane	100	U
P4R7I	7034	3/13/2012	3/16/2012	Hydrogen	100	378.74
P4R7I	7034	3/13/2012	3/16/2012	Methane	100	U

Attachment 5 – Hydrogen and Methane Results

Panel 4 - Hydrogen and Methane Results

Location	Sample ID	Sample Date	Analysis Date	Compound Name	MRL (ppmv)	Concentration (ppmv)
P4R7I	7104	4/10/2012	4/13/2012	Hydrogen	100	168.24
P4R7I	7104	4/10/2012	4/13/2012	Methane	100	U
P4R7I	7182	5/8/2012	5/15/2012	Hydrogen	100	217.16
P4R7I	7182	5/8/2012	5/15/2012	Methane	100	U
P4R7I	7261	6/11/2012	6/18/2012	Hydrogen	100	141.74
P4R7I	7261	6/11/2012	6/18/2012	Methane	100	U

Notes:

J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above the MDL.

Panel 4 sample lines determined as obstructed: (1) P4R4E on April 7, 2011
(2) P4R6E on December 13, 2011
(3) P4R5E on August 14, 2012 (not impactive to results for this reporting period)

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Original Analysis Date	Original Sample ID	Duplicate Analysis Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
1/11/2012	6833	1/11/2012	6833-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
1/11/2012	6833	1/11/2012	6833-dup	1,1-Dichloroethylene	3.99* J	3.87* J	0.12	3.05
1/11/2012	6833	1/11/2012	6833-dup	1,2-Dichloroethane	U	U	0	0.00
1/11/2012	6833	1/11/2012	6833-dup	Carbon Tetrachloride	454.68*	457.38*	-2.7	0.59
1/11/2012	6833	1/11/2012	6833-dup	Chlorobenzene	U	U	0	0.00
1/11/2012	6833	1/11/2012	6833-dup	Chloroform	38.43*	38.90*	-0.47	1.22
1/11/2012	6833	1/11/2012	6833-dup	Methylene Chloride	10.81* J	10.57* J	0.24	2.25
1/11/2012	6833	1/11/2012	6833-dup	Toluene	U	U	0	0.00
1/11/2012	6833	1/11/2012	6833-dup	1,1,1-Trichloroethane	63.82*	63.47*	0.35	0.55
1/18/2012	6843	1/18/2012	6843-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
1/18/2012	6843	1/18/2012	6843-dup	Toluene	0.66* J	0.61* J	0.05	7.87
1/18/2012	6843	1/18/2012	6843-dup	Methylene Chloride	3.98*	3.98*	0	0.00
1/18/2012	6843	1/18/2012	6843-dup	Chloroform	11.05*	10.89*	0.16	1.46
1/18/2012	6843	1/18/2012	6843-dup	Chlorobenzene	U	U	0	0.00
1/18/2012	6843	1/18/2012	6843-dup	Carbon Tetrachloride	140.47*	142.06*	-1.59	1.13
1/18/2012	6843	1/18/2012	6843-dup	1,1-Dichloroethylene	0.53* J	0.50* J	0.03	5.83
1/18/2012	6843	1/18/2012	6843-dup	1,1,1-Trichloroethane	25.37*	25.24*	0.13	0.51
1/18/2012	6843	1/18/2012	6843-dup	1,2-Dichloroethane	U	U	0	0.00
1/19/2012	6869	1/19/2012	6869-dup	Chlorobenzene	U	U	0	0.00
1/19/2012	6869	1/19/2012	6869-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
1/19/2012	6869	1/19/2012	6869-dup	Toluene	87.84	69.12 J	18.72	23.85
1/19/2012	6869	1/19/2012	6869-dup	Methylene Chloride	1207.44	1082.16	125.28	10.94
1/19/2012	6869	1/19/2012	6869-dup	Chloroform	131.76	118.08	13.68	10.95
1/19/2012	6869	1/19/2012	6869-dup	1,1,1-Trichloroethane	4248.72	3931.92	316.8	7.75
1/19/2012	6869	1/19/2012	6869-dup	1,1-Dichloroethylene	54 J	43.2 J	10.8	22.22
1/19/2012	6869	1/19/2012	6869-dup	1,2-Dichloroethane	10.08 J	10.08 J	0	0.00
1/19/2012	6869	1/19/2012	6869-dup	Carbon Tetrachloride	4372.56	4119.12	253.44	5.97
1/25/2012	6871	1/25/2012	6871-dup	1,2-Dichloroethane	U	U	0	0.00
1/25/2012	6871	1/25/2012	6871-dup	Toluene	0.40* J	0.40* J	0	0.00
1/25/2012	6871	1/25/2012	6871-dup	Methylene Chloride	3.48*	3.45*	0.03	0.87
1/25/2012	6871	1/25/2012	6871-dup	Chloroform	9.89*	10.07*	-0.18	1.80
1/25/2012	6871	1/25/2012	6871-dup	Carbon Tetrachloride	152.67*	154.07*	-1.4	0.91
1/25/2012	6871	1/25/2012	6871-dup	1,1-Dichloroethylene	U	U	0	0.00
1/25/2012	6871	1/25/2012	6871-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Original Analysis Date	Original Sample ID	Duplicate Analysis Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
1/25/2012	6871	1/25/2012	6871-dup	1,1,1-Trichloroethane	30.90*	31.71*	-0.81	2.59
1/25/2012	6871	1/25/2012	6871-dup	Chlorobenzene	U	U	0	0.00
1/25/2012	6897	1/25/2012	6897-dup	Chlorobenzene	U	U	0	0.00
1/25/2012	6897	1/25/2012	6897-dup	Carbon Tetrachloride	884422.8	869551.2	14871.6	1.70
1/25/2012	6897	1/25/2012	6897-dup	Toluene	U	U	0	0.00
1/25/2012	6897	1/25/2012	6897-dup	Chloroform	66484.8	65610	874.8	1.32
1/25/2012	6897	1/25/2012	6897-dup	1,1,1-Trichloroethane	160263.36	158863.68	1399.68	0.88
1/25/2012	6897	1/25/2012	6897-dup	1,1-Dichloroethylene	U	U	0	0.00
1/25/2012	6897	1/25/2012	6897-dup	Methylene Chloride	30268.08	30967.92	-699.84	2.29
1/25/2012	6897	1/25/2012	6897-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
1/25/2012	6897	1/25/2012	6897-dup	1,2-Dichloroethane	U	U	0	0.00
2/1/2012	6899	2/1/2012	6899-dup	1,2-Dichloroethane	U	U	0	0.00
2/1/2012	6899	2/1/2012	6899-dup	Toluene	0.58* J	0.53* J	0.05	9.01
2/1/2012	6899	2/1/2012	6899-dup	Methylene Chloride	7.42*	7.37*	0.05	0.68
2/1/2012	6899	2/1/2012	6899-dup	Chloroform	19.21*	18.91*	0.3	1.57
2/1/2012	6899	2/1/2012	6899-dup	Carbon Tetrachloride	229.41*	230.33*	-0.92	0.40
2/1/2012	6899	2/1/2012	6899-dup	1,1-Dichloroethylene	1.74* J	1.60* J	0.14	8.38
2/1/2012	6899	2/1/2012	6899-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
2/1/2012	6899	2/1/2012	6899-dup	1,1,1-Trichloroethane	38.17*	38.17*	0	0.00
2/1/2012	6899	2/1/2012	6899-dup	Chlorobenzene	U	U	0	0.00
2/6/2012	6911	2/6/2012	6911-dup	Chlorobenzene	U	U	0	0.00
2/6/2012	6911	2/6/2012	6911-dup	Methylene Chloride	2.36*	2.42*	-0.06	2.51
2/6/2012	6911	2/6/2012	6911-dup	Toluene	0.43* J	0.43* J	0	0.00
2/6/2012	6911	2/6/2012	6911-dup	Chloroform	5.26*	5.42*	-0.16	3.00
2/6/2012	6911	2/6/2012	6911-dup	1,2-Dichloroethane	U	U	0	0.00
2/6/2012	6911	2/6/2012	6911-dup	1,1-Dichloroethylene	U	U	0	0.00
2/6/2012	6911	2/6/2012	6911-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
2/6/2012	6911	2/6/2012	6911-dup	1,1,1-Trichloroethane	15.50*	15.96*	-0.46	2.92
2/6/2012	6911	2/6/2012	6911-dup	Carbon Tetrachloride	74.62*	76.61*	-1.99	2.63
2/14/2012	6923	2/14/2012	6923-dup	Methylene Chloride	3.50*	3.35*	0.15	4.38
2/14/2012	6923	2/14/2012	6923-dup	1,1,1-Trichloroethane	18.72*	18.39*	0.33	1.78
2/14/2012	6923	2/14/2012	6923-dup	Toluene	0.56* J	0.56* J	0	0.00
2/14/2012	6923	2/14/2012	6923-dup	Chloroform	9.06*	9.11*	-0.05	0.55
2/14/2012	6923	2/14/2012	6923-dup	Chlorobenzene	U	U	0	0.00
2/14/2012	6923	2/14/2012	6923-dup	1,2-Dichloroethane	U	U	0	0.00

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Original Analysis Date	Original Sample ID	Duplicate Analysis Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
2/14/2012	6923	2/14/2012	6923-dup	1,1-Dichloroethylene	U	U	0	0.00
2/14/2012	6923	2/14/2012	6923-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
2/14/2012	6923	2/14/2012	6923-dup	Carbon Tetrachloride	105.55*	103.85*	1.7	1.62
2/14/2012	6948	2/14/2012	6948-dup	1,2-Dichloroethane	U	U	0	0.00
2/14/2012	6948	2/14/2012	6948-dup	Toluene	U	U	0	0.00
2/14/2012	6948	2/14/2012	6948-dup	Methylene Chloride	26375.22	28343.52	-1968.3	7.19
2/14/2012	6948	2/14/2012	6948-dup	Chloroform	58655.34	60886.08	-2230.74	3.73
2/14/2012	6948	2/14/2012	6948-dup	1,1,1-Trichloroethane	136600.02	138305.88	-1705.86	1.24
2/14/2012	6948	2/14/2012	6948-dup	Carbon Tetrachloride	760419.9	765537.48	-5117.58	0.67
2/14/2012	6948	2/14/2012	6948-dup	1,1-Dichloroethylene	U	U	0	0.00
2/14/2012	6948	2/14/2012	6948-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
2/14/2012	6948	2/14/2012	6948-dup	Chlorobenzene	U	U	0	0.00
2/23/2012	6951	2/23/2012	6951-dup	Chloroform	5.93*	5.96*	-0.03	0.50
2/23/2012	6951	2/23/2012	6951-dup	1,2-Dichloroethane	U	U	0	0.00
2/23/2012	6951	2/23/2012	6951-dup	Toluene	0.57* J	0.52* J	0.05	9.17
2/23/2012	6951	2/23/2012	6951-dup	Methylene Chloride	2.56*	2.65*	-0.09	3.45
2/23/2012	6951	2/23/2012	6951-dup	1,1,1-Trichloroethane	15.39*	15.22*	0.17	1.11
2/23/2012	6951	2/23/2012	6951-dup	Chlorobenzene	U	U	0	0.00
2/23/2012	6951	2/23/2012	6951-dup	1,1-Dichloroethylene	U	U	0	0.00
2/23/2012	6951	2/23/2012	6951-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
2/23/2012	6951	2/23/2012	6951-dup	Carbon Tetrachloride	76.36*	76.12*	0.24	0.31
2/28/2012	6972	2/28/2012	6972-dup	Methylene Chloride	288.24	285.12	3.12	1.09
2/28/2012	6972	2/28/2012	6972-dup	Toluene	18.24 J	18 J	0.24	1.32
2/28/2012	6972	2/28/2012	6972-dup	Chloroform	41.04	40.08	0.96	2.37
2/28/2012	6972	2/28/2012	6972-dup	Chlorobenzene	U	U	0	0.00
2/28/2012	6972	2/28/2012	6972-dup	1,2-Dichloroethane	2.88 J	U	2.88	200.00
2/28/2012	6972	2/28/2012	6972-dup	1,1-Dichloroethylene	8.64 J	9.12 J	-0.48	5.41
2/28/2012	6972	2/28/2012	6972-dup	1,1,1-Trichloroethane	1098.24	1048.32	49.92	4.65
2/28/2012	6972	2/28/2012	6972-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
2/28/2012	6972	2/28/2012	6972-dup	Carbon Tetrachloride	1273.68	1207.92	65.76	5.30
2/28/2012	6977	2/28/2012	6977-dup	1,2-Dichloroethane	U	U	0	0.00
2/28/2012	6977	2/28/2012	6977-dup	Methylene Chloride	8.77*	8.39*	0.38	4.43
2/28/2012	6977	2/28/2012	6977-dup	Chloroform	21.81*	20.07*	1.74	8.31
2/28/2012	6977	2/28/2012	6977-dup	1,1,1-Trichloroethane	51.06*	47.12*	3.94	8.03
2/28/2012	6977	2/28/2012	6977-dup	Carbon Tetrachloride	291.71*	271.64*	20.07	7.13

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Original Analysis Date	Original Sample ID	Duplicate Analysis Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
2/28/2012	6977	2/28/2012	6977-dup	1,1-Dichloroethylene	U	U	0	0.00
2/28/2012	6977	2/28/2012	6977-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
2/28/2012	6977	2/28/2012	6977-dup	Toluene	0.58* J	0.64* J	-0.06	9.84
2/28/2012	6977	2/28/2012	6977-dup	Chlorobenzene	U	U	0	0.00
3/1/2012	6989	3/1/2012	6989-dup	Chlorobenzene	U	U	0	0.00
3/1/2012	6989	3/1/2012	6989-dup	Toluene	0.82* J	0.77* J	0.05	6.29
3/1/2012	6989	3/1/2012	6989-dup	Methylene Chloride	9.82*	9.24*	0.58	6.09
3/1/2012	6989	3/1/2012	6989-dup	Chloroform	22.69*	22.40*	0.29	1.29
3/1/2012	6989	3/1/2012	6989-dup	1,2-Dichloroethane	U	U	0	0.00
3/1/2012	6989	3/1/2012	6989-dup	1,1-Dichloroethylene	0.82* J	0.82* J	0	0.00
3/1/2012	6989	3/1/2012	6989-dup	1,1,1-Trichloroethane	47.84*	47.84*	0	0.00
3/1/2012	6989	3/1/2012	6989-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
3/1/2012	6989	3/1/2012	6989-dup	Carbon Tetrachloride	271.03*	273.01*	-1.98	0.73
3/13/2012	6999	3/13/2012	6999-dup	1,2-Dichloroethane	U	U	0	0.00
3/13/2012	6999	3/13/2012	6999-dup	Toluene	0.66* J	0.59* J	0.07	11.20
3/13/2012	6999	3/13/2012	6999-dup	Methylene Chloride	10.19*	9.53*	0.66	6.69
3/13/2012	6999	3/13/2012	6999-dup	Chloroform	32.06*	29.93*	2.13	6.87
3/13/2012	6999	3/13/2012	6999-dup	Carbon Tetrachloride	370.32*	347.92*	22.4	6.24
3/13/2012	6999	3/13/2012	6999-dup	1,1-Dichloroethylene	1.86* J	1.66* J	0.2	11.36
3/13/2012	6999	3/13/2012	6999-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
3/13/2012	6999	3/13/2012	6999-dup	1,1,1-Trichloroethane	56.79*	53.73*	3.06	5.54
3/13/2012	6999	3/13/2012	6999-dup	Chlorobenzene	U	U	0	0.00
3/13/2012	7022	3/13/2012	7022-dup	Chlorobenzene	U	U	0	0.00
3/13/2012	7022	3/13/2012	7022-dup	Methylene Chloride	1286.28	1316.52	-30.24	2.32
3/13/2012	7022	3/13/2012	7022-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
3/13/2012	7022	3/13/2012	7022-dup	Chloroform	147.96	153.36	-5.4	3.58
3/13/2012	7022	3/13/2012	7022-dup	Toluene	57.24 J	60.48 J	-3.24	5.50
3/13/2012	7022	3/13/2012	7022-dup	1,1-Dichloroethylene	33.48 J	35.64 J	-2.16	6.25
3/13/2012	7022	3/13/2012	7022-dup	1,1,1-Trichloroethane	4485.24	4668.84	-183.6	4.01
3/13/2012	7022	3/13/2012	7022-dup	1,2-Dichloroethane	U	U	0	0.00
3/13/2012	7022	3/13/2012	7022-dup	Carbon Tetrachloride	4943.16	5135.4	-192.24	3.81
3/21/2012	7025	3/21/2012	7025-dup	1,2-Dichloroethane	U	U	0	0.00
3/21/2012	7025	3/21/2012	7025-dup	Toluene	0.61* J	0.58* J	0.03	5.04
3/21/2012	7025	3/21/2012	7025-dup	Methylene Chloride	4.67*	4.86*	-0.19	3.99
3/21/2012	7025	3/21/2012	7025-dup	Chloroform	11.55*	12.17*	-0.62	5.23

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Original Analysis Date	Original Sample ID	Duplicate Analysis Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
3/21/2012	7025	3/21/2012	7025-dup	Carbon Tetrachloride	149.03*	154.55*	-5.52	3.64
3/21/2012	7025	3/21/2012	7025-dup	1,1-Dichloroethylene	U	U	0	0.00
3/21/2012	7025	3/21/2012	7025-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
3/21/2012	7025	3/21/2012	7025-dup	1,1,1-Trichloroethane	26.77*	27.64*	-0.87	3.20
3/21/2012	7025	3/21/2012	7025-dup	Chlorobenzene	U	U	0	0.00
3/21/2012	7049	3/21/2012	7049-dup	Carbon Tetrachloride	886522.32	899119.44	-12597.12	1.41
3/21/2012	7049	3/21/2012	7049-dup	Chloroform	67053.42	69152.94	-2099.52	3.08
3/21/2012	7049	3/21/2012	7049-dup	Methylene Chloride	31099.14	32673.78	-1574.64	4.94
3/21/2012	7049	3/21/2012	7049-dup	Chlorobenzene	U	U	0	0.00
3/21/2012	7049	3/21/2012	7049-dup	1,1-Dichloroethylene	U	U	0	0.00
3/21/2012	7049	3/21/2012	7049-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
3/21/2012	7049	3/21/2012	7049-dup	1,1,1-Trichloroethane	158251.32	161925.48	-3674.16	2.30
3/21/2012	7049	3/21/2012	7049-dup	Toluene	1180.98 J	1180.98 J	0	0.00
3/21/2012	7049	3/21/2012	7049-dup	1,2-Dichloroethane	U	U	0	0.00
4/2/2012	7055	4/2/2012	7055-dup	Chlorobenzene	U	U	0	0.00
4/2/2012	7055	4/2/2012	7055-dup	Toluene	0.58* J	0.58* J	0	0.00
4/2/2012	7055	4/2/2012	7055-dup	Chloroform	10.11*	10.38*	-0.27	2.64
4/2/2012	7055	4/2/2012	7055-dup	Carbon Tetrachloride	137.04*	153.47*	-16.43	11.31
4/2/2012	7055	4/2/2012	7055-dup	1,2-Dichloroethane	U	U	0	0.00
4/2/2012	7055	4/2/2012	7055-dup	1,1-Dichloroethylene	U	U	0	0.00
4/2/2012	7055	4/2/2012	7055-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
4/2/2012	7055	4/2/2012	7055-dup	1,1,1-Trichloroethane	24.32*	26.49*	-2.17	8.54
4/2/2012	7055	4/2/2012	7055-dup	Methylene Chloride	4.24* J	4.55*	-0.31	7.05
4/11/2012	7063	4/11/2012	7063-dup	Toluene	0.84* J	0.84* J	0	0.00
4/11/2012	7063	4/11/2012	7063-dup	1,1,1-Trichloroethane	45.84*	51.00*	-5.16	10.66
4/11/2012	7063	4/11/2012	7063-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
4/11/2012	7063	4/11/2012	7063-dup	1,1-Dichloroethylene	U	U	0	0.00
4/11/2012	7063	4/11/2012	7063-dup	1,2-Dichloroethane	U	U	0	0.00
4/11/2012	7063	4/11/2012	7063-dup	Carbon Tetrachloride	234.09*	258.81*	-24.72	10.03
4/11/2012	7063	4/11/2012	7063-dup	Chlorobenzene	U	U	0	0.00
4/11/2012	7063	4/11/2012	7063-dup	Chloroform	19.62*	21.18*	-1.56	7.65
4/11/2012	7063	4/11/2012	7063-dup	Methylene Chloride	8.22*	8.22*	0	0.00
4/12/2012	7073	4/12/2012	7073-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
4/12/2012	7073	4/12/2012	7073-dup	1,1-Dichloroethylene	U	U	0	0.00
4/12/2012	7073	4/12/2012	7073-dup	1,2-Dichloroethane	U	U	0	0.00

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Original Analysis Date	Original Sample ID	Duplicate Analysis Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
4/12/2012	7073	4/12/2012	7073-dup	Carbon Tetrachloride	167.15*	166.08*	1.07	0.64
4/12/2012	7073	4/12/2012	7073-dup	Chlorobenzene	U	U	0	0.00
4/12/2012	7073	4/12/2012	7073-dup	Chloroform	13.28*	12.99*	0.29	2.21
4/12/2012	7073	4/12/2012	7073-dup	Methylene Chloride	5.01*	4.88*	0.13	2.63
4/12/2012	7073	4/12/2012	7073-dup	Toluene	0.76* J	0.69* J	0.07	9.66
4/12/2012	7073	4/12/2012	7073-dup	1,1,1-Trichloroethane	32.22*	31.86*	0.36	1.12
4/11/2012	7095	4/11/2012	7095-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
4/11/2012	7095	4/11/2012	7095-dup	Toluene	32.4 J	32.4 J	0	0.00
4/11/2012	7095	4/11/2012	7095-dup	Methylene Chloride	580.32	592.56	-12.24	2.09
4/11/2012	7095	4/11/2012	7095-dup	Chloroform	82.08	83.52	-1.44	1.74
4/11/2012	7095	4/11/2012	7095-dup	Chlorobenzene	U	U	0	0.00
4/11/2012	7095	4/11/2012	7095-dup	Carbon Tetrachloride	2601.36	2704.32	-102.96	3.88
4/11/2012	7095	4/11/2012	7095-dup	1,1-Dichloroethylene	16.56 J	18.72 J	-2.16	12.24
4/11/2012	7095	4/11/2012	7095-dup	1,1,1-Trichloroethane	2154.96	2265.12	-110.16	4.98
4/11/2012	7095	4/11/2012	7095-dup	1,2-Dichloroethane	U	U	0	0.00
4/13/2012	7097	4/13/2012	7097-dup	Chlorobenzene	U	U	0	0.00
4/13/2012	7097	4/13/2012	7097-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
4/13/2012	7097	4/13/2012	7097-dup	Toluene	0.69* J	0.65* J	0.04	5.97
4/13/2012	7097	4/13/2012	7097-dup	Methylene Chloride	5.57*	5.69*	-0.12	2.13
4/13/2012	7097	4/13/2012	7097-dup	Chloroform	16.80*	17.82*	-1.02	5.89
4/13/2012	7097	4/13/2012	7097-dup	1,1,1-Trichloroethane	39.30*	40.61*	-1.31	3.28
4/13/2012	7097	4/13/2012	7097-dup	1,1-Dichloroethylene	U	U	0	0.00
4/13/2012	7097	4/13/2012	7097-dup	1,2-Dichloroethane	U	U	0	0.00
4/13/2012	7097	4/13/2012	7097-dup	Carbon Tetrachloride	209.15*	217.67*	-8.52	3.99
4/24/2012	7119	4/24/2012	7119-dup	1,2-Dichloroethane	U	U	0	0.00
4/24/2012	7119	4/24/2012	7119-dup	Toluene	U	U	0	0.00
4/24/2012	7119	4/24/2012	7119-dup	Methylene Chloride	21388.86	21520.08	-131.22	0.61
4/24/2012	7119	4/24/2012	7119-dup	Chloroform	47501.64	48551.4	-1049.76	2.19
4/24/2012	7119	4/24/2012	7119-dup	Carbon Tetrachloride	605973.96	616865.22	-10891.26	1.78
4/24/2012	7119	4/24/2012	7119-dup	1,1-Dichloroethylene	U	U	0	0.00
4/24/2012	7119	4/24/2012	7119-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
4/24/2012	7119	4/24/2012	7119-dup	1,1,1-Trichloroethane	110880.9	110880.9	0	0.00
4/24/2012	7119	4/24/2012	7119-dup	Chlorobenzene	U	U	0	0.00
4/25/2012	7127	4/25/2012	7127-dup	Chlorobenzene	U	U	0	0.00
4/25/2012	7127	4/25/2012	7127-dup	Toluene	0.53* J	0.45* J	0.08	16.33

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Original Analysis Date	Original Sample ID	Duplicate Analysis Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
4/25/2012	7127	4/25/2012	7127-dup	Carbon Tetrachloride	125.64*	119.48*	6.16	5.03
4/25/2012	7127	4/25/2012	7127-dup	Chloroform	9.31*	8.99*	0.32	3.50
4/25/2012	7127	4/25/2012	7127-dup	Methylene Chloride	3.74*	3.52*	0.22	6.06
4/25/2012	7127	4/25/2012	7127-dup	1,1-Dichloroethylene	U	U	0	0.00
4/25/2012	7127	4/25/2012	7127-dup	1,1,2,2-Tetrachloroethane	0.61* J	U	0.61	200.00
4/25/2012	7127	4/25/2012	7127-dup	1,1,1-Trichloroethane	24.66*	23.71*	0.95	3.93
4/25/2012	7127	4/25/2012	7127-dup	1,2-Dichloroethane	U	U	0	0.00
4/27/2012	7135	4/27/2012	7135-dup	1,2-Dichloroethane	U	U	0	0.00
4/27/2012	7135	4/27/2012	7135-dup	1,1,1-Trichloroethane	37.77*	36.68*	1.09	2.93
4/27/2012	7135	4/27/2012	7135-dup	Toluene	0.71* J	0.65* J	0.06	8.82
4/27/2012	7135	4/27/2012	7135-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
4/27/2012	7135	4/27/2012	7135-dup	1,1-Dichloroethylene	U	U	0	0.00
4/27/2012	7135	4/27/2012	7135-dup	Chloroform	16.69*	16.31*	0.38	2.30
4/27/2012	7135	4/27/2012	7135-dup	Chlorobenzene	U	U	0	0.00
4/27/2012	7135	4/27/2012	7135-dup	Carbon Tetrachloride	206.41*	199.07*	7.34	3.62
4/27/2012	7135	4/27/2012	7135-dup	Methylene Chloride	6.62*	6.40*	0.22	3.38
5/10/2012	7145	5/10/2012	7145-dup	Methylene Chloride	4.65*	4.54*	0.11	2.39
5/10/2012	7145	5/10/2012	7145-dup	Toluene	0.94* J	0.90* J	0.04	4.35
5/10/2012	7145	5/10/2012	7145-dup	1,1,1-Trichloroethane	28.05*	27.50*	0.55	1.98
5/10/2012	7145	5/10/2012	7145-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
5/10/2012	7145	5/10/2012	7145-dup	1,2-Dichloroethane	U	U	0	0.00
5/10/2012	7145	5/10/2012	7145-dup	Chloroform	11.60*	11.20*	0.4	3.51
5/10/2012	7145	5/10/2012	7145-dup	Chlorobenzene	U	U	0	0.00
5/10/2012	7145	5/10/2012	7145-dup	Carbon Tetrachloride	140.09*	137.14*	2.95	2.13
5/10/2012	7145	5/10/2012	7145-dup	1,1-Dichloroethylene	U	U	0	0.00
5/11/2012	7173	5/11/2012	7173-dup	Toluene	95.04 J	90.72 J	4.32	4.65
5/11/2012	7173	5/11/2012	7173-dup	Carbon Tetrachloride	3410.64	3439.8	-29.16	0.85
5/11/2012	7173	5/11/2012	7173-dup	1,1,1-Trichloroethane	2960.28	2970	-9.72	0.33
5/11/2012	7173	5/11/2012	7173-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
5/11/2012	7173	5/11/2012	7173-dup	Methylene Chloride	825.12	820.8	4.32	0.52
5/11/2012	7173	5/11/2012	7173-dup	1,2-Dichloroethane	U	U	0	0.00
5/11/2012	7173	5/11/2012	7173-dup	Chloroform	106.92 J	106.92 J	0	0.00
5/11/2012	7173	5/11/2012	7173-dup	Chlorobenzene	U	U	0	0.00
5/11/2012	7173	5/11/2012	7173-dup	1,1-Dichloroethylene	36.72 J	33.48 J	3.24	9.23
5/15/2012	7175	5/15/2012	7175-dup	1,2-Dichloroethane	U	U	0	0.00

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Original Analysis Date	Original Sample ID	Duplicate Analysis Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
5/15/2012	7175	5/15/2012	7175-dup	1,1,1-Trichloroethane	38.58*	40.93*	-2.35	5.91
5/15/2012	7175	5/15/2012	7175-dup	Toluene	0.99* J	0.99* J	0	0.00
5/15/2012	7175	5/15/2012	7175-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
5/15/2012	7175	5/15/2012	7175-dup	Carbon Tetrachloride	312.48*	334.37*	-21.89	6.77
5/15/2012	7175	5/15/2012	7175-dup	1,1-Dichloroethylene	U	U	0	0.00
5/15/2012	7175	5/15/2012	7175-dup	Chloroform	32.97*	34.96*	-1.99	5.86
5/15/2012	7175	5/15/2012	7175-dup	Chlorobenzene	U	U	0	0.00
5/15/2012	7175	5/15/2012	7175-dup	Methylene Chloride	7.95*	8.17*	-0.22	2.73
5/18/2012	7197	5/18/2012	7197-dup	1,2-Dichloroethane	U	U	0	0.00
5/18/2012	7197	5/18/2012	7197-dup	1,1,1-Trichloroethane	82056.24	88179.84	-6123.6	7.19
5/18/2012	7197	5/18/2012	7197-dup	Toluene	1399.68 J	1399.68 J	0	0.00
5/18/2012	7197	5/18/2012	7197-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
5/18/2012	7197	5/18/2012	7197-dup	Methylene Chloride	16358.76	17146.08	-787.32	4.70
5/18/2012	7197	5/18/2012	7197-dup	Chloroform	36479.16	38753.64	-2274.48	6.05
5/18/2012	7197	5/18/2012	7197-dup	Chlorobenzene	U	U	0	0.00
5/18/2012	7197	5/18/2012	7197-dup	Carbon Tetrachloride	448684.92	483327	-34642.08	7.43
5/18/2012	7197	5/18/2012	7197-dup	1,1-Dichloroethylene	U	U	0	0.00
5/23/2012	7199	5/23/2012	7199-dup	Toluene	1.20* J	1.13* J	0.07	6.01
5/23/2012	7199	5/23/2012	7199-dup	1,1,1-Trichloroethane	32.69*	33.51*	-0.82	2.48
5/23/2012	7199	5/23/2012	7199-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
5/23/2012	7199	5/23/2012	7199-dup	Methylene Chloride	4.80*	5.05*	-0.25	5.08
5/23/2012	7199	5/23/2012	7199-dup	1,2-Dichloroethane	U	U	0	0.00
5/23/2012	7199	5/23/2012	7199-dup	Chloroform	11.78*	12.22*	-0.44	3.67
5/23/2012	7199	5/23/2012	7199-dup	Carbon Tetrachloride	162.61*	167.38*	-4.77	2.89
5/23/2012	7199	5/23/2012	7199-dup	Chlorobenzene	U	U	0	0.00
5/23/2012	7199	5/23/2012	7199-dup	1,1-Dichloroethylene	U	U	0	0.00
5/24/2012	7211	5/24/2012	7211-dup	1,2-Dichloroethane	U	U	0	0.00
5/24/2012	7211	5/24/2012	7211-dup	Toluene	0.88* J	0.76* J	0.12	14.63
5/24/2012	7211	5/24/2012	7211-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
5/24/2012	7211	5/24/2012	7211-dup	Carbon Tetrachloride	300.15*	257.77*	42.38	15.19
5/24/2012	7211	5/24/2012	7211-dup	1,1-Dichloroethylene	U	U	0	0.00
5/24/2012	7211	5/24/2012	7211-dup	Chloroform	24.84*	22.60*	2.24	9.44
5/24/2012	7211	5/24/2012	7211-dup	Chlorobenzene	U	U	0	0.00
5/24/2012	7211	5/24/2012	7211-dup	1,1,1-Trichloroethane	44.44*	38.08*	6.36	15.41
5/24/2012	7211	5/24/2012	7211-dup	Methylene Chloride	6.65*	5.94*	0.71	11.28

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Original Analysis Date	Original Sample ID	Duplicate Analysis Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
6/5/2012	7223	6/5/2012	7223-dup	Methylene Chloride	7.41*	7.41*	0	0.00
6/5/2012	7223	6/5/2012	7223-dup	1,1,1-Trichloroethane	42.35*	42.19*	0.16	0.38
6/5/2012	7223	6/5/2012	7223-dup	Toluene	2.84* J	2.74* J	0.1	3.58
6/5/2012	7223	6/5/2012	7223-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
6/5/2012	7223	6/5/2012	7223-dup	1,2-Dichloroethane	U	U	0	0.00
6/5/2012	7223	6/5/2012	7223-dup	Chloroform	16.47*	16.50*	-0.03	0.18
6/5/2012	7223	6/5/2012	7223-dup	Carbon Tetrachloride	203.15*	204.06*	-0.91	0.45
6/5/2012	7223	6/5/2012	7223-dup	Chlorobenzene	U	U	0	0.00
6/5/2012	7223	6/5/2012	7223-dup	1,1-Dichloroethylene	U	U	0	0.00
6/7/2012	7249	6/7/2012	7249-dup	1,2-Dichloroethane	U	U	0	0.00
6/7/2012	7249	6/7/2012	7249-dup	1,1,1-Trichloroethane	34.85*	34.71*	0.14	0.40
6/7/2012	7249	6/7/2012	7249-dup	Toluene	1.05* J	1.02* J	0.03	2.90
6/7/2012	7249	6/7/2012	7249-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
6/7/2012	7249	6/7/2012	7249-dup	1,1-Dichloroethylene	U	U	0	0.00
6/7/2012	7249	6/7/2012	7249-dup	Chloroform	14.36*	14.08*	0.28	1.97
6/7/2012	7249	6/7/2012	7249-dup	Chlorobenzene	U	U	0	0.00
6/7/2012	7249	6/7/2012	7249-dup	Carbon Tetrachloride	190.77*	190.00*	0.77	0.40
6/7/2012	7249	6/7/2012	7249-dup	Methylene Chloride	5.09*	4.92*	0.17	3.40
6/18/2012	7246	6/18/2012	7246-dup	Methylene Chloride	606.96	558	48.96	8.41
6/18/2012	7246	6/18/2012	7246-dup	Toluene	55.44 J	48.96 J	6.48	12.41
6/18/2012	7246	6/18/2012	7246-dup	Chlorobenzene	U	U	0	0.00
6/18/2012	7246	6/18/2012	7246-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
6/18/2012	7246	6/18/2012	7246-dup	1,1,1-Trichloroethane	2698.56	2615.76	82.8	3.12
6/18/2012	7246	6/18/2012	7246-dup	Chloroform	85.68	82.8	2.88	3.42
6/18/2012	7246	6/18/2012	7246-dup	Carbon Tetrachloride	3501.36	3330.72	170.64	5.00
6/18/2012	7246	6/18/2012	7246-dup	1,2-Dichloroethane	U	U	0	0.00
6/18/2012	7246	6/18/2012	7246-dup	1,1-Dichloroethylene	28.08 J	23.04 J	5.04	19.72
6/21/2012	7279	6/21/2012	7279-dup	1,2-Dichloroethane	U	U	0	0.00
6/21/2012	7279	6/21/2012	7279-dup	1,1,1-Trichloroethane	37.76*	37.70*	0.06	0.16
6/21/2012	7279	6/21/2012	7279-dup	Toluene	1.05* J	0.98* J	0.07	6.90
6/21/2012	7279	6/21/2012	7279-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
6/21/2012	7279	6/21/2012	7279-dup	1,1-Dichloroethylene	U	U	0	0.00
6/21/2012	7279	6/21/2012	7279-dup	Chloroform	13.51*	13.23*	0.28	2.09
6/21/2012	7279	6/21/2012	7279-dup	Chlorobenzene	U	U	0	0.00
6/21/2012	7279	6/21/2012	7279-dup	Carbon Tetrachloride	204.79*	205.41*	-0.62	0.30

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6A – VOCs – Precision of Laboratory Sample Duplicates

Original Analysis Date	Original Sample ID	Duplicate Analysis Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
6/21/2012	7279	6/21/2012	7279-dup	Methylene Chloride	5.41*	5.32*	0.09	1.68
6/25/2012	7276	6/25/2012	7276-dup	1,1-Dichloroethylene	U	U	0	0.00
6/25/2012	7276	6/25/2012	7276-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
6/25/2012	7276	6/25/2012	7276-dup	Toluene	787.32 J	787.32 J	0	0.00
6/25/2012	7276	6/25/2012	7276-dup	Methylene Chloride	16096.32	16621.2	-524.88	3.21
6/25/2012	7276	6/25/2012	7276-dup	Chloroform	35866.8	37091.52	-1224.72	3.36
6/25/2012	7276	6/25/2012	7276-dup	Chlorobenzene	U	U	0	0.00
6/25/2012	7276	6/25/2012	7276-dup	Carbon Tetrachloride	546487.56	562146.48	-15658.92	2.82
6/25/2012	7276	6/25/2012	7276-dup	1,1,1-Trichloroethane	84418.2	87654.96	-3236.76	3.76
6/25/2012	7276	6/25/2012	7276-dup	1,2-Dichloroethane	U	U	0	0.00
6/25/2012	7287	6/25/2012	7287-dup	Methylene Chloride	2.62*	2.65*	-0.03	1.14
6/25/2012	7287	6/25/2012	7287-dup	1,1,1-Trichloroethane	18.27*	18.25*	0.02	0.11
6/25/2012	7287	6/25/2012	7287-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
6/25/2012	7287	6/25/2012	7287-dup	1,1-Dichloroethylene	U	U	0	0.00
6/25/2012	7287	6/25/2012	7287-dup	1,2-Dichloroethane	U	U	0	0.00
6/25/2012	7287	6/25/2012	7287-dup	Chloroform	6.21*	6.16*	0.05	0.81
6/25/2012	7287	6/25/2012	7287-dup	Chlorobenzene	U	U	0	0.00
6/25/2012	7287	6/25/2012	7287-dup	Carbon Tetrachloride	94.31*	94.11*	0.2	0.21
6/25/2012	7287	6/25/2012	7287-dup	Toluene	0.56* J	0.54* J	0.02	3.64
7/9/2012	7303	7/9/2012	7303-dup	1,1,1-Trichloroethane	19.58*	21.49*	-1.91	9.30
7/9/2012	7303	7/9/2012	7303-dup	Carbon Tetrachloride	103.86*	113.56*	-9.7	8.92
7/9/2012	7303	7/9/2012	7303-dup	Chlorobenzene	U	U	0	0.00
7/9/2012	7303	7/9/2012	7303-dup	Chloroform	7.39*	8.25*	-0.86	11.00
7/9/2012	7303	7/9/2012	7303-dup	1,2-Dichloroethane	U	U	0	0.00
7/9/2012	7303	7/9/2012	7303-dup	1,1-Dichloroethylene	U	U	0	0.00
7/9/2012	7303	7/9/2012	7303-dup	Methylene Chloride	2.75*	2.88*	-0.13	4.62
7/9/2012	7303	7/9/2012	7303-dup	1,1,2,2-Tetrachloroethane	U	U	0	0.00
7/9/2012	7303	7/9/2012	7303-dup	Toluene	0.60* J	0.73* J	-0.13	19.55

Notes:
J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above the MDL.
* Normalized target VOC concentration.
† Technical acceptance criterion for duplicate analysis of a sample is ≤25 RPD, which is only applicable if one or both values are not flagged "U" or "J."

Relative Percent Difference (RPD)
RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS Analysis Date	LCSD Analysis Date	Compound	LCS (% Recovery)	LCD (% Recovery)	Difference	RPD
1/11/2012	1/11/2012	1,1,1-Trichloroethane	94.69	93.22	1.47	1.56
1/11/2012	1/11/2012	1,1,2,2-Tetrachloroethane	92.46	92.28	0.18	0.19
1/11/2012	1/11/2012	1,1-Dichloroethylene	85.86	88.78	-2.92	3.34
1/11/2012	1/11/2012	1,2-Dichloroethane	90.75	89.96	0.79	0.87
1/11/2012	1/11/2012	Carbon Tetrachloride	94.30	91.12	3.18	3.43
1/11/2012	1/11/2012	Chlorobenzene	93.14	95.87	-2.73	2.89
1/11/2012	1/11/2012	Chloroform	92.07	91.42	0.65	0.71
1/11/2012	1/11/2012	Methylene Chloride	88.06	89.58	-1.52	1.71
1/11/2012	1/11/2012	Toluene	91.22	96.84	-5.62	5.98
1/18/2012	1/18/2012	1,1,1-Trichloroethane	95.31	90.08	5.23	5.64
1/18/2012	1/18/2012	1,1,2,2-Tetrachloroethane	91.92	87.06	4.86	5.43
1/18/2012	1/18/2012	1,1-Dichloroethylene	85.89	85.40	0.49	0.57
1/18/2012	1/18/2012	1,2-Dichloroethane	91.48	86.12	5.36	6.04
1/18/2012	1/18/2012	Carbon Tetrachloride	95.18	87.65	7.53	8.24
1/18/2012	1/18/2012	Chlorobenzene	93.23	91.37	1.86	2.02
1/18/2012	1/18/2012	Chloroform	93.23	89.13	4.10	4.50
1/18/2012	1/18/2012	Methylene Chloride	87.60	86.20	1.40	1.61
1/18/2012	1/18/2012	Toluene	90.63	92.34	-1.71	1.87
1/19/2012	1/19/2012	1,1,1-Trichloroethane	88.93	85.90	3.03	3.47
1/19/2012	1/19/2012	1,1,2,2-Tetrachloroethane	87.79	83.09	4.70	5.50
1/19/2012	1/19/2012	1,1-Dichloroethylene	81.07	81.73	-0.66	0.81
1/19/2012	1/19/2012	1,2-Dichloroethane	84.88	82.69	2.19	2.61
1/19/2012	1/19/2012	Carbon Tetrachloride	87.77	83.59	4.18	4.88
1/19/2012	1/19/2012	Chlorobenzene	88.88	88.48	0.40	0.45
1/19/2012	1/19/2012	Chloroform	87.03	86.42	0.61	0.70
1/19/2012	1/19/2012	Methylene Chloride	82.46	82.98	-0.52	0.63
1/19/2012	1/19/2012	Toluene	86.18	89.26	-3.08	3.51
1/25/2012	1/25/2012	1,1,1-Trichloroethane	92.42	90.49	1.93	2.11
1/25/2012	1/25/2012	1,1,2,2-Tetrachloroethane	95.66	92.67	2.99	3.18
1/25/2012	1/25/2012	1,1-Dichloroethylene	84.01	87.66	-3.65	4.25
1/25/2012	1/25/2012	1,2-Dichloroethane	89.04	92.15	-3.11	3.43
1/25/2012	1/25/2012	Carbon Tetrachloride	92.11	89.10	3.01	3.32
1/25/2012	1/25/2012	Chlorobenzene	92.85	96.90	-4.05	4.27
1/25/2012	1/25/2012	Chloroform	90.30	90.73	-0.43	0.48
1/25/2012	1/25/2012	Methylene Chloride	86.72	89.31	-2.59	2.94
1/25/2012	1/25/2012	Toluene	90.95	99.33	-8.38	8.81

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS Analysis Date	LCSD Analysis Date	Compound	LCS (% Recovery)	LCD (% Recovery)	Difference	RPD
2/1/2012	2/1/2012	1,1,1-Trichloroethane	94.34	89.92	4.42	4.80
2/1/2012	2/1/2012	1,1,2,2-Tetrachloroethane	92.71	88.29	4.42	4.88
2/1/2012	2/1/2012	1,1-Dichloroethylene	84.58	86.01	-1.43	1.68
2/1/2012	2/1/2012	1,2-Dichloroethane	90.27	88.31	1.96	2.20
2/1/2012	2/1/2012	Carbon Tetrachloride	93.92	87.83	6.09	6.70
2/1/2012	2/1/2012	Chlorobenzene	93.50	92.09	1.41	1.52
2/1/2012	2/1/2012	Chloroform	90.35	89.63	0.72	0.80
2/1/2012	2/1/2012	Methylene Chloride	86.89	88.02	-1.13	1.29
2/1/2012	2/1/2012	Toluene	90.53	92.15	-1.62	1.77
2/6/2012	2/6/2012	1,1,1-Trichloroethane	84.49	86.06	-1.57	1.84
2/6/2012	2/6/2012	1,1,2,2-Tetrachloroethane	83.18	78.07	5.11	6.34
2/6/2012	2/6/2012	1,1-Dichloroethylene	81.46	85.67	-4.21	5.04
2/6/2012	2/6/2012	1,2-Dichloroethane	77.44	77.82	-0.38	0.49
2/6/2012	2/6/2012	Carbon Tetrachloride	84.64	85.41	-0.77	0.91
2/6/2012	2/6/2012	Chlorobenzene	82.92	79.23	3.69	4.55
2/6/2012	2/6/2012	Chloroform	83.85	85.15	-1.30	1.54
2/6/2012	2/6/2012	Methylene Chloride	83.76	86.94	-3.18	3.73
2/6/2012	2/6/2012	Toluene	78.49	75.37	3.12	4.06
2/14/2012	2/14/2012	1,1,1-Trichloroethane	86.27	84.76	1.51	1.77
2/14/2012	2/14/2012	1,1,2,2-Tetrachloroethane	85.41	79.47	5.94	7.21
2/14/2012	2/14/2012	1,1-Dichloroethylene	83.61	81.45	2.16	2.62
2/14/2012	2/14/2012	1,2-Dichloroethane	82.32	76.40	5.92	7.46
2/14/2012	2/14/2012	Carbon Tetrachloride	86.55	83.22	3.33	3.92
2/14/2012	2/14/2012	Chlorobenzene	85.32	79.33	5.99	7.28
2/14/2012	2/14/2012	Chloroform	86.74	81.69	5.05	6.00
2/14/2012	2/14/2012	Methylene Chloride	86.37	82.97	3.40	4.02
2/14/2012	2/14/2012	Toluene	81.67	75.85	5.82	7.39
2/23/2012	2/23/2012	1,1,1-Trichloroethane	80.91	80.66	0.25	0.31
2/23/2012	2/23/2012	1,1,2,2-Tetrachloroethane	80.82	79.11	1.71	2.14
2/23/2012	2/23/2012	1,1-Dichloroethylene	75.42	80.39	-4.97	6.38
2/23/2012	2/23/2012	1,2-Dichloroethane	73.85	75.06	-1.21	1.63
2/23/2012	2/23/2012	Carbon Tetrachloride	80.67	79.37	1.30	1.62
2/23/2012	2/23/2012	Chlorobenzene	78.43	78.76	-0.33	0.42
2/23/2012	2/23/2012	Chloroform	78.81	79.60	-0.79	1.00
2/23/2012	2/23/2012	Methylene Chloride	79.11	81.61	-2.50	3.11
2/23/2012	2/23/2012	Toluene	73.85	74.88	-1.03	1.39
2/28/2012	2/28/2012	1,1,1-Trichloroethane	87.09	89.83	-2.74	3.10

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS Analysis Date	LCSD Analysis Date	Compound	LCS (% Recovery)	LCD (% Recovery)	Difference	RPD
2/28/2012	2/28/2012	1,1,2,2-Tetrachloroethane	90.32	94.68	-4.36	4.71
2/28/2012	2/28/2012	1,1-Dichloroethylene	81.88	89.10	-7.22	8.45
2/28/2012	2/28/2012	1,2-Dichloroethane	80.99	84.12	-3.13	3.79
2/28/2012	2/28/2012	Carbon Tetrachloride	87.53	88.84	-1.31	1.49
2/28/2012	2/28/2012	Chlorobenzene	86.76	88.31	-1.55	1.77
2/28/2012	2/28/2012	Chloroform	85.19	87.98	-2.79	3.22
2/28/2012	2/28/2012	Methylene Chloride	86.31	92.70	-6.39	7.14
2/28/2012	2/28/2012	Toluene	82.12	86.88	-4.76	5.63
3/1/2012	3/1/2012	1,1,1-Trichloroethane	85.49	83.57	1.92	2.27
3/1/2012	3/1/2012	1,1,2,2-Tetrachloroethane	93.07	89.28	3.79	4.16
3/1/2012	3/1/2012	1,1-Dichloroethylene	84.35	83.07	1.28	1.53
3/1/2012	3/1/2012	1,2-Dichloroethane	81.16	77.75	3.41	4.29
3/1/2012	3/1/2012	Carbon Tetrachloride	85.79	82.64	3.15	3.74
3/1/2012	3/1/2012	Chlorobenzene	84.05	81.72	2.33	2.81
3/1/2012	3/1/2012	Chloroform	84.64	81.55	3.09	3.72
3/1/2012	3/1/2012	Methylene Chloride	87.58	85.94	1.64	1.89
3/1/2012	3/1/2012	Toluene	81.46	79.25	2.21	2.75
3/13/2012	3/13/2012	1,1,1-Trichloroethane	94.36	90.62	3.74	4.04
3/13/2012	3/13/2012	1,1,2,2-Tetrachloroethane	93.27	90.10	3.17	3.46
3/13/2012	3/13/2012	1,1-Dichloroethylene	88.21	85.68	2.53	2.91
3/13/2012	3/13/2012	1,2-Dichloroethane	92.05	87.70	4.35	4.84
3/13/2012	3/13/2012	Carbon Tetrachloride	93.10	87.47	5.63	6.24
3/13/2012	3/13/2012	Chlorobenzene	94.77	93.92	0.85	0.90
3/13/2012	3/13/2012	Chloroform	93.10	89.01	4.09	4.49
3/13/2012	3/13/2012	Methylene Chloride	94.30	89.56	4.74	5.16
3/13/2012	3/13/2012	Toluene	91.34	93.21	-1.87	2.03
3/21/2012	3/21/2012	1,1,1-Trichloroethane	93.91	93.10	0.81	0.87
3/21/2012	3/21/2012	1,1,2,2-Tetrachloroethane	94.09	90.55	3.54	3.83
3/21/2012	3/21/2012	1,1-Dichloroethylene	89.29	89.53	-0.24	0.27
3/21/2012	3/21/2012	1,2-Dichloroethane	94.41	91.84	2.57	2.76
3/21/2012	3/21/2012	Carbon Tetrachloride	93.77	90.30	3.47	3.77
3/21/2012	3/21/2012	Chlorobenzene	93.91	92.45	1.46	1.57
3/21/2012	3/21/2012	Chloroform	93.45	92.54	0.91	0.98
3/21/2012	3/21/2012	Methylene Chloride	95.51	95.06	0.45	0.47
3/21/2012	3/21/2012	Toluene	90.49	91.55	-1.06	1.16
4/2/2012	4/2/2012	1,1,1-Trichloroethane	92.27	92.63	-0.36	0.39
4/2/2012	4/2/2012	1,1,2,2-Tetrachloroethane	92.71	88.98	3.73	4.11

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS Analysis Date	LCSD Analysis Date	Compound	LCS (% Recovery)	LCD (% Recovery)	Difference	RPD
4/2/2012	4/2/2012	1,1-Dichloroethylene	91.46	92.10	-0.64	0.70
4/2/2012	4/2/2012	1,2-Dichloroethane	91.13	89.10	2.03	2.25
4/2/2012	4/2/2012	Carbon Tetrachloride	96.60	95.06	1.54	1.61
4/2/2012	4/2/2012	Chlorobenzene	88.63	89.49	-0.86	0.97
4/2/2012	4/2/2012	Chloroform	90.92	88.88	2.04	2.27
4/2/2012	4/2/2012	Methylene Chloride	90.21	89.71	0.50	0.56
4/2/2012	4/2/2012	Toluene	88.29	90.63	-2.34	2.62
4/11/2012	4/11/2012	1,1,1-Trichloroethane	88.45	92.75	-4.30	4.75
4/11/2012	4/11/2012	1,1,2,2-Tetrachloroethane	85.00	83.19	1.81	2.15
4/11/2012	4/11/2012	1,1-Dichloroethylene	93.69	93.88	-0.19	0.20
4/11/2012	4/11/2012	1,2-Dichloroethane	87.21	90.40	-3.19	3.59
4/11/2012	4/11/2012	Carbon Tetrachloride	91.86	92.56	-0.70	0.76
4/11/2012	4/11/2012	Chlorobenzene	86.80	85.49	1.31	1.52
4/11/2012	4/11/2012	Chloroform	87.07	90.16	-3.09	3.49
4/11/2012	4/11/2012	Methylene Chloride	87.19	87.75	-0.56	0.64
4/11/2012	4/11/2012	Toluene	91.79	90.29	1.50	1.65
4/12/2012	4/12/2012	1,1,1-Trichloroethane	86.33	88.24	-1.91	2.19
4/12/2012	4/12/2012	1,1,2,2-Tetrachloroethane	78.92	80.12	-1.20	1.51
4/12/2012	4/12/2012	1,1-Dichloroethylene	88.79	90.89	-2.10	2.34
4/12/2012	4/12/2012	1,2-Dichloroethane	83.23	86.33	-3.10	3.66
4/12/2012	4/12/2012	Carbon Tetrachloride	87.32	87.92	-0.60	0.68
4/12/2012	4/12/2012	Chlorobenzene	81.54	83.31	-1.77	2.15
4/12/2012	4/12/2012	Chloroform	84.38	86.44	-2.06	2.41
4/12/2012	4/12/2012	Methylene Chloride	82.90	84.92	-2.02	2.41
4/12/2012	4/12/2012	Toluene	84.90	88.10	-3.20	3.70
4/13/2012	4/13/2012	1,1,1-Trichloroethane	86.12	85.69	0.43	0.50
4/13/2012	4/13/2012	1,1,2,2-Tetrachloroethane	80.08	81.37	-1.29	1.60
4/13/2012	4/13/2012	1,1-Dichloroethylene	88.94	88.37	0.57	0.64
4/13/2012	4/13/2012	1,2-Dichloroethane	85.10	86.04	-0.94	1.10
4/13/2012	4/13/2012	Carbon Tetrachloride	89.84	87.64	2.20	2.48
4/13/2012	4/13/2012	Chlorobenzene	82.19	84.25	-2.06	2.48
4/13/2012	4/13/2012	Chloroform	83.63	83.30	0.33	0.40
4/13/2012	4/13/2012	Methylene Chloride	83.83	82.71	1.12	1.35
4/13/2012	4/13/2012	Toluene	86.23	89.05	-2.82	3.22
4/24/2012	4/24/2012	1,1,1-Trichloroethane	95.48	92.55	2.93	3.12
4/24/2012	4/24/2012	1,1,2,2-Tetrachloroethane	84.82	77.44	7.38	9.10
4/24/2012	4/24/2012	1,1-Dichloroethylene	100.23	96.86	3.37	3.42

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS Analysis Date	LCSD Analysis Date	Compound	LCS (% Recovery)	LCD (% Recovery)	Difference	RPD
4/24/2012	4/24/2012	1,2-Dichloroethane	95.04	90.53	4.51	4.86
4/24/2012	4/24/2012	Carbon Tetrachloride	100.88	95.25	5.63	5.74
4/24/2012	4/24/2012	Chlorobenzene	92.27	84.08	8.19	9.29
4/24/2012	4/24/2012	Chloroform	93.44	89.27	4.17	4.56
4/24/2012	4/24/2012	Methylene Chloride	93.29	89.00	4.29	4.71
4/24/2012	4/24/2012	Toluene	96.40	88.94	7.46	8.05
4/25/2012	4/25/2012	1,1,1-Trichloroethane	88.01	95.08	-7.07	7.72
4/25/2012	4/25/2012	1,1,2,2-Tetrachloroethane	75.80	83.79	-7.99	10.01
4/25/2012	4/25/2012	1,1-Dichloroethylene	88.73	96.52	-7.79	8.41
4/25/2012	4/25/2012	1,2-Dichloroethane	86.59	93.68	-7.09	7.87
4/25/2012	4/25/2012	Carbon Tetrachloride	90.59	96.54	-5.95	6.36
4/25/2012	4/25/2012	Chlorobenzene	80.90	91.07	-10.17	11.83
4/25/2012	4/25/2012	Chloroform	84.07	90.65	-6.58	7.53
4/25/2012	4/25/2012	Methylene Chloride	82.54	88.05	-5.51	6.46
4/25/2012	4/25/2012	Toluene	85.03	96.54	-11.51	12.68
4/27/2012	4/27/2012	1,1,1-Trichloroethane	99.94	100.22	-0.28	0.28
4/27/2012	4/27/2012	1,1,2,2-Tetrachloroethane	79.28	87.95	-8.67	10.37
4/27/2012	4/27/2012	1,1-Dichloroethylene	99.39	100.31	-0.92	0.92
4/27/2012	4/27/2012	1,2-Dichloroethane	96.34	100.02	-3.68	3.75
4/27/2012	4/27/2012	Carbon Tetrachloride	104.10	102.25	1.85	1.79
4/27/2012	4/27/2012	Chlorobenzene	87.91	96.09	-8.18	8.89
4/27/2012	4/27/2012	Chloroform	93.28	95.74	-2.46	2.60
4/27/2012	4/27/2012	Methylene Chloride	91.16	91.52	-0.36	0.39
4/27/2012	4/27/2012	Toluene	92.98	103.38	-10.40	10.59
5/10/2012	5/10/2012	1,1,1-Trichloroethane	88.84	87.47	1.37	1.55
5/10/2012	5/10/2012	1,1,2,2-Tetrachloroethane	75.49	77.48	-1.99	2.60
5/10/2012	5/10/2012	1,1-Dichloroethylene	88.14	90.76	-2.62	2.93
5/10/2012	5/10/2012	1,2-Dichloroethane	85.85	85.59	0.26	0.30
5/10/2012	5/10/2012	Carbon Tetrachloride	93.36	90.82	2.54	2.76
5/10/2012	5/10/2012	Chlorobenzene	86.31	88.91	-2.60	2.97
5/10/2012	5/10/2012	Chloroform	86.89	86.78	0.11	0.13
5/10/2012	5/10/2012	Methylene Chloride	81.93	81.89	0.04	0.05
5/10/2012	5/10/2012	Toluene	86.40	89.69	-3.29	3.74
5/15/2012	5/15/2012	1,1,1-Trichloroethane	96.57	91.20	5.37	5.72
5/15/2012	5/15/2012	1,1,2,2-Tetrachloroethane	84.59	79.71	4.88	5.94
5/15/2012	5/15/2012	1,1-Dichloroethylene	90.21	87.38	2.83	3.19
5/15/2012	5/15/2012	1,2-Dichloroethane	94.19	88.98	5.21	5.69

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS Analysis Date	LCSD Analysis Date	Compound	LCS (% Recovery)	LCD (% Recovery)	Difference	RPD
5/15/2012	5/15/2012	Carbon Tetrachloride	100.74	94.39	6.35	6.51
5/15/2012	5/15/2012	Chlorobenzene	92.81	88.48	4.33	4.78
5/15/2012	5/15/2012	Chloroform	93.67	89.06	4.61	5.05
5/15/2012	5/15/2012	Methylene Chloride	89.88	85.94	3.94	4.48
5/15/2012	5/15/2012	Toluene	91.84	87.23	4.61	5.15
5/18/2012	5/18/2012	1,1,1-Trichloroethane	96.85	96.33	0.52	0.54
5/18/2012	5/18/2012	1,1,2,2-Tetrachloroethane	88.36	86.60	1.76	2.01
5/18/2012	5/18/2012	1,1-Dichloroethylene	92.56	93.09	-0.53	0.57
5/18/2012	5/18/2012	1,2-Dichloroethane	95.81	97.09	-1.28	1.33
5/18/2012	5/18/2012	Carbon Tetrachloride	100.92	99.77	1.15	1.15
5/18/2012	5/18/2012	Chlorobenzene	95.00	94.61	0.39	0.41
5/18/2012	5/18/2012	Chloroform	93.51	94.53	-1.02	1.08
5/18/2012	5/18/2012	Methylene Chloride	92.81	93.39	-0.58	0.62
5/18/2012	5/18/2012	Toluene	94.16	94.84	-0.68	0.72
5/23/2012	5/23/2012	1,1,1-Trichloroethane	88.03	94.08	-6.05	6.64
5/23/2012	5/23/2012	1,1,2,2-Tetrachloroethane	83.73	89.09	-5.36	6.20
5/23/2012	5/23/2012	1,1-Dichloroethylene	84.34	91.45	-7.11	8.09
5/23/2012	5/23/2012	1,2-Dichloroethane	84.05	92.46	-8.41	9.53
5/23/2012	5/23/2012	Carbon Tetrachloride	92.37	98.56	-6.19	6.48
5/23/2012	5/23/2012	Chlorobenzene	84.13	91.00	-6.87	7.85
5/23/2012	5/23/2012	Chloroform	84.84	91.55	-6.71	7.61
5/23/2012	5/23/2012	Methylene Chloride	84.39	90.55	-6.16	7.04
5/23/2012	5/23/2012	Toluene	82.49	89.75	-7.26	8.43
5/24/2012	5/24/2012	1,1,1-Trichloroethane	92.84	105.65	-12.81	12.91
5/24/2012	5/24/2012	1,1,2,2-Tetrachloroethane	88.92	95.46	-6.54	7.09
5/24/2012	5/24/2012	1,1-Dichloroethylene	85.44	97.59	-12.15	13.28
5/24/2012	5/24/2012	1,2-Dichloroethane	90.16	101.66	-11.50	11.99
5/24/2012	5/24/2012	Carbon Tetrachloride	97.32	110.00	-12.68	12.23
5/24/2012	5/24/2012	Chlorobenzene	90.42	99.56	-9.14	9.62
5/24/2012	5/24/2012	Chloroform	87.52	99.21	-11.69	12.52
5/24/2012	5/24/2012	Methylene Chloride	84.50	95.40	-10.90	12.12
5/24/2012	5/24/2012	Toluene	88.68	98.16	-9.48	10.15
6/5/2012	6/5/2012	1,1,1-Trichloroethane	94.57	93.20	1.37	1.46
6/5/2012	6/5/2012	1,1,2,2-Tetrachloroethane	93.28	90.71	2.57	2.79
6/5/2012	6/5/2012	1,1-Dichloroethylene	86.87	87.45	-0.58	0.67
6/5/2012	6/5/2012	1,2-Dichloroethane	91.81	91.66	0.15	0.16
6/5/2012	6/5/2012	Carbon Tetrachloride	98.72	96.92	1.80	1.84

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS Analysis Date	LCSD Analysis Date	Compound	LCS (% Recovery)	LCD (% Recovery)	Difference	RPD
6/5/2012	6/5/2012	Chlorobenzene	92.36	90.10	2.26	2.48
6/5/2012	6/5/2012	Chloroform	90.54	90.17	0.37	0.41
6/5/2012	6/5/2012	Methylene Chloride	87.47	87.02	0.45	0.52
6/5/2012	6/5/2012	Toluene	90.98	90.80	0.18	0.20
6/7/2012	6/7/2012	1,1,1-Trichloroethane	91.83	92.64	-0.81	0.88
6/7/2012	6/7/2012	1,1,2,2-Tetrachloroethane	90.39	88.67	1.72	1.92
6/7/2012	6/7/2012	1,1-Dichloroethylene	85.12	85.79	-0.67	0.78
6/7/2012	6/7/2012	1,2-Dichloroethane	88.62	89.96	-1.34	1.50
6/7/2012	6/7/2012	Carbon Tetrachloride	97.46	97.61	-0.15	0.15
6/7/2012	6/7/2012	Chlorobenzene	88.92	89.31	-0.39	0.44
6/7/2012	6/7/2012	Chloroform	87.43	88.88	-1.45	1.64
6/7/2012	6/7/2012	Methylene Chloride	83.47	84.07	-0.60	0.72
6/7/2012	6/7/2012	Toluene	88.09	88.03	0.06	0.07
6/18/2012	6/18/2012	1,1,1-Trichloroethane	96.22	96.02	0.20	0.21
6/18/2012	6/18/2012	1,1,2,2-Tetrachloroethane	91.29	87.86	3.43	3.83
6/18/2012	6/18/2012	1,1-Dichloroethylene	82.99	86.72	-3.73	4.40
6/18/2012	6/18/2012	1,2-Dichloroethane	91.07	92.38	-1.31	1.43
6/18/2012	6/18/2012	Carbon Tetrachloride	108.13	107.67	0.46	0.43
6/18/2012	6/18/2012	Chlorobenzene	88.61	86.74	1.87	2.13
6/18/2012	6/18/2012	Chloroform	87.02	87.87	-0.85	0.97
6/18/2012	6/18/2012	Methylene Chloride	79.65	81.29	-1.64	2.04
6/18/2012	6/18/2012	Toluene	86.46	85.74	0.72	0.84
6/21/2012	6/21/2012	1,1,1-Trichloroethane	104.31	105.94	-1.63	1.55
6/21/2012	6/21/2012	1,1,2,2-Tetrachloroethane	104.88	103.98	0.90	0.86
6/21/2012	6/21/2012	1,1-Dichloroethylene	100.12	102.78	-2.66	2.62
6/21/2012	6/21/2012	1,2-Dichloroethane	104.70	106.98	-2.28	2.15
6/21/2012	6/21/2012	Carbon Tetrachloride	117.34	116.45	0.89	0.76
6/21/2012	6/21/2012	Chlorobenzene	96.43	97.47	-1.04	1.07
6/21/2012	6/21/2012	Chloroform	97.78	99.46	-1.68	1.70
6/21/2012	6/21/2012	Methylene Chloride	102.14	103.00	-0.86	0.84
6/21/2012	6/21/2012	Toluene	97.55	98.93	-1.38	1.40
6/25/2012	6/25/2012	1,1,1-Trichloroethane	102.36	102.04	0.32	0.31
6/25/2012	6/25/2012	1,1,2,2-Tetrachloroethane	110.87	108.30	2.57	2.35
6/25/2012	6/25/2012	1,1-Dichloroethylene	100.95	100.91	0.04	0.04
6/25/2012	6/25/2012	1,2-Dichloroethane	103.72	104.09	-0.37	0.36
6/25/2012	6/25/2012	Carbon Tetrachloride	116.92	114.51	2.41	2.08
6/25/2012	6/25/2012	Chlorobenzene	101.58	99.90	1.68	1.67

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6B – VOCs – Precision/Accuracy of Laboratory Control Samples

LCS Analysis Date	LCSD Analysis Date	Compound	LCS (% Recovery)	LCD (% Recovery)	Difference	RPD
6/25/2012	6/25/2012	Chloroform	98.53	98.26	0.27	0.27
6/25/2012	6/25/2012	Methylene Chloride	102.03	100.94	1.09	1.07
6/25/2012	6/25/2012	Toluene	99.79	98.20	1.59	1.61
7/9/2012	7/9/2012	1,1,1-Trichloroethane	107.66	95.16	12.50	12.33
7/9/2012	7/9/2012	1,1,2,2-Tetrachloroethane	88.53	76.06	12.47	15.15
7/9/2012	7/9/2012	1,1-Dichloroethylene	114.02	101.14	12.88	11.97
7/9/2012	7/9/2012	1,2-Dichloroethane	102.69	92.12	10.57	10.85
7/9/2012	7/9/2012	Carbon Tetrachloride	111.03	111.38	-0.35	0.31
7/9/2012	7/9/2012	Chlorobenzene	92.97	92.51	0.46	0.50
7/9/2012	7/9/2012	Chloroform	98.51	88.51	10.00	10.69
7/9/2012	7/9/2012	Methylene Chloride	93.65	95.75	-2.10	2.22
7/9/2012	7/9/2012	Toluene	90.44	90.15	0.29	0.32

Relative Percent Difference (RPD)

RPD = ABS (A - B) / [(A + B) / 2] x 100 ABS = Absolute value of a number

Attachment 6C – VOCs – Laboratory Method Blanks

Concentrations in ppbv

111TA = 1,1,1-Trichloroethane; **1122T** = 1,1,2,2-Tetrachloroethane; **11DCE** = 1,1-Dichloroethylene; **12DCA** = 1,2-Dichloroethane; **CCL4** = Carbon tetrachloride; **CHBNZ** = Chlorobenzene; **CHFRM** = Chloroform; **DCM** = Methylene chloride; **C7H8** = Toluene

Analysis Date	111TA	1122T	11DCE	12DCA	CCL4	CHBNZ	CHFRM	DCM	C7H8
1/11/2012	U	0.12J	U	U	U	U	U	U	U
1/18/2012	U	0.14J	U	U	U	U	U	U	U
1/19/2012	U	0.12J	U	U	U	U	U	U	U
1/25/2012	U	0.09J	U	U	U	U	U	U	U
2/1/2012	U	0.08J	U	U	U	U	U	U	U
2/6/2012	U	0.11J	U	U	U	U	U	U	U
2/14/2012	U	0.09J	U	U	U	U	U	U	U
2/23/2012	U	0.1J	U	U	U	U	U	U	U
2/28/2012	U	0.1J	U	U	U	U	U	U	U
3/1/2012	U	0.09J	U	U	U	U	U	U	U
3/13/2012	0.1J	0.1J	U	U	0.1J	U	U	0.13J	U
3/21/2012	U	0.08J	U	U	U	U	U	U	U
4/2/2012	U	0.14J	U	U	U	U	U	U	U
4/11/2012	U	U	U	U	U	U	U	U	U
4/12/2012	U	U	U	U	U	U	U	U	U
4/13/2012	U	U	U	U	U	U	U	U	U
4/24/2012	U	0.07J	U	U	U	U	U	U	U
4/25/2012	U	U	U	U	U	U	U	U	U
4/27/2012	U	0.08J	U	U	U	U	U	U	U
5/10/2012	U	0.16J	U	U	U	U	U	U	U
5/15/2012	U	0.18J	U	U	U	U	U	U	U
5/18/2012	U	0.16J	U	U	U	U	U	U	U
5/23/2012	U	0.17J	U	U	U	U	U	U	U
5/24/2012	U	U	U	U	U	U	U	U	U
6/5/2012	U	U	U	U	U	U	U	U	U

Attachment 6C – VOCs – Laboratory Method Blanks

Concentrations in ppbv

111TA = 1,1,1-Trichloroethane; **1122T** = 1,1,2,2-Tetrachloroethane; **11DCE** = 1,1-Dichloroethylene; **12DCA** = 1,2-Dichloroethane; **CCL4** = Carbon tetrachloride; **CHBNZ** = Chlorobenzene; **CHFRM** = Chloroform; **DCM** = Methylene chloride; **C7H8** = Toluene

Analysis Date	111TA	1122T	11DCE	12DCA	CCL4	CHBNZ	CHFRM	DCM	C7H8
6/7/2012	U	0.21J	U	U	U	U	U	U	U
6/18/2012	U	0.13J	U	U	U	U	U	U	U
6/21/2012	U	0.14J	U	U	U	U	U	U	U
6/25/2012	U	0.17J	U	U	U	U	U	U	U
7/9/2012	U	U	U	U	U	U	U	U	U

Notes:

J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above the MDL.

Attachment 6D – VOCs – Field Duplicate Precision

Field Duplicate Precision for Repository VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
VOC-A	2/1/2012	6913	2/1/2012	6915	1,1,1-Trichloroethane	40.64*	48.86*	-8.22	18.37
VOC-A	2/1/2012	6913	2/1/2012	6915	1,1,2,2-Tetrachloroethane	U	U	0	0.00
VOC-A	2/1/2012	6913	2/1/2012	6915	1,1-Dichloroethylene	U	U	0	0.00
VOC-A	2/1/2012	6913	2/1/2012	6915	1,2-Dichloroethane	U	U	0	0.00
VOC-A	2/1/2012	6913	2/1/2012	6915	Carbon Tetrachloride	204.93*	248.32*	-43.39	19.15
VOC-A	2/1/2012	6913	2/1/2012	6915	Chlorobenzene	U	U	0	0.00
VOC-A	2/1/2012	6913	2/1/2012	6915	Chloroform	15.30*	18.45*	-3.15	18.67
VOC-A	2/1/2012	6913	2/1/2012	6915	Methylene Chloride	7.44*	8.86*	-1.42	17.42
VOC-A	2/1/2012	6913	2/1/2012	6915	Toluene	0.73* J	0.82* J	-0.09	11.61
VOC-A	4/3/2012	7073	4/3/2012	7075	1,1,1-Trichloroethane	32.22*	33.65*	-1.43	4.34
VOC-A	4/3/2012	7073	4/3/2012	7075	1,1,2,2-Tetrachloroethane	U	U	0	0.00
VOC-A	4/3/2012	7073	4/3/2012	7075	1,1-Dichloroethylene	U	U	0	0.00
VOC-A	4/3/2012	7073	4/3/2012	7075	1,2-Dichloroethane	U	U	0	0.00
VOC-A	4/3/2012	7073	4/3/2012	7075	Carbon Tetrachloride	167.15*	174.85*	-7.7	4.50
VOC-A	4/3/2012	7073	4/3/2012	7075	Chlorobenzene	U	U	0	0.00
VOC-A	4/3/2012	7073	4/3/2012	7075	Chloroform	13.28*	13.72*	-0.44	3.26
VOC-A	4/3/2012	7073	4/3/2012	7075	Methylene Chloride	5.01*	4.91*	0.1	2.02
VOC-A	4/3/2012	7073	4/3/2012	7075	Toluene	0.76* J	0.69* J	0.07	9.66
VOC-A	6/5/2012	7249	6/5/2012	7251	1,1,1-Trichloroethane	34.85*	36.98*	-2.13	5.93
VOC-A	6/5/2012	7249	6/5/2012	7251	1,1,2,2-Tetrachloroethane	U	U	0	0.00
VOC-A	6/5/2012	7249	6/5/2012	7251	1,1-Dichloroethylene	U	U	0	0.00
VOC-A	6/5/2012	7249	6/5/2012	7251	1,2-Dichloroethane	U	U	0	0.00
VOC-A	6/5/2012	7249	6/5/2012	7251	Carbon Tetrachloride	190.77*	203.81*	-13.04	6.61
VOC-A	6/5/2012	7249	6/5/2012	7251	Chlorobenzene	U	U	0	0.00
VOC-A	6/5/2012	7249	6/5/2012	7251	Chloroform	14.36*	14.69*	-0.33	2.27
VOC-A	6/5/2012	7249	6/5/2012	7251	Methylene Chloride	5.09*	5.20*	-0.11	2.14
VOC-A	6/5/2012	7249	6/5/2012	7251	Toluene	1.05* J	1.02* J	0.03	2.90
VOC-B	2/1/2012	6912	2/1/2012	6914	1,1,1-Trichloroethane	U	U	0	0.00
VOC-B	2/1/2012	6912	2/1/2012	6914	1,1,2,2-Tetrachloroethane	U	U	0	0.00
VOC-B	2/1/2012	6912	2/1/2012	6914	1,1-Dichloroethylene	U	U	0	0.00
VOC-B	2/1/2012	6912	2/1/2012	6914	1,2-Dichloroethane	U	U	0	0.00
VOC-B	2/1/2012	6912	2/1/2012	6914	Carbon Tetrachloride	0.13* J	0.13* J	0	0.00
VOC-B	2/1/2012	6912	2/1/2012	6914	Chlorobenzene	U	U	0	0.00
VOC-B	2/1/2012	6912	2/1/2012	6914	Chloroform	U	U	0	0.00
VOC-B	2/1/2012	6912	2/1/2012	6914	Methylene Chloride	U	U	0	0.00
VOC-B	2/1/2012	6912	2/1/2012	6914	Toluene	0.80* J	0.82* J	-0.02	2.47
VOC-B	4/3/2012	7072	4/3/2012	7074	1,1,1-Trichloroethane	U	U	0	0.00

Attachment 6D – VOCs – Field Duplicate Precision

Field Duplicate Precision for Repository VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
VOC-B	4/3/2012	7072	4/3/2012	7074	1,1,2,2-Tetrachloroethane	U	U	0	0.00
VOC-B	4/3/2012	7072	4/3/2012	7074	1,1-Dichloroethylene	U	U	0	0.00
VOC-B	4/3/2012	7072	4/3/2012	7074	1,2-Dichloroethane	U	U	0	0.00
VOC-B	4/3/2012	7072	4/3/2012	7074	Carbon Tetrachloride	0.16* J	0.16* J	0	0.00
VOC-B	4/3/2012	7072	4/3/2012	7074	Chlorobenzene	U	U	0	0.00
VOC-B	4/3/2012	7072	4/3/2012	7074	Chloroform	U	U	0	0.00
VOC-B	4/3/2012	7072	4/3/2012	7074	Methylene Chloride	U	U	0	0.00
VOC-B	4/3/2012	7072	4/3/2012	7074	Toluene	0.43* J	0.43* J	0	0.00
VOC-B	6/5/2012	7248	6/5/2012	7250	1,1,1-Trichloroethane	U	U	0	0.00
VOC-B	6/5/2012	7248	6/5/2012	7250	1,1,2,2-Tetrachloroethane	U	U	0	0.00
VOC-B	6/5/2012	7248	6/5/2012	7250	1,1-Dichloroethylene	U	U	0	0.00
VOC-B	6/5/2012	7248	6/5/2012	7250	1,2-Dichloroethane	U	U	0	0.00
VOC-B	6/5/2012	7248	6/5/2012	7250	Carbon Tetrachloride	0.13* J	0.13* J	0	0.00
VOC-B	6/5/2012	7248	6/5/2012	7250	Chlorobenzene	U	U	0	0.00
VOC-B	6/5/2012	7248	6/5/2012	7250	Chloroform	U	U	0	0.00
VOC-B	6/5/2012	7248	6/5/2012	7250	Methylene Chloride	U	U	0	0.00
VOC-B	6/5/2012	7248	6/5/2012	7250	Toluene	0.55* J	0.51* J	0.04	7.55

Field Duplicate Precision for Disposal Room VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
P6R4E	5/8/2012	7180	5/8/2012	7181	1,1,1-Trichloroethane	24.825	24.795	0.03	0.12
P6R4E	5/8/2012	7180	5/8/2012	7181	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R4E	5/8/2012	7180	5/8/2012	7181	1,1-Dichloroethylene	U	U	0	0
P6R4E	5/8/2012	7180	5/8/2012	7181	1,2-Dichloroethane	U	U	0	0
P6R4E	5/8/2012	7180	5/8/2012	7181	Carbon Tetrachloride	64.185	64.305	-0.12	0.19
P6R4E	5/8/2012	7180	5/8/2012	7181	Chlorobenzene	U	U	0	0
P6R4E	5/8/2012	7180	5/8/2012	7181	Chloroform	4.305	4.305	0	0
P6R4E	5/8/2012	7180	5/8/2012	7181	Methylene Chloride	0.945 J	0.945 J	0	0
P6R4E	5/8/2012	7180	5/8/2012	7181	Toluene	0.645 J	0.645 J	0	0
P6R4E	6/5/2012	7255	6/5/2012	7256	1,1,1-Trichloroethane	21.36	22.24	-0.88	4.04
P6R4E	6/5/2012	7255	6/5/2012	7256	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R4E	6/5/2012	7255	6/5/2012	7256	1,1-Dichloroethylene	U	U	0	0
P6R4E	6/5/2012	7255	6/5/2012	7256	1,2-Dichloroethane	U	U	0	0
P6R4E	6/5/2012	7255	6/5/2012	7256	Carbon Tetrachloride	111.4	116.86	-5.46	4.78
P6R4E	6/5/2012	7255	6/5/2012	7256	Chlorobenzene	U	U	0	0
P6R4E	6/5/2012	7255	6/5/2012	7256	Chloroform	6.78	7.04	-0.26	3.76

Attachment 6D – VOCs – Field Duplicate Precision

Field Duplicate Precision for Disposal Room VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
P6R4E	6/5/2012	7255	6/5/2012	7256	Methylene Chloride	0.86 J	0.9 J	-0.04	4.55
P6R4E	6/5/2012	7255	6/5/2012	7256	Toluene	0.4 J	0.42 J	-0.02	4.88
P6R5E	1/3/2012	6836	1/3/2012	6837	1,1,1-Trichloroethane	29.46	28.71	0.75	2.58
P6R5E	1/3/2012	6836	1/3/2012	6837	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R5E	1/3/2012	6836	1/3/2012	6837	1,1-Dichloroethylene	U	U	0	0
P6R5E	1/3/2012	6836	1/3/2012	6837	1,2-Dichloroethane	U	U	0	0
P6R5E	1/3/2012	6836	1/3/2012	6837	Carbon Tetrachloride	125.7	121.14	4.56	3.69
P6R5E	1/3/2012	6836	1/3/2012	6837	Chlorobenzene	U	U	0	0
P6R5E	1/3/2012	6836	1/3/2012	6837	Chloroform	8.19	7.68	0.51	6.43
P6R5E	1/3/2012	6836	1/3/2012	6837	Methylene Chloride	0.9 J	0.72 J	0.18	22.22
P6R5E	1/3/2012	6836	1/3/2012	6837	Toluene	0.45 J	0.42 J	0.03	6.9
P6R5E	1/16/2012	6875	1/16/2012	6876	1,1,1-Trichloroethane	48.72	48.48	0.24	0.49
P6R5E	1/16/2012	6875	1/16/2012	6876	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R5E	1/16/2012	6875	1/16/2012	6876	1,1-Dichloroethylene	U	U	0	0
P6R5E	1/16/2012	6875	1/16/2012	6876	1,2-Dichloroethane	U	U	0	0
P6R5E	1/16/2012	6875	1/16/2012	6876	Carbon Tetrachloride	271.74	269.82	1.92	0.71
P6R5E	1/16/2012	6875	1/16/2012	6876	Chlorobenzene	U	U	0	0
P6R5E	1/16/2012	6875	1/16/2012	6876	Chloroform	17.22	16.68	0.54	3.19
P6R5E	1/16/2012	6875	1/16/2012	6876	Methylene Chloride	1.68 J	1.56 J	0.12	7.41
P6R5E	1/16/2012	6875	1/16/2012	6876	Toluene	U	U	0	0
P6R5E	1/30/2012	6916	1/30/2012	6917	1,1,1-Trichloroethane	46.56	44.96	1.6	3.5
P6R5E	1/30/2012	6916	1/30/2012	6917	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R5E	1/30/2012	6916	1/30/2012	6917	1,1-Dichloroethylene	U	U	0	0
P6R5E	1/30/2012	6916	1/30/2012	6917	1,2-Dichloroethane	U	U	0	0
P6R5E	1/30/2012	6916	1/30/2012	6917	Carbon Tetrachloride	197.16	186.24	10.92	5.7
P6R5E	1/30/2012	6916	1/30/2012	6917	Chlorobenzene	U	U	0	0
P6R5E	1/30/2012	6916	1/30/2012	6917	Chloroform	12.36	11.16	1.2	10.2
P6R5E	1/30/2012	6916	1/30/2012	6917	Methylene Chloride	1.16 J	1.16 J	0	0
P6R5E	1/30/2012	6916	1/30/2012	6917	Toluene	0.4 J	0.36 J	0.04	10.53
P6R5E	2/13/2012	6956	2/13/2012	6957	1,1,1-Trichloroethane	50.13	52.92	-2.79	5.41
P6R5E	2/13/2012	6956	2/13/2012	6957	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R5E	2/13/2012	6956	2/13/2012	6957	1,1-Dichloroethylene	U	U	0	0
P6R5E	2/13/2012	6956	2/13/2012	6957	1,2-Dichloroethane	U	U	0	0
P6R5E	2/13/2012	6956	2/13/2012	6957	Carbon Tetrachloride	266.13	278.01	-11.88	4.37
P6R5E	2/13/2012	6956	2/13/2012	6957	Chlorobenzene	U	U	0	0
P6R5E	2/13/2012	6956	2/13/2012	6957	Chloroform	16.38	16.74	-0.36	2.17
P6R5E	2/13/2012	6956	2/13/2012	6957	Methylene Chloride	1.89 J	1.8 J	0.09	4.88
P6R5E	2/13/2012	6956	2/13/2012	6957	Toluene	U	U	0	0

Attachment 6D – VOCs – Field Duplicate Precision

Field Duplicate Precision for Disposal Room VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
P6R5E	2/27/2012	6992	2/27/2012	6993	1,1,1-Trichloroethane	38.34	40.08	-1.74	4.44
P6R5E	2/27/2012	6992	2/27/2012	6993	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R5E	2/27/2012	6992	2/27/2012	6993	1,1-Dichloroethylene	U	U	0	0
P6R5E	2/27/2012	6992	2/27/2012	6993	1,2-Dichloroethane	U	U	0	0
P6R5E	2/27/2012	6992	2/27/2012	6993	Carbon Tetrachloride	129.12	134.25	-5.13	3.9
P6R5E	2/27/2012	6992	2/27/2012	6993	Chlorobenzene	U	U	0	0
P6R5E	2/27/2012	6992	2/27/2012	6993	Chloroform	7.95	7.98	-0.03	0.38
P6R5E	2/27/2012	6992	2/27/2012	6993	Methylene Chloride	1.14 J	0.9 J	0.24	23.53
P6R5E	2/27/2012	6992	2/27/2012	6993	Toluene	0.51 J	0.51 J	0	0
P6R5E	3/12/2012	7028	3/12/2012	7029	1,1,1-Trichloroethane	16.68	15.855	0.82	5.04
P6R5E	3/12/2012	7028	3/12/2012	7029	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R5E	3/12/2012	7028	3/12/2012	7029	1,1-Dichloroethylene	U	U	0	0
P6R5E	3/12/2012	7028	3/12/2012	7029	1,2-Dichloroethane	U	U	0	0
P6R5E	3/12/2012	7028	3/12/2012	7029	Carbon Tetrachloride	71.775	68.97	2.8	3.98
P6R5E	3/12/2012	7028	3/12/2012	7029	Chlorobenzene	U	U	0	0
P6R5E	3/12/2012	7028	3/12/2012	7029	Chloroform	4.965	4.575	0.39	8.18
P6R5E	3/12/2012	7028	3/12/2012	7029	Methylene Chloride	0.675 J	0.585 J	0.09	14.29
P6R5E	3/12/2012	7028	3/12/2012	7029	Toluene	0.33 J	0.315 J	0.01	3.1
P6R5E	3/28/2012	7066	3/28/2012	7067	1,1,1-Trichloroethane	28.44	29.68	-1.24	4.27
P6R5E	3/28/2012	7066	3/28/2012	7067	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R5E	3/28/2012	7066	3/28/2012	7067	1,1-Dichloroethylene	U	U	0	0
P6R5E	3/28/2012	7066	3/28/2012	7067	1,2-Dichloroethane	U	U	0	0
P6R5E	3/28/2012	7066	3/28/2012	7067	Carbon Tetrachloride	152.8	152.6	0.2	0.13
P6R5E	3/28/2012	7066	3/28/2012	7067	Chlorobenzene	U	U	0	0
P6R5E	3/28/2012	7066	3/28/2012	7067	Chloroform	10.88	10.52	0.36	3.36
P6R5E	3/28/2012	7066	3/28/2012	7067	Methylene Chloride	1.4 J	1.76 J	-0.36	22.78
P6R5E	3/28/2012	7066	3/28/2012	7067	Toluene	0.4 J	0.4 J	0	0
P6R5E	4/10/2012	7101	4/10/2012	7102	1,1,1-Trichloroethane	18.63	18.18	0.45	2.44
P6R5E	4/10/2012	7101	4/10/2012	7102	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R5E	4/10/2012	7101	4/10/2012	7102	1,1-Dichloroethylene	U	U	0	0
P6R5E	4/10/2012	7101	4/10/2012	7102	1,2-Dichloroethane	U	U	0	0
P6R5E	4/10/2012	7101	4/10/2012	7102	Carbon Tetrachloride	103.38	102.21	1.17	1.14
P6R5E	4/10/2012	7101	4/10/2012	7102	Chlorobenzene	U	U	0	0
P6R5E	4/10/2012	7101	4/10/2012	7102	Chloroform	7.53	7.26	0.27	3.65
P6R5E	4/10/2012	7101	4/10/2012	7102	Methylene Chloride	0.9 J	0.9 J	0	0
P6R5E	4/10/2012	7101	4/10/2012	7102	Toluene	0.42 J	0.39 J	0.03	7.41
P6R5E	4/23/2012	7139	4/23/2012	7140	1,1,1-Trichloroethane	7.6	6.9	0.7	9.66
P6R5E	4/23/2012	7139	4/23/2012	7140	1,1,2,2-Tetrachloroethane	U	U	0	0

Attachment 6D – VOCs – Field Duplicate Precision

Field Duplicate Precision for Disposal Room VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
P6R5E	4/23/2012	7139	4/23/2012	7140	1,1-Dichloroethylene	U	U	0	0
P6R5E	4/23/2012	7139	4/23/2012	7140	1,2-Dichloroethane	U	U	0	0
P6R5E	4/23/2012	7139	4/23/2012	7140	Carbon Tetrachloride	30.78	27.92	2.86	9.74
P6R5E	4/23/2012	7139	4/23/2012	7140	Chlorobenzene	U	U	0	0
P6R5E	4/23/2012	7139	4/23/2012	7140	Chloroform	2.38	2.11	0.27	12.03
P6R5E	4/23/2012	7139	4/23/2012	7140	Methylene Chloride	0.36 J	0.35 J	0.01	2.82
P6R5E	4/23/2012	7139	4/23/2012	7140	Toluene	0.46 J	0.41 J	0.05	11.49
P6R5E	5/21/2012	7215	5/21/2012	7216 Q	1,1,1-Trichloroethane	10.48	5.98	4.5	54.68
P6R5E	5/21/2012	7215	5/21/2012	7216	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R5E	5/21/2012	7215	5/21/2012	7216	1,1-Dichloroethylene	U	U	0	0
P6R5E	5/21/2012	7215	5/21/2012	7216	1,2-Dichloroethane	U	U	0	0
P6R5E	5/21/2012	7215	5/21/2012	7216 Q	Carbon Tetrachloride	22.08	10.43	11.65	71.67
P6R5E	5/21/2012	7215	5/21/2012	7216	Chlorobenzene	U	U	0	0
P6R5E	5/21/2012	7215	5/21/2012	7216	Chloroform	2.07	0.96 J	1.11	73.27
P6R5E	5/21/2012	7215	5/21/2012	7216	Methylene Chloride	0.48 J	0.29 J	0.19	49.35
P6R5E	5/21/2012	7215	5/21/2012	7216	Toluene	0.29 J	0.23 J	0.06	23.08
P6R5E	6/18/2012	7291	6/18/2012	7292	1,1,1-Trichloroethane	46.41	38.07	8.34	19.74
P6R5E	6/18/2012	7291	6/18/2012	7292	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R5E	6/18/2012	7291	6/18/2012	7292	1,1-Dichloroethylene	U	U	0	0
P6R5E	6/18/2012	7291	6/18/2012	7292	1,2-Dichloroethane	U	U	0	0
P6R5E	6/18/2012	7291	6/18/2012	7292	Carbon Tetrachloride	104.76	73.905	30.85	34.53
P6R5E	6/18/2012	7291	6/18/2012	7292	Chlorobenzene	U	U	0	0
P6R5E	6/18/2012	7291	6/18/2012	7292 Q	Chloroform	7.05	4.38	2.67	46.72
P6R5E	6/18/2012	7291	6/18/2012	7292	Methylene Chloride	1.11 J	0.66 J	0.45	50.85
P6R5E	6/18/2012	7291	6/18/2012	7292	Toluene	0.51 J	0.42 J	0.09	19.35
P6R6E	1/11/2012	6849	1/11/2012	6850 Q	1,1,1-Trichloroethane	244.62	105.66	138.96	79.34
P6R6E	1/11/2012	6849	1/11/2012	6850	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R6E	1/11/2012	6849	1/11/2012	6850	1,1-Dichloroethylene	U	U	0	0
P6R6E	1/11/2012	6849	1/11/2012	6850	1,2-Dichloroethane	U	U	0	0
P6R6E	1/11/2012	6849	1/11/2012	6850 Q	Carbon Tetrachloride	1480.68	590.31	890.37	85.98
P6R6E	1/11/2012	6849	1/11/2012	6850	Chlorobenzene	U	U	0	0
P6R6E	1/11/2012	6849	1/11/2012	6850 Q	Chloroform	87.75	34.2	53.55	87.82
P6R6E	1/11/2012	6849	1/11/2012	6850	Methylene Chloride	8.64 J	3.15 J	5.49	93.13
P6R6E	1/11/2012	6849	1/11/2012	6850	Toluene	U	U	0	0
P6R6E	2/22/2012	6983	2/22/2012	6984 Q	1,1,1-Trichloroethane	96.96	33.76	63.2	96.7
P6R6E	2/22/2012	6983	2/22/2012	6984	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R6E	2/22/2012	6983	2/22/2012	6984	1,1-Dichloroethylene	U	U	0	0
P6R6E	2/22/2012	6983	2/22/2012	6984	1,2-Dichloroethane	U	U	0	0

Attachment 6D – VOCs – Field Duplicate Precision

Field Duplicate Precision for Disposal Room VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
P6R6E	2/22/2012	6983	2/22/2012	6984 Q	Carbon Tetrachloride	587.28	193.92	393.36	100.71
P6R6E	2/22/2012	6983	2/22/2012	6984	Chlorobenzene	U	U	0	0
P6R6E	2/22/2012	6983	2/22/2012	6984 Q	Chloroform	34.32	11.56	22.76	99.22
P6R6E	2/22/2012	6983	2/22/2012	6984	Methylene Chloride	3.72 J	1.32 J	2.4	95.24
P6R6E	2/22/2012	6983	2/22/2012	6984	Toluene	U	U	0	0
P6R6E	4/4/2012	7080	4/4/2012	7081	1,1,1-Trichloroethane	108.54	93.42	15.12	14.97
P6R6E	4/4/2012	7080	4/4/2012	7081	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R6E	4/4/2012	7080	4/4/2012	7081	1,1-Dichloroethylene	U	U	0	0
P6R6E	4/4/2012	7080	4/4/2012	7081	1,2-Dichloroethane	U	U	0	0
P6R6E	4/4/2012	7080	4/4/2012	7081	Carbon Tetrachloride	658.98	562.68	96.3	15.77
P6R6E	4/4/2012	7080	4/4/2012	7081	Chlorobenzene	U	U	0	0
P6R6E	4/4/2012	7080	4/4/2012	7081	Chloroform	41.94	35.64	6.3	16.24
P6R6E	4/4/2012	7080	4/4/2012	7081	Methylene Chloride	4.32 J	4.14 J	0.18	4.26
P6R6E	4/4/2012	7080	4/4/2012	7081	Toluene	U	U	0	0
P6R6E	5/15/2012	7206	5/15/2012	7207	1,1,1-Trichloroethane	1233.63	1296	-62.37	4.93
P6R6E	5/15/2012	7206	5/15/2012	7207	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R6E	5/15/2012	7206	5/15/2012	7207	1,1-Dichloroethylene	U	U	0	0
P6R6E	5/15/2012	7206	5/15/2012	7207	1,2-Dichloroethane	U	U	0	0
P6R6E	5/15/2012	7206	5/15/2012	7207	Carbon Tetrachloride	3819.96	3585.06	234.9	6.34
P6R6E	5/15/2012	7206	5/15/2012	7207	Chlorobenzene	U	U	0	0
P6R6E	5/15/2012	7206	5/15/2012	7207	Chloroform	226.8	216.27	10.53	4.75
P6R6E	5/15/2012	7206	5/15/2012	7207	Methylene Chloride	27.54 J	26.73 J	0.81	2.99
P6R6E	5/15/2012	7206	5/15/2012	7207	Toluene	10.53 J	11.34 J	-0.81	7.41
P6R6I	5/30/2012	7228	5/30/2012	7229	1,1,1-Trichloroethane	983.745	1007.235	-23.49	2.36
P6R6I	5/30/2012	7228	5/30/2012	7229	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R6I	5/30/2012	7228	5/30/2012	7229	1,1-Dichloroethylene	U	U	0	0
P6R6I	5/30/2012	7228	5/30/2012	7229	1,2-Dichloroethane	U	U	0	0
P6R6I	5/30/2012	7228	5/30/2012	7229	Carbon Tetrachloride	2605.365	2743.065	-137.7	5.15
P6R6I	5/30/2012	7228	5/30/2012	7229	Chlorobenzene	U	U	0	0
P6R6I	5/30/2012	7228	5/30/2012	7229	Chloroform	127.575	134.46	-6.88	5.25
P6R6I	5/30/2012	7228	5/30/2012	7229	Methylene Chloride	34.02 J	34.83 J	-0.81	2.35
P6R6I	5/30/2012	7228	5/30/2012	7229	Toluene	6.885 J	6.885 J	0	0
P6R7E	1/23/2012	6903	1/23/2012	6904	1,1,1-Trichloroethane	22948.92	24173.64	-1224.72	5.2
P6R7E	1/23/2012	6903	1/23/2012	6904	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R7E	1/23/2012	6903	1/23/2012	6904	1,1-Dichloroethylene	U	U	0	0
P6R7E	1/23/2012	6903	1/23/2012	6904	1,2-Dichloroethane	U	U	0	0
P6R7E	1/23/2012	6903	1/23/2012	6904	Carbon Tetrachloride	150261.48	158426.28	-8164.8	5.29
P6R7E	1/23/2012	6903	1/23/2012	6904	Chlorobenzene	U	U	0	0

Attachment 6D – VOCs – Field Duplicate Precision

Field Duplicate Precision for Disposal Room VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
P6R7E	1/23/2012	6903	1/23/2012	6904	Chloroform	9156.24	9477	-320.76	3.44
P6R7E	1/23/2012	6903	1/23/2012	6904	Methylene Chloride	787.32 J	845.64 J	-58.32	7.14
P6R7E	1/23/2012	6903	1/23/2012	6904	Toluene	U	U	0	0
P6R7E	3/5/2012	7002	3/5/2012	7003	1,1,1-Trichloroethane	19354.95	19179.99	174.96	0.91
P6R7E	3/5/2012	7002	3/5/2012	7003	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R7E	3/5/2012	7002	3/5/2012	7003	1,1-Dichloroethylene	U	U	0	0
P6R7E	3/5/2012	7002	3/5/2012	7003	1,2-Dichloroethane	U	U	0	0
P6R7E	3/5/2012	7002	3/5/2012	7003	Carbon Tetrachloride	122034.6	122559.48	-524.88	0.43
P6R7E	3/5/2012	7002	3/5/2012	7003	Chlorobenzene	U	U	0	0
P6R7E	3/5/2012	7002	3/5/2012	7003	Chloroform	7370.19	7588.89	-218.7	2.92
P6R7E	3/5/2012	7002	3/5/2012	7003	Methylene Chloride	699.84 J	656.1 J	43.74	6.45
P6R7E	3/5/2012	7002	3/5/2012	7003	Toluene	U	U	0	0
P6R7E	4/16/2012	7131	4/16/2012	7132	1,1,1-Trichloroethane	10191.42	10745.46	-554.04	5.29
P6R7E	4/16/2012	7131	4/16/2012	7132	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R7E	4/16/2012	7131	4/16/2012	7132	1,1-Dichloroethylene	U	U	0	0
P6R7E	4/16/2012	7131	4/16/2012	7132	1,2-Dichloroethane	U	U	0	0
P6R7E	4/16/2012	7131	4/16/2012	7132	Carbon Tetrachloride	67272.12	69838.2	-2566.08	3.74
P6R7E	4/16/2012	7131	4/16/2012	7132	Chlorobenzene	U	U	0	0
P6R7E	4/16/2012	7131	4/16/2012	7132	Chloroform	4038.66	4330.26	-291.6	6.97
P6R7E	4/16/2012	7131	4/16/2012	7132	Methylene Chloride	393.66 J	393.66 J	0	0
P6R7E	4/16/2012	7131	4/16/2012	7132	Toluene	U	U	0	0
P6R7E	6/11/2012	7283	6/11/2012	7284	1,1,1-Trichloroethane	79081.92	82406.16	-3324.24	4.12
P6R7E	6/11/2012	7283	6/11/2012	7284	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R7E	6/11/2012	7283	6/11/2012	7284	1,1-Dichloroethylene	U	U	0	0
P6R7E	6/11/2012	7283	6/11/2012	7284	1,2-Dichloroethane	U	U	0	0
P6R7E	6/11/2012	7283	6/11/2012	7284	Carbon Tetrachloride	534940.2	545700.24	-10760.04	1.99
P6R7E	6/11/2012	7283	6/11/2012	7284	Chlorobenzene	U	U	0	0
P6R7E	6/11/2012	7283	6/11/2012	7284	Chloroform	28518.48	29830.68	-1312.2	4.5
P6R7E	6/11/2012	7283	6/11/2012	7284	Methylene Chloride	3061.8 J	3236.76 J	-174.96	5.56
P6R7E	6/11/2012	7283	6/11/2012	7284	Toluene	U	U	0	0
P6R7I	2/6/2012	6926	2/6/2012	6927	1,1,1-Trichloroethane	40065.84	37149.84	2916	7.55
P6R7I	2/6/2012	6926	2/6/2012	6927	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R7I	2/6/2012	6926	2/6/2012	6927	1,1-Dichloroethylene	U	U	0	0
P6R7I	2/6/2012	6926	2/6/2012	6927	1,2-Dichloroethane	U	U	0	0
P6R7I	2/6/2012	6926	2/6/2012	6927	Carbon Tetrachloride	166620.24	153702.36	12917.88	8.07
P6R7I	2/6/2012	6926	2/6/2012	6927	Chlorobenzene	U	U	0	0
P6R7I	2/6/2012	6926	2/6/2012	6927	Chloroform	9127.08	8777.16	349.92	3.91
P6R7I	2/6/2012	6926	2/6/2012	6927	Methylene Chloride	1224.72 J	1078.92 J	145.8	12.66

Attachment 6D – VOCs – Field Duplicate Precision

Field Duplicate Precision for Disposal Room VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
P6R7I	2/6/2012	6926	2/6/2012	6927	Toluene	U	U	0	0
P6R7I	3/19/2012	7058	3/19/2012	7059	1,1,1-Trichloroethane	6949.8	7722.54	-772.74	10.53
P6R7I	3/19/2012	7058	3/19/2012	7059	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R7I	3/19/2012	7058	3/19/2012	7059	1,1-Dichloroethylene	U	U	0	0
P6R7I	3/19/2012	7058	3/19/2012	7059	1,2-Dichloroethane	U	U	0	0
P6R7I	3/19/2012	7058	3/19/2012	7059	Carbon Tetrachloride	22409.46	24635.34	-2225.88	9.46
P6R7I	3/19/2012	7058	3/19/2012	7059	Chlorobenzene	U	U	0	0
P6R7I	3/19/2012	7058	3/19/2012	7059	Chloroform	1098.36	1249.02	-150.66	12.84
P6R7I	3/19/2012	7058	3/19/2012	7059	Methylene Chloride	184.68 J	218.7 J	-34.02	16.87
P6R7I	3/19/2012	7058	3/19/2012	7059	Toluene	U	U	0	0
P6R7I	5/1/2012	7150	5/1/2012	7151	1,1,1-Trichloroethane	43302.6	45336.51	-2033.91	4.59
P6R7I	5/1/2012	7150	5/1/2012	7151	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R7I	5/1/2012	7150	5/1/2012	7151	1,1-Dichloroethylene	U	U	0	0
P6R7I	5/1/2012	7150	5/1/2012	7151	1,2-Dichloroethane	U	U	0	0
P6R7I	5/1/2012	7150	5/1/2012	7151	Carbon Tetrachloride	189875.34	199323.18	-9447.84	4.86
P6R7I	5/1/2012	7150	5/1/2012	7151	Chlorobenzene	U	U	0	0
P6R7I	5/1/2012	7150	5/1/2012	7151	Chloroform	11284.92	11744.19	-459.27	3.99
P6R7I	5/1/2012	7150	5/1/2012	7151	Methylene Chloride	1705.86 J	1705.86 J	0	0
P6R7I	5/1/2012	7150	5/1/2012	7151	Toluene	U	U	0	0
P6R7I	6/25/2012	7306	6/25/2012	7307	1,1,1-Trichloroethane	58611.6	53800.2	4811.4	8.56
P6R7I	6/25/2012	7306	6/25/2012	7307	1,1,2,2-Tetrachloroethane	U	U	0	0
P6R7I	6/25/2012	7306	6/25/2012	7307	1,1-Dichloroethylene	U	U	0	0
P6R7I	6/25/2012	7306	6/25/2012	7307	1,2-Dichloroethane	U	U	0	0
P6R7I	6/25/2012	7306	6/25/2012	7307	Carbon Tetrachloride	362954.52	309854.16	53100.36	15.78
P6R7I	6/25/2012	7306	6/25/2012	7307	Chlorobenzene	U	U	0	0
P6R7I	6/25/2012	7306	6/25/2012	7307	Chloroform	17670.96	16883.64	787.32	4.56
P6R7I	6/25/2012	7306	6/25/2012	7307	Methylene Chloride	2536.92 J	1924.56 J	612.36	27.45
P6R7I	6/25/2012	7306	6/25/2012	7307	Toluene	U	U	0	0

Field Duplicate Precision for Ongoing Disposal Room VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
P3R1E	1/10/2012	6869	1/10/2012	6870	1,1,1-Trichloroethane	4248.72	4012.56	236.16	5.72
P3R1E	1/10/2012	6869	1/10/2012	6870	1,1,2,2-Tetrachloroethane	U	U	0	0
P3R1E	1/10/2012	6869	1/10/2012	6870	1,1-Dichloroethylene	54 J	42.48 J	11.52	23.88
P3R1E	1/10/2012	6869	1/10/2012	6870	1,2-Dichloroethane	10.08 J	8.64 J	1.44	15.38
P3R1E	1/10/2012	6869	1/10/2012	6870	Carbon Tetrachloride	4372.56	4223.52	149.04	3.47

Attachment 6D – VOCs – Field Duplicate Precision

Field Duplicate Precision for Ongoing Disposal Room VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
P3R1E	1/10/2012	6869	1/10/2012	6870	Chlorobenzene	U	U	0	0
P3R1E	1/10/2012	6869	1/10/2012	6870	Chloroform	131.76	120.24	11.52	9.14
P3R1E	1/10/2012	6869	1/10/2012	6870	Methylene Chloride	1207.44	1100.16	107.28	9.3
P3R1E	1/10/2012	6869	1/10/2012	6870	Toluene	87.84	64.8 J	23.04	30.19
P3R1E	2/16/2012	6972	2/16/2012	6973	1,1,1-Trichloroethane	1098.24	1067.04	31.2	2.88
P3R1E	2/16/2012	6972	2/16/2012	6973	1,1,2,2-Tetrachloroethane	U	U	0	0
P3R1E	2/16/2012	6972	2/16/2012	6973	1,1-Dichloroethylene	8.64 J	9.12 J	-0.48	5.41
P3R1E	2/16/2012	6972	2/16/2012	6973	1,2-Dichloroethane	2.88 J	U	2.88	200
P3R1E	2/16/2012	6972	2/16/2012	6973	Carbon Tetrachloride	1273.68	1228.8	44.88	3.59
P3R1E	2/16/2012	6972	2/16/2012	6973	Chlorobenzene	U	U	0	0
P3R1E	2/16/2012	6972	2/16/2012	6973	Chloroform	41.04	39.84	1.2	2.97
P3R1E	2/16/2012	6972	2/16/2012	6973	Methylene Chloride	288.24	279.36	8.88	3.13
P3R1E	2/16/2012	6972	2/16/2012	6973	Toluene	18.24 J	17.52 J	0.72	4.03
P3R1E	3/6/2012	7022	3/6/2012	7023	1,1,1-Trichloroethane	4485.24	4600.8	-115.56	2.54
P3R1E	3/6/2012	7022	3/6/2012	7023	1,1,2,2-Tetrachloroethane	U	U	0	0
P3R1E	3/6/2012	7022	3/6/2012	7023	1,1-Dichloroethylene	33.48 J	35.64 J	-2.16	6.25
P3R1E	3/6/2012	7022	3/6/2012	7023	1,2-Dichloroethane	U	U	0	0
P3R1E	3/6/2012	7022	3/6/2012	7023	Carbon Tetrachloride	4943.16	5072.76	-129.6	2.59
P3R1E	3/6/2012	7022	3/6/2012	7023	Chlorobenzene	U	U	0	0
P3R1E	3/6/2012	7022	3/6/2012	7023	Chloroform	147.96	154.44	-6.48	4.29
P3R1E	3/6/2012	7022	3/6/2012	7023	Methylene Chloride	1286.28	1320.84	-34.56	2.65
P3R1E	3/6/2012	7022	3/6/2012	7023	Toluene	57.24 J	58.32 J	-1.08	1.87
P3R1E	4/3/2012	7095	4/3/2012	7096	1,1,1-Trichloroethane	2154.96	1933.92	221.04	10.81
P3R1E	4/3/2012	7095	4/3/2012	7096	1,1,2,2-Tetrachloroethane	U	U	0	0
P3R1E	4/3/2012	7095	4/3/2012	7096	1,1-Dichloroethylene	16.56 J	15.12 J	1.44	9.09
P3R1E	4/3/2012	7095	4/3/2012	7096	1,2-Dichloroethane	U	U	0	0
P3R1E	4/3/2012	7095	4/3/2012	7096	Carbon Tetrachloride	2601.36	2313.36	288	11.72
P3R1E	4/3/2012	7095	4/3/2012	7096	Chlorobenzene	U	U	0	0
P3R1E	4/3/2012	7095	4/3/2012	7096	Chloroform	82.08	71.28 J	10.8	14.08
P3R1E	4/3/2012	7095	4/3/2012	7096	Methylene Chloride	580.32	514.8	65.52	11.97
P3R1E	4/3/2012	7095	4/3/2012	7096	Toluene	32.4 J	28.08 J	4.32	14.29
P3R1E	5/1/2012	7173	5/1/2012	7174	1,1,1-Trichloroethane	2960.28	2945.16	15.12	0.51
P3R1E	5/1/2012	7173	5/1/2012	7174	1,1,2,2-Tetrachloroethane	U	U	0	0
P3R1E	5/1/2012	7173	5/1/2012	7174	1,1-Dichloroethylene	36.72 J	32.4 J	4.32	12.5
P3R1E	5/1/2012	7173	5/1/2012	7174	1,2-Dichloroethane	U	U	0	0
P3R1E	5/1/2012	7173	5/1/2012	7174	Carbon Tetrachloride	3410.64	3408.48	2.16	0.06
P3R1E	5/1/2012	7173	5/1/2012	7174	Chlorobenzene	U	U	0	0
P3R1E	5/1/2012	7173	5/1/2012	7174	Chloroform	106.92 J	103.68 J	3.24	3.08

Attachment 6D – VOCs – Field Duplicate Precision

Field Duplicate Precision for Ongoing Disposal Room VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
P3R1E	5/1/2012	7173	5/1/2012	7174	Methylene Chloride	825.12	803.52	21.6	2.65
P3R1E	5/1/2012	7173	5/1/2012	7174	Toluene	95.04 J	84.24 J	10.8	12.05
P3R1E	6/5/2012	7246	6/5/2012	7247	1,1,1-Trichloroethane	2698.56	2453.76	244.8	9.5
P3R1E	6/5/2012	7246	6/5/2012	7247	1,1,2,2-Tetrachloroethane	U	U	0	0
P3R1E	6/5/2012	7246	6/5/2012	7247	1,1-Dichloroethylene	28.08 J	20.88 J	7.2	29.41
P3R1E	6/5/2012	7246	6/5/2012	7247	1,2-Dichloroethane	U	U	0	0
P3R1E	6/5/2012	7246	6/5/2012	7247	Carbon Tetrachloride	3501.36	3242.88	258.48	7.67
P3R1E	6/5/2012	7246	6/5/2012	7247	Chlorobenzene	U	U	0	0
P3R1E	6/5/2012	7246	6/5/2012	7247	Chloroform	85.68	77.04	8.64	10.62
P3R1E	6/5/2012	7246	6/5/2012	7247	Methylene Chloride	606.96	530.64	76.32	13.42
P3R1E	6/5/2012	7246	6/5/2012	7247	Toluene	55.44 J	44.64 J	10.8	21.58
P4R1E	1/17/2012	6897	1/17/2012	6898	1,1,1-Trichloroethane	160263.36	169011.36	-8748	5.31
P4R1E	1/17/2012	6897	1/17/2012	6898	1,1,2,2-Tetrachloroethane	U	U	0	0
P4R1E	1/17/2012	6897	1/17/2012	6898	1,1-Dichloroethylene	U	U	0	0
P4R1E	1/17/2012	6897	1/17/2012	6898	1,2-Dichloroethane	U	U	0	0
P4R1E	1/17/2012	6897	1/17/2012	6898	Carbon Tetrachloride	884422.8	926938.08	-42515.28	4.69
P4R1E	1/17/2012	6897	1/17/2012	6898	Chlorobenzene	U	U	0	0
P4R1E	1/17/2012	6897	1/17/2012	6898	Chloroform	66484.8	72783.36	-6298.56	9.05
P4R1E	1/17/2012	6897	1/17/2012	6898	Methylene Chloride	30268.08	34292.16	-4024.08	12.47
P4R1E	1/17/2012	6897	1/17/2012	6898	Toluene	U	U	0	0
P4R1E	2/7/2012	6948	2/7/2012	6949	1,1,1-Trichloroethane	136600.02	129251.7	7348.32	5.53
P4R1E	2/7/2012	6948	2/7/2012	6949	1,1,2,2-Tetrachloroethane	U	U	0	0
P4R1E	2/7/2012	6948	2/7/2012	6949	1,1-Dichloroethylene	U	U	0	0
P4R1E	2/7/2012	6948	2/7/2012	6949	1,2-Dichloroethane	U	U	0	0
P4R1E	2/7/2012	6948	2/7/2012	6949	Carbon Tetrachloride	760419.9	719872.92	40546.98	5.48
P4R1E	2/7/2012	6948	2/7/2012	6949	Chlorobenzene	U	U	0	0
P4R1E	2/7/2012	6948	2/7/2012	6949	Chloroform	58655.34	55899.72	2755.62	4.81
P4R1E	2/7/2012	6948	2/7/2012	6949	Methylene Chloride	26375.22	26244	131.22	0.5
P4R1E	2/7/2012	6948	2/7/2012	6949	Toluene	U	U	0	0
P4R1E	3/13/2012	7049	3/13/2012	7050	1,1,1-Trichloroethane	158251.32	144998.1	13253.22	8.74
P4R1E	3/13/2012	7049	3/13/2012	7050	1,1,2,2-Tetrachloroethane	U	U	0	0
P4R1E	3/13/2012	7049	3/13/2012	7050	1,1-Dichloroethylene	U	U	0	0
P4R1E	3/13/2012	7049	3/13/2012	7050	1,2-Dichloroethane	U	U	0	0
P4R1E	3/13/2012	7049	3/13/2012	7050	Carbon Tetrachloride	886522.32	812645.46	73876.86	8.7
P4R1E	3/13/2012	7049	3/13/2012	7050	Chlorobenzene	U	U	0	0
P4R1E	3/13/2012	7049	3/13/2012	7050	Chloroform	67053.42	62723.16	4330.26	6.67
P4R1E	3/13/2012	7049	3/13/2012	7050	Methylene Chloride	31099.14	30967.92	131.22	0.42
P4R1E	3/13/2012	7049	3/13/2012	7050	Toluene	1180.98 J	1180.98 J	0	0

Attachment 6D – VOCs – Field Duplicate Precision

Field Duplicate Precision for Ongoing Disposal Room VOC Monitoring

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppbv)	Duplicate (ppbv)	Difference	RPD †
P4R1E	4/10/2012	7119	4/10/2012	7120	1,1,1-Trichloroethane	110880.9	98415	12465.9	11.91
P4R1E	4/10/2012	7119	4/10/2012	7120	1,1,2,2-Tetrachloroethane	U	U	0	0
P4R1E	4/10/2012	7119	4/10/2012	7120	1,1-Dichloroethylene	U	U	0	0
P4R1E	4/10/2012	7119	4/10/2012	7120	1,2-Dichloroethane	U	U	0	0
P4R1E	4/10/2012	7119	4/10/2012	7120	Carbon Tetrachloride	605973.96	555060.6	50913.36	8.77
P4R1E	4/10/2012	7119	4/10/2012	7120	Chlorobenzene	U	U	0	0
P4R1E	4/10/2012	7119	4/10/2012	7120	Chloroform	47501.64	43827.48	3674.16	8.05
P4R1E	4/10/2012	7119	4/10/2012	7120	Methylene Chloride	21388.86	18239.58	3149.28	15.89
P4R1E	4/10/2012	7119	4/10/2012	7120	Toluene	U	U	0	0
P4R1E	5/9/2012	7197	5/9/2012	7198	1,1,1-Trichloroethane	82056.24	78557.04	3499.2	4.36
P4R1E	5/9/2012	7197	5/9/2012	7198	1,1,2,2-Tetrachloroethane	U	U	0	0
P4R1E	5/9/2012	7197	5/9/2012	7198	1,1-Dichloroethylene	U	U	0	0
P4R1E	5/9/2012	7197	5/9/2012	7198	1,2-Dichloroethane	U	U	0	0
P4R1E	5/9/2012	7197	5/9/2012	7198	Carbon Tetrachloride	448684.92	437225.04	11459.88	2.59
P4R1E	5/9/2012	7197	5/9/2012	7198	Chlorobenzene	U	U	0	0
P4R1E	5/9/2012	7197	5/9/2012	7198	Chloroform	36479.16	34642.08	1837.08	5.17
P4R1E	5/9/2012	7197	5/9/2012	7198	Methylene Chloride	16358.76	15309	1049.76	6.63
P4R1E	5/9/2012	7197	5/9/2012	7198	Toluene	1399.68 J	1224.72 J	174.96	13.33
P4R1E	6/11/2012	7276	6/11/2012	7277	1,1,1-Trichloroethane	84418.2	88617.24	-4199.04	4.85
P4R1E	6/11/2012	7276	6/11/2012	7277	1,1,2,2-Tetrachloroethane	U	U	0	0
P4R1E	6/11/2012	7276	6/11/2012	7277	1,1-Dichloroethylene	U	U	0	0
P4R1E	6/11/2012	7276	6/11/2012	7277	1,2-Dichloroethane	U	U	0	0
P4R1E	6/11/2012	7276	6/11/2012	7277	Carbon Tetrachloride	546487.56	563108.76	-16621.2	3
P4R1E	6/11/2012	7276	6/11/2012	7277	Chlorobenzene	U	U	0	0
P4R1E	6/11/2012	7276	6/11/2012	7277	Chloroform	35866.8	37703.88	-1837.08	4.99
P4R1E	6/11/2012	7276	6/11/2012	7277	Methylene Chloride	16096.32	16883.64	-787.32	4.77
P4R1E	6/11/2012	7276	6/11/2012	7277	Toluene	787.32 J	787.32 J	0	0

Notes:
J = Estimated value, below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above the MDL.
* Normalized target VOC concentration.
† Technical acceptance criterion for field duplicates is ≤35 RPD, which is only applicable if one or both values are not flagged "U" or "J."

Attachment 7 – QA/QC Results from Analysis of Hydrogen and Methane Monitoring Samples

LCS/LCSD Results

LCS Analysis Date	LCSD Analysis Date	Compound	LCS (%Recovery)	LCSD (%Recovery)	Difference	RPD
1/13/2012	1/13/2012	Hydrogen	107.04	104.10	2.94	2.78
1/13/2012	1/13/2012	Methane	107.16	101.79	5.37	5.14
1/23/2012	1/23/2012	Hydrogen	101.64	99.02	2.62	2.61
1/23/2012	1/23/2012	Methane	109.90	100.81	9.09	8.63
2/10/2012	2/10/2012	Hydrogen	102.43	106.56	-4.13	3.95
2/10/2012	2/10/2012	Methane	102.01	102.62	-0.61	0.60
2/22/2012	2/22/2012	Hydrogen	102.78	105.17	-2.39	2.30
2/22/2012	2/22/2012	Methane	101.21	94.43	6.78	6.93
3/9/2012	3/9/2012	Hydrogen	105.53	105.60	-0.07	0.07
3/9/2012	3/9/2012	Methane	101.12	104.18	-3.06	2.98
3/16/2012	3/16/2012	Hydrogen	104.76	100.79	3.97	3.86
3/16/2012	3/16/2012	Methane	98.90	101.45	-2.55	2.55
4/9/2012	4/9/2012	Hydrogen	104.37	104.26	0.11	0.11
4/9/2012	4/9/2012	Methane	98.54	102.07	-3.53	3.52
4/13/2012	4/13/2012	Hydrogen	103.50	98.41	5.09	5.04
4/13/2012	4/13/2012	Methane	105.07	99.70	5.37	5.24
5/4/2012	5/4/2012	Hydrogen	101.02	100.45	0.57	0.57
5/4/2012	5/4/2012	Methane	93.55	98.12	-4.57	4.77
5/15/2012	5/15/2012	Hydrogen	103.87	103.13	0.74	0.71
5/15/2012	5/15/2012	Methane	99.45	109.39	-9.94	9.52
6/8/2012	6/8/2012	Hydrogen	101.65	101.70	-0.05	0.05
6/8/2012	6/8/2012	Methane	95.31	102.03	-6.72	6.81
6/18/2012	6/18/2012	Hydrogen	100.42	102.90	-2.48	2.44
6/18/2012	6/18/2012	Methane	96.81	100.42	-3.61	3.66

Notes:

Relative Percent Difference (RPD)
RPD = ABS (A-B) / [(A+B)/2] x 100 ABS = Absolute value of a number

Attachment 7 – QA/QC Results from Analysis of Hydrogen and Methane Monitoring Samples

Laboratory Method Blank

Analysis Date	Hydrogen	Methane
1/13/2012	U	U
1/23/2012	U	U
2/10/2012	U	U
2/22/2012	U	U
3/9/2012	U	U
3/16/2012	U	U
4/9/2012	U	U
4/13/2012	U	U
5/4/2012	U	U
5/15/2012	U	U
6/8/2012	U	U
6/18/2012	U	U

Notes:

J = Estimated value; below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above the MDL.

Attachment 7 – QA/QC Results from Analysis of Hydrogen and Methane Monitoring Samples

Lab Precision

Original Analysis Date	Original Sample ID	Duplicate Analysis Date	Duplicate Sample ID	Compound	Original (ppmv)	Duplicate (ppmv)	Difference	RPD *
1/13/2012	6858	1/13/2012	6858-dup	Hydrogen	52.82 J	50.52 J	2.3	4.45
1/13/2012	6858	1/13/2012	6858-dup	Methane	U	U	0	0.00
1/23/2012	6881	1/23/2012	6881-dup	Hydrogen	529.76	554.42	-24.66	4.55
1/23/2012	6881	1/23/2012	6881-dup	Methane	U	U	0	0.00
2/10/2012	6933	2/10/2012	6933-dup	Hydrogen	435.94	429.02	6.92	1.60
2/10/2012	6933	2/10/2012	6933-dup	Methane	U	U	0	0.00
2/22/2012	6961	2/22/2012	6961-dup	Hydrogen	34.02 J	36.14 J	-2.12	6.04
2/22/2012	6961	2/22/2012	6961-dup	Methane	U	U	0	0.00
3/9/2012	7011	3/9/2012	7011-dup	Hydrogen	45.38 J	38.02 J	7.36	17.65
3/9/2012	7011	3/9/2012	7011-dup	Methane	U	U	0	0.00
3/16/2012	7034	3/16/2012	7034-dup	Hydrogen	378.74	393.64	-14.9	3.86
3/16/2012	7034	3/16/2012	7034-dup	Methane	U	U	0	0.00
4/9/2012	7084	4/9/2012	7084-dup	Hydrogen	29 J	36.48 J	-7.48	22.85
4/9/2012	7084	4/9/2012	7084-dup	Methane	U	U	0	0.00
4/13/2012	7104	4/13/2012	7104-dup	Hydrogen	168.24	152.32	15.92	9.93
4/13/2012	7104	4/13/2012	7104-dup	Methane	U	U	0	0.00
5/4/2012	7162	5/4/2012	7162-dup	Hydrogen	32.72 J	36.24 J	-3.52	10.21
5/4/2012	7162	5/4/2012	7162-dup	Methane	U	U	0	0.00
5/15/2012	7182	5/15/2012	7182-dup	Hydrogen	217.16	217.56	-0.4	0.18
5/15/2012	7182	5/15/2012	7182-dup	Methane	U	U	0	0.00
6/8/2012	7235	6/8/2012	7235-dup	Hydrogen	34.3 J	32.88 J	1.42	4.23
6/8/2012	7235	6/8/2012	7235-dup	Methane	U	U	0	0.00
6/18/2012	7270	6/18/2012	7270-dup	Hydrogen	466.46	455.8	10.66	2.31
6/18/2012	7270	6/18/2012	7270-dup	Methane	U	U	0	0.00

Notes:

J = Estimated value; below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above the MDL.
* Technical acceptance criteria for lab duplicate is ≤25 RPD, which is only applicable if one or both values are not flagged "U" or "J."

Relative Percent Difference (RPD)
RPD = ABS (A-B) / [(A+B)/2] x 100 ABS = Absolute value of a number

Attachment 7 – QA/QC Results from Analysis of Hydrogen and Methane Monitoring Samples

Field Precision

Location	Original Sample Date	Original Sample ID	Duplicate Sample Date	Duplicate Sample ID	Compound	Original (ppmv)	Duplicate (ppmv)	Difference	RPD *
P3R1E	1/10/2012	6869	1/10/2012	6870	Hydrogen	50.88 J	35.2 J	15.68	36.43
P3R1E	1/10/2012	6869	1/10/2012	6870	Methane	U	U	0	0.00
P3R1E	2/16/2012	6972	2/16/2012	6973	Hydrogen	U	U	0	0.00
P3R1E	2/16/2012	6972	2/16/2012	6973	Methane	U	U	0	0.00
P3R1E	3/6/2012	7022	3/6/2012	7023	Hydrogen	32.8 J	37 J	-4.2	12.03
P3R1E	3/6/2012	7022	3/6/2012	7023	Methane	U	U	0	0.00
P3R1E	4/3/2012	7095	4/3/2012	7096	Hydrogen	U	U	0	0.00
P3R1E	4/3/2012	7095	4/3/2012	7096	Methane	U	U	0	0.00
P3R1E	5/1/2012	7173	5/1/2012	7174	Hydrogen	31.26 J	41.1 J	-9.84	27.20
P3R1E	5/1/2012	7173	5/1/2012	7174	Methane	U	U	0	0.00
P3R1E	6/5/2012	7246	6/5/2012	7247	Hydrogen	U	U	0	0.00
P3R1E	6/5/2012	7246	6/5/2012	7247	Methane	U	U	0	0.00
P4R1E	1/17/2012	6897	1/17/2012	6898	Hydrogen	501.8	474.08	27.72	5.68
P4R1E	1/17/2012	6897	1/17/2012	6898	Methane	U	U	0	0.00
P4R1E	2/7/2012	6948	2/7/2012	6949	Hydrogen	414.88	382.66	32.22	8.08
P4R1E	2/7/2012	6948	2/7/2012	6949	Methane	U	U	0	0.00
P4R1E	3/13/2012	7049	3/13/2012	7050	Hydrogen	376.52	369.04	7.48	2.01
P4R1E	3/13/2012	7049	3/13/2012	7050	Methane	U	U	0	0.00
P4R1E	4/10/2012	7119	4/10/2012	7120	Hydrogen	322.28	304.6	17.68	5.64
P4R1E	4/10/2012	7119	4/10/2012	7120	Methane	U	U	0	0.00
P4R1E	5/9/2012	7197	5/9/2012	7198	Hydrogen	278.46	247.98	30.48	11.58
P4R1E	5/9/2012	7197	5/9/2012	7198	Methane	U	U	0	0.00
P4R1E	6/11/2012	7276	6/11/2012	7277	Hydrogen	219.08	186.34	32.74	16.15
P4R1E	6/11/2012	7276	6/11/2012	7277	Methane	U	U	0	0.00

Notes:

J = Estimated value; below method reporting limits (MRL), but above method detection limits (MDL).
U = Compound not detected above the MDL.
* Technical acceptance criteria for field duplicate is ≤35 RPD, which is only applicable if one or both values are not flagged "U" or "J."

Relative Percent Difference (RPD)
RPD = ABS (A-B) / [(A+B)/2] x 100 ABS = Absolute value of a number

DOE/CAO-95-1121

TRANSURANIC WASTE BASELINE INVENTORY REPORT

(REVISION 3)

June 1996

NOTICE TO READERS

This document, Revision 3 of the Transuranic Waste Baseline Inventory Report (TWBIR), has been prepared to document the transuranic (TRU) waste inventory data to be used in the Sandia National Laboratories/New Mexico (SNL/NM) calculations for the Waste Isolation Pilot Plant's (WIPP's) performance assessment (PA). The TWBIR Revision 3, is comprised of previously published information found in Revision 2 of the TWBIR and supplemented with information and data that were specifically requested by the U.S. Department of Energy (DOE) Carlsbad Area Office (CAO) for the SNL/NM PA calculations.

The data contained in this document will also be used as the inventory basis for the WIPP Compliance Certification Application (CCA) to be submitted to the U.S. Environmental Protection Agency. The site information requested in the January 1996 data call has not been included in Revision 3. Future editions of the TWBIR will be identified by the year of data origin.

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ACRONYMS AND ABBREVIATIONS

AE	Argonne National Laboratory-East site identifier
AL	Ames Laboratory site identifier
AM	ARCO Medical Products Company site identifier
AW	ANL-W site identifier
BC	Battelle Columbus Laboratory site identifier
BT	Bettis Atomic Power Laboratory site identifier
C&C Agreement	Agreement for Consultation and Cooperation between the Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant
CAO	Carlsbad Area Office
CCA	Compliance Certification Application
CFR	Code of Federal Regulations
CH	contact-handled
CY	calendar year
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ER	environmental restoration
ET	Energy Technology Engineering Center site identifier
FFCAct	Federal Facilities Compliance Act
IDB	Integrated Data Base
IN	Idaho National Engineering Laboratory site identifier
IT	Inhalation Toxicology Research Institute site identifier
KA	Knolls Atomic Power Laboratory-Schenectady site identifier
kg	kilograms
LA	Los Alamos National Laboratory site identifier
LANL	Los Alamos National Laboratory
LB	Lawrence Berkeley Laboratory site identifier
LL	Lawrence Livermore National Laboratory site identifier
LWA	Land Withdrawal Act
MC	U.S. Army Material Command
MD	Mound Plant site identifier
m^3	cubic meters
mrem	millirem
MU	University of Missouri Research Reactor site identifier
NT	Nevada Test Site site identifier
OR	Oak Ridge National Laboratory site identifier
ORIGEN2	Oak Ridge Isotope Generation and Depletion Code
ORNL	Oak Ridge National Laboratory
PA	performance assessment (in text only)
PA	Paducah Gaseous Diffusion Plant site identifier (in waste profiles only)
PCB	polychlorinated biphenyls
PX	Pantex site identifier
RCRA	Resource Conservation and Recovery Act
RF	Rocky Flats Environmental Technology Site site identifier
RFETS	Rocky Flats Environmental Technology Site

RH	remote-handled
RL	Hanford (Richland) site identifier
SA	Sandia National Laboratories/New Mexico site identifier
SNL/NM	Sandia National Laboratories/New Mexico
SR	Savannah River Site site identifier
SRS	Savannah River Site
TB	Teledyne Brown Engineering
TOC	total organic carbon
TRU	transuranic
TWBIR	Transuranic Waste Baseline Inventory Report
WAC	waste acceptance criteria
WIPP	Waste Isolation Pilot Plant
WMC	waste matrix code
WMP	waste material parameter
WV	West Valley Demonstration Project site identifier

EXECUTIVE SUMMARY

The *Transuranic Waste Baseline Inventory Report* (TWBIR) establishes a methodology for grouping wastes of similar physical and chemical properties from across the U.S. Department of Energy (DOE) transuranic (TRU) waste system into a series of "waste profiles" that can be used as the basis for waste form discussions with regulatory agencies.

The purpose of Revisions 0 and 1 of this report was to provide data to be included in the Sandia National Laboratories/New Mexico (SNL/NM) performance assessment (PA) processes for the Waste Isolation Pilot Plant (WIPP). Revision 2 of the document expanded the original purpose and was also intended to support the WIPP Land Withdrawal Act (LWA) requirement for providing the total DOE TRU waste inventory. The document included a chapter and an appendix that discussed the total DOE TRU waste inventory, including nondefense, commercial, polychlorinated biphenyls (PCB)-contaminated, and buried (predominately pre-1970) TRU wastes that are not planned to be disposed of at WIPP.

Revision 3 of the TWBIR is based on the TWBIR Revision 2 data which are supplemented by data in several memoranda issued during early calendar year (CY) 1996. These memoranda summarize additional data requested by the U. S. Department of Energy/Carlsbad Area Office (DOE/CAO) to support the SNL/NM PA modeling. The primary purpose of Revision 3 is to provide the summary data from TWBIR Revision 2 and the supplemental information used by SNL/NM in the development of the Compliance Certification Application (CCA) to be delivered to the Environmental Protection Agency (EPA), and to support the LWA (Public Law, 1992b). The supplemental information was generated from specific data requests to the TRU waste sites since the publication of Revision 2. The supplemental data discussed in detail in Chapter 3 and Appendices A and B are listed below:

- Radionuclide data in support of the Compliance Certification Application.
- Estimate of complexing agents in TRU solidified waste forms scheduled for disposal in WIPP.
- Estimate for SNL/NM PA calculations of nitrate, sulfate, and phosphate content in transuranic solidified wastes destined for disposal in WIPP.
- Estimate of cement content in TRU solidified waste forms scheduled for disposal in WIPP.

Revision 2 of the TWBIR included both the TRU waste that is allowed to be disposed of in WIPP and the DOE TRU waste that is not currently allowed to be disposed of in WIPP (Public Law, 1992b). Because the primary purpose of this Revision 3 TWBIR is to support the CCA and PA, it includes only the DOE TRU waste that is currently allowed to be disposed of in WIPP.

Revision 3 of the TWBIR is different from previous revisions in that it provides the TRU waste inventory information developed for Revision 2 along with supplemental data. It is necessary for the reader to be familiar with Revision 2 of the TWBIR to understand this TWBIR Revision 3 document. Much of the TWBIR Revision 2 information is referenced, rather than repeated, in this document, resulting in an abbreviated document. Revision 3 of the TWBIR consists of one volume having five chapters and four appendices. There is not a new electronic database for

TWBIR Revision 3 because the data in the Revision 2 database are unchanged; therefore new database diskettes are not being published with this document.

The WIPP anticipated (stored and projected) inventory of TRU waste is defined as the sum of retrievably stored waste plus currently projected TRU waste volumes. Current projections do not include waste generated as a result of future environmental restoration (ER) and decontamination and decommissioning (D&D) activities and have only been developed over a 25 year period, consequently the anticipated inventory for CH-TRU waste is not sufficient to fill the maximum CH-TRU disposal inventory for WIPP (calculated to be approximately 168,500 cubic meters or 5,950,000 cubic feet). Scaling has been developed as a means for SNL/NM to model the impacts of a full repository. Scaling has not been applied to the RH-TRU inventory since the sites have reported sufficient RH-TRU waste to fill the RH-TRU disposal inventory (approximately 7,080 cubic meters or 250,000 cubic feet).

The TWBIR also estimates the WIPP disposal inventory in terms of 12 waste material parameters and additional packaging materials that have been identified by SNL/NM as necessary for PA. The 12 waste material parameters and additional packaging materials are constituents of TRU waste and are input parameters for one or more PA models or are required to adequately describe the waste form.

The 12 waste material parameters and additional packaging materials are listed below:

Waste Material Parameters
- Iron-base metal/alloys
- Aluminum-base metal/alloys
- Other metal/alloys
- Other inorganic materials
- Vitrified
- Cellulosics
- Rubber
- Plastics
- Solidified inorganic material
- Solidified organic material
- Cement (solidified)
- Soils

Packaging Materials
- Steel
- Plastic
- Lead (for RH-TRU waste only)

The waste material parameters are expressed on a weight/volume (kilograms per cubic meter) basis. The occurrence of more than one waste material parameter at the maximum value within a waste stream is highly unlikely. If required by PA calculations, the sampling statistics must be controlled so that several waste material parameters do not get sampled all at their maximum value (weight/volume), thereby exceeding the average weight/volume.

Attached to this Executive Summary are several summary tables from the body of the TWBIR Revision 3 which are frequently requested by TWBIR users:

- Table ES-1. WIPP CH-TRU Waste Material Parameter Disposal Inventory
- Table ES-2. WIPP RH-TRU Waste Material Parameter Disposal Inventory
- Table ES-3. WIPP CH-TRU Waste Anticipated Inventory by Site
- Table ES-4. WIPP RH-TRU Waste Anticipated Inventory by Site
- Table ES-5. Summary Radionuclide Inventory

Table ES-1. WIPP CH-TRU Waste Material Parameter Disposal Inventory*

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	2.6E+03	1.7E+02	0.0E+00
Aluminum Base Metal/Alloys	8.0E+02	1.8E+01	0.0E+00
Other Metal/Alloys	1.6E+03	6.7E+01	0.0E+00
Other Inorganic Materials	1.4E+03	3.1E+01	0.0E+00
Vitrified	2.5E+03	5.5E+01	0.0E+00
Cellulosics	9.6E+02	5.4E+01	0.0E+00
Rubber	6.3E+02	1.0E+01	0.0E+00
Plastics	8.9E+02	3.4E+01	0.0E+00
Solidified Inorganic Material	2.2E+03	5.4E+01	0.0E+00
Solidified Organic Material	1.4E+03	5.6E+00	0.0E+00
Cement (Solidified)	1.2E+03	5.0E+01	0.0E+00
Soils	1.6E+03	4.4E+01	0.0E+00
Container Materials - Kg/m3			
Steel		139	
Plastic/ Liners		26	

*This table is identical to Table ES-1 of TWBIR Revision 2, page ES-4 (DOE, 1995c).

Table ES-2. WIPP RH-TRU Waste Material Parameter Disposal Inventory*

Waste Material Parameters (Kg/m3	Maximum	Average	Minimum
Iron Base Metal/Alloys	1.7E+03	1.0E+02	0.0E+00
Aluminum Base Metal/Alloys	1.7E+02	7.1E+00	0.0E+00
Other Metal/Alloys	9.1E+02	2.5E+02	0.0E+00
Other Inorganic Materials	2.0E+03	6.4E+01	0.0E+00
Vitrified	2.5E+03	4.7E+00	0.0E+00
Cellulosics	5.7E+02	1.7E+01	0.0E+00
Rubber	4.4E+02	3.3E+00	0.0E+00
Plastics	6.2E+02	1.5E+01	0.0E+00
Solidified Inorganic Material	6.1E+02	2.2E+01	0.0E+00
Solidified Organic Material	8.1E+02	9.3E-01	0.0E+00
Cement (Solidified)	5.8E+02	1.9E+01	0.0E+00
Soils	2.4E+01	1.0E+00	0.0E+00

Container Materials - Kg/m3	
Steel	446
Plastic/Liners	3.1
Lead	465
Steel Plug	2145

*This table is identical to Table ES-2 of TWBIR Revision 2, page ES-5 (DOE, 1995c).

Table ES-3. WIPP CH-TRU Waste Anticipated Inventory By Site*

(Cubic Meters)

Storage/Generator Site	Stored Volumes	Projected Volumes	Anticipated Volumes
Ames Laboratory - Iowa State Univ.	0.0E+00	4.2E-01	4.2E-01
Argonne National Laboratory - East	1.1E+01	1.3E+02	1.4E+02
Argonne National Laboratory - West	6.5E+00	7.4E+02	7.5E+02
Bettis Atomic Power Laboratory	0.0E+00	1.2E+02	1.2E+02
Energy Technology Engineering Center	1.7E+00	0.0E+00	1.7E+00
Hanford (Richland) Site	1.2E+04	3.3E+04	4.6E+04
Idaho National Engineering Laboratory	2.9E+04	0.0E+00	2.9E+04
Lawrence Livermore National Laboratory	2.3E+02	7.1E+02	9.4E+02
Los Alamos National Laboratory	1.1E+04	7.4E+03	1.8E+04
Mound Plant	2.7E+02	0.0E+00	2.7E+02
Nevada Test Site	6.2E+02	9.0E+00	6.3E+02
Oak Ridge National Laboratory	1.3E+03	2.6E+02	1.6E+03
Paducah Gaseous Diffusion Plant	0.0E+00	1.9E+00	1.9E+00
Pantex Plant	6.2E-01	0.0E+00	6.2E-01
Rocky Flats Environmental Technology Site	7.1E+02	4.4E+03	5.1E+03
Sandia National Laboratory - Albuquerque	6.7E+00	7.5E+00	1.4E+01
Savannah River Site	2.9E+03	6.8E+03	9.6E+03
Teledyne Brown Engineering	2.1E-01	0.0E+00	2.1E-01
U.S. Army Material Command	2.5E+00	0.0E+00	2.5E+00
University of Missouri Research Reactor	2.1E-01	8.3E-01	1.0E+00
Total CH Volumes	**5.8E+04**	**5.4E+04**	**1.1E+05**

*This table is identical to Table ES-3 of TWBIR Revision 2, page ES-6 (DOE, 1995c).

Table ES-4. WIPP RH-TRU Waste Anticipated Inventory By Site*

(Cubic Meters)

Storage/Generator Site	Stored Volumes	Projected Volumes	Anticipated Volumes
Argonne National Laboratory - West	1.9E+01	1.3E+03	1.3E+03
Battelle Columbus Laboratories	5.8E+02	0.0E+00	5.8E+02
Bettis Atomic Power Laboratory	0.0E+00	6.7E+00	6.7E+00
Energy Technology Engineering Center	8.9E-01	0.0E+00	8.9E-01
Hanford (Richland) Site	2.0E+02	2.2E+04	2.2E+04
Idaho National Engineering Laboratory	2.2E+02	0.0E+00	2.2E+02
Los Alamos National Laboratory	9.4E+01	9.9E+01	1.9E+02
Oak Ridge National Laboratory	2.5E+03	4.5E+02	2.9E+03
Total RH Volumes	**3.6E+03**	**2.3E+04**	**2.7E+04**
Total TRU Waste Volumes	**6.2E+04**	**7.7E+04**	**1.4E+05**

*This table is identical to Table ES-4 of TWBIR Revision 2, page ES-7 (DOE, 1995c).

Table ES-5. Summary Radionuclide Inventory[1*]

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)
Am241	2.62E+00	8.42E-01
Ba137m	4.53E-02	2.89E+01
Cm244	1.87E-01	4.45E-02
Co60	3.83E-04	1.47E+00
Cs137	4.78E-02	3.05E+01
Pu238	1.55E+01	2.05E-01
Pu239	4.66E+00	1.45E+00
Pu240	1.25E+00	7.15E-01
Pu241	1.37E+01	2.00E+01
Sr90	4.07E-02	2.95E+01
Y90	4.07E-02	2.95E+01

[1]Summary shows the ten radionuclides with the highest concentration in curies per cubic meter for both CH-TRU and RH-TRU waste. The list includes eleven radionuclides because the ten radionuclides with the highest concentration are different for CH-TRU and RH-TRU waste.

*This table is an update of Table ES-7, of TWBIR Revision 2, page ES-10 (DOE, 1995c).

1. INTRODUCTION

1.1 BACKGROUND

Transuranic (TRU) waste is defined as waste that is contaminated with alpha-emitting radionuclides with an atomic number greater than 92, with half-lives greater than 20 years, and concentrations of TRU isotopes greater than 100 nanocuries per gram of waste at the time of assay (DOE, 1988). TRU wastes are classified as either contact-handled (CH) waste or remote-handled (RH) waste, depending on the dose rate at the surface of the waste container. CH-TRU wastes are packaged TRU wastes with an external surface dose rate less than 200 millirems (mrem) per hour, while RH-TRU wastes are packaged TRU wastes with an external surface dose rate of 200 mrem or greater per hour (Public Law, 1992b). Unless otherwise indicated, for the purposes of this document, all references to TRU waste include TRU waste and mixed TRU waste (waste that contains both radioactive and hazardous components, as defined by the Atomic Energy Act [Public Law, 1954] and the Resource Conservation and Recovery Act [RCRA] as codified in Title 40 Code of Federal Regulations [CFR] Part 261.3 [EPA, 1980]).

The Waste Isolation Pilot Plant (WIPP) is a TRU waste management facility operated by the U.S. Department of Energy (DOE). The WIPP is currently identified as the permanent disposal site for TRU wastes (in retrievable storage or projected) generated at various DOE sites from defense-related activities of the United States government. The WIPP is scheduled to receive and dispose of TRU defense wastes from 8 major and additional minor DOE TRU waste sites (see Figure 1-1).

The DOE is committed to demonstrating compliance with all applicable regulations prior to permanent disposal of TRU defense wastes in the WIPP repository. These regulations are the environmental standards for management and disposal of TRU defense wastes as mandated in 40 CFR Part 191 (EPA, 1993) and Part 194 (EPA, 1996), and the RCRA regulations. Compliance demonstration through Sandia National Laboratories/New Mexico (SNL/NM) performance assessment (PA) calculations will be based on the inventory of existing and currently projected waste streams compiled in this document and the *Transuranic Waste Baseline Inventory Report* (TWBIR) Revision 2, as reported by the DOE TRU waste sites. Revision 3 of the TWBIR is different from previous revisions in that it provides the TRU waste inventory information developed for Revision 2 along with supplemental data. It is necessary for the reader to be familiar with Revision 2 of the TWBIR (DOE, 1995c) to understand TWBIR Revision 3.

1.2 PURPOSE

The purpose of the TWBIR is to document the total inventory of DOE TRU waste as defined by the DOE TRU waste sites. This document is based on the TWBIR Revision 2 data supplemented by several memoranda prepared during early calendar year (CY) 1996 that summarize additional data requested by the U. S. Department of Energy/Carlsbad Area Office (DOE/CAO) to support the SNL/NM PA modeling. The primary purpose of this document is to provide the summary data from TWBIR Revision 2 and the supplemental information used by SNL/NM for the development of the Compliance Certification Application (CCA) to be delivered to the Environmental Protection Agency (EPA), and to support the Land Withdrawal Act (LWA) (Public Law, 1992b). The supplemental information was generated from specific data requests

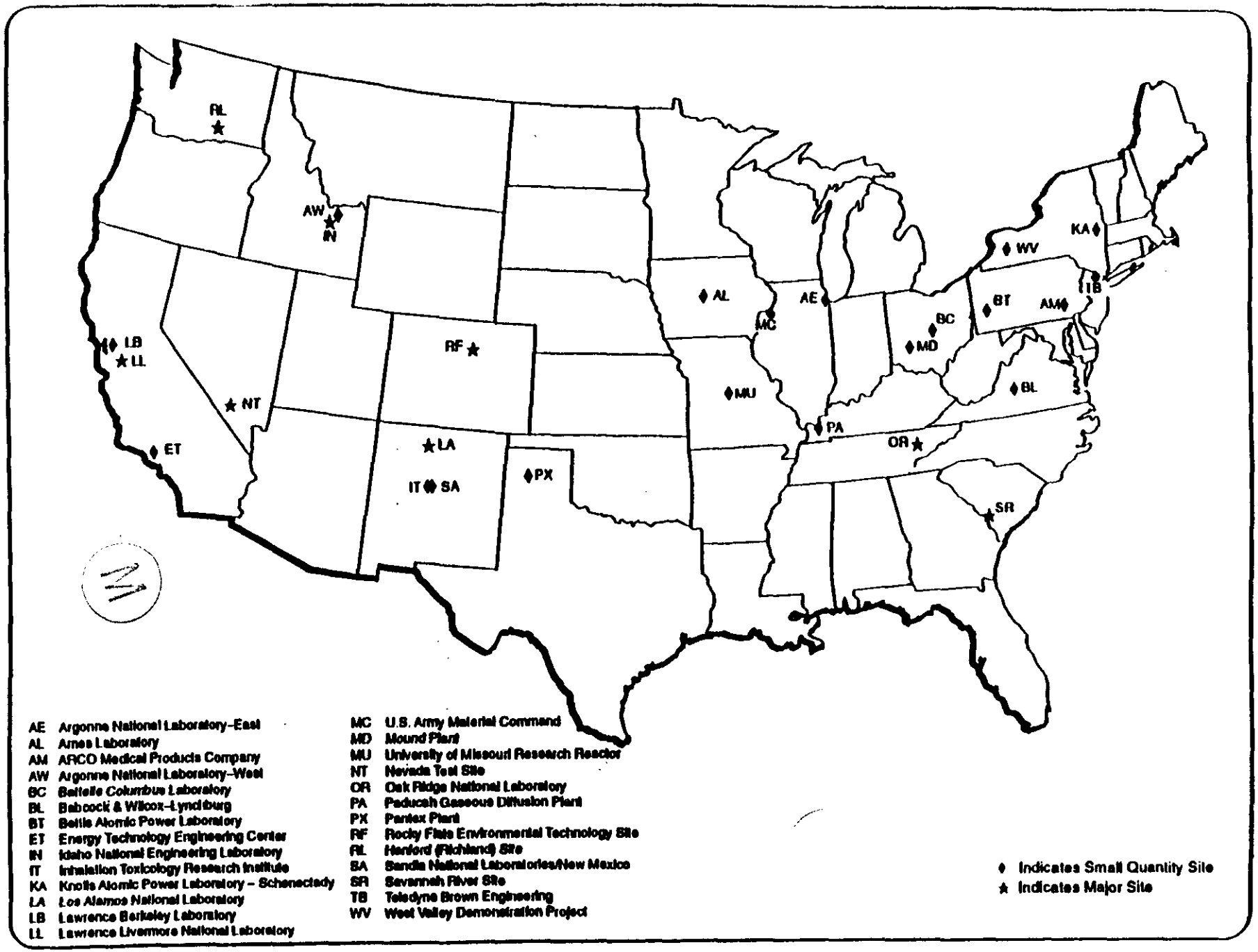

Figure 1-1. U.S. DOE Transuranic Waste Sites*

*This figure is identical to Figure 1-1 in TWBIR Revision 2, page 1-2 (DOE, 1995c).

to the TRU waste sites since the publication of Revision 2.

Revision 2 of the TWBIR included both the TRU waste that is allowed to be disposed of in WIPP and the DOE TRU waste that is not currently allowed to be disposed of in WIPP (Public Law, 1992b). Because the primary purpose of this Revision 3 TWBIR is to support the CCA and PA, it includes only the DOE TRU waste that is currently identified by the sites as being allowed to be disposed of in WIPP.

The TWBIR has been developed from the best available information and acceptable knowledge provided by the DOE TRU waste sites. In support of PA, the TWBIR describes a process for grouping individual waste streams with similar physical and chemical properties into waste profiles, based on their waste matrix code (WMC) (DOE, 1995a) assigned by the DOE TRU waste sites. The individual waste streams are also evaluated to estimate the occurrence and quantities of nonradioactive waste material parameters (WMPs) listed in Table 1-1 (e.g., cellulosics, plastics, iron-base metal/alloys, etc.) that have been identified by SNL/NM as being potentially important to the performance of the WIPP repository. Waste profiles with similar WMCs are then combined across the DOE TRU waste system to provide estimated total volumes and total WMPs.

1.3 WASTE INVENTORY TERMINOLOGY

All terminology in this document is unchanged from the TWBIR Revision 2. A summary of terminology used in this document is provided in this section and in Chapter 5 (Glossary). A list of acronyms and abbreviations used are provided in the front of the document.

Stored Inventory – The part of the TRU inventory currently in retrievable storage at the time of the TWBIR Revision 2 data call for inventory information is known as "stored inventory" in this document. Retrievably stored waste includes waste stored since approximately 1970 in buildings or in berms with earthen cover and does not include any waste that was buried (predominately prior to 1970) (DOE, 1990).

As-Generated Waste – The chemical and physical status of waste when it is generated. The "as-generated" term applies to both stored and projected waste.

Projected Inventory – The part of the TRU waste inventory that has not been generated but is currently estimated to be generated at some time in the future by the TRU waste sites is known as "projected inventory."

Anticipated Inventory – For the TWBIR, this is the sum of the stored and projected inventories, calculated as:

Stored Inventory	+	Projected Inventory	=	Anticipated Inventory

Scaling – The process for adjusting, if needed, the projected inventory to the design limit (disposal inventory) of the WIPP repository is called "scaling."

Stored Inventory + Projected Inventory (scaled as needed) = Disposal Inventory

TABLE 1-1. TECHNICAL DATA NEEDS FOR PERFORMANCE ASSESSMENT WASTE MATERIAL PARAMETERS

Waste Material Parameter	Input Variable in Current PA Models	
	Gas Generation	Mechanical Characteristics
Iron-base metal/alloys	YES	YES
Aluminum-base metal/alloys	-	YES
Other metal/alloys	-	YES
Other inorganic materials	-	YES
Vitrified[1]	-	YES
Cellulosics	YES	YES
Rubber	YES[2]	YES
Plastics	YES[2]	YES
Solidified inorganic material	-	YES
Solidified organic material	-	YES
Cement (solidified)[3,4]	YES	-
Soils[5]	-	YES

[1] Waste material parameter corresponding to treatment, identified by some sites that plan to treat waste in the future.
[2] Only one-half of materials assumed to generate gas.
[3] Percentage of material to generate gas is unknown at the present time.
[4] Information on this waste material parameter is needed for non-PA scoping calculations for assessment of its importance.
[5] May impact colloids.

Disposal Inventory – The inventory volume defined for WIPP emplacement to be used for PA calculations is the "disposal inventory." The LWA defines the total amount of TRU waste allowed for disposal in the WIPP as approximately 175,600 cubic meters (6,200,000 cubic feet) (Public Law, 1992b). The "Agreement for Consultation and Cooperation" (C&C Agreement) limits the RH-TRU inventory to approximately 7,080 cubic meters (250,000 cubic feet) (DOE and State of New Mexico, 1981). Therefore by difference, the CH-TRU inventory will be limited to approximately 168,500 cubic meters (5,950,000 cubic feet) if all of the RH-TRU allowance is filled.

Waste Matrix Code (WMC) - The WMCs were developed by DOE in response to the Federal Facilities Compliance Act (FFCAct) (Public Law, 1992a) as a methodology to aid in categorizing mixed waste streams in the DOE system into a series of five-digit alphanumeric codes (e.g., S3100; Inorganic Process Residues) that represent different physical/chemical matrices (DOE, 1995a).

Final Waste Form – Final waste form of a waste stream refers to the expected physical and chemical form of that stream once the waste has been processed, treated, or repackaged (if necessary) and is ready for disposal. This consists of a series of WMCs that are grouped together. The use of the final waste form helps to group waste streams that are expected to have similar physical and chemical properties at the time of disposal. The final waste form applies to both stored and projected waste. An example of combining three waste streams which either contain particulates or are cemented particulate waste is presented below:

WMC S3100 (inorganic process residues)
WMC S3110 (inorganic particulates)
WMC S3150 (solidified process residues)
] Solidified Inorganics

Particulate waste may be immobilized prior to shipment to WIPP. If so, all three of these waste streams would be the same basic waste form when emplaced in WIPP and have similar physical and chemical properties. The final waste form for this example is solidified inorganics. Table 1-2 presents all anticipated WMCs for TRU waste and indicates the final waste form typically assigned to each WMC for the TWBIR. There are 11 final waste forms used in this TWBIR. The last two rows in Table 1-2, Excluded and Unknown Waste Streams, group WMCs that will not be accepted at WIPP until additional characterization and/or processing occurs to meet the WIPP Waste Acceptance Criteria (WAC) (DOE, 1996).

Waste Material Parameter – This is one (or more) nonradioactive waste constituent(s) that occurs in a TRU waste stream that is an input parameter into one or more PA models or is required to adequately describe the waste form. The waste material parameters and additional packaging materials that are reported in weight/volume (kg/m^3) and included in the TWBIR are:

WASTE MATERIAL PARAMETERS
- Iron-base metal/alloys
- Aluminum-base metal/alloys
- Other metal/alloys
- Other inorganic materials
- Vitrified
- Cellulosics
- Rubber
- Plastics
- Solidified inorganic material
- Solidified organic material
- Cement (solidified)
- Soils

PACKAGING MATERIALS
- Steel
- Plastic
- Lead (for RH-TRU waste only)

WIPP Waste Profile – The WIPP waste profile represents a summary of TRU wastes at all DOE TRU waste sites that have an identical final waste form.

TABLE 1-2. WASTE MATRIX CODES AND THEIR ANTICIPATED FINAL WASTE FORM

Final Waste Form	Waste Matrix Codes
Solidified Inorganics	L1000[1], L1100[1], L1110[1], L1120[1], L1130[1], L1140[1], L1190[1],1200[1], L1210[1], L1220[1], L1230[1], L1240[1], L1290[1], S3000[2], S3100[3], S3110[3], S3111[3], S3112[3], S3113[3], S3115[3], S3118[3], S3119[3], S3120[1], S3121[1], S3122[1], S3123[1], S3124[1], S3125[1], S3129[1], S3130[1 or 3], S3131[1 or 3], S3132[1 or 3], S3139[1 or 3], S3144[3], S3150, S3160[3], S3190[1 or 3], S3900[2], X6000[4], X6200[5], X6300[6], X6400[5], X6900[4], X7300[3], X7500[8], X7510[8], X7520[8], X7530[8], X7590[8], L9000[2], Z1110, Z1190
Salt	S3000[2], S3140, S3141, S3142, S3143, S3149, S3900[2], L9000[2]
Solidified Organics	L2000[1], L2100[1], L2110[1], L2120[1], L2190[1], L2200[1], L2210[1], L2220[1], L2290[1], L2900[1], S3000[2], S3114[3], S3200[3], S3210[3], S3211[3], S3212[3], S3219[3], S3220[1], S3221[1], S3222[1], S3223[1], S3229[1], S3230[3], S3290[1 or 3], S3900[2], S5340[3], X6000[4], X6100[5], X6190[4], X6900[4], L9000[2], Z1110, Z1190
Soils	S4000, S4100, S4200, S4300, S4900,
Uncategorized Metal (Metal Waste Other Than Lead and/or Cadmium)	S3116, S5000[9], S5100[7], S5110, S5111, S5119, S5190, X6200, X7000[10], X7290, X7400[11], X7430, X7490[11], X7520[8], Z1140, Z1190, Z2100[10]
Lead/Cadmium Metal	S5000[9], S5100[7], S5110, S5112, S5113, S5119, S5190, X6220[8], X7000[10], X7200, X7210, X7211, X7212, X7219, X7220, X7290, X7400[11], X7410[11], X7420[11], X7490[11], Z2100[10]
Inorganic Non-Metal	S3117, S3118, S3160, S5000[9], S5100[7], S5120, S5121, S5122, S5123, S5124, S5125, S5126, S5129, S5190, Z1120, Z1150, Z1190
Combustible	S5000[9], S5300, S5310, S5311, S5312, S5313, S5319, S5320, S5330, S5390, Z1130, Z1190, Z1200
Graphite	S5000[9], S5126
Heterogeneous	S5000[9], S5100[9], S5400, S5420, S5440, S5450, S5460, S5490, X7520[8], Z2900
Filter	S5000[9], S5410
Excluded Waste Streams[12]	X7000, X7100, X7600, X7700
Unknown[13]	S5190, X7900, L9000, S9000, Z9000, U9999

TABLE 1-2. WASTE MATRIX CODES AND THEIR ANTICIPATED FINAL WASTE FORM (CONTINUED)

[1] Liquid waste streams are assumed to be solidified prior to being sent to WIPP.

[2] WMCs S3000, S3900, and L9000 are placed in "solidified inorganics," "salt," or "solidified organics," depending on the information provided by the TRU waste site.

[3] Particulate waste streams are assumed to be solidified prior to being sent to WIPP.

[4] WMCs X6000 and X6900 are placed in "solidified organics" or "solidified inorganics" depending on the information provided by the TRU waste site.

[5] Liquid lab pack waste is assumed to be solidified prior to being sent to WIPP.

[6] Solid lab packs are assumed to be solidified prior to being sent to WIPP.

[7] WMC S5100 is placed in "uncategorized metal," "lead-cadmium metal," or "inorganic non-metal" depending on the information provided by the site.

[8] Waste stream is assumed to be treated prior to being sent to WIPP.

[9] WMC S5000 is placed in "uncategorized metal," "lead/cadmium metal," "inorganic non-metal," "combustible," "graphite," "heterogeneous," or "filter," depending on the information provided by the site.

[10] WMC Z2100 is placed in "uncategorized metal" or "lead/cadmium metal" depending on the information provided by the site.

[11] WMCs X7400, X7410, X7420, and X7490 are assumed to be drained of liquid and contain only metal waste.

[12] These waste streams are excluded from disposal in WIPP at this time, e.g., PCB and elemental mercury.

[13] If adequate information is provided by the TRU waste site, these WMCs are changed. If there is not enough information, these waste streams remain as "unknown" and are excluded from disposal in WIPP until characterized.

1.4 METHODOLOGY FOR DEVELOPMENT OF DISPOSAL INVENTORY

Development of the WIPP TRU waste disposal inventory is accomplished by a series of steps starting with the individual waste stream profiles submitted by the TRU waste sites. These waste stream profiles are grouped together, based on similar physical and chemical properties, into common "WIPP waste profiles," which should facilitate discussions with regulatory agencies and stakeholders concerning the disposal waste inventory. The process of grouping similar waste streams is exemplified in Figure 1-2. The waste profiles also contain information on waste material parameters that could affect the performance of the WIPP repository and that may be direct inputs to the PA models.

The CH-TRU anticipated inventory consists of up to 11 overall CH-TRU WIPP final waste forms based on the physical and chemical properties of the waste streams. Because the volume of the CH-TRU anticipated inventory is not sufficient to fill the maximum calculated CH-TRU capacity of WIPP, scaling of the projected CH-TRU inventory is necessary to attain the maximum calculated WIPP CH-TRU disposal inventory of approximately 168,500 cubic meters (5.95 million cubic feet). The scaling factor for CH-TRU waste is computed as follows:

$$\frac{\text{maximum calculated CH-TRU inventory - stored CH-TRU inventory}}{\text{projected CH-TRU inventory}} = \text{CH-TRU scaling factor}$$

The WIPP disposal inventory is the inventory to be used in PA calculations. To calculate the disposal inventory by final waste form for CH-TRU waste, the **projected inventory** is multiplied by the scaling factor, added to the stored inventory for each final waste form, and summed together.

The RH-TRU anticipated inventory is greater than the WIPP C&C Agreement limit (DOE and State of New Mexico, 1981) of approximately 7,080 cubic meters. DOE will abide by the WIPP C&C Agreement for RH-TRU waste volumes and the LWA, which limits the curies of RH-TRU waste allowed in WIPP to 5.1 million curies (Public Law, 1992b). As stated earlier, one purpose of the TWBIR is to report the DOE TRU inventory in such a way that it will facilitate performance assessment by SNL/NM and support development of compliance applications to the appropriate regulatory agencies. Since this is not a WIPP load management document, the RH-TRU inventory has not been scaled back in this document to the regulatory limit. The RH-TRU inventory for WIPP will be averaged across all RH-TRU waste sites and reported as kilograms/cubic meter for the waste material parameters and curies/cubic meter for radionuclides.

1.5 DOCUMENT ORGANIZATION

The TWBIR Revision 3 is organized into chapters of text, figures, tables, and supporting appendices. The contents of remaining chapters in this document are summarized below:

- Chapter 2 provides a summary of the WIPP disposal inventory information previously presented in TWBIR Revision 2.
- Chapter 3 presents supplementary disposal inventory information.
- Chapter 4 provides the document references.

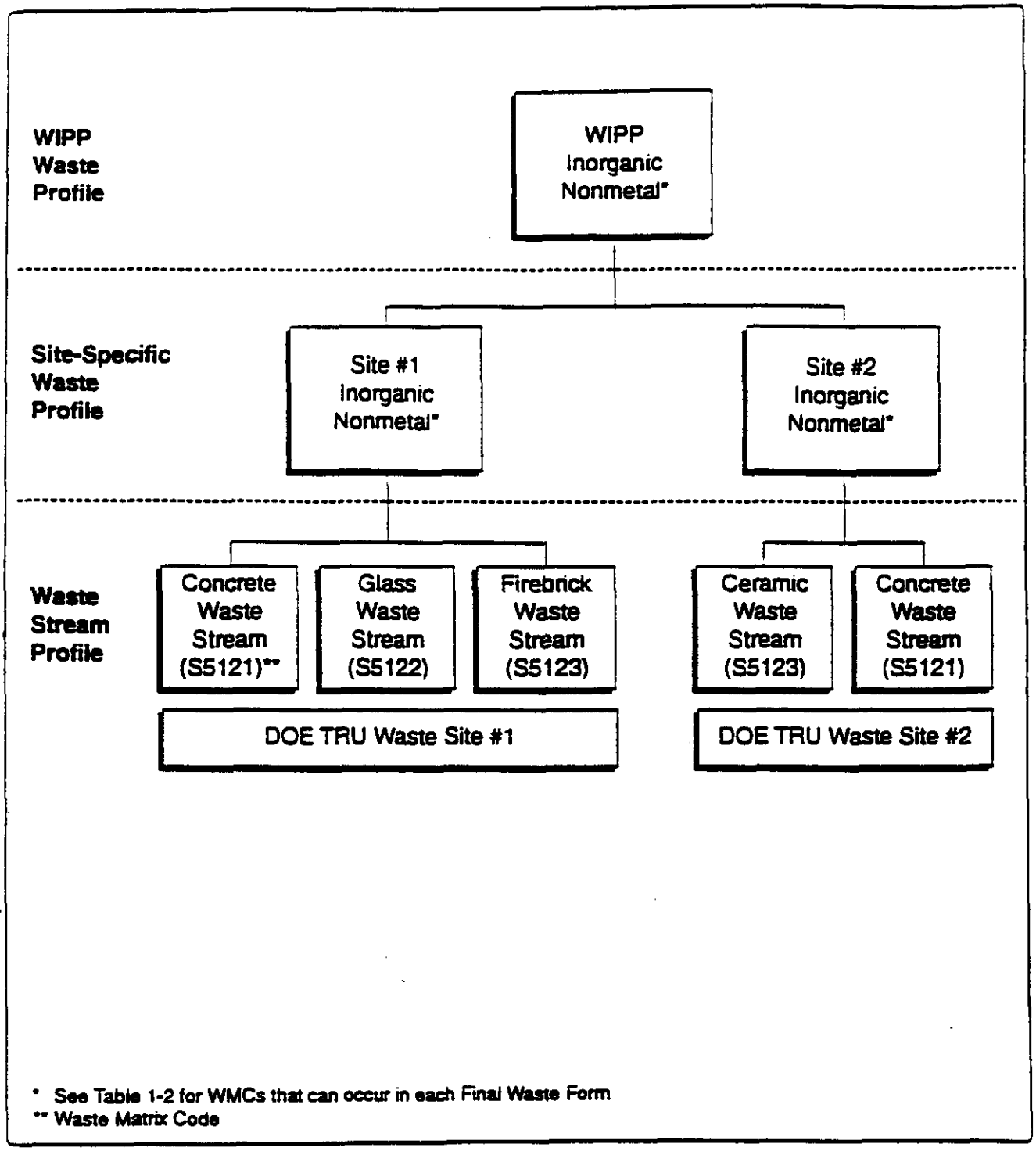

Figure 1-2. Schematic of Waste Stream Profile Methodology*

*This figure is identical to Figure 2-3 of TWBIR Revision 2, page 2-10 (DOE, 1995c).

- Chapter 5 provides a document glossary.
- Appendix A provides the SNL/NM memoranda requesting information to supplement the TWBIR Revision 2.
- Appendix B includes DOE and SNL/NM memoranda that provide information to supplement the TWBIR Revision 2.
- Appendix C provides the site-specific stored radionuclide inventories decayed to December 1995.
- Appendix D provides the correction received from SNL/NM for Cf-252 decayed inventory.

2. SUMMARY OF WIPP DISPOSAL INVENTORY INFORMATION

2.1 INTRODUCTION

The DOE TRU waste sites have assigned an overall final waste form to each waste stream based on the expected physical and chemical form of the waste after the sites process, treat, or repackage the waste (if necessary). Each site provides the stored and projected inventory for each waste stream. The TWBIR generates the WIPP TRU waste inventory by rolling-up the waste stream volumes that have the same final waste form within a site to generate site profiles (see TWBIR Revision 2 [DOE, 1995c] for waste stream and site-specific waste profiles). Then the site-level volumes with the same final waste form are rolled-up to generate the WIPP TRU waste inventory by final waste form (see TWBIR Revision 2 for detailed information on the roll-up methodology).

This chapter summarizes the WIPP-level information for the disposal inventory. The data provided in this chapter are identical to those provided in TWBIR Revision 2. These are the data used by SNL/NM in the WIPP performance assessment to demonstrate regulatory compliance. This chapter will include the following TWBIR Revision 2 information:

- WIPP disposal inventory volumes for each final waste form - taken from Table 3-1 (unchanged) in Section 3.2 of TWBIR Revision 2.
- WIPP disposal inventory waste material parameters - taken from Tables 3-2 and 3-3 (unchanged) in Section 3.3 of TWBIR Revision 2.
- Summary of WIPP anticipated inventory from each site - taken from Tables 4-1 and 4-2 (unchanged) in Chapter 4 of TWBIR Revision 2.

2.2 WIPP DISPOSAL INVENTORY VOLUMES FOR EACH FINAL WASTE FORM

The disposal inventory is defined by the LWA (Public Law, 1992b) and the WIPP C&C Agreement (DOE and the State of New Mexico, 1981) as follows: the maximum allowable WIPP capacity is approximately 175,600 cubic meters, of which RH-TRU disposal inventory is limited to approximately 7,080 cubic meters resulting in a calculated CH-TRU disposal inventory limit of approximately 168,500 cubic meters.

Using volumes for all the retrievably stored and projected defense TRU waste streams (including the mixed and nonmixed TRU waste volumes) a disposal inventory of TRU waste has been developed using the methodology described in Chapter 3 of Revision 2 of the TWBIR. This inventory is presented in Table 2-1 (by final waste forms) and depicts both the anticipated and disposal inventory volumes.

The anticipated CH-TRU inventory volumes are the sum of the stored and projected volumes. Scaling of the disposal inventory is for PA purposes to enable SNL/NM to model a capacity waste load based on currently anticipated profiles.

TABLE 2-1. TRANSURANIC WASTE DISPOSAL INVENTORY FOR WIPP*

Contact Handled Waste (Cubic Meters)

Final Waste Forms	Stored Volumes	Projected Volumes	Anticipated Volumes	WIPP Disposal Volumes
Combustible	5.8E+03	4.6E+03	1.0E+04	1.4E+04
Filter	2.2E+02	5.1E+02	7.3E+02	1.2E+03
Graphite	5.1E+02	4.8E+01	5.6E+02	6.0E+02
Heterogeneous	2.7E+04	1.3E+04	4.0E+04	5.1E+04
Inorganic Non-Metal	3.1E+03	9.4E+02	4.1E+03	4.9E+03
Lead/Cadmium Metal Waste	3.5E+01	3.3E+02	3.7E+02	6.6E+02
Salt Waste	2.1E+01	3.3E+02	3.5E+02	6.4E+02
Soils	4.1E+02	6.0E+03	6.4E+03	1.2E+04
Solidified Inorganics	9.6E+03	4.5E+03	1.4E+04	1.8E+04
Solidified Organics	9.1E+02	7.5E+01	9.8E+02	1.1E+03
Uncategorized Metal	1.1E+04	2.3E+04	3.4E+04	5.4E+04
Total CH Volumes	**5.8E+04**	**5.4E+04**	**1.1E+05**	**1.6E+05**
Remote Handled Waste				
Combustible	3.6E+01	4.9E+01	8.5E+01	
Heterogeneous	2.3E+03	5.5E+03	7.8E+03	
Inorganic Non-Metal	4.6E+01	2.1E+01	6.8E+01	
Lead/Cadmium Metal Waste	7.1E+00	6.7E+01	7.4E+01	
Solidified Inorganics	1.1E+03	2.3E+02	1.3E+03	
Solidified Organics	3.6E+00	0.0E+00	3.6E+00	
Uncategorized Metal	1.2E+02	1.7E+04	1.8E+04	
Total RH Volumes	**3.6E+03**	**2.3E+04**	**2.7E+04**	
Total TRU Waste Volumes	**6.2E+04**	**7.7E+04**	**1.4E+05**	**1.7E+05**

*This table is identical to Table 3-1 of TWBIR Revision 2, page 3-2 (DOE, 1995c).

Applying the formula given in Chapter 1:

$$\frac{1.685 \times 10^5 m^3 \text{ (CH-TRU disposal inventory)} - 5.8 \times 10^4 m^3 \text{ (stored inventory)}}{5.4 \times 10^4 m^3 \text{ (projected inventory)}} \approx 2.05 \text{ (scaling factor)}$$

- Multiply the CH-TRU waste **projected inventory volumes** by the scaling factor for all the final waste forms, and add the stored volumes (which results in the numbers in the "Disposal Inventory" column of Table 2-1).

The CH-TRU waste stream volume on a system-wide final waste form basis is increased by approximately 50 percent to account for the difference between the anticipated inventory and the maximum calculated WIPP CH-TRU disposal inventory.

The RH-TRU WIPP inventory has not been scaled. The RH-TRU anticipated inventory is greater than the amount of RH-TRU waste allowed in the WIPP by the C&C Agreement (DOE and the State of New Mexico, 1981). DOE is committed to abide by all agreements and laws regarding RH-TRU limitations. DOE and SNL/NM will evaluate this inventory to determine the disposal options for all DOE RH-TRU waste. This inventory has not been scaled back to the limit imposed by the C&C Agreement so that all available data are presented to DOE and SNL/NM to conduct modeling and other evaluations to determine the disposition of this waste.

2.3 ROLL-UP OF WIPP WASTE MATERIAL PARAMETERS BY FINAL WASTE FORM

The roll-ups of waste material parameters by final waste forms are developed from the volumes presented in the TWBIR Revision 2. The roll-ups by final waste forms require combining data from several waste streams. A weighted average value for the waste material parameters is calculated from the average densities provided by the TRU waste sites modified by the volume fractions and summed as follows:

$$\text{Average Density of waste material parameter} = \sum \text{Average Density}_i^{*} \times \frac{\text{(Volume TWBIR Stream}_i\text{)}}{\text{(Total Volume of Final Waste Form)}}$$

*where i is an index representing individual waste streams of the same final waste form

The minimum density is chosen as the smallest minimum density of a particular waste material parameter in the TWBIR Revision 2. The maximum density is chosen in a similar manner, except that the largest maximum density is chosen. Thus, the maximum and minimum values reported in Tables 2-2 and 2-3 are the absolute extreme values reported across the system, and in many cases they only apply to a very small volume of waste. If required, the user can use the data in the TWBIR Revision 2 database to calculate a "weighted average maximum" value to obtain a maximum value that may be more representative of the total inventory.

The waste material parameters that are inputs to the PA models are presented in Table 2-2 for CH-TRU waste and Table 2-3 for RH-TRU waste. These tables represent the waste material parameters for the WIPP disposal inventory.

2.4 SUMMARY OF WIPP ANTICIPATED INVENTORY FROM EACH SITE

Each WIPP waste stream from each TRU waste site is characterized in a waste stream profile in TWBIR Revision 2. Summary tables of CH-TRU and RH-TRU WIPP waste volumes by site are provided in Tables 2-4 and 2-5.

Table 2-2. WIPP CH-TRU Waste Material Parameter Disposal Inventory*

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	2.8E+03	1.7E+02	0.0E+00
Aluminum Base Metal/Alloys	8.0E+02	1.8E+01	0.0E+00
Other Metal/Alloys	1.6E+03	6.7E+01	0.0E+00
Other Inorganic Materials	1.4E+03	3.1E+01	0.0E+00
Vitrified	2.5E+03	5.5E+01	0.0E+00
Cellulosics	9.6E+02	5.4E+01	0.0E+00
Rubber	6.3E+02	1.0E+01	0.0E+00
Plastics	8.9E+02	3.4E+01	0.0E+00
Solidified Inorganic Material	2.2E+03	5.4E+01	0.0E+00
Solidified Organic Material	1.4E+03	5.6E+00	0.0E+00
Cement (Solidified)	1.2E+03	5.0E+01	0.0E+00
Soils	1.6E+03	4.4E+01	0.0E+00
Container Materials - Kg/m3			
Steel		139	
Plastic/ Liners		28	

*This table is identical to Table 3-2 in TWBIR Revision 2, page 3-4 (DOE, 1995c).

Table 2-3. WIPP RH-TRU Waste Material Parameter Disposal Inventory*

Waste Material Parameters (Kg/m3	Maximum	Average	Minimum
Iron Base Metal/Alloys	1.7E+03	1.0E+02	0.0E+00
Aluminum Base Metal/Alloys	1.7E+02	7.1E+00	0.0E+00
Other Metal/Alloys	9.1E+02	2.5E+02	0.0E+00
Other Inorganic Materials	2.0E+03	6.4E+01	0.0E+00
Vitrified	2.5E+03	4.7E+00	0.0E+00
Cellulosics	5.7E+02	1.7E+01	0.0E+00
Rubber	4.4E+02	3.3E+00	0.0E+00
Plastics	6.2E+02	1.5E+01	0.0E+00
Solidified Inorganic Material	6.1E+02	2.2E+01	0.0E+00
Solidified Organic Material	8.1E+02	9.3E-01	0.0E+00
Cement (Solidified)	5.8E+02	1.9E+01	0.0E+00
Soils	2.4E+01	1.0E+00	0.0E+00

Container Materials - Kg/m3

Steel	446
Plastic/Liners	3.1
Lead	465
Steel Plug	2145

*This table is identical to Table 3-3 in TWBIR Revision 2, page 3-5 (DOE, 1995c).

Table 2-4. WIPP CH-TRU Waste Anticipated Inventory By Site*

(Cubic Meters)

Storage/Generator Site	Stored Volumes	Projected Volumes	Anticipated Volumes
Ames Laboratory - Iowa State Univ.	0.0E+00	4.2E-01	4.2E-01
Argonne National Laboratory - East	1.1E+01	1.3E+02	1.4E+02
Argonne National Laboratory - West	6.5E+00	7.4E+02	7.5E+02
Bettis Atomic Power Laboratory	0.0E+00	1.2E+02	1.2E+02
Energy Technology Engineering Center	1.7E+00	0.0E+00	1.7E+00
Hanford (Richland) Site	1.2E+04	3.3E+04	4.6E+04
Idaho National Engineering Laboratory	2.9E+04	0.0E+00	2.9E+04
Lawrence Livermore National Laboratory	2.3E+02	7.1E+02	9.4E+02
Los Alamos National Laboratory	1.1E+04	7.4E+03	1.8E+04
Mound Plant	2.7E+02	0.0E+00	2.7E+02
Nevada Test Site	6.2E+02	9.0E+00	6.3E+02
Oak Ridge National Laboratory	1.3E+03	2.6E+02	1.6E+03
Paducah Gaseous Diffusion Plant	0.0E+00	1.9E+00	1.9E+00
Pantex Plant	6.2E-01	0.0E+00	6.2E-01
Rocky Flats Environmental Technology Site	7.1E+02	4.4E+03	5.1E+03
Sandia National Laboratory - Albuquerque	6.7E+00	7.5E+00	1.4E+01
Savannah River Site	2.9E+03	6.8E+03	9.6E+03
Teledyne Brown Engineering	2.1E-01	0.0E+00	2.1E-01
U.S. Army Material Command	2.5E+00	0.0E+00	2.5E+00
University of Missouri Research Reactor	2.1E-01	8.3E-01	1.0E+00
Total CH Volumes	**5.8E+04**	**5.4E+04**	**1.1E+05**

*This table is identical to Table 4-1 in TWBIR Revision 2, page 4-2 (DOE, 1995c).

Table 2-5. WIPP RH-TRU Waste Anticipated Inventory By Site*

(Cubic Meters)

Storage/Generator Site	Stored Volumes	Projected Volumes	Anticipated Volumes
Argonne National Laboratory - West	1.9E+01	1.3E+03	1.3E+03
Battelle Columbus Laboratories	5.8E+02	0.0E+00	5.8E+02
Bettis Atomic Power Laboratory	0.0E+00	6.7E+00	6.7E+00
Energy Technology Engineering Center	8.9E-01	0.0E+00	8.9E-01
Hanford (Richland) Site	2.0E+02	2.2E+04	2.2E+04
Idaho National Engineering Laboratory	2.2E+02	0.0E+00	2.2E+02
Los Alamos National Laboratory	9.4E+01	9.9E+01	1.9E+02
Oak Ridge National Laboratory	2.5E+03	4.5E+02	2.9E+03
Total RH Volumes	**3.6E+03**	**2.3E+04**	**2.7E+04**
Total TRU Waste Volumes	**6.2E+04**	**7.7E+04**	**1.4E+05**

*This table is identical to Table 4-2 in TWBIR Revision 2, page 4-3 (DOE, 1995c).

3. SUPPLEMENTAL DISPOSAL INVENTORY INFORMATION

3.1 INTRODUCTION

This chapter summarizes supplemental information about the WIPP disposal inventory that was requested by SNL/NM in support of WIPP PA either after the publication of Revision 2 of the TWBIR or that was not available from the TRU waste sites at the time of publication of Revision 2 of the TWBIR in December 1995 (DOE, 1995c). Appendices A-1 through A-3 are the three memoranda from SNL/NM requesting supplemental information about the WIPP TRU waste inventory.

The first memorandum from SNL/NM (dated November 6, 1995), entitled "CH and RH-TRU Waste Parameters Potentially Important in WIPP PA" (Appendix A-1), was included as Appendix B in Revision 2 of the TWBIR. This memorandum requested information on certain nonradioactive materials present in the TRU waste (nitrates, sulfates, phosphates, cement, and organic ligands), and also requested information on residues present at TRU waste sites other than Rocky Flats Environmental Technology Site (RFETS). The information on residues was provided in Revision 2 of the TWBIR. However, the remainder of the requested information had to be obtained from the sites after the publication of Revision 2 and is presented in this document.

The second and the third memoranda from SNL/NM (dated January 11 and January 30, 1996), both entitled "Information Needed from TWBIR (Revision 2/Addendum)" (Appendices A-2 and A-3), requested additional information about the WIPP disposal radionuclide inventory. This information is also presented in the main body of this document.

The supplemental information provided to SNL/NM in response to the memoranda referenced above is discussed in the following sections:

- Supplemental Radionuclide Information (Section 3.2)
- Supplemental Information for Other Constituents (Section 3.3)

3.2 SUPPLEMENTAL RADIONUCLIDE INFORMATION

In response to the memoranda requesting radionuclide information (Appendices A-2 and A-3), two sets of radionuclide information were provided in support of WIPP PA (Appendices B-1 and B-2). Appendix B-1 is an update of the WIPP disposal radionuclide inventory presented in Table 3-4 of Revision 2 of the TWBIR, while Appendix B-2 presents preliminary activity calculations for seven radionuclides on a waste stream basis. The memoranda reporting these supplemental data and the details of the methodology for calculations are included in Appendices B-1 and B-2. A summary of the information provided by DOE to SNL/NM and the major assumptions used in deriving portions of the data are presented in Sections 3.2.1 and 3.2.2.

3.2.1 Revised WIPP Disposal Radionuclide Inventory

A revised estimate of the WIPP disposal radionuclide inventory (i.e., Table 3-4 in TWBIR Revision 2) was not specifically requested by SNL/NM in the memoranda included in Appendices A-1 through A-3. However, after the publication of TWBIR Revision 2, new and updated

radionuclide information became available from four sites (Hanford, Oak Ridge National Laboratory [ORNL], RFETS, and Savannah River Site [SRS]). A review of the new information indicated that it may result in considerable changes to the WIPP disposal radionuclide inventory published in Revision 2 of the TWBIR. Therefore, the disposal radionuclide inventory was recalculated on the basis of the new information and the results provided to SNL/NM in a format identical to Table 3-4 in TWBIR Revision 2 (see Table 3-1). The methodology and the assumptions used for recalculation of the radionuclide inventory are identical to those described in TWBIR Revision 2, except that the new radionuclide information from the four sites was incorporated. The new information from the four sites is summarized below:

- Hanford Site reported corrections to the values for Cf-252, Cm-244, and Cm-245 from their earlier submittals for the Integrated Data Base (IDB) (DOE, 1995b).

- Preliminary sludge sampling data were obtained for the ORNL RH-TRU sludges, which showed that the primary uranium isotope present in these sludges is U-238 (not U-235, as reported in their previous IDB submittals). The uranium curies reported for RH-TRU waste in previous ORNL IDB submittals were redistributed based on the preliminary sludge sampling data. This corrected the previously high estimates of U-235 in the ORNL RH-TRU inventory.

- The RFETS provided undecayed yearly activity data for the radionuclides present in the RFETS residues, which enabled activity decay calculations for these radionuclides. This was not provided for in TWBIR Revision 2; therefore the radionuclide activity from these residues could not be decayed.

- The SRS provided a break-up of radionuclide activity data for SRS waste between on-site and off-site waste (i.e., waste from other sites that was shipped to SRS for storage in the early 1970s). The activity from the off-site waste was included in the WIPP disposal radionuclide inventory but excluded from any extrapolations for SRS projected waste under the assumption that there would be no future accumulation of off-site Pu-238 dominant waste at SRS.

Based on the above information, Table 3-1 provides the revised WIPP disposal radionuclide inventory estimated in curies per cubic meter and total curies for each radionuclide for both CH-TRU and RH-TRU waste. The revised stored radionuclide inventory for each site in decayed curies is provided in Appendix C for both CH-TRU and RH-TRU waste. Appendix C includes the effect of all corrections, additions, or revisions to the site radionuclide inventories used to develop Table 3-1 and is an update of Appendix D in TWBIR Revision 2. All numbers in Appendix C are decayed to December 1995 using the Oak Ridge Isotope Generation and Depletion Code (ORIGEN 2) (Croff, 1980; 1983).

Based on the total curies shown in Table 3-1, it is estimated that approximately 98.9 percent of the total CH-TRU curies is contributed by Pu-238, Pu-239, Pu-240, Pu-241, and Am-241. In contrast, approximately 96.5 percent of the total RH-TRU curies is contributed by Cs-137, Sr-90, Ba-137m, Pu-241, and Y-90. Thus, the remaining radionuclides contribute a very small fraction of the total curies for the repository.

In comparison to TWBIR Revision 2, the most significant change in the revised disposal radionuclide inventory shown in Table 3-1 is the *decrease* in the estimated concentration of Pu-

Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA[1]*

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Ac225	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Ac227	3.61E-06	1.07E-07	6.08E-01	7.57E-04
Ac228	4.43E-06	1.10E-05	7.47E-01	7.77E-02
Ag109m	9.32E-05	NR	1.57E+01	NR
Ag110	4.19E-14	2.46E-13	7.07E-09	1.74E-09
Ag110m	3.15E-12	1.85E-11	5.31E-07	1.31E-07
Am241	2.62E+00	8.42E-01	4.42E+05	5.96E+03
Am242	1.04E-05	NR	1.75E+00	NR
Am242m	1.04E-05	NR	1.75E+00	NR
Am243	1.93E-04	3.23E-08	3.26E+01	2.28E-04
Am245	7.89E-15	4.06E-20	1.33E-09	2.87E-16
At217	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Ba137m	4.53E-02	2.89E+01	7.63E+03	2.04E+05
Bi210	1.52E-05	1.01E-09	2.55E+00	7.16E-06
Bi211	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Bi212	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Bi213	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Bi214	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Bk249	5.44E-10	2.80E-15	9.16E-05	1.98E-11
Bk250	2.59E-16	NR	4.37E-11	NR

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

*This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
C14	6.43E-05	2.90E-04	1.08E+01	2.05E+00
Cd109	9.31E-05	NR	1.57E+01	NR
Cd113m	1.08E-11	7.71E-11	1.82E-06	5.46E-07
Ce144	3.71E-07	7.24E-04	6.26E-02	5.13E+00
Cf249	3.81E-07	6.31E-07	6.42E-02	4.47E-03
Cf250	1.96E-06	NR	3.30E-01	NR
Cf251	2.24E-08	NR	3.78E-03	NR
Cf252[3]	1.44E-05	1.82E-04	2.43E+00	1.29E+00
Cm242	6.76E-06	NR	1.14E+00	NR
Cm243	1.61E-05	6.99E-03	2.72E+00	4.95E+01
Cm244	1.87E-01	4.45E-02	3.15E+04	3.15E+02
Cm245	6.81E-08	2.07E-10	1.15E-02	1.46E-06
Cm246	6.06E-07	NR	1.02E-01	NR
Cm247	1.91E-14	NR	3.21E-09	NR
Cm248[3]	2.19E-07	2.89E-08	3.69E-02	2.05E-04
Co58	1.81E-18	1.75E-15	3.05E-13	1.24E-11
Co60	3.83E-04	1.47E+00	6.46E+01	1.04E+04
Cr51	NR	4.29E-10	NR	3.04E-06
Cs134	7.97E-08	2.60E-03	1.34E-02	1.84E+01
Cs135	2.98E-09	1.66E-08	5.02E-04	1.17E-04

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

* This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Cs137	4.78E-02	3.05E+01	8.06E+03	2.16E+05
Es254	2.51E-16	NR	4.24E-11	NR
Eu150	2.08E-10	NR	3.51E-05	NR
Eu152	7.46E-06	1.73E-01	1.26E+00	1.22E+03
Eu154	6.80E-06	8.34E-02	1.15E+00	5.91E+02
Eu155	5.62E-06	1.67E-02	9.46E-01	1.18E+02
Fe55	1.13E-10	2.38E-05	1.91E-05	1.69E-01
Fe59	1.57E-12	NR	2.64E-07	NR
Fr221	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Fr223	4.98E-08	1.48E-09	8.39E-03	1.04E-05
H3	5.16E-06	9.33E-06	8.69E-01	6.60E-02
I129	4.18E-12	NR	7.05E-07	NR
Kr85	1.20E-06	2.37E-04	2.02E-01	1.68E+00
Mn54	5.05E-09	3.32E-06	8.51E-04	2.35E-02
Nb95	1.51E-14	9.45E-05	2.54E-09	6.69E-01
Nb95m	5.04E-17	3.17E-07	8.50E-12	2.24E-03
Ni59	4.47E-08	NR	7.52E-03	NR
Ni63	5.46E-06	1.40E-04	9.19E-01	9.88E-01
Np237	3.33E-04	4.02E-04	5.61E+01	2.85E+00
Np238	5.20E-08	NR	8.77E-03	NR

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

*This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Np239	1.93E-04	3.23E-08	3.26E+01	2.28E-04
Np240m	8.91E-12	3.12E-15	1.50E-06	2.21E-11
Pa231	2.67E-06	2.70E-07	4.51E-01	1.91E-03
Pa233	3.33E-04	4.02E-04	5.61E+01	2.85E+00
Pa234	3.05E-07	1.92E-06	5.14E-02	1.36E-02
Pa234m	2.35E-04	1.48E-03	3.96E+01	1.05E+01
Pb209	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Pb210	1.52E-05	1.01E-09	2.55E+00	7.16E-06
Pb211	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Pb212	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Pb214	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Pd107	4.40E-10	2.45E-09	7.41E-05	1.73E-05
Pm147	4.67E-05	1.52E-03	7.87E+00	1.07E+01
Po210	1.52E-05	1.01E-09	2.55E+00	7.16E-06
Po211	1.01E-08	3.00E-10	1.71E-03	2.12E-06
Po212	1.03E-04	6.66E-06	1.73E+01	4.72E-02
Po213	1.67E-05	1.62E-05	2.82E+00	1.15E-01
Po214	6.91E-05	5.05E-09	1.16E+01	3.57E-05
Po215	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Po216	1.61E-04	1.04E-05	2.71E+01	7.36E-02

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

*This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Po218	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Pr144	3.67E-07	7.16E-04	6.18E-02	5.07E+00
Pu236	6.16E-08	NR	1.04E-02	NR
Pu238	1.55E+01	2.05E-01	2.61E+06	1.45E+03
Pu239	4.66E+00	1.45E+00	7.85E+05	1.03E+04
Pu240	1.25E+00	7.15E-01	2.10E+05	5.07E+03
Pu241	1.37E+01	2.00E+01	2.31E+06	1.42E+05
Pu242	6.96E-03	2.11E-05	1.17E+03	1.50E-01
Pu243	1.91E-14	NR	3.21E-09	NR
Pu244	8.92E-12	3.12E-15	1.50E-06	2.21E-11
Ra223	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Ra224	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Ra225	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Ra226	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Ra228	4.43E-06	1.10E-05	7.47E-01	7.77E-02
Rh106	1.72E-07	1.54E-03	2.90E-02	1.09E+01
Rn219	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Rn220	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Rn222	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Ru106	1.72E-07	1.54E-03	2.90E-02	1.09E+01

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

*This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Sb125	7.17E-07	2.67E-04	1.21E-01	1.89E+00
Sb126	8.02E-10	4.46E-09	1.35E-04	3.16E-05
Sb126m	5.73E-09	3.18E-08	9.65E-04	2.25E-04
Se79	2.58E-09	1.44E-08	4.35E-04	1.02E-04
Sm151	8.72E-06	5.05E-05	1.47E+00	3.57E-01
Sn119m	2.46E-11	1.35E-10	4.14E-06	9.59E-07
Sn121m	1.58E-07	9.45E-07	2.66E-02	6.69E-03
Sn126	5.73E-09	3.18E-08	9.65E-04	2.25E-04
Sr90	4.07E-02	2.95E+01	6.85E+03	2.09E+05
Ta182	NR	5.95E-12	NR	4.21E-08
Tc99	1.49E-04	8.26E-07	2.52E+01	5.85E-03
Te125m	1.75E-07	6.57E-05	2.95E-02	4.65E-01
Te127	7.72E-13	2.41E-13	1.30E-07	1.71E-09
Te127m	7.88E-13	2.47E-13	1.33E-07	1.75E-09
Th227	3.56E-06	1.06E-07	6.01E-01	7.47E-04
Th228	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Th229	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Th230	4.78E-07	1.07E-06	8.06E-02	7.56E-03
Th231	7.59E-05	6.53E-04	1.28E+01	4.63E+00
Th232	5.42E-06	1.31E-05	9.13E-01	9.25E-02

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

* This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Th234	2.35E-04	1.48E-03	3.96E+01	1.05E+01
Tl207	3.61E-06	1.07E-07	6.07E-01	7.56E-04
Tl208	5.77E-05	3.74E-06	9.73E+00	2.65E-02
Tl209	3.69E-07	3.58E-07	6.22E-02	2.53E-03
U232	1.53E-04	NR	2.58E+01	NR
U233	1.06E-02	2.23E-02	1.79E+03	1.58E+02
U234	2.76E-03	6.03E-03	4.65E+02	4.27E+01
U235	7.59E-05	6.53E-04	1.28E+01	4.63E+00
U236	1.98E-06	1.37E-05	3.33E-01	9.68E-02
U237	3.36E-04	4.91E-04	5.66E+01	3.48E+00
U238	2.35E-04	1.48E-03	3.96E+01	1.05E+01
U240	8.91E-12	3.12E-15	1.50E-06	2.21E-11
Y90	4.07E-02	2.95E+01	6.85E+03	2.09E+05
Zr93	3.34E-08	1.86E-07	5.63E-03	1.32E-03
Zr95	6.80E-15	4.27E-05	1.15E-09	3.02E-01
TOTALS	**3.81E+01**	**1.43E+02**	**6.42E+06**	**1.02E+06**

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

*This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

238 for the CH-TRU waste in the repository. This is primarily due to the exclusion of the SRS off-site waste from any future extrapolations. Since this off-site waste has a high concentration of Pu-238, excluding it from the extrapolations decreases the amount of Pu-238 in the projected portion of the inventory. It should be noted that this off-site waste is included in the stored waste portion of the disposal radionuclide inventory. The decrease in the Pu-238 also causes a decrease in the total estimated curies for CH-TRU waste in the repository.

Based on the data corrections from Hanford Site to the Cm-244 and Cm-245 inventories, the estimated concentration of Cm-244 has increased, while that of Cm-245 has decreased. Similarly, based on the correction to the reported value of Cf-252 from the Hanford Site, the revised concentration of Cf-252 has decreased significantly from the values estimated in Revision 2 of the TWBIR. The effect of decaying the activity from the RFETS residues has resulted in a minor decrease in the estimated concentration of Pu-241. Since Pu-241 decays to Am-241, the decrease in the Pu-241 concentration is also accompanied by a corresponding increase in the concentration of Am-241.

The major change for the RH-TRU waste from TWBIR Revision 2 is the decrease in the estimated concentration of U-235 and an increase in the concentration of U-238. Both are a result of the preliminary sludge sampling data from ORNL mentioned earlier.

3.2.2 Activity Calculations for Waste Streams

As documented in the SNL/NM memoranda in Appendices A-2 and A-3, data on radionuclide activity on a waste stream basis was requested for 21 radionuclides. However, the request was subsequently limited to seven radionuclides by SNL/NM WIPP PA staff (Am-241, Cm-244, Pu-238, Pu-239, Pu-240, Pu-241, and U-234). Appendix B-2 presents the results provided to SNL/NM by DOE/CAO in response to this data request.

Since many sites did not have the ability to provide radionuclide data on a detailed waste stream basis for every waste stream in TWBIR Revision 2, the radionuclide activities for many individual waste streams (especially for projected waste) were not reported by the sites for TWBIR Revision 2. Therefore, the radionuclide activity data for the WIPP disposal inventory cannot be directly obtained on a waste stream basis by running queries on the TWBIR Revision 2 database. Due to the unavailability of detailed radionuclide data on a waste stream basis for many waste streams, the WIPP disposal radionuclide inventory presented in all revisions of the TWBIR has always been developed on the basis of the site-level radionuclide inventories reported by the sites in the IDB.

For the sake of consistency with the revised WIPP disposal radionuclide inventory in Attachment A of Appendix B-1 (which is also based on the site-level IDB data), assumptions were required in order to estimate the waste stream radionuclide activities presented in Appendix B-2. These assumptions can be found in Appendix B-2 and are not reproduced here. Thus, it should be noted that the data in Appendix B-2 are *derived* on the basis of assumptions and not directly obtainable from the TWBIR Revision 2 database. Because of the unavailability of the radionuclide data on a waste stream basis, some of the waste streams from small sites are not included in the activity table in Appendix B-2. Efforts are currently underway to ensure that the sites will be able to provide radionuclide data on a waste stream basis for most waste streams in future updates of the TWBIR so that radionuclide activity data for the WIPP disposal inventory can be directly obtained from the TWBIR database.

3.3 SUPPLEMENTAL INFORMATION FOR OTHER CONSTITUENTS

SNL/NM and DOE/CAO requested supplemental information on several constituents in TRU waste (see Appendix A-1) that were not able to be estimated based on the information reported by the TRU waste sites in Revision 2 of the TWBIR (DOE, 1995c). The information requested can be divided into three general categories which were requested on solidified waste forms destined for disposal in WIPP:

- Complexing Agents
- Nitrate, Sulfate, and Phosphate
- Cement

The TWBIR team worked with those major sites that generate/store most of the solidified waste forms: Los Alamos National Laboratory (LANL), RFETS/INEL, and ORNL. A summary of the results of these supplemental information requests is provided in Section 3.3.1, 3.3.2 and 3.3.3 and the memoranda reporting the data are located in Appendices B-3 through B-7. The detailed methodology for calculating the estimates of these physical/chemical constituents are provided in each memorandum in these Appendices.

3.3.1 Estimate of Complexing Agents in Transuranic Solidified Waste Forms Scheduled for Disposal in WIPP

The information on complexing agents in the waste was provided in a series of three memoranda to DOE/CAO. The initial memorandum, entitled "Preliminary Estimate of Complexing Agents in TRU Waste Forms Scheduled for Disposal in WIPP," provided in Appendix B-3, represents the earliest estimate of complexing agents in the TRU Waste. The Appendix B-3 memorandum was superseded by the second estimate, entitled "Current Estimate of Complexing Agents in Transuranic Solidified Waste Forms Scheduled for Disposal in WIPP," provided in Appendix B-4. After the Appendix B-4 memorandum was issued, preliminary information from the January 1996 data submittal from INEL was received. The data submittal indicated that over 90% of the stored waste at INEL would be vitrified, a process that should destroy complexing agents in TRU waste. Based on the preliminary data from INEL, the estimated amount of complexing agents due to RFETS waste stored at INEL could be reduced from that reported in Appendix B-4. A synopsis of the INEL information is reported in the third memorandum that estimates complexing agents in the waste, entitled "Revision of Current Estimate of Complexing Agents in Transuranic Solidified Waste Forms Scheduled for Disposal in WIPP," provided in Appendix B-5.

Table 3-2 provides a summary of the anticipated mass (in kilograms) of complexing agents in TRU waste reported by RFETS/INEL, LANL, and Hanford. The estimates in Table 3-2 include the anticipated reduction in mass of complexing agents reported from RFETS/INEL based on the preliminary data for proposed vitrification of waste at INEL (Appendix B-5). In addition to the mass of complexing agents reported in Table 3-2, ORNL has provided an estimate of total organic carbon (TOC) in their RH-TRU sludges (Table 3-3). ORNL does not have any analytical data to quantitatively estimate which organic chemicals are responsible for the TOC content of the sludges. However, ORNL has provided a list of chemicals, summarized in Table 3-3, that could contribute to the TOC value reported (see Table 1 in Appendix B-4). It is estimated that most of the TOC in the tanks is not associated with complexing agents, but that has not been verified at this time. As a conservatism, PA calculations can assume that any complexing agents listed in Table 3-3 could form the bulk of the TOC in the ORNL RH-TRU tanks.

Table 3-2. Estimates of Complexing Agents in Transuranic Waste from RFETS, INEL, LANL, and Hanford*

Compound	Low Estimate (kg)	Recommended Estimate (kg)	High Estimate (kg)
Ascorbic Acid	18	30	34
Acetic Acid	27	44	50
Sodium Acetate	141	282	333
Citric Acid	1110	1120	1130
Sodium Citrate	51	102	120
Oxalic Acid	13700	13700	13700
EDTA	3	6	7
8-Hydroxyquinoline	6	12	14
Tributyl Phosphate	102	111	115
1,10 Phenanthroline	0.03	0.06	0.07
Dihexyl-n,n-diethyl carbamoylmethyl phosphonate	9	18	22

* Refer to Appendices B-4 and B-5 for methodology of calculated estimates.

Table 3-3. Estimate of Total Organic Carbon (TOC) in ORNL Transuranic Sludge Tanks and Possible Complexing Agents that can Contribute to TOC.

Total Organic Carbon in ORNL Transuranic Sludge = 3691 kg

Possible Complexing Agents and Other Organic Compounds* in ORNL RH-TRU Sludges:

Acetic Acid
Acetone
Adogen-364-HP (–triluarylamine)
Carbon tetrachloride
Deodorized mineral spirits (Amsco)
2,5-di-tert-butylhydroquinone (DBHQ)
Diethylbenzene (DEB)
Diethylenetriaminepentaacetic acid (DPTA)
Di (2-ethylhexyl) phosphoric acid (HDEHP)
Di-isopropylbenzene (DIPB)
Ethanol
Ether
Ethylenediaminetetraacetic acid (EDTA)
2-ethyl-1-hexanol
α-hydroxyisobutyric acid
Isopropanol
Methanol
n-dodecane
n-paraffin (NPH)
Oxalic Acid
Thenoyltrifluoroacetone (TTA)
Tributylphosphate (TBP)
Trichloroethylene (TCE)
Xylene

*Adapted from Table 1 in Appendix B-4.

3.3.2 Estimate of Nitrate, Sulfate, and Phosphate Content in Transuranic Solidified Wastes for Disposal in WIPP

Estimates of nitrate and sulfate in solidified TRU final waste forms were provided in the memorandum entitled "Preliminary Estimate for SNL/NM Performance Assessment Calculations of Nitrate, Sulfate, and Phosphate in Transuranic Solidified Wastes Destined for Disposal in WIPP," provided in Appendix B-6. In that memorandum, it is estimated that densities for the overall disposal inventory are as follows: 9.2 kilograms/cubic meter for nitrate and 3.6 kilograms/cubic meter for sulfate. No estimate of phosphate was reported due to lack of sufficient information.

3.3.3 Estimate of Cement in TRU Solidified Waste Forms for Disposal in WIPP

An estimate of cement (portland-based) in solidified TRU final waste forms was calculated in the memorandum entitled "Estimate of Cement Content in TRU Solidified Waste Forms Scheduled for Disposal in WIPP," provided in Appendix B-7. The estimated density of cement over the entire disposal inventory is 48.6 kilogram/cubic meter. This estimate includes both CH-TRU and RH-TRU final waste forms. The portland cement reported is both reacted and unreacted cement in the waste. There are no data available to estimate the percentage of reacted versus unreacted cement in the waste.

4. REFERENCES

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Croff, A. G., 1980, *A User's Manual for the ORIGEN2 Code*, ORNL/TM-7175, Oak Ridge National Laboratory, July 1980.

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EPA – See U.S. Environmental Protection Agency.

SNL/NM – See Sandia National Laboratory/NM.

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U.S. Department of Energy, 1990, *Final Supplement Environmental Impact Statement*, Volume 3, DOE/EIS-0026-FS, January 1990.

U.S. Department of Energy, 1988, *Radioactive Waste Management*, DOE Order 5820.2A, U.S. Department of Energy, Washington, D.C., September 26, 1988.

U.S. Department of Energy and State of New Mexico, 1981, "Agreement for Consultation and Cooperation Between the Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant," July 1, 1981 (dated April 18, 1988).

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U.S. Environmental Protection Agency, 1993, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*, 40 CFR 191, Final Rule, Federal Register, Vol. 58, Page 66398, December 20, 1993.

U.S. Environmental Protection Agency, 1980, *Listing of Hazardous Waste*, 40 Code of Federal Regulations, Part 261, May 19, 1980.

5. GLOSSARY

40 CFR Part 191, Protection of Environment. EPA: Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes – The EPA's environmental standards for the storage (Subpart A) and disposal (Subpart B) of spent nuclear fuel, and high-level and TRU radioactive wastes. This is the primary post-closure standard that applies to WIPP.

Anticipated Inventory – The sum of the stored and projected inventories, as defined in this document.

As-Generated Waste – The chemical and physical status of waste when it is generated.

Buried Waste – TRU waste buried in shallow trenches prior to the 1970 Atomic Energy Commission policy that required TRU waste to be retrievably stored.

Code of Federal Regulations (CFR) – (1) A codification of the general and permanent rules published in the **Federal Register** by the department and agencies of the federal government. The CFR is divided into 50 titles that represent broad areas subject to federal regulation. It is issued quarterly and revised annually. (2) All federal regulations in force are published annually in codified form in the CFR.

Contact-Handled (CH) TRU Waste – Packaged TRU wastes with an external surface dose rate of less than 200 mrem per hour.

Defense Waste – (1) Radioactive waste from any activity performed in whole or in part in support of DOE atomic energy defense activities; excludes waste under purview of the Nuclear Regulatory Commission or generated by the commercial nuclear power industry. (2) Nuclear waste derived mostly from the manufacture of nuclear weapons, weapons-related research programs, the operation of naval reactors, and the decontamination of nuclear weapons production facilities.

Department of Energy Site – A DOE-owned or -controlled tract used for DOE operations. Either a tract owned by DOE or a tract leased or otherwise made available to the federal government under terms that afford to DOE rights of access and control substantially equal to those that DOE would possess if it were the holder of the fee (or pertinent interest therein) as agent of and on behalf of the government. One or more DOE operations/program activities are carried out within the boundaries of the described tract.

Disposal – Emplacement of waste in a manner that assures isolation from the biosphere for the foreseeable future with no intent of retrieval and that requires deliberate action to regain access to the waste. For example, disposal of wastes in a mined geologic repository occurs when all of the shafts to the repository area are backfilled and sealed.

Disposal Inventory – The inventory volume defined for WIPP emplacement to be used for PA calculations is the "disposal inventory." The LWA defines the total amount of TRU waste allowed in the WIPP as 6,200,000 cubic feet (approximately 176,000 cubic meters) (Public Law, 1992b). The "Agreement for Consultation and Cooperation" (C&C Agreement) limits the RH-TRU inventory to 250,000 cubic feet (approximately 7,080 cubic meters) (DOE and State of New

Mexico, 1981). Therefore by difference, the CH-TRU inventory is limited to 5,950,000 cubic feet (approximately 168,500 cubic meters).

Final Waste Form – Consists of a series of WMCs that for PA purposes have similar physical and chemical properties.

Integrated Data Base (IDB) – The latest version of the IDB, the *Integrated Data Base for [1995]: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics* (DOE, 1995b).

Land Withdrawal Act - The 1992 legislation passed by the U.S. Congress withdrawing the surface land and underlying minerals at the WIPP site from public use, transferring the property from the DOI to the DOE, and enabling the start of the WIPP Test Phase. The LWA sets prerequisites to be met before the start of the Test Phase, such as the repromulgation by EPA of 40 CFR 191 and the concurrence of EPA with the Test Phase Plan (Public Law, 1992b).

Mixed TRU Waste – TRU waste that contains both radioactive and hazardous components as defined by the Atomic Energy Act and the RCRA as codified in 40 CFR Parts 261.3 (EPA, 1980).

Newly Generated Wastes – See Projected Inventory.

Performance Assessment (PA) – (1) A systematic analysis of the potential risks posed by waste management systems to the public and environment and a comparison of those risks to established performance objectives. (2) An analysis that (a) identifies the processes and events that might affect the disposal system, (b) examines the effects of these processes and events on the performance of the disposal system, and (c) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable. (3) A term used to denote all activities (qualitative and quantitative) carried out to (a) determine the long-term ability of a site/facility to effectively isolate the waste and ensure the long-term health and safety of the public and (b) provide the basis for demonstrating regulatory compliance.

Projected Inventory – That part of the inventory that has not been generated but is estimated to be generated at some time in the future by the TRU waste generator/storage sites. The estimated timeframe may vary, but is usually between 20 and 30 years. "Newly generated waste" also is sometimes used as a synonym for the projected inventory.

Radioactive – Term used to refer to an unstable atomic nucleus that decays with the spontaneous emission of ionizing radiation (also see "radionuclide").

Radionuclide – (1) A species of atom having an unstable nucleus, that is subject to spontaneous decay or disintegration and usually accompanied by the emission of ionizing radiation. (2) Any nuclide that emits radiation. A nuclide is a species of atom characterized by the constitution of its nucleus and hence by the number of protons, the number of neutron, and the energy content.

Remote-Handled (RH) TRU Waste – Packaged TRU wastes with an external surface dose rate equal to or exceeding 200 mrem per hour.

Resource Conservation and Recovery Act (RCRA) – (1) Establishes a system for controlling hazardous waste from generation to disposal. (2) A Federal law passed in 1976, and amended under the HSWA of 1984, that established a structure to track and regulate hazardous wastes from the time of generation to disposal. The law requires safe and secure procedures to be used in treating, handling, transporting, storing, and disposing of hazardous substances. RCRA is designed to prevent new uncontrolled hazardous waste sites. The law also regulates the disposal of solid waste that may not be considered hazardous. (3) Specifically, Subtitle D of RCRA governs the management of solid waste. (Note: 40 CFR Parts 260-272 are the regulations for complying with RCRA with respect to hazardous waste and hazardous waste treatment, storage, and disposal facilities.)

Scaling – The process for adjusting the anticipated inventory to equal the maximum authorized disposal inventory of the WIPP repository for the purposes of WIPP performance assessment modeling.

Stored Inventory – That part of the TRU waste inventory currently in retrievable storage as of the time of the last data call for inventory information. Retrievably stored waste includes waste stored in buildings or in berms with earthen cover since 1970 and does not include any waste that was buried prior to 1970. Stored inventory can be in the "as-generated" form or "final waste form."

Transuranic – Pertaining to elements that have atomic numbers greater than 92, including neptunium, plutonium, americium, and curium; all are radioactive, are not naturally occurring, and are members of the actinide group.

Transuranic (TRU) Waste – (1) Waste containing alpha-emitting radionuclides with an atomic number greater than 92 and half-lives greater than 20 years, at concentrations of TRU isotopes greater than 100 nanocuries per gram of waste. **This core definition appears in modified form in various relevant documents as follows**: (a) For purposes of management, DOE Order 5820.2A: (i) considers TRU waste, as defined above, "without regard to source or form" *(The proposed revision to the Order [DOE Order 5820.2A Major Issues for Revision, May 6, 1992]* contemplates removing this clause); (ii) allows head of field elements to determine that wastes containing other alpha-emitting radionuclides must be managed as TRU waste; and (iii) adds "at time of assay," implying both that the classification of a waste as TRU waste is to be made based on an assay, and that such classification can be superseded only by another assay. (b) For purposes of setting standards for management and disposal, 40 CFR 191.02(i) adds "except for: (i) high-level wastes; (ii) wastes that the DOE has determined, with the concurrence of the EPA Administrator, do not need the degree of isolation required by this part; or (iii) wastes that the Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR 61." (2) Waste materials contaminated with U-233 (and its daughter products), with certain isotopes of plutonium, or with other nuclides with atomic numbers greater than 92. In order to be classified as TRU waste, the long-lived alpha activity from subject isotopes must exceed 100 nanocuries per gram of waste material independent of the level of beta-gamma activity. These wastes are produced primarily from reprocessing spent fuel and from the use of plutonium in the fabrication of nuclear weapons. (3) Wastes that are contaminated with radioactive elements heavier than uranium, thus the name trans-(or beyond) uranic.

Waste Acceptance Criteria (WAC) – The criteria used to determine if waste packages are acceptable. For the purposes of this document, WAC refers to WIPP WAC.

Waste Form – The physical form of the waste such as sludges, combustibles, metals, etc.

TRU Waste Sites – The 8 major DOE facilities and several smaller sites throughout the U.S. that generate and store TRU waste.

Waste Isolation Pilot Plant (WIPP) – (1) The project authorized under Section 213 of the DOE National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Public Law, 1979) to demonstrate the safe and environmentally sound disposal of radioactive waste materials generated by atomic energy defense activities. (2) A research and development facility located near Carlsbad, New Mexico to be used to demonstrate a practical, long-term solution to a complex problem: the safe disposal in deep geologic repositories of TRU waste resulting from DOE activities.

Waste Material Parameter – A waste material that occurs in TRU waste that is an input parameter into one (or more) current PA model(s) or is required to adequately describe the waste form.

Waste Matrix Code (WMC) – A DOE-developed coding system for grouping waste streams that have similar matrix constituents, especially for treatment objectives. This coding system allows waste streams within the DOE TRU waste system that have similar physical and chemical waste form properties to be categorized together. WMCs also have been called "waste treatability codes" in other DOE documents. An example of a WMC for "heterogeneous waste" is 5400 (DOE, 1995a).

Waste Stream – A flow of waste materials with specific definable characteristics that remain the same throughout the life of the process generating the waste stream.

Waste Stream Profile – A description of a CH-TRU or RH-TRU waste stream destined for shipment to and disposal in WIPP, if authorized under permits and certifications by appropriate regulatory agencies for disposal in the WIPP repository. The waste stream profile is presented in tabular format and is intended to provide a summary of the important information about a particular waste stream.

WIPP Waste Profile – Represents a summary of TRU waste at all DOE TRU waste generator/storage sites that have an identical Final Waste Form.

SUBCHAPTER D—WATER PROGRAMS (CONTINUED)

PART 136—GUIDELINES ESTABLISHING TEST PROCEDURES FOR THE ANALYSIS OF POLLUTANTS

Sec.

136.1 Applicability.
136.2 Definitions.
136.3 Identification of test procedures.
136.4 Application for alternate test procedures.
136.5 Approval of alternate test procedures.
APPENDIX A TO PART 136—METHODS FOR ORGANIC CHEMICAL ANALYSIS OF MUNICIPAL AND INDUSTRIAL WASTEWATER
APPENDIX B TO PART 136—DEFINITION AND PROCEDURE FOR THE DETERMINATION OF THE METHOD DETECTION LIMIT—REVISION 1.11
APPENDIX C TO PART 136—INDUCTIVELY COUPLED PLASMA—ATOMIC EMISSION SPECTROMETRIC METHOD FOR TRACE ELEMENT ANALYSIS OF WATER AND WASTES METHOD 200.7
APPENDIX D TO PART 136—PRECISION AND RECOVERY STATEMENTS FOR METHODS FOR MEASURING METALS

AUTHORITY: Secs. 301, 304(h), 307 and 501(a), Pub. L. 95–217, 91 Stat. 1566, et seq. (33 U.S.C. 1251, et seq.) (the Federal Water Pollution Control Act Amendments of 1972 as amended by the Clean Water Act of 1977).

§ 136.1 Applicability.

The procedures prescribed herein shall, except as noted in § 136.5, be used to perform the measurements indicated whenever the waste constituent specified is required to be measured for:

(a) An application submitted to the Administrator, or to a State having an approved NPDES program for a permit under section 402 of the Clean Water Act of 1977, as amended (CWA), and/or to reports required to be submitted under NPDES permits or other requests for quantitative or qualitative effluent data under parts 122 to 125 of title 40, and,

(b) Reports required to be submitted by discharges under the NPDES established by parts 124 and 125 of this chapter, and,

(c) Certifications issued by States pursuant to section 401 of the CWA, as amended.

[38 FR 28758, Oct. 16, 1973, as amended at 49 FR 43250, Oct. 26, 1984]

§ 136.2 Definitions.

As used in this part, the term:

(a) *Act* means the Clean Water Act of 1977, Pub. L. 95–217, 91 Stat. 1566, et seq. (33 U.S.C. 1251 et seq.) (The Federal Water Pollution Control Act Amendments of 1972 as amended by the Clean Water Act of 1977).

(b) *Administrator* means the Administrator of the U.S. Environmental Protection Agency.

(c) *Regional Administrator* means one of the EPA Regional Administrators.

(d) *Director* means the Director of the State Agency authorized to carry out an approved National Pollutant Discharge Elimination System Program under section 402 of the Act.

(e) *National Pollutant Discharge Elimination System (NPDES)* means the national system for the issuance of permits under section 402 of the Act and includes any State or interstate program which has been approved by the Administrator, in whole or in part, pursuant to section 402 of the Act.

(f) *Detection limit* means the minimum concentration of an analyte (substance) that can be measured and reported with a 99% confidence that the analyte concentration is greater than zero as determined by the procedure set forth at appendix B of this part.

[38 FR 28758, Oct. 16, 1973, as amended at 49 FR 43250, Oct. 26, 1984]

§ 136.3 Identification of test procedures.

(a) Parameters or pollutants, for which methods are approved, are listed together with test procedure descriptions and references in Tables IA, IB, IC, ID, IE, and IF. The full text of the referenced test procedures are incorporated by reference into Tables IA, IB, IC, ID, IE, and IF. The incorporation by reference of these documents, as specified in paragraph (b) of this section, was approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. Copies of the documents may be obtained from the sources listed in paragraph (b) of

this section. Information regarding obtaining these documents can be obtained from the EPA Office of Water Statistics and Analytical Support Branch at 202–566–1000. Documents may be inspected at EPA's Water Docket, EPA West, 1301 Constitution Avenue, NW., Room B135, Washington, DC (Telephone: 202-566–2426); or at the Office of the Federal Register, 800 North Capitol Street, NW., Suite 700, Washington, DC. These test procedures are incorporated as they exist on the day of approval and a notice of anys change in these test procedures will be published in the FEDERAL REGISTER. The discharge parameter values for which reports are required must be determined by one of the standard analytical test procedures incorporated by reference and described in Tables IA, IB, IC, IE, and IF, or by any alternate test procedure which has been approved by the Administrator under the provisions of paragraph (d) of this section and §§136.4 and 136.5. Under certain circumstances (paragraph (b) or (c) of this section or 40 CFR 401.13) other test procedures may be more advantageous when such other test procedures have been previously approved by the Regional Administrator of the Region in which the discharge will occur, and providing the Director of the State in which such discharge will occur does not object to the use of such alternate test procedure.

TABLE IA—LIST OF APPROVED BIOLOGICAL METHODS

Parameter and units	Method [1]	EPA	*Standard Methods* 18th, 19th, 20th ed.	ASTM	USGS
Bacteria:					
1. Coiform (fecal), number per 100 mL	Most Probable Number (MPN), 5 tube	p. 132 [3]	9221C E [4]		
	3 dilution, or Membrane filter (MF) [2] single step	p. 124 [3]	9222D [4]		B–0050–85 [5]
2. Coliform (fecal) in presence of choline, number per 100 mL.	MPN, 5 tube, 3 dilution, or	p. 132 [3]	9221C E [4]		
	MF, single step [6]	p. 124 [3]	9221D [4]		
3. Coliform (total), number per 100 mL	MPN, 5 tube, 3 dilution, or	p. 114 [3]	9221B [4]		
	MF [2] single step or two step	p. 108 [3]	9222B [4]		B–0025–85 [5]
4. Coliform (total), in presence of clorine, number per 100 mL.	MPN, 5 tube, 3 dilution, or	p. 114 [3]	9221B [4]		
	MF [2] with enrichment	p. 111 [3]	9222 (B+B.5c) [4]		
5. Fecal streptococci, number per 100 mL	MPN, 5 tube, 3 dilution	p. 139 [3]	9230B [4]		
	MF [2] or	p. 136 [3]	9230C [4]		B–0055–85 [5]
	Plate count	p. 143 [3]			
Aquatic Toxicity:					
6. Toxicity, acute, fresh water organisms, LC50, percent effluent.	Ceriodaphnia dubia acute	[7] 2002.0			
	Daphnia pulex and Daphnia magna acute	[7] 2021.0			
	Fathead minnow, Pimephales promelas, and Bannerfin shiner, Cyprinella leedsi, acute.	[7] 2001.0.			
	Rainbow trout, Oncorhynchus mykiss, and brook trout, Salvelinus fontinalis, acute.	[7] 2019.0.			
7. Toxicity, acute, estuarine and marine organisms of the Atlantic Ocean and Gulf of Mexico, LC50, percent effluent.	Mysid, Mysidopsis, bahia, acute	[7] 2007.0			
	Sheepshead minnow, Cyprinodon variegatus, acute.	[7] 2004.0			
	Silverside, Menidia beryllina, Menidia menidia, and Menidia peninsulae, acute.	[7] 2006.0.			
8. Toxicity, chronic, fresh water organisms, NOEC or IC25, percent effluent.	Fathead minnow, Pimephales promelas, larval survival and growth.	[8] 1000.0			
	Fathead minnow, Pimephales promelas, embryo-larval survival and teratogenicity.	[8] 1001.0.			
	Daphnia, Ceriodaphnia dubia, survival and reproduction.	[8] 1002.0.			
	Green alga, Selenastrum capricornutum, growth	[8] 1003.0.			
9. Toxicity, chronic, estuarine and marine organisms of the Atlantic Ocean and Gulf of Mexico, NOEC or IC25, percent effluent.	Sheepshead minnow, Cyprinodon variegatus, larval survival and growth.	[9] 1004.0			
	Sheepshead minnow, Cyprinodon variegatus, embryo-larval survival and teratogenicty.	[9] 1005.0			
	Inland silverside, Menidia beryllina, larval survival and growth.	[9] 1006.0			
	Mysid, Mysidopsis bahia, survival, growth, and fecundity.	[9] 1007.0.			
	Sea urchin, Arbacia punctulata, fertilization	[9] 1008.0.			

Notes to Table IA:

[1] The method must be specified when results are reported.

[2] A 0.45 μm membrane filter (MF) or other pore size certified by the manufacturer to fully retain organisms to be cultivated and to be free of extractables which could interfere with their growth.

[3] USEPA. 1978. Microbiological Methods for Monitoring the Environment, Water, and Wastes. Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio. EPA/600/8–78/017.
[4] APHA. 1998, 1995, 1992. Standard Methods for the Examination of Water and Wastewater. American Public Health Association. 20th, 19th, and 18th Editions. Amer. Publ. Hlth. Assoc., Washington, DC.
[5] USGS. 1989. U.S. Geological Survey Techniques of Water-Resource Investigations, Book 5, Laboratory Analysis, Chapter A4, Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples, U.S. Geological Survey, U.S. Department of the Interior, Reston, Virginia.
[6] Because the MF technique usually yields low and variable recovery from chlorinated wastewaters, the Most Probable Number method will be required to resolve any controversies.
[7] USEPA. October 2002. Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms. Fifth Edition. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA 821–R–02–012.
[8] USEPA. October 2002. Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms. Fourth Edition. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA 821–R–02–013.
[9] USEPA. October 2002. Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Marine and Estuarine Organisms. Third Edition. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA 821–R–02–014.

TABLE IB—LIST OF APPROVED INORGANIC TEST PROCEDURES

Parameter, units and method	Reference (method number or page)				
	EPA [1, 35]	*Standard Methods* [Edition(s)]	ASTM	USGS [2]	Other
1. Acidity, as $CaCO_3$, mg/L:					
Electrometric endpoint or phenolphthalein endpoint.	305.1	2310 B(4a) [18th, 19th, 20th].	D1067–92	I–1020–85	
				I–2030–85	
2. Alkalinity, as $CaCO_3$, mg/L:					
Electrometric of Colorimetric titration to pH 4.5, manual or automatic.	310.1	2320 B [18th, 19th, 20th]	D1067–92	I–1030–85	973.43 [3]
	310.2.			I–2030–85	
3. Aluminium—Total,[4] mg/L; Digestion [4] followed by:					
AA direct aspiration [36]	202.1	3111 D [18th, 19th]		I–3051–85	
AA furnace	202.2	3113 B [18th, 19th].			
Inductively Coupled Plasma/Atomic Emission Spectrometry (ICP/AES) [36].	200.7 [5]	3120 B [18th, 19th, 20th]		I–4471–97 [50]	
Direct Current Plasma (DCP) [36]			D4190–94		Note 34.
Colorimetric (Eriochrome cyanine R).		3500–Al B [20th] and 3500–Al D [18th, 19th].			
4. Ammonia (as N), mg/L:					
Manual, distillation (at pH 9.5) [6] followed by.	350.2	4500–NH_3 B [18th, 19th, 20th].			973.49 [3]
Nesslerization	350.2	4500–NH_3 C [18th]	D1426–98(A)	I–3520–85	973.49 [3]
Titration	350.2	4500–NH_3 C [19th, 20th] and 4500–NH_3 E [18th].			
Electrode	350.3	4500–NH_3 D or E [19th, 20th] and 4500–NH_3 F or G [18th].	D1426–98(B).		
Automated phenate, or	350.1	4500–NH_3 G [19th, 20th] and 4500–NH_3 H [18th].		I–4523–85	
Automated electrode					Note 7.

5. Antimony–Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration[36]	204.1	3111 B [18th, 19th]			
AA furnace	204.2	3113 B [18th, 19th]			
ICP/AES[36]	200.7[5]	3120 B [18th, 19th, 20th]			
6. Arsenic–Total[4] mg/L:					
Digestion[4] followed by	206.5				
AA gaseous hydride	206.3	3114 B 4.d [18th, 19th]	D2972–97(B)	I–3062–85	
AA furnace	206.2	3113 B [18th, 19th]	D2972–97(C)	I–4063–98[49]	
ICP/AES[36] or	200.7[5]	3120 B [18th, 19th, 20th].			
Colorimetric (SDDC)	206.4	3500–As B [20th] and 3500–As C [18th, 19th].	D2972–97(A)	I–3060–85	
7. Barium–Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration[14]	208.1	3111 D [18th, 19th]		I–3084–85	
AA furnace	208.2	3113 B [18th, 19th]	D4382–95		
ICP/AES[14]	200.7[5]	3120 B [18th, 19th, 20th]			
DCP[14]					Note 34.
8. Beryllium–Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration	210.1	3111 D [18th, 19th]	D3645–93(88)(A)	I–3095–85	
AA furnace	210.2	3113 B [18th, 19th]	D3645–93(88)(B)		
ICP/AES	200.7[5]	3120 B [18th, 19th, 20th]		I–4471–97[50]	
DCP, or			D4190–94		Note 34.
Colorimetric (aluminon		3500–Be D [18th, 19th]			
9. Biochemical oxygen demand (BOD_5), mg/L:					
Dissolved Oxygen Depletion	405.1	5210 B [18th, 19th, 20th]		I–1578–78[8]	973.44,[3] p. 17[9]
10. Boron[37]–Total, mg/L:					
Colorimetric (curcumin)	212.3	4500–B B [18th, 19th, 20th]		I–3112–85	
ICP/AES, or	200.7[5]	3120 B [18th, 19th, 20th]		I–4471–97[50]	
DCP			D4190–94		Note 34.
11. Bromide, mg/L:					
Titrimetric	320.1		D1246–95(C)	I–1125–85	p. S44[10]
12. Cadmium—Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration[36]	213.1	3111 B or C [18th, 19th]	D3557–95 (A or B)	I–3135–85 or I–3136–85	974.27,[3] p. 37[9]
AA furnace	213.2	3113 B [18th, 19th]	D3557–95(D)	I–4138–89[51]	
ICP/AES[36]	200.7[5]	3120 B [18th, 19th, 20th]		I–1472–85 or I–4471–97[50]	
DCP[36]			D4190–94		Note 34.
Voltametry[11], or			D3557–95(C).		
Colorimetric (Dithizone)		3500–Cd D [18th, 19th].			
13. Calcium—Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration	215.1	3111 B [18th, 19th]	D511–93(B)	I–3152–85	
ICP/AES	200.7[5]	3120 B [18th, 19th, 20th]		I–4471–97[50]	
DCP, or					Note 34.
Titrimetric (EDTA)	215.2	3500–Ca B [20th] and 3500–Ca D [18th, 19th].	D511–93(A).		
14. Carbonaceous biochemical oxygen demand (CBOD 3), mg/L[12]:					

TABLE IB—LIST OF APPROVED INORGANIC TEST PROCEDURES—Continued

Parameter, units and method	Reference (method number or page)				
	EPA [1, 35]	*Standard Methods* [Edition(s)]	ASTM	USGS [2]	Other
Dissolved Oxygen Depletion with nitrification inhibitor.	.....	5210 B [18th, 19th, 20th].			
15. Chemical oxygen demand (COD), mg/L; Titrimetric	410.1	5220 C [18th, 19th, 20th] ...	D1252–95(A)	I–3560–85	973.46,[3] p. 17 [9]
or	410.2	.....	.....	I–3562–85	
Spectrophotometric, manual or automatic.	410.3. 410.4.	5220 D [18th, 19th, 20th] ...	D1252–95(B)	I–3561–85	Notes 13, 14.
16. Chloride, mg/L:					
Titrimetric (silver nitrate) or	.....	4500–Cl^- B [18th, 19th, 20th].	D512–89(B)	I–1183–85	
(Mercuric nitrate)	325.3	4500–Cl^- C [18th, 19th, 20th].	D512–89(A)	I–1184–85	973.51 [3]
Colorimetric, manual or	.....	.....	.....	I–1187–85	
Automated (Ferricyanide)	325.1 or 325.2	4500–Cl^- E [18th, 19th, 20th].	.....	I–2187–85	
17. Chlorine—Total residual, mg/L; Titrimetric:					
Amperometric direct	330.1	4500–Cl D [18th, 19th, 20th].	D1253–86(92).		
Iodometric direct	330.3	4500–Cl B [18th, 19th, 20th].			
Back titration ether end-point [15] or.	330.2	4500–Cl C [18th, 19th, 20th].			
DPD–FAS	330.4	4500–Cl F [18th, 19th, 20th].			
Spectrophotometric, DPD	330.5	4500–Cl G [18th, 19th, 20th].			
Or Electrode	.....	.....	.....	.....	Note 16.
18. Chromium VI dissolved, mg/L; 0.45 micron filtration followed by:					
AA chelation-extraction or	218.4	3111 C [18th, 19th]	.....	I–1232–85	
Colorimetric (Diphenylcarbazide)	.....	3500–Cr B [20th] and 3500–Cr D [18th, 19th].	D1687–92(A)	I–1230–85	
19. Chromium-Total,[4] mg/L; Digestion [4] followed by:					
AA direct aspiration [36]	218.1	3111 B [18th, 19th]	D1687–92(B)	I–3236–85	974.27 [3]
AA chelation-extraction	218.3	3111 C [18th, 19th].			
AA furnace	218.2	3113 B [18th, 19th]	D1687–92(C)	I–3233–93 [46].	
ICP/AES [36]	200.7 [5]	3120 B [18th, 19th, 20th].			
DCP [36] or	.....	.....	D4190–94	.....	Note 34.
Colorimetric (Diphenylcarbazide)	.....	3500–Cr B [20th] and 3500–Cr D [18th, 19th].			

20. Cobalt—Total,[4] mg/L; Digestion [4] followed by:					
AA direct aspiration	219.1	3111 B or C [18th, 19th]	D3558–94(A or B)	I–3239–85	p. 37 [9]
AA furnace	219.2	3113 B [18th, 19th]	D3558–94(C)	I–4243–89 [51].	
ICP/AES	200.7 [5]	3120 B [18th, 19th, 20th]		I–4471–97 [50].	
DCP			D4190–94		Note 34.
21. Color platinum cobalt units or dominant wavelength, hue, luminance purity:					
Colorimetric (ADMI), or.					
(Platinum cobalt), or	110.1	2120 E [18th, 19th, 20th]			Note 18.
Spectrophotometric	110.2	2120 B [18th, 19th, 20th]		I–1250–85	
	110.3	2120 C [18th, 19th, 20th].			
22. Copper—Total,[4] mg/L; Digestion [4] followed by:					
AA direct aspiration [36]	220.1	3111 B or C [18th, 19th]	D1688–95(A or B)	I–3270–85 or I–3271–85	974.27 [3] p. 37 [9]
AA furnace	220.2	3113 B [18th, 19th]	D1688–95(C)	I–4274–89 [51]	
ICP/AES [36]	200.7 [5]	3120 B [18th, 19th, 20th]		I—4471—97 [50]	
DCP [36] or			D4190–94		Note 34.
Colorimetric (Neocuproine) or		3500–Cu B [20th] and 3500–Cu D [18th, 19th].			
(Bicinchoninate)		3500–Cu C [20th] and 3500–As B [18th, 19th].			Note 19.
23. Cyanide—Total, mg/L:					
Manual distillation with $MgCl_2$ followed by..		4500–CN C [18th, 19th, 20th].	D2036–98(A)		
Titrimetric, or		4500–CN D [18th, 19th, 20th].			p. 22 [9]
Spectrophotometric, manual or	335.2 [31]	4500–CN E [18th, 19th, 20th].	D2036–98(A)	I–3300–85	
Automated [20]	335.3 [31]			I–4302–85	
24. Available Cyanide, mg/L:					
Manual distillation with $MgCl_2$ followed by titrimetric or Spectrophotometric.	335.1	4500–CN G [18th, 19th, 20th].	D2036–98(B)		
Flow injection and ligand exchange, followed by amperometry.					OIA–1677 [44]
25. Fluoride—Total, mg/L:					
Manual distillation [6] followed by		4500–F B [18th, 19th, 20th]			
Electrode, manual or	340.2	4500–F C [18th, 19th, 20th]	D1179–93(B)		
Automated				I–4327–85	
Colorimetric (SPADNS)	340.1	4500–F D [18th, 19th, 20th]	D1179–93(A)		
Or Automated complexone	340.3	4500–F E [18th, 19th, 20th]			
26. Gold—Total,[4] mg/L; Digestion [4] followed by:					
AA direct aspiration	231.1	3111 B [18th, 19th]			
AA furnace, or	231.2				
DCP					Note 34.

TABLE IB—LIST OF APPROVED INORGANIC TEST PROCEDURES—Continued

Parameter, units and method	Reference (method number or page)				
	EPA [1, 35]	*Standard Methods* [Edition(s)]	ASTM	USGS [2]	Other
27. Hardness—Total, as $CaCO_3$, mg/L:					
Automated colorimetric,	130.1				
Titrimetric (EDTA), or Ca plus Mg as their carbonates, by inductively coupled plasma or AA direct aspiration (See Parameters 13 and 33).	130.2	2340 B or C [18th, 19th, 20th].	D1126–86(92)	I–1338–85	973.52B [3]
28. Hydrogen ion (pH), pH units:					
Electrometric measurement, or	150.1	4500–H^+ B [18th, 19th, 20th].	D1293–84 (90)(A or B)	I–1586–85	973.41 [3]
Automated electrode				I–2587–85	Note 21.
29. Iridium—Total,[4] mg/L; Digestion [4] followed by:					
AA direct aspiration or	235.1	3111 B [18th, 19th]			
AA furnace	235.2				
30. Iron—Total,[4] mg/L; Digestion [4] followed by:					
AA direct aspiration [36]	236.1	3111 B or C [18th, 19th]	D1068–96(A or B)	I–3381–85	974.27 [3]
AA furnace	236.2	3113 B [18th, 19th]	D1068–96(C)		
ICP/AES [36]	200.7 [5]	3120 B [18th, 19th, 20th]		I–4471–97 [50]	
DCP [36] or			D4190–94		Note 34.
Colorimetric (Phenanthroline)		3500–Fe B [20th] and 3500–Fe D [18th, 19th].	D1068–96(D)		Note 22.
31. Kjeldahl Nitrogen—Total, (as N), mg/L:					
Digestion and distillation followed by.	351.3	4500–N_{org} B or C and 4500–NH_3 B [18th, 19th, 20th].	D3590–89(A)		
Titration	351.3		D3590–89(A)		973.48 [3]
Nesslerization	351.3	4500–NH_3 C [18th]	D3590–89(A)		
Electrode	351.3	4500–NH_3 C [19th, 20th] and 4500–NH_3 E [18th].			
Automated phenate colorimetric	351.1			I–4551–78[8]	
Semi-automated block digestor colorimetric.	351.2		D3590–89(B)	I–4515–91 [45].	
Manual or block digestor potentiometric.	351.4		D3590–89(A)		
Block digester, followed by Auto distillation and Titration, or.					Note 39.
Nesslerization, or					Note 40.
Flow injection gas diffusion					Note 41.

32. Lead—Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration[36]	239.1	3111 B or C [18th, 19th]	D3559–96(A or B)	I–3399–85	974.27[3]
AA furnace	239.2	3113 B [18th, 19th]	D3559–96(D)	I–4403–89[51]	
ICP/AES[36]	200.7[5]	3120 B [18th, 19th, 20th]		I–4471–97[50]	
DCP[36]			D4190–94		Note 34.
Voltametry[11] or			D3559–96(C)		
Colorimetric (Dithizone)		3500–Pb B [20th] and 3500–Pb D [18th, 19th].			
33. Magnesium—Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration	242.1	3111 B [18th, 19th]	D511–93(B)	I–3447–85	974.27[3]
ICP/AES	200.7[5]	3120 B [18th, 19th, 20th]		I–4471–97[50]	
DCP or					Note 34.
Gravimetric		3500–Mg D [18th, 19th]			
34. Manganese-Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration[36]	243.1	3111 B [18th, 19th]	D858–95(A or B)	I–3454–85	974.27[3]
AA furnace	243.2	3113 B [18th, 19th]	D858–95(C)		
ICP/AES[36]	200.7[5]	3120 B [18th, 19th, 20th]		I–4471–97[50]	
DCP[36], or			D4190–94		Note 34
Colorimetric (Persulfate), or		3500–Mn B [20th] and 3500–Mn D [18th, 19th].			920.203[3]
(Periodate)					Note 23.
35. Mercury—Total,[4] mg/L:					
Cold vapor, manual or	245.1	3112 B [18th, 19th]	D3223–91	I–3462–85	977.22[3]
Automated	245.2				
Oxidation, purge and trap, and cold vapor atomic fluorescence spectrometry (ng/L).	1631E[43]				
36. Molybdenum—Total[4], mg/L; Digestion[4] followed by:					
AA direct aspiration	246.1	3111 D [18th, 19th]		I–3490–85	
AA furnace	246.2	3113 B [18th, 19th]		I–3492–96[47]	
ICP/AES	200.7[5]	3120 B [18th, 19th, 20th]		I–4471–97[50]	
DCP					Note 34.
37. Nickel—Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration[36]	249.1	3111 B or C [18th, 19th]	D1886–90(A or B)	I–3499–85.	
AA furnace	249.2	3113 B [18th, 19th]	D1886–90(C)	I–4503–89[51].	
ICP/AES[36]	200.7[5]	3120 B [18th, 19th, 20th]		I–4471–97[50].	
DCP[36], or			D4190–94		Note 34.
Colorimetric (heptoxime)		3500–Ni D [17th].			
38. Nitrate (as N), mg/L:					
Colorimetric (Brucine sulfate), or Nitrate-nitrite N minus Nitrite N (See parameters 39 and 40).	352.1				973.50,[3] 419D,[17] p. 28[9]
39. Nitrate-nitrite (as N), mg/L:					

TABLE IB—LIST OF APPROVED INORGANIC TEST PROCEDURES—Continued

Parameter, units and method	Reference (method number or page)				
	EPA [1, 35]	*Standard Methods* [Edition(s)]	ASTM	USGS [2]	Other
Cadmium reduction, Manual or ..	353.3	4500–NO_3^- E [18th, 19th, 20th].	D3867–99(B).		
Automated, or	353.2	4500–NO_3^- F [18th, 19th, 20th].	D3867–99(A)	I–4545–85.	
Automated hydrazine	353.1	4500–NO_3^- H [18th, 19th, 20th].			
40. Nitrite (as N), mg/L; Spectrophotometric:					
Manual or	354.1	4500–NO_2^- B [18th, 19th, 20th].			Note 25.
Automated (Diazotization)				I–4540–85.	
41. Oil and grease—Total recoverable, mg/L:					
Gravimetric (extraction)	413.1	5520B [18th, 19th, 20th] [38].			
Oil and grease and non-polar material, mg/L: Hexane extractable material (HEM): n-Hexane extraction and gravimetry.	1664A [42]	5520B [18th, 19th, 20th] [38].			
Silica gel treated HEM (SGT–HEM): Silica gel treatment and gravimetry.	1664A [42].				
42. Organic carbon—Total (TOC), mg/L:					
Combustion or oxidation	415.1	5310 B, C, or D [18th, 19th, 20th].	D2579–93 (A or B)		973.47,[3] p. 14 [24]
43. Organic nitrogen (as N), mg/L: Total Kjeldahl N (Parameter 31) minus ammonia N (Parameter 4).					
44. Orthophosphate (as P), mg/L; Ascorbic acid method:					
Automated, or	365.1	4500–P F [18th, 19th, 20th]		I–4601–85	973.56 [3]
Manual single reagent	365.2	4500–P E [18th, 19th, 20th]	D515–88(A)		973.55 [3]
Manual two reagent	365.3.				
45. Osmium—Total [4], mg/L; Digestion [4] followed by:					
AA direct aspiration, or	252.1	3111 D [18th, 19th].			
AA furnace	252.2.				
46. Oxygen, dissolved, mg/L:					
Winkler (Azide modification), or	360.2	4500–O C [18th, 19th, 20th]	D888–92(A)	I–1575–78 [8]	973.45B [3]
Electrode	360.1	4500–O G [18th, 19th, 20th].	D888–92(B)	I–1576–78 [8].	

47. Palladium—Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration, or	253.1	3111 B [18th, 19th]			p. S27[10]
AA furnace	253.2				p. S28[10]
DCP					Note 34.
48. Phenols, mg/L:					
Manual distillation[26]	420.1				Note 27.
Followed by:.					
Colorimetric (4AAP) manual, or.	420.1				Note 27.
Automated[19]	420.2.				
49. Phosphorus (elemental), mg/L:					
Gas-liquid chromatography					Note 28.
50. Phosphorus—Total, mg/L:					
Persulfate digestion followed by	365.2	4500–P B, 5 [18th, 19th, 20th].			973.55[3]
Manual or	365.2 or 365.3	4500–P E [18th, 19th, 20th]	D515–88(A)		
Automated ascorbic acid reduction.	365.1	4500–P F [18th, 19th, 20th]		I–4600–85	973.56[3]
Semi-automated block digestor	365.4		D515–88(B)	I–4610–91[48].	
51. Platinum—Total,[4] mg/L: Digestion[4] followed by:					
AA direct aspiration	255.1	3111 B [18th, 19th].			
AA furnace	255.2.				
DCP					Note 34
52. Potassium—Total,[4] mg/L: Digestion[4] followed by:					
AA direct aspiration	258.1	3111 B [18th, 19th]		I–3630–85	973.53[3]
ICP/AES	200.7[5]	3120 B [18th, 19th, 20th].			
Flame photometric, or		3500–K B [20th] and 3500–K D [18th, 19th].			
Colorimetric					317 B[17]
53. Residue—Total, mg/L:					
Gravimetric, 103–105°	160.3	2540 B [18th, 19th, 20th]		I–3750–85.	
54. Residue—filterable, mg/L:					
Gravimetric, 180°	160.1	2540 C [18th, 19th, 20th]		I–1750–85.	
55. Residue—nonfilterable (TSS), mg/L:					
Gravimetric, 103–105° post washing of residue.	160.2	2540 D [18th, 19th, 20th]		I–3765–85.	
56. Residue—settleable, mg/L:					
Volumetric, (Imhoff cone), or gravimetric.	160.5	2540 F [18th, 19th, 20th].			
57. Residue—Volatile, mg/L:					
Gravimetric, 550°	160.4			I–3753–85.	
58. Rhodium-Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration, or	265.1	3111 B [18th, 19th].			
AA furnace	265.2.				

TABLE IB—LIST OF APPROVED INORGANIC TEST PROCEDURES—Continued

Parameter, units and method	Reference (method number or page)				
	EPA [1, 35]	*Standard Methods* [Edition(s)]	ASTM	USGS [2]	Other
59. Ruthenium—Total,[4] mg/L; Digestion [4] followed by:					
AA direct aspiration, or	267.1	3111 B [18th, 19th].			
AA furnace	267.2.				
60. Selenium—Total,[4] mg/L; Digestion [4] followed by:					
AA furnace	270.2	3113 B [18th, 19th]	D3859–98(B)	I–4668–98 [49].	
ICP/AES,[36] or	200.7 [5]	3120 B [18th, 19th, 20th].			
AA gaseous hydride		3114 B [18th, 19th]	D3859–98(A)	I–3667–85.	
61. Silica [37]—Dissolved, mg/L; 0.45 micron filtration followed by:					
Colorimetric, Manual or	370.1	4500–SiO_2 C [20th] and 4500–Si D [18th, 19th].	D859–94	I–1700–85.	
Automated (Molybdosilicate), or				I–2700–85.	
ICP	200.7 [5]	3120 B [18th, 19th, 20th]		I–4471–97 [50].	
62. Silver—Total,[4] mg/L: Digestion [4 29] followed by:					
AA direct aspiration	272.1	3111 B or C [18th, 19th]		I–3720–85	974.27,[3] p. 37 [9]
AA furnace	272.2	3113 B [18th, 19th]		I–4724–89 [51]	
ICP/AES	200.7 [5]	3120 B [18th, 19th, 20th]		I–4471–97 [50]	
DCP					Note 34.
63. Sodium—Total,[4] mg/L; Digestion [4] followed by:					
AA direct aspiration	273.1	3111 B [18th, 19th]		I–3735–85	973.54 [3]
ICP/AES	200.7 [5]	3120 B [18th, 19th, 20th]		I–4471–97 [50]	
DCP, or					Note 34.
Flame photometric		3500 Na B [20th] and 3500 Na D [18th, 19th].			
64. Specific conductance, micromhos/cm at 25 °C:					
Wheatstone bridge	120.1	2510 B [18th, 19th, 20th]	D1125–95(A)	I–2781–85	973.40 [3]
65. Sulfate (as SO_4), mg/L:					
Automated colorimetric (barium chloranilate).	375.1.				
Gravimetric	375.3	4500–SO_4^{-2}C or D [18th, 19th, 20th].			925.54 [3]
Turbidimetric	375.4		D516–90		426C [30]
66. Sulfide (as S), mg/L:					
Titrimetric (iodine), or	376.1	4500–S^{-2}F [19th, 20th] or 4500–S^{-2}E [18th].		I–3840–85.	
Colorimetric (methylene blue)	376.2	4500–S^{-2}D [18th, 19th, 20th].			
67. Sulfite (as SO_3), mg/L:					

Titrimetric (iodine-iodate)	377.1	4500–SO_3^{-2}B [18th, 19th, 20th].			
68. Surfactants, mg/L:					
Colorimetric (methylene blue)	425.1	5540 C [18th, 19th, 20th]	D2330–88.		
69. Temperature, °C:					
Thermometric	170.1	2550 B [18th, 19th, 20th]			Note 32.
70. Thallium—Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration	279.1	3111 B [18th, 19th].			
AA furnace	279.2.				
ICP/AES	200.7[5]	3120 B [18th, 19th, 20th].			
71. Tin—Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration	282.1	3111 B [18th, 19th]		I–3850–78[8].	
AA furnace, or	282.2	3113 B [18th, 19th].			
ICP/AES	200.7[5].				
72. Titanium—Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration	283.1	3111 D [18th, 19th].			
AA furnace	283.2.				
DCP					Note 34.
73. Turbidity, NTU:					
Nephelometric	180.1	2130 B [18th, 19th, 20th]	D1889–94(A)	I–3860–85.	
74. Vanadium—Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration	286.1	3111 D [18th, 19th].			
AA furnace	286.2		D3373–93.		
ICP/AES	200.7[5]	3120 B [18th, 19th, 20th]		I–4471–97[50].	
DCP, or			D4190–94		Note 34.
Colorimetric (Gallic Acid)		3500–V B [20th] and 3500–V D [18th, 19th].			
75. Zinc—Total,[4] mg/L; Digestion[4] followed by:					
AA direct aspiration[36]	289.1	3111 B or C [18th, 19th]	D1691–95(A or B)	I–3900–85	974.27,[3] p. 37[9]
AA furnace	289.2.				
ICP/AES[36]	200.7[5]	3120 B [18th, 19th, 20th]		I–4471–97[50].	
DCP,[36] or			D4190–94		Note 34.
Colorimetric (Dithizone) or		3500–Zn E [18th, 19th].			
(Zincon)		3500–Zn B [20th] and 3500–Zn F [18th, 19th].			Note 33.

Table 1B Notes:

[1] "Methods for Chemical Analysis of Water and Wastes," Environmental Protection Agency, Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI), EPA–600/4–79–020, Revised March 1983 and 1979 where applicable.

[2] Fishman, M.J., *et al.* "Methods for Analysis of Inorganic Substances in Water and Fluvial Sediments, "U.S. Department of the Interior, Techniques of Water-Resource Investigations of the U.S. Geological Survey, Denver, CO, Revised 1989, unless otherwise stated.

[3] "Official Methods of Analysis of the Association of Official Analytical Chemists," methods manual, 15th ed. (1990).

[4] For the determination of total metals the sample is not filtered before processing. A digestion procedure is required to solubilize suspended material and to destroy possible organic-metal complexes. Two digestion procedures are given in ''Methods for Chemical Analysis of Water and Wastes, 1979 and 1983''. One (Section 4.1.3), is a vigorous digestion using nitric acid. A less vigorous digestion using nitric and hydrochloric acids (Section 4.1.4) is preferred; however, the analyst should be cautioned that this mild digestion may not suffice for all samples types. Particularly, if a colorimetric procedure is to be employed, it is necessary to ensure that all organo-metallic bonds be broken so that the metal is in a reactive state. In those situations, the vigorous digestion is to be preferred making certain that at no time does the sample go to dryness. Samples containing large amounts of organic materials may also benefit by this vigorous digestion, however, vigorous digestion with concentrated nitric acid will convert antimony and tin to insoluble oxides and render them unavailable for analysis. Use of ICP/AES as well as determinations for certain elements such as antimony, arsenic, the noble metals, mercury, selenium, silver, tin, and titanium require a modified sample digestion procedure and in all cases the method write-up should be consulted for specific instructions and/or cautions.

Note to Table 1B Note 4: If the digestion procedure for direct aspiration AA included in one of the other approved references is different than the above, the EPA procedure must be used. Dissolved metals are defined as those constituents which will pass through a 0.45 micron membrane filter. Following filtration of the sample, the referenced procedure for total metals must be followed. Sample digestion of the filtrate for dissolved metals (or digestion of the original sample solution for total metals) may be omitted for AA (direct aspiration or graphite furnace) and ICP analyses, provided the sample solution to be analyzed meets the following criteria:

a. has a low COD (<20)

b. is visibly transparent with a turbidity measurement of 1 NTU or less

c. is colorless with no perceptible odor, and

d. is of one liquid phase and free of particulate or suspended matter following acidification.

[5] The full text of Method 200.7, ''Inductively Coupled Plasma Atomic Emission Spectrometric Method for Trace Element Analysis of Water and Wastes,'' is given at Appendix C of this Part 136.

[6] Manual distillation is not required if comparability data on representative effluent samples are on company file to show that this preliminary distillation step is not necessary: however, manual distillation will be required to resolve any controversies.

[7] Ammonia, Automated Electrode Method, Industrial Method Number 379–75 WE, dated February 19, 1976, Bran & Luebbe (Technicon) Auto Analyzer II, Bran & Luebbe Analyzing Technologies, Inc., Elmsford, NY 10523.

[8] The approved method is that cited in ''Methods for Determination of Inorganic Substances in Water and Fluvial Sediments'', USGS TWRI, Book 5, Chapter A1 (1979).

[9] American National Standard on Photographic Processing Effluents, Apr. 2, 1975. Available from ANSI, 25 West 43rd Street, New York, NY 10036.

[10] ''Selected Analytical Methods Approved and Cited by the United States Environmental Protection Agency'', Supplement to the Fifteenth Edition of Standard Methods for the Examination of Water and Wastewater (1981).

[11] The use of normal and differential pulse voltage ramps to increase sensitivity and resolution is acceptable.

[12] Carbonaceous biochemical oxygen demand ($CBOD_5$) must not be confused with the traditional BOD_5 test method which measures ''total BOD''. The addition of the nitrification inhibitor is not a procedural option, but must be included to report the $CBOD_5$ parameter. A discharger whose permit requires reporting the traditional BOD_5 may not use a nitrification inhibitor in the procedure for reporting the results. Only when a discharger's permit specifically states $CBOD_5$ is required can the permittee report data using a nitrification inhibitor.

[13] OIC Chemical Oxygen Demand Method, Oceanography International Corporation, 1978, 512 West Loop, PO Box 2980, College Station, TX 77840.

[14] Chemical Oxygen Demand, Method 8000, Hach Handbook of Water Analysis, 1979, Hach Chemical Company, PO Box 389, Loveland, CO 80537.

[15] The back titration method will be used to resolve controversy.

[16] Orion Research Instruction Manual, Residual Chlorine Electrode Model 97–70, 1977, Orion Research Incorporated, 840 Memorial Drive, Cambridge, MA 02138. The calibration graph for the Orion residual chlorine method must be derived using a reagent blank and three standard solutions, containing 0.2, 1.0, and 5.0 mL 0.00281 N potassium iodate/100 mL solution, respectively.

[17] The approved method is that cited in Standard Methods for the Examination of Water and Wastewater, 14th Edition, 1976.

[18] National Council of the Paper Industry for Air and Stream Improvement, Inc. Technical Bulletin 253, December 1971.

[19] Copper, Biocinchoinate Method, Method 8506, Hach Handbook of Water Analysis, 1979, Hach Chemical Company, PO Box 389, Loveland, CO 80537.

[20] After the manual distillation is completed, the autoanalyzer manifolds in EPA Methods 335.3 (cyanide) or 420.2 (phenols) are simplified by connecting the re-sample line directly to the sampler. When using the manifold setup shown in Method 335.3, the buffer 6.2 should be replaced with the buffer 7.6 found in Method 335.2.

[21] Hydrogen ion (pH) Automated Electrode Method, Industrial Method Number 378–75WA, October 1976, Bran & Luebbe (Technicon) Autoanalyzer II. Bran & Luebbe Analyzing Technologies, Inc., Elmsford, NY 10523.

[22] Iron, 1,10-Phenanthroline Method, Method 8008, 1980, Hach Chemical Company, PO Box 389, Loveland, CO 80537.

[23] Manganese, Periodate Oxidation Method, Method 8034, Hach Handbook of Wastewater Analysis, 1979, pages 2–113 and 2–117, Hach Chemical Company, Loveland, CO 80537.

[24] Wershaw, R.L., *et al*, ''Methods for Analysis of Organic Substances in Water,'' Techniques of Water-Resources Investigation of the U.S. Geological Survey, Book 5, Chapter A3, (1972 Revised 1987) p. 14.

[25] Nitrogen, Nitrite, Method 8507, Hach Chemical Company, PO Box 389, Loveland, CO 80537.

[26] Just prior to distillation, adjust the sulfuric-acid-preserved sample to pH 4 with 1 + 9 NaOH.

[27] The approved method is cited in Standard Methods for the Examination of Water and Wastewater, 14th Edition. The colorimetric reaction is conducted at a pH of 10.0±0.2. The approved methods are given on pp 576–81 of the 14th Edition: Method 510A for distillation, Method 510B for the manual colorimetric procedure, or Method 510C for the manual spectrometric procedure.

[28] R.F. Addison and R.G. Ackman, ''Direct Determination of Elemental Phosphorus by Gas-Liquid Chromatography,'' Journal of Chromatography, Vol. 47, No. 3, pp. 421–426, 1970.

[29] Approved methods for the analysis of silver in industrial wastewaters at concentrations of 1 mg/L and above are inadequate where silver exists as an inorganic halide. Silver halides such as the bromide and chloride are relatively insoluble in reagents such as nitric acid but are readily soluble in an aqueous buffer of sodium thiosulfate and sodium hydroxide to pH of 12. Therefore, for levels of silver above 1 mg/L, 20 mL of sample should be diluted to 100 mL by adding 40 mL each of 2 M $Na_2S_2O_3$ and NaOH. Standards should be prepared in the same manner. For levels of silver below 1 mg/L the approved method is satisfactory.

[30] The approved method is that cited in Standard Methods for the Examination of Water and Wastewater, 15th Edition.

[31] EPA Methods 335.2 and 335.3 require the NaOH absorber solution final concentration to be adjusted to 0.25 N before colorimetric determination of total cyanide.
[32] Stevens, H.H., Ficke, J.F., and Smoot, G.F., ''Water Temperature—Influential Factors, Field Measurement and Data Presentation,'' Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 1, Chapter D1, 1975.
[33] Zinc, Zincon Method, Method 8009, Hach Handbook of Water Analysis, 1979, pages 2–231 and 2–333, Hach Chemical Company, Loveland, CO 80537.
[34] ''Direct Current Plasma (DCP) Optical Emission Spectrometric Method for Trace Elemental Analysis of Water and Wastes, Method AES0029,'' 1986—Revised 1991, Thermo Jarrell Ash Corporation, 27 Forge Parkway, Franklin, MA 02038.
[35] Precision and recovery statements for the atomic absorption direct aspiration and graphite furnace methods, and for the spectrophotometric SDDC method for arsenic are provided in Appendix D of this part titled, ''Precision and Recovery Statements for Methods for Measuring Metals''.
[36] ''Closed Vessel Microwave Digestion of Wastewater Samples for Determination of Metals'', CEM Corporation, PO Box 200, Matthews, NC 28106–0200, April 16, 1992. Available from the CEM Corporation.
[37] When determining boron and silica, only plastic, PTFE, or quartz laboratory ware may be used from start until completion of analysis.
[38] Only use Trichlorotrifluorethane (1,1,2-trichloro-1,2,2-trifluoroethane; CFC–113) extraction solvent when determining Total Recoverable Oil and Grease (analogous to EPA Method 413.1). Only use *n*-hexane extraction solvent when determining Hexane Extractable Material (analogous to EPA Method 1664A). Use of other extraction solvents is strictly prohibited.
[39] Nitrogen, Total Kjeldahl, Method PAI–DK01 (Block Digestion, Steam Distillation, Titrimetric Detection), revised 12/22/94, OI Analytical/ALPKEM, PO Box 9010, College Station, TX 77842.
[40] Nitrogen, Total Kjeldahl, Method PAI–DK02 (Block Digestion, Steam Distillation, Colorimetric Detection), revised 12/22/94, OI Analytical/ALPKEM, PO Box 9010, College Station, TX 77842.
[41] Nitrogen, Total Kjeldahl, Method PAI–DK03 (Block Digestion, Automated FIA Gas Diffusion), revised 12/22/94, OI Analytical/ALPKEM, PO Box 9010, College Station, TX 77842.
[42] Method 1664, Revision A ''n-Hexane Extractable Material (HEM; Oil and Grease) and Silica Gel Treated n-Hexane Extractable Material (SGT–HEM; Non-polar Material) by Extraction and Gravimetry'' EPA–821–R–98–002, February 1999. Available at NTIS, PB–121949, U.S. Department of Commerce, 5285 Port Royal, Springfield, Virginia 22161.
[43] USEPA. 2002. Method 1631, Revision E, ''Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry.'' September 2002. Office of Water, U.S. Environmental Protection Agency (EPA–821–R–02–019). The application of clean techniques described in EPA's draft Method 1669: Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels (EPA–821–R–96–011) are recommended to preclude contamination at low-level, trace metal determinations.
[44] Available Cyanide, Method OIA–1677 (Available Cyanide by Flow Injection, Ligand Exchange, and Amperometry), ALPKEM, A Division of OI Analytical, PO Box 9010, College Station, TX 77842–9010.
[45] ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Ammonia Plus Organic Nitrogen by a Kjeldahl Digestion Method'', Open File Report (OFR) 00–170.
[46] ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Chromium in Water by Graphite Furnace Atomic Absorption Spectrophotometry'', Open File Report (OFR) 93–449.
[47] ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Molybdenum by Graphite Furnace Atomic Absorption Spectrophotometry'', Open File Report (OFR) 97–198.
[48] ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Total Phosphorus by Kjeldahl Digestion Method and an Automated Colorimetric Finish That Includes Dialysis'' Open File Report (OFR) 92–146.
[49] ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Arsenic and Selenium in Water and Sediment by Graphite Furnace-Atomic Absorption Spectrometry'' Open File Report (OFR) 98–639.
[50] ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Elements in Whole-water Digests Using Inductively Coupled Plasma-Optical Emission Spectrometry and Inductively Coupled Plasma-Mass Spectrometry'', Open File Report (OFR) 98–165.
[51] ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Inorganic and Organic Constituents in Water and Fluvial Sediment'', Open File Report (OFR) 93–125.

TABLE IC—LIST OF APPROVED TEST PROCEDURES FOR NON-PESTICIDE ORGANIC COMPOUNDS

Parameter [1]	EPA method number [2, 7]			Other approved methods		
	GC	GC/MS	HPLC	*Standard Methods* [Edition(s)]	ASTM	Other
1. Acenaphthene	610	625, 1625B	610	6440 B [18th, 19th, 20th].	D4657–92	Note 9, p.27.
2. Acenaphthylene	610	625, 1625B	610	6440 B, 6410 B [18th, 19th, 20th].	D4657–92	Note 9, p.27.
3. Acrolein	603	624[4], 1624B				
4. Acrylonitrile	603	624[4], 1624B				
5. Anthracene	610	625, 1625B	610	6410 B, 6440 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27.

TABLE IC—LIST OF APPROVED TEST PROCEDURES FOR NON-PESTICIDE ORGANIC COMPOUNDS—Continued

Parameter [1]	EPA method number [2, 7]			Other approved methods		
	GC	GC/MS	HPLC	*Standard Methods* [Edition(s)]	ASTM	Other
6. Benzene	602	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6220 B [18th, 19th].		
7. Benzidine		625[5], 1625B	605			Note 3, p.1.
8. Benzo(a)anthracene	610	625, 1625B	610	6410 B, 6440 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27.
9. Benzo(a)pyrene	610,	625, 1625B	610	6410 B, 6440 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27.
10. Benzo(b)fluoranthene	610	625, 1625B	610	6410 B, 6440 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27.
11. Benzo(g, h, i)perylene	610	625, 1625B	610	6410 B, 6440 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27.
12. Benzo(k)fluoranthene	610	625, 1625B	610	6410 B, 6440 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27.
13. Benzyl chloride						Note 3, p 130: Note 6, p. S102.
14. Benzyl butyl phthalate	606	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
15. Bis(2-chloroethoxy) methane	611	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
16. Bis(2-chloroethyl) ether	611	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
17. Bis(2-ethylhexyl) phthalate	606	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
18. Bromodichloromethane	601	624, 1624B		6200 C [20th] and 6230 B [18th, 19th], 6200 B [20th] and 6210 B [18th, 19th].		
19. Bromoform	601	624, 1624B		6200 C [20th] and 6230 B [18th, 19th], 6200 B [20th] and 6210 B [18th, 19th].		
20. Bromomethane	601	624, 1624B		6200 C [20th] and 6230 B [18th, 19th], 6200 B [20th] and 6210 B [18th, 19th].		
21. 4-Bromophenylphenyl ether	611	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
22. Carbon tetrachloride	601	624, 1624B		6200 C [20th] and 6230 B [18th, 19th].		Note 3, p. 130.
23. 4-Chloro-3-methylphenol	604	625,1625B		6410 B, 6420 B [18th, 19th, 20th].		Note 9, p. 27.

24. Chlorobenzene	601, 602	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6220 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th],.		Note 3, p. 130.
25. Chloroethane	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		
26. 2-Chloroethylvinyl ether	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		
27. Chloroform:	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		Note 3, p 130.
28. Chloromethane	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th] 6200C [20th] and 6230 B [18th, 19th].		
29. 2-Chloronaphthalene	612	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
30. 2-Chlorophenol	604	625, 1625B		6410 B, 6420 B [18th, 19th, 20th].		Note 9, p. 27.
31. 4-Chlorophenylphenyl ether	611	625, 1625B		6410 B, [18th, 19th, 20th].		Note 9, p. 27.
32. Chrysene	610	625, 1625B	610	6410 B, 6440 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27.
33. Dibenzo(a,h)anthracene	610	625, 1625B	610	6410 B, 6440 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27.
34. Dibromochloromethane	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th] 6200 C [20th] and 6230 B [18th, 19th].		
35. 1,2-Dichlorobenzene	601, 602, 612	624, 625, 1625B ..		6200 C [20th] and 6220 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th], 6410 B [18th, 19th, 20th].		Note 9, p 27.
36. 1,3-Dichlorobenzene	601, 602, 612	624, 625, 1625B ..		6200 C [20th] and 6220 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th], 6410 B [18th, 19th, 20th].		Note 9, p. 27.

TABLE IC—LIST OF APPROVED TEST PROCEDURES FOR NON-PESTICIDE ORGANIC COMPOUNDS—Continued

Parameter [1]	EPA method number [2, 7]			Other approved methods		
	GC	GC/MS	HPLC	*Standard Methods* [Edition(s)]	ASTM	Other
37. 1,4-Dichlorobenzene	601, 602, 612	624, 625, 1625B		6200 C [20th] and 6220 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th], 6410 B [18th, 19th, 20th].		Note 9, p. 27.
38. 3,3-Dichlorobenzidine		625, 1625B	605	6410 B [18th, 19th, 20th].		
39. Dichlorodifluoromethane	601			6200 C [20th] and 6230 B [18th, 19th].		
40. 1,1-Dichloroethane	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		
41. 1,2-Dichloroethane	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		
42. 1,1-Dichloroethene	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		
43. trans-1,2-Dichloroethene	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		
44. 2,4-Dichlorophenol	604	625, 1625B		6410 B, 6420 B [18th, 19th, 20th].		Note 9, p. 27.
45. 1,2-Dichloropropane	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		
46. cis-1,3-Dichloropropene	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		
47. trans-1,3-Dichloropropene	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		
48. Diethyl phthalate	606	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.

49. 2,4-Dimethylphenol	604	625, 1625B		6410 B, 6420 B [18th, 19th, 20th].		Note 9, p. 27.
50. Dimethyl phthalate	606	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
51. Di-n-butyl phthalate	606	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
52. Di-n-octyl phthalate	606	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
53. 2,3-Dinitrophenol	604	625, 1625B		6410 B, 6420 B [18th, 19th, 20th].		
54. 2,4-Dinitrotoluene	609	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
55. 2,6-Dinitrotoluene	609	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
56. Epichlorohydrin						Note 3, p. 130; Note 6, p. S102.
57. Ethylbenzene	602	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6220 B [18th, 19th].		
58. Fluoranthene	610	625, 1625B	610	6410 B, 6440 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27.
59. Fluorene	610	625, 1625B	610	6410 B, 6440 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27.
60. 1,2,3,4,6,7,8-Heptachloro- dibenzofuran		1613B				
61. 1,2,3,4,7,8,9-Heptachloro- dibenzofuran		1613B				
62. 1,2,3,4,6,7,8-Heptachloro- dibenzo-p-dioxin		1613B				
63. Hexachlorobenzene	612	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
64. Hexachlorobutadiene	612	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
65. Hexachlorocyclopentadiene	612	[5]625, 1625B		6410 [18th, 19th, 20th]		Note 9, p. 27.
66. 1,2,3,4,7,8-Hexachloro- dibenzofuran		1613B.				
67. 1,2,3,6,7,8-Hexachloro- dibenzofuran		1613B.				
68. 1,2,3,7,8,9-Hexachloro- dibenzofuran		1613B.				
69. 2,3,4,6,7,8-Hexachloro- dibenzofuran		1613B.				
70. 1,2,3,4,7,8-Hexachloro- dibenzo-p-dioxin		1613B.				
71. 1,2,3,6,7,8-Hexachloro- dibenzo-p-dioxin		1613B.				
72. 1,2,3,7,8,9-Hexachloro- dibenzo-p-dioxin		1613B.				
73. Hexachloroethane	616	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
74. Ideno(1,2,3-cd) pyrene	610	625, 1625B	610	6410 B, 6440 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27.
75. Isophorone	609	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27.
76. Methylene chloride	601	624, 1624B		6200 C [20th] and 6230 B [18th, 19th].		Note 3, p. 130.
77. 2-Methyl-4,6-dinitrophenol	604	625, 1625B		6420 B, 6410 B [18th, 19th, 20th].		Note 9, p. 27.

TABLE IC—LIST OF APPROVED TEST PROCEDURES FOR NON-PESTICIDE ORGANIC COMPOUNDS—Continued

Parameter [1]	EPA method number [2, 7]			Other approved methods		
	GC	GC/MS	HPLC	*Standard Methods* [Edition(s)]	ASTM	Other
78. Naphthalene	610	625, 1625B	610	6440 B, 6410 B [18th, 19th, 20th].		Note 9, p. 27.
79. Nitrobenzene	609	625, 1625B		6410 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27.
80. 2-Nitrophenol	604	625, 1625B		6410 B, 6420 B [18th, 19th, 20th].		Note 9, p. 27
81. 4-Nitrophenol	604	625, 1625B		6410 B, 6420 B [18th, 19th, 20th].		Note 9, p. 27
82. N-Nitrosodimethylamine	607	625[5], 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27
83. N-Nitrosodi-n-propylamine	607	625, 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27
84. N-Nitrosodiphenylamine	607	625[5], 1625B		6410 B [18th, 19th, 20th].		Note 9, p. 27
85. Octachlorodibenzofuran		1613B.				
86. Octachlorodibenzo-p-dioxin		1613B.				
87. 2,2'-Oxybis(2-chloropropane) [also known as bis(2-chloroisopropyl) ether].	611	625, 1625B		6410 B [18th, 19th, 20th].		
88. PCB–1016	608	625		6410 B [18th, 19th, 20th].		Note 3, p. 43
89. PCB–1221	608	625		6410 B [18th, 19th, 20th].		Note 3, p. 43
90. PCB–1232	608	625		6410 B [18th, 19th, 20th].		Note 3, p. 43
91. PCB–1242	608	625		6410 B [18th, 19th, 20th].		Note 3, p. 43
92. PCB–1248	608	625.				
93. PCB–1254	608	625		6410 B [18th, 19th, 20th].		Note 3, p. 43
94. PCB–1260	608	625		6410 B, 6630 B [18th, 19th, 20th].		Note 3, p. 43
95. 1,2,3,7,8-Pentachloro- dibenzofuran		1613B.				
96. 2,3,4,7,8-Pentachloro- dibenzofuran		1613B.				
97. 1,2,3,7,8,-Pentachlorodibenzo-p-dioxin		1613B.				
98. Pentachlorophenol	604	625, 1625B		6410 B, 6630 B [18th, 19th, 20th].		Note 3, p. 140; Note 9, p. 27
99. Phenanthrene	610	625, 1625B	610	6410 B, 6440 B [18th, 19th, 20th].	D4657–92	Note 9, p. 27
100. Phenol	604	625, 1625B		6420 B, 6410 B [18th, 19th, 20th].		Note 9, p. 27
101. Pyrene	610	625, 1625B	610	6440 B, 6410 B D4675–92 [18th, 19th, 20th].	D4675–92	Note 9, p. 27

102. 2,3,7,8-Tetrachloro- dibenzofuran		1613B.				
103. 2,3,7,8-Tetrachlorodibenzo-p-dioxin		613, 1613B.				
104. 1,1,2,2-Tetrachloroethane	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		Note 3, p. 130
105. Tetrachloroethene	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		Note 3, p. 130
106. Toluene	602	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6220 B [18th, 19th].		
107. 1,2,4-Trichlorobenzene	612	625, 1625B		6410 B [18th, 19th, 20th].		Note 3, p. 130; Note 9, p. 27.
108. 1,1,1-Trichloroethane	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		
109. 1,1,2-Trichloroethane	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		Note 3, p. 130
110. Trichloroethene	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		
111. Trichlorofluoromethane	601	624		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		
112. 2,4,6-Trichlorophenol	604	625, 1625B		6420 B, 6410 B [18th, 19th, 20th].		Note 9, p. 27.
113. Vinyl chloride	601	624, 1624B		6200 B [20th] and 6210 B [18th, 19th], 6200 C [20th] and 6230 B [18th, 19th].		

Table IC notes:

[1] All parameters are expressed in micrograms per liter (µg/L) except for Method 1613B in which the parameters are expressed in picograms per liter (pg/L).

[2] The full text of Methods 601–613, 624, 625, 1624B, and 1625B, are given at Appendix A, ''Test Procedures for Analysis of Organic Pollutants,'' of this Part 136. The full text of Method 1613B is incorporated by reference into this Part 136 and is available from the National Technical Information Services as stock number PB95–104774. The standardized test procedure to be used to determine the method detection limit (MDL) for these test procedures is given at Appendix B, ''Definition and Procedure for the Determination of the Method Detection Limit,'' of this Part 136.

[3] ''Methods for Benzidine: Chlorinated Organic Compounds, Pentachlorophenol and Pesticides in Water and Wastewater,'' U.S. Environmental Protection Agency, September, 1978.

[4] Method 624 may be extended to screen samples for Acrolein and Acrylonitrile. However, when they are known to be present, the preferred method for these two compounds is Method 603 or Method 1624B.

[5] Method 625 may be extended to include benzidine, hexachlorocyclopentadiene, N-nitrosodimethylamine, and N-nitrosodiphenylamine. However, when they are known to be present, Methods 605, 607, and 612, orMethod 1625B, are preferred methods for these compounds.

[6] ''Selected Analytical Methods Approved and Cited by the United States Environmental Protection Agency,'' Supplement to the Fifteenth Edition of Standard Methods for the Examination of Water and Wastewater (1981).

[7] Each Analyst must make an initial, one-time demonstration of their ability to generate acceptable precision and accuracy with Methods 601–603, 624, 625, 1624B, and 1625B (See Appendix A of this Part 136) in accordance with procedures each in Section 8.2 of each of these Methods. Additionally, each laboratory, on an on-going basis must spike and analyze 10% (5% for Methods 624 and 625 and 100% for methods 1624B and 1625B) of all samples to monitor and evaluate laboratory data quality in accordance with Sections 8.3 and 8.4 of these Methods. When the recovery of any parameter falls outside the warning limits, the analytical results for that parameter in the unspiked sample are suspect and cannot be reported to demonstrate regulatory compliance.

NOTE: These warning limits are promulgated as an ''interim final action with a request for comments.''

[8] ''Organochlorine Pesticides and PCBs in Wastewater Using Empore TM Disk'' 3M Corporation Revised 10/28/94.

[9] USGS Method 0–3116–87 from ''Methods of Analysis by U.S. Geological Survey National Water Quality Laboratory—Determination of Inorganic and Organic Constituents in Water and Fluvial Sediments'' U.S. Geological Survey, Open File Report 93–125.

TABLE ID—LIST OF APPROVED TEST PROCEDURES FOR PESTICIDES [1]

Parameter	Method	EPA [2, 7]	*Standard Methods* 18th, 19th, 20th Ed.	ASTM	Other
1. Aldrin	GC	608	6630 B & C	D3086–90	Note 3, p. 7; Note 4, p. 27; Note 8.
	GC/MS	625	6410 B		
2. Ametryn	GC				Note 3, p. 83; Note 6, p S68.
3. Aminocarb	TLC				Note 3, p. 94; Note 6, p. S16.
4. Atraton	GC				Note 3, p. 83; Note 6, p. S68.
5. Atrazine	GC				Note 3, p. 83; Note 6, p. S68; Note 9.
6. Azinphos methyl	GC				Note 3, p. 25; Note 6, p. S51.
7. Barban	TLC				Note 3, p. 104; Note 6, p. S64.
8. α-BHC	GC	608	6630 B & C	D3086–90	Note 3, p. 7; Note 8.
	GC/MS	625 [5]	6410 B.		
9. β-BHC	GC	608	6630 C	D3086–90	Note 8.
	GC/MS	625 [5]	6410 B.		
10. δ-BHC	GC	608	6630 C	D3086–90	Note 8.
	GC/MS	625 [5]	6410 B.		
11. γ-BHC (Lindane)	GC	608	6630 B & C	D3086–90	Note 3, p. 7; Note 4, p. 27; Note 8.
	GC/MS	625	6410 B.		
12. Captan	GC		6630 B	D3086–90	Note 3, p. 7.
13. Carbaryl	TLC				Note 3, p. 94, Note 6, p. S60.
14. Carbophenothion	GC				Note 4, p. 27; Note 6, p. S73.
15. Chlordane	GC	608	6630 B & C	D3086–90	Note 3, p. 7; Note 4, p. 27; Note 8.
	GC/MS	625	6410 B.		
16. Chloropropham	TLC				Note 3, p. 104; Note 6, p. S64.
17. 2,4-D	GC		6640 B		Note 3, p. 115; Note 4, p. 40.
18. 4,4′-DDD	GC	608	6630 B & C	D3086–90	Note 3, p. 7; Note 4, p. 27; Note 8.
	GC/MS	625	6410 B.		
19. 4,4′-DDE	GC	608	6630 B & C	D3086–90	Note 3, p. 7; Note 4, p. 27; Note 8.
	GC/MS	625	6410 B.		
20. 4,4′-DDT	GC	608	6630 B & C	D3086–90	Note 3, p. 7; Note 4, p. 27; Note 8.
	GC/MS	625	6410 B.		
21. Demeton-O	GC				Note 3, p. 25; Note 6, p. S51.
22. Demeton-S	GC				Note 3, p. 25; Note 6, p. S51.
23. Diazinon	GC				Note 3, p. 25; Note 4, p. 27; Note 6, p. S51.
24. Dicamba	GC				Note 3, p. 115.
25. Dichlofenthion	GC				Note 4, p. 27; Note 6, p. S73.
26. Dichloran	GC		6630 B & C		Note 3, p. 7.

27. Dicofol	GC			D3086–90.	
28. Dieldrin	GC	608	6630 B & C		Note 3, p. 7; Note 4, p. 27; Note 8.
	GC/MS	625	6410 B.		
29. Dioxathion	GC				Note 4, p. 27; Note 6, p. S73.
30. Disulfoton	GC				Note 3, p. 25; Note 6 p. S51.
31. Diuron	TLC				Note 3, p. 104; Note 6, p. S64.
32. Endosulfan I	GC	608	6630 B & C	D3086–90	Note 3, p. 7; Note 4, p. 27; Note 8.
	GC/MS	625[5]	6410 B.		
33. Endosulfan II	GC	608	6630 B & C	D3086–90	Note 3, p. 7; Note 8.
	GC/MS	625[5]	6410 B.		
34. Endosulfan Sulfate	GC	608	6630 C		Note 8.
	GC/MS	625	6410 B.		
35. Endrin	GC	608	6630 B & C	D3086–90	Note 3, p. 7; Note 4, p. 27; Note 8.
	GC/MS	625[5]	6410 B.		
36. Endrin aldehyde	GC	608			Note 8.
	GC/MS	625.			
37. Ethion	GC				Note 4, p. 27; Note 6, p. S73.
38. Fenuron	TLC				Note 3, p. 104; Note 6, p. S64.
39. Fenuron-TCA	TLC				Note 3, p. 104; Note 6, p. S64.
40. Heptachlor	GC	608	6630 B & C	3086–90	Note 3, p. 7; Note 4, p. 27; Note 8.
	GC/MS	625	6410 B.		
41. Heptachlor epoxide	GC	608	6630 B & C	D3086–90	Note 3, p. 7; Note 4, p. 27; Note 6, p. S73; Note 8.
	GC/MS	625	6410 B.		
42. Isodrin	GC				Note 4, p. 27; Note 6, p. S73.
43. Linuron	GC				Note 3, p. 104; Note 6, p. S64.
44. Malathion	GC		6630 C		Note 3, p. 25; Note 4, p. 27; Note 6, p. S51
45. Methiocarb	TLC				Note 3, p. 94; Note 6, p. S60.
46. Methoxychlor	GC		6630 B & C	D3086–90	Note 3, p. 7; Note 4, p. 27; Note 8.
47. Mexacarbate	TLC				Note 3, p. 94; Note 6, p. S60.
48. Mirex	GC		6630 B & C		Note 3, p. 7; Note 4, p. 27.
49. Monuron	TLC				Note 3, p. 104; Note 6, p. S64.
50. Monuron	TLC				Note 3, p. 104; Note 6, p. S64.
51. Nuburon	TLC				Note 3, p. 104; Note 6, p. S64.
52. Parathion methyl	GC		6630 C		Note 3, p. 25; Note 4, p. 27.
53. Parathion ethyl	GC		6630 C		Note 3, p. 25; Note 4, p. 27.
54. PCNB	GC		6630 B & C		Note 3, p. 7.
55. Perthane	GC			D3086–90	Note 4, p. 27.
56. Prometron	GC				Note 3, p. 83; Note 6, p. S68; Note 9.
57. Prometryn	GC				Note 3, p. 83; Note 6, p. S68; Note 9.
58. Propazine	GC				Note 3, p. 83; Note 6, p. S68; Note 9.
59. Propham	TLC				Note 3, p. 104; Note 6, p. S64.
60. Propoxur	TLC				Note 3, p. 94; Note 6, p. S60.
61. Secbumeton	TLC				Note 3, p. 83; Note 6, p. S68.
62. Siduron	TLC				Note 3, p. 104; Note 6, p. S64.
63. Simazine	GC				Note 3, p. 83; Note 6, p. S68; Note 9.
64. Strobane	GC		6630 B & C		Note 3, p. 7.
65. Swep	TLC				Note 3, p. 104; Note 6, p. S64.
66. 2,4,5-T	GC		6640 B		Note 3, p. 115; Note 4, p. 40.

TABLE ID—LIST OF APPROVED TEST PROCEDURES FOR PESTICIDES [1]—Continued

Parameter	Method	EPA [2, 7]	*Standard Methods* 18th, 19th, 20th Ed.	ASTM	Other
67. 2,4,5-TP (Silvex)	GC		6640 B		Note 3, p. 115; Note 4, p. 40.
68. Terbuthylazine	GC				Note 3, p. 83; Note 6, p. S68.
69. Toxaphene	GC	608	6630 B & C	D3086—90	Note 3, p. 7; Note 4, p. 27; Note 8.
	GC/MS	625	6410B.		
70. Trifluralin	GC		6630 B		Note 3, p. 7; Note 9.

Table ID notes:

[1] Pesticides are listed in this table by common name for the convenience of the reader. Additional pesticides may be found under Table 1C, where entries are listed by chemical name.

[2] The full text of Methods 608 and 625 are given at Appendix A. ''Test Procedures for Analysis of Organic Pollutants,'' of this Part 136. The standardized test procedure to be used to determine the method detection limit (MDL) for these test procedures is given at Appendix B, ''Definition and Procedure for the Determination of the Method Detection Limit,'' of this Part 136.

[3] ''Methods for Benzidine, Chlorinated Organic Compounds, Pentachlorophenol and Pesticides in Water and Wastewater,'' U.S. Environmental Protection Agency, September 1978. This EPA publication includes thin-layer chromatography (TLC) methods.

[4] ''Methods for Analysis of Organic Substances in Water and Fluvial Sediments,'' Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 5, Chapter A3 (1987).

[5] The method may be extended to include α-BHC, γ-BHC, endosulfan I, endosulfan II, and endrin. However, when they are known to exist, Method 608 is the preferred method.

[6] ''Selected Analytical Methods Approved and Cited by the United States Environmental Protection Agency.'' Supplement to the Fifteenth Edition of Standard Methods for the Examination of Water and Wastewater (1981).

[7] Each analyst must make an initial, one-time, demonstration of their ability to generate acceptable precision and accuracy with Methods 608 and 625 (See Appendix A of this Part 136) in accordance with procedures given in Section 8.2 of each of these methods. Additionally, each laboratory, on an on-going basis, must spike and analyze 10% of all samples analyzed with Method 608 or 5% of all samples analyzed with Method 625 to monitor and evaluate laboratory data quality in accordance with Sections 8.3 and 8.4 of these methods. When the recovery of any parameter falls outside the warning limits, the analytical results for that parameter in the unspiked sample are suspect and cannot be reported to demonstrate regulatory compliance. These quality control requirements also apply to the Standard Methods, ASTM Methods, and other Methods cited.

Note: These warning limits are promulgated as an ''Interim final action with a request for comments.''

[8] ''Organochlorine Pesticides and PCBs in Wastewater Using Empore™ Disk'', 3M Corporation, Revised 10/28/94.

[9] USGS Method 0–3106–93 from ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Triazine and Other Nitrogen-containing Compounds by Gas Chromatography with Nitrogen Phosphorus Detectors'' U.S. Geological Survey Open File Report 94–37.

TABLE IE—LIST OF APPROVED RADIOLOGIC TEST PROCEDURES

Parameter and units	Method	Reference (method number or page)			
		EPA [1]	*Standard Methods* 18th, 19th, 20th Ed.	ASTM	USGS [2]
1. Alpha-Total, pCi per liter	Proportional or scintillation counter	900	7110 B	D1943–90	pp. 75 and 78 [3]
2. Alpha-Counting error, pCi per liter	Proportional or scintillation counter	Appendix B	7110 B	D1943–90	p. 79
3. Beta-Total, pCi per liter	Proportional counter	900.0	7110 B	D1890–90	pp. 75 and 78 [3]
4. Beta-Counting error, pCi	Proportional counter	Appendix B	7110 B	D1890–90	p. 79
5. (a) Radium Total pCi per liter	Proportional counter	903.0	7500Ra B	D2460–90	
(b) Ra, pCi per liter	Scintillation counter	903.1	7500Ra C	D3454–91	p. 81

Table 1E notes:

[1] ''Prescribed Procedures for Measurement of Radioactivity in Drinking Water,'' EPA–600/4–80–032 (1980), U.S. Environmental Protection Agency, August 1980.

[2] Fishman, M.J. and Brown, Eugene, ''Selected Methods of the U.S. Geological Survey of Analysis of Wastewaters,'' U.S. Geological Survey, Open-File Report 76–177 (1976).

[3] The method found on p. 75 measures only the dissolved portion while the method on p. 78 measures only the suspended portion. Therefore, the two results must be added to obtain the ''total''.

TABLE IF—LIST OF APPROVED METHODS FOR PHARMACEUTICAL POLLUTANTS

Pharmaceuticals pollutants	CAS registry No.	Analytical method number
acetonitrile	75–05–8	1666/1671/D3371/D3695.
n-amyl acetate	628–63–7	1666/D3695.
n-amyl alcohol	71–41–0	1666/D3695
benzene	71–43–2	D4763/D3695/502.2/524.2.
n-butyl-acetate	123–86–4	1666/D3695.
tert-butyl alcohol	75–65–0	1666.
chlorobenzene	108–90–7	502.2/524.2.
chloroform	67–66–3	502.2/524.2/551.
o-dichlorobenzene	95–50–1	1625C/502.2/524.2.
1,2-dichloroethane	107–06–2	D3695/502.2/524.2.
diethylamine	109–89–7	1666/1671.
dimethyl sulfoxide	67–68–5	1666/1671.
ethanol	64–17–5	1666/1671/D3695.
ethyl acetate	141–78–6	1666/D3695.
n-heptane	142–82–5	1666/D3695.
n-hexane	110–54–3	1666/D3695.
isobutyraldehyde	78–84–2	1666/1667.
isopropanol	67–63–0	1666/D3695.
isopropyl acetate	108–21–4	1666/D3695.
isopropyl ether	108–20–3	1666/D3695.
methanol	67–56–1	1666/1671/D3695.
Methyl Cellosolve Δ	109–86–4	1666/1671
methylene chloride	75–09–2	502.2/524.2
methyl formate	107–31–3	1666.
4-methyl-2-pentanone (MIBK)	108–10–1	1624C/1666/D3695/D4763/524.2.
phenol	108–95–2	D4763.
n-propanol	71–23–8	1666/1671/D3695.
2-propanone (acetone)	67–64–1	D3695/D4763/524.2.
tetrahydrofuran	109–99–9	1666/524.2.
toluene	108–88–3	D3695/D4763/502.2/524.2.
triethlyamine	121–44–8	1666/1671.
xylenes	(Note 1)	1624C/1666.

Table 1F note:
1. 1624C: m-xylene 108–38–3, o,p-xylene E–14095 (Not a CAS number; this is the number provided in the Environmental Monitoring Methods Index (EMMI) database.); 1666: m,p-xylene 136777–61–2, o-xylene 95–47–6.

(b) The full texts of the methods from the following references which are cited in Tables IA, IB, IC, ID, IE,and IF are incorporated by reference into this regulation and may be obtained from the sources identified. All costs cited are subject to change and must be verified from the indicated sources. The full texts of all the test procedures cited are available for inspection at the National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 26 West Martin Luther King Dr., Cincinnati, OH 45268 and the Office of the Federal Register, 800 North Capitol Street, NW., Suite 700, Washington, DC.

REFERENCES, SOURCES, COSTS, AND TABLE CITATIONS:

(1) The full texts of Methods 601–613, 624, 625, 1613, 1624, and 1625 are printed in appendix A of this part 136. The full text for determining the method detection limit when using the test procedures is given in appendix B of this part 136. The full text of Method 200.7 is printed in appendix C of this part 136. Cited in: Table IB, Note 5; Table IC, Note 2; and Table ID, Note 2.

(2) USEPA. 1978. Microbiological Methods for Monitoring the Environment, Water, and Wastes. Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio. EPA/600/8–78/017. Available from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161, Publ. No. PB–290329/AS. Cost: $36.95. Table IA, Note 3.

(3) ''Methods for Chemical Analysis of Water and Wastes,'' U.S. Environmental Protection Agency, EPA–600/4–79–020, March 1979, or ''Methods for Chemical Analysis of Water and Wastes,'' U.S. Environmental Protection Agency, EPA–600/4–79–020, Revised March 1983. Available from: ORD Publications, CERI, U.S. Environmental

Protection Agency, Cincinnati, Ohio 45268, Table IB, Note 1.

(4) ''Methods for Benzidine, Chlorinated Organic Compounds, Pentachlorophenol and Pesticides in Water and Wastewater,'' U.S. Environmental Protection Agency, 1978. Available from: ORD Publications, CERI, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268, Table IC, Note 3; Table D, Note 3.

(5) ''Prescribed Procedures for Measurement of Radioactivity in Drinking Water,'' U.S. Environmental Protection Agency, EPA–600/4–80–032, 1980. Available from: ORD Publications, CERI, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268, Table IE, Note 1.

(6) American Public Health Association. 1992, 1995, and 1998. Standard Methods for the Examination of Water and Wastewater. 18th, 19th, and 20th Edition (respectively). Available from: Amer. Publ. Hlth. Assoc., 1015 15th Street, NW., Washington, DC 20005. Table IA, Note 4. Tables IB, IC, ID, IE.

(7) Ibid, 15th Edition, 1980. Table IB, Note 30; Table ID.

(8) Ibid, 14th Edition, 1975. Table IB, Notes 17 and 27.

(9) ''Selected Analytical Methods Approved and Cited by the United States Environmental Protection Agency,'' Supplement to the 15th Edition of Standard Methods for the Examination of Water and Wastewater, 1981. Available from: American Public Health Association, 1015 Fifteenth Street NW., Washington, DC 20036. Cost available from publisher. Table IB, Note 10; Table IC, Note 6; Table ID, Note 6.

(10) Annual Book of ASTM Standards, Water, and Environmental Technology, Section 11, Volumes 11.01 and 11.02, 1994, 1996, and 1999. Available from: ASTM International, 100 Barr Harbor Drive, P.O. Box C–700, West Conshohocken, PA 19428–2959. Tables IB, IC, ID, and IE.

(11) USGS. 1989. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Laboratory Analysis, Chapter A4, Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples, U.S. Geological Survey, U.S. Department of the Interior, Reston, Virginia. Available from: USGS Books and Open-File Reports Section, Federal Center, Box 25425, Denver, Colorado 80225. Cost: $18.00. Table IA, Note 5.

(12) ''Methods for Determination of Inorganic Substances in Water and Fluvial Sediments,'' by M.J. Fishman and Linda C. Friedman, Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 5 Chapter A1 (1989). Available from: U.S. Geological Survey, Denver Federal Center, Box 25425, Denver, CO 80225. Cost: $108.75 (subject to change). Table IB, Note 2.

(13) ''Methods for Determination of Inorganic Substances in Water and Fluvial Sediments,'' N.W. Skougstad and others, editors. Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 5, Chapter A1 (1979). Available from: U.S. Geological Survey, Denver Federal Center, Box 25425, Denver, CO 80225. Cost: $10.00 (subject to change), Table IB, Note 8.

(14) ''Methods for the Determination of Organic Substances in Water and Fluvial Sediments,'' Wershaw, R.L., et al, Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 5, Chapter A3 (1987). Available from: U.S. Geological Survey, Denver Federal Center, Box 25425, Denver, CO 80225. Cost: $0.90 (subject to change). Table IB, Note 24; Table ID, Note 4.

(15) ''Water Temperature—Influential Factors, Field Measurement and Data Presentation,'' by H.H. Stevens, Jr., J. Ficke, and G.F. Smoot, Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 1, Chapter D1, 1975. Available from: U.S. Geological Survey, Denver Federal Center, Box 25425, Denver, CO 80225. Cost: $1.60 (subject to change). Table IB, Note 32.

(16) ''Selected Methods of the U.S. Geological Survey of Analysis of Wastewaters,'' by M.J. Fishman and Eugene Brown; U.S. Geological Survey Open File Report 76–77 (1976). Available from: U.S. Geological Survey, Branch of Distribution, 1200 South Eads Street, Arlington, VA 22202. Cost: $13.50 (subject to change). Table IE, Note 2.

(17) ''Official Methods of Analysis of the Association of Official Analytical Chemicals'', Methods manual, 15th Edition (1990). Price: $240.00. Available

from: The Association of Official Analytical Chemists, 2200 Wilson Boulevard, Suite 400, Arlington, VA 22201. Table IB, Note 3.

(18) ''American National Standard on Photographic Processing Effluents,'' April 2, 1975. Available from: American National Standards Institute, 1430 Broadway, New York, New York 10018. Table IB, Note 9.

(19) ''An Investigation of Improved Procedures for Measurement of Mill Effluent and Receiving Water Color,'' NCASI Technical Bulletin No. 253, December 1971. Available from: National Council of the Paper Industry for Air and Stream Improvements, Inc., 260 Madison Avenue, New York, NY 10016. Cost available from publisher. Table IB, Note 18.

(20) Ammonia, Automated Electrode Method, Industrial Method Number 379–75WE, dated February 19, 1976. Technicon Auto Analyzer II. Method and price available from Technicon Industrial Systems, Tarrytown, New York 10591. Table IB, Note 7.

(21) Chemical Oxygen Demand, Method 8000, Hach Handbook of Water Analysis, 1979. Method price available from Hach Chemical Company, P.O. Box 389, Loveland, Colorado 80537. Table IB, Note 14.

(22) OIC Chemical Oxygen Demand Method, 1978. Method and price available from Oceanography International Corporation, 512 West Loop, P.O. Box 2980, College Station, Texas 77840. Table IB, Note 13.

(23) ORION Research Instruction Manual, Residual Chlorine Electrode Model 97–70, 1977. Method and price available from ORION Research Incorporation, 840 Memorial Drive, Cambridge, Massachusetts 02138. Table IB, Note 16.

(24) Bicinchoninate Method for Copper. Method 8506, Hach Handbook of Water Analysis, 1979, Method and price available from Hach Chemical Company, P.O. Box 300, Loveland, Colorado 80537. Table IB, Note 19.

(25) Hydrogen Ion (pH) Automated Electrode Method, Industrial Method Number 378–75WA. October 1976. Bran & Luebbe (Technicon) Auto Analyzer II. Method and price available from Bran & Luebbe Analyzing Technologies, Inc. Elmsford, N.Y. 10523. Table IB, Note 21.

(26) 1,10-Phenanthroline Method using FerroVer Iron Reagent for Water, Hach Method 8008, 1980. Method and price available from Hach Chemical Company, P.O. Box 389 Loveland, Colorado 80537. Table IB, Note 22.

(27) Periodate Oxidation Method for Manganese, Method 8034, Hach Handbook for Water Analysis, 1979. Method and price available from Hach Chemical Company, P.O. Box 389, Loveland, Colorado 80537. Table IB, Note 23.

(28) Nitrogen, Nitrite—Low Range, Diazotization Method for Water and Wastewater, Hach Method 8507, 1979. Method and price available from Hach Chemical Company, P.O. Box 389, Loveland, Colorado 80537. Table IB, Note 25.

(29) Zincon Method for Zinc, Method 8009. Hach Handbook for Water Analysis, 1979. Method and price available from Hach Chemical Company, P.O. Box 389, Loveland, Colorado 80537. Table IB, Note 33.

(30) ''Direct Determination of Elemental Phosphorus by Gas-Liquid Chromatography,'' by R.F. Addison and R.G. Ackman, Journal of Chromatography, Volume 47, No. 3, pp. 421–426, 1970. Available in most public libraries. Back volumes of the Journal of Chromatography are available from Elsevier/North-Holland, Inc., Journal Information Centre, 52 Vanderbilt Avenue, New York, NY 10164. Cost available from publisher. Table IB, Note 28.

(31) ''Direct Current Plasma (DCP) Optical Emission Spectrometric Method for Trace Elemental Analysis of Water and Wastes'', Method AES 0029, 1986-Revised 1991, Fison Instruments, Inc., 32 Commerce Center, Cherry Hill Drive, Danvers, MA 01923. Table B, Note 34.

(32) ''Closed Vessel Microwave Digestion of Wastewater Samples for Determination of Metals, CEM Corporation, P.O. Box 200, Matthews, North Carolina 28106–0200, April 16, 1992. Available from the CEM Corporation. Table IB, Note 36.

(33) ''Organochlorine Pesticides and PCBs in Wastewater Using Empore ™ Disk'' Test Method 3M 0222, Revised 10/28/94. 3M Corporation, 3M Center Building 220–9E–10, St. Paul, MN 55144–1000. Method available from 3M Corporation. Table IC, Note 8 and Table ID, Note 8.

(34) USEPA. October 2002. Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms. Fifth Edition. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA 821–R–02–012. Available from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161, Publ. No. PB2002–108488. Table IA, Note 7.

(35) ''Nitrogen, Total Kjeldahl, Method PAI–DK01 (Block Digestion, Steam Distillation, Titrimetric Detection)'', revised 12/22/94. Available from Perstorp Analytical Corporation, 9445 SW Ridder Rd., Suite 310, P.O. Box 648, Wilsonville, OK 97070. Table IB, Note 39.

(36) ''Nitrogen, Total Kjeldahl, Method PAI–DK02 (Block Digestion, Steam Distillation, Colorimetric Detection)'', revised 12/22/94. Available from Perstorp Analytical Corporation, 9445 SW Ridder Rd., Suite 310, P.O. Box 648, Wilsonville, OK 97070. Table IB, Note 40.

(37) ''Nitrogen, Total Kjeldahl, Method PAI–DK03 (Block Digestion, Automated FIA Gas Diffusion)'', revised 12/22/94. Available from Perstorp Analytical Corporation, 9445 SW Ridder Rd., Suite 310, P.O. Box 648, Wilsonville, OK 97070. Table IB, Note 41.

(38) USEPA. October 2002. Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms. Fourth Edition. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA 821–R–02–013. Available from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161, Publ. No. PB2002–108489. Table IA, Note 8.

(39) USEPA. October 2002. Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Marine and Estuarine Organisms. Third Edition. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA 821–R–02–014. Available from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161, Publ. No. PB2002–108490. Table IA, Note 9.

(40) EPA Methods 1666, 1667, and 1671 listed in the table above are published in the compendium titled Analytical Methods for the Determination of Pollutants in Pharmaceutical Manufacturing Industry Wastewaters (EPA 821–B–98–016). EPA Methods 502.2 and 524.2 have been incorporated by reference into 40 CFR 141.24 and are in Methods for the Determination of Organic Compounds in Drinking Water, EPA–600/4–88–039, December 1988, Revised, July 1991, and Methods for the Determination of Organic Compounds in Drinking Water-Supplement II, EPA–600/R–92–129, August 1992, respectively. These EPA test method compendia are available from the National Technical Information Service, NTIS PB91–231480 and PB92–207703, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. The toll-free number is 800–553–6847. ASTM test methods D3371, D3695, and D4763 are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428–2959.

(41) USEPA. 2002. Method 1631, Revision E, ''Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry.'' September 2002. Office of Water, U.S. Environmental Protection Agency (EPA–821–R–02–019). Available from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. Publication No. PB2002–108220. Cost: $25.50 (subject to change).

(42) [Reserved]

(43) Method OIA–1677, Available Cyanide by Flow Injection, Ligand Exchange, and Amperometry. August 1999. ALPKEM, OI Analytical, Box 648, Wilsonville, Oregon 97070 (EPA–821–R–99–013). Available from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. Publication No. PB99–132011. Cost: $22.50. Table IB, Note 44.

(44) ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory Determination of Ammonium Plus Organic Nitrogen by a Kjeldahl Digestion Method and an Automated Photometric Finish that Includes Digest Cleanup by Gas Diffusion'', Open File Report (OFR) 00–170. Available from: U.S. Geological Survey, Denver Federal Center, Box 25425, Denver, CO 80225. Table IB, Note 45.

(45) ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Chromium in Water by Graphite Furnace Atomic Absorption Spectrophotometry'', Open File Report (OFR) 93–449. Available from: U.S. Geological Survey, Denver Federal Center, Box 25425, Denver, CO 80225. Table IB, Note 46.

(46) ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Molybdenum in Water by Graphite Furnace Atomic Absorption Spectrophotometry'', Open File Report (OFR) 97–198. Available from: U.S. Geological Survey, Denver Federal Center, Box 25425, Denver, CO 80225. Table IB, Note 47.

(47) ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Total Phosphorus by Kjeldahl Digestion Method and an Automated Colorimetric Finish That Includes Dialysis'' Open File Report (OFR) 92–146. Available from: U.S. Geological Survey, Denver Federal Center, Box 25425, Denver, CO 80225. Table IB, Note 48.

(48) ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Arsenic and Selenium in Water and Sediment by Graphite Furnace—Atomic Absorption Spectrometry'' Open File Report (OFR) 98–639. Table IB, Note 49.

(49) ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Elements in Whole-Water Digests Using Inductively Coupled Plasma-Optical Emission Spectrometry and Inductively Coupled Plasma-Mass Spectrometry'' , Open File Report (OFR) 98–165. Available from: U.S. Geological Survey, Denver Federal Center, Box 25425, Denver, CO 80225. Table IB, Note 50.

(50) ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Triazine and Other Nitrogen-containing Compounds by Gas Chromatography with Nitrogen Phosphorus Detectors'' U.S.Geological Survey Open File Report 94–37. Available from: U.S. Geological Survey, Denver Federal Center, Box 25425, Denver, CO 80225. Table ID, Note 9.

(51) ''Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Inorganic and Organic Constituents in Water and Fluvial Sediments'', Open File Report (OFR) 93–125. Available from: U.S. Geological Survey, Denver Federal Center, Box 25425, Denver, CO 80225. Table IB, Note 51; Table IC, Note 9.

(c) Under certain circumstances the Regional Administrator or the Director in the Region or State where the discharge will occur may determine for a particular discharge that additional parameters or pollutants must be reported. Under such circumstances, additional test procedures for analysis of pollutants may be specified by the Regional Administrator, or the Director upon the recommendation of the Director of the Environmental Monitoring Systems Laboratory—Cincinnati.

(d) Under certain circumstances, the Administrator may approve, upon recommendation by the Director, Environmental Monitoring Systems Laboratory—Cincinnati, additional alternate test procedures for nationwide use.

(e) Sample preservation procedures, container materials, and maximum allowable holding times for parameters cited in Tables IA, IB, IC, ID, and IE are prescribed in Table II. Any person may apply for a variance from the prescribed preservation techniques, container materials, and maximum holding times applicable to samples taken from a specific discharge. Applications for variances may be made by letters to the Regional Administrator in the Region in which the discharge will occur. Sufficient data should be provided to assure such variance does not adversely affect the integrity of the sample. Such data will be forwarded, by the Regional Administrator, to the Director of the Environmental Monitoring Systems Laboratory—Cincinnati, Ohio for technical review and recommendations for action on the variance application. Upon receipt of the recommendations from the Director of the Environmental Monitoring

Systems Laboratory, the Regional Administrator may grant a variance applicable to the specific charge to the applicant. A decision to approve or deny a variance will be made within 90 days of receipt of the application by the Regional Administrator.

TABLE II—REQUIRED CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES

Parameter No./name	Container [1]	Preservation [2, 3]	Maximum holding time [4]
Table IA—Bacteria Tests:			
1–4 Coliform, fecal and total	P,G	Cool, 4C, 0.008% $Na_2S_2O_3$ [5]	6 hours.
5 Fecal streptococci	P,G	Cool, 4C, 0.008% $Na_2S_2O_3$ [5]	6 hours.
Table IA—Aquatic Toxicity Tests:			
6–10 Toxicity, acute and chronic	P,G	Cool, 4 °C [16]	36 hours.
Table IB—Inorganic Tests:			
1. Acidity	P, G	Cool, 4°C	14 days.
2. Alkalinity	P, G	....do	Do.
4. Ammonia	P, G	Cool, 4°C, H_2SO_4 to pH<2	28 days.
9. Biochemical oxygen demand	P, G	Cool, 4°C	48 hours.
10. Boron	P, PFTE, or Quartz.	HNO_3 TO pH<2	6 months.
11. Bromide	P, G	None required	28 days.
14. Biochemical oxygen demand, carbonaceous	P, G	Cool, 4°C	48 hours.
15. Chemical oxygen demand	P, G	Cool, 4°C, H_2SO_4 to pH<2	28 days.
16. Chloride	P, G	None required	Do.
17. Chlorine, total residual	P, G	....do	Analyze immediately.
21. Color	P, G	Cool, 4°C	48 hours.
23–24. Cyanide, total and amenable to chlorination.	P, G	Cool, 4°C, NaOH to pH>12, 0.6g ascorbic acid [5].	14 days.[6]
25. Fluoride	P	None required	28 days.
27. Hardness	P, G	HNO_3 to pH<2, H_2SO_4 to pH<2	6 months.
28. Hydrogen ion (pH)	P, G	None required	Analyze immediately.
31, 43. Kjeldahl and organic nitrogen	P, G	Cool, 4°C, H_2SO_4 to pH<2	28 days.
Metals:[7]			
18. Chromium VI [7]	P, G	Cool, 4 °C	24 hours.
35. Mercury [17]	P, G	HNO_3 to pH<2	28 days.
3, 5–8, 12,13, 19, 20, 22, 26, 29, 30, 32–34, 36, 37, 45, 47, 51, 52, 58–60, 62, 63, 70–72, 74, 75. Metals except boron, chromium VI and mercury [7].	P, G	do	6 months.
38. Nitrate	P, G	Cool, 4°C	48 hours.
39. Nitrate-nitrite	P, G	Cool, 4°C, H_2SO_4 to pH<2	28 days.
40. Nitrite	P, G	Cool, 4°C	48 hours.
41. Oil and grease	G	Cool to 4°C, HCl or H_2SO_4 to pH<2.	28 days.
42. Organic Carbon	P, G	Cool to 4 °C HC1 or H_2SO4 or H_3PO4, to pH<2.	28 days.
44. Orthophosphate	P, G	Filter immediately, Cool, 4°C	48 hours.
46. Oxygen, Dissolved Probe	G Bottle and top.	None required	Analyze immediately.
47. Winkler	....do	Fix on site and store in dark	8 hours.
48. Phenols	G only	Cool, 4°C, H_2SO_4 to pH<2	28 days.
49. Phosphorus (elemental)	G	Cool, 4°C	48 hours.
50. Phosphorus, total	P, G	Cool, 4°C, H_2SO_4 to pH<2	28 days.
53. Residue, total	P, G	Cool, 4°C	7 days.
54. Residue, Filterable	P, G	....do	7 days.
55. Residue, Nonfilterable (TSS)	P, G	....do	7 days.
56. Residue, Settleable	P, G	....do	48 hours.
57. Residue, volatile	P, G	....do	7 days.
61. Silica	P, PFTE, or Quartz.	Cool, 4 °C	28 days.
64. Specific conductance	P, G	....do	Do.
65. Sulfate	P, G	....do	Do.
66. Sulfide	P, G	Cool, 4°C add zinc acetate plus sodium hydroxide to pH>9.	7 days.
67. Sulfite	P, G	None required	Analyze immediately.
68. Surfactants	P ,G	Cool, 4°C	48 hours.
69. Temperature	P, G	None required	Analyze.
73. Turbidity	P, G	Cool, 4°C	48 hours.
Table IC—Organic Tests [8]			
13, 18–20, 22, 24–28, 34–37, 39–43, 45–47, 56, 76, 104, 105, 108–111, 113. Purgeable Halocarbons.	G, Teflon-lined septum.	Cool, 4 °C, 0.008% $Na_2S_2O_3$ [5].	14 days.

TABLE II—REQUIRED CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES—Continued

Parameter No./name	Container [1]	Preservation [2, 3]	Maximum holding time [4]
6, 57, 106. Purgeable aromatic hydrocarbons	.....do	Cool, 4 °C, 0.008% $Na_2S_2O_3$,[5] HCl to pH2[9].	Do.
3, 4. Acrolein and acrylonitrile	.....do	Cool, 4 °C, 0.008% $Na_2S_2O_3$,[5] adjust pH to 4–5[10].	Do.
23, 30, 44, 49, 53, 77, 80, 81, 98, 100, 112. Phenols [11].	G, Teflon-lined cap..	Cool, 4 °C, 0.008% $Na_2S_2O_3$ [5]	7 days until extraction; 40 days after extraction.
7, 38. Benzidines [11]	.....do	.....do	7 days until extraction.[13]
14, 17, 48, 50–52. Phthalate esters [11]	.....do	Cool, 4 °C	7 days until extraction; 40 days after extraction.
82–84. Nitrosamines [11 14]	.....do	Cool, 4 °C, 0.008% $Na_2S_2O_3$,[5] store in dark.	Do.
88–94. PCBs [11]	.....do	Cool, 4 °C	Do.
54, 55, 75, 79. Nitroaromatics and isophorone [11]	.....do	Cool, 4 °C, 0.008% $Na_2S_2O_3$,[5] store in dark.	Do.
1, 2, 5, 8–12, 32, 33, 58, 59, 74, 78, 99, 101. Polynuclear aromatic hydrocarbons [11].	.....do	.....do	Do.
15, 16, 21, 31, 87. Haloethers [11]	.....do	Cool, 4 °C, 0.008% $Na_2S_2O_3$ [5]	Do.
29, 35–37, 63–65, 73, 107. Chlorinated hydrocarbons [11].	.....do	Cool, 4 °C	Do.
60–62, 66–72, 85, 86, 95–97, 102, 103. CDDs/CDFs [11].			
aqueous: field and lab preservation.	G	Cool, 0–4 °C, pH<9, 0.008% $Na_2S_2O_3$ [5].	1 year.
Solids, mixed phase, and tissue: field preservation..	.....do	Cool, <4 °C	7 days.
Solids, mixed phase, and tissue: lab preservation	.....do	Freeze, < −10 °C	1 year.
Table ID—Pesticides Tests:			
1–70. Pesticides [11]	.....do	Cool, 4°C, pH 5–9 [15]	Do.
Table IE—Radiological Tests:			
1–5. Alpha, beta and radium	P, G	HNO_3 to pH<2	6 months.

Table II Notes

[1] Polyethylene (P) or glass (G). For microbiology, plastic sample containers must be made of sterilizable materials (polypropylene or other autoclavable plastic).

[2] Sample preservation should be performed immediately upon sample collection. For composite chemical samples each aliquot should be preserved at the time of collection. When use of an automated sampler makes it impossible to preserve each aliquot, then chemical samples may be preserved by maintaining at 4°C until compositing and sample splitting is completed.

[3] When any sample is to be shipped by common carrier or sent through the United States Mails, it must comply with the Department of Transportation Hazardous Materials Regulations (49 CFR part 172). The person offering such material for transportation is responsible for ensuring such compliance. For the preservation requirements of Table II, the Office of Hazardous Materials, Materials Transportation Bureau, Department of Transportation has determined that the Hazardous Materials Regulations do not apply to the following materials: Hydrochloric acid (HCl) in water solutions at concentrations of 0.04% by weight or less (pH about 1.96 or greater); Nitric acid (HNO_3) in water solutions at concentrations of 0.15% by weight or less (pH about 1.62 or greater); Sulfuric acid (H_2SO_4) in water solutions at concentrations of 0.35% by weight or less (pH about 1.15 or greater); and Sodium hydroxide (NaOH) in water solutions at concentrations of 0.080% by weight or less (pH about 12.30 or less).

[4] Samples should be analyzed as soon as possible after collection. The times listed are the maximum times that samples may be held before analysis and still be considered valid. Samples may be held for longer periods only if the permittee, or monitoring laboratory, has data on file to show that for the specific types of samples under study, the analytes are stable for the longer time, and has received a variance from the Regional Administrator under § 136.3(e). Some samples may not be stable for the maximum time period given in the table. A permittee, or monitoring laboratory, is obligated to hold the sample for a shorter time if knowledge exists to show that this is necessary to maintain sample stability. See § 136.3(e) for details. The term ''analyze immediately'' usually means within 15 minutes or less of sample collection.

[5] Should only be used in the presence of residual chlorine.

[6] Maximum holding time is 24 hours when sulfide is present. Optionally all samples may be tested with lead acetate paper before pH adjustments in order to determine if sulfide is present. If sulfide is present, it can be removed by the addition of cadmium nitrate powder until a negative spot test is obtained. The sample is filtered and then NaOH is added to pH 12.

[7] Samples should be filtered immediately on-site before adding preservative for dissolved metals.

[8] Guidance applies to samples to be analyzed by GC, LC, or GC/MS for specific compounds.

[9] Sample receiving no pH adjustment must be analyzed within seven days of sampling.

[10] The pH adjustment is not required if acrolein will not be measured. Samples for acrolein receiving no pH adjustment must be analyzed within 3 days of sampling.

[11] When the extractable analytes of concern fall within a single chemical category, the specified preservative and maximum holding times should be observed for optimum safeguard of sample integrity. When the analytes of concern fall within two or more chemical categories, the sample may be preserved by cooling to 4°C, reducing residual chlorine with 0.008% sodium thiosulfate, storing in the dark, and adjusting the pH to 6–9; samples preserved in this manner may be held for seven days before extraction and for forty days after extraction. Exceptions to this optional preservation and holding time procedure are noted in footnote 5 (re the requirement for thiosulfate reduction of residual chlorine), and footnotes 12, 13 (re the analysis of benzidine).

[12] If 1,2-diphenylhydrazine is likely to be present, adjust the pH of the sample to 4.0±0.2 to prevent rearrangement to benzidine.

[13] Extracts may be stored up to 7 days before analysis if storage is conducted under an inert (oxidant-free) atmosphere.

[14] For the analysis of diphenylnitrosamine, add 0.008% $Na_2S_2O_3$ and adjust pH to 7–10 with NaOH within 24 hours of sampling.

[15] The pH adjustment may be performed upon receipt at the laboratory and may be omitted if the samples are extracted within 72 hours of collection. For the analysis of aldrin, add 0.008% $Na_2S_2O_3$.

[16] Sufficient ice should be placed with the samples in the shipping container to ensure that ice is still present when the samples arrive at the laboratory. However, even if ice is present when the samples arrive, it is necessary to immediately measure the temperature of the samples and confirm that the 4C temperature maximum has not been exceeded. In the isolated cases where it can be documented that this holding temperature can not be met, the permittee can be given the option of on-site testing or can request a variance. The request for a variance should include supportive data which show that the toxicity of the effluent samples is not reduced because of the increased holding temperature.

[17] Samples collected for the determination of trace level mercury (100 ng/L) using EPA Method 1631 must be collected in tightly-capped fluoropolymer or glass bottles and preserved with BrCl or HCl solution within 48 hours of sample collection. The time to preservation may be extended to 28 days if a sample is oxidized in the sample bottle. Samples collected for dissolved trace level mercury should be filtered in the laboratory. However, if circumstances prevent overnight shipment, samples should be filtered in a designated clean area in the field in accordance with procedures given in Method 1669. Samples that have been collected for determination of total or dissolved trace level mercury must be analyzed within 90 days of sample collection.

[38 FR 28758, Oct. 16, 1973, as amended at 41 FR 52781, Dec. 1, 1976; 49 FR 43251, 43258, 43259, Oct. 26, 1984; 50 FR 691, 692, 695, Jan. 4, 1985; 51 FR 23693, June 30, 1986; 52 FR 33543, Sept. 3, 1987; 55 FR 24534, June 15, 1990; 55 FR 33440, Aug. 15, 1990; 56 FR 50759, Oct. 8, 1991; 57 FR 41833, Sept. 11, 1992; 58 FR 4505, Jan. 31, 1994; 60 FR 17160, Apr. 4, 1995; 60 FR 39588, 39590, Aug. 2, 1995; 60 FR 44672, Aug. 28, 1995; 60 FR 53542, 53543, Oct. 16, 1995; 62 FR 48403, 48404, Sept. 15, 1997; 63 FR 50423, Sept. 21, 1998; 64 FR 4978, Feb. 2, 1999; 64 FR 10392, Mar. 4, 1999; 64 FR 26327, May 14, 1999; 64 FR 30433, 30434, June 8, 1999; 64 FR 73423, Dec. 30, 1999; 66 FR 32776, June 18, 2001; 67 FR 65226, Oct. 23, 2002; 67 FR 65886, Oct. 29, 2002; 67 FR 69971, Nov. 19, 2002]

§ 136.4 Application for alternate test procedures.

(a) Any person may apply to the Regional Administrator in the Region where the discharge occurs for approval of an alternative test procedure.

(b) When the discharge for which an alternative test procedure is proposed occurs within a State having a permit program approved pursuant to section 402 of the Act, the applicant shall submit his application to the Regional Administrator through the Director of the State agency having responsibility for issuance of NPDES permits within such State.

(c) Unless and until printed application forms are made available, an application for an alternate test procedure may be made by letter in triplicate. Any application for an alternate test procedure under this paragraph (c) shall:

(1) Provide the name and address of the responsible person or firm making the discharge (if not the applicant) and the applicable ID number of the existing or pending permit, issuing agency, and type of permit for which the alternate test procedure is requested, and the discharge serial number.

(2) Identify the pollutant or parameter for which approval of an alternate testing procedure is being requested.

(3) Provide justification for using testing procedures other than those specified in Table I.

(4) Provide a detailed description of the proposed alternate test procedure, together with references to published studies of the applicability of the alternate test procedure to the effluents in question.

(d) An application for approval of an alternate test procedure for nationwide use may be made by letter in triplicate to the Director, Analytical Methods Staff, Office of Science and Technology (4303), Office of Water, U.S. Environmental Protection Agency, 1200 Pennsylvania Ave., NW., Washington, DC 20460. Any application for an alternate test procedure under this paragraph (d) shall:

(1) Provide the name and address of the responsible person or firm making the application.

(2) Identify the pollutant(s) or parameter(s) for which nationwide approval of an alternate testing procedure is being requested.

(3) Provide a detailed description of the proposed alternate procedure, together with references to published or other studies confirming the general applicability of the alternate test procedure to the pollutant(s) or parameter(s) in waste water discharges from representative and specified industrial or other categories.

(4) Provide comparability data for the performance of the proposed alternate test procedure compared to the performance of the approved test procedures.

[38 FR 28760, Oct. 16, 1973, as amended at 41 FR 52785, Dec. 1, 1976; 62 FR 30763, June 5, 1997]

§ 136.5 Approval of alternate test procedures.

(a) The Regional Administrator of the region in which the discharge will occur has final responsibility for approval of any alternate test procedure proposed by the responsible person or firm making the discharge.

(b) Within thirty days of receipt of an application, the Director will forward such application proposed by the responsible person or firm making the discharge, together with his recommendations, to the Regional Administrator. Where the Director recommends rejection of the application for scientific and technical reasons which he provides, the Regional Administrator shall deny the application, and shall forward a copy of the rejected application and his decision to the Director of the State Permit Program and to the Director of the Analytical Methods Staff, Washington, DC.

(c) Before approving any application for an alternate test procedure proposed by the responsible person or firm making the discharge, the Regional Administrator shall forward a copy of the application to the Director of the Analytical Methods Staff, Washington, DC.

(d) Within ninety days of receipt by the Regional Administrator of an application for an alternate test procedure, proposed by the responsible person or firm making the discharge, the Regional Administrator shall notify the applicant and the appropriate State agency of approval or rejection, or shall specify the additional information which is required to determine whether to approve the proposed test procedure. Prior to the expiration of such ninety day period, a recommendation providing the scientific and other technical basis for acceptance or rejection will be forwarded to the Regional Administrator by the Director of the Analytical Methods Staff, Washington, DC. A copy of all approval and rejection notifications will be forwarded to the Director, Analytical Methods Staff, Washington, DC, for the purposes of national coordination.

(e) *Approval for nationwide use.* (1) Within sixty days of the receipt by the Director of the Analytical Methods Staff, Washington, DC, of an application for an alternate test procedure for nationwide use, the Director of the Analytical Methods Staff shall notify the applicant in writing whether the application is complete. If the application is incomplete, the applicant shall be informed of the information necessary to make the application complete.

(2) Within ninety days of the receipt of a complete package, the Analytical Methods Staff shall perform any analysis necessary to determine whether the alternate method satisfies the applicable requirements of this part, and the Director of the Analytical Methods Staff shall recommend to the Administrator that he/she approve or reject the application and shall also notify the applicant of such recommendation.

(3) As expeditiously as practicable, an alternate method determined by the Administrator to satisfy the applicable requirements of this part shall be proposed by EPA for incorporation in subsection 136.3 of 40 CFR part 136. EPA shall make available for review all the factual bases for its proposal, including any performance data submitted by the applicant and any available EPA analysis of those data.

(4) Following a period of public comment, EPA shall, as expeditiously as practicable, publish in the FEDERAL REGISTER a final decision to approve or reject the alternate method.

[38 FR 28760, Oct. 16, 1973, as amended at 41 FR 52785, Dec. 1, 1976; 55 FR 33440, Aug. 15, 1990; 62 FR 30763, June 5, 1997]

APPENDIX A TO PART 136—METHODS FOR ORGANIC CHEMICAL ANALYSIS OF MUNICIPAL AND INDUSTRIAL WASTEWATER

METHOD 601—PURGEABLE HALOCARBONS

1. Scope and Application

1.1 This method covers the determination of 29 purgeable halocarbons.

The following parameters may be determined by this method:

Parameter	STORET No.	CAS No.
Bromodichloromethane	32101	75–27–4
Bromoform	32104	75–25–2
Bromomethane	34413	74–83–9
Carbon tetrachloride	32102	56–23–5
Chlorobenzene	34301	108–90–7
Chloroethane	34311	75–00–3
2-Chloroethylvinyl ether	34576	100–75–8
Chloroform	32106	67–66–3

Parameter	STORET No.	CAS No.
Chloromethane	34418	74–87–3
Dibromochloromethane	32105	124–48–1
1,2-Dichlorobenzene	34536	95–50–1
1,3-Dichlorobenzene	34566	541–73–1
1,4-Dichlorobenzene	34571	106–46–7
Dichlorodifluoromethane	34668	75–71–8
1,1-Dichloroethane	34496	75–34–3
1,2-Dichloroethane	34531	107–06–2
1,1-Dichloroethane	34501	75–35–4
trans-1,2-Dichloroethene	34546	156–60–5
1,2-Dichloropropane	34541	78–87–5
cis-1,3-Dichloropropene	34704	10061–01–5
trans-1,3-Dichloropropene	34699	10061–02–6
Methylene chloride	34423	75–09–2
1,1,2,2-Tetrachloroethane	34516	79–34–5
Tetrachloroethene	34475	127–18–4
1,1,1-Trichloroethane	34506	71–55–6
1,1,2-Trichloroethane	34511	79–00–5
Tetrachloroethene	39180	79–01–6
Trichlorofluoromethane	34488	75–69–4
Vinyl chloride	39715	75–01–4

1.2 This is a purge and trap gas chromatographic (GC) method applicable to the determination of the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for any or all of the compounds above, compound identifications should be supported by at least one additional qualitative technique. This method describes analytical conditions for a second gas chromatographic column that can be used to confirm measurements made with the primary column. Method 624 provides gas chromatograph/mass spectrometer (GC/MS) conditions appropriate for the qualitative and quantitative confirmation of results for most of the parameters listed above.

1.3 The method detection limit (MDL, defined in Section 12.1)[1] for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.4 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.5 This method is restricted to use by or under the supervision of analysts experienced in the operation of a purge and trap system and a gas chromatograph and in the interpretation of gas chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 An inert gas is bubbled through a 5-mL water sample contained in a specially-designed purging chamber at ambient temperature. The halocarbons are efficiently transferred from the aqueous phase to the vapor phase. The vapor is swept through a sorbent trap where the halocarbons are trapped. After purging is completed, the trap is heated and backflushed with the inert gas to desorb the halocarbons onto a gas chromatographic column. The gas chromatograph is temperature programmed to separate the halocarbons which are then detected with a halide-specific detector.[2,3]

2.2 The method provides an optional gas chromatographic column that may be helpful in resolving the compounds of interest from interferences that may occur.

3. Interferences

3.1 Impurities in the purge gas and organic compounds outgassing from the plumbing ahead of the trap account for the majority of contamination problems. The analytical system must be demonstrated to be free from contamination under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3. The use of non-Teflon plastic tubing, non-Teflon thread sealants, or flow controllers with rubber components in the purge and trap system should be avoided.

3.2 Samples can be contaminated by diffusion of volatile organics (particularly fluorocarbons and methylene chloride) through the septum seal ilto the sample during shipment and storage. A field reagent blank prepared from reagent water and carried through the sampling and handling protocol can serve as a check on such contamination.

3.3 Contamination by carry-over can occur whenever high level and low level samples are sequentially analyzed. To reduce carry-over, the purging device and sample syringe must be rinsed with reagent water between sample analyses. Whenever an unusually concentrated sample is encountered, it should be followed by an analysis of reagent water to check for cross contamination. For samples containing large amounts of water-soluble materials, suspended solids, high boiling compounds or high organohalide levels, it may be necessary to wash out the purging device with a detergent solution, rinse it with distilled water, and then dry it in a 105°C oven between analyses. The trap and other parts of the system are also subject to contamination; therefore, frequent bakeout and purging of the entire system may be required.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of

OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified[4–6] for the information of the analyst.

4.2 The following parameters covered by this method have been tentatively classified as known or suspected, human or mammalian carcinogens: carbon tetrachloride, chloroform, 1,4-dichlorobenzene, and vinyl chloride. Primary standards of these toxic compounds should be prepared in a hood. A NIOSH/MESA approved toxic gas respirator should be worn when the analyst handles high concentrations of these toxic compounds.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete sampling.

5.1.1 Vial—25-mL capacity or larger, equipped with a screw cap with a hole in the center (Pierce #13075 or equivalent). Detergent wash, rinse with tap and distilled water, and dry at 105 °C before use.

5.1.2 Septum—Teflon-faced silicone (Pierce #12722 or equivalent). Detergent wash, rinse with tap and distilled water, and dry at 105 °C for 1 h before use.

5.2 Purge and trap system—The purge and trap system consists of three separate pieces of equipment: a purging device, trap, and desorber. Several complete systems are now commercially available.

5.2.1 The purging device must be designed to accept 5-mL samples with a water column at least 3 cm deep. The gaseous head space between the water column and the trap must have a total volume of less than 15 mL. The purge gas must pass through the water column as finely divided bubbles with a diameter of less than 3 mm at the origin. The purge gas must be introduced no more than 5 mm from the base of the water column. The purging device illustrated in Figure 1 meets these design criteria.

5.2.2 The trap must be at least 25 cm long and have an inside diameter of at least 0.105 in. The trap must be packed to contain the following minimum lengths of adsorbents: 1.0 cm of methyl silicone coated packing (Section 6.3.3), 7.7 cm of 2,6-diphenylene oxide polymer (Section 6.3.2), 7.7 cm of silica gel (Section 6.3.4), 7.7 cm of coconut charcoal (Section 6.3.1). If it is not necessary to analyze for dichlorodifluoromethane, the charcoal can be eliminated, and the polymer section lengthened to 15 cm. The minimum specifications for the trap are illustrated in Figure 2.

5.2.3 The desorber must be capable of rapidly heating the trap to 180 °C. The polymer section of the trap should not be heated higher than 180 °C and the remaining sections should not exceed 200 °C. The desorber illustrated in Figure 2 meets these design criteria.

5.2.4 The purge and trap system may be assembled as a separate unit or be coupled to a gas chromatograph as illustrated in Figures 3 and 4.

5.3 Gas chromatograph—An analytical system complete with a temperature programmable gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, gases, detector, and strip-chart recorder. A data system is recommended for measuring peak areas.

5.3.1 Column 1—8 ft long × 0.1 in. ID stainless steel or glass, packed with 1% SP–1000 on Carbopack B (60/80 mesh) or equivalent. This column was used to develop the method performance statements in Section 12. Guidelines for the use of alternate column packings are provided in Section 10.1.

5.3.2 Column 2—6 ft long × 0.1 in. ID stainless steel or glass, packed with chemically bonded n-octane on Porasil-C (100/120 mesh) or equivalent.

5.3.3 Detector—Electrolytic conductivity or microcoulometric detector. These types of detectors have proven effective in the analysis of wastewaters for the parameters listed in the scope (Section 1.1). The electrolytic conductivity detector was used to develop the method performance statements in Section 12. Guidelines for the use of alternate detectors are provided in Section 10.1.

5.4 Syringes—5-mL glass hypodermic with Luerlok tip (two each), if applicable to the purging device.

5.5 Micro syringes—25-μL, 0.006 in. ID needle.

5.6 Syringe valve—2-way, with Luer ends (three each).

5.7 Syringe—5-mL, gas-tight with shut-off valve.

5.8 Bottle—15-mL, screw-cap, with Teflon cap liner.

5.9 Balance—Analytical, capable of accurately weighing 0.0001 g.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.1.1 Reagent water can be generated by passing tap water through a carbon filter bed containing about 1 lb of activated carbon (Filtrasorb-300, Calgon Corp., or equivalent).

6.1.2 A water purification system (Millipore Super-Q or equivalent) may be used to generate reagent water.

6.1.3 Reagent water may also be prepared by boiling water for 15 min. Subsequently, while maintaining the temperature at 90°C, bubble a contaminant-free inert gas through the water for 1 h. While still hot, transfer

the water to a narrow mouth screw-cap bottle and seal with a Teflon-lined septum and cap.

6.2 Sodium thiosulfate—(ACS) Granular.

6.3 Trap Materials:

6.3.1 Coconut charcoal—6/10 mesh sieved to 26 mesh, Barnabey Cheney, CA–580–26 lot # M–2649 or equivalent.

6.3.2 2,6-Diphenylene oxide polymer—Tenax, (60/80 mesh), chromatographic grade or equivalent.

6.3.3 Methyl silicone packing—3% OV–1 on Chromosorb-W (60/80 mesh) or equivalent.

6.3.4 Silica gel—35/60 mesh, Davison, grade-15 or equivalent.

6.4 Methanol—Pesticide quality or equivalent.

6.5 Stock standard solutions—Stock standard solutions may be prepared from pure standard materials or purchased as certified solutions. Prepare stock standard solutions in methanol using assayed liquids or gases as appropriate. Because of the toxicity of some of the organohalides, primary dilutions of these materials should be prepared in a hood. A NIOSH/MESA approved toxic gas respirator should be used when the analyst handles high concentrations of such materials.

6.5.1 Place about 9.8 mL of methanol into a 10-mL ground glass stoppered volumetric flask. Allow the flask to stand, unstoppered, for about 10 min or until all alcohol wetted surfaces have dried. Weigh the flask to the learest 0.1 mg.

6.5.2 Add the assayed reference material:

6.5.2.1 Liquid—Using a 100 µL syringe, immediately add two or more drops of assayed reference material to the flask, then reweigh. Be sure that the drops fall directly into the alcohol without contacting the neck of the flask.

6.5.2.2 Gases—To prepare standards for any of the six halocarbons that boil below 30 °C (bromomethane, chloroethane, chloromethane, dichlorodifluoromethane, trichlorofluoromethane, vinyl chloride), fill a 5-mL valved gas-tight syringe with the reference standard to the 5.0-mL mark. Lower the needle to 5 mm above the methanol meniscus. Slowly introduce the reference standard above the surface of the liquid (the heavy gas will rapidly dissolve into the methanol).

6.5.3 Reweigh, dilute to volume, stopper, then mix by inverting the flask several times. Calculate the concentration in µg/µL from the net gain in weight. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the malufacturer or by an independent source.

6.5.4 Transfer the stock standard solution into a Teflon-sealed screw-cap bottle. Store, with minimal headspace, at −10 to −20 °C and protect from light.

6.5.5 Prepare fresh standards weekly for the six gases and 2-chloroethylvinyl ether. All other standards must be replaced after one month, or sooner if comparison with check standards indicates a problem.

6.6 Secondary dilution standards—Using stock standard solutions, prepare secondary dilution standards in methanol that contain the compounds of interest, either singly or mixed together. The secondary dilution standards should be prepared at concentrations such that the aqueous calibration standards prepared in Section 7.3.1 or 7.4.1 will bracket the working range of the analytical system. Secondary dilution standards should be stored with minimal headspace and should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.7 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Assemble a purge and trap system that meets the specifications in Section 5.2. Condition the trap overnight at 180 °C by backflushing with an inert gas flow of at least 20 mL/min. Condition the trap for 10 min once daily prior to use.

7.2 Connect the purge and trap system to a gas chromatograph. The gas chromatograph must be operated using temperature and flow rate conditions equivalent to those given in Table 1. Calibrate the purge and trap-gas chromatographic system using either the external standard technique (Section 7.3) or the internal standard technique (Section 7.4).

7.3 External standard calibration procedure:

7.3.1 Prepare calibration standards at a miminum of three concentration levels for each parameter by carefully adding 20.0 µL of one or more secondary dilution standards to 100, 500, or 1000 µL of reagent water. A 25-µL syringe with a 0.006 in. ID needle should be used for this operation. One of the external standards should be at a concentration near, but above, the MDL (Table 1) and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector. These aqueous standards can be stored up to 24 h, if held in sealed vials with zero headspace as described in Section 9.2. If not so stored, they must be discarded after 1 h.

7.3.2 Analyze each calibration standard according to Section 10, and tabulate peak height or area responses versus the concentration in the standard. The results can be used to prepare a calibration curve for each compound. Alternatively, if the ratio of

response to concentration (calibration factor) is a constant over the working range (<10% relative standard deviation, RSD), linearity through the origin can be assumed and the average ratio or calibration factor can be used in place of a calibration curve.

7.4 Internal standard calibration procedure—To use this approach, the analyst must select one or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Because of these limitations, no internal standard can be suggested that is applicable to all samples. The compounds recommended for use as surrogate spikes in Section 8.7 have been used successfully as internal standards, because of their generally unique retention times.

7.4.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest as described in Section 7.3.1.

7.4.2 Prepare a spiking solution containing each of the internal standards using the procedures described in Sections 6.5 and 6.6. It is recommended that the secondary dilution standard be prepared at a concentration of 15 µg/mL of each internal standard compound. The addition of 10 µL of this standard to 5.0 mL of sample or calibration standard would be equivalent to 30 µg/L.

7.4.3 Analyze each calibration standard according to Section 10, adding 10 µL of internal standard spiking solution directly to the syringe (Section 10.4). Tabulate peak height or area responses against concentration for each compound and internal standard, and calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

C_{is}=Concentration of the internal standard.

C_s=Concentration of the parameter to be measured.

If the RF value over the working range is a constant (<10% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.5 The working calibration curve, calibration factor, or RF must be verified on each working day by the measurement of a QC check sample.

7.5.1 Prepare the QC check sample as described in Section 8.2.2.

7.5.2 Analyze the QC check sample according to Section 10.

7.5.3 For each parameter, compare the response (Q) with the corresponding calibration acceptance criteria found in Table 2. If the responses for all parameters of interest fall within the designated ranges, analysis of actual samples can begin. If any individual Q falls outside the range, proceed according to Section 7.5.4.

NOTE: The large number of parameters in Table 2 present a substantial probability that one or more will not meet the calibration acceptance criteria when all parameters are analyzed.

7.5.4 Repeat the test only for those parameters that failed to meet the calibration acceptance criteria. If the response for a parameter does not fall within the range in this second test, a new calibration curve, calibration factor, or RF must be prepared for that parameter according to Section 7.3 or 7.4.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Section 10.1) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Each day, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system are under control.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing each parameter of interest at a concentration of 10 µg/mL in methanol. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Prepare a QC check sample to contain 20 µg/L of each parameter by adding 200 µL of QC check sample concentrate to 100 mL of reagent water.

8.2.3 Analyze four 5-mL aliquots of the well-mixed QC check sample according to Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter of interest using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 2. If s and $\bar{X}$ for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual $\bar{X}$ falls outside the range for accuracy, then the system performance is unacceptable for that parameter.

NOTE: The large number of parameters in Table 2 present a substantial probability that one or more will fail at least one of the acceptance criteria when all parameters are analyzed.

8.2.6 When one or more of the parameters tested fail at least one of the acceptance criteria, the analyst must proceed according to Section 8.2.6.1 or 8.2.6.2.

8.2.6.1 Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.3.

8.2.6.2 Beginning with Section 8.2.3, repeat the test only for those parameters that failed to meet criteria. Repeated failure, however, will confirm a general problem with the measurement system. If this occurs, locate and correct the source of the problem and repeat the test for all compounds of interest beginning with Section 8.2.3.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spiked sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at 20 µg/L or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.2 Analyze one 5-mL sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second 5-mL sample aliquot with 10 µL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100(A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 2. These acceptance criteria were calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[7] If spiking was performed at a concentration lower than 20 µg/L, the analyst must use either the QC acceptance criteria in Table 2, or optional QC acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recovery of a parameter: (1) Calculate accuracy (X′) using the equation in Table 3, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 3, substituting X′ for X; (3) calculate the range for recovery at the spike concentration as (100 X′/T)±2.44(100 S′/T)%.[7]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4 If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory. If the entire list of parameters in Table 2 must be measured in the sample in Section 8.3, the probability that the analysis of a QC check standard will be required is high. In this case the QC check standard should be routinely analyzed with the spiked sample.

8.4.1 Prepare the QC check standard by adding 10 µL of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 5 mL of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 2. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $P-2s_p$ to $P+2s_p$. If $\bar{p}$=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as gas chromatography with a dissimilar column, specific element detector, or mass spectrometer must be used. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

8.7 The analyst should monitor both the performance of the analytical system and the effectiveness of the method in dealing with each sample matrix by spiking each sample, standard, and reagent water blank with surrogate halocarbons. A combination of bromochloromethane, 2-bromo-1-chloropropane, and 1,4-dichlorobutane is recommended to encompass the range of the temperature program used in this method. From stock standard solutions prepared as in Section 6.5, add a volume to give 750 µg of each surrogate to 45 mL of reagent water contained in a 50-mL volumetric flask, mix and dilute to volume for a concentration of 15 ng/µL. Add 10 µL of this surrogate spiking solution directly into the 5-mL syringe with every sample and reference standard analyzed. Prepare a fresh surrogate spiking solution on a weekly basis. If the internal standard calibration procedure is being used, the surrogate compounds may be added directly to the internal standard spiking solution (Section 7.4.2).

9. Sample Collection, Preservation, and Handling

9.1 All samples must be iced or refrigerated from the time of collection until analysis. If the sample contains free or combined chlorine, add sodium thiosulfate preservative (10 mg/40 mL is sufficient for up to 5 ppm Cl_2) to the empty sample bottle just prior to shipping to the sampling site. EPA Methods 330.4 and 330.5 may be used for measurement of residual chlorine.[8] Field test kits are available for this purpose.

9.2 Grab samples must be collected in glass containers having a total volume of at least 25 mL. Fill the sample bottle just to overflowing in such a manner that no air bubbles pass through the sample as the bottle is being filled. Seal the bottle so that no air bubbles are entrapped in it. If preservative has been added, shake vigorously for 1 min. Maintain the hermetic seal on the sample bottle until time of analysis.

9.3 All samples must be analyzed within 14 days of collection.[3]

10. Procedure

10.1 Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are estimated retention times and MDL that can be achieved under these conditions. An example of the separations achieved by Column 1 is shown in Figure 5. Other packed columns,

chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met.

10.2 Calibrate the system daily as described in Section 7.

10.3 Adjust the purge gas (nitrogen or helium) flow rate to 40 mL/min. Attach the trap inlet to the purging device, and set the purge and trap system to purge (Figure 3). Open the syringe valve located on the purging device sample introduction needle.

10.4 Allow the sample to come to ambient temperature prior to introducing it to the syringe. Remove the plunger from a 5-mL syringe and attach a closed syringe valve. Open the sample bottle (or standard) and carefully pour the sample into the syringe barrel to just short of overflowing. Replace the syringe plunger and compress the sample. Open the syringe valve and vent any residual air while adjusting the sample volume to 5.0 mL. Since this process of taking an aliquot destroys the validity of the sample for future analysis, the analyst should fill a second syringe at this time to protect against possible loss of data. Add 10.0 µL of the surrogate spiking solution (Section 8.7) and 10.0 µL of the internal standard spiking solution (Section 7.4.2), if applicable, through the valve bore, then close the valve.

10.5 Attach the syringe-syringe valve assembly to the syringe valve on the purging device. Open the syringe valves and inject the sample into the purging chamber.

10.6 Close both valves and purge the sample for 11.0±0.1 min at ambient temperature.

10.7 After the 11-min purge time, attach the trap to the chromatograph, adjust the purge and trap system to the desorb mode (Figure 4), and begin to temperature program the gas chromatograph. Introduce the trapped materials to the GC column by rapidly heating the trap to 180 °C while backflushing the trap with an inert gas between 20 and 60 mL/min for 4 min. If rapid heating of the trap cannot be achieved, the GC column must be used as a secondary trap by cooling it to 30 °C (subambient temperature, if poor peak geometry or random retention time problems persist) instead of the initial program temperature of 45 °C

10.8 While the trap is being desorbed into the gas chromatograph, empty the purging chamber using the sample introduction syringe. Wash the chamber with two 5-mL flushes of reagent water.

10.9 After desorbing the sample for 4 min, recondition the trap by returning the purge and trap system to the purge mode. Wait 15 s then close the syringe valve on the purging device to begin gas flow through the trap. The trap temperature should be maintained at 180 °C After approximately 7 min, turn off the trap heater and open the syringe valve to stop the gas flow through the trap. When the trap is cool, the next sample can be analyzed.

10.10 Identify the parameters in the sample by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

10.11 If the response for a peak exceeds the working range of the system, prepare a dilution of the sample with reagent water from the aliquot in the second syringe and reanalyze.

11. Calculations

11.1 Determine the concentration of individual compounds in the sample.

11.1.1 If the external standard calibration procedure is used, calculate the concentration of the parameter being measured from the peak response using the calibration curve or calibration factor determined in Section 7.3.2.

11.1.2 If the internal standard calibration procedure is used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.4.3 and Equation 2.

Equation 2

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(C_{is})}{(A_{is})(RF)}$$

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

C_{is}=Concentration of the internal standard.

11.2 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

12. Method Performance

12.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentration listed in Table 1 were obtained using reagent water.[11]. Similar results were achieved using representative wastewaters. The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

12.2 This method is recommended for use in the concentration range from the MDL to

1000×MDL. Direct aqueous injection techniques should be used to measure concentration levels above 1000×MDL.

12.3 This method was tested by 20 laboratories using reagent water, drinking water, surface water, and three industrial wastewaters spiked at six concentrations over the range 8.0 to 500 µg/L.[9] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 3.

References

1. 40 CFR part 136, appendix B.

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4. ''Carcinogens—Working With Carcinogens,'' Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, Publication No. 77–206, August 1977.

5. ''OSHA Safety and Health Standards, General Industry'' (29 CFR part 1910), Occupational Safety and Health Administration, OSHA 2206 (Revised, January 1976).

6. ''Safety in Academic Chemistry Laboratories,'' American Chemical Society Publication, Committee on Chemical Safety, 3rd Edition, 1979.

7. Provost, L.P., and Elder, R.S. ''Interpretation of Percent Recovery Data,'' *American Laboratory, 15,* 58–63 (1983). (The value 2.44 used in the equation in Section 8.3.3 is two times the value 1.22 derived in this report.)

8. ''Methods 330.4 (Titrimetric, DPD–FAS) and 330.5 (Spectrophotometric, DPD) for Chlorine, Total Residual,'' Methods for Chemical Analysis of Water and Wastes, EPA 600/4–79–020, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268, March 1979.

9. ''EPA Method Study 24, Method 601—Purgeable Halocarbons by the Purge and Trap Method,'' EPA 600/4–84–064, National Technical Information Service, PB84–212448, Springfield, Virginia 22161, July 1984.

10. ''Method Validation Data for EPA Method 601,'' Memorandum from B. Potter, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268, November 10, 1983.

11. Bellar, T. A., Unpublished data, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268, 1981.

TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention time (min)		Method detection limit (µg/L)
	Column 1	Column 2	
Chloromethane	1.50	5.28	0.08
Bromomethane	2.17	7.05	1.18
Dichlorodifluoromethane	2.62	nd	1.81
Vinyl chloride	2.67	5.28	0.18
Chloroethane	3.33	8.68	0.52
Methylene chloride	5.25	10.1	0.25
Trichlorofluoromethane	7.18	nd	nd
1,1-Dichloroethene	7.93	7.72	0.13
1,1-Dichloroethane	9.30	12.6	0.07
trans-1,2-Dichloroethene	10.1	9.38	0.10
Chloroform	10.7	12.1	0.05
1,2-Dichloroethane	11.4	15.4	0.03
1,1,1-Trichloroethane	12.6	13.1	0.03
Carbon tetrachloride	13.0	14.4	0.12
Bromodichloromethane	13.7	14.6	0.10
1,2-Dichloropropane	14.9	16.6	0.04
cis-1,3-Dichloropropene	15.2	16.6	0.34
Trichloroethene	15.8	13.1	0.12
Dibromochloromethane	16.5	16.6	0.09
1,1,2-Trichloroethane	16.5	18.1	0.02
trans-1,3-Dichloropropene	16.5	18.0	0.20
2-Chloroethylvinyl ether	18.0	nd	0.13
Bromoform	19.2	19.2	0.20
1,1,2,2-Tetrachloroethane	21.6	nd	0.03
Tetrachloroethene	21.7	15.0	0.03
Chlorobenzene	24.2	18.8	0.25
1,3-Dichlorobenzene	34.0	22.4	0.32
1,2-Dichlorobenzene	34.9	23.5	0.15

TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS—Continued

Parameter	Retention time (min)		Method detection limit (µg/L)
	Column 1	Column 2	
1,4-Dichlorobenzene	35.4	22.3	0.24

Column 1 conditions: Carbopack B (60/80 mesh) coated with 1% SP–1000 packed in an 8 ft × 0.1 in. ID stainless steel or glass column with helium carrier gas at 40 mL/min flow rate. Column temperature held at 45 °C for 3 min then programmed at 8 °C/min to 220 °C and held for 15 min.

Column 2 conditions: Porisil-C (100/120 mesh) coated with n-octane packed in a 6 ft × 0.1 in. ID stainless steel or glass column with helium carrier gas at 40 mL/min flow rate. Column temperature held at 50 °C for 3 min then programmed at 6 °C/min to 170 °C and held for 4 min.

nd=not determined.

TABLE 2—CALIBRATION AND QC ACCEPTANCE CRITERIA—METHOD 601 [a]

Parameter	Range for Q (µg/L)	Limit for s (µg/L)	Range for $\bar{X}$ (µg/L)	Range P, P_s (%)
Bromodichloromethane	15.2–24.8	4.3	10.7–32.0	42–172
Bromoform	14.7–25.3	4.7	5.0–29.3	13–159
Bromomethane	11.7–28.3	7.6	3.4–24.5	D–144
Carbon tetrachloride	13.7–26.3	5.6	11.8–25.3	43–143
Chlorobenzene	14.4–25.6	5.0	10.2–27.4	38–150
Chloroethane	15.4–24.6	4.4	11.3–25.2	46–137
2-Chloroethylvinyl ether	12.0–28.0	8.3	4.5–35.5	14–186
Chloroform	15.0–25.0	4.5	12.4–24.0	49–133
Chloromethane	11.9–28.1	7.4	D–34.9	D–193
Dibromochloromethane	13.1–26.9	6.3	7.9–35.1	24–191
1,2-Dichlorobenzene	14.0–26.0	5.5	1.7–38.9	D–208
1,3-Dichlorobenzene	9.9–30.1	9.1	6.2–32.6	7–187
1,4-Dichlorobenzene	13.9–26.1	5.5	11.5–25.5	42–143
1,1-Dichloroethane	16.8–23.2	3.2	11.2–24.6	47–132
1,2-Dichloroethane	14.3–25.7	5.2	13.0–26.5	51–147
1,1-Dichloroethene	12.6–27.4	6.6	10.2–27.3	28–167
trans-1,2-Dichloroethene	12.8–27.2	6.4	11.4–27.1	38–155
1,2-Dichloropropane	14.8–25.2	5.2	10.1–29.9	44–156
cis-1,3-Dichloropropene	12.8–27.2	7.3	6.2–33.8	22–178
trans-1,3-Dichloropropene	12.8–27.2	7.3	6.2–33.8	22–178
Methylene chloride	15.5–24.5	4.0	7.0–27.6	25–162
1,1,2,2-Tetrachloroethane	9.8–30.2	9.2	6.6–31.8	8–184
Tetrachloroethene	14.0–26.0	5.4	8.1–29.6	26–162
1,1,1-Trichloroethane	14.2–25.8	4.9	10.8–24.8	41–138
1,1,2-Trichloroethane	15.7–24.3	3.9	9.6–25.4	39–136
Trichloroethene	15.4–24.6	4.2	9.2–26.6	35–146
Trichlorofluoromethane	13.3–26.7	6.0	7.4–28.1	21–156
Vinyl chloride	13.7–26.3	5.7	8.2–29.9	28–163

[a] Criteria were calculated assuming a QC check sample concentration of 20 µg/L.

Q=Concentration measured in QC check sample, in µg/L (Section 7.5.3).

s=Standard deviation of four recovery measurements, in µg/L (Section 8.2.4).

X=Average recovery for four recovery measurements, in µg/L (Section 8.2.4).

P, P_s=Percent recovery measured (Section 8.3.2, Section 8.4.2).

D=Detected; result must be greater than zero.

NOTE: These criteria are based directly upon the method performance data in Table 3. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 3.

TABLE 3—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 601

Parameter	Accuracy, as recovery, X' (µg/L)	Single analyst precision, s_r' (µg/L)	Overall precision, S' (µg/L)
Bromodichloromethane	$1.12C - 1.02$	$0.11\bar{X}+0.04$	$0.20\bar{X}+1.00$
Bromoform	$0.96C - 2.05$	$0.12\bar{X}+0.58$	$0.21\bar{X}+2.41$
Bromomethane	$0.76C - 1.27$	$0.28\bar{X}+0.27$	$0.36\bar{X}+0.94$
Carbon tetrachloride	$0.98C - 1.04$	$0.15\bar{X}+0.38$	$0.20\bar{X}+0.39$
Chlorobenzene	$1.00C - 1.23$	$0.15\bar{X} - 0.02$	$0.18\bar{X}+1.21$
Choroethane	$0.99C - 1.53$	$0.14\bar{X} - 0.13$	$0.17\bar{X}+0.63$
2-Chloroethylvinyl ether [a]	1.00C	$0.20\bar{X}$	$0.35\bar{X}$
Chloroform	$0.93C - 0.39$	$0.13\bar{X}+0.15$	$0.19\bar{X} - 0.02$
Chloromethane	0.77C+0.18	$0.28\bar{X} - 0.31$	$0.52\bar{X}+1.31$
Dibromochloromethane	0.94C+2.72	$0.11\bar{X}+1.10$	$0.24\bar{X}+1.68$
1,2-Dichlorobenzene	0.93C+1.70	$0.20\bar{X}+0.97$	$0.13\bar{X}+6.13$
1,3-Dichlorobenzene	0.95C+0.43	$0.14\bar{X}+2.33$	$0.26\bar{X}+2.34$
1,4-Dichlorobenzene	$0.93C - 0.09$	$0.15\bar{X}+0.29$	$0.20\bar{X}+0.41$
1,1-Dichloroethane	$0.95C - 1.08$	$0.09\bar{X}+0.17$	$0.14\bar{X}+0.94$
1,2-Dichloroethane	$1.04C - 1.06$	$0.11\bar{X}+0.70$	$0.15\bar{X}+0.94$

TABLE 3—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 601—Continued

Parameter	Accuracy, as recovery, X' (µg/L)	Single analyst precision, s_r' (µg/L)	Overall precision, S' (µg/L)
1,1-Dichloroethene	$0.98C - 0.87$	$0.21\bar{X} - 0.23$	$0.29\bar{X} - 0.40$
trans-1,2-Dichloroethene	$0.97C - 0.16$	$0.11\bar{X} + 1.46$	$0.17\bar{X} + 1.46$
1,2-Dichloropropane [a]	1.00C	$0.13\bar{X}$	$0.23\bar{X}$
cis-1,3-Dichloropropene [a]	1.00C	$0.18\bar{X}$	$0.32\bar{X}$
trans-1,3-Dichloropropene [a]	1.00C	$0.18\bar{X}$	$0.32\bar{X}$
Methylene chloride	$0.91C - 0.93$	$0.11\bar{X} + 0.33$	$0.21\bar{X} + 1.43$
1,1,2,2-Tetrachloroethene	$0.95C + 0.19$	$0.14\bar{X} + 2.41$	$0.23\bar{X} + 2.79$
Tetrachloroethene	$0.94C + 0.06$	$0.14\bar{X} + 0.38$	$0.18\bar{X} + 2.21$
1,1,1-Trichloroethane	$0.90C - 0.16$	$0.15\bar{X} + 0.04$	$0.20\bar{X} + 0.37$
1,1,2-Trichloroethane	$0.86C + 0.30$	$0.13\bar{X} - 0.14$	$0.19\bar{X} + 0.67$
Trichloroethene	$0.87C + 0.48$	$0.13\bar{X} - 0.03$	$0.23\bar{X} + 0.30$
Trichlorofluoromethane	$0.89C - 0.07$	$0.15\bar{X} + 0.67$	$0.26\bar{X} + 0.91$
Vinyl chloride	$0.97C - 0.36$	$0.13\bar{X} + 0.65$	$0.27\bar{X} + 0.40$

$\bar{X}'$=Expected recovery for one or more measurements of a sample containing a concentration of C, in µg/L.
s_r'=Expected single analyst standard deviation of measurements at an average concentration found of $\bar{X}$, in µg/L.
S^1=Expected interlaboratory standard deviation of measurements at an average concentration found of $\bar{X}$, in µg/L.
C=True value for the concentration, in µg/L.
$\bar{X}$=Average recovery found for measurements of samples containing a concentration of C, in µg/L.
[a] Estimates based upon the performance in a single laboratory.[10]

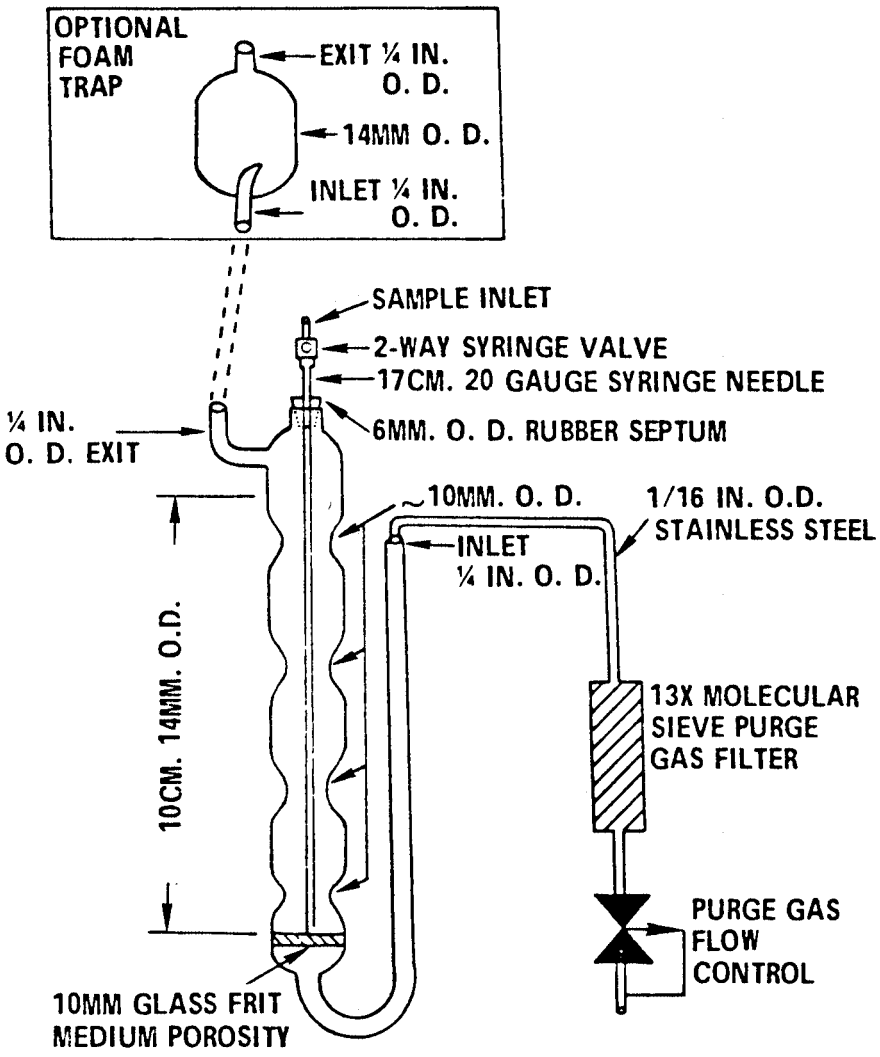

Figure 1. Purging device.

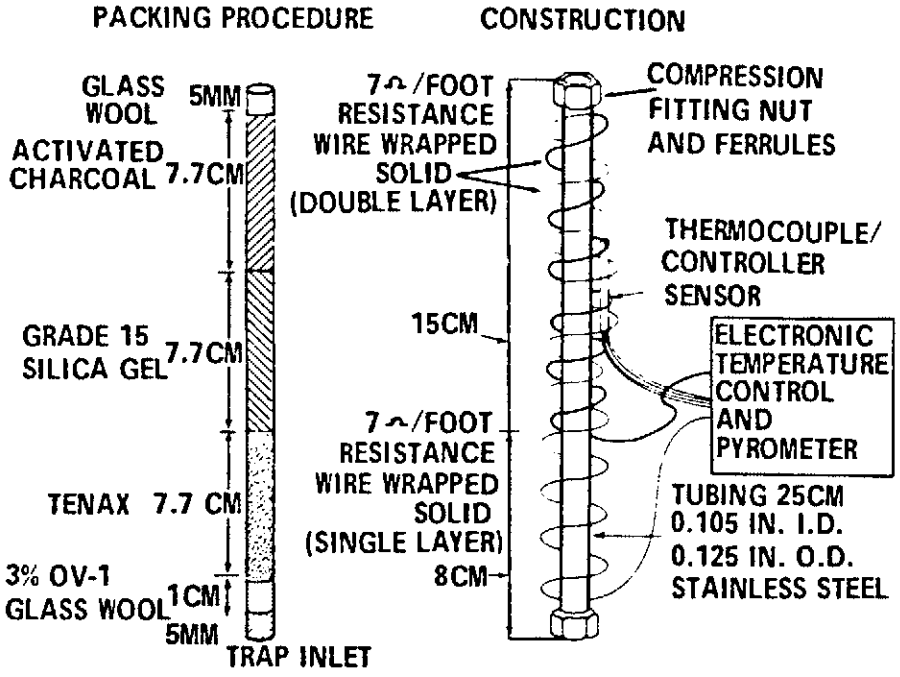

Figure 2. Trap packings and construction to include desorb capability

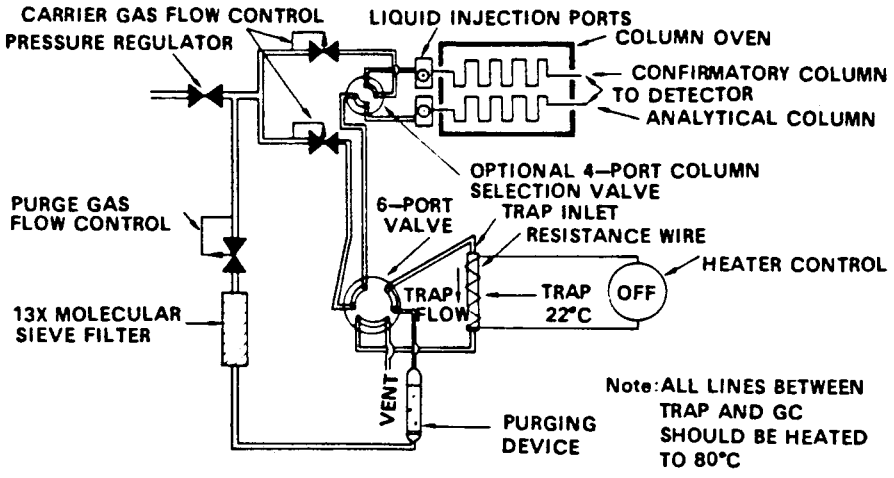

Figure 3. Purge and trap system-purge mode.

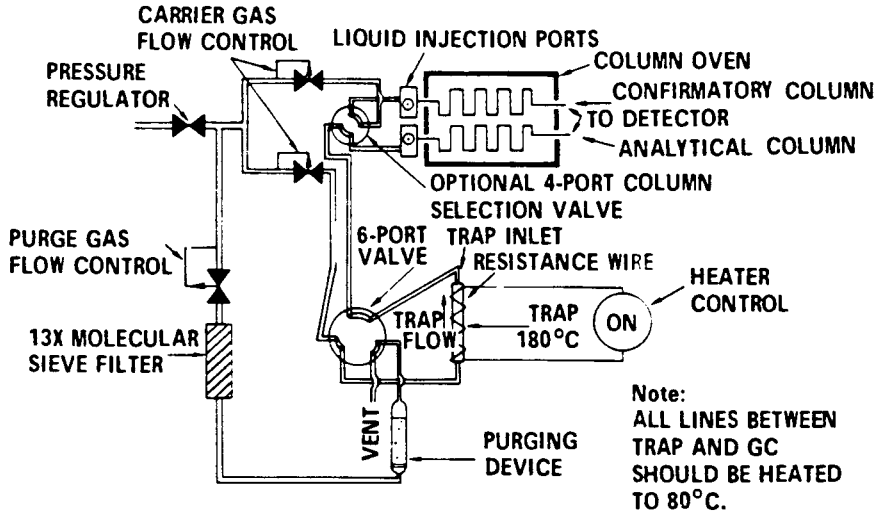

Figure 4. Purge and trap system - desorb mode.

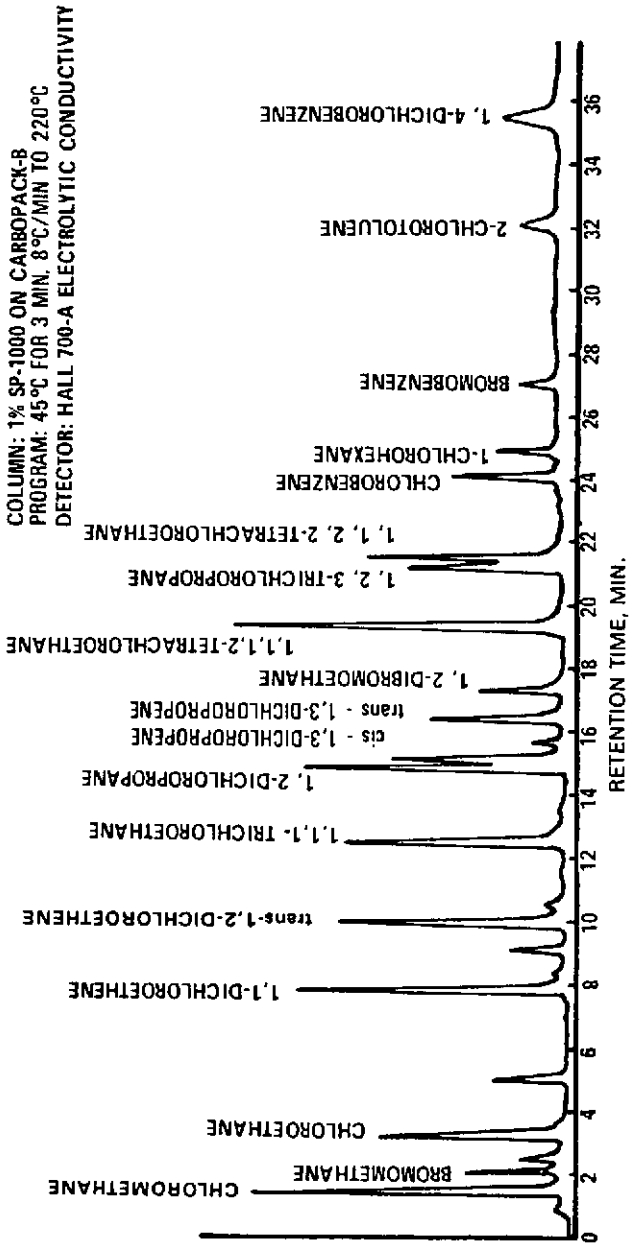

Figure 5. Gas chromatogram of purgeable halocarbons.

METHOD 602—PURGEABLE AROMATICS

1. Scope and Application

1.1 This method covers the determination of various purgeable aromatics. The following parameters may be determined by this method:

Parameter	STORET No.	CAS No.
Benzene	34030	71–43–2
Chlorobenzene	34301	108–90–7
1,2-Dichlorobenzene	34536	95–50–1
1,3-Dichlorobenzene	34566	541–73–1
1,4-Dichlorobenzene	34571	106–46–7
Ethylbenzene	34371	100–41–4
Toluene	34010	108–88–3

1.2 This is a purge and trap gas chromatographic (GC) method applicable to the determination of the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for any or all of the compounds above, compound identifications should be supported by at least one additional qualitative technique. This method describes analytical conditions for a second gas chromatographic column that can be used to confirm measurements made with the primary column. Method 624 provides gas chromatograph/mass spectrometer (GC/MS) conditions appropriate for the qualitative and quantitative confirmation of results for all of the parameters listed above.

1.3 The method detection limit (MDL, defined in Section 12.1)[1] for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.4 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.5 This method is restricted to use by or under the supervision of analysts experienced in the operation of a purge and trap system and a gas chromatograph and in the interpretation of gas chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 An inert gas is bubbled through a 5-mL water sample contained in a specially-designed purging chamber at ambient temperature. The aromatics are efficiently transferred from the aqueous phase to the vapor phase. The vapor is swept through a sorbent trap where the aromatics are trapped. After purging is completed, the trap is heated and backflushed with the inert gas to desorb the aromatics onto a gas chromatographic column. The gas chromatograph is temperature programmed to separate the aromatics which are then detected with a photoionization detector.[2,3]

2.2 The method provides an optional gas chromatographic column that may be helpful in resolving the compounds of interest from interferences that may occur.

3. Interferences

3.1 Impurities in the purge gas and organic compounds outgassing from the plumbing ahead of the trap account for the majority of contamination problems. The analytical system must be demonstrated to be free from contamination under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3. The use of non-Teflon plastic tubing, non-Teflon thread sealants, or flow controllers with rubber components in the purge and trap system should be avoided.

3.2 Samples can be contaminated by diffusion of volatile organics through the septum seal into the sample during shipment and storage. A field reagent blank prepared from reagent water and carried through the sampling and handling protocol can serve as a check on such contamination.

3.3 Contamination by carry-over can occur whenever high level and low level samples are sequentially analyzed. To reduce carry-over, the purging device and sample syringe must be rinsed with reagent water between sample analyses. Whenever an unusually concentrated sample is encountered, it should be followed by an analysis of reagent water to check for cross contamination. For samples containing large amounts of water-soluble materials, suspended solids, high boiling compounds or high aromatic levels, it may be necessary to wash the purging device with a detergent solution, rinse it with distilled water, and then dry it in an oven at 105 °C between analyses. The trap and other parts of the system are also subject to contamination; therefore, frequent bakeout and purging of the entire system may be required.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety

are available and have been identified[4–6] for the information of the analyst.

4.2 The following parameters covered by this method have been tentatively classified as known or suspected, human or mammalian carcinogens: benzene and 1,4-dichlorobenzene. Primary standards of these toxic compounds should be prepared in a hood. A NIOSH/MESA approved toxic gas respirator should be worn when the analyst handles high concentrations of these toxic compounds.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete sampling.

5.1.1 Vial]25-mL capacity or larger, equipped with a screw cap with a hole in the center (Pierce #13075 or equivalent). Detergent wash, rinse with tap and distilled water, and dry at 105 °C before use.

5.1.2 Septum—Teflon-faced silicone (Pierce #12722 or equivalent). Detergent wash, rinse with tap and distilled water, and dry at 105 °C for 1 h before use.

5.2 Purge and trap system—The purge and trap system consists of three separate pieces of equipment: A purging device, trap, and desorber. Several complete systems are now commercially available.

5.2.1 The purging device must be designed to accept 5-mL samples with a water column at least 3 cm deep. The gaseous head space between the water column and the trap must have a total volume of less than 15 mL. The purge gas must pass through the water column as finely divided bubbles with a diameter of less than 3 mm at the origin. The purge gas must be introduced no more than 5 mm from the base of the water column. The purging device illustrated in Figure 1 meets these design criteria.

5.2.2 The trap must be at least 25 cm long and have an inside diameter of at least 0.105 in.

5.2.2.1 The trap is packed with 1 cm of methyl silicone coated packing (Section 6.4.2) and 23 cm of 2,6-diphenylene oxide polymer (Section 6.4.1) as shown in Figure 2. This trap was used to develop the method performance statements in Section 12.

5.2.2.2 Alternatively, either of the two traps described in Method 601 may be used, although water vapor will preclude the measurement of low concentrations of benzene.

5.2.3 The desorber must be capable of rapidly heating the trap to 180 °C. The polymer section of the trap should not be heated higher than 180 °C and the remaining sections should not exceed 200 °C. The desorber illustrated in Figure 2 meets these design criteria.

5.2.4 The purge and trap system may be assembled as a separate unit or be coupled to a gas chromatograph as illustrated in Figures 3, 4, and 5.

5.3 Gas chromatograph—An analytical system complete with a temperature programmable gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, gases, detector, and strip-chart recorder. A data system is recommended for measuring peak areas.

5.3.1 Column 1—6 ft long × 0.082 in. ID stainless steel or glass, packed with 5% SP–1200 and 1.75% Bentone-34 on Supelcoport (100/120 mesh) or equivalent. This column was used to develop the method performance statements in Section 12. Guidelines for the use of alternate column packings are provided in Section 10.1.

5.3.2 Column 2—8 ft long × 0.1 in ID stainless steel or glass, packed with 5% 1,2,3-Tris(2-cyanoethoxy)propane on Chromosorb W–AW (60/80 mesh) or equivalent.

5.3.3 Detector—Photoionization detector (h-Nu Systems, Inc. Model PI–51–02 or equivalent). This type of detector has been proven effective in the analysis of wastewaters for the parameters listed in the scope (Section 1.1), and was used to develop the method performance statements in Section 12. Guidelines for the use of alternate detectors are provided in Section 10.1.

5.4 Syringes—5-mL glass hypodermic with Luerlok tip (two each), if applicable to the purging device.

5.5 Micro syringes—25-μL, 0.006 in. ID needle.

5.6 Syringe valve—2-way, with Luer ends (three each).

5.7 Bottle—15-mL, screw-cap, with Teflon cap liner.

5.8 Balance—Analytical, capable of accurately weighing 0.0001 g.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.1.1 Reagent water can be generated by passing tap water through a carbon filter bed containing about 1 lb of activated carbon (Filtrasorb-300, Calgon Corp., or equivalent).

6.1.2 A water purification system (Millipore Super-Q or equivalent) may be used to generate reagent water.

6.1.3 Reagent water may also be prepared by boiling water for 15 min. Subsequently, while maintaining the temperature at 90 °C, bubble a contaminant-free inert gas through the water for 1 h. While still hot, transfer the water to a narrow mouth screw-cap bottle and seal with a Teflon-lined septum and cap.

6.2 Sodium thiosulfate—(ACS) Granular.

6.3 Hydrochloric acid (1+1)—Add 50 mL of concentrated HCl (ACS) to 50 mL of reagent water.

6.4 Trap Materials:

6.4.1 2,6-Diphenylene oxide polymer—Tenax, (60/80 mesh), chromatographic grade or equivalent.

6.4.2 Methyl silicone packing—3% OV–1 on Chromosorb-W (60/80 mesh) or equivalent.

6.5 Methanol—Pesticide quality or equivalent.

6.6 Stock standard solutions—Stock standard solutions may be prepared from pure standard materials or purchased as certified solutions. Prepare stock standard solutions in methanol using assayed liquids. Because of the toxicity of benzene and 1,4-dichlorobenzene, primary dilutions of these materials should be prepared in a hood. A NIOSH/MESA approved toxic gas respirator should be used when the analyst handles high concentrations of such materials.

6.6.1 Place about 9.8 mL of methanol into a 10–mL ground glass stoppered volumetric flask. Allow the flask to stand, unstoppered, for about 10 min or until all alcohol wetted surfaces have dried. Weigh the flask to the nearest 0.1 mg.

6.6.2 Using a 100–µL syringe, immediately add two or more drops of assayed reference material to the flask, then reweigh. Be sure that the drops fall directly into the alcohol without contacting the neck of the flask.

6.6.3 Reweigh, dilute to volume, stopper, then mix by inverting the flask several times. Calculate the concentration in µg/µL from the net gain in weight. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the manufacturer or by an independent source.

6.6.4 Transfer the stock standard solution into a Teflon-sealed screw-cap bottle. Store at 4 °C and protect from light.

6.6.5 All standards must be replaced after one month, or sooner if comparison with check standards indicates a problem.

6.7 Secondary dilution standards—Using stock standard solutions, prepare secondary dilution standards in methanol that contain the compounds of interest, either singly or mixed together. The secondary dilution standards should be prepared at concentrations such that the aqueous calibration standards prepared in Section 7.3.1 or 7.4.1 will bracket the working range of the analytical system. Secondary solution standards must be stored with zero headspace and should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.8 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Assemble a purge and trap system that meets the specifications in Section 5.2. Condition the trap overnight at 180 °C by backflushing with an inert gas flow of at least 20 mL/min. Condition the trap for 10 min once daily prior to use.

7.2 Connect the purge and trap system to a gas chromatograph. The gas chromatograph must be operated using temperature and flow rate conditions equivalent to those given in Table 1. Calibrate the purge and trap-gas chromatographic system using either the external standard technique (Section 7.3) or the internal standard technique (Section 7.4).

7.3 External standard calibration procedure:

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter by carefully adding 20.0 µL of one or more secondary dilution standards to 100, 500, or 1000 mL of reagent water. A 25–µL syringe with a 0.006 in. ID needle should be used for this operation. One of the external standards should be at a concentration near, but above, the MDL (Table 1) and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector. These aqueous standards must be prepared fresh daily.

7.3.2 Analyze each calibration standard according to Section 10, and tabulate peak height or area responses versus the concentration in the standard. The results can be used to prepare a calibration curve for each compound. Alternatively, if the ratio of response to concentration (calibration factor) is a constant over the working range (<10% relative standard deviation, RSD), linearity through the origin can be assumed and the average ratio or calibration factor can be used in place of a calibration curve.

7.4 Internal standard calibration procedure—To use this approach, the analyst must select one or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Because of these limitations, no internal standard can be suggested that is applicable to all samples. The compound, α,α,α,-trifluorotoluene, recommended as a surrogate spiking compound in Section 8.7 has been used successfully as an internal standard.

7.4.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest as described in Section 7.3.1.

7.4.2 Prepare a spiking solution containing each of the internal standards using the procedures described in Sections 6.6 and 6.7. It is recommended that the secondary dilution standard be prepared at a concentration of 15 µg/mL of each internal standard compound. The addition of 10 µl of this

standard to 5.0 mL of sample or calibration standard would be equivalent to 30 µg/L.

7.4.3 Analyze each calibration standard according to Section 10, adding 10 µL of internal standard spiking solution directly to the syringe (Section 10.4). Tabulate peak height or area responses against concentration for each compound and internal standard, and calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

C_{is}=Concentration of the internal standard

C_s=Concentration of the parameter to be measured.

If the RF value over the working range is a constant (<10% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.5 The working calibration curve, calibration factor, or RF must be verified on each working day by the measurement of a QC check sample.

7.5.1 Prepare the QC check sample as described in Section 8.2.2.

7.5.2 Analyze the QC check sample according to Section 10.

7.5.3 For each parameter, compare the response (Q) with the corresponding calibration acceptance criteria found in Table 2. If the responses for all parameters of interest fall within the designated ranges, analysis of actual samples can begin. If any individual Q falls outside the range, a new calibration curve, calibration factor, or RF must be prepared for that parameter according to Section 7.3 or 7.4.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The mimimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Section 10.1) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Each day, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system are under control.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing each parameter of interest at a concentration of 10 µg/mL in methanol. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Prepare a QC check sample to contain 20 µg/L of each parameter by adding 200 µL of QC check sample concentrate to 100 mL of reagant water.

8.2.3 Analyze four 5-mL aliquots of the well-mixed QC check sample according to Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter of interest using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria

for precision and accuracy, respectively, found in Table 2. If s and $\bar{X}$ for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual $\bar{X}$ falls outside the range for accuracy, the system performance is unacceptable for that parameter.

NOTE: The large number of parameters in Table 2 present a substantial probability that one or more will fail at least one of the acceptance criteria when all parameters are analyzed.

8.2.6 When one or more of the parameters tested fail at least one of the acceptance criteria, the analyst must proceed according to Section 8.2.6.1 or 8.2.6.2.

8.2.6.1 Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.3.

8.2.6.2 Beginning with Section 8.2.3, repeat the test only for those parameters that failed to meet criteria. Repeated failure, however, will confirm a general problem with the measurement system. If this occurs, locate and correct the source of the problem and repeat the test for all compounds of interest beginning with Section 8.2.3.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spiked sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at 20 µg/L or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.2 Analyze one 5-mL sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second 5-mL sample aliquot with 10 µL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100(A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 2. These acceptance criteria were calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[7] If spiking was performed at a concentration lower than 20 µg/L, the analyst must use either the QC acceptance criteria in Table 2, or optional QC acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recovery of a parameter: (1) Calculate accuracy (X′) using the equation in Table 3, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 3, substituting X′ for X; (3) calculate the range for recovery at the spike concentration as (100 X′/T) ±2.44(100 S′/T)%.[7]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4 If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory.

8.4.1 Prepare the QC check standard by adding 10 µL of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 5 mL of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 2. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P)

and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $P-2s_p$ to $P+2s_p$. If P=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as gas chromatography with a dissimilar column, specific element detector, or mass spectrometer must be used. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

8.7 The analyst should monitor both the performance of the analytical system and the effectiveness of the method in dealing with each sample matrix by spiking each sample, standard, and reagent water blank with surrogate compounds (e.g. α, α, α,-trifluorotoluene) that encompass the range of the temperature program used in this method. From stock standard solutions prepared as in Section 6.6, add a volume to give 750 µg of each surrogate to 45 mL of reagent water contained in a 50-mL volumetric flask, mix and dilute to volume for a concentration of 15 mg/µL. Add 10 µL of this surrogate spiking solution directly into the 5-mL syringe with every sample and reference standard analyzed. Prepare a fresh surrogate spiking solution on a weekly basis. If the internal standard calibration procedure is being used, the surrogate compounds may be added directly to the internal standard spiking solution (Section 7.4.2).

9. Sample Collection, Preservation, and Handling

9.1 The samples must be iced or refrigerated from the time of collection until analysis. If the sample contains free or combined chlorine, add sodium thiosulfate preservative (10 mg/40 mL is sufficient for up to 5 ppm Cl_2) to the empty sample bottle just prior to shipping to the sampling site. EPA Method 330.4 or 330.5 may be used for measurement of residual chlorine.[8] Field test kits are available for this purpose.

9.2 Collect about 500 mL of sample in a clean container. Adjust the pH of the sample to about 2 by adding 1+1 HCl while stirring. Fill the sample bottle in such a manner that no air bubbles pass through the sample as the bottle is being filled. Seal the bottle so that no air bubbles are entrapped in it. Maintain the hermetic seal on the sample bottle until time of analysis.

9.3 All samples must be analyzed within 14 days of collection.[3]

10. Procedure

10.1 Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are estimated retention times and MDL that can be achieved under these conditions. An example of the separations achieved by Column 1 is shown in Figure 6. Other packed columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met.

10.2 Calibrate the system daily as described in Section 7.

10.3 Adjust the purge gas (nitrogen or helium) flow rate to 40 mL/min. Attach the trap inlet to the purging device, and set the purge and trap system to purge (Figure 3). Open the syringe valve located on the purging device sample introduction needle.

10.4 Allow the sample to come to ambient temperature prior to introducing it to the syringe. Remove the plunger from a 5-mL syringe and attach a closed syringe valve. Open the sample bottle (or standard) and carefully pour the sample into the syringe barrel to just short of overflowing. Replace the syringe plunger and compress the sample. Open the syringe valve and vent any residual air while adjusting the sample volume to 5.0 mL. Since this process of taking an aliquot destroys the validity of the sample for future analysis, the analyst should fill a second syringe at this time to protect against possible loss of data. Add 10.0 µL of the surrogate spiking solution (Section 8.7) and 10.0 µL of the internal standard spiking solution (Section 7.4.2), if applicable, through the valve bore, then close the valve.

10.5 Attach the syringe-syringe valve assembly to the syringe valve on the purging device. Open the syringe valves and inject the sample into the purging chamber.

10.6 Close both valves and purge the sample for 12.0±0.1 min at ambient temperature.

10.7 After the 12-min purge time, disconnect the purging device from the trap. Dry the trap by maintaining a flow of 40 mL/min of dry purge gas through it for 6 min (Figure 4). If the purging device has no provision for bypassing the purger for this step, a dry purger should be inserted into the device to minimize moisture in the gas. Attach the trap to the chromatograph, adjust the purge and trap system to the desorb mode (Figure 5), and begin to temperature program the gas chromatograph. Introduce the trapped materials to the GC column by rapidly heating the trap to 180 °C while backflushing the trap with an inert gas between 20 and 60 mL/min for 4 min. If rapid heating of the trap cannot be achieved, the GC column must be used as

a secondary trap by cooling it to 30 °C (subambient temperature, if poor peak geometry and random retention time problems persist) instead of the initial program temperature of 50 °C.

10.8 While the trap is being desorbed into the gas chromatograph column, empty the purging chamber using the sample introduction syringe. Wash the chamber with two 5-mL flushes of reagent water.

10.9 After desorbing the sample for 4 min, recondition the trap by returning the purge and trap system to the purge mode. Wait 15 s, then close the syringe valve on the purging device to begin gas flow through the trap. The trap temperature should be maintained at 180 °C. After approximately 7 min, turn off the trap heater and open the syringe valve to stop the gas flow through the trap. When the trap is cool, the next sample can be analyzed.

10.10 Identify the parameters in the sample by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

10.11 If the response for a peak exceeds the working range of the system, prepare a dilution of the sample with reagent water from the aliquot in the second syringe and reanalyze.

11. Calculations

11.1 Determine the concentration of individual compounds in the sample.

11.1.1 If the external standard calibration procedure is used, calculate the concentration of the parameter being measured from the peak response using the calibration curve or calibration factor determined in Section 7.3.2.

11.1.2 If the internal standard calibration procedure is used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.4.3 and Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(C_{is})}{(A_{is})(RF)}$$

Equation 2

where:

A_s = Response for the parameter to be measured.

A_{is} = Response for the internal standard.

C_{is} = Concentration of the internal standard.

11.2 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

12. Method Performance

12.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentrations listed in Table 1 were obtained using reagent water.[9] Similar results were achieved using representative wastewaters. The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

12.2 This method has been demonstrated to be applicable for the concentration range from the MDL to 100 × MDL.[9] Direct aqueous injection techniques should be used to measure concentration levels above 1000 × MDL.

12.3 This method was tested by 20 laboratories using reagent water, drinking water, surface water, and three industrial wastewaters spiked at six concentrations over the range 2.1 to 550 µg/L.[9] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 3.

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4. ''Carcinogens—Working with Carcinogens,'' Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health. Publication No. 77–206, August 1977.

5. ''OSHA Safety and Health Standards, General Industry,'' (29 CFR part 1910), Occupational Safety and Health Administration, OSHA 2206 (Revised, January 1976).

6. ''Safety in Academic Chemistry Laboratories,'' American Chemical Society Publication, Committee on Safety, 3rd Edition, 1979.

7. Provost, L.P., and Elder, R.S. ''Interpretation of Percent Recovery Data,'' *American Laboratory, 15*, 58-63 (1983). (The value 2.44 used in the equation in Section 8.3.3. is two times the value 1.22 derived in this report.)

8.''Methods 330.4 (Titrimetric, DPD–FAS) and 330.5 (Spectrophotometric, DPD) for Chlorine, Total Residual,'' Methods for Chemical Analysis of Water and Wastes, EPA–600/4–79–020, U.S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268. March 1979.

9. ''EPA Method Study 25, Method 602, Purgeable Aromatics,'' EPA 600/4–84–042, National Technical Information Service, PB84–196682, Springfield, Virginia 22161, May 1984.

TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention time (min)		Method detection limit (μg/L)
	Column 1	Column 2	
Benzene	3.33	2.75	0.2

TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS—Continued

Parameter	Retention time (min)		Method detection limit (μg/L)
	Column 1	Column 2	
Toluene	5.75	4.25	0.2
Ethylbenzene	8.25	6.25	0.2
Chlorobenzene	9.17	8.02	0.2
1,4-Dichlorobenzene	16.8	16.2	0.3
1,3-Dichlorobenzene	18.2	15.0	0.4
1,2-Dichlorobenzene	25.9	19.4	0.4

Column 1 conditions: Supelcoport (100/120 mesh) coated with 5% SP–1200/1.75% Bentone-34 packed in a 6 ft × 0.085 in. ID stainless steel column with helium carrier gas at 36 mL/min flow rate. Column temperature held at 50 °C for 2 min then programmed at 6 °C/min to 90 °C for a final hold.

Column 2 conditions: Chromosorb W–AW (60/80 mesh) coated with 5% 1,2,3-Tris(2-cyanoethyoxy)propane packed in a 6 ft × 0.085 in. ID stainless steel column with helium carrier gas at 30 mL/min flow rate. Column temperature held at 40 °C for 2 min then programmed at 2 °C/min to 100 °C for a final hold.

TABLE 2—CALIBRATION AND QC ACCEPTANCE CRITERIA—METHOD 602 [a]

Parameter	Range for Q (μg/L)	Limit for s (μg/L)	Range for $\bar{X}$ (μg/L)	Range for P, P_s(%)
Benzene	15.4–24.6	4.1	10.0–27.9	39–150
Chlorobenzene	16.1–23.9	3.5	12.7–25.4	55–135
1,2-Dichlorobenzene	13.6–26.4	5.8	10.6–27.6	37–154
1,3-Dichlorobenzene	14.5–25.5	5.0	12.8–25.5	50–141
1,4-Dichlorobenzene	13.9–26.1	5.5	11.6–25.5	42–143
Ethylbenzene	12.6–27.4	6.7	10.0–28.2	32–160
Toluene	15.5–24.5	4.0	11.2–27.7	46–148

Q=Concentration measured in QC check sample, in μg/L (Section 7.5.3).
s=Standard deviation of four recovery measurements, in μg/L (Section 8.2.4).
$\bar{X}$=Average recovery for four recovery measurements, in μg/L (Section 8.2.4).
P_s, P=Percent recovery measured (Section 8.3.2, Section 8.4.2).
[a] Criteria were calculated assuming a QC check sample concentration of 20 μg/L.

Note: These criteria are based directly upon the method performance data in Table 3. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 3.

TABLE 3—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 602

Parameter	Accuracy, as recovery, X′ (μg/L)	Single analyst precision, s′ (μg/L)	Overall precision, S′ (μg/L)
Benzene	0.92C+0.57	0.09$\bar{X}$+0.59	0.21$\bar{X}$+0.56
Chlorobenzene	0.95C+0.02	0.09$\bar{X}$+0.23	0.17$\bar{X}$+0.10
1,2-Dichlorobenzene	0.93C+0.52	0.17$\bar{X}$ − 0.04	0.22$\bar{X}$+0.53
1,3-Dichlorobenzene	0.96C − 0.05	0.15$\bar{X}$ − 0.10	0.19$\bar{X}$+0.09
1,4-Dichlorobenzene	0.93C − 0.09	0.15$\bar{X}$+0.28	0.20$\bar{X}$+0.41
Ethylbenzene	0.94C+0.31	0.17$\bar{X}$+0.46	0.26$\bar{X}$+0.23
Toluene	0.94C+0.65	0.09$\bar{X}$+0.48	0.18$\bar{X}$+0.71

X′=Expected recovery for one or more measurements of a sample containing a concentration of C, in μg/L.
S′=Expected single analyst standard deviation of measurements at an average concentration found of $\bar{X}$, in X μg/L.
S′=Expected interlaboratory standard deviation of measurements at an average concentration found of X, in μg/L.
C=True value for the Concentration, in μg/L.
$\bar{X}$=Average recovery found for measurements of samples containing a concentration of C, in μg/L.

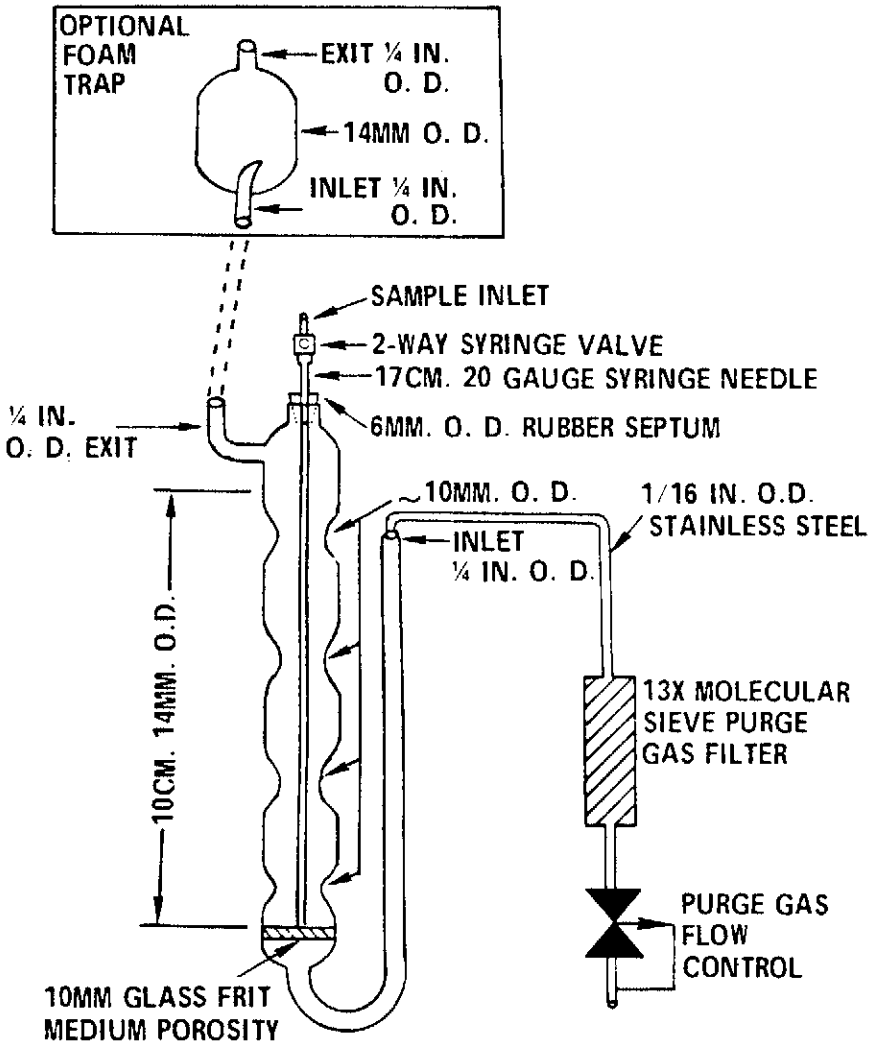

Figure 1. Purging device.

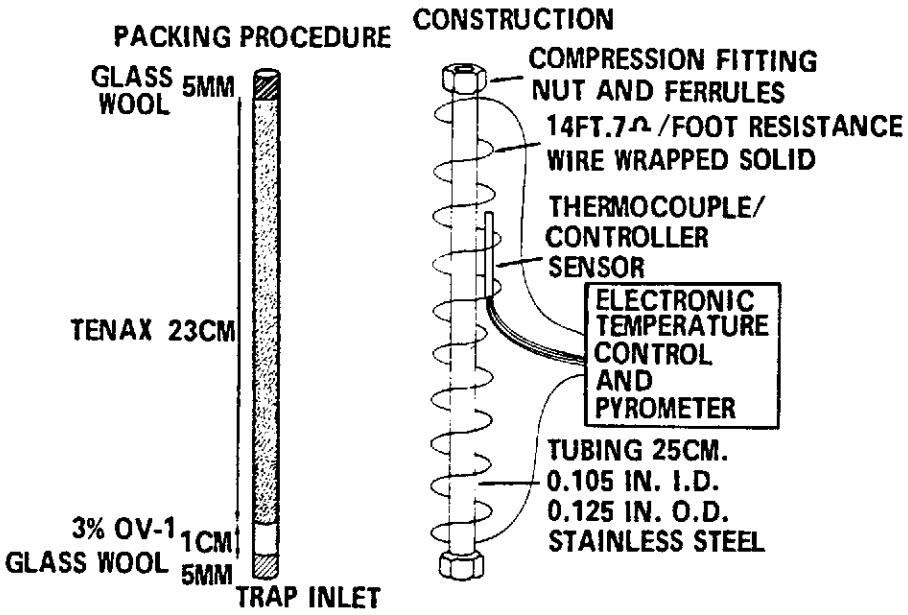

Figure 2. Trap packings and construction to include desorb capability.

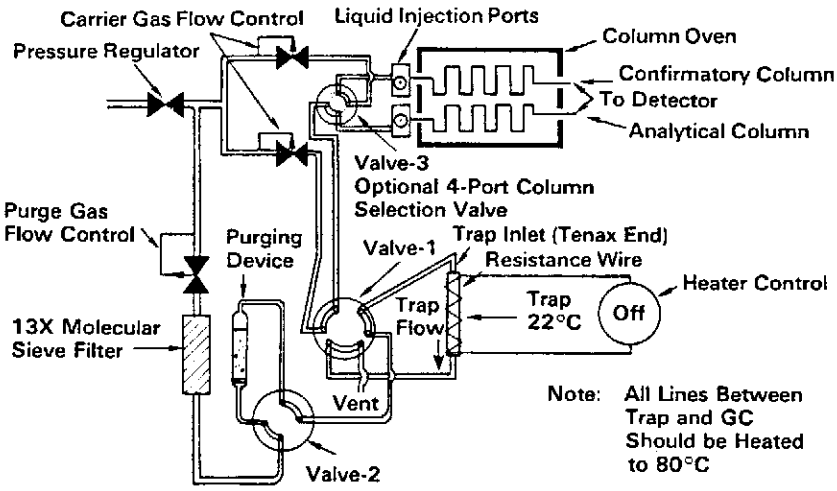

Figure 3. Purge and trap system - purge mode.

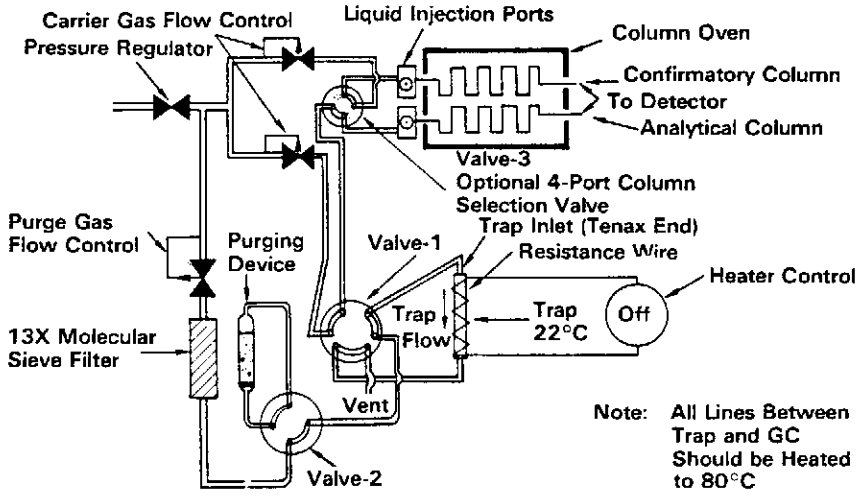

Figure 4. Purge and trap system-dry mode.

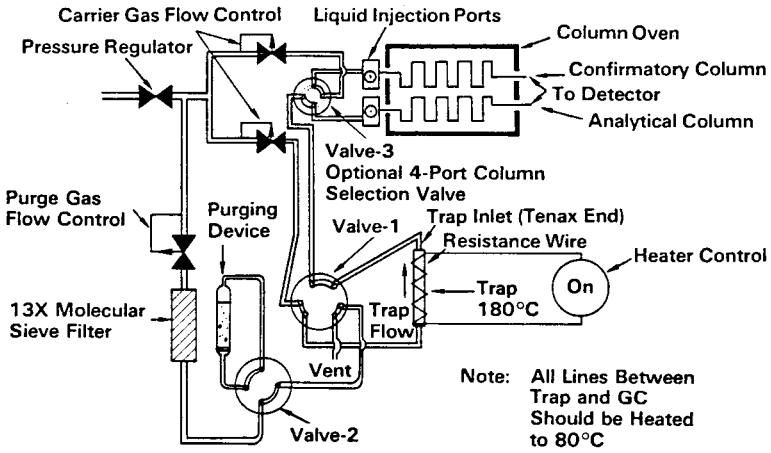

Figure 5. Purge and trap system-desorb mode.

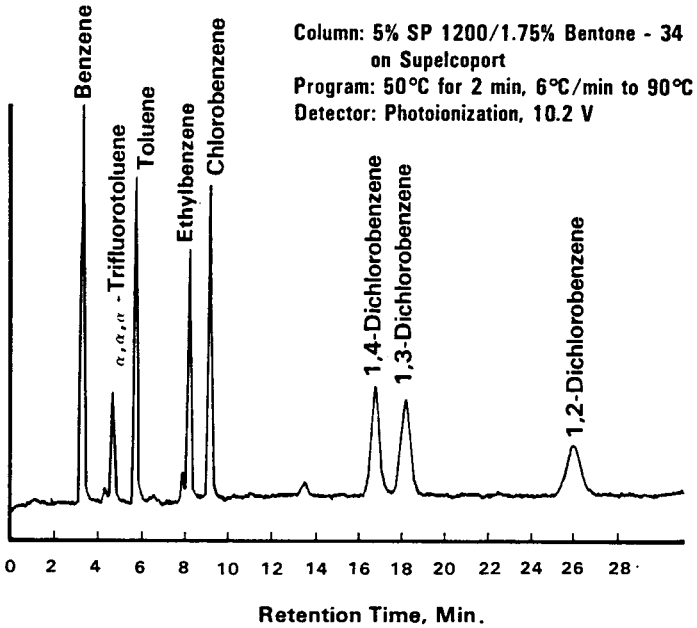

Figure 6. Gas chromatogram of purgeable aromatics.

METHOD 603—ACROLEIN AND ACRYLONITRILE

1. Scope and Application

1.1 This method covers the determination of acrolein and acrylonitrile. The following parameters may be determined by this method:

Parameter	STORET No.	CAS No.
Acrolein	34210	107–02–8
Acrylonitrile	34215	107–13–1

1.2 This is a purge and trap gas chromatographic (GC) method applicable to the determination of the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for either or both of the compounds above, compound identifications should be supported by at least one additional qualitative technique. This method describes analytical conditions for a second gas chromatographic column that can be used to confirm measurements made with the primary column. Method 624 provides gas chromatograph/mass spectrometer (GC/MS) conditions appropriate for the qualitative and quantitative confirmation of results for the parameters listed above, if used with the purge and trap conditions described in this method.

1.3 The method detection limit (MDL, defined in Section 12.1)[1] for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.4 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.5 This method is restricted to use by or under the supervision of analysts experienced in the operation of a purge and trap system and a gas chromatograph and in the interpretation of gas chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 An inert gas is bubbled through a 5-mL water sample contained in a heated purging chamber. Acrolein and acrylonitrile are transferred from the aqueous phase to the vapor phase. The vapor is swept through a sorbent trap where the analytes are trapped. After the purge is completed, the trap is heated and backflushed with the inert gas to desorb the compound onto a gas chromatographic column. The gas chromatograph is temperature programmed to separate the analytes which are then detected with a flame ionization detector.[2,3]

2.2 The method provides an optional gas chromatographic column that may be helpful in resolving the compounds of interest from the interferences that may occur.

3. Interferences

3.1 Impurities in the purge gas and organic compound outgassing from the plumbing of the trap account for the majority of contamination problems. The analytical system must be demonstrated to be free from contamination under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3. The use of non-Teflon plastic tubing, non-Teflon thread sealants, or flow controllers with rubber components in the purge and trap system should be avoided.

3.2 Samples can be contaminated by diffusion of volatile organics through the septum seal into the sample during shipment and storage. A field reagent blank prepared from reagent water and carried through the sampling and handling protocol can serve as a check on such contamination.

3.3 Contamination by carry-over can occur whenever high level and low level samples are sequentially analyzed. To reduce carry-over, the purging device and sample syringe must be rinsed between samples with reagent water. Whenever an unusually concentrated sample is encountered, it should be followed by an analysis of reagent water to check for cross contamination. For samples containing large amounts of water-soluble materials, suspended solids, high boiling compounds or high analyte levels, it may be necessary to wash the purging device with a detergent solution, rinse it with distilled water, and then dry it in an oven at 105°C between analyses. The trap and other parts of the system are also subject to contamination, therefore, frequent bakeout and purging of the entire system may be required.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this view point, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified[4,6] for the information of the analyst.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete sampling.

5.1.1 Vial—25-mL capacity or larger, equipped with a screw cap with a hole in the center (Pierce #13075 or equivalent). Detergent wash, rinse with tap and distilled water, and dry at 105 °C before use.

5.1.2 Septum—Teflon-faced silicone (Pierce #12722 or equivalent). Detergent wash, rinse with tap and distilled water and dry at 105 °C for 1 h before use.

5.2 Purge and trap system—The purge and trap system consists of three separate pieces of equipment: a purging device, trap, and desorber. Several complete systems are now commercially available.

5.2.1 The purging device must be designed to accept 5-mL, samples with a water column at least 3 cm deep. The gaseous head space between the water column and the trap must have a total volume of less than 15 mL. The purge gas must pass through the water column as finely divided bubbles with a diameter of less than 3 mm at the origin. The purge gas must be introduced no more than 5 mm from the base of the water column. The purging device must be capable of being heated to 85 °C within 3.0 min after transfer of the sample to the purging device and being held at 85 ±2 °C during the purge cycle. The entire water column in the purging device must be heated. Design of this modification to the standard purging device is optional, however, use of a water bath is suggested.

5.2.1.1 Heating mantle—To be used to heat water bath.

5.2.1.2 Temperature controller—Equipped with thermocouple/sensor to accurately control water bath temperature to ±2 °C. The purging device illustrated in Figure 1 meets these design criteria.

5.2.2 The trap must be at least 25 cm long and have an inside diameter of at least 0.105 in. The trap must be packed to contain 1.0 cm of methyl silicone coated packing (Section 6.5.2) and 23 cm of 2,6-diphenylene oxide polymer (Section 6.5.1). The minimum specifications for the trap are illustrated in Figure 2.

5.2.3 The desorber must be capable of rapidly heating the trap to 180 °C, The desorber illustrated in Figure 2 meets these design criteria.

5.2.4 The purge and trap system may be assembled as a separate unit as illustrated in Figure 3 or be coupled to a gas chromatograph.

5.3 pH paper—Narrow pH range, about 3.5 to 5.5 (Fisher Scientific Short Range Alkacid No. 2, #14–837–2 or equivalent).

5.4 Gas chromatograph—An analytical system complete with a temperature programmable gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, gases, detector, and strip-chart recorder. A data system is recommended for measuring peak areas.

5.4.1 Column 1—10 ft long × 2 mm ID glass or stainless steel, packed with Porapak-QS (80/100 mesh) or equivalent. This column was used to develop the method performance statements in Section 12. Guidelines for the use of alternate column packings are provided in Section 10.1.

5.4.2 Column 2—6 ft long × 0.1 in. ID glass or stainless steel, packed with Chromosorb 101 (60/80 mesh) or equivalent.

5.4.3 Detector—Flame ionization detector. This type of detector has proven effective in the analysis of wastewaters for the parameters listed in the scope (Section 1.1), and was used to develop the method performance statements in Section 12. Guidelines for the use of alternate detectors are provided in Section 10.1.

5.5 Syringes—5-mL, glass hypodermic with Luerlok tip (two each).

5.6 Micro syringes—25-μL, 0.006 in. ID needle.

5.7 Syringe valve—2-way, with Luer ends (three each).

5.8 Bottle—15-mL, screw-cap, with Teflon cap liner.

5.9 Balance—Analytical, capable of accurately weighing 0.0001 g.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.1.1 Reagent water can be generated by passing tap water through a carbon filter bed containing about 1 lb of activated carbon (Filtrasorb-300, Calgon Corp., or equivalent).

6.1.2 A water purification system (Millipore Super-Q or equivalent) may be used to generate reagent water.

6.1.3 Regent water may also be prepared by boiling water for 15 min. Subsequently, while maintaining the temperature at 90 °C, bubble a contaminant-free inert gas through the water for 1 h. While still hot, transfer the water to a narrow mouth screw-cap bottle and seal with a Teflon-lined septum and cap.

6.2 Sodium thiosulfate—(ACS) Granular.

6.3 Sodium hydroxide solution (10 N)—Dissolve 40 g of NaOH (ACS) in reagent water and dilute to 100 mL.

6.4 Hydrochloric acid (1+1)—Slowly, add 50 mL of concentrated HCl (ACS) to 50 mL of reagent water.

6.5 Trap Materials:

6.5.1 2,6-Diphenylene oxide polymer—Tenax (60/80 mesh), chromatographic grade or equivalent.

6.5.2 Methyl silicone packing—3% OV–1 on Chromosorb–W (60/80 mesh) or equivalent.

6.6 Stock standard solutions—Stock standard solutions may be prepared from pure standard materials or purchased as certified solutions. Prepare stock standard solutions in reagent water using assayed liquids. Since acrolein and acrylonitrile are lachrymators, primary dilutions of these compounds should be prepared in a hood. A NIOSH/MESA approved toxic gas respirator should be used when the analyst handles high concentrations of such materials.

6.6.1 Place about 9.8 mL of reagent water into a 10-mL ground glass stoppered volumetric flask. For acrolein standards the reagent water must be adjusted to pH 4 to 5. Weight the flask to the nearest 0.1 mg.

6.6.2 Using a 100-µL syringe, immediately add two or more drops of assayed reference material to the flask, then reweigh. Be sure that the drops fall directly into the water without contacting the neck of the flask.

6.6.3 Reweigh, dilute to volume, stopper, then mix by inverting the flask several times. Calculate the concentration in µg/µL from the net gain in weight. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock staldard. Optionally, stock standard solutions may be prepared using the pure standard material by volumetrically measuring the appropriate amounts and determining the weight of the material using the density of the material. Commercially prepared stock standards may be used at any concentration if they are certified by the manufactaurer or by an independent source.

6.6.4 Transfer the stock standard solution into a Teflon-sealed screw-cap bottle. Store at 4 °C and protect from light.

6.6.5 Prepare fresh standards daily.

6.7 Secondary dilution standards—Using stock standard solutions, prepare secondary dilution standards in reagent water that contain the compounds of interest, either singly or mixed together. The secondary dilution standards should be prepared at concentrations such that the aqueous calibration standards prepared in Section 7.3.1 or 7.4.1 will bracket the working range of the analytical system. Secondary dilution standards should be prepared daily and stored at 4 °C.

6.8 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Assemble a purge and trap system that meets the specifications in Section 5.2. Condition the trap overnight at 180 °C by backflushing with an inert gas flow of at least 20 mL/min. Condition the trap for 10 min once daily prior to use.

7.2 Connect the purge and trap system to a gas chromatograph. The gas chromatograph must be operated using temperature and flow rate conditions equivalent to those given in Table 1. Calibrate the purge and trap-gas chromatographic system using either the external standard technique (Section 7.3) or the internal standard technique (Section 7.4).

7.3 External standard calibration procedure:

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter by carefully adding 20.0 µL of one or more secondary dilution standards to 100, 500, or 1000 mL of reagent water. A 25-µL syringe with a 0.006 in. ID needle should be used for this operation. One of the external standards should be at a concentration near, but above, the MDL and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector. These standards must be prepared fresh daily.

7.3.2 Analyze each calibration standard according to Section 10, and tabulate peak height or area responses versus the concentration of the standard. The results can be used to prepare a calibration curve for each compound. Alternatively, if the ratio of response to concentration (calibration factor) is a constant over the working range (< 10% relative standard deviation, RSD), linearity through the origin can be assumed and the average ratio or calibration factor can be used in place of a calibration curve.

7.4 Internal standard calibration procedure—To use this approach, the analyst must select one or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Because of these limitations, no internal standard can be suggested that is applicable to all samples.

7.4.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest as described in Section 7.3.1.

7.4.2 Prepare a spiking solution containing each of the internal standards using the procedures described in Sections 6.6 and 6.7. It is recommended that the secondary dilution standard be prepared at a concentration of 15 µg/mL of each internal standard compound. The addition of 10 µL of this standard to 5.0 mL of sample or calibration standard would be equivalent to 30 µg/L.

7.4.3 Analyze each calibration standard according to Section 10, adding 10 µL of internal standard spiking solution directly to the syringe (Section 10.4). Tabulate peak height or area responses against concentration for each compound and internal standard, and calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:
A_s=Response for the parameter to be measured.
A_{is}=Response for the internal standard.
C_{is}=Concentration of the internal standard.
C_s=Concentration of the parameter to be measured.

If the RF value over the working range is a constant (<10% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.5 The working calibration curve, calibration factor, or RF must be verified on each working day by the measurement of a QC check sample.

7.5.1 Prepare the QC check sample as described in Section 8.2.2.

7.5.2 Analyze the QC check sample according to Section 10.

7.5.3 For each parameter, compare the response (Q) with the corresponding calibration acceptance criteria found in Table 2. If the responses for all parameters of interest fall within the designated ranges, analysis of actual samples can begin. If any individual Q falls outside the range, a new calibration curve, calibration factor, or RF must be prepared for that parameter according to Section 7.3 or 7.4.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Section 10.1) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Each day, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system are under control.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing each parameter of interest at a concentration of 25 µg/mL in reagent water. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Prepare a QC check sample to contain 50 µg/L of each parameter by adding 200 µL of QC check sample concentrate to 100 mL of reagent water.

8.2.3 Analyze four 5-mL aliquots of the well-mixed QC check sample according to Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 3. If s and $\bar{X}$ for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If either s exceeds the precision limit or $\bar{X}$ falls outside the range for accuracy, the system performance is unacceptable for that parameter. Locate and correct the source of the

problem and repeat the test for each compound of interest.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spiked sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at 50 µg/L or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.2 Analyze one 5-mL sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second 5-mL sample aliquot with 10 µL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100(A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 3. These acceptance criteria were calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[7]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4 If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory.

8.4.1 Prepare the QC check standard by adding 10 µL of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 5 mL of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 3. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $P-2s_p$ to $P+2s_p$. If P=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as gas chromatography with a dissimilar column or mass spectrometer must be used. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 All samples must be iced or refrigerated from the time of collection until analysis. If the sample contains free or combined chlorine, add sodium thiosulfate preservative (10 mg/40 mL is sufficient for up to 5 ppm Cl_2) to the empty sample bottle just prior to shipping to the sampling site. EPA Methods 330.4 and 330.5 may be used for measurement of residual chlorine.[8] Field test kits are available for this purpose.

9.2 If acrolein is to be analyzed, collect about 500 mL of sample in a clean glass container. Adjust the pH of the sample to 4 to 5 using acid or base, measuring with narrow

range pH paper. Samples for acrolein analysis receiving no pH adjustment must be analyzed within 3 days of sampling.

9.3 Grab samples must be collected in glass containers having a total volume of at least 25 mL. Fill the sample bottle just to overflowing in such a manner that no air bubbles pass through the sample as the bottle is being filled. Seal the bottle so that no air bubbles are entrapped in it. If preservative has been added, shake vigorously for 1 min. Maintain the hermetic seal on the sample bottle until time of analysis.

9.4 All samples must be analyzed within 14 days of collection.[3]

10. Procedure

10.1 Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are estimated retention times and MDL that can be achieved under these conditions. An example of the separations achieved by Column 1 is shown in Figure 5. Other packed columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met.

10.2 Calibrate the system daily as described in Section 7.

10.3 Adjust the purge gas (nitrogen or helium) flow rate to 20 mL-min. Attach the trap inlet to the purging device, and set the purge and trap system to purge (Figure 3). Open the syringe valve located on the purging device sample introduction needle.

10.4 Remove the plunger from a 5-mL syringe and attach a closed syringe valve. Open the sample bottle (or standard) and carefully pour the sample into the syringe barrel to just short of overflowing. Replace the syringe plunger and compress the sample. Open the syringe valve and vent any residual air while adjusting the sample volume to 5.0 mL. Since this process of taking an aliquot destroys the validity of the sample for future analysis, the analyst should fill a second syringe at this time to protect against possible loss of data. Add 10.0 µL of the internal standard spiking solution (Section 7.4.2), if applicable, through the valve bore then close the valve.

10.5 Attach the syringe-syringe valve assembly to the syringe valve on the purging device. Open the syringe valves and inject the sample into the purging chamber.

10.6 Close both valves and purge the sample for 15.0 ± 0.1 min while heating at 85 ± 2 °C.

10.7 After the 15-min purge time, attach the trap to the chromatograph, adjust the purge and trap system to the desorb mode (Figure 4), and begin to temperature program the gas chromatograph. Introduce the trapped materials to the GC column by rapidly heating the trap to 180 °C while backflushing the trap with an inert gas between 20 and 60 mL/min for 1.5 min.

10.8 While the trap is being desorbed into the gas chromatograph, empty the purging chamber using the sample introduction syringe. Wash the chamber with two 5-mL flushes of reagent water.

10.9 After desorbing the sample for 1.5 min, recondition the trap by returning the purge and trap system to the purge mode. Wait 15 s then close the syringe valve on the purging device to begin gas flow through the trap. The trap temperature should be maintained at 210 °C. After approximately 7 min, turn off the trap heater and open the syringe valve to stop the gas flow through the trap. When the trap is cool, the next sample can be analyzed.

10.10 Identify the parameters in the sample by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

11. Calculations

11.1 Determine the concentration of individual compounds in the sample.

11.1.1 If the external standard calibration procedure is used, calculate the concentration of the parameter being measured from the peak response using the calibration curve or calibration factor determined in Section 7.3.2.

11.1.2 If the internal standard calibration procedure is used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.4.3 and Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(C_{is})}{(A_{is})(RF)}$$

Equation 2

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

C_{is}=Concentration of the internal standard.

11.2 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

12. Method Performance

12.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above

zero.[1] The MDL concentrations listed in Table 1 were obtained using reagent water.[9] The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

12.2 This method is recommended for the concentration range from the MDL to 1,000×MDL. Direct aqueous injection techniques should be used to measure concentration levels above 1,000×MDL.

12.3 In a single laboratory (Battelle-Columbus), the average recoveries and standard deviations presented in Table 2 were obtained.[9] Seven replicate samples were analyzed at each spike level.

References

1. 40 CFR part 136, appendix B.

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3. ''Evaluate Test Procedures for Acrolein and Acrylonitrile,'' Special letter report for EPA Project 4719–A, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268, 27 June 1979.

4. ''Carcinogens—Working With Carcinogens,'' Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, Publication No. 77–206, August 1977.

5. ''OSHA Safety and Health Standards, General Industry,'' (29 CFR part 1910), Occupational Safety and Health Administration, OSHA 2206 (Revised, January 1976).

6. ''Safety in Academic Chemistry Laboratories,'' American Chemical Society Publication, Committee on Chemical Safety, 3rd Edition, 1979.

7. Provost, L.P., and Elder, R.S. ''Interpretation of Percent Recovery Data,'' *American Laboratory, 15,* 58–63 (1983).

8. ''Methods 330.4 (Titrimetric, DPD–FAS) and 330.5 (Spectrophotometric, DPD) for Chlorine, Total Residual,'' Methods for Chemical Analysis of Water and Wastes, EPA–600/4–79–020, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268, March 1979.

9. ''Evaluation of Method 603 (Modified),'' EPA–600/4–84–ABC, National Technical Information Service, PB84–, Springfield, Virginia 22161, Nov. 1984.

TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention time (min)		Method detection limit (μg/L)
	Column 1	Column 2	
Acrolein	10.6	8.2	0.7
Acrylonitrile	12.7	9.8	0.5

Column 1 conditions: Porapak-QS (80/100 mesh) packed in a 10 ft × 2 mm ID glass or stainless steel column with helium carrier gas at 30 mL/min flow rate. Column temperature held isothermal at 110 °C for 1.5 min (during desorption), then heated as rapidly as possible to 150 °C and held for 20 min; column bakeout at 190 °C for 10 min.[9]

Column 2 conditions: Chromosorb 101 (60/80 mesh) packed in a 6 ft. × 0.1 in. ID glass or stainless steel column with helium carrier gas at 40 mL/min flow rate. Column temperature held isothermal at 80 °C for 4 min, then programmed at 50 °C/min to 120 °C and held for 12 min.

TABLE 2—SINGLE LABORATORY ACCURACY AND PRECISION—METHOD 603

Parameter	Sample matrix	Spike conc. (μg/L)	Average recovery (μg/L)	Standard deviation (μg/L)	Average percent recovery
Acrolein	RW	5.0	5.2	0.2	104
	RW	50.0	51.4	0.7	103
	POTW	5.0	4.0	0.2	80
	POTW	50.0	44.4	0.8	89
	IW	5.0	0.1	0.1	2
	IW	100.0	9.3	1.1	9
Acrylonitrile	RW	5.0	4.2	0.2	84
	RW	50.0	51.4	1.5	103
	POTW	20.0	20.1	0.8	100
	POTW	100.0	101.3	1.5	101
	IW	10.0	9.1	0.8	91
	IW	100.0	104.0	3.2	104

ARW=Reagent water.
APOTW=Prechlorination secondary effluent from a municipal sewage treatment plant.
AIW=Industrial wastewater containing an unidentified acrolein reactant.

TABLE 3—CALIBRATION AND QC ACCEPTANCE CRITERIA—METHOD 603[A]

Parameter	Range for Q (μg/L)	Limit for S (μg/L)	Range for X (μg/L)	Range for P, P_s (%)
Acrolein	45.9–54.1	4.6	42.9–60.1	88–118

TABLE 3—CALIBRATION AND QC ACCEPTANCE CRITERIA—METHOD 603[A]—Continued

Parameter	Range for Q (μg/L)	Limit for S (μg/L)	Range for X (μg/L)	Range for P, P_s (%)
Acrylonitrile	41.2–58.8	9.9	33.1–69.9	71–135

[a]=Criteria were calculated assuming a QC check sample concentration of 50 μg/L.[9]
Q=Concentration measured in QC check sample, in μg/L (Section 7.5.3).
s=Standard deviation of four recovery measurements, in μg/L (Section 8.2.4).
X=Average recovery for four recovery measurements, in μg/L (Section 8.2.4).
P, P_s=Percent recovery measured (Section 8.3.2, Section 8.4.2).

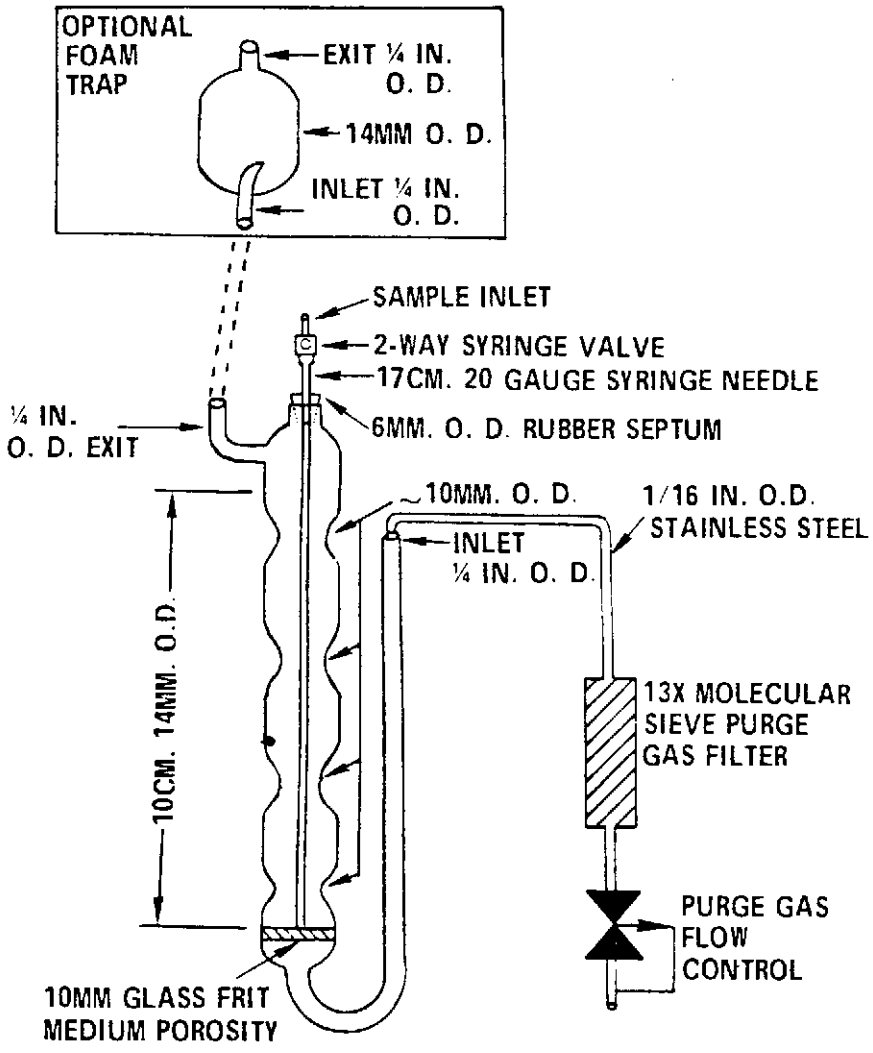

Figure 1. Purging device.

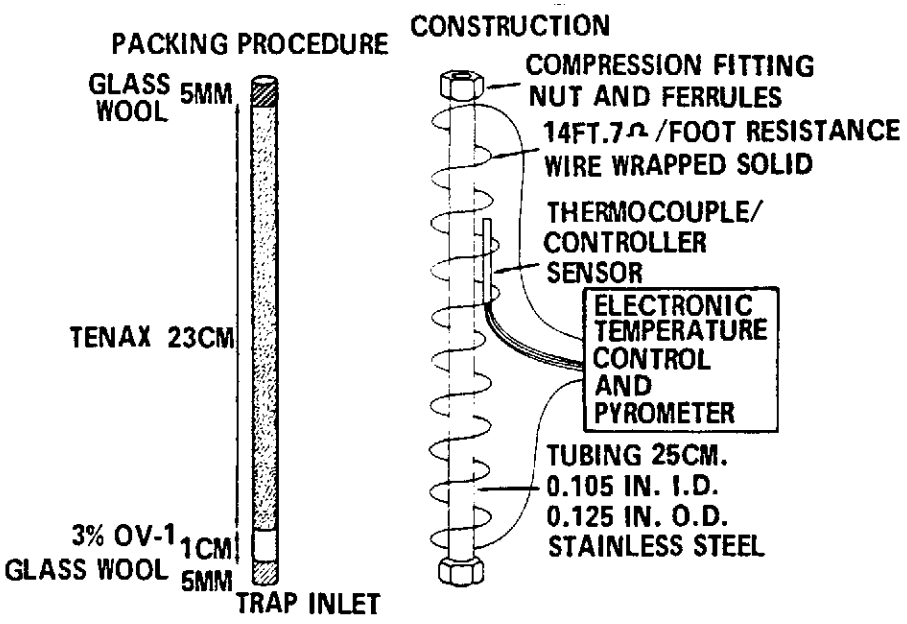

Figure 2. Trap packings and construction to include desorb capability.

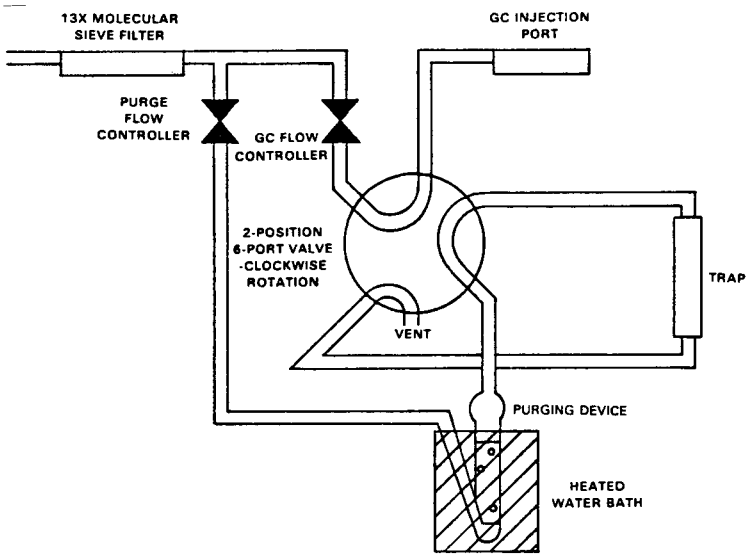

Figure 3. Purge and trap system-purge mode.

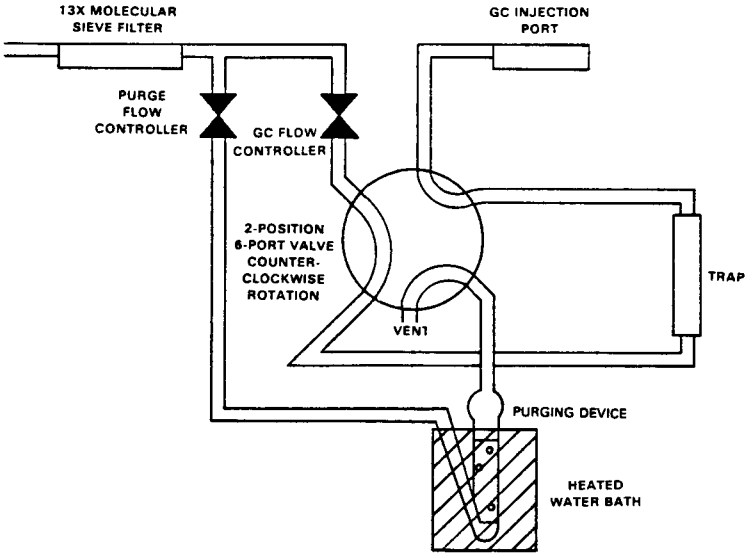

Figure 4. Purge and trap system-desorb mode.

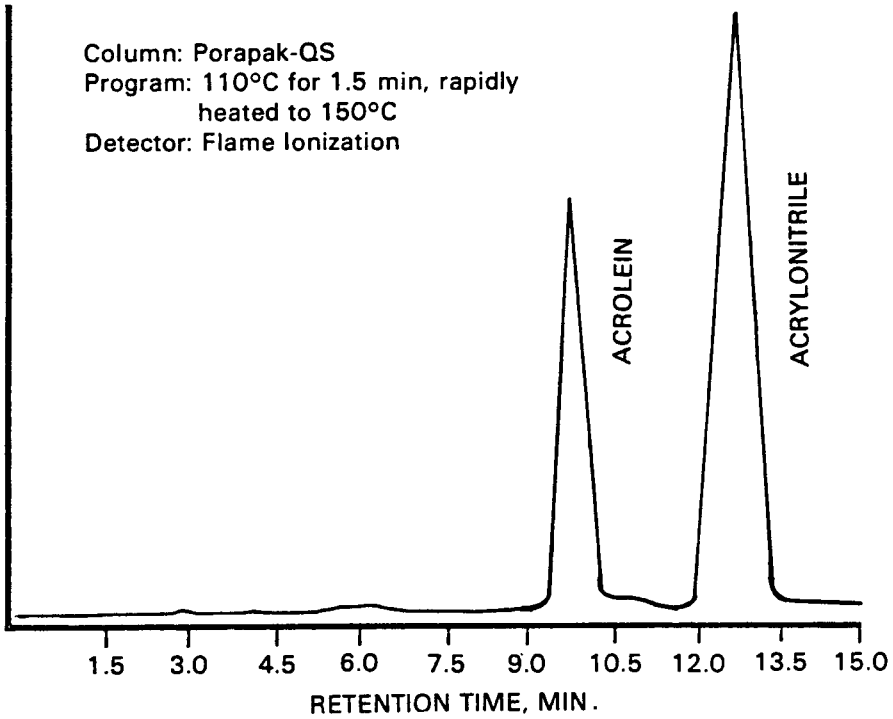

Figure 5. Gas chromatogram of acrolein and acrylonitrile.

METHOD 604—PHENOLS

1. Scope and Application

1.1 This method covers the determination of phenol and certain substituted phenols. The following parameters may be determined by this method:

Parameter	STORET No.	CAS No.
4-Chloro-3-methylphenol	34452	59–50–7
2–-Chlorophenol	34586	95–57–8
2,4-Dichlorophenol	34601	120–83–2
2,4-Dimethylphenol	34606	105–67–9
2,4-Dinitrophenol	34616	51–28–5
2-Methyl-4,6-dinitrophenol	34657	534–52–1
2-Nitrophenol	34591	88–75–5
4-Nitrophenol	34646	100–02–7
Pentachlorophenol	39032	87–86–5
Phenol	34694	108–95–2
2,4,6-Trichlorophenol	34621	88–06–2

1.2 This is a flame ionization detector gas chromatographic (FIDGC) method applicable to the determination of the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for any or all of the compounds above, compound identifications should be supported by at least one additional qualitative technique. This method describes analytical conditions for derivatization, cleanup, and electron capture detector gas chromatography (ECDGC) that can be used to confirm measurements made by FIDGC. Method 625 provides gas chromatograph/mass spectrometer (GC/MS) conditions appropriate for the qualitative and quantitative confirmation of results for all of the parameters listed above, using the extract produced by this method.

1.3 The method detection limit (MDL, defined in Section 14.1)[1] for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix. The MDL listed in Table 1 for each parameter was achieved with a flame ionization detector (FID). The MDLs that were achieved when the derivatization cleanup and electron capture detector (ECD) were employed are presented in Table 2.

1.4 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.5 This method is restricted to use by or under the supervision of analysts experienced in the use of a gas chromatograph and in the interpretation of gas chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 A measured volume of sample, approximately 1-L, is acidified and extracted with methylene chloride using a separatory funnel. The methylene chloride extract is dried and exchanged to 2-propanol during concentration to a volume of 10 mL or less. The extract is separated by gas chromatography and the phenols are then measured with an FID.[2]

2.2 A preliminary sample wash under basic conditions can be employed for samples having high general organic and organic base interferences.

2.3 The method also provides for a derivatization and column chromatography cleanup procedure to aid in the elimination of interferences.[2,3] The derivatives are analyzed by ECDGC.

3. Interferences

3.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that lead to discrete artifacts and/or elevated baselines in gas chromatograms. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3.

3.1.1 Glassware must be scrupulously cleaned.[4] Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. Solvent rinsing should be followed by detergent washing with hot water, and rinses with tap water and distilled water. The glassware should then be drained dry, and heated in a muffle furnace at 400 °C for 15 to 30 min. Some thermally stable materials, such as PCBs, may not be eliminated by this treatment. Solvent rinses with acetone and pesticide quality hexane may be substituted for the muffle furnace heating. Thorough rinsing with such solvents usually eliminates PCB interference. Volumetric ware should not be heated in a muffle furnace. After drying and cooling, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Store inverted or capped with aluminum foil.

3.1.2 The use of high purity reagents and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

3.2 Matrix interferences may be caused by contaminants that are coextracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature and diversity of the industrial complex or municipality being sampled. The derivatization cleanup procedure in Section 12 can be used to overcome many of these interferences, but unique samples may require additional cleanup approaches to achieve the MDL listed in Tables 1 and 2.

3.3 The basic sample wash (Section 10.2) may cause significantly reduced recovery of phenol and 2,4-dimethylphenol. The analyst must recognize that results obtained under these conditions are minimum concentrations.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this mothod has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified[5—7] for the information of analyst.

4.2 Special care should be taken in handling pentafluorobenzyl bromide, which is a lachrymator, and 18-crown-6-ether, which is highly toxic.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete or composite sampling.

5.1.1 Grab sample bottle—1–L or 1-qt, amber glass, fitted with a screw cap lined with Teflon. Foil may be substituted for Teflon if the sample is not corrosive. If amber bottles are not available, protect samples from light. The bottle and cap liner must be washed, rinsed with acetone or methylene chloride, and dried before use to minimize contamination.

5.1.2 Automatic sampler (optional)—The sampler must incorporate glass sample containers for the collection of a minimum of 250 mL of sample. Sample containers must be kept refrigerated at 4°C and protected from light during compositing. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be

used. Before use, however, the compressible tubing should be thoroughly rinsed with methanol, followed by repeated rinsings with distilled water to minimize the potential for contamination of the sample. An integrating flow meter is required to collect flow proportional composites.

5.2 Glassware (All specifications are suggested. Catalog numbers are included for illustration only.):

5.2.1 Separatory funnel—2–L, with Teflon stopcock.

5.2.2 Drying column—Chromatographic column, 400 mm long × 19 mm ID, with coarse frit filter disc.

5.2.3 Chromatographic column—100 mm long × 10 mm ID, with Teflon stopcock.

5.2.4 Concentrator tube, Kuderna-Danish—10-mL, graduated (Kontes K–570050–1025 or equivalent). Calibration must be checked at the volumes employed in the test. Ground glass stopper is used to prevent evaporation of extracts.

5.2.5 Evaporative flask, Kuderna-Danish—500-mL (Kontes K–570001–0500 or equivalent). Attach to concentrator tube with springs.

5.2.6 Snyder column, Kuderna-Danish—Three-ball macro (Kontes K–503000–0121 or equivalent).

5.2.7 Snyder column, Kuderna-Danish—Two-ball micro (Kontes K–569001–0219 or equivalent).

5.2.8 Vials—10 to 15-mL, amber glass, with Teflon-lined screw cap.

5.2.9 Reaction flask—15 to 25-mL round bottom flask, with standard tapered joint, fitted with a water-cooled condenser and U-shaped drying tube containing granular calcium chloride.

5.3 Boiling chips—Approximately 10/40 mesh. Heat to 400 °C for 30 min or Soxhlet extract with methylene chloride.

5.4 Water bath—Heated, with concentric ring cover, capable of temperature control (±2°C). The bath should be used in a hood.

5.5 Balance—Analytical, capable of accurately weighting 0.0001 g.

5.6 Gas chromatograph—An analytical system complete with a temperature programmable gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, gases, detector, and strip-chart recorder. A data system is recommended for measuring peak areas.

5.6.1 Column for underivatized phenols—1.8 m long × 2 mm ID glass, packed with 1% SP–1240DA on Supelcoport (80/100 mesh) or equivalent. This column was used to develop the method performance statements in Section 14. Guidelines for the use of alternate column packings are provided in Section 11.1.

5.6.2 Column for derivatized phenols—1.8 m long × 2 mm ID glass, packed with 5% OV–17 on Chromosorb W–AW–DMCS (80/100 mesh) or equivalent. This column has proven effective in the analysis of wastewaters for derivatization products of the parameters listed in the scope (Section 1.1), and was used to develop the method performance statements in Section 14. Guidelines for the use of alternate column packings are provided in Section 11.1.

5.6.3 Detectors—Flame ionization and electron capture detectors. The FID is used when determining the parent phenols. The ECD is used when determining the derivatized phenols. Guidelines for the use of alternatve detectors are provided in Section 11.1.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.2 Sodium hydroxide solution (10 N)—Dissolve 40 g of NaOH (ACS) in reagent water and dilute to 100 mL.

6.3 Sodium hydroxide solution (1 N)—Dissolve 4 g of NaOH (ACS) in reagent water and dilute to 100 mL.

6.4 Sodium sulfate—(ACS) Granular, anhydrous. Purify by heating at 400°C for 4 h in a shallow tray.

6.5 Sodium thiosulfate—(ACS) Granular.

6.6 Sulfuric acid (1+1)—Slowly, add 50 mL of H_2SO_4 (ACS, sp. gr. 1.84) to 50 mL of reagent water.

6.7 Sulfuric acid (1 N)—Slowly, add 58 mL of H_2SO_4 (ACS, sp. gr. 1.84) to reagent water and dilute to 1 L.

6.8 Potassium carbonate—(ACS) Powdered.

6.9 Pentafluorobenzyl bromide (α-Bromopentafluorotoluene)—97% minimum purity.

NOTE: This chemical is a lachrymator. (See Section 4.2.)

6.10 18-crown-6-ether (1,4,7,10,13,16-Hexaoxacyclooctadecane)—98% minimum purity.

NOTE: This chemical is highly toxic.

6.11 Derivatization reagent—Add 1 mL of pentafluorobenzyl bromide and 1 g of 18-crown-6-ether to a 50-mL volumetric flask and dilute to volume with 2-propanol. Prepare fresh weekly. This operation should be carried out in a hood. Store at 4 °C and protect from light.

6.12 Acetone, hexane, methanol, methylene chloride, 2-propanol, toluene—Pesticide quality or equivalent.

6.13 Silica gel—100/200 mesh, Davison, grade-923 or equivalent. Activate at 130 °C overnight and store in a desiccator.

6.14 Stock standard solutions (1.00 µg/µL)—Stock standard solutions may be prepared from pure standard materials or purchased as certified solutions.

6.14.1 Prepare stock standard solutions by accurately weighing about 0.0100 g of pure material. Dissolve the material in 2-propanol

and dilute to volume in a 10-mL volumetric flask. Larger volumes can be used at the convenience of the analyst. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the manufacturer or by an independent source.

6.14.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4 °C and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.14.3 Stock standard solutions must be replaced after six months, or sooner if comparison with check standards indicates a problem.

6.15 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 To calibrate the FIDGC for the anaylsis of underivatized phenols, establish gas chromatographic operating conditions equivalent to those given in Table 1. The gas chromatographic system can be calibrated using the external standard technique (Section 7.2) or the internal standard technique (Section 7.3).

7.2 External standard calibration procedure for FIDGC:

7.2.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask and diluting to volume with 2-propanol. One of the external standards should be at a concentration near, but above, the MDL (Table 1) and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.2.2 Using injections of 2 to 5 µl, analyze each calibration standard according to Section 11 and tabulate peak height or area responses against the mass injected. The results can be used to prepare a calibration curve for each compound. Alternatively, if the ratio of response to amount injected (calibration factor) is a constant over the working range (<10% relative standard deviation, RSD), linearity through the origin can be assumed and the average ratio or calibration factor can be used in place of a calibration curve.

7.3 Internal standard calibration procedure for FIDGC—To use this approach, the analyst must select one or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Because of these limitations, no internal standard can be suggested that is applicable to all samples.

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask. To each calibration standard, add a known constant amount of one or more internal standards, and dilute to volume with 2-propanol. One of the standards should be at a concentration near, but above, the MDL and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.3.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 11 and tabulate peak height or area responses against concentration for each compound and internal standard. Calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

C_{is}=Concentration of the internal standard (µg/L).

C_s=Concentration of the parameter to be measured (µg/L).

If the RF value over the working range is a constant (<10% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.4 The working calibration curve, calibration factor, or RF must be verified on each working day by the measurement of one or more calibration standards. If the response for any parameter varies from the predicted response by more than ±15%, a new calibration curve must be prepared for that compound.

7.5 To calibrate the ECDGC for the analysis of phenol derivatives, establish gas chromatographic operating conditions equivalent to those given in Table 2.

7.5.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask and diluting to volume with 2-propanol. One of the external standards should be at a concentration near, but above, the MDL (Table 2) and the other concentrations should correspond to the expected

range of concentrations found in real samples or should define the working range of the detector.

7.5.2 Each time samples are to be derivatized, simultaneously treat a 1-mL aliquot of each calibration standard as described in Section 12.

7.5.3 After derivatization, analyze 2 to 5 µL of each column eluate collected according to the method beginning in Section 12.8 and tabulate peak height or area responses against the calculated equivalent mass of underivatized phenol injected. The results can be used to prepare a calibration curve for each compound.

7.6 Before using any cleanup procedure, the analyst must process a series of calibration standards through the procedure to validate elution patterns and the absence of interferences from the reagents.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Sections 10.6 and 11.1) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Before processing any samples the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system and glassware are under control. Each time a set of samples is extracted or reagents are changed a reagent water blank must be processed as a safeguard against laboratory contamination.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing each parameter of interest at a concentration of 100 µg/mL in 2-propanol. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Using a pipet, prepare QC check samples at a concentration of 100 µg/L by adding 1.00 mL of QC check sample concentrate to each of four 1-L aliquots of reagent water.

8.2.3 Analyze the well-mixed QC check samples according to the method beginning in Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 3. If s and $\bar{X}$ for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual $\bar{X}$ falls outside the range for accuracy, the system performance is unacceptable for that parameter.

NOTE: The large number of parameters in Talbe 3 present a substantial probability that one or more will fail at least one of the acceptance criteria when all parameters are analyzed.

8.2.6 When one or more of the parameters tested fail at least one of the acceptance criteria, the analyst must proceed according to Section 8.2.6.1 or 8.2.6.2.

8.2.6.1 Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.2.

8.2.6.2 Beginning with Section 8.2.2, repeat the test only for those parameters that failed to meet criteria. Repeated failure, however, will confirm a general problem with the measurement system. If this occurs, locate and correct the source of the problem and repeat the test for all compounds of interest beginning with Section 8.2.2.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spiked sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at 100 µg/L or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.3 If it is impractical to determine background levels before spiking (e.g., maximum holding times will be exceeded), the spike concentration should be (1) the regulatory concentration limit, if any, or, if none, (2) the larger of either 5 times higher than the expected background concentration or 100 µg/L.

8.3.2 Analyze one sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second sample aliquot with 1.0 mL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100(A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 3. These acceptance criteria were calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[8] If spiking was performed at a concentration lower than 100 µg/L, the analyst must use either the QC acceptance criteria in Table 3, or optional QC acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recovery of a parameter: (1) Calculate accuracy (X′) using the equation in Table 4, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 4, substituting X′ for $\bar{X}$; (3) calculate the range for recovery at the spike concentration as (100 X′/T)±2.44(100 S′/T)%.[8]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4 If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory.

8.4.1 Prepare the QC check standard by adding 1.0 mL of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 1 L of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 3. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery ($\bar{P}$) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $\bar{P}-2s_p$ to $\bar{P}+2s_p$. If $\bar{P}$=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6. It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates

may be analyzed to assess the precision of the environmental measurements. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as gas chromatography with a dissimilar column, specific element detector, or mass spectrometer must be used. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 Grab samples must be collected in glass containers. Conventional sampling practices[9] should be followed, except that the bottle must not be prerinsed with sample before collection. Composite samples should be collected in refrigerated glass containers in accordance with the requirements of the program. Automatic sampling equipment must be as free as possible of Tygon tubing and other potential sources of contamination.

9.2 All samples must be iced or refrigerated at 4 °C from the time of collection until extraction. Fill the sample bottles and, if residual chlorine is present, add 80 mg of sodium thiosulfate per liter of sample and mix well. EPA Methods 330.4 and 330.5 may be used for measurement of residual chlorine.[10] Field test kits are available for this purpose.

9.3 All samples must be extracted within 7 days of collection and completely analyzed within 40 days of extraction.[2]

10. Sample Extraction

10.1 Mark the water meniscus on the side of sample bottle for later determination of sample volume. Pour the entire sample into a 2-L separatory funnel.

10.2 For samples high in organic content, the analyst may solvent wash the sample at basic pH as prescribed in Sections 10.2.1 and 10.2.2 to remove potential method interferences. Prolonged or exhaustive contact with solvent during the wash may result in low recovery of some of the phenols, notably phenol and 2,4-dimethylphenol. For relatively clean samples, the wash should be omitted and the extraction, beginning with Section 10.3, should be followed.

10.2.1 Adjust the pH of the sample to 12.0 or greater with sodium hydroxide solution.

10.2.2 Add 60 mL of methylene chloride to the sample by shaking the funnel for 1 min with periodic venting to release excess pressure. Discard the solvent layer. The wash can be repeated up to two additional times if significant color is being removed.

10.3 Adjust the sample to a pH of 1 to 2 with sulfuric acid.

10.4 Add 60 mL of methylene chloride to the sample bottle, seal, and shake 30 s to rinse the inner surface. Transfer the solvent to the separatory funnel and extract the sample by shaking the funnel for 2 min. with periodic venting to release excess pressure. Allow the organic layer to separate from the water phase for a minimum of 10 min. If the emulsion interface between layers is more than one-third the volume of the solvent layer, the analyst must employ mechanical techniques to complete the phase separation. The optimum technique depends upon the sample, but may include stirring, filtration of the emulsion through glass wool, centrifugation, or other physical methods. Collect the methylene chloride extract in a 250-mL Erlenmeyer flask.

10.5 Add a second 60-mL volume of methylene chloride to the sample bottle and repeat the extraction procedure a second time, combining the extracts in the Erlenmeyer flask. Perform a third extraction in the same manner.

10.6 Assemble a Kuderna-Danish (K–D) concentrator by attaching a 10-mL concentrator tube to a 500-mL evaporative flask. Other concentration devices or techniques may be used in place of the K–D concentrator if the requirements of Section 8.2 are met.

10.7 Pour the combined extract through a solvent-rinsed drying column containing about 10 cm of anhydrous sodium sulfate, and collect the extract in the K–D concentrator. Rinse the Erlenmeyer flask and column with 20 to 30 mL of methylene chloride to complete the quantitative transfer.

10.8 Add one or two clean boiling chips to the evaporative flask and attach a three-ball Snyder column. Prewet the Snyder column by adding about 1 mL of methylene chloride to the top. Place the K–D apparatus on a hot water bath (60 to 65 °C) so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15 to 20 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches 1 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min.

10.9 Increase the temperature of the hot water bath to 95 to 100 °C. Remove the Synder column and rinse the flask and its lower joint into the concentrator tube with 1 to 2 mL of 2-propanol. A 5-mL syringe is recommended for this operation. Attach a two-ball micro-Snyder column to the concentrator tube and prewet the column by adding about 0.5 mL of 2-propanol to the top. Place the micro-K–D apparatus on the water bath so that the concentrator tube is partially immersed in the hot water. Adjust the vertical position of the apparatus and the water temperature as required to complete

concentration in 5 to 10 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood. When the apparent volume of liquid reaches 2.5 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min. Add an additional 2 mL of 2-propanol through the top of the micro-Snyder column and resume concentrating as before. When the apparent volume of liquid reaches 0.5 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min.

10.10 Remove the micro-Snyder column and rinse its lower joint into the concentrator tube with a minimum amount of 2-propanol. Adjust the extract volume to 1.0 mL. Stopper the concentrator tube and store refrigerated at 4 °C if further processing will not be performed immediately. If the extract will be stored longer than two days, it should be transferred to a Teflon-sealed screw-cap vial. If the sample extract requires no further cleanup, proceed with FIDGC analysis (Section 11). If the sample requires further cleanup, proceed to Section 12.

10.11 Determine the original sample volume by refilling the sample bottle to the mark and transferring the liquid to a 1000-mL graduated cylinder. Record the sample volume to the nearest 5 mL.

11. Flame Ionization Detector Gas Chromatography

11.1 Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are retention times and MDL that can be achieved under these conditions. An example of the separations achieved by this column is shown in Figure 1. Other packed or capillary (open-tubular) columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met.

11.2 Calibrate the system daily as described in Section 7.

11.3 If the internal standard calibration procedure is used, the internal standard must be added to the sample extract and mixed thoroughly immediately before injection into the gas chromatograph.

11.4 Inject 2 to 5 µL of the sample extract or standard into the gas chromatograph using the solvent-flush technique.[11] Smaller (1.0 µL) volumes may be injected if automatic devices are employed. Record the volume injected to the nearest 0.05 µL, and the resulting peak size in area or peak height units.

11.5 Identify the parameters in the sample by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound may be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

11.6 If the response for a peak exceeds the working range of the system, dilute the extract and reanalyze.

11.7 If the measurement of the peak response is prevented by the presence of interferences, an alternative gas chromatographic procedure is required. Section 12 describes a derivatization and column chromatographic procedure which has been tested and found to be a practical means of analyzing phenols in complex extracts.

12. Derivatization and Electron Capture Detector Gas Chromatography

12.1 Pipet a 1.0-mL aliquot of the 2-propanol solution of standard or sample extract into a glass reaction vial. Add 1.0 mL of derivatizing reagent (Section 6.11). This amount of reagent is sufficient to derivatize a solution whose total phenolic content does not exceed 0.3 mg/mL.

12.2 Add about 3 mg of potassium carbonate to the solution and shake gently.

12.3 Cap the mixture and heat it for 4 h at 80 °C in a hot water bath.

12.4 Remove the solution from the hot water bath and allow it to cool.

12.5 Add 10 mL of hexane to the reaction flask and shake vigorously for 1 min. Add 3.0 mL of distilled, deionized water to the reaction flask and shake for 2 min. Decant a portion of the organic layer into a concentrator tube and cap with a glass stopper.

12.6 Place 4.0 g of silica gel into a chromatographic column. Tap the column to settle the silica gel and add about 2 g of anhydrous sodium sulfate to the top.

12.7 Preelute the column with 6 mL of hexane. Discard the eluate and just prior to exposure of the sodium sulfate layer to the air, pipet onto the column 2.0 mL of the hexane solution (Section 12.5) that contains the derivatized sample or standard. Elute the column with 10.0 mL of hexane and discard the eluate. Elute the column, in order, with: 10.0 mL of 15% toluene in hexane (Fraction 1); 10.0 mL of 40% toluene in hexane (Fraction 2); 10.0 mL of 75% toluene in hexane (Fraction 3); and 10.0 mL of 15% 2-propanol in toluene (Fraction 4). All elution mixtures are prepared on a volume: volume basis. Elution patterns for the phenolic derivatives are shown in Table 2. Fractions may be combined as desired, depending upon the specific phenols of interest or level of interferences.

12.8 Analyze the fractions by ECDGC. Table 2 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are retention times and MDL that can be achieved under these conditions. An example of the separations

achieved by this column is shown in Figure 2.

12.9 Calibrate the system daily with a minimum of three aliquots of calibration standards, containing each of the phenols of interest that are derivatized according to Section 7.5.

12.10 Inject 2 to 5 µL of the column fractions into the gas chromatograph using the solvent-flush technique. Smaller (1.0 µL) volumes can be injected if automatic devices are employed. Record the volume injected to the nearest 0.05 µL, and the resulting peak size in area or peak height units. If the peak response exceeds the linear range of the system, dilute the extract and reanalyze.

13. Calculations

13.1 Determine the concentration of individual compounds in the sample analyzed by FIDGC (without derivatization) as indicated below.

13.1.1 If the external standard calibration procedure is used, calculate the amount of material injected from the peak response using the calibration curve or calibration factor determined in Section 7.2.2. The concentration in the sample can be calculated from Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A)(V_t)}{(V_i)(V_s)}$$

Equation 2

where:

A=Amount of material injected (ng).

V_i=Volume of extract injected (µL).

V_t=Volume of total extract (µL).

V_s=Volume of water extracted (mL).

13.1.2 If the internal standard calibration procedure is used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.3.2 and Equation 3.

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(I_s)}{(A_{is})(RF)(V_o)}$$

Equation 3

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

I_s=Amount of internal standard added to each extract (µg).

V_o=Volume of water extracted (L).

13.2 Determine the concentration of individual compounds in the sample analyzed by derivatization and ECDGC according to Equation 4.

$$\text{Concentration } (\mu g/L) = \frac{(A)(V_t)(B)(D)}{(V_i)(V_s)(C)(E)}$$

Equation 4

where:

A=Mass of underivatized phenol represented by area of peak in sample chromatogram, determined from calibration curve in Section 7.5.3 (ng).

V_i=Volume of eluate injected (µL).

V_t=Total volume of column eluate or combined fractions from which V_i was taken (µL).

V_s=Volume of water extracted in Section 10.10 (mL).

B=Total volume of hexane added in Section 12.5 (mL).

C=Volume of hexane sample solution added to cleanup column in Section 12.7 (mL).

D=Total volume of 2-propanol extract prior to derivatization (mL).

E=Volume of 2-propanol extract carried through derivatization in Section 12.1 (mL).

13.3 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

14. Method Performance

14.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentrations listed in Tables 1 and 2 were obtained using reagent water.[12] Similar results were achieved using representative wastewaters. The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

14.2 This method was tested by 20 laboratories using reagent water, drinking water, surface water, and three industrial wastewaters spiked as six concentrations over the range 12 to 450 µg/L.[13] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships for a flame ionization detector are presented in Table 4.

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TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention time (min)	Method detection limit (μg/L)
2-Chlorophenol	1.70	0.31
2-Nitrophenol	2.00	0.45
Phenol	3.01	0.14
2,4-Dimethylphenol	4.03	0.32
2,4-Dichlorophenol	4.30	0.39
2,4,6-Trichlorophenol	6.05	0.64
4-Chloro-3-methylphenol	7.50	0.36
2,4-Dinitrophenol	10.00	13.0
2-Methyl-4,6-dinitrophenol	10.24	16.0
Pentachlorophenol	12.42	7.4
4-Nitrophenol	24.25	2.8

Column conditions: Supelcoport (80/100 mesh) coated with 1% SP–1240DA packed in a 1.8 m long × 2 mm ID glass column with nitrogen carrier gas at 30 mL/min flow rate. Column temperature was 80 °C at injection, programmed immediately at 8 °C/min to 150 °C final temperature. MDL were determined with an FID.

TABLE 2—SILICA GEL FRACTIONATION AND ELECTRON CAPTURE GAS CHROMATOGRAPHY OF PFBB DERIVATIVES

Parent compound	Percent recovery by fraction[a]				Retention time (min)	Method detection limit (μg/L)
	1	2	3	4		
2-Chlorophenol	.....	90	1	.....	3.3	0.58
2-Nitrophenol	.....	.....	9	90	9.1	0.77
Phenol	.....	90	10	.....	1.8	2.2
2,4-Dimethylphenol	.....	95	7	.....	2.9	0.63
2,4-Dichlorophenol	.....	95	1	.....	5.8	0.68
2,4,6-Trichlorophenol	50	50	.....	.....	7.0	0.58
4-Chloro-3-methylphenol	.....	84	14	.....	4.8	1.8
Pentachlorophenol	75	20	.....	.....	28.8	0.59
4-Nitrophenol	.....	.....	1	90	14.0	0.70

Column conditions: Chromosorb W–AW–DMCS (80/100 mesh) coated with 5% OV–17 packed in a 1.8 m long × 2.0 mm ID glass column with 5% methane/95% argon carrier gas at 30 mL/min flow rate. Column temperature held isothermal at 200 °C. MDL were determined with an ECD.

[a] Eluant composition:
Fraction 1—15% toluene in hexane.
Fraction 2—40% toluene in hexane.
Fraction 3—75% toluene in hexane.
Fraction 4—15% 2-propanol in toluene.

TABLE 3—QC ACCEPTANCE CRITERIA—METHOD 604

Parameter	Test conc. (μg/L)	Limit for s (μg/L)	Range for $\bar{X}$ (μg/L)	Range for P, P_s (percent)
4-Chloro-3-methylphenol	100	16.6	56.7–113.4	49–122
2-Chlorophenol	100	27.0	54.1–110.2	38–126
2,4-Dichlorophenol	100	25.1	59.7–103.3	44–119
2,4-Dimethylphenol	100	33.3	50.4–100.0	24–118
4,6-Dinitro-2-methylphenol	100	25.0	42.4–123.6	30–136
2,4-Dinitrophenol	100	36.0	31.7–125.1	12–145
2-Nitrophenol	100	22.5	56.6–103.8	43–117
4-Nitrophenol	100	19.0	22.7–100.0	13–110
Pentachlorophenol	100	32.4	56.7–113.5	36–134
Phenol	100	14.1	32.4–100.0	23–108
2,4,6-Trichlorophenol	100	16.6	60.8–110.4	53–119

$\underline{s}$—Standard deviation of four recovery measurements, in μg/L (Section 8.2.4).
$\bar{X}$—Average recovery for four recovery measurements, in μg/L (Section 8.2.4).
P, P_s—Percent recovery measured (Section 8.3.2, Section 8.4.2).

NOTE: These criteria are based directly upon the method performance data in Table 4. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 4.

TABLE 4—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 604

Parameter	Accuracy, as recovery, X' (μg/L)	Single Analyst precision, s_r' (μg/L)	Overall precision, S' (μg/L)
4-Chloro-3-methylphenol	0.87C–1.97	$0.11\bar{X}$–0.21	$0.16\bar{X}$+1.41
2-Chlorophenol	0.83C–0.84	$0.18\bar{X}$+0.20	$0.21\bar{X}$+0.75
2,4-Dichlorophenol	0.81C+0.48	$0.17\bar{X}$–0.02	$0.18\bar{X}$+0.62
2,4-Dimethylphenol	0.62C–1.64	$0.30\bar{X}$–0.89	$0.25\bar{X}$+0.48
4,6-Dinitro-2-methylphenol	0.84C–1.01	$0.15\bar{X}$+1.25	$0.19\bar{X}$+5.85
2,4-Dinitrophenol	0.80C–1.58	$0.27\bar{X}$–1.15	$0.29\bar{X}$+4.51
2-Nitrophenol	0.81C–0.76	$0.15\bar{X}$+0.44	$0.14\bar{X}$+3.84
4-Nitrophenol	0.46C+0.18	$0.17\bar{X}$+2.43	$0.19\bar{X}$+4.79
Pentachlorophenol	0.83C+2.07	$0.22\bar{X}$–0.58	$0.23\bar{X}$+0.57
Phenol	0.43C+0.11	$0.20\bar{X}$–0.88	$0.17\bar{X}$+0.77
2,4,6-Trichlorophenol	0.86C–0.40	$0.10\bar{X}$+0.53	$0.13\bar{X}$+2.40

X'=Expected recovery for one or more measurements of a sample containing a concentration of C, in μg/L.
s_r'=Expected single analyst standard deviation of measurements at an average concentration found of $\bar{X}$, in μg/L.
S'=Expected interlaboratory standard deviation of measurements at an average concentration found of X, in μg/L.
$\underline{C}$=True value for the concentration, in μg/L.
$\bar{X}$=Average recovery found for measurements of samples containing a concentration of C, in μg/L.

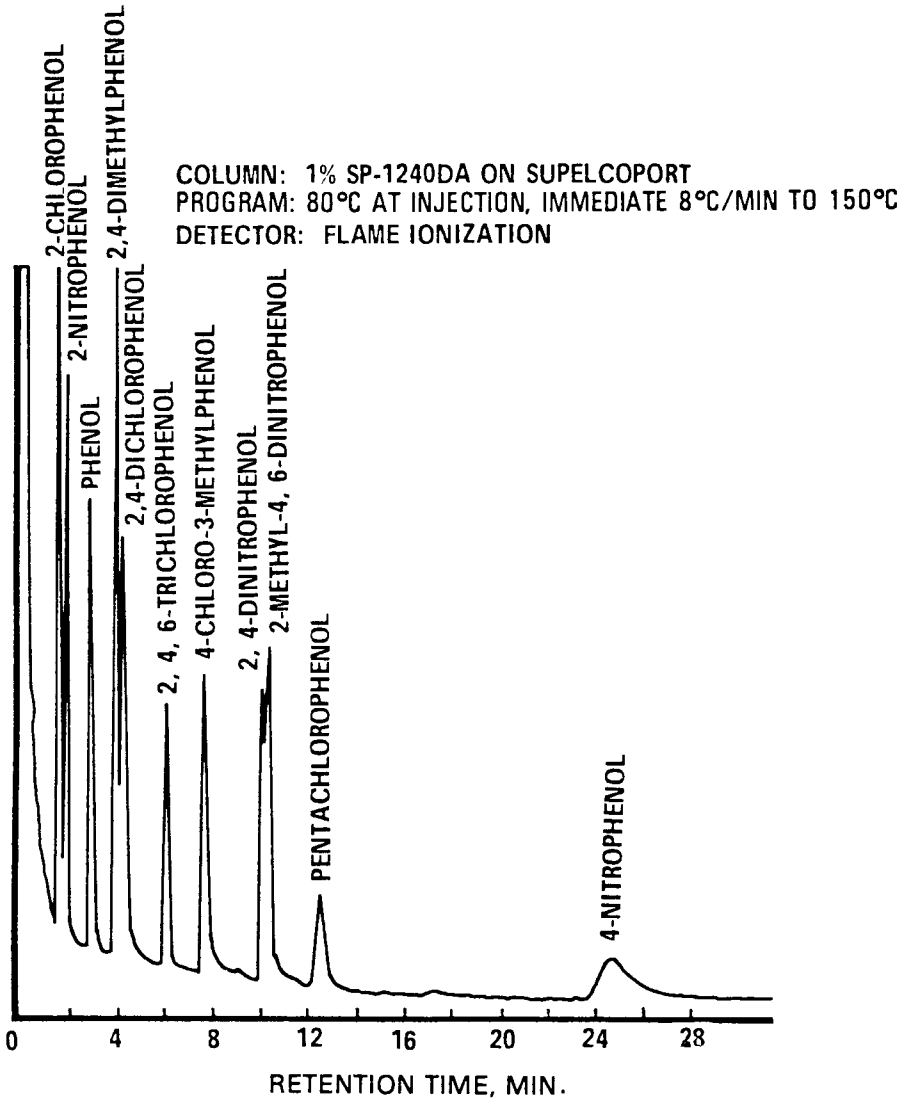

Figure 1. Gas chromatogram of phenols.

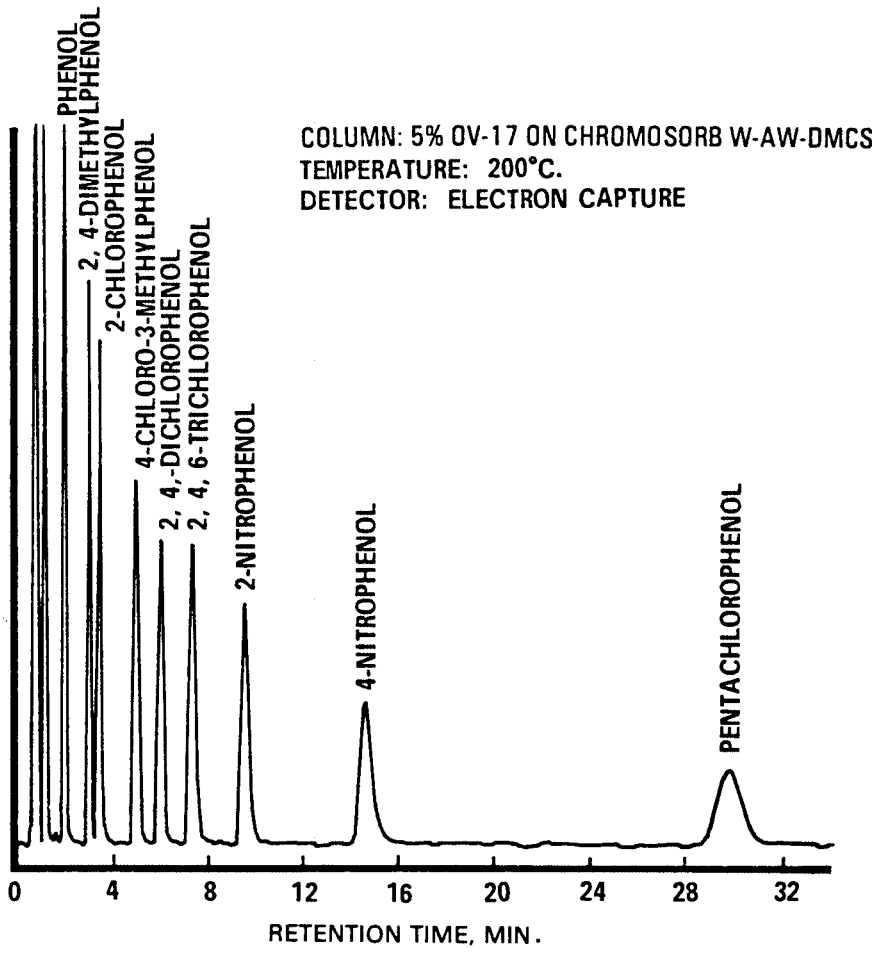

Figure 2. Gas chromatogram of PFB derivatives of phenols.

METHOD 605—BENZIDINES

1. Scope and Application

1.1 This method covers the determination of certain benzidines. The following parameters can be determined by this method:

Parameter	Storet No	CAS No.
Benzidine	39120	92–87–5
3,3′-Dichlorobenzidine	34631	91–94–1

1.2 This is a high performance liquid chromatography (HPLC) method applicable to the determination of the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for the compounds above, identifications should be supported by at least one additional qualitative technique. This method describes electrochemical conditions at a second potential which can be used to confirm measurements made with this method. Method 625 provides gas chromatograph/mass spectrometer (GC/MS) conditions appropriate for the qualitative and quantitative confirmation of results for the parameters listed above, using the extract produced by this method.

1.3 The method detection limit (MDL, defined in Section 14.1)[1] for each parameter is

listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of the interferences in the sample matrix.

1.4 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.5 This method is restricted to use by or under the supervision of analysts experienced in the use of HPLC instrumentation and in the interpretation of liquid chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 A measured volume of sample, approximately 1–L, is extracted with chloroform using liquid-liquid extractions in a separatory funnel. The chloroform extract is extracted with acid. The acid extract is then neutralized and extracted with chloroform. The final chloroform extract is exchanged to methanol while being concentrated using a rotary evaporator. The extract is mixed with buffer and separated by HPLC. The benzidine compounds are measured with an electrochemical detector.[2]

2.2 The acid back-extraction acts as a general purpose cleanup to aid in the elimination of interferences.

3. Interferences

3.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that lead to discrete artifacts and/or elevated baselines in chromatograms. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3.

3.1.1 Glassware must be scrupulously cleaned.[3] Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. Solvent rinsing should be followed by detergent washing with hot water, and rinses with tap water and distilled water. The glassware should then be drained dry, and heated in a muffle furnace at 400 °C for 15 to 30 min. Some thermally stable materials may not be eliminated by this treatment. Solvent rinses with acetone and pesticide quality hexane may be substituted for the muffle furnace heating. Volumetric ware should not be heated in a muffle furnace. After drying and cooling, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Store inverted or capped with aluminum foil.

3.1.2 The use of high purity reagents and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

3.2 Matrix interferences may be caused by contaminants that are co-extracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature and diversity of the industrial complex or municipality being sampled. The cleanup procedures that are inherent in the extraction step are used to overcome many of these interferences, but unique samples may require additional cleanup approaches to achieve the MDL listed in Table 1.

3.3 Some dye plant effluents contain large amounts of components with retention times closed to benzidine. In these cases, it has been found useful to reduce the electrode potential in order to eliminate interferences and still detect benzidine. (See Section 12.7.)

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health harzard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified [4–6] for the information of the analyst.

4.2 The following parameters covered by this method have been tentatively classified as known or suspected, human or mammalian carcinogens: benzidine and 3,3′-dichlorobenzidine. Primary standards of these toxic compounds should be prepared in a hood. A NIOSH/MESA approved toxic gas respirator should be worn when the analyst handles high concentrations of these toxic compounds.

4.3 Exposure to chloroform should be minimized by performing all extractions and extract concentrations in a hood or other well-ventiliated area.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete or composite sampling.

5.1.1 Grab sample bottle—1–L or 1-qt, amber glass, fitted with a screw cap lined with Teflon. Foil may be substituted for Teflon if the sample is not corrosive. If amber bottles are not available, protect samples from light. The bottle and cap liner must be washed, rinsed with acetone or methylene

chloride, and dried before use to minimize contamination.

5.1.2 Automatic sampler (optional)—The sampler must incorporate glass sample containers for the collection of a minimum of 250 mL of sample. Sample containers must be kept refrigerated at 4°C and protected from light during compositing. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used. Before use, however, the compressible tubing should be thoroughly rinsed with methanol, followed by repeated rinsings with distilled water to minimize the potential for contamination of the sample. An integrating flow meter is required to collect flow proportional composites.

5.2 Glassware (All specifications are suggested):

5.2.1 Separatory funnels—2000, 1000, and 250-mL, with Teflon stopcock.

5.2.2 Vials—10 to 15-mL, amber glass, with Teflon-lined screw cap.

5.2.3 Rotary evaporator.

5.2.4 Flasks—Round bottom, 100–mL, with 24/40 joints.

5.2.5 Centrifuge tubes—Conical, graduated, with Teflon-lined screw caps.

5.2.6 Pipettes—Pasteur, with bulbs.

5.3 Balance—Analytical, capable of accurately weighing 0.0001 g.

5.4 High performance liquid chromatograph (HPLC)—An analytical system complete with column supplies, high pressure syringes, detector, and compatible recorder. A data system is recommended for measuring peak areas and retention times.

5.4.1 Solvent delivery system—With pulse damper, Altex 110A or equivalent.

5.4.2 Injection valve (optional)—Waters U6K or equivalent.

5.4.3 Electrochemical detector—Bioanalytical Systems LC–2A with glassy carbon electrode, or equivalent. This detector has proven effective in the analysis of wastewaters for the parameters listed in the scope (Section 1.1), and was used to develop the method performance statements in Section 14. Guidelines for the use of alternate detectors are provided in Section 12.1.

5.4.4 Electrode polishing kit—Princeton Applied Research Model 9320 or equivalent.

5.4.5 Column—Lichrosorb RP–2, 5 micron particle diameter, in a 25 cm × 4.6 mm ID stainless steel column. This column was used to develop the method performance statements in Section 14. Guidelines for the use of alternate column packings are provided in Section 12.1.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.2 Sodium hydroxide solution (5 N)—Dissolve 20 g of NaOH (ACS) in reagent water and dilute to 100 mL.

6.3 Sodium hydroxide solution (1 M)—Dissolve 40 g of NaOH (ACS) in reagent water and dilute to 1 L.

6.4 Sodium thiosulfate—(ACS) Granular.

6.5 Sodium tribasic phosphate (0.4 M)—Dissolve 160 g of trisodium phosphate decahydrate (ACS) in reagent water and dilute to 1 L.

6.6 Sulfuric acid (1+1)—Slowly, add 50 mL of H_2SO_4 (ACS, sp. gr. 1.84) to 50 mL of reagent water.

6.7 Sulfuric acid (1 M)—Slowly, add 58 mL of H_2SO_4 (ACS, sp. gr. 1.84) to reagent water and dilute to 1 L.

6.8 Acetate buffer (0.1 M, pH 4.7)—Dissolve 5.8 mL of glacial acetic acid (ACS) and 13.6 g of sodium acetate trihydrate (ACS) in reagent water which has been purified by filtration through a RO–4 Millipore System or equivalent and dilute to 1 L.

6.9 Acetonitrile, chloroform (preserved with 1% ethanol), methanol—Pesticide quality or equivalent.

6.10 Mobile phase—Place equal volumes of filtered acetonitrile (Millipore type FH filter or equivalent) and filtered acetate buffer (Millipore type GS filter or equivalent) in a narrow-mouth, glass container and mix thoroughly. Prepare fresh weekly. Degas daily by sonicating under vacuum, by heating an stirring, or by purging with helium.

6.11 Stock standard solutions (1.00 µg/µL)—Stock standard solutions may be prepared from pure standard materials or purchased as certified solutions.

6.11.1 Prepare stock standard solutions by accurately weighing about 0.0100 g of pure material. Dissolve the material in methanol and dilute to volume in a 10–mL volumetric flask. Larger volumes can be used at the convenience of the analyst. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the manufacturer or by an independent source.

6.11.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4 °C and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.11.3 Stock standard solutions must be replaced after six months, or sooner if comparison with check standards indicates a problem.

6.12 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Establish chromatographic operating conditions equivalent to those given in Table 1. The HPLC system can be calibrated using the external standard technique (Section 7.2) or the internal standard technique (Section 7.3).

7.2 External standard calibration procedure:

7.2.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask and diluting to volume with mobile phase. One of the external standards should be at a concentration near, but above, the MDL (Table 1) and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.2.2 Using syringe injections of 5 to 25 µL or a constant volume injection loop, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against the mass injected. The results can be used to prepare a calibration curve for each compound. Alternatively, if the ratio of response to amount injected (calibration factor) is a constant over the working range (<10% relative standard deviation, RSD), linearity through the origin can be assumed and the average ratio or calibration factor can be used in place of a calibration curve.

7.3 Internal standard calibration procedure—To use this approach, the analyst must select one or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Because of these limitations, no internal standard can be suggested that is applicable to all samples.

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask. To each calibration standard, add a known constant amount of one or more internal standards, and dilute to volume with mobile phase. One of the standards should be at a concentration near, but above, the MDL and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.3.2 Using syringe injections of 5 to 25 µL or a constant volume injection loop, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against concentration for each compound and internal standard. Calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

C_{is}=Concentration of the internal standard (µg/L).

C_s=Concentration of the parameter to be measured (µg/L).

If the RF value over the working range is a constant (<10% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.4 The working calibration curve, calibration factor, or RF must be verified on each working day by the measurement of one or more calibration standards. If the response for any parameter varies from the predicted response by more than ±15%, a new calibration curve must be prepared for that compound. If serious loss of response occurs, polish the electrode and recalibrate.

7.5 Before using any cleanup procedure, the analyst must process a series of calibration standards through the procedure to validate elution patterns and the absence of interferences from the reagents.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Sections 10.9, 11.1, and 12.1) to improve the separations or lower the cost of measurements. Each time such a modification is made to

the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Before processing any samples, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system and glassware are under control. Each time a set of samples is extracted or reagents are changed, a reagent water blank must be processed as a safeguard against laboratory contamination.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing benzidine and/or 3,3′-dichlorobenzidine at a concentration of 50 µg/mL each in methanol. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Using a pipet, prepare QC check samples at a concentration of 50 µg/L by adding 1.00 mL of QC check sample concentrate to each of four 1–L-L aliquots of reagent water.

8.2.3 Analyze the well-mixed QC check samples according to the method beginning in Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 2. If s and X for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual $\bar{X}$ falls outside the range for accuracy, the system performance is unacceptable for that parameter. Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.2.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spiked sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at 50 µg/L or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.3 If it is impractical to determine background levels before spiking (e.g., maximum holding times will be exceeded), the spike concentration should be (1) the regulatory concentration limit, if any; or, if none (2) the larger of either 5 times higher than the expected background concentration or 50 µg/L.

8.3.2 Analyze one sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second sample aliquot with 1.0 mL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100(A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 2. These acceptance criteria were calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[7] If spiking was performed at a concentration lower than 50 µg/L, the analyst must use either the QC acceptance criteria in Table 2, or optional QC acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recovery of a parameter: (1) Calculate accuracy (X′) using the equation in Table 3, substituting

the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 3, substituting X′ for X; (3) calculate the range for recovery at the spike concentration as (100 X′/T)±2.44(100 S′/T)%.[7]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4 If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory.

8.4.1 Prepare the QC check standard by adding 1.0 mL of QC check sample concentrate (Sections 8.2.1 or 8.3.2) to 1 L of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 2. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $P-2s_p$ to $P+2s_p$. If P=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as HPLC with a dissimilar column, gas chromatography, or mass spectrometer must be used. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 Grab samples must be collected in glass containers. Conventional sampling practices[8] should be followed, except that the bottle must not be prerinsed with sample before collection. Composite samples should be collected in refrigerated glass containers in accordance with the requirements of the program. Automatic sampling equipment must be as free as possible of Tygon tubing and other potential sources of contamination.

9.2 All samples must be iced or refrigerated at 4°C and stored in the dark from the time of collection until extraction. Both benzidine and 3,3′-dichlorobenzidine are easily oxidized. Fill the sample bottles and, if residual chlorine is present, add 80 mg of sodium thiosulfate per liter of sample and mix well. EPA Methods 330.4 and 330.5 may be used for measurement of residual chlorine.[9] Field test kits are available for this purpose. After mixing, adjust the pH of the sample to a range of 2 to 7 with sulfuric acid.

9.3 If 1,2-diphenylhydrazine is likely to be present, adjust the pH of the sample to 4.0± 0.2 to prevent rearrangement to benzidine.

9.4 All samples must be extracted within 7 days of collection. Extracts may be held up to 7 days before analysis, if stored under an inert (oxidant free) atmosphere.[2] The extract should be protected from light.

10. Sample Extraction

10.1 Mark the water meniscus on the side of the sample bottle for later determination of sample volume. Pour the entire sample into a 2–L separatory funnel. Check the pH of the sample with wide-range pH paper and adjust to within the range of 6.5 to 7.5 with sodium hydroxide solution or sulfuric acid.

10.2 Add 100 mL of chloroform to the sample bottle, seal, and shake 30 s to rinse the inner surface. (Caution: Handle chloroform in a well ventilated area.) Transfer the solvent to the separatory funnel and extract the sample by shaking the funnel for 2 min with periodic venting to release excess pressure. Allow the organic layer to separate from the water phase for a minimum of 10 min. If the emulsion interface between layers is more than one-third the volume of the solvent layer, the analyst must employ mechanical techniques to complete the phase separation. The optimum technique depends upon the sample, but may include stirring, filtration of the emulsion through glass

wool, centrifugation, or other physical methods. Collect the chloroform extract in a 250-mL separatory funnel.

10.3 Add a 50-mL volume of chloroform to the sample bottle and repeat the extraction procedure a second time, combining the extracts in the separatory funnel. Perform a third extraction in the same manner.

10.4 Separate and discard any aqueous layer remaining in the 250-mL separatory funnel after combining the organic extracts. Add 25 mL of 1 M sulfuric acid and extract the sample by shaking the funnel for 2 min. Transfer the aqueous layer to a 250-mL beaker. Extract with two additional 25-mL portions of 1 M sulfuric acid and combine the acid extracts in the beaker.

10.5 Place a stirbar in the 250-mL beaker and stir the acid extract while carefully adding 5 mL of 0.4 M sodium tribasic phosphate. While monitoring with a pH meter, neutralize the extract to a pH between 6 and 7 by dropwise addition of 5 N sodium hydroxide solution while stirring the solution vigorously. Approximately 25 to 30 mL of 5 N sodium hydroxide solution will be required and it should be added over at least a 2-min period. Do not allow the sample pH to exceed 8.

10.6 Transfer the neutralized extract into a 250-mL separatory funnel. Add 30 mL of chloroform and shake the funnel for 2 min. Allow the phases to separate, and transfer the organic layer to a second 250-mL separatory funnel.

10.7 Extract the aqueous layer with two additional 20-mL aliquots of chloroform as before. Combine the extracts in the 250-mL separatory funnel.

10.8 Add 20 mL of reagent water to the combined organic layers and shake for 30 s.

10.9 Transfer the organic extract into a 100-mL round bottom flask. Add 20 mL of methanol and concentrate to 5 mL with a rotary evaporator at reduced pressure and 35 °C. An aspirator is recommended for use as the source of vacuum. Chill the receiver with ice. This operation requires approximately 10 min. Other concentration techniques may be used if the requirements of Section 8.2 are met.

10.10 Using a 9-in. Pasteur pipette, transfer the extract to a 15-mL, conical, screw-cap centrifuge tube. Rinse the flask, including the entire side wall, with 2-mL portions of methanol and combine with the original extract.

10.11 Carefully concentrate the extract to 0.5 mL using a gentle stream of nitrogen while heating in a 30 °C water bath. Dilute to 2 mL with methanol, reconcentrate to 1 mL, and dilute to 5 mL with acetate buffer. Mix the extract thoroughly. Cap the centrifuge tube and store refrigerated and protected from light if further processing will not be performed immediately. If the extract will be stored longer than two days, it should be transferred to a Teflon-sealed screw-cap vial. If the sample extract requires no further cleanup, proceed with HPLC analysis (Section 12). If the sample requires further cleanup, proceed to Section 11.

10.12 Determine the original sample volume by refilling the sample bottle to the mark and transferring the liquid to a 1,000-mL graduated cylinder. Record the sample volume to the nearest 5 mL.

11. Cleanup and Separation

11.1 Cleanup procedures may not be necessary for a relatively clean sample matrix. If particular circumstances demand the use of a cleanup procedure, the analyst first must demonstrate that the requirements of Section 8.2 can be met using the method as revised to incorporate the cleanup procedure.

12. High Performance Liquid Chromatography

12.1 Table 1 summarizes the recommended operating conditions for the HPLC. Included in this table are retention times, capacity factors, and MDL that can be achieved under these conditions. An example of the separations achieved by this HPLC column is shown in Figure 1. Other HPLC columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met. When the HPLC is idle, it is advisable to maintain a 0.1 mL/min flow through the column to prolong column life.

12.2 Calibrate the system daily as described in Section 7.

12.3 If the internal standard calibration procedure is being used, the internal standard must be added to the sample extract and mixed thoroughly immediately before injection into the instrument.

12.4 Inject 5 to 25 µL of the sample extract or standard into the HPLC. If constant volume injection loops are not used, record the volume injected to the nearest 0.05 µL, and the resulting peak size in area or peak height units.

12.5 Identify the parameters in the sample by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

12.6 If the response for a peak exceeds the working range of the system, dilute the extract with mobile phase and reanalyze.

12.7 If the measurement of the peak response for benzidine is prevented by the presence of interferences, reduce the electrode

potential to +0.6 V and reanalyze. If the benzidine peak is still obscured by interferences, further cleanup is required.

13. Calculations

13.1 Determine the concentration of individual compounds in the sample.

13.1.1 If the external standard calibration procedure is used, calculate the amount of material injected from the peak response using the calibration curve or calibration factor determined in Section 7.2.2. The concentration in the sample can be calculated from Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A)(V_t)}{(V_i)(V_s)}$$

Equation 2

where:
A=Amount of material injected (ng).
V_i=Volume of extract injected (µL).
V_t=Volume of total extract (µL).
V_s=Volume of water extracted (mL).

13.1.2 If the internal standard calibration procedure is used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.3.2 and Equation 3.

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(I_s)}{(A_{is})(RF)(V_o)}$$

Equation 3

where:
A_s=Response for the parameter to be measured.
A_{is}=Response for the internal standard.
I_s=Amount of internal standard added to each extract (µg).
V_o=Volume of water extracted (L).

13.2 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

14. Method Performance

14.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentrations listed in Table 1 were obtained using reagent water.[10] Similar results were achieved using representative wastewaters. The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

14.2 This method has been tested for linearity of spike recovery from reagent water and has been demonstrated to be applicable over the concentration range from 7×MDL to 3000×MDL.[10]

14.3 This method was tested by 17 laboratories using reagent water, drinking water, surface water, and three industrial wastewaters spiked at six concentrations over the range 1.0 to 70 µg/L.[11] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 3.

References

1. 40 CFR part 136, appendix B.

2. ''Determination of Benzidines in Industrial and Muncipal Wastewaters,'' EPA 600/4–82–022, National Technical Information Service, PB82–196320, Springfield, Virginia 22161, April 1982.

3. ASTM Annual Book of Standards, Part 31, D3694–78. ''Standard Practices for Preparation of Sample Containers and for Preservation of Organic Constituents,'' American Society for Testing and Materials, Philadelphia.

4. ''Carcinogens—Working With Carcinogens,'' Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, Publication No. 77–206, August 1977.

5. ''OSHA Safety and Health Standards, General Industry,'' (29 CFR part 1910), Occupational Safety and Health Administration, OSHA 2206 (Revised, January 1976).

6. ''Safety in Academic Chemistry Laboratories,'' American Chemical Society Publication, Committee on Chemical Safety, 3rd Edition, 1979.

7. Provost, L.P., and Elder, R.S. ''Interpretation of Percent Recovery Data,'' *American* Laboratory, 15, 58–63 (1983). (The value 2.44 used in the equation in Section 8.3.3 is two times the value 1.22 derived in this report.)

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9. ''Methods 330.4 (Titrimetric, DPD–FAS) and 330.5 (Spectrophotometric, DPD) for Chlorine Total Residual,'' Methods for Chemical Analysis of Water and Wastes, EPA–600/4–79–020, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268, March 1979.

10. ''EPA Method Study 15, Method 605 (Benzidines),'' EPA 600/4–84–062, National Technical Information Service, PB84–211176, Springfield, Virginia 22161, June 1984.

11. ''EPA Method Validation Study 15, Method 605 (Benzidines),'' Report for EPA Contract 68–03–2624 (In preparation).

TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention time (min)	Column capacity factor (k′)	Method detection limit (μg/L)
Benzidine	6.1	1.44	0.08
3,3′-Dichlorobenzidine	12.1	3.84	0.13

HPLC Column conditions: Lichrosorb RP–2, 5 micron particle size, in a 25 cm×4.6 mm ID stainless steel column. Mobile Phase: 0.8 mL/min of 50% acetonitrile/50% 0.1M pH 4.7 acetate buffer. The MDL were determined using an electrochemical detector operated at +0.8 V.

TABLE 2—QC ACCEPTANCE CRITERIA—METHOD 605

Parameter	Test conc. (μg/L)	Limit for s (μg/L)	Range for X (μg/L)	Range for P, P_s (percent)
Benzidine	50	18.7	9.1–61.0	D–140
3.3′-Dichlorobenzidine	50	23.6	18.7–50.0	5–128

$\underline{s}$=Standard deviation of four recovery measurements, in μg/L (Section 8.2.4).
$\overline{X}$=Average recovery for four recovery measurements, in μg/L (Section 8.2.4).
P, P_s=Percent recovery measured (Section 8.3.2, Section 8.4.2).
D=Detected; result must be greater than zero.

Note: These criteria are based directly upon the method performance data in Table 3. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 3.

TABLE 3—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 605

Parameter	Accuracy, as recovery, X′(μg/L)	Single analyst precision, s_r' (μg/L)	Overall precision, S′ (μg/L)
Benzidine	0.70C+0.06	$0.28\overline{X}+0.19$	$0.40\overline{X}+0.18$
3,3′-Dichlorobenzidine	0.66C+0.23	$0.39\overline{X}-0.05$	$0.38\overline{X}+0.02$

X′=Expected recovery for one or more measurements of a sample containing a concentration of C, in $\underline{\mu g}$/L.
s_r'=Expected single analyst standard deviation of measurements at an average concentration found of $\underline{X}$, in μg/L.
S′=Expected interlaboratory standard deviation of measurements at an average concentration found of X, in μg/L.
$\underline{C}$=True value for the concentration, in μg/L.
$\overline{X}$=Average recovery found for measurements of samples containing a concentration of C, in μg/L.

COLUMN: LICHROSORB RP-2
MOBILE PHASE: 50% ACETONITRILE IN ACETATE BUFFER
DETECTOR: ELECTROCHEMICAL AT + 0.8 V

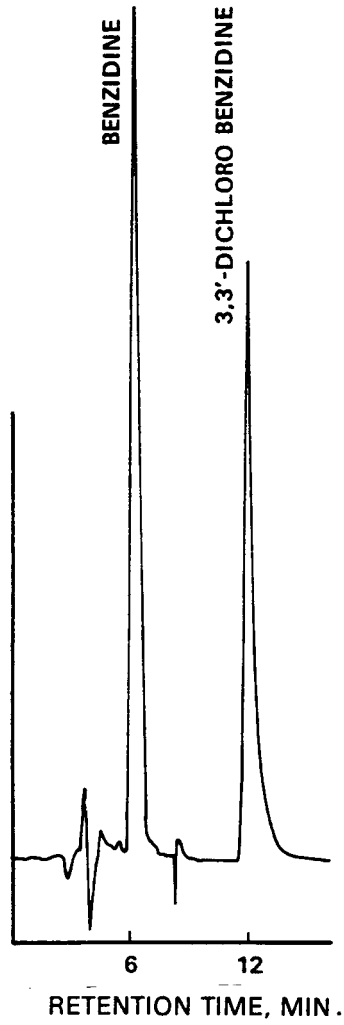

Figure 1. Liquid chromatogram of benzidines.

METHOD 606—PHTHALATE ESTER

1. Scope and Application

1.1 This method covers the determination of certain phthalate esters. The following parameters can be determined by this method:

Parameter	STORET No.	CAS No.
Bis(2-ethylhexyl) phthalate	39100	117–81–7
Butyl benzyl phthalate	34292	85–68–7
Di-n-butyl phthalate	39110	84–74–2
Diethyl phthalate	34336	84–66–2
Dimethyl phthalate	34341	131–11–3
Di-n-octyl phthalate	34596	117–84–0

1.2 This is a gas chromatographic (GC) method applicable to the determination of the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for any or all of the compounds above, compound identifications should be supported by at least one additional qualitative technique. This method describes analytical conditions for a second gas chromatographic column that can be used to confirm measurements made with the primary column. Method 625 provides gas chromatograph/mass spectrometer (GC/MS) conditions appropriate for the qualitative and quantitative confirmation of results for all of the parameters listed above, using the extract produced by this method.

1.3 The method detection limit (MDL, defined in Section 14.1)[1] for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.4 The sample extraction and concentration steps in this method are essentially the same as in Methods 608, 609, 611, and 612. Thus, a single sample may be extracted to measure the parameters included in the scope of each of these methods. When cleanup is required, the concentration levels must be high enough to permit selecting aliquots, as necessary, to apply appropriate cleanup procedures. The analyst is allowed the latitude, under Section 12, to select chromatographic conditions appropriate for the simultaneous measurement of combinations of these parameters.

1.5 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.6 This method is restricted to use by or under the supervision of analysts experienced in the use of a gas chromatograph and in the interpretation of gas chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 A measured volume of sample, approximately 1–L, is extracted with methylene chloride using a separatory funnel. The methylene chloride extract is dried and exchanged to hexane during concentration to a volume of 10 mL or less. The extract is separated by gas chromatography and the phthalate esters are then measured with an electron capture detector.[2]

2.2 Analysis for phthalates is especially complicated by their ubiquitous occurrence in the environment. The method provides Florisil and alumina column cleanup procedures to aid in the elimination of interferences that may be encountered.

3. Interferences

3.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that lead to discrete artifacts and/or elevated baselines in gas chromatograms. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3.

3.1.1 Glassware must be scrupulously cleaned.[3] Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. Solvent rinsing should be followed by detergent washing with hot water, and rinses with tap water and distilled water. The glassware should then be drained dry, and heated in a muffle furnace at 400 °C for 15 to 30 min. Some thermally stable materials, such as PCBs, may not be eliminated by this treatment. Solvent rinses with acetone and pesticide quality hexane may be substituted for the muffle furnace heating. Thorough rinsing with such solvents usually eliminates PCB interference. Volumetric ware should not be heated in a muffle furnace. After drying and cooling, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Store inverted or capped with aluminum foil.

3.1.2 The use of high purity reagents and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

3.2 Phthalate esters are contaminants in many products commonly found in the laboratory. It is particularly important to avoid the use of plastics because phthalates are commonly used as plasticizers and are easily extracted from plastic materials. Serious phthalate contamination can result at any time, if consistent quality control is not practiced. Great care must be experienced to prevent such contamination. Exhaustive cleanup of reagents and glassware may be required to eliminate background phthalate contamination.[4,5]

3.3 Matrix interferences may be caused by contaminants that are co-extracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature and diversity of the industrial complex or municipality being sampled. The cleanup procedures in Section 11 can be used to overcome many of these interferences, but unique samples may require additional cleanup approaches to achieve the MDL listed in Table 1.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified [6–8] for the information of the analyst.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete or composite sampling.

5.1.1 Grab sample bottle—1–L or 1–qt, amber glass, fitted with a screw cap lined with Teflon. Foil may be substituted for Teflon if the sample is not corrosive. If amber bottles are not available, protect samples from light. The bottle and cap liner must be washed, rinsed with acetone or methylene chloride, and dried before use to minimize contamination.

5.1.2 Automatic sampler (optional)—The sampler must incorporate glass sample containers for the collection of a minimum of 250 mL of sample. Sample containers must be kept refrigerated at 4 °C and protected from light during compositing. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used. Before use, however, the compressible tubing should be thoroughly rinsed with methanol, followed by repeated rinsings with distilled water to minimize the potential for contamination of the sample. An integrating flow meter is required to collect flow proportional composites.

5.2 Glassware (All specifications are suggested. Catalog numbers are included for illustration only).

5.2.1 Separatory funnel—2–L, with Teflon stopcock.

5.2.2 Drying column—Chromatographic column, approximately 400 mm long × 19 mm ID, with coarse frit filter disc.

5.2.3 Chromatographic column—300 mm long × 10 mm ID, with Teflon stopcock and coarse frit filter disc at bottom (Kontes K–420540–0213 or equivalent).

5.2.4 Concentrator tube, Kuderna-Danish—10–mL, graduated (Kontes K–570050–1025 or equivalent). Calibration must be checked at the volumes employed in the test. Ground glass stopper is used to prevent evaporation of extracts.

5.2.5 Evaporative flask, Kuderna-Danish—500–mL (Kontes K–570001–0500 or equivalent). Attach to concentrator tube with springs.

5.2.6 Snyder column, Kuderna-Danish—Three-ball macro (Kontes K–503000–0121 or equivalent).

5.2.7 Snyder column, Kuderna-Danish—Two-ball micro (Kontes K–569001–0219 or equivalent).

5.2.8 Vials—10 to 15–mL, amber glass, with Teflon-lined screw cap.

5.3 Boiling chips—Approximately 10/40 mesh. Heat to 400 °C for 30 min or Soxhlet extract with methylene chloride.

5.4 Water bath—Heated, with concentric ring cover, capable of temperature control (±2 °C). The bath should be used in a hood.

5.5 Balance—Analytical, capable of accurately weighing 0.0001 g.

5.6 Gas chromatograph—An analytical system complete with gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, gases, detector, and strip-chart recorder. A data system is recommended for measuring peak areas.

5.6.1 Column 1—1.8 m long × 4 mm ID glass, packed with 1.5% SP–2250/1.95% SP–2401 Supelcoport (100/120 mesh) or equivalent. This column was used to develop the method performance statemelts in Section 14. Guidelines for the use of alternate column packings are provided in Section 12.1.

5.6.2 Column 2—1.8 m long × 4 mm ID glass, packed with 3% OV–1 on Supelcoport (100/120 mesh) or equivalent.

5.6.3 Detector—Electron capture detector. This detector has proven effective in the analysis of wastewaters for the parameters listed in the scope (Section 1.1), and was used to develop the method performance statements in Section 14. Guidelines for the use of alternate detectors are provided in Section 12.1.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.2 Acetone, hexane, isooctane, methylene chloride, methanol—Pesticide quality or equivalent.

6.3 Ethyl ether—nanograde, redistilled in glass if necessary.

6.3.1 Ethyl ether must be shown to be free of peroxides before it is used as indicated by

EM Laboratories Quant test strips. (Available from Scientific Products Co., Cat. No. P1126–8, and other suppliers.)

6.3.2 Procedures recommended for removal of peroxides are provided with the test strips. After cleanup, 20 mL of ethyl alcohol preservative must be added to each liter of ether.

6.4 Sodium sulfate—(ACS) Granular, anhydrous. Several levels of purification may be required in order to reduce background phthalate levels to an acceptable level: 1) Heat 4 h at 400 °C in a shallow tray, 2) Heat 16 h at 450 to 500 °C in a shallow tray, 3) Soxhlet extract with methylene chloride for 48 h.

6.5 Florisil—PR grade (60/100 mesh). Purchase activated at 1250 °F and store in the dark in glass containers with ground glass stoppers or foil-lined screw caps. To prepare for use, place 100 g of Florisil into a 500-mL beaker and heat for approximately 16 h at 40 °C. After heating transfer to a 500-mL reagent bottle. Tightly seal and cool to room temperature. When cool add 3 mL of reagent water. Mix thoroughly by shaking or rolling for 10 min and let it stand for at least 2 h. Keep the bottle sealed tightly.

6.6 Alumina—Neutral activity Super I, W200 series (ICN Life Sciences Group, No. 404583). To prepare for use, place 100 g of alumina into a 500-mL beaker and heat for approximately 16 h at 400 °C. After heating transfer to a 500-mL reagent bottle. Tightly seal and cool to room temperature. When cool add 3 mL of reagent water. Mix thoroughly by shaking or rolling for 10 min and let it stand for at least 2 h. Keep the bottle sealed tightly.

6.7 Stock standard solutions (1.00 µg/µL)—Stock standard solutions can be prepared from pure standard materials or purchased as certified solutions.

6.7.1 Prepare stock standard solutions by accurately weighing about 0.0100 g of pure material. Dissolve the material in isooctane and dilute to volume in a 10-mL volumetric flask. Larger volumes can be used at the convenience of the analyst. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the manufacturer or by an independent source.

6.7.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4 °C and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.7.3 Stock standard solutions must be replaced after six months, or sooner if comparison with check standards indicates a problem.

6.8 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Establish gas chromatograph operating conditions equivalent to those given in Table 1. The gas chromatographic system can be calibrated using the external standard technique (Section 7.2) or the internal standard technique (Section 7.3).

7.2 External standard calibration procedure:

7.2.1 Prepared calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask and diluting to volume with isooctane. One of the external standards should be at a concentration near, but above, the MDL (Table 1) and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.2.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against the mass injected. The results can be used to prepare a calibration curve for each compound. Alternatively, if the ratio of response to amount injected (calibration factor) is a constant over the working range (<10% relative standard deviation, RSD), linearity through the origin can be assumed and the average ratio or calibration factor can be used in place of a calibration curve.

7.3 Internal standard calibration procedure—To use this approach, the analyst must select one or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Because of these limitations, no internal standard can be suggested that is applicable to all samples.

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flash. To each calibration standard, add a known constant amount of one or more internal standards, and dilute to volume with isooctane. One of the standards should be at a concentraton near, but above, the MDL and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.3.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against concentration for each compound and internal standard. Calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

C_{is}=Concentration of the internal standard (µg/L).

C_s=Concentration of the parameter to be measured (µg/L).

If the RF value over the working range is a constant (<10% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.4 The working calibration curve, calibration factor, or RF must be verified on each working day by the measurement of one or more calibration standards. If the response for any parameter varies from the predicted response by more than ±15%, a new calibration curve must be prepared for that compound.

7.5 Before using any cleanup procedure, the analyst must process a series of calibration standards through the procedure to validate elution patterns and the absence of interferences from the reagents.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Sections 10.4, 11.1, and 12.1) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Before processing any samples, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system and glassware are under control. Each time a set of samples is extracted or reagents are changed, a reagent water blank must be processed as a safeguard against laboratory contamination.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality contrml (QC) check sample concentrate is required containing each parameter of interest at the following concentrations in acetone: butyl benzyl phthalate, 10 µg/mL; bis(2-ethylhexyl) phthalate, 50 µg/mL; di-n-octyl phthalate, 50 µg/mL; any other phthlate, 25 µg/mL. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agancy, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Using a pipet, prepare QC check samples at the test concentrations shown in Table 2 by adding 1.00 mL of QC check sample concentrate to each of four 1–L aliquots of reagent water.

8.2.3 Analyze the well-mixed QC check samples according to the method beginning in Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 2. If s and $\bar{X}$ for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual $\bar{X}$ falls outside the range for accuracy, the system performance is unacceptable for that parameter. Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.2.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spiked sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at the test concentration in Section 8.2.2 or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.3 If it is impractical to determine background levels before spiking (e.g., maximum holding times will be exceeded), the spike concentration should be (1) the regulatory concentration limit, if any; or, if none (2) the larger of either 5 times higher than the expected background concentration or the test concentration in Section 8.2.2.

8.3.2 Analyze one sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second sample aliquot with 1.0 mL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100(A-B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 2. These acceptance criteria were calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[9] If spiking was performed at a concentration lower than the test concentration in Section 8.2.2, the analyst must use either the QC acceptance criteria in Table 2, or optional QC acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recovery of a parameter: (1) Calculate accuracy (X′) using the equation in Table 3, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 3, substituting X′ for X; (3) calculate the range for recovery at the spike concentration as (100 X′/T)±2.44(100 S′/T)%.[9]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4 If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory.

8.4.1 Prepare the QC check standard by adding 1.0 mL of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 1 L of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 2. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $P-2s_p$ to $P+2s_p$. If P=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%.

Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as gas chromatography with a dissimilar column, specific element detector, or mass spectrometer must be used. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 Grab samples must be collected in glass containers. Conventional sampling practices[10] should be followed, except that the bottle must not be prerinsed with sample before collection. Composite samples should be collected in refrigerated glass containers in accordance with the requirements of the program. Automatic sampling equipment must be as free as possible of Tygon tubing and other potential sources of contamination.

9.2 All samples must be iced or refrigerated at 4 °C from the time of collection until extraction.

9.3 All samples must be extracted within 7 days of collection and completely analyzed within 40 days of extraction.[2]

10. Sample Extraction

10.1 Mark the water meniscus on the side of the sample bottle for later determination of sample volume. Pour the entire sample into a 2–L separatory funnel.

10.2 Add 60 mL of methylene chloride to the sample bottle, seal, and shake 30 s to rinse the inner surface. Transfer the solvent to the separatory funnel and extract the sample by shaking the funnel for 2 min. with periodic venting to release excess pressure. Allow the organic layer to separate from the water phase for a minimum of 10 min. If the emulsion interface between layers is more than one-third the volume of the solvent layer, the analyst must employ mechanical techniques to complete the phrase separation. The optimum technique depends upon the sample, but may include stirring, filtration of the emulsion through glass wool, centrifugation, or other physical methods. Collect the methylene chloride extract in a 250-mL Erlenmeyer flask.

10.3 Add a second 60-mL volume of methylene chloride to the sample bottle and repeat the extraction procedure a second time, combining the extracts in the Erlenmeyer flask. Perform a third extraction in the same manner.

10.4 Assemble a Kuderna-Danish (K–D) concentrator by attaching a 10-mL concentrator tube to a 500-mL evaporative flask. Other concentrator devices or techniques may be used in place of the K–D concentrator if the requirements of Section 8.2 are met.

10.5 Pour the combined extract through a solvent-rinsed drying column containing about 10 cm of anhydrous sodium sulfate, and collect the extract in the K–D concentrator. Rinse the Erlenmeyer flask and column with 20 to 30 mL of methylene chloride to complete the quantitative transfer.

10.6 Add one or two clean boiling chips to the evaporative flask and attach a three-ball Snyder column. Prewet the Snyder column by adding about 1 mL of methylene chloride to the top. Place the K–D apparatus on a hot water bath (60 to 65 °C) so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15 to 20 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches 1 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min.

10.7 Increase the temperature of the hot water bath to about 80 °C. Momentarily remove the Snyder column, add 50 mL of hexane and a new boiling chip, and reattach the Snyder column. Concentrate the extract as in Section 10.6, except use hexane to prewet the column. The elapsed time of concentration should be 5 to 10 min.

10.8 Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1 to 2 mL of hexane. A 5-mL syringe is recommended for this operation. Adjust the extract volume to 10 mL. Stopper the concentrator tube and store refrigerated if further processing will not be performed immediately. If the extract will be stored longer than two days, it should be transferred to a Teflon-sealed screw-cap vial. If the sample extract requires no further cleanup, proceed with gas chromatographic analysis (Section 12). If the sample requires further cleanup, proceed to Section 11.

10.9 Determine the original sample volume by refilling the sample bottle to the mark and transferring the liquid to a 1000-mL graduated cylinder. Record the sample volume to the nearest 5 mL.

11. Cleanup and Separation

11. Cleanup procedures may not be necessary for a relatively clean sample matrix. If particular circumstances demand the use

of a cleanup procedure, the analyst may use either procedure below or any other appropriate procedure. However, the analyst first must demonstrate that the requirements of Section 8.2 can be met using the method as revised to incorporate the cleanup procedure.

11.2 If the entire extract is to be cleaned up by one of the following procedures, it must be concentrated to 2.0 mL. To the concentrator tube in Section 10.8, add a clean boiling chip and attach a two-ball micro-Snyder column. Prewet the column by adding about 0.5 mL of hexane to the top. Place the micro-K–D apparatus on a hot water bath (80 °C) so that the concentrator tube is partially immersed in the hot water. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 5 to 10 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood. When the apparent volume of liquid reaches about 0.5 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min. Remove the micro-Snyder column and rinse its lower joint into the concentrator tube with 0.2 mL of hexane. Adjust the final volume to 2.0 mL and proceed with one of the following cleanup procedures.

11.3 Florisil column cleanup for phthalate esters:

11.3.1 Place 10 g of Florisil into a chromatographic column. Tap the column to settle the Florisil and add 1 cm of anhydrous sodium sulfate to the top.

11.3.2 Preelute the column with 40 mL of hexane. The rate for all elutions should be about 2 mL/min. Discard the eluate and just prior to exposure of the sodium sulfate layer to the air, quantitatively transfer the 2-mL sample extract onto the column using an additional 2 mL of hexane to complete the transfer. Just prior to exposure of the sodium sulfate layer to the air, add 40 mL of hexane and continue the elution of the column. Discard this hexane eluate.

11.3.3 Next, elute the column with 100 mL of 20% ethyl ether in hexane (V/V) into a 500-mL K–D flask equipped with a 10-mL concentrator tube. Concentrate the collected fraction as in Section 10.6. No solvent exchange is necessary. Adjust the volume of the cleaned up extract to 10 mL in the concentrator tube and analyze by gas chromatography (Section 12).

11.4 Alumina column cleanup for phthalate esters:

11.4.1 Place 10 g of alumina into a chromatographic column. Tap the column to settle the alumina and add 1 cm of anhydrous sodium sulfate to the top.

11.4.2 Preelute the column with 40 mL of hexane. The rate for all elutions should be about 2 mL/min. Discard the eluate and just prior to exposure of the sodium sulfate layer to the air, quantitatively transfer the 2-mL sample extract onto the column using an additional 2 mL of hexane to complete the transfer. Just prior to exposure of the sodium sulfate layer to the air, add 35 mL of hexane and continue the elution of the column. Discard this hexane eluate.

11.4.3 Next, elute the column with 140 mL of 20% ethyl ether in hexane (V/V) into a 500-mL K–D flask equipped with a 10–mL concentrator type. Concentrate the collected fraction as in Section 10.6. No solvent exchange is necessary. Adjust the volume of the cleaned up extract to 10 mL in the concentrator tube and analyze by gas chromatography (Section 12).

12. Gas Chromatography

12.1 Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are retention times and MDL that can be achieved under these conditions. Examples of the separations achieved by Column 1 are shown in Figures 1 and 2. Other packed or capillary (open-tubular) columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met.

12.2 Calibrate the system daily as described in Section 7.

12.3 If the internal standard calibration procedure is being used, the internal staldard must be added to the sample extract and mixed thoroughly immediately before injection into the gas chromatograph.

12.4 Inject 2 to 5 µL of the sample extract or standard into the gas-chromatograph using the solvent-flush technique.[11] Smaller (1.0 µL) volumes may be injected if automatic devices are employed. Record the volume injected to the nearest 0.05 µL, and the resulting peak size in area or peak height units.

12.5 Identify the parameters in the sample by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

12.6 If the response for a peak exceeds the working range of the system, dilute the extract and reanalyze.

12.7 If the measurement of the peak response is prevented by the presence of interferences, further cleanup is required.

13. Calculations

13.1 Determine the concentration of individual compounds in the sample.

13.1.1 If the external standard calibration procedure is used, calculate the amount of material injected from the peak response using the calibration curve or calibration factor determined in Section 7.2.2. The concentration in the sample can be calculated from Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A)(V_t)}{(V_i)(Vs)}$$

Equation 2

where:
A=Amount of material injected (ng).
V_i=Volume of extract injected (μL).
V_t=Volume of total extract (μL).
V_s=Volume of water extracted (mL).

13.1.2 If the internal standard calibration procedure is used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.3.2 and Equation 3.

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(I_s)}{(A_{is})(RF)(V_o)}$$

Equation 3

where:
A_s=Response for the parameter to be measured.
A_{is}=Response for the internal standard.
I_s=Amount of internal standard added to each extract (μg).
V_o=Volume of water extracted (L).

13.2 Report results in μg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

14. Method Performance

14.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentrations listed in Table 1 were obtained using reagent water.[12] Similar results were achieved using representative wastewaters. The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

14.2 This method has been tested for linearity of spike recovery from reagent water and has been demonstrated to be applicable over the concentration range from 5 × MDL to 1000 × MDL with the following exceptions: dimethyl and diethyl phthalate recoveries at 1000 × MDL were low (70%); bis-2-ethylhexyl and di-n-octyl phthalate recoveries at 5 × MDL were low (60%).[12]

14.3 This method was tested by 16 laboratories using reagent water, drinking water, surface water, and three industrial wastewaters spiked at six concentrations over the range 0.7 to 106 μg/L.[13] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 3.

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TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention time (min)		Method detection limit (μg/L)
	Column 1	Column 2	
Dimethyl phthalate	2.03	0.95	0.29
Diethyl phthalate	2.82	1.27	0.49
Di-n-butyl phthalate	8.65	3.50	0.36
Butyl benzyl phthalate	[a]6.94	[a]5.11	0.34
Bis(2-ethylhexyl) phthalate	[a]8.92	[a]10.5	2.0
Di-n-octyl phthalate	[a]16.2	[a]18.0	3.0

Column 1 conditions: Supelcoport (100/120 mesh) coated with 1.5% SP–2250/1.95% SP–2401 packed in a 1.8 m long × 4 mm ID glass column with 5% methane/95% argon carrier gas at 60 mL/min flow rate. Column temperature held isothermal at 180°C, except where otherwise indicated.

Column 2 conditions: Supelcoport (100/120 mesh) coated with 3% OV–1 packed in a 1.8 m long × 4 mm ID glass column with 5% methane/95% argon carrier gas at 60 mL/min flow rate. Column temperature held isothermal at 200 °C, except where otherwise indicated.

[a] 220 °C column temperature.

TABLE 2—QC ACCEPTANCE CRITERIA—METHOD 606

Parameter	Test conc. (μg/L)	Limit for s (μg/L)	Range for X (μg/L)	Range for P, P_s (percent)
Bis(2-ethylhexyl) phthalate	50	38.4	1.2–55.9	D–158
Butyl benzyl phthalate	10	4.2	5.7–11.0	30–136
Di-n-butyl phthalate	25	8.9	10.3–29.6	23–136
Diethyl phthalate	25	9.0	1.9–33.4	D–149
Dimethyl phathalate	25	9.5	1.3–35.5	D–156
Di-n-octyl phthalate	50	13.4	D–50.0	D–114

$\underline{s}$=Standard deviation of four recovery measurements, in μg/L (Section 8.2.4).
$\bar{X}$=Average recovery for four recovery measurements, in μg/L (Section 8.2.4).
P, P_s=Percent recovery measured (Section 8.3.2, Section 8.4.2).
D=Detected; result must be greater than zero.

Note: These criteria are based directly upon the method performance data in Table 3. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 3.

TABLE 3—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 606

Parameter	Accuracy, as recovery, X′ (μg/L)	Single analyst precision, s_r' (μg/L)	Overall precision, S′ (μg/L)
Bis(2-ethylhexyl) phthalate	0.53C+2.02	$0.80\bar{X}-2.54$	$0.73\bar{X}-0.17$
Butyl benzyl phthalate	0.82C+0.13	$0.26\bar{X}+0.04$	$0.25\bar{X}+0.07$
Di-n-butyl phthalate	0.79C+0.17	$0.23\bar{X}+0.20$	$0.29\bar{X}+0.06$
Diethyl phthalate	0.70C+0.13	$0.27\bar{X}+0.05$	$0.45\bar{X}+0.11$
Dimethyl phthalate	0.73C+0.17	$0.26\bar{X}+0.14$	$0.44\bar{X}+0.31$
Di-n-octyl phthalate	0.35C − 0.71	$0.38\bar{X}+0.71$	$0.62\bar{X}+0.34$

$\bar{X}'$=Expected recovery for one or more measurements of a sample containing a concentration of C, in μg/L.
s_r'=Expected single analyst standard deviation of measurements at an average concentration found of $\bar{X}$, in μg/L.
S′=Expected interlaboratory standard deviation of measurements at an average concentration found of X, in μg/L.
$\underline{C}$=True value for the concentration, in μg/L.
$\bar{X}$=Average recovery found for measurements of samples containing a concentration of C, in μg/L.

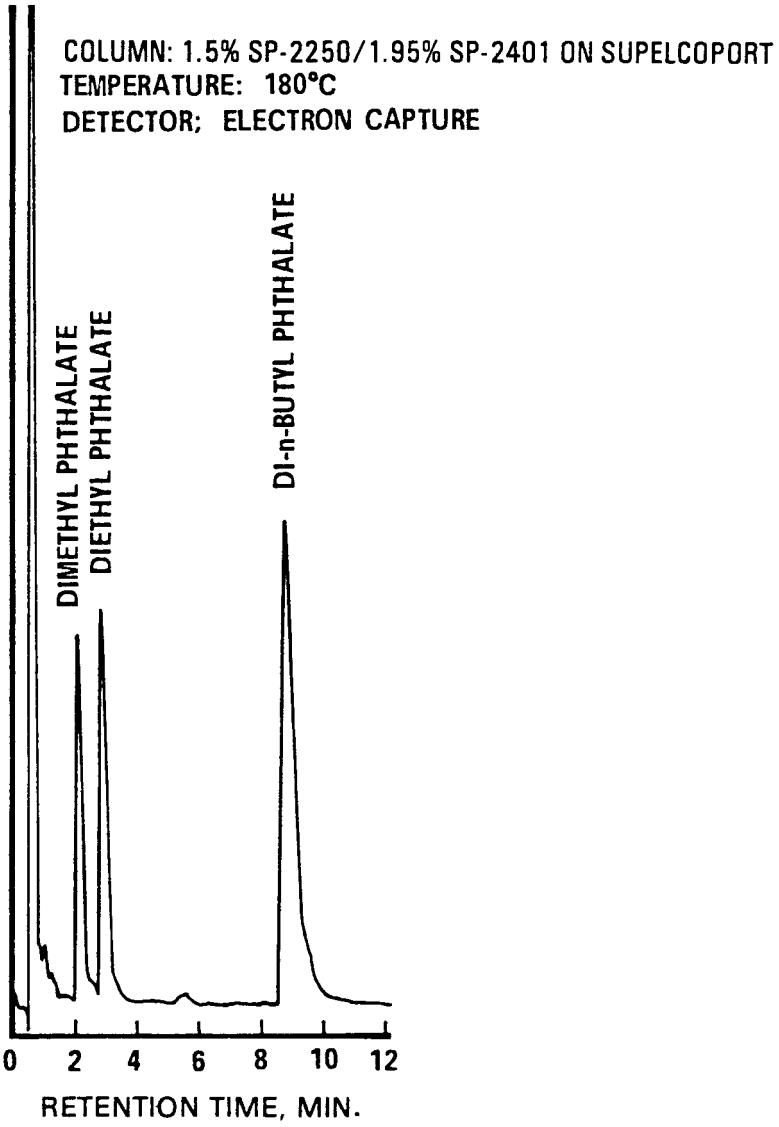

Figure 1. Gas chromatogram of phthalates.

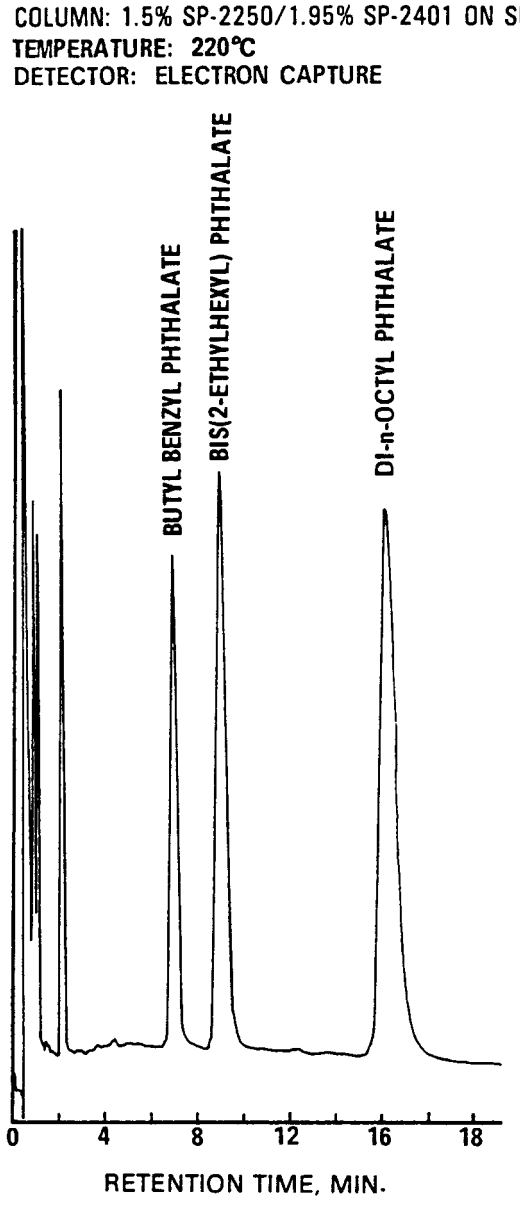

Figure 2. Gas chromatogram of phthalates.

METHOD 607—NITROSAMINES

1. Scope and Application

1.1 This method covers the determination of certain nitrosamines. The following parameters can be determined by this method:

Parameter	Storet No.	CAS No.
N-Nitrosodimethylamine	34438	62–75–9
N-Nitrosodiphenylamine	34433	86–30–6
N-Nitrosodi-n-propylamine	34428	621–64–7

1.2 This is a gas chromatographic (GC) method applicable to the determination of the parameters listed above in municipal and industrial discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for any or all of the compmunds above, compound identifications should be supported by at least one additional qualitative technique. This method describes analytical conditimns for a second gas chromatographic column that can be used to confirm measurements made with the primary column. Method 625 provides gas chromatograph/mass spectrometer (GC/MS) conditions appropriate for the qualitative and quantitative confirmation of results for N-nitrosodi-n-propylamine. In order to confirm the presence of N-nitrosodiphenylamine, the cleanup procedure specified in Section 11.3 or 11.4 must be used. In order to confirm the presence of N-nitrosodimethylamine by GC/MS, Column 1 of this method must be substituted for the column recommended in Method 625. Confirmation of these parameters using GC-high resolution mass spectrometry or a Thermal Energy Analyzer is also recommended. [1,2]

1.3 The method detection limit (MDL, defined in Section 14.1)[3] for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.4 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.5 This method is restricted to use by or under the supervision of analysts experienced in the use of a gas chromatograph and in the interpretation of gas chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 A measured volume of sample, approximately 1–L, is extracted with methylene chloride using a separatory funnel. The methylene chloride extract is washed with dilute hydrochloric acid to remove free amines, dried, and concentrated to a volume of 10 mL or less. After the extract has been exchanged to methanol, it is separated by gas chromatography and the parameters are then measured with a nitrogen-phosphorus detector.[4]

2.2 The method provides Florisil and alumina column cleanup procedures to separate diphenylamine from the nitrosamines and to aid in the elimination of interferences that may be encountered.

3. Interferences

3.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that lead to discrete artifacts and/or elevated baselines in gas chromatograms. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3.

3.1.1 Glassware must be scrupulously cleaned.[5] Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. Solvent rinsing should be followed by detergent washing with hot water, and rinses with tap water and distilled water. The glassware should then be drained dry, and heated in a muffle furnace at 400 °C for 15 to 30 min. Solvent rinses with acetone and pesticide quality hexane may be substituted for the muffle furnace heating. Volumetric ware should not be heated in a muffle furnace. After drying and cooling, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Store inverted or capped with aluminum foil.

3.1.2 The use of high purity reagents and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

3.2 Matrix interferences may be caused by contaminants that are co-extracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature and diversity of the industrial complex or municipality being sampled. The cleanup procedures in Section 11 can be used to overcome many of these interferences, but unique samples may require additional cleanup approaches to achieve the MDL listed in Table 1.

3.3 N-Nitrosodiphenylamine is reported[6–9] to undergo transnitrosation reactions. Care must be exercised in the heating or concentrating of solutions containing this compound in the presence of reactive amines.

3.4 The sensitive and selective Thermal Energy Analyzer and the reductive Hall detector may be used in place of the nitrogen-phosphorus detector when interferences are encountered. The Thermal Energy Analyzer offers the highest selectivity of the non-MS detectors.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified [10–12] for the information of the analyst.

4.2 These nitrosamines are known carcinogens [13–17], therefore, utmost care must be exercised in the handling of these materials. Nitrosamine reference standards and standard solutions should be handled and prepared in a ventilated glove box within a properly ventilated room.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete or composite sampling.

5.1.1 Grab sample bottle—1–L or 1-qt, amber glass, fitted with a screw cap lined with Teflon. Foil may be substituted for Teflon if the sample is not corrosive. If amber bottles are not available, protect samples from light. The bottle and cap liner must be washed, rinsed with acetone or methylene chloride, and dried before use to minimize contamination.

5.1.2 Automatic sampler (optional)—The sampler must incorporate glass sample containers for the collection of a minimum of 250 mL of sample. Sample containers must be kept refrigerated at 4 °C and protected from light during compositing. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used. Before use, however, the compressible tubing should be thoroughly rinsed with methanol, followed by repeated rinsings with distilled water to minimize the potential for contamination of the sample. An integrating flowmeter is required to collect flow proportional composites.

5.2 Glassware (All specifications are suggested. Catalog numbers are included for illustration only.):

5.2.1 Separatory funnels—2–L and 250–mL, with Teflon stopcock.

5.2.2 Drying column—Chromatographic column, approximately 400 mm long × 19 mm ID, with coarse frit filter disc.

5.2.3 Concentrator tube, Kuderna-Danish—10-mL, graduated (Kontes K–570050–1025 or equivalent). Calibration must be checked at the volumes employed in the test. Ground glass stopper is used to prevent evaporation of extracts.

5.2.4 Evaporative flask, Kuderna-Danish—500-mL (Kontes K–570001–0500 or equivalent). Attach to concentrator tube with springs.

5.2.5 Snyder column, Kuderna-Danish—Three-ball macro (Kontes K–503000–0121 or equivalent).

5.2.6 Snyder column, Kuderna-Danish—Two-ball micro (Kontes K–569001–0219 or equivalent).

5.2.7 Vials—10 to 15-mL, amber glass, with Teflon-lined screw cap.

5.2.8 Chromatographic column—Approximately 400 mm long × 22 mm ID, with Teflon stopcock and coarse frit filter disc at bottom (Kontes K–420540–0234 or equivalent), for use in Florisil column cleanup procedure.

5.2.9 Chromatographic column—Approximately 300 mm long × 10 mm ID, with Teflon stopcock and coarse frit filter disc at bottom (Kontes K–420540–0213 or equivalent), for use in alumina column cleanup procedure.

5.3 Boiling chips—Approximately 10/40 mesh. Heat to 400 °C for 30 min or Soxhlet extract with methylene chloride.

5.4 Water bath—Heated, with concentric ring cover, capable of temperature control (±2 °C). The bath should be used in a hood.

5.5 Balance—Analytical, capable of accurately weighing 0.0001 g.

5.6 Gas chromatograph—An analytical system complete with gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, gases, detector, and strip-chart recorder. A data system is recommended for measuring peak areas.

5.6.1 Column 1—1.8 m long × 4 mm ID glass, packed with 10% Carbowax 20 M/2% KOH on Chromosorb W–AW (80/100 mesh) or equivalent. This column was used to develop the method performance statements in Section 14. Guidelines for the use of alternate column packings are provided in Section 12.2.

5.6.2 Column 2—1.8 m long × 4 mm ID glass, packed with 10% SP–2250 on Supelcoport (100/120 mesh) or equivalent.

5.6.3 Detector—Nitrogen-phosphorus, reductive Hall, or Thermal Energy Analyzer detector.[1,2] These detectors have proven effective in the analysis of wastewaters for the parameters listed in the scope (Section 1.1). A nitrogen-phosphorus detector was used to develop the method performance statements in Section 14. Guidelines for the use of alternate detectors are provided in Section 12.2.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.2 Sodium hydroxide solution (10 N)—Dissolve 40 g of NaOH (ACS) in reagent water and dilute to 100 ml.

6.3 Sodium thiosulfate—(ACS) Granular.

6.4 Sulfuric acid (1+1)—Slowly, add 50 mL of H_2SO_4 (ACS, sp. gr. 1.84) to 50 mL of reagent water.

6.5 Sodium sulfate—(ACS) Granular, anhydrous. Purify by heating at 400 °C for 4 h in a shallow tray.

6.6 Hydrochloric acid (1+9)—Add one volume of concentrated HCl (ACS) to nine volumes of reagent water.

6.7 Acetone, methanol, methylene chloride, pentane—Pesticide quality or equivalent.

6.8 Ethyl ether—Nanograde, redistilled in glass if necessary.

6.8.1 Ethyl ether must be shown to be free of peroxides before it is used as indicated by EM Laboratories Quant test strips. (Available from Scientific Products Co., Cat No. P1126–8, and other suppliers.)

6.8.2 Procedures recommended for removal of peroxides are provided with the test strips. After cleanup, 20 mL of ethyl alcohol preservative must be added to each liter of ether.

6.9 Florisil—PR grade (60/100 mesh). Purchase activated at 1250 °F and store in the dark in glass containers with ground glass stoppers or foil-lined screw caps. Before use, activate each batch at least 16 h at 130 °C in a foil-covered glass container and allow to cool.

6.10 Alumina—Basic activity Super I, W200 series (ICN Life Sciences Group, No. 404571, or equivalent). To prepare for use, place 100 g of alumina into a 500-mL reagent bottle and add 2 mL of reagent water. Mix the alumina preparation thoroughly by shaking or rolling for 10 min and let it stand for at least 2 h. The preparation should be homogeneous before use. Keep the bottle sealed tightly to ensure proper activity.

6.11 Stock standard solutions (1.00 µg/µL)—Stock standard solutions can be prepared from pure standard materials or purchased as certified solutions.

6.11.1 Prepare stock standard solutions by accurately weighing about 0.0100 g of pure material. Dissolve the material in methanol and dilute to volume in a 10-mL volumetric flask. Larger volumes can be used at the convenience of the analyst. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the manufacturer or by an independent source.

6.11.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4 °C and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.11.3 Stock standard solutions must be replaced after six months, or sooner if comparison with check standards indicates a problem.

6.12 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Establish gas chromatographic operating conditions equivalent to those given in Table 1. The gas chromatographic system can be calibrated using the external standard technique (Section 7.2) or the internal standard technique (Section 7.3).

7.2 External standard calibration procedure:

7.2.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask and diluting to volume with methanol. One of the external standards should be at a concentraton near, but above, the MDL (Table 1) and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.2.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against the mass injected. The results can be used to prepare a calibration curve for each compound. Alternatively, if the ratio of response to amount injected (calibration factor) is a constant over the working range (<10% relative standard deviation, RSD), linearity through the origin can be assumed and the average ratio or calibration factor can be used in place of a calibration curve.

7.3 Internal standard calibration procedure—To use this approach, the analyst must select one or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Because of these limitations, no internal standard can be suggested that is applicable to all samples.

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask. To each calibration standard, add a known constant amount of one or more internal standards, and dilute to volume with methanol. One of the standards should be at a concentration near, but above, the MDL and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.3.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against concentration for each compound and internal standard. Calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:
A_s=Response for the parameter to be measured.
A_{is}=Response for the internal standard.
C_{is}=Concentration of the internal standard (µg/L).
C_s=Concentration of the parameter to be measured (µg/L).

If the RF value over the working range is a constant (<10% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.4 The working calibration curve, calibration factor, or RF must be verified on each working day by the measurement of one or more calibration standards. If the response for any parameter varies from the predicted response by more than ±15%, a new calibration curve must be prepared for that compound.

7.5 Before using any cleanup procedure, the analyst must process a series of calibration standards through the procedure to validate elution patterns and the absence of interferences from the reagents.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Sections 10.4, 11.1, and 12.2) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Before processing any samples, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system and glassware are under control. Each time a set of samples is extracted or reagents are changed, a reagent water blank must be processed as a safeguard against laboratory contamination.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing each parameter of interest at a concentration of 20 µg/mL in methanol. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Using a pipet, prepare QC check samples at a concentration of 20 µg/L by adding 1.00 mL of QC check sample concentrate to each of four 1–L aliquots of reagent water.

8.2.3 Analyze the well-mixed QC check samples according to the method beginning in Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria for precision and accuracy, respectively,

found in Table 2. If s and $\bar{X}$ for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual $\bar{X}$ falls outside the range for accuracy, the system performance is unacceptable for that parameter. Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.2.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spiked sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at 20 µg/L or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.3 If it is impractical to determine background levels before spiking (e.g., maximum holding times will be exceeded), the spike concentration should be (1) the regulatory concentration limit, if any; or, if none (2) the larger of either 5 times higher than the expected background concentration or 20 µg/L.

8.3.2 Analyze one sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second sample aliquot with 1.0 mL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100(A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 2. These acceptance criteria were caluclated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[18] If spiking was performed at a concentration lower than 20 µg/L, the analyst must use either the QC acceptance criteria in Table 2, or optional QC acceptance criteria caluclated for the specific spike concentration. To calculate optional acceptance crtieria for the recovery of a parameter: (1) Calculate accuracy (X′) using the equation in Table 3, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 3, substituting X′ for $\bar{X}$; (3) calculate the range for recovery at the spike concentration as (100 X′/T) ± 2.44(100 S′/T)%.[18]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4 If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory.

8.4.1 Prepare the QC check standard by adding 1.0 mL of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 1 L of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 2. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $P-2s_p$ to $P+2s_p$. If P=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 It is recommended that the laboratory adopt additional quality assurance practices

for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as gas chromatography with a dissimilar column, specific element detector, or mass spectrometer must be used. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 Grab samples must be collected in glass containers. Conventional sampling practices[19] should be followed, except that the bottle must not be prerinsed with sample before collection. Composite samples should be collected in refrigerated glass containers in accordance with the requirements of the program. Automatic sampling equipment must be as free as possible of Tygon tubing and other potential sources of contamination.

9.2 All samples must be iced or refrigerated at 4 °C from the time of collection until extraction. Fill the sample bottles and, if residual chlorine is present, add 80 mg of sodium thiosulfate per liter of sample and mix well. EPA Methods 330.4 and 330.5 may be used for measurement of residual chlorine.[20] Field test kits are available for this purpose. If N-nitrosodiphenylamine is to be determined, adjust the sample pH to 7 to 10 with sodium hydroxide solution or sulfuric acid.

9.3 All samples must be extracted within 7 days of collection and completely analyzed within 40 days of extraction.[4]

9.4 Nitrosamines are known to be light sensitive.[7] Samples should be stored in amber or foil-wrapped bottles in order to minimize photolytic decomposition.

10. Sample Extraction

10.1 Mark the water meniscus on the side of the sample bottle for later determination of sample volume. Pour the entire sample into a 2–L separatory funnel. Check the pH of the sample with wide-range pH paper and adjust to within the range of 5 to 9 with sodium hydroxide solution or sulfuric acid.

10.2 Add 60 mL of methylene chloride to the sample bottle, seal, and shake 30 s to rinse the inner surface. Transfer the solvent to the separatory funnel and extract the sample by shaking the funnel for 2 min with periodic venting to release excess pressure. Allow the organic layer to separate from the water phase for a minimum of 10 min. If the emulsion interface between layers is more than one-third the volume of the solvent layer, the analyst must employ mechanical techniques to complete the phase separation. The optimum technique depends upon the sample, but may include stirring, filtration of the emulsion through glass wool, centrifugation, or other physical methods. Collect the methylene chloride extract in a 250-mL Erlenmeyer flask.

10.3 Add a second 60-mL volume of methylene chloride to the sample bottle and repeat the extraction procedure a second time, combining the extracts in the Erlenmeyer flask. Perform a third extraction in the same manner.

10.4 Assemble a Kuderna-Danish (K–D) concentrator by attaching a 10-mL concentrator tube to a 500-mL evaporative flask. Other concentration devices or techniques may be used in place of the K–D concentrator if the requirements of Section 8.2 are met.

10.5 Add 10 mL of hydrochloric acid to the combined extracts and shake for 2 min. Allow the layers to separate. Pour the combined extract through a solvent-rinsed drying column containing about 10 cm of anhydrous sodium sulfate, and collect the extract in the K–D concentrator. Rinse the Erlenmeyer flask and column with 20 to 30 mL of methylene chloride to complete the quantitative transfer.

10.6 Add one or two clean boiling chips to the evaporative flask and attach a three-ball Snyder column. Prewet the Snyder column by adding about 1 mL of methylene chloride to the top. Place the K–D apparatus on a hot water bath (60 to 65°C) so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15 to 20 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches 1 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min.

10.7 Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1 to 2 mL of methylene chloride. A 5-mL syringe is recommended for this operation. Stopper the concentrator tube and store refrigerated if further processing will not be performed immediately. If the extract will be stored longer than two days, it should be transferred to a Teflon-sealed screw-cap vial. If N-nitrosodiphenylamine is to be measured by gas chromatography, the analyst must first use a cleanup column to eliminate diphenylamine interference (Section 11). If N-nitrosodiphenylamine is of no interest, the analyst may proceed directly with gas chromatographic analysis (Section 12).

10.8 Determine the original sample volume by refilling the sample bottle to the mark and transferring the liquid to a 1000-mL graduated cylinder. Record the sample volume to the nearest 5 mL.

11. Cleanup and Separation

11.1 Cleanup procedures may not be necessary for a relatively clean sample matrix. If particular circumstances demand the use of a cleanup procedure, the analyst may use either procedure below or any other appropriate procedure. However, the analyst first must demonstrate that the requirements of Section 8.2 can be met using the method as revised to incorporate the cleanup procedure. Diphenylamine, if present in the original sample extract, must be separated from the nitrosamines if N-nitrosodiphenylamine is to be determined by this method.

11.2 If the entire extract is to be cleaned up by one of the following procedures, it must be concentrated to 2.0 mL. To the concentrator tube in Section 10.7, add a clean boiling chip and attach a two-ball micro-Snyder column. Prewet the column by adding about 0.5 mL of methylene chloride to the top. Place the micr-K–D apparatus on a hot water bath (60 to 65°C) so that the concentrator tube is partially immersed in the hot water. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 5 to 10 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood. When the apparent volume of liquid reaches about 0.5 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min. Remove the micro-Snyder column and rinse its lower joint into the concentrator tube with 0.2 mL of methylene chloride. Adjust the final volume to 2.0 mL and proceed with one of the following cleanup procedures.

11.3 Florisil column cleanup for nitrosamines:

11.3.1 Place 22 g of activated Florisil into a 22-mm ID chromatographic column. Tap the column to settle the Florisil and add about 5 mm of anhydrous sodium sulfate to the top.

11.3.2 Preelute the column with 40 mL of ethyl ether/pentane (15+85)(V/V). Discard the eluate and just prior to exposure of the sodium sulfate layer to the air, quantitatively transfer the 2-mL sample extract onto the column using an additional 2 mL of pentane to complete the transfer.

11.3.3 Elute the column with 90 mL of ethyl ether/pentane (15+85)(V/V) and discard the eluate. This fraction will contain the diphenylamine, if it is present in the extract.

11.3.4 Next, elute the column with 100 mL of acetone/ethyl ether (5+95)(V/V) into a 500-mL K–D flask equipped with a 10-mL concentrator tube. This fraction will contain all of the nitrosamines listed in the scope of the method.

11.3.5 Add 15 mL of methanol to the collected fraction and concentrate as in Section 10.6, except use pentane to prewet the column and set the water bath at 70 to 75°C. When the apparatus is cool, remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1 to 2 mL of pentane. Analyze by gas chromatography (Section 12).

11.4 Alumina column cleanup for nitrosamines:

11.4.1 Place 12 g of the alumina preparation (Section 6.10) into a 10-mm ID chromatographic column. Tap the column to settle the alumina and add 1 to 2 cm of anhydrous sodium sulfate to the top.

11.4.2 Preelute the column with 10 mL of ethyl ether/pentane (3+7)(V/V). Discard the eluate (about 2 mL) and just prior to exposure of the sodium sulfate layer to the air, quantitatively transfer the 2 mL sample extract onto the column using an additional 2 mL of pentane to complete the transfer.

11.4.3 Just prior to exposure of the sodium sulfate layer to the air, add 70 mL of ethyl ether/pentane (3+7)(V/V). Discard the first 10 mL of eluate. Collect the remainder of the eluate in a 500–mL K–D flask equipped with a 10 mL concentrator tube. This fraction contains N-nitrosodiphenylamine and probably a small amount of N-nitrosodi-n-propylamine.

11.4.4 Next, elute the column with 60 mL of ethyl ether/pentane (1+1)(V/V), collecting the eluate in a second K–D flask equipped with a 10–mL concentrator tube. Add 15 mL of methanol to the K–D flask. This fraction will contain N-nitrosodimethylamine, most of the N-nitrosodi-n-propylamine and any diphenylamine that is present.

11.4.5 Concentrate both fractions as in Section 10.6, except use pentane to prewet the column. When the apparatus is cool, remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1 to 2 mL of pentane. Analyze the fractions by gas chromatography (Section 12).

12. Gas Chromatography

12.1 N-nitrosodiphenylamine completely reacts to form diphenylamine at the normal operating temperatures of a GC injection port (200 to 250°C). Thus, N-nitrosodiphenylamine is chromatographed and detected as diphenylamine. Accurate determination depends on removal of diphenylamine that may be present in the original extract prior to GC analysis (See Section 11).

12.2 Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are retention times and MDL that can be achieved under these conditions. Examples of the separations achieved by Column 1 are shown in

Figures 1 and 2. Other packed or capillary (open-tubular) columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met.

12.3 Calibrate the system daily as described in Section 7.

12.4 If the extract has not been subjected to one of the cleanup procedures in Section 11, it is necessary to exchange the solvent from methylene chloride to methanol before the thermionic detector can be used. To a 1 to 10-mL volume of methylene chloride extract in a concentrator tube, add 2 mL of methanol and a clean boiling chip. Attach a two-ball micro-Snyder column to the concentrator tube. Prewet the column by adding about 0.5 mL of methylene chloride to the top. Place the micro-K–D apparatus on a boiling (100 °C) water bath so that the concentrator tube is partially immersed in the hot water. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 5 to 10 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood. When the apparent volume of liquid reaches about 0.5 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min. Remove the micro-Snyder column and rinse its lower joint into the concentrator tube with 0.2 mL of methanol. Adjust the final volume to 2.0 mL.

12.5 If the internal standard calibration procedure is being used, the internal standard must be added to the sample extract and mixed thoroughly immediately before injection into the gas chromatograph.

12.6 Inject 2 to 5 µL of the sample extract or standard into the gas chromatograph using the solvent-flush technique.[21] Smaller (1.0 µL) volumes may be injected if automatic devices are employed. Record the volume injected to the nearest 0.05 µL, and the resulting peak size in area or peak height units.

12.7 Identify the parameters in the sample by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

12.8 If the response for a peak exceeds the working range of the system, dilute the extract and reanalyze.

12.9 If the measurement of the peak response is prevented by the presence of interferences, further cleanup is required.

13. Calculations

13.1 Determine the concentration of individual compounds in the sample.

13.1.1 If the external standard calibration procedure is used, calculate the amount of material injected from the peak response using the calibration curve or calibration factor determined in Section 7.2.2. The concentration in the sample can be calculated from Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A)(V_t)}{(V_i)(V_s)}$$

Equation 2

where:

A=Amount of material injected (ng).
V_i=Volume of extract injected (µL).
V_t=Volume of total extract (µL).
V_s=Volume of water extracted (mL).

13.1.2 If the internal standard calibration procedure is used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.3.2 and Equation 3.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 3

where:

A_s=Response for the parameter to be measured.
A_{is}=Response for the internal standard.
I_s=Amount of internal standard added to each extract (µg).
V_o=Volume of water extracted (L).

13.2 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

14. Method Performance

14.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[3] The MDL concentrations listed in Table 1 were obtained using reagent water.[22] Similar results were achieved using representative wastewaters. The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

14.2 This method has been tested for linearity of spike recovery from reagent water and has been demonstrated to be applicable over the concentration range from 4 × MDL to 1000 × MDL.[22]

14.3 This method was tested by 17 laboratories using reagent water, drinking water, surface water, and three industrial wastewaters spiked at six concentrations

over the range 0.8 to 55 µg/L.[23] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 3.

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TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention time (min)		Method detection limit (μg/L)
	Column 1	Column 2	
N-Nitrosodimethylamine	4.1	0.88	0.15
N-Nitrosodi-n-propylamine	12.1	4.2	.46
N-Nitrosodiphenylamine [a]	[b] 12.8	[c] 6.4	.81

Column 1 conditions: Chromosorb W–AW (80/100 mesh) coated with 10% Carbowax 20 M/2% KOH packed in a 1.8 m long × 4mm ID glass column with helium carrier gas at 40 mL/min flow rate. Column temperature held isothermal at 110 °C, except where otherwise indicated.

Column 2 conditions: Supelcoport (100/120 mesh) coated with 10% SP–2250 packed in a 1.8 m long × 4 mm ID glass column with helium carrier gas at 40 mL/min flow rate. Column temperature held isothermal at 120 °C, except where otherwise indicated.

[a] Measured as diphenylamine.

[b] 220 °C column temperature.

[c] 210 °C column temperature.

TABLE 2—QC ACCEPTANCE CRITERIA—METHOD 607

Parameter	Test conc. (μg/L)	Limit for s (μg/L)	Range for $\bar{X}$ (μg/L)	Range for P, P_s (percent)
N–Nitrosodimethylamine	20	3.4	4.6–20.0	13–109
N–Nitrosodiphenyl	20	6.1	2.1–24.5	D–139
N–Nitrosodi-n-propylamine	20	5.7	11.5–26.8	45–146

$\underline{s}$=Standard deviation for four recovery measurements, in μg/L (Section 8.2.4).

$\bar{X}$=Average recovery for four recovery measurements, in μg/L (Section 8.2.4).

P, P_s=Percent recovery measured (Section 8.3.2, Section 8.4.2).

D=Detected; result must be greater than zero.

NOTE: These criteria are based directly upon the method performance data in Table 3. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 3.

TABLE 3—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 607

Parameter	Accuracy, as recovery, X′ (μg/L)	Single analyst precision, s_r' (μg/L)	Overall precision, S′ (μg/L)
N–Nitrosodimethylamine	0.37C+0.06	$0.25\bar{X}-0.04$	$0.25\bar{X}+0.11$
N–Nitrosodiphenylamine	0.64C+0.52	$0.36\bar{X}-1.53$	$0.46\bar{X}-0.47$
N–Nitrosodi-n-propylamine	0.96C − 0.07	$0.15\bar{X}+0.13$	$0.21\bar{X}+0.15$

X′=Expected recovery for one or more measurements of a sample containing a concentration of C, in μg/L.

s_r'=Expected single analyst standard deviation of measurements at an average concentration found of $\underline{X}$, in μg/L.

S′=Expected interlaboratory standard deviation of measurements at an average concentration found of X, in μg/L.

$\underline{C}$=True value for the concentration, in μg/L.

X=Average recovery found for measurements of samples containing a concentration of C, in μg/L.

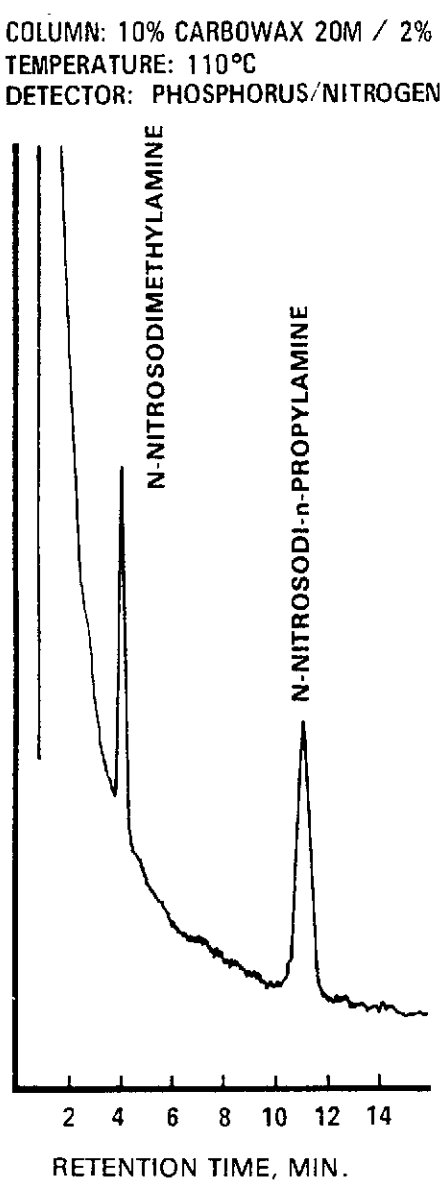

Figure 1. Gas chromatogram of nitrosamines.

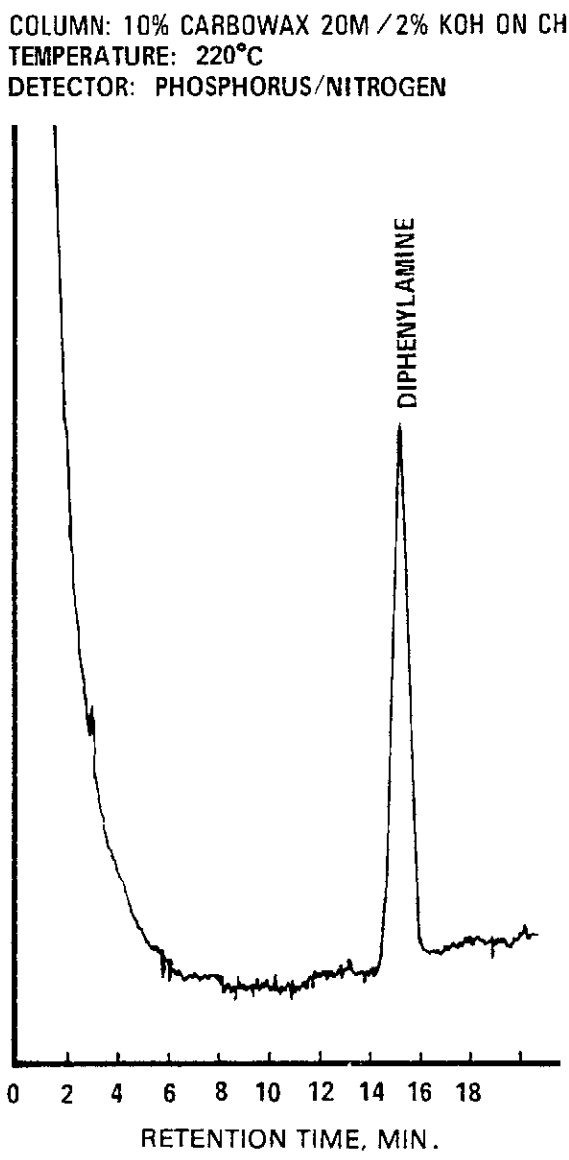

Figure 2. Gas chromatogram of N-nitrosodiphenylamine as diphenylamine.

METHOD 608—ORGANOCHLORINE PESTICIDES AND PCBS

1. Scope and Application

1.1 This method covers the determination of certain organochlorine pesticides and PCBs. The following parameters can be determined by this method:

Parameter	STORET No.	CAS No.
Aldrin	39330	309–00–2
α–BHC	39337	319–84–6
β–BHC	39338	319–85–7
δ–BHC	34259	319–86–8
γ–BHC	39340	58–89–9
Chlordane	39350	57–74–9
4,4′–DDD	39310	72–54–8
4,4′–DDE	39320	72–55–9
4,4′–DDT	39300	50–29–3
Dieldrin	39380	60–57–1
Endosulfan I	34361	959–98–8
Endosulfan II	34356	33212–65–9
Endosulfan sulfate	34351	1031–07–8
Eldrin	39390	72–20–8
Endrin aldehyde	34366	7421–93–4
Heptachlor	39410	76–44–8
Heptachlor epoxide	39420	1024–57–3
Toxaphene	39400	8001–35–2
PCB–1016	34671	12674–11–2
PCB–1221	39488	1104–28–2
PCB–1232	39492	11141–16–5
PCB–1242	39496	53469–21–9
PCB–1248	39500	12672–29–6
PCB–1254	39504	11097–69–1
PCB–1260	39508	11096–82–5

1.2 This is a gas chromatographic (GC) method applicable to the determination of the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for any or all of the compounds above, compound identifications should be supported by at least one additional qualitative technique. This method describes analytical conditions for a second gas chromatographic column that can be used to confirm measurements made with the primary column. Method 625 provides gas chromatograph/mass spectrometer (GC/MS) conditions appropriate for the qualitative and quantitative confirmation of results for all of the parameters listed above, using the extract produced by this method.

1.3 The method detection limit (MDL, defined in Section 14.1)[1] for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.4 The sample extraction and concentration steps in this method are essentially the same as in Methods 606, 609, 611, and 612. Thus, a single sample may be extracted to measure the parameters included in the scope of each of these methods. When cleanup is required, the concentration levels must be high enough to permit selecting aliquots, as necessary, to apply appropriate cleanup procedures. The analyst is allowed the latitude, under Section 12, to select chromatographic conditions appropriate for the simultaneous measurement of combinations of these parameters.

1.5 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.6 This method is restricted to use by or under the supervision of analysts experienced in the use of a gas chromatograph and in the interpretation of gas chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 A measured volume of sample, approximately 1–L, is extracted with methylene chloride using a separatory funnel. The methylene chloride extract is dried and exchanged to hexane during concentration to a volume of 10 mL or less. The extract is separated by gas chromatography and the parameters are then measured with an electron capture detector.[2]

2.2 The method provides a Florisil column cleanup procedure and an elemental sulfur removal procedure to aid in the elimination of interferences that may be encountered.

3. Interferences

3.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that lead to discrete artifacts and/or elevated baselines in gas chromatograms. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3.

3.1.1 Glassware must be scrupulously cleaned.[3] Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. Solvent rinsing should be followed by detergent washing with hot water, and rinses with tap water and distilled water. The glassware should then be drained dry, and heated in a muffle furnace at 400 °C for 15 to 30 min. Some thermally stable materials, such as PCBs, may not be eliminated by this treatment. Solvent rinses with acetone and pesticide quality hexane may be substituted for the muffle furnace heating. Thorough rinsing with such solvents usually eliminates PCB interference. Volumetric ware should not be heated in a muffle furnace. After drying and cooling, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Store inverted or capped with aluminum foil.

3.1.2 The use of high purity reagents and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

3.2 Interferences by phthalate esters can pose a major problem in pesticide analysis when using the electron capture detector. These compounds generally appear in the chromatogram as large late eluting peaks, especially in the 15 and 50% fractions from Florisil. Common flexible plastics contain varying amounts of phthalates. These phthalates are easily extracted or leached from such materials during laboratory operations. Cross contamination of clean glassware routinely occurs when plastics are handled during extraction steps, especially when solvent-wetted surfaces are handled. Interferences from phthalates can best be minimized by avoiding the use of plastics in the laboratory. Exhaustive cleanup of reagents and glassware may be required to eliminate background phthalate contamination.[4,5] The interferences from phthalate esters can be avoided by using a microcoulometric or electrolytic conductivity detector.

3.3 Matrix interferences may be caused by contaminants that are co-extracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature and diversity of the industrial complex or municipality being sampled. The cleanup procedures in Section 11 can be used to overcome many of these interferences, but unique samples may require additional cleanup approaches to achieve the MDL listed in Table 1.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified[6–8] for the information of the analyst.

4.2 The following parameters covered by this method have been tentatively classified as known or suspected, human or mammalian carcinogens: 4,4′-DDT, 4,4′–DDD, the BHCs, and the PCBs. Primary standards of these toxic compounds should be prepared in a hood. A NIOSH/MESA approved toxic gas respirator should be worn when the analyst handles high concentrations of these toxic compounds.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete or composite sampling.

5.1.1 Grab sample bottle—1–L or 1-qt, amber glass, fitted with a screw cap lined with Teflon. Foil may be substituted for Teflon if the sample is not corrosive. If amber bottles are not available, protect samples from light. The bottle and cap liner must be washed, rinsed with acetone or methylene chloride, and dried before use to minimize contamination.

5.1.2 Automatic sampler (optional)—The sampler must incorporate glass sample containers for the collection of a minimum of 250 mL of sample. Sample containers must be kept refrigerated at 4 °C and protected from light during composting. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used. Before use, however, the compressible tubing should be thoroughly rinsed with methanol, followed by repeated rinsings with distilled water to minimize the potential for contamination of the sample. An integrating flow meter is required to collect flow proportional composites.

5.2. Glassware (All specifications are suggested. Catalog numbers are included for illustration only.):

5.2.1 Separatory funnel—2–L, with Teflon stopcock.

5.2.2 Drying column—Chromatographic column, approximately 400 mm long × 19 mm ID, with coarse frit filter disc.

5.2.3 Chromatographic column—400 mm long × 22 mm ID, with Teflon stopcock and coarse frit filter disc (Kontes K–42054 or equivalent).

5.2.4 Concentrator tube, Kuderna-Danish—10–mL, graduated (Kontes K–570050–1025 or equivalent). Calibration must be checked at the volumes employed in the test. Ground glass stopper is used to prevent evaporation of extracts.

5.2.5 Evaporative flask, Kuderna-Danish—500–mL (Kontes K–570001–0500 or equivalent). Attach to concentrator tube with springs.

5.2.6 Snyder column, Kuderna/Danish—Three-ball macro (Kontes K–503000–0121 or equivalent).

5.2.7 Vials—10 to 15–mL, amber glass, with Teflon-lined screw cap.

5.3 Boiling chips—Approximately 10/40 mesh. Heat to 400 °C for 30 min or Soxhlet extract with methylene chloride.

5.4 Water bath—Heated, with concentric ring cover, capable of temperature control (±2 °C). The bath should be used in a hood.

5.5 Balance—Analytical, capable of accurately weighing 0.0001 g.

5.6 Gas chromatograph—An analytical system complete with gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, gases, detector, and strip-

chart recorder. A data system is recommended for measuring peak areas.

5.6.1 Column 1—1.8 m long × 4 mm ID glass, packed with 1.5% SP–2250/1.95% SP–2401 on Supelcoport (100/120 mesh) or equivalent. This column was used to develop the method performance statements in Section 14. Guidelines for the use of alternate column packings are provided in Section 12.1.

5.6.2 Column 2—1.8 m long × 4 mm ID glass, packed with 3% OV–1 on Supelcoport (100/120 mesh) or equivalent.

5.6.3 Detector—Electron capture detector. This detector has proven effective in the analysis of wastewaters for the parameters listed in the scope (Section 1.1), and was used to develop the method performance statements in Section 14. Guidelines for the use of alternate detectors are provided in Section 12.1.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.2 Sodium hydroxide solution (10 N)—Dissolve 40 g of NaOH (ACS) in reagent water and dilute to 100 mL.

6.3 Sodium thiosulfate—(ACS) Granular.

6.4 Sulfuric acid (1+1)—Slowly, add 50 mL to H_2SO_4 (ACS, sp. gr. 1.84) to 50 mL of reagent water.

6.5 Acetone, hexane, isooctane, methylene chloride—Pesticide quality or equivalent.

6.6 Ethyl ether—Nanograde, redistilled in glass if necessary.

6.6.1 Ethyl ether must be shown to be free of peroxides before it is used as indicated by EM Laboratories Quant test strips. (Available from Scientific Products Co., Cat. No. P1126–8, and other suppliers.)

6.6.2 Procedures recommended for removal of peroxides are provided with the test strips. After cleanup, 20 mL of ethyl alcohol preservative must be added to each liter of ether.

6.7 Sodium sulfate—(ACS) Granular, anhydrous. Purify by heating at 400 °C for 4 h in a shallow tray.

6.8 Florisil—PR grade (60/100 mesh). Purchase activated at 1250 °F and store in the dark in glass containers with ground glass stoppers or foil-lined screw caps. Before use, activate each batch at least 16 h at 130 °C in a foil-covered glass container and allow to cool.

6.9 Mercury—Triple distilled.

6.10 Copper powder—Activated.

6.11 Stock standard solutions (1.00 µg/µL)—Stock standard solutions can be prepared from pure standard materials or purchased as certified solutions.

6.11.1 Prepare stock standard solutions by accurately weighing about 0.0100 g of pure material. Dissolve the material in isooctane and dilute to volume in a 10-mL volumetric flask. Larger volumes can be used at the convenience of the analyst. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the manufacturer or by an independent source.

6.11.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4 °C and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.11.3 Stock standard solutions must be replaced after six months, or sooner if comparison with check standards indicates a problem.

6.12 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Establish gas chromatographic operating conditions equivalent to those given in Table 1. The gas chromatographic system can be calibrated using the external standard technique (Section 7.2) or the internal standard technique (Section 7.3).

7.2 External standard calibration procedure:

7.2.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask and diluting to volume with isooctane. One of the external standards should be at a concentration near, but above, the MDL (Table 1) and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.2.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against the mass injected. The results can be used to prepare a calibration curve for each compound. Alternatively, if the ratio of response to amount injected (calibration factor) is a constant over the working range (<10% relative standard deviation, RSD), linearity through the origin can be assumed and the average ratio or calibration factor can be used in place of a calibration curve.

7.3 Internal standard calibration procedure—To use this approach, the analyst must select one or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Because of these limitations, no internal standard can

be suggested that is applicable to all samples.

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask. To each calibration standard, add a known constant amount of one or more internal standards, and dilute to volume with isooctane. One of the standards should be at a concentration near, but above, the MDL and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.3.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against concentration for each compound and internal standard. Calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

C_{is}=Concentration of the internal standard (µg/L).

C_s=Concentraton of the parameter to be measured (µg/L).

If the RF value over the working range is a constant (<10% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.4 The working calibration curve, calibration factor, or RF must be verified on each working day by the measurement of one or more calibration standards. If the response for any parameter varies from the predicted response by more than ±15%, the test must be repeated using a fresh calibration standard. Alternatively, a new calibration curve must be prepared for that compound.

7.5 The cleanup procedure in Section 11 utilizes Florisil column chromatography. Florisil from different batches or sources may vary in adsorptive capacity. To standardize the amount of Florisil which is used, the use of lauric acid value[9] is suggested. The referenced procedure determines the adsorption from hexane solution of lauric acid (mg) per g of Florisil. The amount of Florisil to be used for each column is calculated by dividing 110 by this ratio and multiplying by 20 g.

7.6 Before using any cleanup procedure, the analyst must process a series of calibration standards through the procedure to validate elution patterns and the absence of interferences from the reagents.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Sections 10.4, 11.1, and 12.1) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Before processing any samples, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system and glassware are under control. Each time a set of samples is extracted or reagents are changed, a reagent water blank must be processed as a safeguard against laboratory contamination.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing each single-component parameter of interest at the following concentrations in acetone: 4,4′–DDD, 10 µg/mL; 4,4′–DDT, 10 µg/mL; endosulfan II, 10 µg/mL; endosulfan sulfate, 10 µg/mL; endrin, 10 µg/mL; any other single-component pesticide, 2 µg/mL. If this method is only to be used to analyze for PCBs, chlordane, or toxaphene, the QC check sample concentrate should contain the most representative multicomponent parameter at a concentration of 50 µg/mL in acetone. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Using a pipet, prepare QC check samples at the test concentrations shown in Table 3 by adding 1.00 mL of QC check sample concentrate to each of four 1–L aliquots of reagent water.

8.2.3 Analyze the well-mixed QC check samples according to the method beginning in Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/mL; and the standard deviation of the recovery (s) in µg/mL, for each parameter using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 3. If s and $\bar{X}$ for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual $\bar{X}$ falls outside the range for accuracy, the system performance is unacceptable for that parameter.

NOTE: The large number of parameters in Table 3 present a substantial probability that one or more will fail at least one of the acceptance criteria when all parameters are analyzed.

8.2.6 When one or more of the parameters tested fail at least one of the acceptance criteria, the analyst must proceed according to Section 8.2.6.1 or 8.2.6.2.

8.2.6.1 Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.2.

8.2.6.2 Beginning with Section 8.2.2, repeat the test only for those parameters that failed to meet criteria. Repeated failure, however, will confirm a general problem with the measurement system. If this occurs, locate and correct the source of the problem and repeat the test for all compmunds of interest beginning with Section 8.2.2.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spiked sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at the test concentration in Section 8.2.2 or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.3 If it is impractical to determine background levels before spiking (e.g., maximum holding times will be exceeded), the spike concentration should be (1) the regulatory concentration limit, if any; or, if none (2) the larger of either 5 times higher than the expected background concentration or the test concentration in Section 8.2.2.

8.3.2 Analyze one sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second sample aliquot with 1.0 mL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100(A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 3. These acceptance criteria were calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[10] If spiking was performed at a concentration lower than the test concentration in Section 8.2.2, the analyst must use either the QC acceptance criteria in Table 3, or optional QC acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recovery of a parameter: (1) Calculate accuracy (X′) using the equation in Table 4, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 4, substituting X′

for $\bar{X}$; (3) calculate the range for recovery at the spike concentration as (100 X′/T)±2.44(100 S′/T)%.[10]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4 If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory. If the entire list of parameters in Table 3 must be measured in the sample in Section 8.3, the probability that the analysis of a QC check standard will be required is high. In this case the QC check standard should be routinely analyzed with the spike sample.

8.4.1 Prepare the QC check standard by adding 1.0 mL of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 1 L of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standards to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 3. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $P-2\,s_p$ to $P+2\,s_p$. If P=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as gas chromatography with a dissimilar column, specific element detector, or mass spectrometer must be used. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 Grab samples must be collected in glass containers. Conventional sampling practices[11] should be followed, except that the bottle must not be prerinsed with sample before collection. Composite samples should be collected in refrigerated glass containers in accordance with the requirements of the program. Automatic sampling equipment must be as free as possible of Tygon tubing and other potential sources of contamination.

9.2 All samples must be iced or refrigerated at 4 °C from the time of collection until extraction. If the samples will not be extracted within 72 h of collection, the sample should be adjusted to a pH range of 5.0 to 9.0 with sodium hydroxide solution or sulfuric acid. Record the volume of acid or base used. If aldrin is to be determined, add sodium thiosulfate when residual chlorine is present. EPA Methods 330.4 and 330.5 may be used for measurement of residual chlorine.[12] Field test kits are available for this purpose.

9.3 All samples must be extracted within 7 days of collection and completely analyzed within 40 days of extraction.[2]

10. Sample Extraction

10.1 Mark the water meniscus on the side of the sample bottle for later determination of sample volume. Pour the entire sample into a 2–L separatory funnel.

10.2 Add 60 mL of methylene chloride to the sample bottle, seal, and shake 30 s to rinse the inner surface. Transfer the solvent to the separatory funnel and extract the sample by shaking the funnel for 2 min. with periodic venting to release excess pressure. Allow the organic layer to separate from the water phase for a minimum of 10 min. If the emulsion interface between layers is more than one-third the volume of the solvent layer, the analyst must employ mechanical techniques to complete the phase separation. The optium technique depends upon the sample, but may include stirring, filtration of the emulsion through glass wool, centrifugation, or other physical methods. Collect the methylene chloride extract in a 250–mL Erlenmeyer flask.

10.3 Add a second 60-mL volume of methylene chloride to the sample bottle and repeat the extraction procedure a second time, combining the extracts in the Erlenmeyer flask. Perform a third extraction in the same manner.

10.4 Assemble a Kuderna-Danish (K–D) concentrator by attaching a 10-mL concentrator tube to a 500-mL evaporative flask. Other concentration devices or techniques may be used in place of the K–D concentrator if the requirements of Section 8.2 are met.

10.5 Pour the combined extract through a solvent-rinsed drying column containing about 10 cm of anhydrous sodium sulfate, and collect the extract in the K–D concentrator. Rinse the Erlenmeyer flask and column with 20 to 30 mL of methylene chloride to complete the quantitative transfer.

10.6 Add one or two clean boiling chips to the evaporative flask and attach a three-ball Snyder column. Prewet the Snyder column by adding about 1 mL of methylene chloride to the top. Place the K–D apparatus on a hot water bath (60 to 65 °C) so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15 to 20 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches 1 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min.

10.7 Increase the temperature of the hot water bath to about 80 °C. Momeltarily remove the Snyder column, add 50 mL of hexane and a new boiling chip, and reattach the Snyder column. Concentrate the extract as in Section 10.6, except use hexane to prewet the column. The elapsed time of concentration should be 5 to 10 min.

10.8 Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1 to 2 mL of hexane. A 5-mL syringe is recommended for this operation. Stopper the concentrator tube and store refrigerated if further processing will not be performed immediately. If the extract will be stored longer than two days, it should be transferred to a Teflon-sealed screw-cap vial. If the sample extract requires no further cleanup, proceed with gas chromatographic analysis (Section 12). If the sample requires further cleanup, proceed to Section 11.

10.9 Determine the original sample volume by refilling the sample bottle to the mark and transferring the liquid to a 1000-mL graduated cylinder. Record the sample volume to the nearest 5 mL.

11. Cleanup and Separation

11.1 Cleanup procedures may not be necessary for a relatively clean sample matrix. If particular circumstances demand the use of a cleanup procedure, the analyst may use either procedure below or any other appropriate procedure. However, the analyst first must demonstrate that the requirements of Section 8.2 can be met using the method as revised to incorporate the cleanup procedure. The Florisil column allows for a select fractionation of the compounds and will eliminate polar interferences. Elemental sulfur, which interferes with the electron capture gas chromatography of certain pesticides, can be removed by the technique described in Section 11.3.

11.2 Florisil column cleanup:

11.2.1 Place a weight of Florisil (nominally 20 g) predetermined by calibration (Section 7.5), into a chromatographic column. Tap the column to settle the Florisil and add 1 to 2 cm of anhydrous sodium sulfate to the top.

11.2.2 Add 60 mL of hexane to wet and rinse the sodium sulfate and Florisil. Just prior to exposure of the sodium sulfate layer to the air, stop the elution of the hexane by closing the stopcock on the chromatographic column. Discard the eluate.

11.2.3 Adjust the sample extract volume to 10 mL with hexane and transfer it from the K–D concentrator tube onto the column. Rinse the tube twice with 1 to 2 mL of hexane, adding each rinse to the column.

11.2.4 Place a 500-mL K–D flask and clean concentrator tube under the chromatographic column. Drain the column into the flask until the sodium sulfate layer is nearly exposed. Elute the column with 200 mL of 6% ethyl ether in hexane (V/V) (Fraction 1) at a rate of about 5 mL/min. Remove the K–D flask and set it aside for later concentration. Elute the column again, using 200 mL of 15% ethyl ether in hexane (V/V) (Fraction 2), into a second K–D flask. Perform the third elution using 200 mL of 50% ethyl ether in hexane (V/V) (Fraction 3). The elution patterns for the pesticides and PCBs are shown in Table 2.

11.2.5 Concentrate the fractions as in Section 10.6, except use hexane to prewet the column and set the water bath at about 85 °C. When the apparatus is cool, remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with hexane. Adjust the volume of each fraction to 10 mL with hexane and analyze by gas chromatography (Section 12).

11.3 Elemental sulfur will usually elute entirely in Fraction 1 of the Florisil column cleanup. To remove sulfur interference from this fraction or the original extract, pipet 1.00 mL of the concentrated extract into a clean concentrator tube or Teflon-sealed vial. Add one to three drops of mercury and

seal.[13] Agitate the contents of the vial for 15 to 30 s. Prolonged shaking (2 h) may be required. If so, this may be accomplished with a reciprocal shaker. Alternatively, activated copper powder may be used for sulfur removal.[14] Analyze by gas chromatography.

12. Gas Chromatography

12.1 Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are retention times and MDL that can be achieved under these conditions. Examples of the separations achieved by Column 1 are shown in Figures 1 to 10. Other packed or capillary (open-tubular) columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met.

12.2 Calibrate the system daily as described in Section 7.

12.3 If the internal standard calibration procedure is being used, the internal standard must be added to the sample extract and mixed thoroughly immediately before injection into the gas chromatograph.

12.4 Inject 2 to 5 µL of the sample extract or standard into the gas chromatograph using the solvent-flush technique.[15] Smaller (1.0 uL) volumes may be injected if automatic devices are employed. Record the volume injected to the nearest 0.05 µL, the total extract volume, and the resulting peak size in area or peak height units.

12.5 Identify the parameters in the sample by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

12.6 If the response for a peak exceeds the working range of the system, dilute the extract and reanalyze.

12.7 If the measurement of the peak response is prevented by the presence of interferences, further cleanup is required.

13. Calculations

13.1 Determine the concentration of individual compounds in the sample.

13.1.1 If the external standard calibration procedure is used, calculate the amount of material injected from the peak response using the calibration curve or calibration factor determined in Section 7.2.2. The concentration in the sample can be calculated from Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A)(V_t)}{(V_i)(V_s)}$$

Equation 2

where:
A=Amount of material injected (ng).
V_i=Volume of extract injected (µL).
V_t=Volume of total extract (µL).
V_s=Volume of water extracted (mL).

13.1.2 If the internal standard calibration procedure is used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.3.2 and Equation 3.

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(I_s)}{(A_{is})(RF)(V_o)}$$

Equation 3

where:
A_s=Response for the parameter to be measured.
A_{is}=Response for the internal standard.
I_s=Amount of internal standard added to each extract (µg).
V_o=Volume of water extracted (L).

13.2 When it is apparent that two or more PCB (Aroclor) mixtures are present, the Webb and McCall procedure[16] may be used to identify and quantify the Aroclors.

13.3 For multicomponent mixtures (chlordane, toxaphene, and PCBs) match retention times of peaks in the standards with peaks in the sample. Quantitate every identifiable peak unless interference with individual peaks persist after cleanup. Add peak height or peak area of each identified peak in the chromatogram. Calculate as total response in the sample versus total response in the standard.

13.4 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

14. Method Performance

14.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentrations listed in Table 1 were obtained using reagent water.[17] Similar results were achieved using representative wastewaters. The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

14.2 This method has been tested for linearity of spike recovery from reagent water and has been demonstrated to be applicable over the concentration range from 4×MDL to 1000×MDL with the following exceptions: Chlordane recovery at 4×MDL was low (60%);

Toxaphene recovery was demonstrated linear over the range of 10×MDL to 1000×MDL.[17]

14.3 This method was tested by 20 laboratories using reagent water, drinking water, surface water, and three industrial wastewaters spiked at six concentrations.[18] Concentrations used in the study ranged from 0.5 to 30 µg/L for single-component pesticides and from 8.5 to 400 µg/L for multicomponent parameters. Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 4.

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TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention time (min)		Method detection limit (µg/L)
	Col. 1	Col. 2	
α-BHC	1.35	1.82	0.003
γ-BHC	1.70	2.13	0.004
β-BHC	1.90	1.97	0.006
Heptachlor	2.00	3.35	0.003
δ-BHC	2.15	2.20	0.009
Aldrin	2.40	4.10	0.004
Heptachlor epoxide	3.50	5.00	0.083
Endosulfan I	4.50	6.20	0.014

TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS—Continued

Parameter	Retention time (min)		Method detection limit (μg/L)
	Col. 1	Col. 2	
4,4′-DDE	5.13	7.15	0.004
Dieldrin	5.45	7.23	0.002
Endrin	6.55	8.10	0.006
4,4′-DDD	7.83	9.08	0.011
Endosulfan II	8.00	8.28	0.004
4,4′-DDT	9.40	11.75	0.012
Endrin aldehyde	11.82	9.30	0.023
Endosulfan sulfate	14.22	10.70	0.066
Chlordane	mr	mr	0.014
Toxaphene	mr	mr	0.24
PCB–1016	mr	mr	nd
PCB–1221	mr	mr	nd
PCB–1232	mt	mr	nd
PCB–1242	mr	mr	0.065
PCB–1248	mr	mr	nd
PCB–1254	mr	mr	nd
PCB–1260	mr	mr	nd

AColumn 1 conditions: Supelcoport (100/120 mesh) coated with 1.5% SP–2250/1.95% SP–2401 packed in a 1.8 m long × 4 mm ID glass column with 5% methane/95% argon carrier gas at 60 mL/min flow rate. Column temperature held isothermal at 200 °C, except for PCB–1016 through PCB–1248, should be measured at 160 °C.

AColumn 2 conditions: Supelcoport (100/120 mesh) coated with 3% OV–1 packed in a 1.8 m long × 4 mm ID glass column with 5% methane/95% argon carrier gas at 60 mL/min flow rate. Column temperature held isothermal at 200 °C for the pesticides; at 140 °C for PCB–1221 and 1232; and at 170 °C for PCB–1016 and 1242 to 1268.

Amr=Multiple peak response. See Figures 2 thru 10.

And=Not determined.

TABLE 2—DISTRIBUTION OF CHLORINATED PESTICIDES AND PCBS INTO FLORISIL COLUMN FRACTIONS 2

Parameter	Percent recovery by fraction[a]		
	1	2	3
Aldrin	100	.....	.....
α-BHC	100	.....	.....
β-BHC	97	.....	.....
δ-BHC	98	.....	.....
γ-BHC	100	.....	.....
Chlordane	100	.....	.....
4,4′–DDD	99	.....	.....
4,4′–DDE	98	.....	.....
4,4′–DDT	100	.....	.....
Dieldrin	0	100	.....
Endosulfan I	37	64	.....
Endosulfan II	0	7	91
Endosulfan sulfate	0	0	106
Endrin	4	96	.....
Endrin aldehyde	0	68	26
Heptachlor	100	.....	.....
Heptachlor epoxide	100	.....	.....
Toxaphene	96	.....	.....
PCB–1016	97	.....	.....
PCB–1221	97	.....	.....
PCB–1232	95	4	.....
PCB–1242	97	.....	.....
PCB–1248	103	.....	.....
PCB–1254	90	.....	.....
PCB–1260	95	.....	.....

[a] Eluant composition:
Fraction 1–6% ethyl ether in hexane.
Fraction 2–15% ethyl ether in hexane.
Fraction 3–50% ethyl ether in hexane.

TABLE 3—QC ACCEPTANCE CRITERIA—METHOD 608

Parameter	Test conc. (μg/L)	Limit for s (μg/L)	Range for X (μg/L)	Range for P, P_s(%)
Aldrin	2.0	0.42	1.08–2.24	42–122
α-BHC	2.0	0.48	0.98–2.44	37–134

TABLE 3—QC ACCEPTANCE CRITERIA—METHOD 608—Continued

Parameter	Test conc. (μg/L)	Limit for s (μg/L)	Range for X (μg/L)	Range for P, P_s(%)
β-BHC	2.0	0.64	0.78–2.60	17–147
δ-BHC	2.0	0.72	1.01–2.37	19–140
γ-BHC	2.0	0.46	0.86–2.32	32–127
Chlordane	50	10.0	27.6–54.3	45–119
4,4′–DDD	10	2.8	4.8–12.6	31–141
4,4′–DDE	2.0	0.55	1.08–2.60	30–145
4,4′–DDT	10	3.6	4.6–13.7	25–160
Dieldrin	2.0	0.76	1.15–2.49	36–146
Endosulfan I	2.0	0.49	1.14–2.82	45–153
Endosulfan II	10	6.1	2.2–17.1	D–202
Endosulfan Sulfate	10	2.7	3.8–13.2	26–144
Endrin	10	3.7	5.1–12.6	30–147
Heptachlor	2.0	0.40	0.86–2.00	34–111
Heptachlor epoxide	2.0	0.41	1.13–2.63	37–142
Toxaphene	50.0	12.7	27.8–55.6	41–126
PCB-1016	50	10.0	30.5–51.5	50–114
PCB-1221	50	24.4	22.1–75.2	15–178
PCB-1232	50	17.9	14.0–98.5	10–215
PCB-1242	50	12.2	24.8–69.6	39–150
PCB-1248	50	15.9	29.0–70.2	38–158
PCB-1254	50	13.8	22.2–57.9	29–131
PCB-1260	50	10.4	18.7–54.9	8–127

$\underline{s}$=Standard deviation of four recovery measurements, in μg/L (Section 8.2.4).
$\bar{X}$=Average recovery for four recovery measurements, in μg/L (Section 8.2.4).
P, P_s=Percent recovery measured (Section 8.3.2, Section 8.4.2).
D=Detected; result must be greater than zero.

NOTE: These criteria are based directly upon the method performance data in Table 4. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 4.

TABLE 4—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 608

Parameter	Accuracy, as recovery, X′ (μg/L)	Single analyst precision, s_r' (μg/L)	Overall precision, S′ (μg/L)
Aldrin	0.81C+0.04	$0.16\bar{X}-0.04$	$0.20\bar{X}-0.01$
α-BHC	0.84C+0.03	$0.13\bar{X}+0.04$	$0.23\bar{X}-0.00$
β-BHC	0.81C+0.07	$0.22\bar{X}-0.02$	$0.33\bar{X}-0.05$
δ-BHC	0.81C+0.07	$0.18\bar{X}+0.09$	$0.25\bar{X}+0.03$
γ-BHC	0.82C−0.05	$0.12\bar{X}+0.06$	$0.22\bar{X}+0.04$
Chlordane	0.82C−0.04	$0.13\bar{X}+0.13$	$0.18\bar{X}+0.18$
4,4′-DDD	0.84C+0.30	$0.20\bar{X}-0.18$	$0.27\bar{X}-0.14$
4,4′-DDE	0.85C+0.14	$0.13\bar{X}+0.06$	$0.28\bar{X}-0.09$
4,4′-DDT	0.93C−0.13	$0.17\bar{X}+0.39$	$0.31\bar{X}-0.21$
Dieldrin	0.90C+0.02	$0.12\bar{X}+0.19$	$0.16\bar{X}+0.16$
Endosulfan I	0.97C+0.04	$0.10\bar{X}+0.07$	$0.18\bar{X}+0.08$
Endosulfan II	0.93C+0.34	$0.41\bar{X}$—0.65	$0.47\bar{X}-0.20$
Endosulfan Sulfate	0.89C−0.37	$0.13\bar{X}+0.33$	$0.24\bar{X}+0.35$
Endrin	0.89C−0.04	$0.20\bar{X}+0.25$	$0.24\bar{X}+0.25$
Heptachlor	0.69C+0.04	$0.06\bar{X}+0.13$	$0.16\bar{X}+0.08$
Heptachlor epoxide	0.89C+0.10	$0.18\bar{X}-0.11$	$0.25\bar{X}-0.08$
Toxaphene	0.80C+1.74	$0.09\bar{X}+3.20$	$0.20\bar{X}+0.22$
PCB–1016	0.81C+0.50	$0.13\bar{X}+0.15$	$0.15\bar{X}+0.45$
PCB–1221	0.96C+0.65	$0.29\bar{X}-0.76$	$0.35\bar{X}-0.62$
PCB–1232	0.91C+10.79	$0.21\bar{X}-1.93$	$0.31\bar{X}+3.50$
PCB–1242	0.93C+0.70	$0.11\bar{X}+1.40$	$0.21\bar{X}+1.52$
PCB–1248	0.97C+1.06	$0.17\bar{X}+0.41$	$0.25\bar{X}-0.37$
PCB–1254	0.76C+2.07	$0.15\bar{X}+1.66$	$0.17\bar{X}+3.62$
PCB–1260	0.66C+3.76	$0.22\bar{X}-2.37$	$0.39\bar{X}-4.86$

X′=Expected recovery for one or more measurements of a sample containing a concentration of C, in μg/L.
s_r'=Expected single analyst standard deviation of measurements at an average concentration found of $\bar{X}$, in μg/L.
S′=Expected interlaboratory standard deviation of measurements at an average concentration found of $\bar{X}$, in μg/L.
$\underline{C}$=True value for the concentration, in μg/L.
$\bar{X}$=Average recovery found for measurements of samples containing a concentration of C, in μg/L.

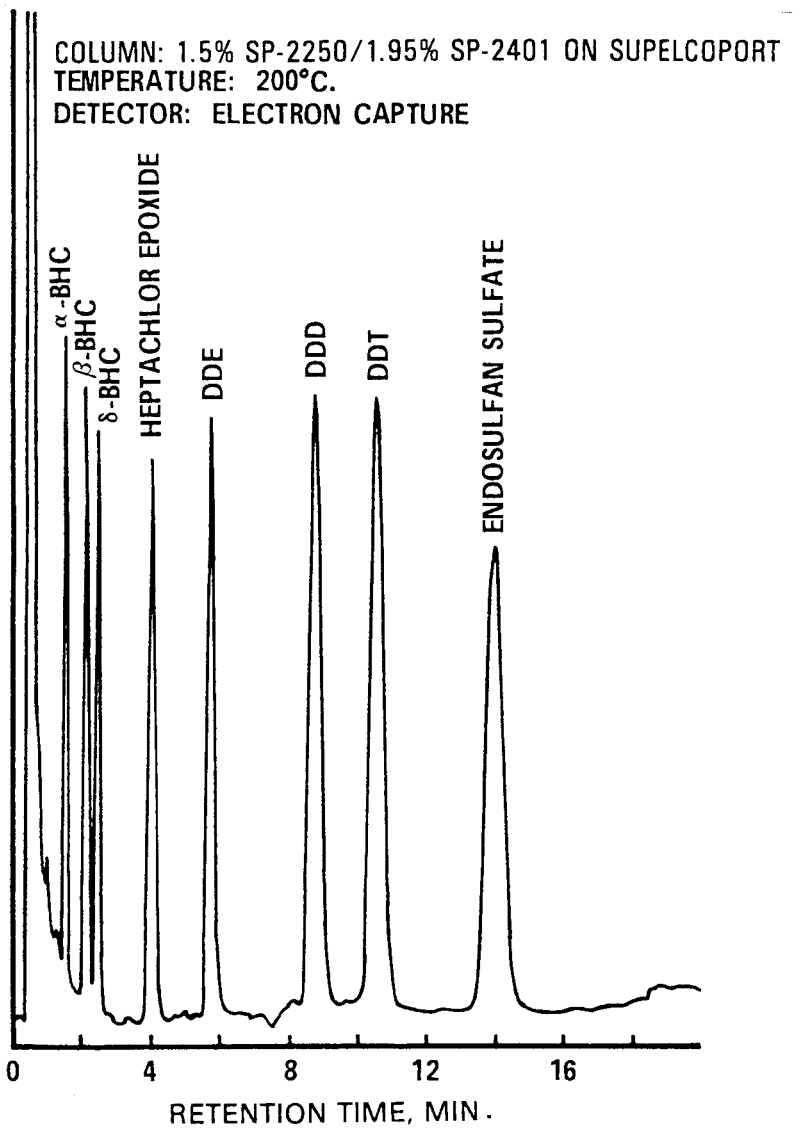

Figure 1. Gas chromatogram of pesticides.

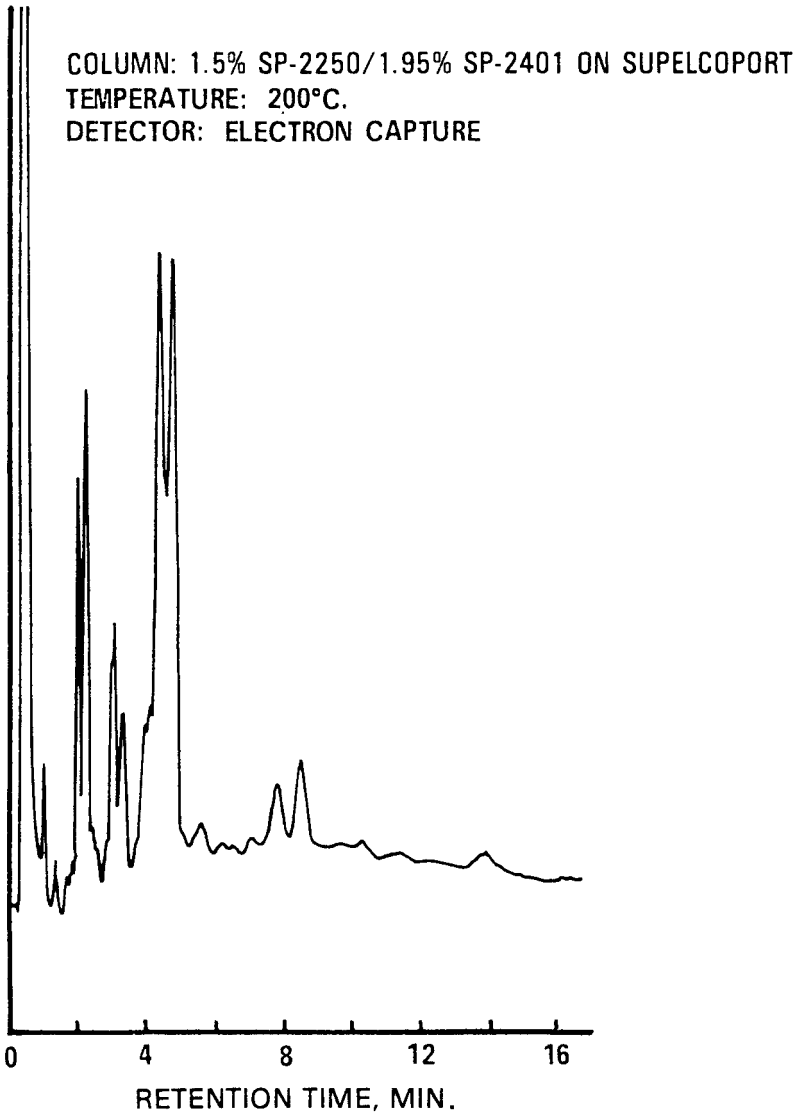

Figure 2. Gas chromatogram of chlordane.

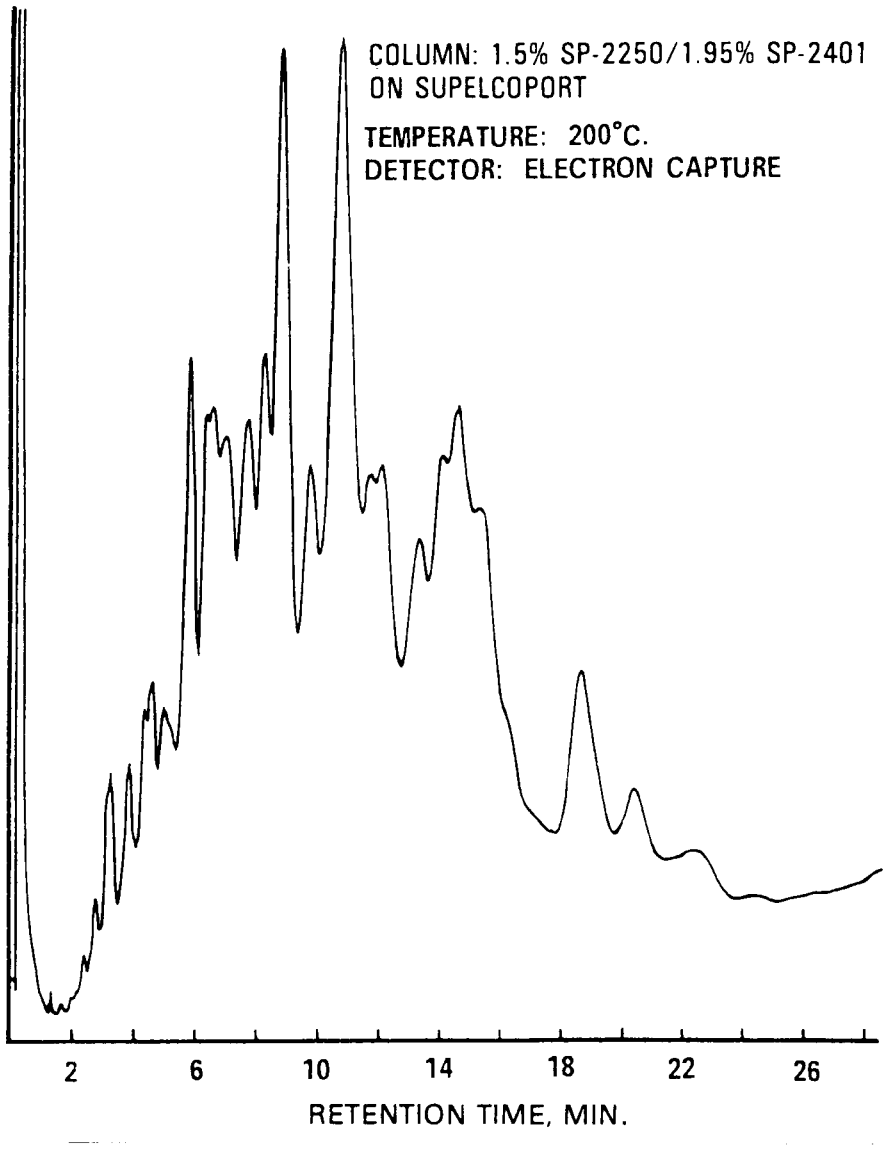

Figure 3. Gas chromatogram of toxaphene.

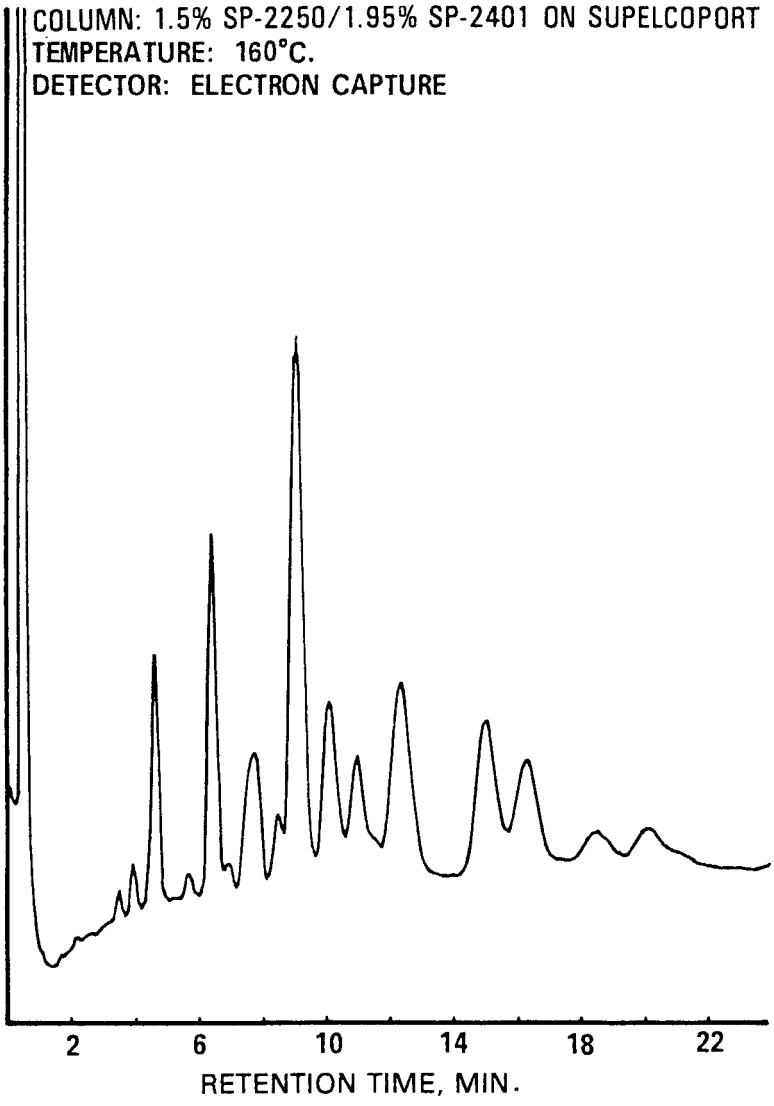

Figure 4. Gas chromatogram of PCB-1016.

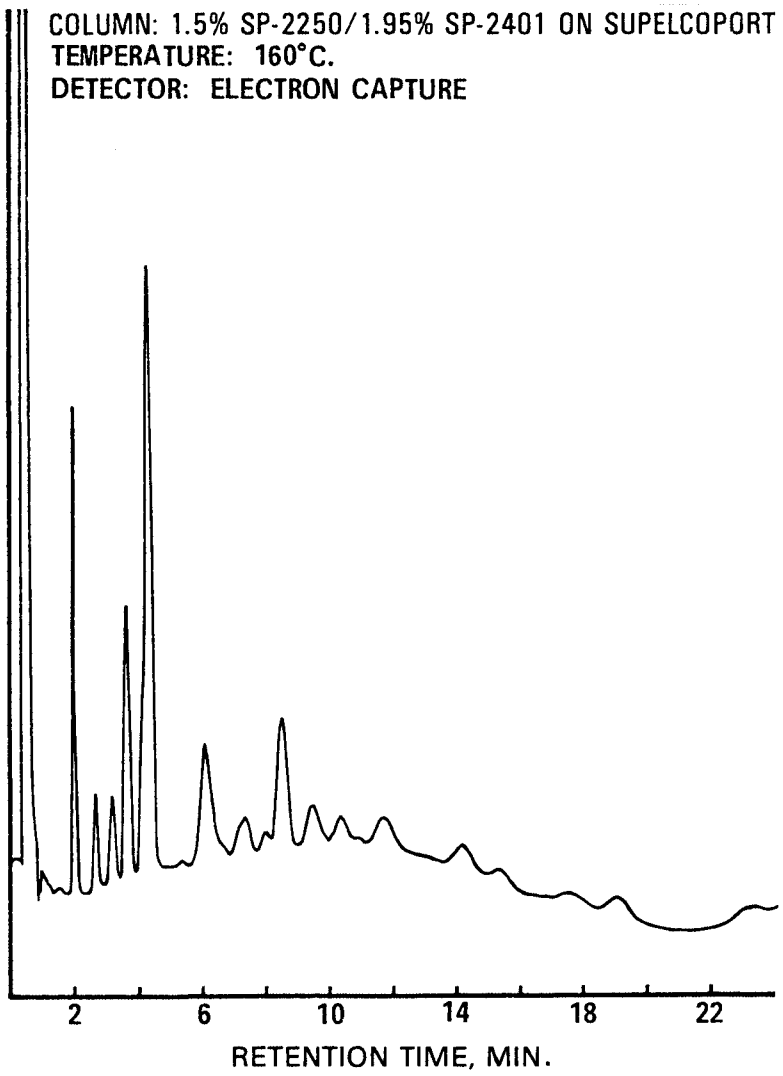

Figure 5. Gas chromatogram of PCB-1221.

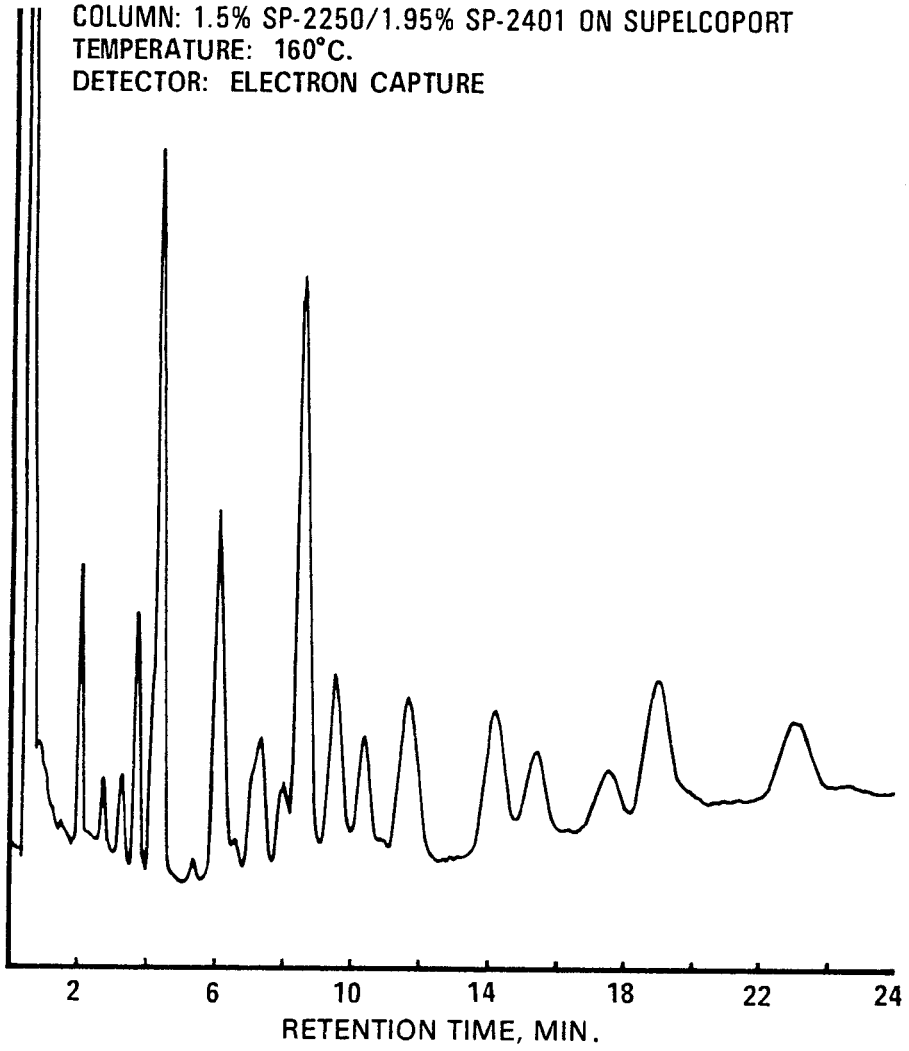

Figure 6. Gas chromatogram of PCB-1232.

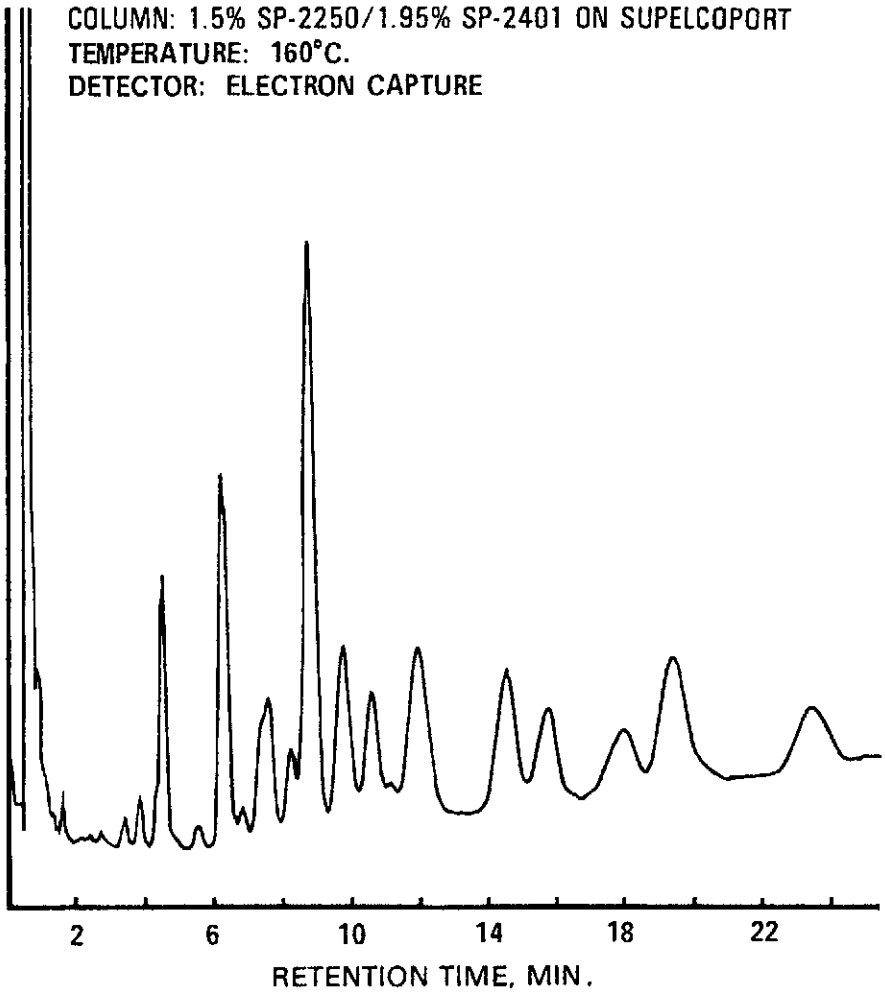

Figure 7. Gas chromatogram of PCB-1242.

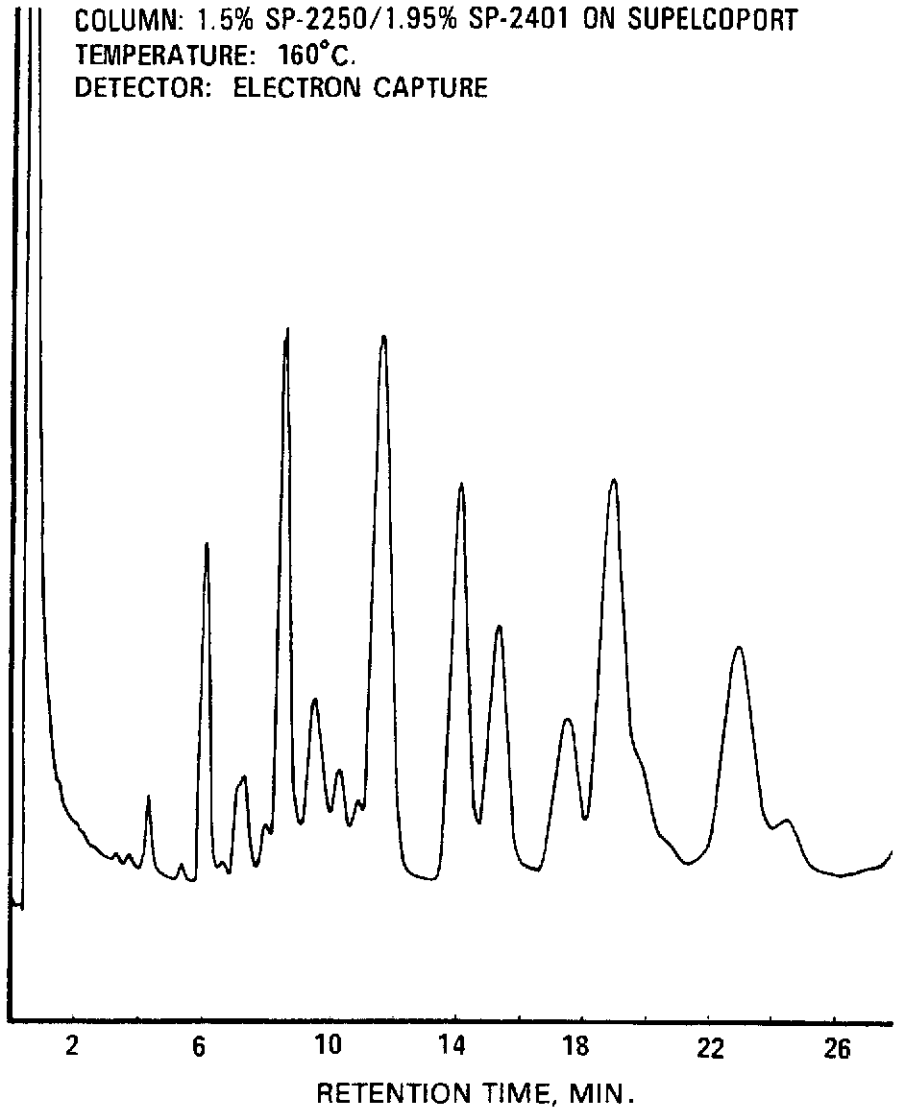

Figure 8. Gas chromatogram of PCB-1248.

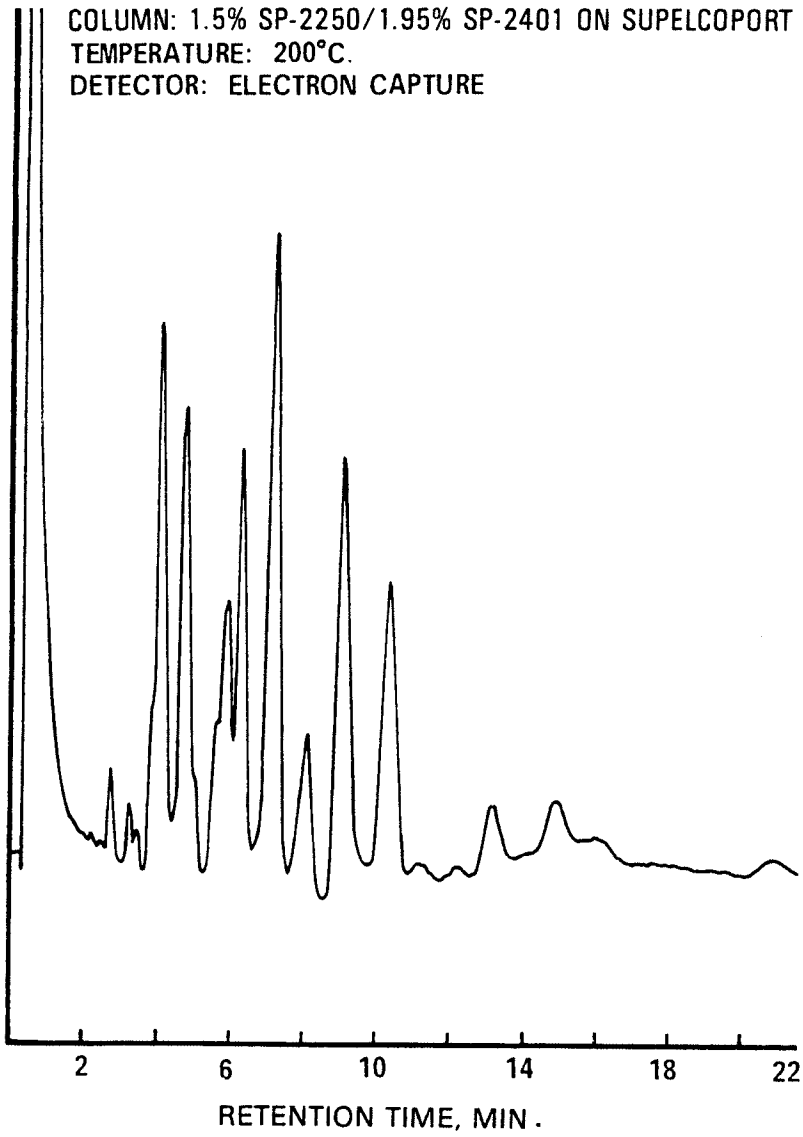

Figure 9. Gas chromatogram of PCB-1254.

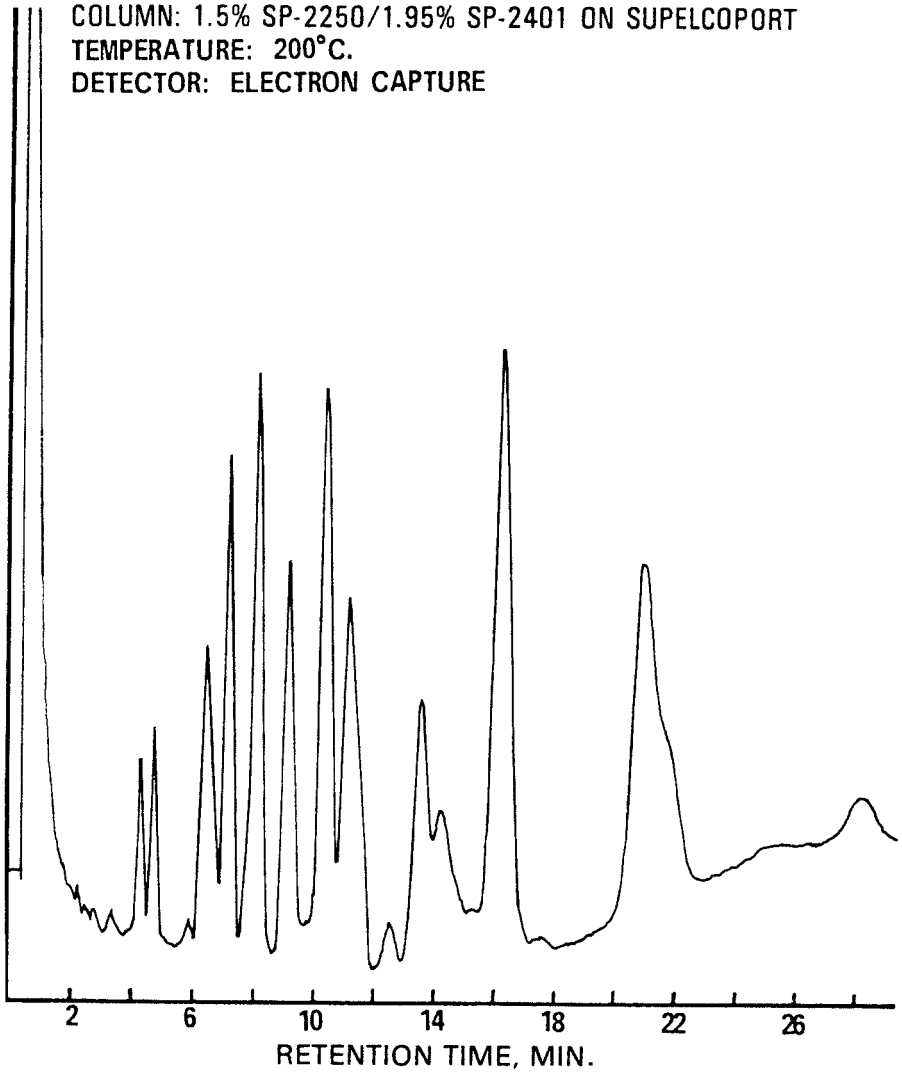

Figure 10. Gas chromatogram of PCB-1260.

METHOD 609—NITROAROMATICS AND ISOPHORONE

1. Scope and Application

1.1 This method covers the determination of certain nitroaromatics and isophorone. The following parameters may be determined by this method:

Parameter	STORET No.	CAS No.
2,4-Dinitrotoluene	34611	121–14–2
2,6-Dinitrotoluene	34626	606–20–2
Isophorone	34408	78–59–1
Nitrobenzene	34447	98–95–3

1.2 This is a gas chromatographic (GC) method applicable to the determination of

the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for any or all of the compounds above, compound identifications should be supported by at least one additional qualitative technique. This method describes analytical conditions for a second gas chromatographic column that can be used to confirm measurements made with the primary column. Method 625 provides gas chromatograph/mass spectrometer (GC/MS) conditions appropriate for the qualitative and quantitative confirmation of results for all of the parameters listed above, using the extract produced by this method.

1.3 The method detection limit (MDL, defined in Section 14.1)[1] for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.4 The sample extraction and concentration steps in this method are essentially the same as in Methods 606, 608, 611, and 612. Thus, a single sample may be extracted to measure the parameters included in the scope of each of these methods. When cleanup is required, the concentration levels must be high enough to permit selecting aliquots, as necessary, to apply appropriate cleanup procedures. The analyst is allowed the latitude, under Section 12, to select chromatographic conditions appropriate for the simultaneous measurement of combinations of these parameters.

1.5 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.6 This method is restricted to use by or under the supervision of analysts experienced in the use of a gas chromatograph and in the interpretation of gas chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 A measured volume of sample, approximately 1–L, is extracted with methylene chloride using a separatory funnel. The methylene chloride extract is dried and exchanged to hexane during concentration to a volume of 10 mL or less. Isophorone and nitrobenzene are measured by flame ionization detector gas chromatography (FIDGC). The dinitrotoluenes are measured by electron capture detector gas chromatography (ECDGC).[2]

2.2 The method provides a Florisil column cleanup procedure to aid in the elimination of interferences that may be encountered.

3. Interferences

3.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that lead to discrete artifacts and/or elevated baseliles in gas chromatograms. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3.

3.1.1 Glassware must be scrupulously cleaned.[3] Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. Solvent rinsing should be followed by detergent washing with hot water, and rinses with tap water and distilled water. The glassware should then be drained dry, and heated in a muffle furnace at 400 °C for 15 to 30 min. Some thermally stable materials, such as PCBs, may not be eliminated by this treatment. Solvent rinses with acetone and pesticide quality hexane may be substituted for the muffle furnace heating. Thorough rinsing with such solvents usually eliminates PCB interference. Volumetric ware should not be heated in a muffle furnace. After drying and cooling, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Store inverted or capped with aluminum foil.

3.1.2 The use of high purity reagents and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

3.2 Matrix interferences may be caused by contaminants that are co-extracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature and diversity of the industrial complex or municipality being sampled. The cleanup procedure in Section 11 can be used to overcome many of these interferences, but unique samples may require additional cleanup approaches to achieve the MDL listed in Table 1.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified[4-6] for the information of the analyst.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete or composite sampling.

5.1.1 Grab sample bottle—1–L or 1-qt, amber glass, fitted with a screw cap lined with Teflon. Foil may be substituted for Teflon if the sample is not corrosive. If amber bottles are not available, protect samples from light. The bottle and cap liner must be washed, rinsed with acetone or methylene chloride, and dried before use to minimize contamination.

5.1.2 Automatic sampler (optional)—The sampler must incorporate glass sample containers for the collection of a minimum of 250 mL of sample. Sample containers must be kept refrigerated at 4°C and protected from light during compositing. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used. Before use, however, the compressible tubing should be thoroughly rinsed with methanol, followed by repeated rinsings with distilled water to minimize the potential for contamination of the sample. An integrating flow meter is required to collect flow proportional composites.

5.2 Glassware (All specifications are suggested. Catalog numbers are included for illustration only.):

5.2.1 Separatory funnel—2–L, with Teflon stopcock.

5.2.2 Drying column—Chromatographic column, approximately 400 mm long × 19 mm ID, with coarse frit filter disc.

5.2.3 Chromatographic column—100 mm long × 10 mm ID, with Teflon stopcock.

5.2.4 Concentrator tube, Kuderna-Danish—10-mL, graduated (Kontes K–570050–1025 or equivalent). Calibration must be checked at the volumes employed in the test. Ground glass stopper is used to prevent evaporation of extracts.

5.2.5 Evaporative flask, Kuderna-Danish—500-mL (Kontes K–570001–0500 or equivalent). Attach to concentrator tube with springs.

5.2.6 Snyder column, Kuderna-Danish—Three-ball macro (Kontes K–503000–0121 or equivalent).

5.2.7 Snyder column, Kuderna-Danish—Two-ball micro (Kontes K–569001–0219 or equivalent).

5.2.8 Vials—10 to 15-mL, amber glass, with Teflon-lined screw cap.

5.3 Boiling chips—Approximately 10/40 mesh. Heat to 400°C for 30 min or Soxhlet extract with methylene chloride.

5.4 Water bath—Heated, with concentric ring cover, capable of temperature control (±2°C). The bath should be used in a hood.

5.5 Balance—Analytical, capable of accurately weighing 0.0001 g.

5.6 Gas chromatograph—An analytical system complete with gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, gases, detector, and strip-chart recorder. A data system is recommended for measuring peak areas.

5.6.1 Column 1—1.2 m long × 2 or 4 mm ID glass, packed with 1.95% QF–1/1.5% OV–17 on Gas-Chrom Q (80/100 mesh) or equivalent. This column was used to develop the method performance statements given in Section 14. Guidelines for the use of alternate column packings are provided in Section 12.1.

5.6.2 Column 2—3.0 m long × 2 or 4 mm ID glass, packed with 3% OV–101 on Gas-Chrom Q (80/100 mesh) or equivalent.

5.6.3 Detectors—Flame ionization and electron capture detectors. The flame ionization detector (FID) is used when determining isophorone and nitrobenzene. The electron capture detector (ECD) is used when determining the dinitrotoluenes. Both detectors have proven effective in the analysis of wastewaters and were used in develop the method performance statements in Section 14. Guidelines for the use to alternate detectors are provided in Section 12.1.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.2 Sodium hydroxide solution (10 N)—Dissolve 40 g of NaOH (ACS) in reagent water and dilute to 100 mL.

6.3 Sulfuric acid (1+1)—Slowly, add 50 mL of H_2SO_4 (ACS, sp. gr. 1.84) to 50 mL of reagent water.

6.4 Acetone, hexane, methanol, methylene chloride—Pesticide quality or equivalent.

6.5 Sodium sulfate—(ACS) Granular, anhydrous. Purify by heating at 400 °C for 4 h in a shallow tray.

6.6 Florisil—PR grade (60/100 mesh). Purchase activated at 1250 °F and store in dark in glass containers with ground glass stoppers or foil-lined screw caps. Before use, activate each batch at least 16 h at 200 °C in a foil-covered glass container and allow to cool.

6.7 Stock standard solutions (1.00 µg/µL)—Stock standard solutions can be prepared from pure standard materials or purchased as certified solutions.

6.7.1 Prepare stock standard solutions by accurately weighing about 0.0100 g of pure material. Dissolve the material in hexane and dilute to volume in a 10-mL volumetric flask. Larger volumes can be used at the convenience of the analyst. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the manufacturer or by an independent source.

6.7.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles.

Store at 4 °C and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.7.3 Stock standard solutions must be replaced after six months, or sooner if comparison with check standards indicates a problem.

6.8 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Establish gas chromatographic operating conditions equivalent to those given in Table 1. The gas chromatographic system can be calibrated using the external standard technique (Section 7.2) or the internal standard technique (Section 7.3).

7.2 External standard calibration procedure:

7.2.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask and diluting to volume with hexane. One of the external standards should be at a concentration near, but above, the MDL (Table 1) and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.2.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against the mass injected. The results can be used to prepare a calibration curve for each compound. Alternatively, if the ratio of response to amount injected (calibration factor) is a constant over the working range (<10% relative standard deviation, RSD) linearity through the origin can be assumed and the average ratio or calibration factor can be used in place of a calibration curve.

7.3 Internal standard calibration procedure—To use this approach, the analyst must select one or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Because of these limitations, no internal standard can be suggested that is applicable to all samples.

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flash. To each calibration standard, add a known constant amount of one or more internal standards, and dilute to volume with hexane. One of the standards should be at a concentration near, but above, the MDL and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.3.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against concentration for each compound and internal standard. Calculate response factors (RF) for each compound using Equation 1.

Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

C_{is}=Concentration of the internal standard (µg/L).

C_s=Concentration of the parameter to be measured (µg/L).

If the RF value over the working range is a constant (<10% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.4 The working calibration curve, calibration factor, or RF must be verified on each working day by the measurement of one or more calibration standards. If the response for any parameter varies from the predicted response by more than ±15%, a new calibration curve must be prepared for that compound.

7.5 Before using any cleanup procedure, the analyst must process a series of calibration standards through the procedure to validate elution patterns and the absence of interferences from the reagents.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to

generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Sections 10.4, 11.1, and 12.1) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Before processing any samples, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system and glassware are under control. Each time a set of samples is extracted or reagents are changed, a reagent water blank must be processed as a safeguard against laboratory contamination.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1,5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing each parameter of interest in acetone at a concentration of 20 µg/mL for each dinitrotoluene and 100 µg/mL for isophorone and nitrobenzene. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Using a pipet, prepare QC check samples at the test concentrations shown in Table 2 by adding 1.00 mL of QC check sample concentrate to each of four 1–L aliquots of reagent water.

8.2.3 Analyze the well-mixed QC check samples according to the method beginning in Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 2. If s and $\bar{X}$ for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual $\bar{X}$ falls outside the range for accuracy, the system performance is unacceptable for that parameter. Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.2.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spiked sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at the test concentration in Section 8.2.2 or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.3 If it is impractical to determile background levels before spiking (e.g., maximum holding times will be exceeded), the spike concentration should be (1) the regulatory concentration limit, if any; or, if none (2) the larger of either 5 times higher than the expected background concentration or the test concentration in Section 8.2.2.

8.3.2 Analyze one sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second sample aliquot with 1.0 mL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100 (A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 2. These acceptance criteria were calculated to include an allowance for error in measurement

of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[7] If spiking was performed at a concentration lower than the test concentration in Section 8.2.2, the analyst must use either the QC acceptance criteria in Table 2, or optional QC acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recovery of a parameter: (1) Calculate accuracy (X′) using the equation in Table 3, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 3, substituting X′ for X8; (3) calculate the range for recovery at the spike concentration as (100 X′/T) ±2.44 (100 S′/T)%.[7]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4. If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory.

8.4.1 Prepare the QC check standard by adding 1.0 mL of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 1 L of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 2. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $\bar{P}-2s_p$ to $\bar{P}+2s_p$. If P=90% and s_p = 10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as gas chromatography with a dissimilar column, specific element detector, or mass spectrometer must be used. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 Grab samples must be collected in glass containers. Conventional sampling practices[8] should be followed, except that the bottle must not be prerinsed with sample before collection. Composite samples should be collected in refrigerated glass containers in accordance with the requirements of the program. Automatic sampling equipment must be as free as possible of Tygon tubing and other potential sources of contamination.

9.2 All samples must be iced or refrigerated at 4 °C from the time of collection until extraction.

9.3 All samples must be extracted within 7 days of collection and completely analyzed within 40 days of extraction.[2]

10. Sample Extraction

10.1 Mark the water meniscus on the side of the sample bottle for later determination of sample volume. Pour the entire sample into a 2–L separatory funnel. Check the pH of the sample with wide-range pH paper and adjust to within the range of 5 to 9 with sodium hydroxide solution or sulfuric acid.

10.2 Add 60 mL of methylene chloride to the sample bottle, seal, and shake 30 s to rinse the inner surface. Transfer the solvent to the separatory funnel and extract the sample by shaking the funnel for 2 min. with periodic venting to release excess pressure. Allow the organic layer to separate from the water phase for a minimum of 10 min. If the emulsion interface between layers is more than one-third the volume of the solvent layer, the analyst must employ mechanical techniques to complete the phase separation. The optimum technique depends upon the sample, but may include stirring, filtration

of the emulsion through glass wool, centrifugation, or other physical methods. Collect the methylene chloride extract in a 250-mL Erlenmeyer flask.

10.3 Add a second 60-mL volume of methylene chloride to the sample bottle and repeat the extraction procedure a second time, combining the extracts in the Erlenmeyer flask. Perform a third extraction in the same manner.

10.4 Assemble a Kuderna-Danish (K–D) concentrator by attaching a 10-mL concentrator tube to a 500-mL evaporative flask. Other concentration devices or techniques may be used in place of the K–D concentrator if the requirements of Section 8.2 are met.

10.5 Pour the combined extract through a solvent-rinsed drying column containing about 10 cm of anhydrous sodium sulfate, and collect the extract in the K–D concentrator. Rinse the Erlenmeyer flask and column with 20 to 30 mL of methylene chloride to complete the quantitative transfer.

10.6 Sections 10.7 and 10.8 describe a procedure for exchanging the methylene chloride solvent to hexane while concentrating the extract volume to 1.0 mL. When it is not necessary to achieve the MDL in Table 2, the solvent exchange may be made by the addition of 50 mL of hexane and concentration to 10 mL as described in Method 606, Sections 10.7 and 10.8.

10.7 Add one or two clean boiling chips to the evaporative flask and attach a three-ball Snyder column. Prewet the Snyder column by adding about 1 mL of methylene chloride to the top. Place the K–D apparatus on a hot water bath (60 to 65 °C) so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15 to 20 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches 1 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min.

10.8 Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1 to 2 mL of methylene chloride. A 5-mL syringe is recommended for this operation. Add 1 to 2 mL of hexane and a clean boiling chip to the concentrator tube and attach a two-ball micro-Snyder column. Prewet the column by adding about 0.5 mL of hexane to the top. Place the micro-K–D apparatus on a hot water bath (60 to 65 °C) so that the concentrator tube is partially immersed in the hot water. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 5 to 10 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood. When the apparent volume of liquid reaches 0.5 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min.

10.9 Remove the micro-Snyder column and rinse its lower joint into the concentrator tube with a minimum amount of hexane. Adjust the extract volume to 1.0 mL. Stopper the concentrator tube and store refrigerated if further processing will not be performed immediately. If the extract will be stored longer than two days, it should be transferred to a Teflon-sealed screw-cap vial. If the sample extract requires no further cleanup, proceed with gas chromatographic analysis (Section 12). If the sample requires further cleanup, proceed to Section 11.

10.10 Determine the original sample volume by refilling the sample bottle to the mark and transferring the liquid to a 1000-mL graduated cylinder. Record the sample volume to the nearest 5 mL.

11. Cleanup and Separation

11.1 Cleanup procedures may not be necessary for a relatively clean sample matrix. If particular circumstances demand the use of a cleanup procedure, the analyst may use the procedure below or any other appropriate procedure. However, the analyst first must demonstrate that the requirements of Section 8.2 can be met using the method as revised to incorporate the cleanup procedure.

11.2 Florisil column cleanup:

11.2.1 Prepare a slurry of 10 g of activated Florisil in methylene chloride/hexane (1+9)(V/V) and place the Florisil into a chromatographic column. Tap the column to settle the Florisil and add 1 cm of anhydrous sodium sulfate to the top. Adjust the elution rate to about 2 mL/min.

11.2.2 Just prior to exposure of the sodium sulfate layer to the air, quantitatively transfer the sample extract onto the column using an additional 2 mL of hexane to complete the transfer. Just prior to exposure of the sodium sulfate layer to the air, add 30 mL of methylene chloride/hexane (1 + 9)(V/V) and continue the elution of the column. Discard the eluate.

11.2.3 Next, elute the column with 30 mL of acetone/methylene chloride (1 + 9)(V/V) into a 500-mL K–D flask equipped with a 10-mL concentrator tube. Concentrate the collected fraction as in Sections 10.6, 10.7, 10.8, and 10.9 including the solvent exchange to 1 mL of hexane. This fraction should contain the nitroaromatics and isophorone. Analyze by gas chromatography (Section 12).

12. Gas Chromatography

12.1 Isophorone and nitrobenzene are analyzed by injection of a portion of the extract into an FIDGC. The dinitrotoluenes are analyzed by a separate injection into an ECDGC.

Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are retention times and MDL that can be achieved under these conditions. Examples of the separations achieved by Column 1 are shown in Figures 1 and 2. Other packed or capillary (open-tubular) columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met.

12.2 Calibrate the system daily as described in Section 7.

12.3 If the internal standard calibration procedure is being used, the internal standard must be added to the same extract and mixed thoroughly immediately before injection into the gas chromatograph.

12.4 Inject 2 to 5 µL of the sample extract or standard into the gas chromatograph using the solvent-flush technique.[9] Smaller (1.0 µL) volumes may be injected if automatic devices are employed. Record the volume injected to the nearest 0.05 µL, the total extract volume, and the resulting peak size in area or peak height units.

12.5 Identify the parameters in the sample by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

12.6 If the response for a peak exceeds the working range of the system, dilute the extract and reanalyze.

12.7 If the measurement of the peak response is prevented by the presence of interferences, further cleanup is required.

13. Calculations

13.1 Determine the concentration of individual compounds in the sample.

13.1.1 If the external standard calibration procedure is used, calculate the amount of material injected from the peak response using the calibration curve or calibration factor determined in Section 7.2.2. The concentration in the sample can be calculated from Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A)(V_t)}{(V_i)(V_s)}$$

Equation 2

where:
A=Amount of material injected (ng).
V_i=Volume of extract injected (µL).
V_t=Volume of total extract (µL).
V_s=Volume of water extracted (mL).

13.1.2 If the internal standard calibration procedure is used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.3.2 and Equation 3.

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(I_s)}{(A_{is})(RF)(V_o)}$$

Equation 3

where:
A_s=Response for the parameter to be measured.
A_{is}=Response for the internal standard.
I_s=Amount of internal standard added to each extract (µg).
V_o=Volume of water extracted (L).

13.2 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

14. Method Performance

14.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentrations listed in Table 1 were obtained using reagent water.[10] Similar results were achieved using representative wastewaters. The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

14.2 This method has been tested for linearity of spike recovery from reagent water and has been demonstrated to be applicable over the concentration range from 7×MDL to 1000×MDL.[10]

14.3 This method was tested by 18 laboratories using reagent water, drinking water, surface water, and three industrial wastewaters spiked at six concentrations over the range 1.0 to 515 µg/L.[11] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 3.

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TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention time (min)		Method detection limit (μg/L)	
	Col. 1	Col. 2	ECDGC	FIDGC
Nitrobenzene	3.31	4.31	13.7	3.6
2,6-Dinitrotoluene	3.52	4.75	0.01	–
Isophorone	4.49	5.72	15.7	5.7
2,4-Dinitrotoluene	5.35	6.54	0.02	–

AAColumn 1 conditions: Gas-Chrom Q (80/100 mesh) coated with 1.95% QF–1/1.5% OV–17 packed in a 1.2 m long × 2 mm or 4 mm ID glass column. A 2 mm ID column and nitrogen carrier gas at 44 mL/min flow rate were used when determining isophorone and nitrobenzene by FIDGC. The column temperature was held isothermal at 85 °C. A 4 mm ID column and 10% methane/90% argon carrier gas at 44 mL/min flow rate were used when determining the dinitrotoluenes by ECDGC. The column temperature was held isothermal at 145 °C.

AAColumn 2 conditions: Gas-Chrom Q (80/100 mesh) coated with 3% OV–101 packed in a 3.0 m long × 2 mm or 4 mm ID glass column. A 2 mm ID column and nitrogen carrier gas at 44 mL/min flow rate were used when determining isophorone and nitrobenzene by FIDGC. The column temperature was held isothermal at 100 °C. A 4 mm ID column and 10% methane/90% argon carrier gas at 44 mL/min flow rate were used when determining the dinitrotoluenes by ECDGC. The column temperature was held isothermal at 150 °C.

TABLE 2—QC ACCEPTANCE CRITERIA—METHOD 609

Parameter	Test Conc. (μg/L)	Limit for s (μg/L)	Range for $\bar{X}$ (μg/L)	Range for P, P_s (%)
2,4-Dinitrotoluene	20	5.1	3.6–22.8	6–125
2,6-Dinitrotoluene	20	4.8	3.8–23.0	8–126
Isophorone	100	32.3	8.0–100.0	D–117
Nitrobenzene	100	33.3	25.7–100.0	6–118

s=Standard deviation of four recovery measurements, in μg/L (Section 8.2.4).
X=Average recovery for four recovery measurements, in μg/L (Section 8.2.4).
P, P_s=Percent recovery measured (Section 8.3.2, Section 8.4.2).
D=Detected; result must be greater than zero.

NOTE: These criteria are based directly upon the method performance data in Table 3. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 3.

TABLE 3—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 609

Parameter	Accuracy, as recovery, X′ (μg/L)	Single analyst precision, s_r' (μg/L)	Overall precision, S′ (μg/L)
2,4-Dinitrotoluene	0.65C+0.22	$0.20\bar{X}+0.08$	$0.37\bar{X}-0.07$
2,6-Dinitrotoluene	0.66C+0.20	$0.19\bar{X}+0.06$	$0.36\bar{X}-0.00$
Isophorone	0.49C+2.93	$0.28\bar{X}+2.77$	$0.46\bar{X}+0.31$
Nitrobenzene	0.60C+2.00	$0.25\bar{X}+2.53$	$0.37\bar{X}-0.78$

X′=Expected recovery for one or more measurements of a sample containing a concentration of C, in μg/L.
s_r'=Expected single analyst standard deviation of measurements at an average concentration found of $\bar{X}$, in μg/L.
S′=Expected interlaboratory standard deviation of measurements at an average concentration found of $\bar{X}$, in μg/L.
C=True value for the concentration, in μg/L.
X=Average recovery found for measurements of samples containing a concentration of C, in μg/L.

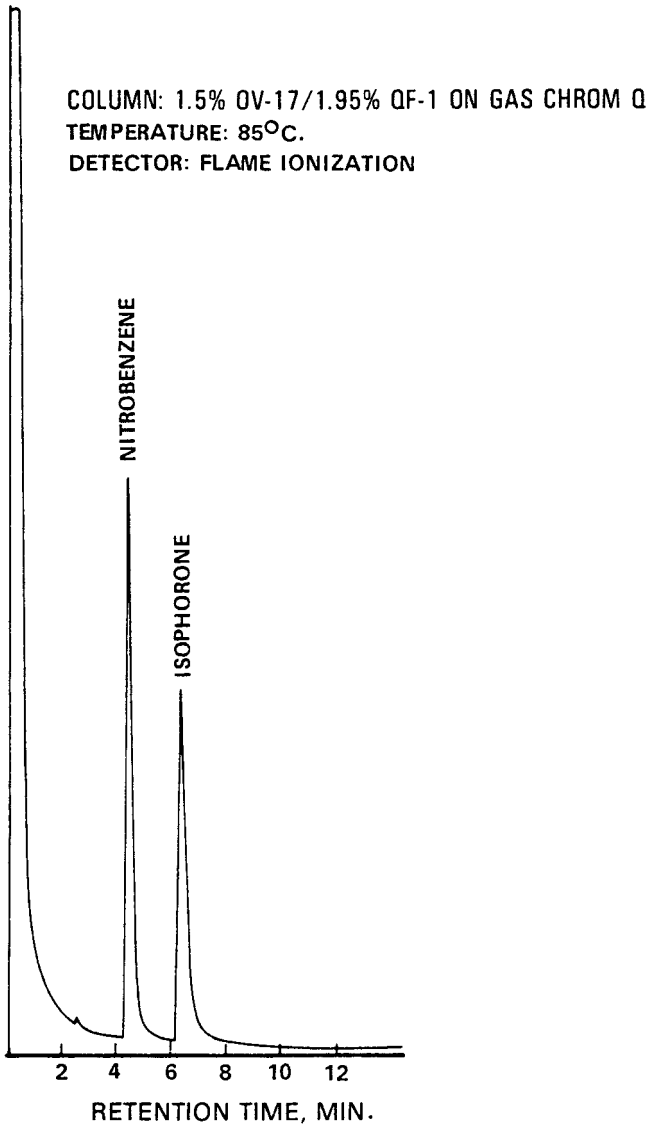

Figure 1. Gas chromatogram of nitrobenzene and isophorone.

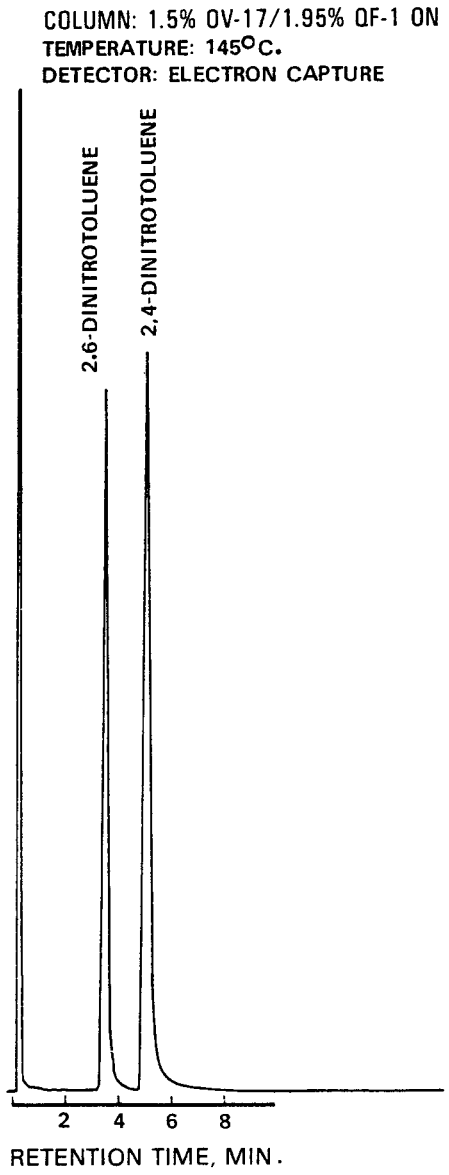

Figure 2. Gas chromatogram of dinitrotoluenes.

METHOD 610—POLYNUCLEAR AROMATIC HYDROCARBONS

1. Scope and Application

1.1 This method covers the determination of certain polynuclear aromatic hydrocarbons (PAH). The following parameters can be determined by this method:

Parameter	STORET No.	CAS No.
Acenaphthene	34205	83–32–9
Acenaphthylene	34200	208–96–8
Anthracene	34220	120–12–7
Benzo(a)anthracene	34526	56–55–3
Benzo(a)pyrene	34247	50–32–8
Benzo(b)fluoranthene	34230	205–99–2
Benzo(ghi)perylene	34521	191–24–2
Benzo(k)fluoranthene	34242	207–08–9
Chrysene	34320	218–01–9
Dibenzo(a,h)anthracene	34556	53–70–3
Fluoranthene	34376	206–44–0
Fluorene	34381	86–73–7
Indeno(1,2,3-cd)pyrene	34403	193–39–5
Naphthalene	34696	91–20–3
Phenanthrene	34461	85–01–8
Pyrene	34469	129–00–0

1.2 This is a chromatographic method applicable to the determination of the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for any or all of the compounds above, compound identifications should be supported by at least one additional qualitative technique. Method 625 provides gas chromatograph/mass spectrometer (GC/MS) conditions appropriate for the qualitative and quantitative confirmation of results for many of the parameters listed above, using the extract produced by this method.

1.3 This method provides for both high performance liquid chromatographic (HPLC) and gas chromatographic (GC) approaches for the determination of PAHs. The gas chromatographic procedure does not adequately resolve the following four pairs of compounds: Anthracene and phenanthrene; chrysene and benzo(a)anthracene; benzo(b)fluoranthene and benzo(k)fluoranthene; and dibenzo(a,h) anthracene and indeno (1,2,3-cd)pyrene. Unless the purpose for the analysis can be served by reporting the sum of an unresolved pair, the liquid chromatographic approach must be used for these compounds. The liquid chromatographic method does resolve all 16 of the PAHs listed.

1.4 The method detection limit (MDL, defined in Section 15.1)[1] for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.5 The sample extraction and concentration steps in this method are essentially the same as in Methods 606, 608, 609, 611, and 612. Thus, a single sample may be extracted to measure the parameters included in the scope of each of these methods. When cleanup is required, the concentration levels must be high enough to permit selecting aliquots, as necessary, to apply appropriate cleanup procedures. Selection of the aliquots must be made prior to the solvent exchange steps of this method. The analyst is allowed the latitude, under Sections 12 and 13, to select chromatographic conditions appropriate for the simultaneous measurement of combinations of these parameters.

1.6 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.7 This method is restricted to use by or under the supervision of analysts experienced in the use of HPLC and GC systems and in the interpretation of liquid and gas chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 A measured volume of sample, approximately 1–L, is extracted with methylene chloride using a separatory funnel. The methylene chloride extract is dried and concentrated to a volume of 10 mL or less. The extract is then separated by HPLC or GC. Ultraviolet (UV) and fluorescence detectors are used with HPLC to identify and measure the PAHs. A flame ionization detector is used with GC.[2]

2.2 The method provides a silica gel column cleanup procedure to aid in the elimination of interferences that may be encountered.

3. Interferences

3.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardward that lead to discrete artifacts and/or elevated baselines in the chromatograms. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3.

3.1.1 Glassware must be scrupulously cleaned.[3] Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. Solvent rinsing should be followed by detergent washing with hot water, and rinses with tap water and distilled water. The glassware should then be drained dry, and heated in a muffle furnace at 400 °C for 15 to 30 min. Some thermally stable materials, such as PCBs, may not be eliminated by this treatment. Solvent rinses with acetone and pesticide quality hexane may be

substituted for the muffle furnace heating. Thorough rinsing with such solvents usually eliminates PCB interference. Volumetric ware should not be heated in a muffle furnace. After drying and cooling, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Store inverted or capped with aluminum foil.

3.1.2 The use of high purity reagents and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

3.2 Matrix interferences may be caused by contaminants that are co-extracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature and diversity of the industrial complex or municipality being sampled. The cleanup procedure in Section 11 can be used to overcome many of these interferences, but unique samples may require additional cleanup approaches to achieve the MDL listed in Table 1.

3.3 The extent of interferences that may be encountered using liquid chromatographic techniques has not been fully assessed. Although the HPLC conditions described allow for a unique resolution of the specific PAH compounds covered by this method, other PAH compounds may interfere.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method have not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified[4-6] for the information of the analyst.

4.2 The following parameters covered by this method have been tentatively classified as known or suspected, human or mammalian carcinogens: benzo(a)anthracene, benzo(a)pyrene, and dibenzo(a,h)-anthracene. Primary standards of these toxic compounds should be prepared in a hood. A NIOSH/MESA approved toxic gas respirator should be worn when the analyst handles high concentrations of these toxic compounds.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete or composite sampling.

5.1.1 Grab sample bottle—1–L or 1-qt, amber glass, fitted with a screw cap lined with Teflon. Foil may be substituted for Teflon if the sample is not corrosive. If amber bottles are not available, protect samples from light. The bottle and cap liner must be washed, rinsed with acetone or methylene chloride, and dried before use to minimize contamination.

5.1.2 Automatic sampler (optional)—The sampler must incorporate glass sample containers for the collection of a minimum of 250 mL of sample. Sample containers must be kept refrigerated at 4°C and protected from light during compositing. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used. Before use, however, the compressible tubing should be thoroughly rinsed with methanol, followed by repeated rinsings with distilled water to minimize the potential for contamination of the sample. An integrating flow meter is required to collect flow proportional composites.

5.2 Glassware (All specifications are suggested. Catalog numbers are included for illustration only.):

5.2.1 Separatory funnel—2–L, with Teflon stopcock.

5.2.2 Drying column—Chromatographic column, approximately 400 mm long × 19 mm ID, with coarse frit filter disc.

5.2.3 Concentrator tube, Kuderna-Danish—10-mL, graduated (Kontes K–570050–1025 or equivalent). Calibration must be checked at the volumes employed in the test. Ground glass stopper is used to prevent evaporation of extracts.

5.2.4 Evaporative flask, Kuderna-Danish—500-mL (Kontes K–570001–0500 or equivalent). Attach to concentrator tube with springs.

5.2.5 Snyder column, Kuderna-Danish—Three-ball macro (Kontes K–503000–0121 or equivalent).

5.2.6 Snyder column, Kuderna-Danish—Two-ball micro (Kontes K–569001–0219 or equivalent).

5.2.7 Vials—10 to 15-mL, amber glass, with Teflon-lined screw cap.

5.2.8 Chromatographic column—250 mm long × 10 mm ID, with coarse frit filter disc at bottom and Teflon stopcock.

5.3 Boiling chips—Approximately 10/40 mesh. Heat to 400 °C for 30 min or Soxhlet extract with methylene chloride.

5.4 Water bath—Heated, with concentric ring cover, capable of temperature control (±2 °C). The bath should be used in a hood.

5.5 Balance—Analytical, capable of accurately weighing 0.0001 g.

5.6 High performance liquid chromatograph (HPLC)—An analytical system complete with column supplies, high pressure syringes, detectors, and compatible strip-chart recorder. A data system is recommended for measuring peak areas and retention times.

5.6.1 Gradient pumping system—Constant flow.

5.6.2 Reverse phase column—HC–ODS Sil-X, 5 micron particle diameter, in a 25 cm × 2.6 mm ID stainless steel column (Perkin Elmer No. 089–0716 or equivalent). This column was used to develop the method performance statements in Section 15. Guidelines for the use of alternate column packings are provided in Section 12.2.

5.6.3 Detectors—Fluorescence and/or UV detectors. The fluorescence detector is used for excitation at 280 nm and emission greater than 389 nm cutoff (Corning 3–75 or equivalent). Fluorometers should have dispersive optics for excitation and can utilize either filter or dispersive optics at the emission detector. The UV detector is used at 254 nm and should be coupled to the fluorescence detector. These detectors were used to develop the method performance statements in Section 15. Guidelines for the use of alternate detectors are provided in Section 12.2.

5.7 Gas chromatograph—An analytical system complete with temperature programmable gas chromatograph suitable for on-column or splitless injection and all required accessories including syringes, analytical columns, gases, detector, and strip-chart recorder. A data system is recommended for measuring peak areas.

5.7.1 Column—1.8 m long × 2 mm ID glass, packed with 3% OV–17 on Chromosorb W–AW–DCMS (100/120 mesh) or equivalent. This column was used to develop the retention time data in Table 2. Guidelines for the use of alternate column packings are provided in Section 13.3.

5.7.2 Detector—Flame ionization detector. This detector has proven effective in the analysis of wastewaters for the parameters listed in the scope (Section 1.1), excluding the four pairs of unresolved compounds listed in Section 1.3. Guidelines for the use of alternate detectors are provided in Section 13.3.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.2 Sodium thiosulfate—(ACS) Granular.

6.3 Cyclohexane, methanol, acetone, methylene chloride, pentane—Pesticide quality or equivalent.

6.4 Acetonitrile—HPLC quality, distilled in glass.

6.5 Sodium sulfate—(ACS) Granular, anhydrous. Purify by heating at 400 °C for 4 h in a shallow tray.

6.6 Silica gel—100/200 mesh, desiccant, Davison, grade-923 or equivalent. Before use, activate for at least 16 h at 130 °C in a shallow glass tray, loosely covered with foil.

6.7 Stock standard solutions (1.00 µg/µL)—Stock standard solutions can be prepared from pure standard materials or purchased as certified solutions.

6.7.1 Prepare stock standard solutions by accurately weighing about 0.0100 g of pure material. Dissolve the material in acetonitrile and dilute to volume in a 10-mL volumetric flask. Larger volumes can be used at the convenience of the analyst. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the manufacturer or by an independent source.

6.7.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4 °C and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.7.3 Stock standard solutions must be replaced after six months, or sooner if comparison with check standards indicates a problem.

6.8 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Establish liquid or gas chromatographic operating conditions equivalent to those given in Table 1 or 2. The chromatographic system can be calibrated using the external standard technique (Section 7.2) or the internal standard technique (Section 7.3).

7.2 External standard calibration procedure:

7.2.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask and diluting to volume with acetonitrile. One of the external standards should be at a concentration near, but above, the MDL (Table 1) and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.2.2 Using injections of 5 to 25 µL for HPLC and 2 to 5 µL for GC, analyze each calibration standard according to Section 12 or 13, as appropriate. Tabulate peak height or area responses against the mass injected. The results can be used to prepare a calibration curve for each compound. Alternatively, if the ratio of response to amount injected (calibration factor) is a constant over the working range (<10% relative standard deviation, RSD), linearity through the origin can be assumed and the average ratio or calibration factor can be used in place of a calibration curve.

7.3 Internal standard calibration procedure—To use this approach, the analyst must select one or more internal standards that are similar in analytical behavior to the

compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Because of these limitations, no internal standard can be suggested that is applicable to all samples.

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask. To each calibration standard, add a known constant amount of one or more internal standards, and dilute to volume with acetonitrile. One of the standards should be at a concentration near, but above, the MDL and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.3.2 Using injections of 5 to 25 µL for HPLC and 2 to 5 µL for GC, analyze each calibration standard according to Section 12 or 13, as appropriate. Tabulate peak height or area responses against concentration for each compound and internal standard. Calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

C_{is}=Concentration of the internal standard (µg/L).

C_s=Concentration of the parameter to be measured (µg/L).

If the RF value over the working range is a constant (<10% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.4 The working calibration curve, calibration factor, or RF must be verified on each working day by the measurement of one or more calibration standards. If the response for any parameter varies from the predicted response by more than ±15%, the test must be repeated using a fresh calibration standard. Alternatively, a new calibration curve must be prepared for that compound.

7.5 Before using any cleanup procedure, the analyst must process a series of calibration standards through the procedure to validate elution patterns and the absence of interferences from the reagents.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Sections 10.4, 11.1, 12.2, and 13.3) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Before processing any samples the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system and glassware are under control. Each time a set of samples is extracted or reagents are changed a reagent water blank must be processed as a safeguard against laboratory contamination.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing each parameter of interest at the following concentrations in acetonitrile: 100 µg/mL of any

of the six early-eluting PAHs (naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene); 5 µg/mL of benzo(k)fluoranthene; and 10 µg/mL of any of the other PAHs. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Using a pipet, prepare QC check samples at the test concentrations shown in Table 3 by adding 1.00 mL of QC check sample concentrate to each of four 1–L aliquots of reagent water.

8.2.3 Analyze the well-mixed QC check samples according to the method beginning in Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 3. If s and $\bar{X}$ for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual X falls outside the range for accuracy, the system performance is unacceptable for that parameter.

NOTE: The large number of parameters in Table 3 present a substantial probability that one or more will fail at least one of the acceptance criteria when all parameters are analyzed.

8.2.6 When one or more of the parameters tested fail at least one of the acceptance criteria, the analyst must proceed according to Section 8.2.6.1 or 8.2.6.2.

8.2.6.1 Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.2.

8.2.6.2 Beginning with Section 8.2.2, repeat the test only for those parameters that failed to meet criteria. Repeated failure, however, will confirm a general problem with the measurement system. If this occurs, locate and correct the source of the problem and repeat the test for all compounds of interest beginning with Section 8.2.2.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spiked sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at the test concentration in Section 8.2.2 or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.3 If it is impractical to determine background levels before spiking (e.g., maximum holding times will be exceeded), the spike concentration should be (1) the regulatory concentration limit, if any; or, if none, (2) the larger of either 5 times higher than the expected background concentration or the test concentration in Section 8.2.2.

8.3.2 Analyze one sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second sample aliquot with 1.0 mL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100 (A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 3. These acceptance criteria were calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[7] If spiking was performed at a concentration lower than the test concentration in Section 8.2.2, the analyst must use either the QC acceptance criteria in Table 3, or optional QC acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recovery of a parameter: (1) Calculate accuracy (X′) using the equation in Table 4, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 4, substituting X′ for X; (3) calculate the range for recovery at the spike concentration as (100 X′/T)±2.44(100 S′/T)%.[7]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter

that failed the critiera must be analyzed as described in Section 8.4.

8.4 If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory. If the entire list of parameters in Table 3 must be measured in the sample in Section 8.3, the probability that the analysis of a QC check standard will be required is high. In this case the QC check standard should be routinely analyzed with the spike sample.

8.4.1 Prepare the QC check standard by adding 1.0 mL of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 1 L of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 3. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $P-2s_p$ to $P+2s_p$. If P=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as gas chromatography with a dissimilar column, specific element detector, or mass spectrometer must be used. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 Grab samples must be collected in glass containers. Conventional sampling practices[8] should be followed, except that the bottle must not be prerinsed with sample before collection. Composite samples should be collected in refrigerated glass containers in accordance with the requirements of the program. Automatic sampling equipment must be as free as possible of Tygon tubing and other potential sources of contamination.

9.2 All samples must be iced or refrigerated at 4°C from the time of collection until extraction. PAHs are known to be light sensitive; therefore, samples, extracts, and standards should be stored in amber or foil-wrapped bottles in order to minimize photolytic decomposition. Fill the sample bottles and, if residual chlorine is present, add 80 mg of sodium thiosulfate per liter of sample and mix well. EPA Methods 330.4 and 330.5 may be used for measurement of residual chlorine.[9] Field test kits are available for this purpose.

9.3 All samples must be extracted within 7 days of collection and completely analyzed within 40 days of extraction.[2]

10. Sample Extraction

10.1 Mark the water meniscus on the side of the sample bottle for later determination of sample volume. Pour the entire sample into a 2–L separatory funnel.

10.2 Add 60 mL of methylene chloride to the sample bottle, seal, and shake 30 s to rinse the inner surface. Transfer the solvent to the separatory funnel and extract the sample by shaking the funnel for 2 min. with periodic venting to release excess pressure. Allow the organic layer to separate from the water phase for a minimum of 10 min. If the emulsion interface between layers is more than one-third the volume of the solvent layer, the analyst must employ mechanical techniques to complete the phase separation. The optimum technique depends upon the sample, but may include stirring, filtration of the emulsion through glass wool, centrifugation, or other physical methods. Collect the methylene chloride extract in a 250–mL Erlenmeyer flask.

10.3 Add a second 60-mL volume of methylene chloride to the sample bottle and repeat the extraction procedure a second time, combining the extracts in the Erlenmeyer flask. Perform a third extraction in the same manner.

10.4 Assemble a Kuderna-Danish (K–D) concentrator by attaching a 10-mL concentrator tube to a 500-mL evaporative flask. Other concentration devices or techniques may be used in place of the K–D concentrator if the requirements of Section 8.2 are met.

10.5 Pour the combined extract through a solvent-rinsed drying column containing about 10 cm of anhydrous sodium sulfate, and collect the extract in the K–D concentrator. Rinse the Erlenmeyer flask and column with 20 to 30 mL of methylene chloride to complete the quantitative transfer.

10.6 Add one or two clean boiling chips to the evaporative flask and attach a three-ball Snyder column. Prewet the Snyder column by adding about 1 mL of methylene chloride to the top. Place the K–D apparatus on a hot water bath (60 to 65 °C) so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15 to 20 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches 1 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min.

10.7 Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1 to 2 mL of methylene chloride. A 5-mL syringe is recommended for this operation. Stopper the concentrator tube and store refrigerated if further processing will not be performed immediately. If the extract will be stored longer than two days, it should be transferred to a Teflon-sealed screw-cap vial and protected from light. If the sample extract requires no further cleanup, proceed with gas or liquid chromatographic analysis (Section 12 or 13). If the sample requires further cleanup, proceed to Section 11.

10.8 Determine the original sample volume by refilling the sample bottle to the mark and transferring the liquid to a 1000-mL graduated cylinder. Record the sample volume to the nearest 5 mL.

11. Cleanup and Separation

11.1 Cleanup procedures may not be necessary for a relatively clean sample matrix. If particular circumstances demand the use of a cleanup procedure, the analyst may use the procedure below or any other appropriate procedure. However, the analyst first must demonstrate that the requirements of Section 8.2 can be met using the methods as revised to incorporate the cleanup procedure.

11.2 Before the silica gel cleanup technique can be utilized, the extract solvent must be exchanged to cyclohexane. Add 1 to 10 mL of the sample extract (in methylene chloride) and a boiling chip to a clean K–D concentrator tube. Add 4 mL of cyclohexane and attach a two-ball micro-Snyder column. Prewet the column by adding 0.5 mL of methylene chloride to the top. Place the micro-K–D apparatus on a boiling (100 °C) water bath so that the concentrator tube is partially immersed in the hot water. Adjust the vertical position of the apparatus and the water temperature as required to complete concentration in 5 to 10 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood. When the apparent volume of the liquid reaches 0.5 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min. Remove the micro-Snyder column and rinse its lower joint into the concentrator tube with a minimum amount of cyclohexane. Adjust the extract volume to about 2 mL.

11.3 Silica gel column cleanup for PAHs:

11.3.1 Prepare a slurry of 10 g of activiated silica gel in methylene chloride and place this into a 10-mm ID chromatographic column. Tap the column to settle the silica gel and elute the methylene chloride. Add 1 to 2 cm of anhydrous sodium sulfate to the top of the silica gel.

11.3.2 Preelute the column with 40 mL of pentane. The rate for all elutions should be about 2 mL/min. Discard the eluate and just prior to exposure of the sodium sulfate layer to the air, transfer the 2-mL cyclohexane sample extract onto the column using an additional 2 mL cyclohexane to complete the transfer. Just prior to exposure of the sodium sulfate layer to the air, add 25 mL of pentane and continue the elution of the column. Discard this pentane eluate.

11.3.3 Next, elute the column with 25 mL of methylene chloride/pentane (4+6)(V/V) into a 500-mL K–D flask equipped with a 10-mL concentrator tube. Concentrate the collected fraction to less than 10 mL as in Section 10.6. When the apparatus is cool, remove the Snyder column and rinse the flask and its lower joint with pentane. Proceed with HPLC or GC analysis.

12. High Performance Liquid Chromatography

12.1 To the extract in the concentrator tube, add 4 mL of acetonitrile and a new boiling chip, then attach a two-ball micro-Snyder column. Concentrate the solvent as in Section 10.6, except set the water bath at 95 to 100 °C. When the apparatus is cool, remove the micro-Snyder column and rinse its lower joint into the concentrator tube with about 0.2 mL of acetonitrile. Adjust the extract volume to 1.0 mL.

12.2 Table 1 summarizes the recommended operating conditions for the HPLC. Included in this table are retention times, capacity factors, and MDL that can be achieved under

these conditions. The UV detector is recommended for the determination of naphthalene, acenaphthylene, acenapthene, and fluorene and the fluorescence detector is recommended for the remaining PAHs. Examples of the separations achieved by this HPLC column are shown in Figures 1 and 2. Other HPLC columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met.

12.3 Calibrate the system daily as described in Section 7.

12.4 If the internal standard calibration procedure is being used, the internal standard must be added to the sample extract and mixed thoroughly immediately before injection into the instrument.

12.5 Inject 5 to 25 µL of the sample extract or standard into the HPLC using a high pressure syringe or a constant volume sample injection loop. Record the volume injected to the nearest 0.1 µL, and the resulting peak size in area or peak height units. Re-equilibrate the HPLC column at the initial gradient conditions for at least 10 min between injections.

12.6 Identify the parameters in the sample by comparing the retention time of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

12.7 If the response for a peak exceeds the working range of the system, dilute the extract with acetonitrile and reanalyze.

12.8 If the measurement of the peak response is prevented by the presence of interferences, further cleanup is required.

13. Gas Chromatography

13.1 The packed column GC procedure will not resolve certain isomeric pairs as indicated in Section 1.3 and Table 2. The liquid chromatographic procedure (Section 12) must be used for these parameters.

13.2 To achieve maximum sensitivity with this method, the extract must be concentrated to 1.0 mL. Add a clean boiling chip to the methylene chloride extract in the concentrator tube. Attach a two-ball micro-Snyder column. Prewet the micro-Snyder column by adding about 0.5 mL of methylene chloride to the top. Place the micro-K–D apparatus on a hot water bath (60 to 65 °C) so that the concentrator tube is partially immersed in the hot water. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 5 to 10 min. At the proper rate of distillation the balls will actively chatter but the chambers will not flood. When the apparent volume of liquid reaches 0.5 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min. Remove the micro-Snyder column and rinse its lower joint into the concentrator tube with a minimum amount of methylene chloride. Adjust the final volume to 1.0 mL and stopper the concentrator tube.

13.3 Table 2 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are retention times that were obtained under these conditions. An example of the separations achieved by this column is shown in Figure 3. Other packed or capillary (open-tubular) columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met.

13.4 Calibrate the gas chromatographic system daily as described in Section 7.

13.5 If the internal standard calibration procedure is being used, the internal standard must be added to the sample extract and mixed thoroughly immediately before injection into the gas chromatograph.

13.6 Inject 2 to 5 µL of the sample extract or standard into the gas chromatograph using the solvent-flush technique.[10] Smaller (1.0 µL) volumes may be injected if automatic devices are employed. Record the volume injected to the nearest 0.05 µL, and the resulting peak size in area or peak height units.

13.7 Identify the parameters in the sample by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

13.8 If the response for a peak exceeds the working range of the system, dilute the extract and reanalyze.

13.9 If the measurement of the peak response is prevented by the presence of interferences, further cleanup is required.

14. Calculations

14.1 Determine the concentration of individual compounds in the sample.

14.1.1 If the external standard calibration procedure is used, calculate the amount of material injected from the peak response using the calibration curve or calibration factor determined in Section 7.2.2. The concentration in the sample can be calculated from Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A)(V_t)}{(V_i)(V_s)}$$

Equation 2

where:
A=Amount of material injected (ng).
V_i=Volume of extract injected (µL).
V_t=Volume of total extract (µL).
V_s=Volume of water extracted (mL).

13.1.2 If the internal standard calibration procedure is used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.3.2 and Equation 3.

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(I_s)}{(A_{is})(RF)(V_o)}$$

Equation 3

where:
A_s=Response for the parameter to be measured.
A_{is}=Response for the internal standard.
I_s=Amount of internal standard added to each extract (µg).
V_o=Volume of water extracted (L).

14.2 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

15. Method Performance

15.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentrations listed in Table 1 were obtained using reagent water.[11] Similar results were achieved using representative wastewaters. MDL for the GC approach were not determined. The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

15.2 This method has been tested for linearity of spike recovery from reagent water and has been demonstrated to be applicable over the concentration range from 8 × MDL to 800 × MDL[11] with the following exception: benzo(ghi)perylene recovery at 80 × and 800 × MDL were low (35% and 45%, respectively).

15.3 This method was tested by 16 laboratories using reagent water, drinking water, surface water, and three industrial wastewaters spiked at six concentrations over the range 0.1 to 425 µg/L.[12] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 4.

References

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TABLE 1—HIGH PERFORMANCE LIQUID CHROMATOGRAPHY CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention time (min)	Column capacity factor (k')	Method detection limit (µg/L)[a]
Naphthalene	16.6	12.2	1.8
Acenaphthylene	18.5	13.7	2.3
Acenaphthene	20.5	15.2	1.8
Fluorene	21.2	15.8	0.21
Phenanthrene	22.1	16.6	0.64
Anthracene	23.4	17.6	0.66
Fluoranthene	24.5	18.5	0.21
Pyrene	25.4	19.1	0.27
Benzo(a)anthracene	28.5	21.6	0.013
Chrysene	29.3	22.2	0.15
Benzo(b)fluoranthene	31.6	24.0	0.018
Benzo(k)fluoranthene	32.9	25.1	0.017
Benzo(a)pyrene	33.9	25.9	0.023
Dibenzo(a,h)anthracene	35.7	27.4	0.030
Benzo(ghi)perylene	36.3	27.8	0.076
Indeno(1,2,3-cd)pyrene	37.4	28.7	0.043

AAAHPLC column conditions: Reverse phase HC–ODS Sil–X, 5 micron particle size, in a 25 cm × 2.6 mm ID stainless steel column. Isocratic elution for 5 min. using acetonitrile/water (4+6), then linear gradient elution to 100% acetonitrile over 25 min. at 0.5 mL/min flow rate. If columns having other internal diameters are used, the flow rate should be adjusted to maintain a linear velocity of 2 mm/sec.

[a] The MDL for naphthalene, acenaphthylene, acenaphthene, and fluorene were determined using a UV detector. All others were determined using a fluorescence detector.

TABLE 2—GAS CHROMATOGRAPHIC CONDITIONS AND RETENTION TIMES

Parameter	Retention time (min)
Naphthalene	4.5
Acenaphthylene	10.4
Acenaphthene	10.8
Fluorene	12.6
Phenanthrene	15.9
Anthracene	15.9
Fluoranthene	19.8
Pyrene	20.6
Benzo(a)anthracene	24.7
Chrysene	24.7
Benzo(b)fluoranthene	28.0
Benzo(k)fluoranthene	28.0
Benzo(a)pyrene	29.4
Dibenzo(a,h)anthracene	36.2
Indeno(1,2,3-cd)pyrene	36.2
Benzo(ghi)perylene	38.6

GC Column conditions: Chromosorb W–AW–DCMS (100/120 mesh) coated with 3% OV–17 packed in a 1.8 × 2 mm ID glass column with nitrogen carrier gas at 40 mL/min. flow rate. Column temperature was held at 100 °C for 4 min., then programmed at 8 °C/min. to a final hold at 280 °C.

TABLE 3—QC ACCEPTANCE CRITERIA—METHOD 610

Parameter	Test conc. (µg/L)	Limit for s (µg/L)	Range for $\bar{X}$ (µg/L)	Range for P, P_s (%)
Acenaphthene	100	40.3	D–105.7	D–124
Acenaphthylene	100	45.1	22.1–112.1	D–139
Anthracene	100	28.7	11.2–112.3	D–126
Benzo(a)anthracene	10	4.0	3.1–11.6	12–135
Benzo(a)pyrene	10	4.0	0.2–11.0	D–128
Benzo(b)fluor-anthene	10	3.1	1.8–13.8	6–150
Benzo(ghi)perylene	10	2.3	D–10.7	D–116
Benzo(k)fluo-ranthene	5	2.5	D–7.0	D–159
Chrysene	10	4.2	D–17.5	D–199
Dibenzo(a,h)an-thracene	10	2.0	0.3–10.0	D–110
Fluoranthene	10	3.0	2.7–11.1	14–123
Fluorene	100	43.0	D–119	D–142
Indeno(1,2,3–cd)pyrene	10	3.0	1.2–10.0	D–116
Naphthalene	100	40.7	21.5–100.0	D–122
Phenanthrene	100	37.7	8.4–133.7	D–155
Pyrene	10	3.4	1.4–12.1	D–140

s=Standard deviation of four recovery measurements, in µg/L (Section 8.2.4).
X=Average recovery for four recovery measurements, in µg/L (Section 8.2.4).
P, P_s=Percent recovery measured (Section 8.3.2, Section 8.4.2).
D=Detected; result must be greater than zero.

NOTE: These criteria are based directly upon the method performance data in Table 4. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 4.

TABLE 4—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 610

Parameter	Accuracy, as recovery, X′ (μg/L)	Single analyst precision, s_r' (μg/L)	Overall precision, S′ (μg/L)
Acenaphthene	0.52C + 0.54	0.39$\bar{X}$ + 0.76	0.53$\bar{X}$ + 1.32
Acenaphthylene	0.69C − 1.89	0.36$\bar{X}$ + 0.29	0.42$\bar{X}$ + 0.52
Anthracene	0.63C − 1.26	0.23$\bar{X}$ + 1.16	0.41$\bar{X}$ + 0.45
Benzo(a)anthracene	0.73C + 0.05	0.28$\bar{X}$ + 0.04	0.34$\bar{X}$ + 0.02
Benzo(a)pyrene	0.56C + 0.01	0.38$\bar{X}$ − 0.01	0.53$\bar{X}$ − 0.01
Benzo(b)fluoranthene	0.78C + 0.01	0.21$\bar{X}$ + 0.01	0.38$\bar{X}$ − 0.00
Benzo(ghi)perylene	0.44C + 0.30	0.25$\bar{X}$ + 0.04	0.58$\bar{X}$ + 0.10
Benzo(k)fluoranthene	0.59C + 0.00	0.44$\bar{X}$ − 0.00	0.69$\bar{X}$ + 0.01
Chrysene	0.77C − 0.18	0.32$\bar{X}$ − 0.18	0.66$\bar{X}$ − 0.22
Dibenzo(a,h)anthracene	0.41C + 0.11	0.24$\bar{X}$ + 0.02	0.45$\bar{X}$ + 0.03
Fluoranthene	0.68C + 0.07	0.22$\bar{X}$ + 0.06	0.32$\bar{X}$ + 0.03
Fluorene	0.56C − 0.52	0.44$\bar{X}$ − 1.12	0.63$\bar{X}$ − 0.65
Indeno(1,2,3–cd)pyrene	0.54C + 0.06	0.29$\bar{X}$ + 0.02	0.42$\bar{X}$ + 0.01
Naphthalene	0.57C − 0.70	0.39$\bar{X}$ − 0.18	0.41$\bar{X}$ + 0.74
Phenanthrene	0.72C − 0.95	0.29$\bar{X}$ + 0.05	0.47$\bar{X}$ − 0.25
Pyrene	0.69C − 0.12	0.25$\bar{X}$ + 0.14	0.42$\bar{X}$ − 0.00

X′=Expected recovery for one or more measurements of a sample containing a concentration of C, in μg/L.
s_r'=Expected single analyst standard deviation of measurements at an average concentration found of $\bar{X}$, in μg/L.
S′=Expected interlaboratory standard deviation of measurements at an average concentration found of $\bar{X}$, in μg/L.
C=True value for the concentration, in μg/L.
$\bar{X}$=Average recovery found for measurements of samples containing a concentration of C, in μg/L.

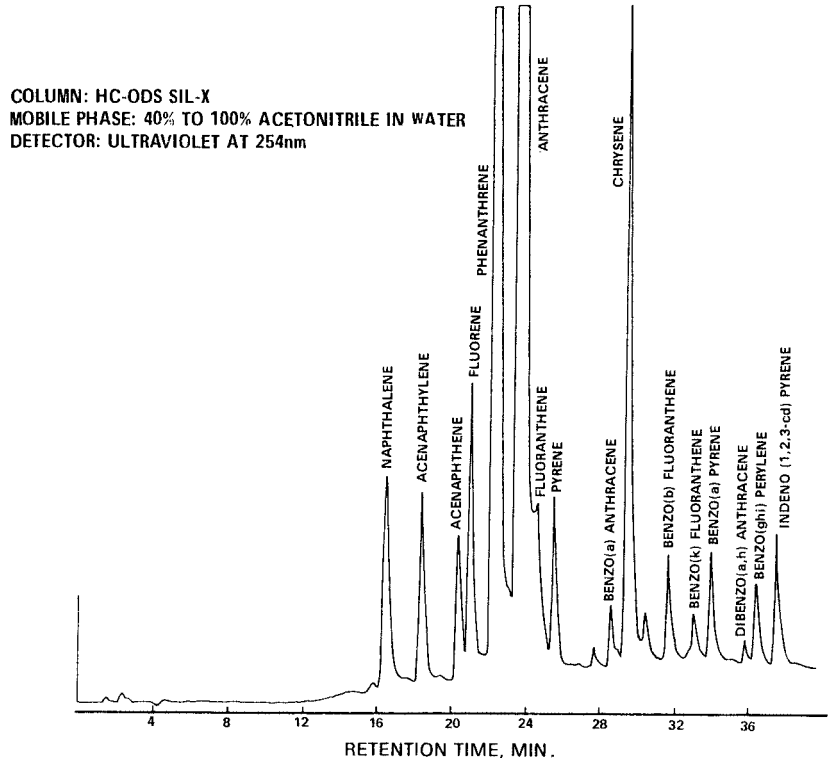

Figure 1. Liquid chromatogram of polynuclear aromatic hydrocarbons.

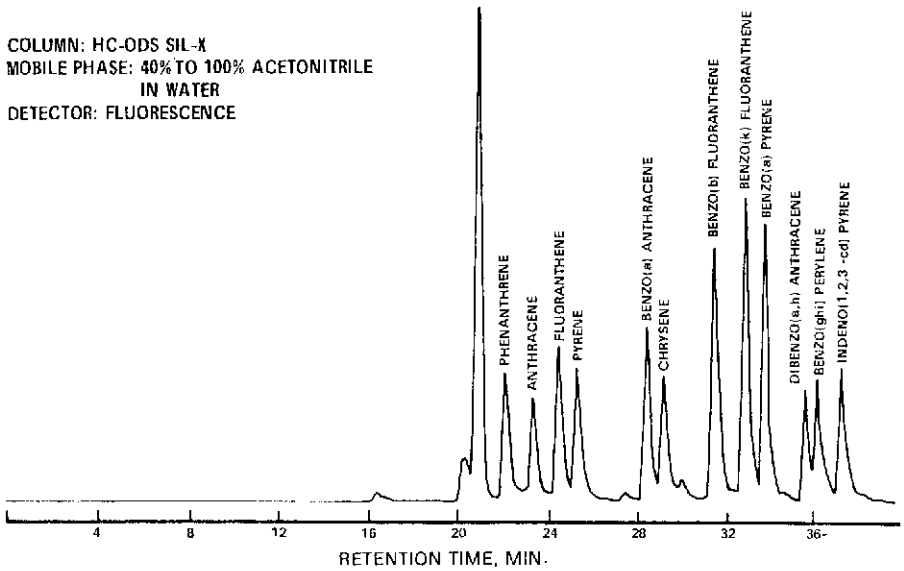

Figure 2. Liquid chromatogram of polynuclear aromatic hydrocarbons.

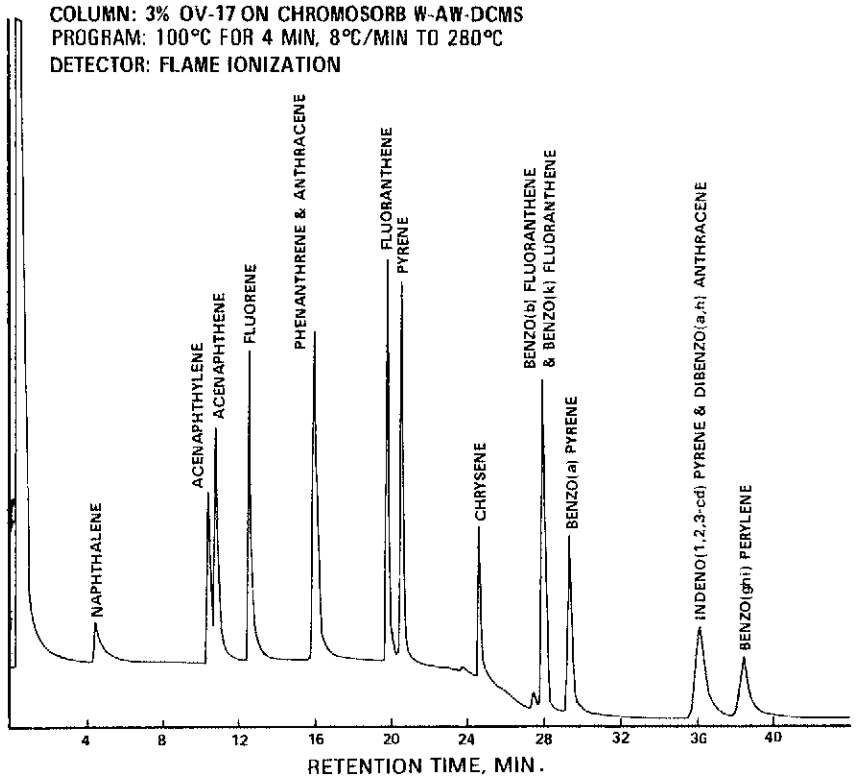

Figure 3. Gas chromatogram of polynuclear aromatic hydrocarbons.

METHOD 611—HALOETHERS

1. Scope and Application

1.1 This method covers the determination of certain haloethers. The following parameters can be determined by this method:

Parameter	STORET No.	CAS No.
Bis(2-chloroethyl) ether	34273	111–44–4
Bis(2-chloroethoxy) methane	34278	111–91–1
Bis(2-chloroisopropyl) ether	34283	108–60–1
4-Bromophenyl phenyl ether	34636	101–55–3
4-Chlorophenyl phenyl either	34641	7005–72–3

1.2 This is a gas chromatographic (GC) method applicable to the determination of the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for any or all of the compounds above, compound identifications should be supported by at least one additional qualitative technique. This method describes analytical conditions for a second gas chromatographic column that can be used to confirm measurements made with the primary column. Method 625 provides gas chromatograph/mass spectrometer (GC/MS) conditions appropriate for the qualitative and quantitative confirmation of results for all of the parameters listed above, using the extract produced by this method.

1.3 The method detection limit (MDL, defined in Section 14.1)[1] for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.4 The sample extraction and concentration steps in this method are essentially the same as in Methods 606, 608, 609, and 612. Thus, a single sample may be extracted to measure the parameters included in the scope of each of these methods. When cleanup is required, the concentration levels must be high enough to permit selecting aliquots, as necessary, to apply appropriate cleanup procedures. The analyst is allowed the latitude, under Section 12, to select

chromatographic conditions appropriate for the simultaneous measurement of combinations of these parameters.

1.5 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.6 This method is restricted to use by or under the supervision of analysts experienced in the use of a gas chromatograph and in the interpretation of gas chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 A measured volume of sample, approximately 1–L, is extracted with methylene chloride using a separatory funnel. The methylene chloride extract is dried and exchanged to hexane during concentration to a volume of 10 mL or less. The extract is separated by gas chromatography and the parameters are then measured with a halide specific detector.[2]

2.2 The method provides a Florisil column cleanup procedure to aid in the elimination of interferences that may be encountered.

3. Interferences

3.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that lead to discrete artifacts and/or elevated baselines in gas chromatograms. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3.

3.1.1 Glassware must be scrupulously cleaned.[3] Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. Solvent rinsing should be followed be detergent washing with hot water, and rinses with tap water and distilled water. The glassware should then be drained dry, and heated in a muffle furnace at 400 °C for 15 to 30 min. Some thermally stable materials, such a PCBs, may not be eliminated by this treatment. Solvent rinses with acetone and pesticide quality hexane may be substituted for the muffle furnace heating. Thorough rinsing with such solvents usually eliminates PCB interference. Volumetric ware should not be heated in a muffle furnace. After drying and cooling, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Store inverted or capped with aluminum foil.

3.1.2 The use of high purity reagents and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

3.2 Matrix interferences may be caused by contaminants that are co-extracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature and diversity of the industrial complex or municipality being sampled. The cleanup procedure in Section 11 can be used to overcome many of these interferences, but unique samples may require additional cleanup approaches to achieve the MDL listed in Table 1.

3.3 Dichlorobenzenes are known to coelute with haloethers under some gas chromatographic conditions. If these materials are present together in a sample, it may be necessary to analyze the extract with two different column packings to completely resolve all of the compounds.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified[4-6] for the information of the analyst.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete or composite sampling.

5.1.1 Grab sample bottle—1-L or 1-qt, amber glass, fitted with a screw cap lined with Teflon. Foil may be substituted for Teflon if the sample is not corrosive. If amber bottles are not available, protect samples from light. The bottle and cap liner must be washed, rinsed with acetone or methylene chloride, and dried before use to minimize contamination.

5.1.2 Automatic sampler (optional)—The sampler must incorporate glass sample containers for the collection of a minimum of 250 mL of sample. Sample containers must be kept refrigerated at 4 °C and protected from light during compositing. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used. Before use, however, the compressible tubing should be thoroughly rinsed with methanol, followed by repeated rinsings with distilled water to minimize the potential for contamination of the sample. An integrating

flow meter is required to collect flow proportional composites.

5.2 Glassware (All specifications are suggested. Catalog numbers are included for illustration only.):

5.2.1 Separatory funnel—2-L, with Teflon stopcock.

5.2.2 Drying column—Chromatographic column, approximately 400 mm long × 19 mm ID, with coarse frit filter disc.

5.2.3 Chromatographic column—400 mm long × 19 mm ID, with Teflon stopcock and coarse frit filter disc at bottom (Kontes K–420540–0224 or equivalent).

5.2.4 Concentrator tube, Kuderna-Danish—10-mL, graduated (Kontes K–570050–1025 or equivalent). Calibration must be checked at the volumes employed in the test. Ground glass stopper is used to prevent evaporation of extracts.

5.2.5 Evaporative flask, Kuderna-Danish—500-mL (Kontes K–570001–0500 or equivalent). Attach to concentrator tube with springs.

5.2.6 Snyder column, Kuderna-Danish—Three-ball macro (Kontes K–503000–0121 or equivalent).

5.2.7 Vials—10 to 15-mL, amber glass, with Teflon-lined screw cap.

5.3 Boiling chips—Approximately 10/40 mesh. Heat to 400 °C for 30 min or Soxhlet extract with methylene chloride.

5.4 Water bath—Heated, with concentric ring cover, capable of temperature control (±2°C). The bath should be used in a hood.

5.5 Balance—Analytical, capable of accurately weighing 0.0001 g.

5.6 Gas chromatograph—An analytical system complete with temperature programmable gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, gases, detector, and strip-chart recorder. A data system is recommended for measuring peak areas.

5.6.1 Column 1—1.8 m long × 2 mm ID glass, packed with 3% SP–1000 on Supelcoport (100/120 mesh) or equivalent. This column was used to develop the method performance statements in Section 14. Guidelines for the use of alternate column packings are provided in Section 12.1.

5.6.2 Column 2—1.8 m long × 2 mm ID glass, packed with 2,6-diphenylene oxide polymer (60/80 mesh), Tenax, or equivalent.

5.6.3 Detector—Halide specific detector: electrolytic conductivity or microcoulometric. These detectors have proven effective in the analysis of wastewaters for the parameters listed in the scope (Section 1.1). The Hall conductivity detector was used to develop the method performance statements in Section 14. Guidelines for the use of alternate detectors are provided in Section 12.1. Although less selective, an electron capture detector is an acceptable alternative.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.2 Sodium thiosulfate—(ACS) Granular.

6.3 Acetone, hexane, methanol, methylene chloride, petroleum ether (boiling range 30–60 °C)—Pesticide quality or equivalent.

6.4 Sodium sulfate—(ACS) Granular, anhydrous. Purify by heating at 400 °C for 4 h in a shallow tray.

6.5 Florisil—PR Grade (60/100 mesh). Purchase activated at 1250 °F and store in the dark in glass containers with ground glass stoppers or foil-lined screw caps. Before use, activate each batch at least 16 h at 130 °C in a foil-covered glass container and allow to cool.

6.6 Ethyl ether—Nanograde, redistilled in glass if necessary.

6.6.1 Ethyl ether must be shown to be free of peroxides before it is used as indicated by EM Laboratories Quant test strips. (Available from Scientific Products Co., Cat. No. P1126–8, and other suppliers.)

6.6.2 Procedures recommended for removal of peroxides are provided with the test strips. After cleanup, 20 mL of ethyl alcohol preservative must be added to each liter of ether.

6.7 Stock standard solutions (1.00 µg/µL)—Stock standard solutions can be prepared from pure standard materials or purchased as certified solutions.

6.7.1 Prepare stock standard solutions by accurately weighing about 0.0100 g of pure material. Dissolve the material in acetone and dilute to volume in a 10-mL volumetric flask. Larger volumes can be used at the convenience of the analyst. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the manufacturer or by an independent source.

6.7.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4 °C and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.7.3 Stock standard solutions must be replaced after six months, or sooner if comparison with check standards indicates a problem.

6.8 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Establish gas chromatographic operating conditions equivalent to those given in Table 1. The gas chromatographic system

can be calibrated using the external standard technique (Section 7.2) or the internal standard technique (Section 7.3).

7.2 External standard calibration procedure:

7.2.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask and diluting to volume with hexane. One of the external standards should be at a concentration near, but above, the MDL (Table 1) and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.2.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against the mass injected. The results can be used to prepare a calibration curve for each compound. Alternatively, if the ratio of response to amount injected (calibration factor) is a constant over the working range (<10% relative standard deviation, RSD), linearity through the origin can be assumed and the average ratio or calibration factor can be used in place of a calibration curve.

7.3 Internal standard calibration procedure—To use this approach, the analyst must select one or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Because of these limitations, no internal standard can be suggested that is applicable to all samples.

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask. To each calibration standard, add a known constant amount of one or more internal standards, and dilute to volume with hexane. One of the standards should be at a concentration near, but above, the MDL and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.3.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against concentration for each compound and internal standard. Calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

C_{is}=Concentration of the internal standard (µg/L).

C_s=Concentration of the parameter to be measured (µg/L).

If the RF value over the working range is a constant (<10% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.4 The working calibration curve, calibration factor, or RF must be verified on each working day by the measurement of one or more calibration standards. If the response for any parameter varies from the predicted response by more than ±15%, a new calibration curve must be prepared for that compound.

7.5 The cleanup procedure in Section 11 utilizes Florisil column chromatography. Florisil from different batches or sources may vary in adsorptive capacity. To standardize the amount of Florisil which is used, the use of lauric acid value[7] is suggested. The referenced procedure determines the adsorption from hexane solution of lauric acid (mg) per g of Florisil. The amount of Florisil to be used for each column is calculated by dividing 110 by this ratio and multiplying by 20 g.

7.6 Before using any cleanup procedure, the analyst must process a series of calibration standards through the procedure to validate elution patterns and the absence of interferences from the reagents.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Sections 10.4, 11.1, and 12.1) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Before processing any samples, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system and glassware are under control. Each time a set of samples is extracted or reagents are changed, a reagent water blank must be processed as a safeguard against laboratory contamination.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing each parameter of interest at a concentration of 100 µg/mL in acetone. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Using a pipet, prepare QC check samples at a concentration of 100 µg/L by adding 1.00 mL of QC check sample concentrate to each of four 1–L aliquots of reagent water.

8.2.3 Analyze the well-mixed QC check samples according to the method beginning in Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 2. If s and $\bar{X}$ for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual X falls outside the range for accuracy, the system performance is unacceptable for that parameter. Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.2.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spiked sample per month is required.

8.3.1. The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at 100 µg/L or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.3 If it is impractical to determine background levels before spiking (e.g., maximum holding times will be exceeded), the spike concentration should be (1) the regulatory concentration limit, if any; or, if none (2) the larger of either 5 times higher than the expected background concentration or 100 µg/L.

8.3.2 Analyze one sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second sample aliquot with 1.0 mL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100(A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 2. These acceptance criteria were calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[8] If spiking was performed at a concentration lower than 100 µg/L, the analyst must use either the QC acceptance criteria in Table 2, or optional QC

acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recovery of a parameter: (1) Calculate accuracy (X′) using the equation in Table 3, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 3, substituting X′ for X; (3) calculate the range for recovery at the spike concentration as (100 X′/T)±2.44(100 S′/T)%.[8]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4 If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory.

8.4.1 Prepare the QC check standard by adding 1.0 m/L of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 1 L of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 2. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $P-2s_p$ to $P+2s_p$. If P=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as gas chromatography with a dissimilar column, specific element detector, or mass spectrometer must be used. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 Grab samples must be collected in glass containers. Conventional sampling practices[9] should be followed, except that the bottle must not be prerinsed with sample before collection. Composite samples should be collected in refrigerated glass containers in accordance with the requirements of the program. Automatic sampling equipment must be as free as possible of Tygon tubing and other potential sources of contamination.

9.2 All samples must be iced or refrigerated at 4°C from the time of collection until extraction. Fill the sample bottles and, if residual chlorine is present, add 80 mg of sodium thiosulfate per liter of sample and mix well. EPA Methods 330.4 and 330.5 may be used for measurement of residual chlorine.[10] Field test kits are available for this purpose.

9.3 All samples must be extracted within 7 days of collection and completely analyzed within 40 days of extraction.[2]

10. Sample Extraction

10.1 Mark the water meniscus on the side of the sample bottle for later determination of sample volume. Pour the entire sample into a 2-L separatory funnel.

10.2 Add 60 mL methylene chloride to the sample bottle, seal, and shake 30 s to rinse the inner surface. Transfer the solvent to the separatory funnel and extract the sample by shaking the funnel for 2 min with periodic venting to release excess pressure. Allow the organic layer to separate from the water phase for a minimum of 10 min. If the emulsion interface between layers is more than one-third the volume of the solvent layer, the analyst must employ mechanical techniques to complete the phase separation. The optimum technique depends upon the sample, but may include stirring, filtration of the emulsion through glass wool, centrifugation, or other physical methods. Collect the methylene chloride extract in a 250-mL Erlenmeyer flask.

10.3 Add a second 60-mL volume of methylene chloride to the sample bottle and repeat the extraction procedure a second time, combining the extracts in the Erlenmeyer

flask. Perform a third extraction in the same manner.

10.4 Assemble a Kuderna-Danish (K–D) concentrator by attaching a 10-mL concentrator tube to a 500-mL evaporative flask. Other concentration devices or techniques may be used in place of the K–D concentrator if the requirements of Section 8.2 are met.

10.5 Pour the combined extract through a solvent-rinsed drying column containing about 10 cm of anhydrous sodium sulfate, and collect the extract in the K–D concentrator. Rinse the Erlenmeyer flask and column with 20 to 30 mL of methylene chloride to complete the quantitative transfer.

10.6 Add one or two clean boiling chips to the evaporative flask and attach a three-ball Snyder column. Prewet the Snyder column by adding about 1 mL of methylene chloride to the top. Place the K–D apparatus on a hot water bath (60 to 65 °C) so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15 to 20 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches 1 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min.

NOTE: Some of the haloethers are very volatile and significant losses will occur in concentration steps if care is not exercised. It is important to maintain a constant gentle evaporation rate and not to allow the liquid volume to fall below 1 to 2 mL before removing the K–D apparatus from the hot water bath.

10.7 Momentarily remove the Snyder column, add 50 mL of hexane and a new boiling chip, and reattach the Snyder column. Raise the temperature of the water bath to 85 to 90 °C. Concentrate the extract as in Section 10.6, except use hexane to prewet the column. The elapsed time of concentration should be 5 to 10 min.

10.8 Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1 to 2 mL of hexane. A 5-mL syringe is recommended for this operation. Stopper the concentrator tube and store refrigerated if further processing will not be performed immediately. If the extract will be stored longer than two days, it should be transferred to a Teflon-sealed screw-cap vial. If the sample extract requires no further cleanup, proceed with gas chromatographic analysis (Section 12). If the sample requires further cleanup, proceed to Section 11.

10.9 Determine the original sample volume by refilling the sample bottle to the mark and transferring the liquid to a 1000-mL graduated cylinder. Record the sample volume to the nearest 5 mL.

11. Cleanup and Separation

11.1 Cleanup procedures may not be necessary for a relatively clean sample matrix. If particular circumstances demand the use of a cleanup procedure, the analyst may use the procedure below or any other appropriate procedure. However, the analyst first must demonstrate that the requirements of Section 8.2 can be met using the method as revised to incorporate the cleanup procedure.

11.2 Florisil column cleanup for haloethers:

11.2.1 Adjust the sample extract volume to 10 mL.

11.2.2 Place a weight of Florisil (nominally 20 g) predetermined by calibration (Section 7.5), into a chromatographic column. Tap the column to settle the Florisil and add 1 to 2 cm of anhydrous sodium sulfate to the top.

11.2.3 Preelute the column with 50 to 60 mL of petroleum ether. Discard the eluate and just prior to exposure of the sodium sulfate layer to the air, quantitatively transfer the sample extract onto the column by decantation and subsequent petroleum ether washings. Discard the eluate. Just prior to exposure of the sodium sulfate layer to the air, begin eluting the column with 300 mL of ethyl ether/petroleum ether (6+94) (V/V). Adjust the elution rate to approximately 5 mL/min and collect the eluate in a 500-mL K–D flask equipped with a 10-mL concentrator tube. This fraction should contain all of the haloethers.

11.2.4 Concentrate the fraction as in Section 10.6, except use hexane to prewet the column. When the apparatus is cool, remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with hexane. Adjust the volume of the cleaned up extract to 10 mL with hexane and analyze by gas chromatography (Section 12).

12. Gas Chromatography

12.1 Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are retention times and MDL that can be achieved under these conditions. Examples of the separations achieved by Columns 1 and 2 are shown in Figures 1 and 2, respectively. Other packed or capillary (open-tubular) columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met.

12.2 Calibrate the system daily as described in Section 7.

12.3 If the internal standard calibration procedure is being used, the internal standard must be added to the sample extract and mixed thoroughly immediately before injection into the gas chromatrograph.

12.4 Inject 2 to 5 µL of the sample extract or standard into the gas chromatograph using the solvent-flush technique.[11] Smaller (1.0 µL) volumes may be injected if automatic devices are employed. Record the volume injected to the nearest 0.05 µL, the total extract volume, and the resulting peak size in area or peak height units.

12.5 Identify the parameters in the sample by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weight heavily in the interpretation of chromatograms.

12.6 If the response for a peak exceeds the working range of the system, dilute the extract and reanalyze.

12.7 If the measurement of the peak response is prevented by the presence of interferences, further cleanup is required.

13. Calculations

13.1 Determine the concentration of individual compounds in the sample.

13.1.1 If the external standard calibration procedure is used, calculate the amount of material injected from the peak response using the calibration curve or calibration factor determined in Section 7.2.2. The concentration in the sample can be calculated from Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A)(V_t)}{(V_i)(V_s)}$$

Equation 2

where:
A=Amount of material injected (ng).
V_i=Volume of extract injected (µL).
V_t=Volume of total extract (µL).
V_s=Volume of water extracted (mL).

13.1.2 If the internal standard calibration procedure is used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.3.2 and Equation 3.

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(I_s)}{(A_{is})(RF)(V_o)}$$

Equation 3

where:
A_s=Response for the parameter to be measured.
A_{is}=Response for the internal standard.
I_s=Amount of internal standard added to each extract (µg).
V_o=Volume of water extracted (L).

13.2 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

14. Method Performance

14.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentrations listed in Table 1 were obtained using reagent water.[12] Similar results were achieved using representative wastewaters. The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

14.2 This method has been tested for linearity of spike recovery from reagent water and has been demonstrated to be applicable over the concentration range from 4 × MDL to 1000 × MDL.[12]

14.3 This method was tested by 20 laboratories using reagent water, drinking water, surface water, and three industrial wastewaters spiked at six concentrations over the range 1.0 to 626 µ/L.[12] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 3.

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TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHODS DETECTION LIMITS

Parameters	Retention time (min)		Method detection limit (μ/L)
	Column 1	Column 2	
Bis(2-chloroisopropyl) ether	8.4	9.7	0.8
Bis(2-chloroethyl) ether	9.3	9.1	0.3
Bis(2-chloroethoxy) methane	13.1	10.0	0.5
4-Chlorophenyl ether	19.4	15.0	3.9
4-Bromophenyl phenyl ether	21.2	16.2	2.3

AColumn 1 conditions: Supelcoport (100/120 mesh) coated with 3% SP–1000 packed in a 1.8 m long × 2 mm ID glass column with helium carrier gas at 40 mL/min. flow rate. Column temperature held at 60 °C for 2 min. after injection then programmed at 8 °C/min. to 230 °C and held for 4 min. Under these conditions the retention time for Aldrin is 22.6 min.

AColumn 2 conditions: Tenax–GC (60/80 mesh) packed in a 1.8 m long × 2mm ID glass column with helium carrier gas at 40 mL/min. flow rate. Column temperature held at 150 °C for 4 min. after injection then programmed at 16 °C/min. to 310 °C. Under these conditions the retention time for Aldrin is 18.4 min.

TABLE 2—QC ACCEPTANCE CRITERIA—METHOD 611

Parameter	Test conc. (μg/L)	Limit for s (μg/L)	Range for $\bar{X}$ (μg/L)	Range for P, P_s percent
Bis (2-chloroethyl)ether	100	26.3	26.3–136.8	11–152
Bis (2-chloroethoxy)methane	100	25.7	27.3–115.0	12–128
Bis (2-chloroisopropyl)ether	100	32.7	26.4–147.0	9–165
4-Bromophenyl phenyl ether	100	39.3	7.6 –167.5	D–189
4-Chlorophenyl phenyl ether	100	30.7	15.4–152.5	D–170

$\underline{s}$=Standard deviation of four recovery measurements, in μg/L (Section 8.2.4).
$\bar{X}$=Average recovery for four recovery measurements, in μg/L (Section 8.2.4).
P, P_s=Percent recovery measured (Section 8.3.2, Section 8.4.2).
D=Detected; result must be greater than zero.

NOTE: These criteria are based directly upon the method performance data in Table 3. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 3.

TABLE 3—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 611

Parameter	Accuracy, as recovery, X′ (μg/L)	Single analyst precision, s_r' (μg/L)	Overall precision, S′ (μg/L)
Bis(2-chloroethyl) ether	0.81C+0.54	$0.19\bar{X}+0.28$	$0.35\bar{X}+0,36$
Bis(2-chloroethoxy) methane	0.71C+0.13	$0.20\bar{X}+0.15$	$0.33\bar{X}+0.11$
Bis(2-chloroisopropyl) ether	0.85C+1.67	$0.20\bar{X}+1.05$	$0.36\bar{X}+0.79$
4–Bromophenyl phenyl ether	0.85C+2.55	$0.25\bar{X}+0.21$	$0.47\bar{X}+0.37$
4–Chlorophenyl phenyl ether	0.82C+1.97	$0.18\bar{X}+2.13$	$0.41\bar{X}+0.55$

X′ = Expected recovery for one or more measuremelts of a sample containing a concentration of C, in μg/L.
s_r' = Expected single analyst standard deviation of measurements at an average concentration found of $\underline{X}$, in μg/L.
S′ = Expected interlaboratory standard deviation of measurements at an average concentration found of X, in μg/L.
$\underline{C}$ =True value for the concentration, in μg/L.
$\bar{X}$ = Average recovery found for measurements of samples containing a concentration of C, in μg/L.

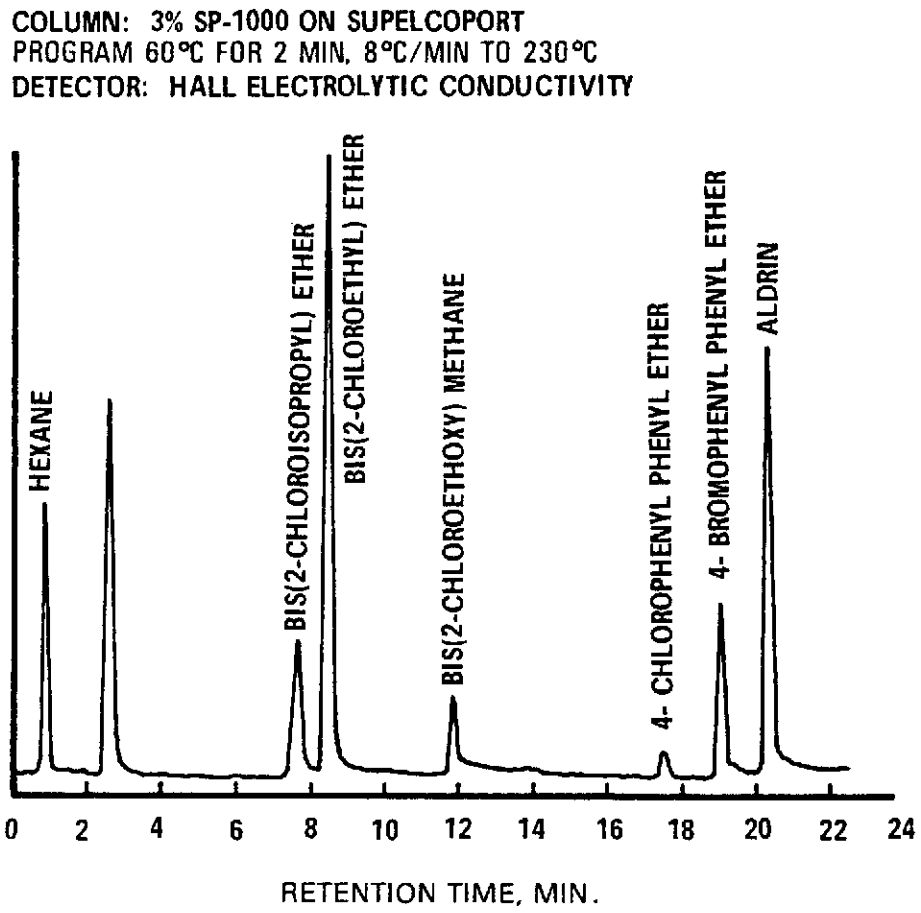

Figure 1. Gas chromatogram of haloethers.

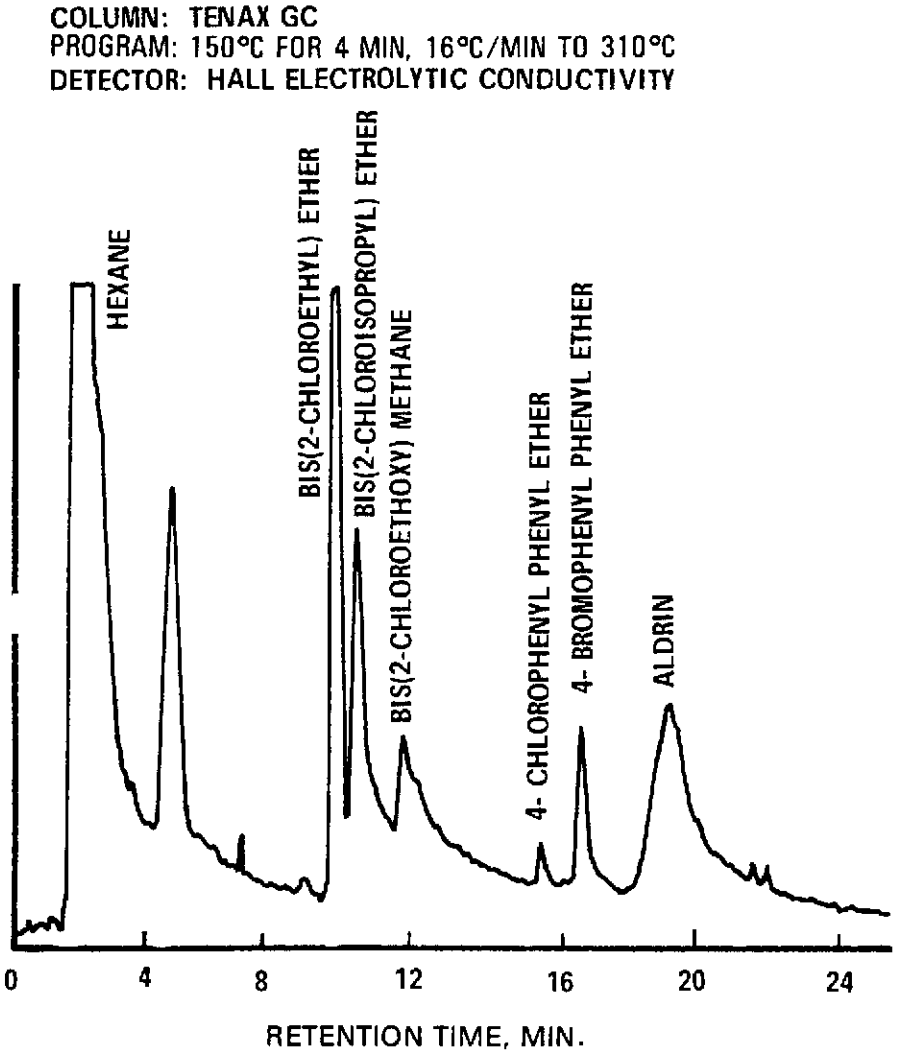

Figure 2. Gas chromatogram of haloethers.

METHOD 612—CHLORINATED HYDROCARBONS

1. Scope and Application

1.1 This method covers the determination of certain chlorinated hydrocarbons. The following parameters can be determined by this method:

Parameter	STORET No.	CAS No.
2-Chloronaphthalene	34581	91–58–7
1,2-Dichlorobenzene	34536	95–50–1
1,3-Dichlorobenzene	34566	541–73–1
1,4-Dichlorobenzene	34571	106–46–7
Hexachlorobenzene	39700	118–74–1
Hexachlorobutadiene	34391	87–68–3
Hexachlorocyclopentadiene	34386	77–47–4
Hexachloroethane	34396	67–72–1

Parameter	STORET No.	CAS No.
1,2,4-Trichlorobenzene	34551	120–82–1

1.2 This is a gas chromatographic (GC) method applicable to the determination of the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1. When this method is used to analyze unfamiliar samples for any or all of the compounds above, compound identifications should be supported by at least one additional qualitative technique. This method describes a second gas chromatographic column that can be used to confirm measurements made with the primary column. Method 625 provides gas chromatograph/mass spectrometer (GC/MS) conditions appropriate for the qualitative and quantitative confirmation of results for all of the parameters listed above, using the extract produced by this method.

1.3 The method detection limit (MDL, defined in Section 14.1)[1] for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.4 The sample extraction and concentration steps in this method are essentially the same as in Methods 606, 608, 609, and 611. Thus, a single sample may be extracted to measure the parameters included in the scope of each of these methods. When cleanup is required, the concentration levels must be high enough to permit selecting aliquots, as necessary, to apply appropriate cleanup procedures. The analyst is allowed the latitude, under Section 12, to select chromatographic conditions appropriate for the simultaneous measurement of combinations of these parameters.

1.5 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.6 This method is restricted to use by or under the supervision of analysts experienced in the use of a gas chromatograph and in the interpretation of gas chromatograms. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 A measured volume of sample, approximately 1–L, is extracted with methylene chloride using a separatory funnel. The methylene chloride extract is dried and exchanged to hexane during concentration to a volume of 10 mL or less. The extract is separated by gas chromatography and the parameters are then measured with an electron capture detector.[2]

2.2 The method provides a Florisil column cleanup procedure to aid in the elimination of interferences that may be encountered.

3. Interferences

3.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that lead to discrete artifacts and/or elevated baselines in gas chromatograms. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3.

3.1.1 Glassware must be scrupulously cleaned.[3] Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. Solvent rinsing should be followed by detergent washing with hot water, and rinses with tap water and distilled water. The glassware should then be drained dry, and heated in a muffle furnace at 400 °C for 15 to 30 min. Some thermally stable materials, such as PCBs, may not be eliminated by this treatment. Solvent rinses with acetone and pesticide quality hexane may be substituted for the muffle furnace heating. Thorough rinsing with such solvents usually eliminates PCB interference. Volumetric ware should not be heated in a muffle furnace. After drying and cooling, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Store inverted or capped with aluminum foil.

3.1.2 The use of high purity reagents and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

3.2 Matrix interferences may be caused by contaminants that are co-extracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature and diversity of the industrial complex or municipality being sampled. The cleanup procedure in Section 11 can be used to overcome many of these interferences, but unique samples may require additional cleanup approaches to achieve the MDL listed in Table 1.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all

personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified[4–6] for the information of the analyst.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete or composite sampling.

5.1.1 Grab sample bottle—1cL or 1-qt, amber glass, fitted with a screw cap lined with Teflon. Foil may be substituted for Teflon if the sample is not corrosive. If amber bottles are not available, protect samples from light. The bottle and cap liner must be washed, rinsed with acetone or methylene chloride, and dried before use to minimize contamination.

5.1.2 Automatic sampler (optional)—The sampler must incorporate glass sample containers for the collection of a minimum of 250 mL of sample. Sample containers must be kept refrigerated at 4 °C and protected from light during compositing. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used. Before use, however, the compressible tubing should be thoroughly rinsed with methanol, followed by repeated rinsings with distilled water to minimize the potential for contamination of the sample. An integrating flow meter is required to collect flow proportional composites.

5.2 Glassware (All specifications are suggested. Catalog numbers are included for illustration only.):

5.2.1 Separatory funnel—2–L, with Teflon stopcock.

5.2.2 Drying column—Chromatographic column, approximately 400 mm long × 19 mm ID, with coarse frit filter disc.

5.2.3 Chromatographic column—300 long × 10 mm ID, with Teflon stopcock and coarse frit filter disc at bottom.

5.2.4 Concentrator tube, Kuderna-Danish—10-mL, graduated (Kontes K–570050–1025 or equivalent). Calibration must be checked at the volumes employed in the test. Ground glass stopper is used to prevent evaporation of extracts.

5.2.5 Evaporative flask, Kuderna-Danish—500-mL (Kontes K–570001–0500 or equivalent). Attach to concentrator tube with springs.

5.2.6 Snyder column, Kuderna-Danish—Three-ball macro (Kontes K–503000–0121 or equivalent).

5.2.7 Vials—10 to 15-mL, amber glass, with Teflon-lined screw cap.

5.3 Boiling chips—Approximately 10/40 mesh. Heat to 400 °C for 30 min or Soxhlet extract with methylene chloride.

5.4 Water bath—Heated, with concentric ring cover, capable of temperature control (±2 °C). The bath should be used in a hood.

5.5 Balance—Analytical, capable of accurately weighing 0.0001 g.

5.6 Gas chromatograph—An analytical system complete with gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, gases, detector, and strip-chart recorder. A data system is recommended for measuring peak areas.

5.6.1 Column 1—1.8 m long × 2 mm ID glass, packed with 1% SP–1000 on Supelcoport (100/120 mesh) or equivalent. Guidelines for the use of alternate column packings are provide in Section 12.1.

5.6.2 Column 2—1.8 m long ×2 mm ID glass, packed with 1.5% OV–1/2.4% OV–225 on Supelcoport (80/100 mesh) or equivalent. This column was used to develop the method performance statements in Section 14.

5.6.3 Detector— Electron capture detector. This detector has proven effective in the analysis of wastewaters for the parameters listed in the scope (Section 1.1), and was used to develop the method performance statements in Section 14. Guidelines for the use of alternate detectors are provided in Section 12.1.

6. Reagents

6.1 Reagent water— Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.2 Acetone, hexane, isooctane, methanol, methylene chloride, petroleum ether (boiling range 30 to 60 °C)—Pesticide quality or equivalent.

6.3 Sodium sulfate—(ACS) Granular, anhydrous. Purify heating at 400 °C for 4 h in a shallow tray.

6.4 Florisil—PR grade (60/100 mesh). Purchase activated at 1250 °F and store in the dark in glass containers with ground glass stoppers or foil-lined screw caps. Before use, activate each batch at least 16 h at 130 °C in a foil-covered glass container and allow to cool.

6.5 Stock standard solution (1.00 µg/µL)—Stock standard solutions can be prepared from pure standard materials or purchased as certified solutions.

6.5.1 Prepare stock standard solutions by accurately weighing about 0.0100 g of pure material. Dissolve the material in isooctane and dilute to volume in a 120-mL volumetric flask. Larger volumes can be used at the convenience of the analyst. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the manufacturer or by an independent source.

6.5.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4 °C and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.5.3 Stock standard solutions must be replaced after six months, or sooner if comparision with check standards indicates a problem.

6.6 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Establish gas chromatographic operating conditions equivalent to those given in Table 1. The gas chromatographic system can be calibrated using the external standard technique (Section 7.2) or the internal standard technique (Section 7.3).

7.2 External standard calibration procedure:

7.2.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask and diluting to volume with isooctane. One of the external standards should be at a concentration near, but above, the MDL (Table 1) and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.2.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against the mass injected. The results can be used to prepare a calibration curve for each compound. Alternatively, if the ratio of response to amount injected (calibration factor) is a constant over the working range (<10% relative standard deviation, RSD), linearity through the origin can be assumed and the average ratio or calibration factor can be used in place of a calibration curve.

7.3 Internal standard calibration procedure—To use this approach, the analyst must select one or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Because of these limitations, no internal standard can be suggested that is applicable to all samples.

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding volumes of one or more stock standards to a volumetric flask. To each calibration standard, add a known constant amount of one or more internal standards, and dilute to volume with isooctane. One of the standards should be at a concentration near, but above, the MDL and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the detector.

7.3.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 12 and tabulate peak height or area responses against concentration for each compound and internal standard. Calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:

A_s=Response for the parameter to be measured.

A_{is}=Response for the internal standard.

C_{is}=Concentration of the internal standard (µg/L).

C_s=Concentration of the parameter to be measured (µg/L).

If the RF value over the working range is a constant (<10% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.4 The working calibration curve, calibration factor, or RF must be verified on each working day by the measurement of one or more calibration standards. If the response for any parameter varies from the predicted response by more than ±15%, a new calibration curve must be prepared for that compound.

7.5 Before using any cleanup procedure, the analyst must process a series of calibration standards through the procedure to validate elution patterns and the absence of interferences from the reagents.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When the results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Sections 10.4, 11.1, and 12.1) to improve the separations or lower the cost of measurements. Each time such modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Before processing any samples, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system and glassware are under control. Each time a set of samples is extracted or reagents are changed, a reagent water blank must be processed as a safeguard against laboratory contamination.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing each parameter of interest at the following concentrations in acetone: Hexachloro-substituted parameters, 10 µg/mL; any other chlorinated hydrocarbon, 100 µg/mL. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Using a pipet, prepare QC check samples at the test concentrations shown in Table 2 by adding 1.00 mL of QC check sample concentrate to each of four 1–L aliquots of reagent water.

8.2.3 Analyze the well-mixed QC check samples according to the method beginning in Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 2. If s and $\bar{X}$ for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual $\bar{X}$ falls outside the range for accuracy, the system performance is unacceptable for that parameter.

NOTE: The large number of parameters in Table 2 presents a substantial probability that one or more will fail at least one of the acceptance criteria when all parameters are analyzed.

8.2.6 When one or more of the parameters tested fail at least one of the acceptance criteria, the analyst must proceed according to Section 8.2.6.1 or 8.2.6.2.

8.2.6.1 Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.2.

8.2.6.2 Beginning with Section 8.2.2, repeat the test only for those parameters that failed to meet criteria. Repeated failure, however, will confirm a general problem with the measurement system. If this occurs, locate and correct the source of the problem and repeat the test for all compounds of interest beginning with Section 8.2.2.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spike sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at the test concentration in Section 8.2.2 or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.3 If it is impractical to determine background levels before spiking (e.g., maximum holding times will be exceeded), the spike concentration should be (1) the regulatory concentration limit, if any; or, if none by (2) the larger of either 5 times higher than the expected background concentration or the test concentration in Section 8.2.2.

8.3.2 Analyze one sample aliquot to determine the background concentration (B) of each parameter. In necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second sample aliquot with 1.0 mL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100 (A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 2. These acceptance criteria were calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[7] If spiking was performed at a concentration lower than the test concentration in Section 8.2.2, the analyst must use either the QC acceptance criteria in Table 2, or optional QC acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recovery of a parameter: (1) Calculate accuracy (X′) using the equation in Table 3, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 3, substituting X′ for X; (3) calculate the range for recovery at the spike concentration as (100 X′/T) ± 2.44 (100 S′/T)%.[7]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4. If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory.

8.4.1 Prepare the QC check standard by adding 1.0 mL of QC check sample concentrate (Sections 8.2.1 or 8.3.2) to 1 L of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 2. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $P-2s_p$ to $P+2s_p$. If P=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. When doubt exists over the identification of a peak on the chromatogram, confirmatory techniques such as gas chromatography with a dissimilar column, specific element detector, or mass spectrometer must be used. Whenever possible, the laboratory should analyze standard reference materials and participate in relevent performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 Grab samples must be collected in glass containers. Conventional sampling practices[8] should be followed, except that the bottle must not be prerinsed with sample before collection. Composite samples should be collected in refrigerated glass containers in accordance with the requirements of the program. Automatic sampling equipment must be as free as possible of Tygon tubing and other potential sources of contamination.

9.2 All samples must be iced or refrigerated at 4°C from the time of collection until extraction.

9.3 All samples must be extracted within 7 days of collection and completely analyzed within 40 days of extraction.[2]

10. Sample Extraction

10.1 Mark the water meniscus on the side of the sample bottle for later determination of sample volume. Pour the entire sample into a 2–L separatory funnel.

10.2 Add 60 mL of methylele chloride to the sample bottle, seal, and shake 30 s to rinse the inner surface. Transfer the solvent to the separatory funnel and extract the sample by shaking the funnel for 2 min with periodic venting to release excess pressure. Allow the organic layer to separate from the water phase for a minimum of 10 min. If the emulsion interface between layers is more than one-third the volume of the solvent layer, the analyst must employ mechanical techniques to complete the phase separation. The optimum technique depends upon the sample, but may include stirring, filtration of the emulsion through glass wool, centrifugation, or other physical methods. Collect the methylene chloride extract in a 250-mL Erlenmeyer flask.

10.3 Add a second 60-mL volume of methylene chloride to the sample bottle and repeat the extraction procedure a second time, combining the extracts in the Erlenmeyer flask. Perform a third extraction in the same manner.

10.4 Assemble a Kuderna-Danish (K–D) concentrator by attaching a 10-mL concentrator tube to a 500-mL evaporative flask. Other concentration devices or techniques may be used in place of the K–D concentrator if the requirements of Section 8.2 are met.

10.5 Pour the combined extract through a solvent-rinsed drying column containing about 10 cm of anhydrous sodium sulfate, and collect the extract in the K–D concentrator. Rinse the Erlenmeyer flask and column with 20 to 30 mL of methylene chloride to complete the quantitative transfer.

10.6 Add one or two clean boiling chips to the evaporative flask and attach a three-ball Snyder column. Prewet the Snyder column by adding about 1 mL of methylene chloride to the top. Place the K–D apparatus on a hot water bath (60 to 65 °C) so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15 to 20 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches 1 to 2 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min.

NOTE: The dichloribenzenes have a sufficiently high volatility that significant losses may occur in concentration steps if care is not exercised. It is important to maintain a constant gentle evaporation rate and not to allow the liquid volume to fall below 1 to 2 mL before removing the K–D apparatus from the hot water bath.

10.7 Momentarily remove the Snyder column, add 50 mL of hexane and a new boiling chip, and reattach the Snyder column. Raise the tempeature of the water bath to 85 to 90 °C. Concentrate the extract as in Section 10.6, except use hexane to prewet the column. The elapsed time of concentration should be 5 to 10 min.

10.8 Romove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1 to 2 mL of hexane. A 5-mL syringe is recommended for this operation. Stopper the concentrator tube and store refrigerated if further processing will not be performed immediately. If the extract will be stored longer than two days, it should be transferred to a Teflon-sealed screw-cap vial. If the sample extract requires no further cleanup, proceed with gas chromatographic analysis (Section 12). If the sample requires further cleanup, proceed to Section 11.

10.9 Determine the original sample volume by refilling the sample bottle to the mark and transferring the liquid to a 1000-mL graduated cylinder. Record the sample volume to the nearest 5 mL.

11. Cleanup and Separation

11.1 Cleanup procedures may not be necessary for a relatively clean sample matrix. If particular circumstances demand the use of a cleanup procedure, the analyst may use the procedure below or any other appropriate procedure. However, the analyst first must demonstrate that the requirements of Section 8.2 can be met using the method as revised to incorporate the cleanup procedure.

11.2 Florisil column cleanup for chlorinated hydrocarbons:

11.2.1 Adjust the sample extract to 10 mL with hexane.

11.2.2 Place 12 g of Florisil into a chromatographic column. Tap the column to settle the Florisil and add 1 to 2 cm of anhydrous sodium sulfate to the top.

11.2.3 Preelute the column with 100 mL of petroleum ether. Discard the eluate and just prior to exposure of the sodium sulfate layer to the air, quantitatively transfer the sample extract onto the column by decantation and subsequent petroleum ether washings. Discard the eluate. Just prior to exposure of the sodium sulfate layer to the air, begin eluting the column with 200 mL of petroleum ether and collect the eluate in a 500-mL K–D flask equipped with a 10-mL concentrator tube. This fraction should contain all of the chlorinated hydrocarbons.

11.2.4 Concentrate the fraction as in Section 10.6, except use hexane to prewet the column. When the apparatus is cool, remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with hexane. Analyze by gas chromatography (Section 12).

12. Gas Chromatography

12.1 Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are retention times and MDL that can be achieved under these conditions. Examples of the separations achieved by Columl 2 are shown in Figures 1 and 2. Other packed or capillary (open-tubular) columns, chromatographic conditions, or detectors may be used if the requirements of Section 8.2 are met.

12.2 Calibrate the system daily as described in Section 7.

12.3 If the internal standard calibration procedure is being used, the internal standard must be added to the sample extract and mixed throughly immediately before injection into the gas chromatograph.

12.4 Inject 2 to 5 µL of the sample extract or standard into the gas chromatograph using the solvent-flush techlique.[9] Smaller (1.0 µL) volumes may be injected if automatic devices are employed. Record the volume injected to the nearest 0.05 µL, the total extract volume, and the resulting peak size in area or peak height units.

12.5 Identify the parameters in the sample by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. The width of the retention time window used to make identifications should be based upon measurements of actual retention time variations of standards over the course of a day. Three times the standard deviation of a retention time for a compound can be used to calculate a suggested window size; however, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

12.6 If the response for a peak exceeds the working range of the system, dilute the extract and reanalyze.

12.7 If the measurement of the peak response is prevented by the presence of interferences, further cleanup is required.

13. Calculations

13.1 Determine the concentration of individual compounds in the sample.

13.1.1 If the external standard calibration procedure is used, calculate the amount of material injected from the peak response using the calibration curve or calibration factor determined in Section 7.2.2. The concentration in the sample can be calculated from Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A)(V_t)}{(V_i)(V_s)}$$

Equation 2

where:
A=Amount of material injected (ng).
V_i=Volume of extract injected (µL).
V_t=Volume of total extract (µL).
V_s=Volume of water extracted (mL).

13.1.2 If the internal standard calibration procedure is used, calculate the concentration in the sample using the response factor (RF) determined in Section 7.3.2 and Equation 3.

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(I_s)}{(A_{is})(RF)(V_o)}$$

Equation 3

where:
A_s=Response for the parameter to be measured.
A_{is}=Response for the internal standard.
I_s=Amount of internal standard added to each extract (µg).
V_o=Volume of water extracted (L).

13.2 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

14. Method Performance

14.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentrations listed in Table 1 were obtained using reagent water.[10] Similar results were achieved using representative wastewaters. The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

14.2 This method has been tested for linearity of spike recovery from reagent water and has been demonstrated to be applicable over the concentration range from 4×MDL to 1000×MDL.[10]

14.3 This method was tested by 20 laboratories using reagent water, drinking water, surface water, and three industrial wastewaters spiked at six concentrations over the range 1.0 to 356 µg/L.[11] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 3.

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4. ''Carcinogens—Working With Carcinogens,'' Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, Publication No. 77–206, August 1977.

5. ''OSHA Safety and Health Standards, General Industry,'' (29 CFR part 1910), Occupational Safety and Health Administration, OSHA 2206 (Revised, January 1976).

6. ''Safety in Academic Chemistry Laboratories,'' American Chemical Society Publication, Committee on Chemical Safety, 3rd Edition, 1979.

7. Provost, L.P., and Elder, R.S. ''Interpretation of Percent Recovery Data,''*American Laboratory, 15,* 58–63 (1983). (The value 2.44 used in the equation in Section 8.3.3 is two times the value 1.22 derived in this report.)

8. ASTM Annual Book of Standards, Part 31, D3370–76. ''Standard Practices for Sampling Water,'' American Society for Testing and Materials, Philadelphia.

9. Burke, J.A. ''Gas Chromatography for Pesticide Residue Analysis; Some Practical Aspects,'' *Journal of the Association of Official Analytical Chemists, 48,* 1037 (1965).

10. ''Development of Detection Limits, EPA Method 612, Chlorinated Hydrocarbons,'' Special letter report for EPA Contract 68–03–2625, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268.

11. ''EPA Method Study Method 612—Chlorinated Hydrocarbons,'' EPA 600/4–84–039, National Technical Information Service, PB84–187772, Springfield, Virginia 22161, May 1984.

12. ''Method Performance for Hexachlorocyclopentadiene by Method 612,'' Memorandum from R. Slater, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268, December 7, 1983.

TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention time (min)		Method detection limit (μg/L)
	Column 1	Column 2	
1,3-Dichlorobenzene	4.5	6.8	1.19
Hexachloroethane	4.9	8.3	0.03
1,4-Dichlorobenzene	5.2	7.6	1.34
1,2-Dichlorobenzene	6.6	9.3	1.14
Hexachlorobutadiene	7.7	20.0	0.34
1,2,4-Trichlorobenzene	15.5	22.3	0.05
Hexachlorocyclopentadiene	nd	[c]16.5	0.40
2-Chloronaphthalene	[a]2.7	[b]3.6	0.94
Hexachlorobenzene	[a]5.6	[b]10.1	0.05

Column 1 conditions: Supelcoport (100/120 mesh) coated with 1% SP–1000 packed in a 1.8 m × 2 mm ID glass column with 5% methane/95% argon carrier gas at 25 mL/min. flow rate. Column temperature held isothermal at 65 °C, except where otherwise indicated.

Column 2 conditions: Supelcoport (80/100 mesh) coated with 1.5% OV–1/2.4% OV–225 packed in a 1.8 m × 2 mm ID glass column with 5% methane/95% argon carrier gas at 25 mL/min. flow rate. Column temperature held isothermal at 75 °C, except where otherwise indicated.

nd=Not determined.

[a] 150 °C column temperature.

[b] 165 °C column temperature.

[c] 100 °C column temperature.

TABLE 2—QC ACCEPTANCE CRITERIA—METHOD 612

Parameter	Test conc. (μg/L)	Limit for s (μg/L)	Range for $\bar{X}$ (μg/L)	Range for P, P_s (percent)
2-Chloronaphthalene	100	37.3	29.5–126.9	9–148
1,2-Dichlorobenzene	100	28.3	23.5–145.1	9–160
1,3-Dichlorobenzene	100	26.4	7.2–138.6	D–150
1,4-Dichlorobenzene	100	20.8	22.7–126.9	13–137
Hexachlorobenzene	10	2.4	2.6–14.8	15–159
Hexachlorobutadiene	10	2.2	D–12.7	D–139
Hexachlorocyclopentadiene	10	2.5	D–10.4	D–111
Hexachloroethane	10	3.3	2.4–12.3	8–139
1,2,4-Trichlorobenzene	100	31.6	20.2–133.7	5–149

s=Standard deviation of four recovery measurements, in μg/L (Section 8.2.4).

$\bar{X}$=Average recovery for four recovery measurements, in μg/L (Section 8.2.4).

P, P_s=Percent recovery measured (Section 8.3.2, Section 8.4.2).

D=Detected; result must be greater than zero.

NOTE: These criteria are based directly upon the method performance data in Table 3. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 3.

TABLE 3—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 612

Parameter	Acccuracy, as recovery, X′ (μg/L)	Single analyst precision, s_r' (μg/L)	Overall precision, S′ (μg/L)
2-Chloronaphthalene	0.75C+3.21	$0.28\bar{X}-1.17$	$0.38\bar{X}-1.39$
1,2-Dichlorobenzene	0.85C − 0.70	$0.22\bar{X}-2.95$	$0.41\bar{X}-3.92$
1,3-Dichlorobenzene	0.72C+0.87	$0.21\bar{X}-1.03$	$0.49\bar{X}-3.98$
1,4-Dichlorobenzene	0.72C+2.80	$0.16\bar{X}-0.48$	$0.35\bar{X}-0.57$
Hexachlorobenzene	0.87C − 0.02	$0.14\bar{X}+0.07$	$0.36\bar{X}-0.19$
Hexachlorobutadiene	0.61C+0.03	$0.18\bar{X}+0.08$	$0.53\bar{X}-0.12$
Hexachlorocyclopentadiene[a]	0.47C	$0.24\bar{X}$	$0.50\bar{X}$
Hexachloroethane	0.74C − 0.02	$0.23\bar{X}+0.07$	$0.36\bar{X}-0.00$
1,2,4-Trichlorobenzene	0.76C+0.98	$0.23\bar{X}-0.44$	$0.40\bar{X}-1.37$

X′=Expected recovery for one or more measurements of a sample containing a concentration of C, in μg/L.
s_r'=Expected single analyst standard deviation of measurements at an average concentration found of $\underline{X}$, in μg/L.
S′=Expected interlaboratory standard deviation of measurements at an average concentration found of X, in μg/L.
$\underline{C}$=True value for the concentration, in μg/L.
$\bar{X}$=Average recovery found for measurements of samples containing a concentration of C, in μg/L.

[a] Estimates based upon the performance in a single laboratory.[12]

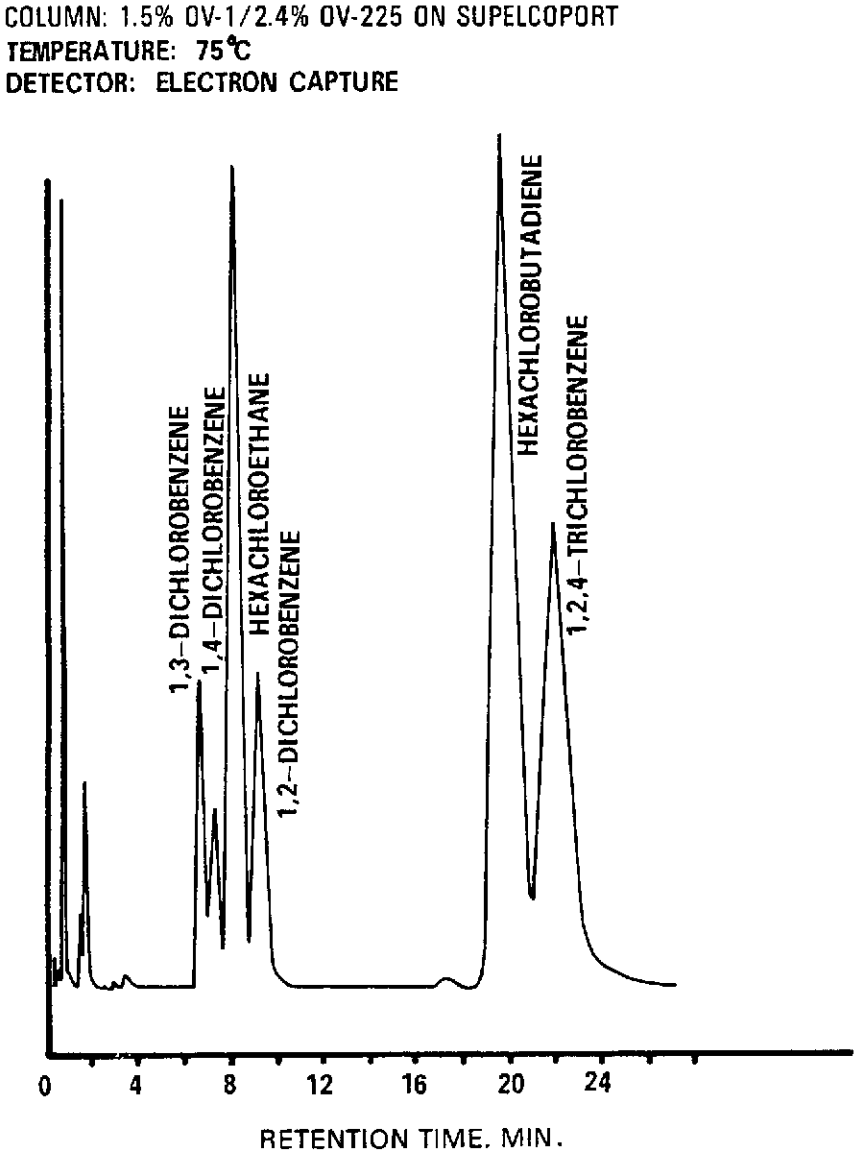

Figure 1. Gas chromatogram of chlorinated hydrocarbons.

COLUMN: 1.5% OV-1/2.4% OV-225 ON SUPELCOPORT
TEMPERATURE: 165°C
DETECTOR: ELECTRON CAPTURE

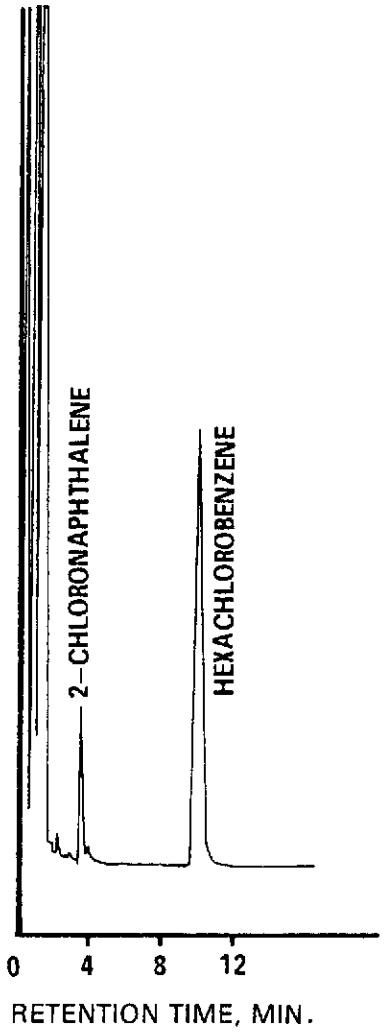

Figure 2. Gas chromatogram of chlorinated hydrocarbons.

METHOD 613—2,3,7,8-TETRACHLORODIBENZO-P-DIOXIN

1. Scope and Application

1.1 This method covers the determination of 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). The following parameter may be determined by this method:

Parameter	STORET No.	GAS No.
2,3,7,8-TCDD	34675	1746–01–6

1.2 This is a gas chromatographic/mass spectrometer (GC/MS) method applicable to the determination of 2,3,7,8–TCDD in municipal and industrial discharges as provided under 40 CFR 136.1. Method 625 may be used to screen samples for 2,3,7,8–TCDD. When the screening test is positive, the final qualitative confirmation and quantification must be made using Method 613.

1.3 The method detection limit (MDL, defined in Section 14.1)[1] for 2,3,7,8–TCDD is listed in Table 1. The MDL for a specific wastewater may be different from that listed, depending upon the nature of interferences in the sample matrix.

1.4 Because of the extreme toxicity of this compound, the analyst must prevent exposure to himself, of to others, by materials knows or believed to contain 2,3,7,8–TCDD. Section 4 of this method contains guidelines and protocols that serve as minimum safe-handling standards in a limited-access laboratory.

1.5 Any modification of this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.6 This method is restricted to use by or under the supervision of analysts experienced in the use of a gas chromatograph/mass spectrometer and in the interpretation of mass spectra. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 A measured volume of sample, approximately 1–L, is spiked with an internal standard of labeled 2,3,7,8–TCDD and extracted with methylene chloride using a separatory funnel. The methylene chloride extract is exchanged to hexane during concentration to a volume of 1.0 mL or less. The extract is then analyzed by capillary column GC/MS to separate and measure 2,3,7,8–TCDD.[2,3]

2.2 The method provides selected column chromatographic cleanup proceudres to aid in the elimination of interferences that may be encountered.

3. Interferences

3.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that lead to discrete artifacts and/or elevated backgrounds at the masses (m/z) monitored. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3.

3.1.1 Glassware must be scrupulously cleaned.[4] Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. Solvent rinsing should be followed by detergent washing with hot water, and rinses with tap water and distilled water. The glassware should then be drained dry, and heated in a muffle furnace at 400 °C for 15 to 30 min. Some thermally stable materials, such as PCBs, may not be eliminated by the treatment. Solvent rinses with acetone and pesticide quality hexane may be substituted for the muffle furnace heating. Thorough rinsing with such solvents usually eliminates PCB interference. Volumetric ware should not be heated in a muffle furnace. After drying and cooling, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Store inverted or capped with aluminum foil.

3.1.2 The use of high purity reagents and solvents helps to mininmize interference problems. Purification of solvents by distillation in all-glass systems may be required.

3.2 Matrix interferences may be caused by contaminants that are coextracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature and diversity of the industrial complex or municipality being sampled. 2,3,7,8–TCDD is often associated with other interfering chlorinated compounds which are at concentrations several magnitudes higher than that of 2,3,7,8–TCDD. The cleanup producers in Section 11 can be used to overcome many of these interferences, but unique samples may require additional cleanup approaches[1,5–7] to eliminate false positives and achieve the MDL listed in Table 1.

3.3 The primary column, SP–2330 or equivalent, resolves 2,3,7,8–TCDD from the other 21 TCDD insomers. Positive results using any other gas chromatographic column must be confirmed using the primary column.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to

the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified[8–10] for the information of the analyst. Benzene and 2,3,7,8–TCDD have been identified as suspected human or mammalian carcinogens.

4.2 Each laboratory must develop a strict safety program for handling 2,3,7,8–TCDD. The following laboratory practices are recommended:

4.2.1 Contamination of the laboratory will be minimized by conducting all manipulations in a hood.

4.2.2 The effluents of sample splitters for the gas chromatograph and roughing pumps on the GC/MS should pass through either a column of activated charcoal or be bubbled through a trap containing oil or high-boiling alcohols.

4.2.3 Liquid waste should be dissolved in methanol or ethanol and irradiated with ultraviolet light with a wavelength greater than 290 nm for several days. (Use F 40 BL lamps or equivalent). Analyze liquid wastes and dispose of the solutions when 2,3,7,8–TCDD can no longer be detected.

4.3 Dow Chemical U.S.A. has issued the following precautimns (revised November 1978) for safe handling of 2,3,7,8–TCDD in the laboratory:

4.3.1 The following statements on safe handling are as complete as possible on the basis of available toxicological information. The precautions for safe handling and use are necessarily general in nature since detailed, specific recommendations can be made only for the particular exposure and circumstances of each individual use. Inquiries about specific operations or uses may be addressed to the Dow Chemical Company. Assistance in evaluating the health hazards of particular plant conditions may be obtained from certain consulting laboratories and from State Departments of Health or of Labor, many of which have an industrial health service. 2,3,7,8–TCDD is extremely toxic to laboratory animals. However, it has been handled for years without injury in analytical and biological laboratories. Techniques used in handling radioactive and infectious materials are applicable to 2,3,7,8,–TCDD.

4.3.1.1 Protective equipment—Throwaway plastic gloves, apron or lab coat, safety glasses, and a lab hood adequate for radioactive work.

4.3.1.2 Training—Workers must be trained in the proper method of removing contaminated gloves and clothing without contacting the exterior surfaces.

4.3.1.3 Personal hygiene—Thorough washing of hands and forearms after each manipulation and before breaks (coffee, lunch, and shift).

4.3.1.4 Confinement—Isolated work area, posted with signs, segregated glassware and tools, plastic-backed absorbent paper on benchtops.

4.3.1.5 Waste—Good technique includes minimizing contaminated waste. Plastic bag liners should be used in waste cans. Janitors must be trained in the safe handling of waste.

4.3.1.6 Disposal of wastes—2,3,7,8–TCDD decomposes above 800 °C. Low-level waste such as absorbent paper, tissues, animal remains, and plastic gloves may be burned in a good incinerator. Gross quantities (milligrams) should be packaged securely and disposed through commercial or governmental channels which are capable of handling high-level radioactive wastes or extremely toxic wastes. Liquids should be allowed to evaporate in a good hood and in a disposable container. Residues may then be handled as above.

4.3.1.7 Decontamination—For personal decontamination, use any mild soap with plenty of scrubbing action. For decontamination of glassware, tools, and surfaces, Chlorothene NU Solvent (Trademark of the Dow Chemical Company) is the least toxic solvent shown to be effective. Satisfactory cleaning may be accomplished by rinsing with Chlorothene, then washing with any detergent and water. Dishwater may be disposed to the sewer. It is prudent to minimize solvent wastes because they may require special disposal through commercial sources which are expensive.

4.3.1.8 Laundry—Clothing known to be contaminated should be disposed with the precautions described under Section 4.3.1.6. Lab coats or other clothing worn in 2,3,7,8–TCDD work areas may be laundered.

Clothing should be collected in plastic bags. Persons who convey the bags and launder the clothing should be advised of the hazard and trained in proper handling. The clothing may be put into a washer without contact if the launderer knows the problem. The washer should be run through a cycle before being used again for other clothing.

4.3.1.9 Wipe tests—A useful method of determining cleanliness of work surfaces and tools is to wipe the surface with a piece of filter paper. Extraction and analysis by gas chromatography can achieve a limit of sensitivity of 0.1 µg per wipe. Less than 1 µg of 2,3,7,8–TCDD per sample indicates acceptable cleanliness; anything higher warrants further cleaning. More than 10 µg on a wipe sample constitutes an acute hazard and requires prompt cleaning before further use of the equipment or work space. A high (>10 µg)

2,3,7,8–TCDD level indicates that unacceptable work practices have been employed in the past.

4.3.1.10 Inhalation—Any procedure that may produce airborne contamination must be done with good ventilation. Gross losses to a ventilation system must not be allowed. Handling of the dilute solutions normally used in analytical and animal work presents no inhalation hazards except in the case of an accident.

4.3.1.11 Accidents—Remove contaminated clothing immediately, taking precautions not to contaminate skin or other articles. Wash exposed skin vigorously and repeatedly until medical attention is obtained.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete or composite sampling.

5.1.1 Grab sample bottle—1–L or 1-qt, amber glass, fitted with a screw cap lined with Teflon. Foil may be substituted for Teflon if the sample is not corrosive. If amber bottles are not available, protect samples from light. The bottle and cap liner must be washed, rinsed with acetone or methylene chloride, and dried before use to minimize contamination.

5.1.2 Automatic sampler (optional)—The sampler must incorporate glass sample containers for the collection of a minimum of 250 mL of sample. Sample containers must be kept refrigerated at 4 °C and protected from light during compositing. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used. Before use, however, the compressible tubing should be thoroughly rinsed with methanol, followed by repeated rinsings with distilled water to minimize the potential for contamination of the sample. An integrating flow meter is required to collect flow proportional composites.

5.1.3 Clearly label all samples as ''POISON'' and ship according to U.S. Department of Transportation regulations.

5.2 Glassware (All specifications are suggested. Catalog numbers are included for illustration only.):

5.2.1 Separatory funnels—2–L and 125-mL, with Teflon stopcock.

5.2.2 Concentrator tube, Kuderna-Danish—10-mL, graduated (Kontes K–570050–1025 or equivalent). Calibration must be checked at the volumes employed in the test. Ground glass stopper is used to prevent evaporation of extracts.

5.2.3 Evaporative flask, Kuderna-Danish—500–mL (Kontes K–570001–0500 or equivalent). Attach to concentrator tube with springs.

5.2.4 Snyder column, Kuderna-Danish—Three-ball macro (Kontes K–503000–0121 or equivalent).

5.2.5 Snyder column, Kuderna-Danish—Two-ball micro (Kontes K–569001–0219 or equivalent).

5.2.6 Vials—10 to 15–mL, amber glass, with Teflon-lined screw cap.

5.2.7 Chromatographic column—300 mm long × 10 mm ID, with Teflon stopcock and coarse frit filter disc at bottom.

5.2.8 Chromatographic column—400 mm long × 11 mm ID, with Teflon stopcock and coarse frit filter disc at bottom.

5.3 Boiling chips—Approximately 10/40 mesh. Heat to 400 °C for 30 min or Soxhlet extract with methylene chloride.

5.4 Water bath—Heated, with concentric ring cover, capable of temperature control (±2 °C). The bath should be used in a hood.

5.5 GC/MS system:

5.5.1 Gas chromatograph—An analytical system complete with a temperature programmable gas chromatograph and all required accessories including syringes, analytical columns, and gases. The injection port must be designed for capillary columns. Either split, splitless, or on-column injection techniques may be employed, as long as the requirements of Section 7.1.1 are achieved.

5.5.2 Column—60 m long × 0.25 mm ID glass or fused silica, coated with SP–2330 (or equivalent) with a film thickness of 0.2 µm. Any equivalent column must resolve 2, 3, 7, 8–TCDD from the other 21 TCDD isomers.[16]

5.5.3 Mass spectrometer—Either a low resolution mass spectrometer (LRMS) or a high resolution mass spectrometer (HRMS) may be used. The mass spectrometer must be equipped with a 70 V (nominal) ion source and be capable of aquiring m/z abundance data in real time selected ion monitoring (SIM) for groups of four or more masses.

5.5.4 GC/MS interface—Any GC to MS interface can be used that achieves the requirements of Section 7.1.1. GC to MS interfaces constructed of all glass or glass-lined materials are recommended. Glass surfaces can be deactivated by silanizing with dichlorodimethylsilane. To achieve maximum sensitivity, the exit end of the capillary column should be placed in the ion source. A short piece of fused silica capillary can be used as the interface to overcome problems associated with straightening the exit end of glass capillary columns.

5.5.5 The SIM data acquired during the chromatographic program is defined as the Selected Ion Current Profile (SICP). The SICP can be acquired under computer control or as a real time analog output. If computer control is used, there must be software available to plot the SICP and report peak height or area data for any m/z in the SICP between specified time or scan number limits.

5.6 Balance—Analytical, capable of accurately weighing 0.0001 g.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of 2, 3, 7, 8–TCDD.

6.2 Sodium hydroxide solution (10 N)—Dissolve 40 g of NaOH (ACS) in reagent water and dilute to 100 mL. Wash the solution with methylene chloride and hexane before use.

6.3 Sodium thiosulfate—(ACS) Granular.

6.4 Sulfuric acid—Concentrated (ACS, sp. gr. 1.84).

6.5 Acetone, methylene chloride, hexane, benzene, ortho-xylene, tetradecane—Pesticide quality or equivalent.

6.6 Sodium sulfate—(ACS) Granular, anhydrous. Purify by heating at 400 °C for 4 h in a shallow tray.

6.7 Alumina—Neutral, 80/200 mesh (Fisher Scientific Co., No. A–540 or equivalent). Before use, activate for 24 h at 130 °C in a foil-covered glass container.

6.8 Silica gel—High purity grade, 100/120 mesh (Fisher Scientific Co., No. S–679 or equivalent).

6.9 Stock standard solutions (1.00 µg/µL)—Stock standard solutimns can be prepared from pure standard materials or purchased as certified solutions. Acetone should be used as the solvent for spiking solutions; ortho-xylene is recommended for calibration standards for split injectors; and tetradecane is recommended for splitless or on-colum injectors. Analyze stock internal standards to verify the absence of native 2,3,7,8–TCDD.

6.9.1 Prepare stock standard solutions of 2,3,7,8–TCDD (mol wt 320) and either $^{37}C1_4$ 2,3,7,8–TCDD (mol wt 328) or $^{13}C1_{12}$ 2,3,7,8–TCDD (mol wt 332) in an isolated area by accurately weighing about 0.0100 g of pure material. Dissolve the material in pesticide quality solvent and dilute to volume in a 10-mL volumetric flask. When compound purity is assayed to be 96% or greater, the weight can be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards can be used at any concentration if they are certified by the manufacturer or by an independent source.

6.9.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store in an isolated refrigerator protected from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards or spiking solutions from them.

6.9.3 Stock standard solutions must be replaced after six months, or sooner if comparison with check standards indicates a problem.

6.10 Internal standard spiking solution (25 ng/mL)—Using stock standard solution, prepare a spiking solution in acetone of either $^{13}Cl_{12}$ or $^{37}Cl_4$ 2,3,7,8–TCDD at a concentration of 25 ng/mL. (See Section 10.2)

6.11 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Establish gas chromatograhic operating conditions equivalent to those given in Table 1 and SIM conditions for the mass spectrometer as described in Section 12.2 The GC/MS system must be calibrated using the internal standard technique.

7.1.1 Using stock standards, prepare calibration standards that will allow measurement of relative response factors of at least three concentration ratios of 2,3,7,8–TCDD to internal standard. Each calibration standard must be prepared to contain the internal standard at a concentration of 25 ng/mL. If any interferences are contributed by the internal standard at m/z 320 and 322, its concentration may be reduced in the calibration standards and in the internal standard spiking solution (Section 6.10). One of the calibration standards should contain 2,3,7,8–TCDD at a concentration near, but above, the MDL and the other 2,3,7,8–TCDD concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the GC/MS system.

7.1.2 Using injections of 2 to 5 µL, analyze each calibration standardaccording to Section 12 and tabulate peak height or area response against the concentration of 2,3,7,8–TCDD and internal standard. Calculate response factors (RF) for 2,3,7,8–TCDD using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:

A_s=SIM response for 2,3,7,8–TCDD m/z 320.

A_{is}=SIM response for the internal standard, m/z 332 for $^{13}C_{12}$ 2,3,7,8–TCDD m/z 328 for $^{37}Cl_4$ 2,3,7,8–TCDD.

C_{is}=Concentration of the internal standard (µg/L).

C_s=Concentration of 2,3,7,8–TCDD (µg/L).

If the RF value over the working range is a constant (<10% relative standard deviation, RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.1.3 The working calibration curve or RF must be verified on each working day by the measurement of one or more 2,3,7,8–TCDD calibration standards. If the response for 2,3,7,8–TCDD varies from the predicted response by more than ±15%, the test must be repeated using a fresh calibration standard. Alternatively, a new calibration curve must be prepared.

7.2 Before using any cleanup procedure, the analyst must process a series of calibration standards through the procedure to validate elution patterns and the absence of interferences from the reagents.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Sections 10.5, 11.1, and 12.1) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2

8.1.3 Before processing any samples, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system and glassware are under control. Each time a set of samples is extracted or reagents are changed, a reagent water blank must be processed as a safeguard against laboratory contamination.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 10% of all samples with native 2,3,7,8–TCDD to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 10% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing 2,3,7,8–TCDD at a concentration of 0.100 µg/mL in acetone. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Using a pipet, prepare QC check samples at a concentration of 0.100 µg/L (100 ng/L) by adding 1.00 mL of QC check sample concentrate to each of four 1–L aliquots of reagent water.

8.2.3 Analyze the well-mixed QC check samples according to the method beginning in Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for 2,3,7,8–TCDD using the four results.

8.2.5 Compare s and ($\bar{X}$) with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 2. If s and $\bar{X}$ meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If s exceeds the precision limit or $\bar{X}$ falls outside the range for accuracy, the system performance is unacceptable for 2,3,7,8–TCDD. Locate and correct the source of the problem and repeat the test beginning with Section 8.2.2.

8.3 The laboratory must, on an ongoing basis, spike at least 10% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing one to ten samples per month, at least one spiked sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of 2,3,7,8–TCDD in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of 2,3,7,8–TCDD in the sample is not being checked against a limit specific to that parameter, the spike should be at 0.100 µg/L or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.3 If it is impractical to determine background levels before spiking (e.g., maximum holding times will be exceeded), the

spike concentration should be (1) the regulatory concentration limit, if any; or, if none (2) the larger of either 5 times higher than the expected background concentration or 0.100 µg/L.

8.3.2 Analyze one sample aliquot to determine the background concentration (B) of 2,3,7,8–TCDD. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentration in the sample. Spike a second sample aliquot with 1.0 mL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of 2,3,7,8–TCDD. Calculate percent recovery (P) as 100(A–B)%T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for 2,3,7,8–TCDD with the corresponding QC acceptance criteria found in Table 2. These acceptance criteria were calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[11] If spiking was performed at a concentration lower than 0.100 µg/L, the analyst must use either the QC acceptance criteria in Table 2, or optional QC acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recovery of 2,3,7,8–TCDD: (1) Calculate accuracy (X′) using the equation in Table 3, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 3, substituting X′ for X; (3) calculate the range for recovery at the spike concentration as (100 X′/T)±2.44(100 S′/T)%.[11]

8.3.4 If the recovery of 2,3,7,8–TCDD falls outside the designated range for recovery, a check standard must be analyzed as described in Section 8.4.

8.4 If the recovery of 2,3,7,8–TCDD fails the acceptance criteria for recovery in Section 8.3, a QC check standard must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the complexity of the sample matrix and the performance of the laboratory.

8.4.1 Prepare the QC check standard by adding 1.0 mL of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 1 L of reagent water.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of 2,3,7,8–TCDD. Calculate the percent recovery (P_s) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) with the corresponding QC acceptance criteria found in Table 2. If the recovery of 2,3,7,8–TCDD falls outside the designated range, the laboratory performance is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for 2,3,7,8–TCDD in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery ($\bar{P}$) and the spandard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $\bar{P}-2s_p$ to $\bar{P}+2s_p$. If $\bar{P}$=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 Grab samples must be collected in glass containers. Conventional sampling practices[12] should be followed, except that the bottle must not be prerinsed with sample before collection. Composite samples should be collected in refrigerated glass containers in accordance with the requirements of the program. Automatic sampling equipment must be as free as possible of Tygon tubing and other potential sources of contamination.

9.2 All samples must be iced or refrigerated at 4 °C and protected from light from the time of collection until extraction. Fill the sample bottles and, if residual chlorine is present, add 80 mg of sodium thiosulfate per liter of sample and mix well. EPA Methods 330.4 and 330.5 may be used for measurement of residual chlorine.[13] Field test kits are available for this purpose.

9.3 Label all samples and containers ''POISON'' and ship according to applicable U.S. Department of Transportation regulations.

9.4 All samples must be extracted within 7 days of collection and completely analyzed within 40 days of extraction.[2]

10. Sample Extraction

CAUTION: When using this method to analyze for 2,3,7,8–TCDD, all of the following operations must be performed in a limited-access laboratory with the analyst wearing full

protective covering for all exposed skin surfaces. See Section 4.2.

10.1 Mark the water meniscus on the side of the sample bottle for later determination of sample volume. Pour the entire sample into a 2–L separatory funnel.

10.2 Add 1.00 mL of internal standard spiking solution to the sample in the separatory funnel. If the final extract will be concentrated to a fixed volume below 1.00 mL (Section 12.3), only that volume of spiking solution should be added to the sample so that the final extract will contain 25 ng/mL of internal standard at the time of analysis.

10.3 Add 60 mL of methylene chloride to the sample bottle, seal, and shake 30 s to rinse the inner surface. Transfer the solvent to the separatory funnel and extract the sample by shaking the funnel for 2 min. with periodic venting to release excess pressure. Allow the organic layer to separate from the water phase for a minimum of 10 min. If the emulsion interface between layers is more than one-third the vmlume of the solvent layer, the analyst must employ mechanical techniques to complete the phase separation. The optimum technique depends upon the sample, but may include stirring, filtration of the emulsion through glass wool, centrifugation, or other physical methods. Collect the methylene chloride extract in a 250-mL Erlenmeyer flask.

10.4 Add a second 60-mL volume of methylene chloride to the sample bottle and repeat the extraction procedure a second time, combining the extracts in the Erlenmeyer flask. Perform a third extraction in the same manner.

10.5 Assemble a Kuderna-Danish (K–D) concentrator by attaching a 10-mL concentrator tube to a 500-mL evaporative flask. Other concentration devices or techniques may be used in place of the K–D concentrator if the requirements of Section 8.2 are met.

10.6 Pour the combined extract into the K–D concentrator. Rinse the Erlenmeyer flask with 20 to 30 mL of methylele chloride to complete the quantitative transfer.

10.7 Add one or two clean boiling chips to the evaporative flask and attach a three-ball Snyder column. Prewet the Snyder column by adding about 1 mL of methylene chloride to the top. Place the K–D apparatus on a hot water bath (60 to 65 °C) so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15 to 20 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches 1 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min.

10.8 Momentarily remove the Snyder column, add 50 mL of hexane and a new boiling chip, and reattach the Snyder column. Raise the temperature of the water bath to 85 to 90°C. Concentrate the extract as in Section 10.7, except use hexane to prewet the column. Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1 to 2 mL of hexane. A 5-mL syringe is recommended for this operation. Set aside the K–D glassware for reuse in Section 10.14.

10.9 Pour the hexane extract from the concentrator tube into a 125-mL separatory funnel. Rinse the concentrator tube four times with 10-mL aliquots of hexane. Combine all rinses in the 125-mL separatory funnel.

10.10 Add 50 mL of sodium hydroxide solution to the funnel and shake for 30 to 60 s. Discard the aqueous phase.

10.11 Perform a second wash of the organic layer with 50 mL of reagent water. Discard the aqueous phase.

10.12 Wash the hexane layer with a least two 50-mL aliquots of concentrated sulfuric acid. Continue washing the hexane layer with 50-mL aliquots of concentrated sulfuric acid until the acid layer remains colorless. Discard all acid fractions.

10.13 Wash the hexane layer with two 50-mL aliquots of reagent water. Discard the aqueous phases.

10.14 Transfer the hexane extract into a 125-mL Erlenmeyer flask containing 1 to 2 g of anhydrous sodium sulfate. Swirl the flask for 30 s and decant the hexane extract into the reassembled K–D apparatus. Complete the quantitative transfer with two 10-mL hexane rinses of the Erlenmeyer flask.

10.15 Replace the one or two clean boiling chips and concentrate the extract to 6 to 10 mL as in Section 10.8.

10.16 Add a clean boiling chip to the concentrator tube and attach a two-ball micro-Snyder column. Prewet the column by adding about 1 mL of hexane to the top. Place the micro-K–D apparatus on the water bath so that the concentrator tube is partially immersed in the hot water. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 5 to 10 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood. When the apparent volume of liquid reaches about 0.5 mL, remove the K–D apparatus and allow it to drain and cool for at least 10 min. Remove the micro-Snyder column and rinse its lower joint into the concentrator tube with 0.2 mL of hexane.

Adjust the extract volume to 1.0 mL with hexane. Stopper the concentrator tube and store refrigerated and protected from light if further processing will not be performed immediately. If the extract will be stored

longer than two days, it should be transferred to a Teflon-sealed screw-cap vial. If the sample extract requires no further cleanup, proceed with GC/MS analysis (Section 12). If the sample requires further cleanup, proceed to Section 11.

10.17 Determine the original sample volume by refilling the sample bottle to the mark and transferring the liquid to a 1000-mL graduated cylinder. Record the sample volume to the nearest 5 mL.

11. Cleanup and Separation

11.1 Cleanup procedures may not be necessary for a relatively clean sample matrix. If particular circumstances demand the use of a cleanup procedure, the analyst may use either procedure below or any other appropriate procedure.[1,5–7] However, the analyst first must demonstrate that the requirements of Section 8.2 can be met using the method as revised to incorporate the cleanup procedure. Two cleanup column options are offered to the analyst in this section. The alumina column should be used first to overcome interferences. If background problems are still encountered, the silica gel column may be helpful.

11.2 Alumina column cleanup for 2,3,7,8–TCDD:

11.2.1 Fill a 300 mm long × 10 mm ID chromatographic column with activated alumina to the 150 mm level. Tap the column gently to settle the alumina and add 10 mm of anhydrous sodium sulfate to the top.

11.2.2 Preelute the column with 50 mL of hexane. Adjust the elution rate to 1 mL/min. Discard the eluate and just prior to exposure of the sodium sulfate layer to the air, quantitatively transfer the 1.0-mL sample extract onto the column using two 2-mL portions of hexane to complete the transfer.

11.2.3 Just prior to exposure of the sodium sulfate layer to the air, add 50 mL of 3% methylene chloride/95% hexane (V/V) and continue the elution of the column. Discard the eluate.

11.2.4 Next, elute the column with 50 mL of 20% methylene chloride/80% hexane (V/V) into a 500-mL K–D flask equipped with a 10-mL concentrator tube. Concentrate the collected fraction to 1.0 mL as in Section 10.16 and analyze by GC/MS (Section 12).

11.3 Silica gel column cleanup for 2,3,7,8–TCDD:

11.3.1 Fill a 400 mm long × 11 mm ID chromatmgraphic column with silica gel to the 300 mm level. Tap the column gently to settle the silica gel and add 10 mm of anhydrous sodium sulfate to the top.

11.3.2 Preelute the column with 50 mL of 20% benzene/80% hexane (V/V). Adjust the elution rate to 1 mL/min. Discard the eluate and just prior to exposure of the sodium sulfate layer to the air, quantitatively transfer the 1.0-mL sample extract onto the column using two 2-mL portions of 20% benzene/80% hexane to complete the transfer.

11.3.3 Just prior to exposure of the sodium sulfate layer to the air, add 40 mL of 20% benzene/80% hexane to the column. Collect the eluate in a clean 500-mL K–D flask equipped with a 10-mL concentrator tube. Concentrate the collected fraction to 1.0 mL as in Section 10.16 and analyze by GC/MS.

12. GC/MS Analysis

12.1 Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are retention times and MDL that can be achieved under these conditions. Other capillary columns or chromatographic conditions may be used if the requirements of Sections 5.5.2 and 8.2 are met.

12.2 Analyze standards and samples with the mass spectrometer operating in the selected ion monitoring (SIM) mode using a dwell time to give at least seven points per peak. For LRMS, use masses at m/z 320, 322, and 257 for 2,3,7,8–TCDD and either m/z 328 for $^{37}Cl_4$ 2,3,7,8–TCDD or m/z 332 for $^{13}C_{12}$ 2,3,7,8–TCDD. For HRMS, use masses at m/z 319.8965 and 321.8936 for 2,3,7,8–TCDD and either m/z 327.8847 for $^{37}Cl_4$ 2,3,7,8–TCDD or m/z 331.9367 for $^{13}C_{12}$ 2,3,7,8–TCDD.

12.3 If lower detection limits are required, the extract may be carefully evaporated to dryness under a gentle stream of nitrogen with the concentrator tube in a water bath at about 40 °C. Conduct this operation immediately before GC/MS analysis. Redissolve the extract in the desired final volume of ortho-xylene or tetradecane.

12.4 Calibrate the system daily as described in Section 7.

12.5 Inject 2 to 5 µL of the sample extract into the gas chromatograph. The volume of calibration standard injected must be measured, or be the same as all sample injection volumes.

12.6 The presence of 2,3,7,8–TCDD is qualitatively confirmed if all of the following criteria are achieved:

12.6.1 The gas chromatographic column must resolve 2,3,7,8–TCDD from the other 21 TCDD isomers.

12.6.2 The masses for native 2,3,7,8–TCDD (LRMS-m/z 320, 322, and 257 and HRMS-m/z 320 and 322) and labeled 2,3,7,8–TCDD (m/z 328 or 332) must exhibit a simultaneous maximum at a retention time that matches that of native 2,3,7,8–TCDD in the calibration standard, with the performance specifications of the analytical system.

12.6.3 The chlorine isotope ratio at m/z 320 and m/z 322 must agree to within±10% of that in the calibration standard.

12.6.4 The signal of all peaks must be greater than 2.5 times the noise level.

12.7 For quantitation, measure the response of the m/z 320 peak for 2,3,7,8–TCDD

and the m/z 332 peak for $^{13}C_{12}$ 2,3,7,8–TCDD or the m/z 328 peak for $^{37}Cl_4$ 2,3,7,8–TCDD.

12.8 Co-eluting impurities are suspected if all criteria are achieved except those in Section 12.6.3. In this case, another SIM analysis using masses at m/z 257, 259, 320 and either m/a 328 or m/z 322 can be performed. The masses at m/z 257 and m/z 259 are indicative of the loss of one chlorine and one carbonyl group from 2,3,7,8–TCDD. If masses m/z 257 and m/z 259 give a chlorine isotope ratio that agrees to within ±10% of the same cluster in the calibration standards, then the presence of TCDD can be confirmed. Co-eluting DDD, DDE, and PCB residues can be confirmed, but will require another injection using the appropriate SIM masses or full repetitive mass scans. If the response for $^{37}Cl_4$ 2,3,7,8–TCDD at m/z 328 is too large, PCB contamination is suspected and can be confirmed by examining the response at both m/z 326 and m/z 328. The $^{37}Cl_4$ 2,3,7,8–TCDD internal standard gives negligible response at m/z 326. These pesticide residues can be removed using the alumina column cleanup procedure.

12.9 If broad background interference restricts the sensitivity of the GC/MS analysis, the analyst should employ additional cleanup procedures and reanalyze by GC/MS.

12.10 In those circumstances where these procedures do not yield a definitive conclusion, the use of high resolution mass spectrometry is suggested.[5]

13. Calculations

13.1 Calculate the concentration of 2,3,7,8–TCDD in the sample using the response factor (RF) determined in Section 7.1.2 and Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A)(V_t)}{(V_i)(V_s)}$$

Equation 2

where:

A_s=SIM response for 2,3,7,8–TCDD at m/z 320.

A_{is}=SIM response for the internal standard at m/z 328 or 332.

I_s=Amount of internal standard added to each extract (μg).

V_o=Volume of water extracted (L).

13.2 For each sample, calculate the percent recovery of the internal standard by comparing the area of the m/z peak measured in the sample to the area of the same peak in the calibration standard. If the recovery is below 50%, the analyst should review all aspects of his analytical technique.

13.3 Report results in μg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

14. Method Performance

14.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentration listed in Table 1 was obtained using reagent water.[14] The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

14.2 This method was tested by 11 laboratories using reagent water, drinking water, surface water, and three industrial wastewaters spiked at six concentrations over the range 0.02 to 0.20 μg/L.[15] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 3.

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TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMIT

Parameter	Retention time (min)	Method detection limit (μg/L)
2,3,7,8–TCDD	13.1	0.002

Column conditions: SP–2330 coated on a 60 m long × 0.25 mm ID glass column with hydrogen carrier gas at 40 cm/sec linear velocity, splitless injection using tetradecane. Column temperature held isothermal at 200°C for 1 min, then programmed at 8°C/min to 250 °C and held. Use of helium carrier gas will approximately double the retention time.

TABLE 2—QC ACCEPTANCE CRITERIA—METHOD 613

Parameter	Test conc. (μg/L)	Limit for s (μg/L)	Range for X (μg/L)	Range for P, P_s (%)
2,3,7,8–TCDD	0.100	0.0276	0.0523–0.1226	45–129

s=Standard deviation of four recovery measurements, in μg/L (Section 8.2.4).
X=Average recovery for four recovery measurements, in μg/L (Section 8.2.4).
P, P_s=Percent recovery measured (Section 8.3.2, Section 8.4.2).

NOTE: These criteria are based directly upon the method performance data in Table 3. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 3.

TABLE 3—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 613

Parameter	Accuracy, as recovery, X′ (μg/L)	Single analyst, precision, s_r' (μ/L)	Overall precision, S′ (μ/g/L)
2,3,7,8-TCDD	0.86C+0.00145	$0.13\bar{X}$+0.00129	$0.19\bar{X}$+0.00028

X′=Expected recovery for one or more measurements. of a sample containing a concentration of C, in μg/L.
s_r'=Expected single analyst standard deviation of measurements at an average concentration found of X, in μg/L.
S′=Expected interlaboratory standard deviation of measurements at an average concentration found of X, in μg/L.
C=True value for the concentration, in μg/L.
X=Average recovery found for measurements of samples containing a concentration of C, in μg/L.

METHOD 624—PURGEABLES

1. Scope and Application

1.1 This method covers the determination of a number of purgeable organics. The following parameters may be determined by this method:

Parameter	STORET No.	CAS No.
Benzene	34030	71–43–2
Bromodichloromethane	32101	75–27–4
Bromoform	32104	75–25–2
Bromomethane	34413	74–83–9
Carbon tetrachloride	32102	56–23–5
Chlorobenzene	34301	108–90–7
Chloroethane	34311	75–00–3
2-Chloroethylvinyl ether	34576	110–75–8
Chloroform	32106	67–66–3
Chloromethane	34418	74–87–3
Dibromochloromethane	32105	124–48–1
1,2-Dichlorobenzene	34536	95–50–1
1,3-Dichlorobenzene	34566	541–73–1
1,4-Dichlorobenzene	34571	106–46–7
1,1-Dichloroethane	34496	75–34–3
1,2-Dichloroethane	34531	107–06–2
1,1-Dichloroethane	34501	75–35–4
trans-1,2-Dichloroethene	34546	156–60–5
1,2-Dichloropropane	34541	78–87–5
cis-1,3-Dichloropropene	34704	10061–01–5
trans-1,3-Dichloropropene	34699	10061–02–6
Ethyl benzene	34371	100–41–4
Methylene chloride	34423	75–09–2
1,1,2,2-Tetrachloroethane	34516	79–34–5
Tetrachloroethene	34475	127–18–4
Toluene	34010	108–88–3
1,1,1-Trichloroethene	34506	71–55–6
1,1,2-Trichloroethene	34511	79–00–5
Trichloroethane	39180	79–01–6
Trichlorofluoromethane	34488	75–69–4
Vinyl chloride	39175	75–01–4

1.2 The method may be extended to screen samples for acrolein (STORET No. 34210, CAS No. 107–02–8) and acrylonitrile (STORET No. 34215, CAS No. 107–13–1), however, the preferred method for these two compounds in Method 603.

1.3 This is a purge and trap gas chromatographic/mass spectrometer (GC/MS) method applicable to the determination of the compounds listed above in municipal and industrial discharges as provided under 40 CFR 136.1.

1.4 The method detection limit (MDL, defined in Section 14.1)[1] for each parameter is listed in Table 1. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.5 Any modification to this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5. Depending upon the nature of the modification and the extent of intended use, the applicant may be required to demonstrate that the modifications will produce equivalent results when applied to relevant wastewaters.

1.6 This method is restricted to use by or under the supervision of analysts experienced in the operation of a purge and trap system and a gas chromatograph/mass spectrometer and in the interpretation of mass spectra. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 An inert gas is bubbled through a 5-mL water sample contained in a specially-designed purging chamber at ambient temperature. The purgeables are efficiently transferred from the aqueous phase to the vapor phase. The vapor is swept through a sorbent trap where the purgeables are trapped. After purging is completed, the trap is heated and backflushed with the inert gas to desorb the purgeables onto a gas chromatographic column. The gas chromatograph is temperature programmed to separate the purgeables which are then detected with a mass spectrometer.[2,3]

3. Interferences

3.1 Impurities in the purge gas, organic compounds outgassing from the plumbing ahead of the trap, and solvent vapors in the laboratory account for the majority of contamination problems. The analytical system must be demonstated to be free from contamination under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3. The use of non-Teflon plastic tubing, non-Teflon thread sealants, or flow controllers with rubber components in the purge and trap system should be avoided.

3.2 Samples can be contaminated by diffusion of volatile organics (particularly fluorocarbons and methylene chloride) through the septum seal into the sample during shipment and storage. A field reagent blank prepared from reagent water and carried through the sampling and handling protocol can serve as a check on such contamination.

3.3 Contamination by carry-over can occur whenever high level and low level samples are sequentially analyzed. To reduce carry-over, the purging device and sample syringe must be rinsed with reagent water between sample analyses. Whenever an unusually concentrated sample is encountered, it should be followed by an analysis of reagent water to check for cross contamination. For samples containing large amounts of water-soluble materials, suspended solids, high boiling compounds or high pureeable levels, it may be necessary to wash the purging device with a detergent solution, rinse it with distilled water, and then dry it in a 105 °C oven between analyses. The trap and other parts of the system are also subject to contamination; therefore, frequent bakeout and purging of the entire system may be required.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this methmd. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified[4–6] for the information of the analyst.

4.2. The following parameters covered by this method have been tentatively classified as known or suspected, human or mammalian carcinogens: benzene, carbon tetrachloride, chloroform, 1,4-dichlorobenzene, and vinyl chloride. Primary standards of these toxic compounds should be prepared in a hood. A NIOSH/MESA approved toxic gas respirator should be worn when the analyst handles high concentrations of these toxic compounds.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete sampling.

5.1.1 Vial—25-mL capacity or larger, equipped with a screw cap with a hole in the center (Pierce #13075 or equivalent). Detergent wash, rinse with tap and distilled water, and dry at 105 °C before use.

5.1.2 Septum—Teflon-faced silicane (Pierce #12722 or equivalent). Detergent wash, rinse with tap and distilled water, and dry at 105 °C for 1 h before use.

5.2 Purge and trap system—The purge and trap system consists of three separate pieces of equipment: A purging device, trap, and desorber. Several complete systems are now commercially available.

5.2.1 The purging device must be designed to accept 5-mL samples with a water column at least 3 cm deep. The gaseous head space between the water column and the trap must have a total volume of less than 15 mL. The purge gas must pass though the water column as finely divided bubbles with a diameter of less than 3 mm at the origin. The purge gas must be introduced no more than 5 mm from the base of the water column. The purging device illustrated in Figure 1 meets these design criteria.

5.2.2 The trap must be at least 25 cm long and have an inside diameter of at least 0.105 in. The trap must be packed to contain the following minimum lengths of adsorbents: 1.0 cm of methyl silicone coated packing (Section 6.3.2), 15 cm of 2,6-dyphenylene oxide polymer (Section 6.3.1), and 8 cm of silica gel (Section 6.3.3). The minimum specifications for the trap are illustrated in Figure 2.

5.2.3 The desorber should be capable of rapidly heating the trap to 180 °C. The polymer section of the trap should not be heated higher than 180 °C and the remaining sections should not exceed 200 °C. The desorber illustrated in Figure 2 meets these design criteria.

5.2.4 The purge and trap system may be assembled as a separate unit or be coupled to a gas chromatograph as illustrated in Figures 3 and 4.

5.3 GC/MS system:

5.3.1 Gas chromatograph—An analytical system complete with a temperature programmable gas chromatograph suitable for on-column injection and all required accessories including syringes, analytical columns, and gases.

5.3.2 Column—6 ft long × 0.1 in ID stainless steel or glass, packed with 1% SP–1000 on Carbopack B (60/80 mesh) or equivalent. This column was used to develop the method performance statements in Section 14. Guidelines for the use of alternate column packings are provided in Section 11.1.

5.3.3 Mass spectrometer—Capable of scanning from 20 to 260 amu every 7 s or less, utilizing 70 V (nominal) electron energy in the electron impact ionization mode, and producing a mass spectrum which meets all the criteria in Table 2 when 50 ng of 4-bromofluorobenzene (BFB) is injected through the GC inlet.

5.3.4 GC/MS interface—Any GC to MS interface that gives acceptable calibration points at 50 ng or less per injection for each of the parameters of interest and achieves all acceptable performance criteria (Section 10) may be used. GC to MS interfaces constructed of all glass or glass-lined materials are recommended. Glass can be deactivated by silanizing with dichlorodimethylsilane.

5.3.5 Data system—A computer system must be interfaced to the mass spectrometer that allows the continuous acquisition and storage on machine-readable media of all mass spectra obtained throughout the duration of the chromatographic program. The computer must have software that allows searching any GC/MS data file for specific m/z (masses) and plotting such m/z abundances versus time or scan number. This type of plot is defined as an Extracted Ion Current Profile (EICP). Software must also be available that allows integrating the abundance in any EICP between specified time or scan number limits.

5.4 Syringes—5-mL, glass hypodermic with Luerlok tip (two each), if applicable to the purging device.

5.5 Micro syringes—25-μL, 0.006 in. ID needle.

5.6 Syringe valve—2-way, with Luer ends (three each).

5.7 Syringe—5-mL, gas-tight with shut-off valve.

5.8 Bottle—15-mL, screw-cap, with Teflon cap liner.

5.9 Balance—Analytical, capable of accurately weighing 0.0001 g.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.1.1 Reagent water can be generated by passing tap water through a carbon filter bed containing about 1 lb of activated carbon (Filtrasorb–300, Calgon Corp., or equivalent).

6.1.2 A water purification system (Millipore Super–Q or equivalent) may be used to generate reagent water.

6.1.3 Reagent water may also be prepared by boiling water for 15 min. Subsequently, while maintaining the temperature at 90 °C, bubble a contaminant-free inert gas through the water for 1 h. While still hot, transfer the water to a narrow mouth screw-cap bottle and seal with a Teflon-lined septum and cap.

6.2 Sodium thiosulfate—(ACS) Granular.

6.3 Trap materials:

6.3.1 2,6-Diphenylene oxide polymer—Tenax, (60/80 mesh), chromatographic grade or equivalent.

6.3.2 Methyl silicone packing—3% OV–1 on Chromosorb-W (60/80 mesh) or equivalent.

6.3.3 Silica gel—35/60 mesh, Davison, grade-15 or equivalent.

6.4 Methanol—Pesticide quality or equivalent.

6.5 Stock standard solutions—Stock standard solutions may be prepared from pure standard materials or purchased as certified solutions. Prepare stock standard solutions in methanol using assayed liquids or gases as appropriate. Because of the toxicity of some of the compounds, primary dilutions of these materials should be prepared in a hood. A NIOSH/MESA approved toxic gas respirator should be used when the analyst handles high concentrations of such materials.

6.5.1 Place about 9.8 mL of methanol into a 10-mL ground glass stoppered volumetric flask. Allow the flask to stand, unstoppered, for about 10 min or until all alcohol wetted surfaces have dried. Weigh the flask to the nearest 0.1 mg.

6.5.2 Add the assayed reference material:

6.5.2.1 Liquids—Using a 100-µL syringe, immediately add two or more drops of assayed reference material to the flask, then reweigh. Be sure that the drops fall directly into the alcohol without contacting the neck of the flask.

6.5.2.2 Gases—To prepare standards for any of the four halocarbons that boil below 30 °C (bromomethane, chloroethane, chloromethane, and vinyl chloride), fill a 5-mL valved gas-tight syringe with the reference standard to the 5.0-mL mark. Lower the needle to 5 mm above the methanol meniscus. Slowly introduce the reference standard above the surface of the liquid (the heavy gas will rapidly dissolve in the methanol).

6.5.3 Reweigh, dilute to volume, stopper, then mix by inverting the flask several times. Calculate the concentration in µg/µL from the net gain in weight. When compound purity is assayed to be 96% or greater, the weight may be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards may be used at any concentration if they are certified by the manufacturer or by an independent source.

6.5.4 Transfer the stock standard solution into a Teflon-sealed screw-cap bottle. Store, with minimal headspace, at −10 to −20 °C and protect from light.

6.5.5 Prepare fresh standards weekly for the four gases and 2-chloroethylvinyl ether. All other standards must be replaced after one month, or sooner if comparison with check standards indicates a problem.

6.6 Secondary dilution standards—Using stock solutions, prepare secondary dilution standards in methanol that contain the compounds of interest, either singly or mixed together. The secondary dilution standards should be prepared at concentrations such that the aqueous calibration standards prepared in Section 7.3 will bracket the working range of the analytical system. Secondary dilution standards should be stored with minimal headspace and should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.7 Surrogate standard spiking solution—Select a minimum of three surrogate compounds from Table 3. Prepare stock standard solutions for each surrogate standard in methanol as described in Section 6.5. Prepare a surrogate standard spiking solution from these stock standards at a concentration of 15 µg/mL in water. Store the solutions at 4 °C in Teflon-sealed glass containers with a minimum of headspace. The solutions should be checked frequently for stability. The addition of 10 µL of this solution of 5 mL of sample or standard is equivalent to a concentration of 30 µg/L of each surrogate standard.

6.8 BFB Standard—Prepare a 25 µg/mL solution of BFB in methanol.

6.9 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Assemble a purge and trap system that meets the specifications in Section 5.2. Condition the trap overnight at 180 °C by backflushing with an inert gas flow of at least 20 mL/min. Condition the trap for 10 min once daily prior to use.

7.2 Connect the purge and trap system to a gas chromatograph. The gas chromatograph must be operated using temperature and flow rate conditions equivalent to those given in Table 1.

7.3 Internal standard calibration procedure—To use this approach, the analyst must select three or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standard is not affected by method or matrix interferences. Some recommended internal standards are listed in Table 3.

7.3.1 Prepare calibration standards at a minimum of three concentration levels for each parameter by carefully adding 20.0 µL of one or more secondary dilution standards to 50, 250, or 500 mL of reagent water. A 25-µL syringe with a 0.006 in. ID needle should be used for this operation. One of the calibration standards should be at a concentration near, but above, the MDL (Table 1) and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the GC/MS system. These aqueous standards can be stored up to 24 h, if held in sealed vials with zero headspace as described in Section 9.2. If not so stored, they must be discarded after 1 h.

7.3.2 Prepare a spiking solution containing each of the internal standards using the procedures described in Sections 6.5 and

6.6. It is recommended that the secondary dilution standard be prepared at a concentration of 15 µg/mL of each internal standard compound. The addition of 10 µL of this standard to 5.0 mL of sample or calibration standard would be equivalent to 30 µg/L.

7.3.3 Analyze each calibration standard according to Section 11, adding 10 µL of internal standard spiking solution directly to the syringe (Section 11.4). Tabulate the area response of the characteristic m/z against concentration for each compound and internal standard, and calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:

A_s=Area of the characteristic m/z for the parameter to be measured.

A_{is}=Area of the characteristic m/z for the inernal standard.

C_{is}=Concentration of the internal standard.

C_s=Concentration of the parameter to be measured.

If the RF value over the working range is a constant (<35% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.4 The working calibration curve or RF must be verified on each working day by the measurement of a QC check sample.

7.4.1 Prepare the QC check sample as described in Section 8.2.2.

7.4.2 Analyze the QC check sample according to the method beginning in Section 10.

7.4.3 For each parameter, compare the response (Q) with the corresponding calibration acceptance criteria found in Table 5. If the responses for all parameters of interest fall within the designated ranges, analysis of actual samples can begin. If any individual Q falls outside the range, proceed according to Section 7.4.4.

NOTE: The large number of parameters in Table 5 present a substantial probability that one or more will not meet the calibration acceptance criteria when all parameters are analyzed.

7.4.4 Repeat the test only for those parameters that failed to meet the calibration acceptance criteria. If the response for a parameter does not fall within the range in this second test, a new calibration curve or RF must be prepared for that parameter according to Section 7.3.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occurring in chromatography, the analyst is permitted certain options (detailed in Section 11.1) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Each day, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system are under control.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 5% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 5% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must spike all samples with surrogate standards to monitor continuing laboratory performance. This procedure is described in Section 8.5.

8.1.7 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.6.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing each parameter of interest at a concentration of 10 µg/mL in methanol. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample

concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Prepare a QC check sample to contain 20 µg/L of each parameter by adding 200 µL of QC check sample concentrate to 100 mL of reagent water.

8.2.3 Analyze four 5-mL aliquots of the well-mixed QC check sample according to the method beginning in Section 10.

8.2.4 Calculate the average recovery ($\bar{X}$) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter of interest using the four results.

8.2.5 For each parameter compare s and $\bar{X}$ with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 5. If s and $\bar{X}$ for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual $\bar{X}$ falls outside the range for accuracy, the system performance is unacceptable for that parameter.

NOTE: The large number of parameters in Table 5 present a substantial probability that one or more will fail at least one of the acceptance criteria when all parameters are analyzed.

8.2.6 When one or more of the parameters tested fail at least one of the acceptance criteria, the analyst must proceed according to Section 8.2.6.1 or 8.2.6.2.

8.2.6.1 Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.3.

8.2.6.2 Beginning with Section 8.2.3, repeat the test only for those parameters that failed to meet criteria. Repeated failure, however, will confirm a general problem with the measurement system. If this occurs, locate and correct the source of the problem and repeat the test for all compounds of interest beginning with Section 8.2.3.

8.3 The laboratory must, on an ongoing basis, spike at least 5% of the samples from each sample site being monitored to assess accuracy. For laboratories analyzing 1 to 20 samples per month, at least one spiked sample per month is required.

8.3.1 The concentration of the spike in the sample should be determined as follows:

8.3.1.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at 20 µg/L or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.2 Analyze one 5-mL sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second 5-mL sample aliquot with 10 µL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100(A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 5. These acceptance criteria wer calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[7] If spiking was performed at a concentration lower than 20 µg/L, the analyst must use either the QC acceptance criteria in Table 5, or optional QC acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recoveryof a parameter: (1) Calculate accuracy (X′) using the equation in Table 6, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 6, substituting X′ for X; (3) calculate the range for recovery at the spike concentration as (100 X′/T) (±2.44(100 S′/T)%.[7]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4 If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required anlaysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory. If the entire list of parameters in Table 5 must be measured in the sample in Section 8.3, the probability that the analysis of a QC check standard will be required is high. In this case the QC check standard should be routinely analyzed with the spiked sample.

8.4.1 Prepare the QC check standard by adding 10 µL of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 5 mL of reagent water. The QC check standard needs only to

contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_S) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_S) for each parameter with the corresponding QC acceptance criteria found in Table 5. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As a quality control check, the laboratory must spike all samples with the surrogate standard spiking solutions as described in Section 11.4, and calculate the percent recovery of each surrogate compound.

8.6 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent recovery interval from $P—2s_p$ to $P + 2s_p$. If P=90% and s_p=10%, for example, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each parameter a regular basis (e.g. after each five to ten new accuracy measurements).

8.7 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 All samples must be iced or refrigerated from the time of collection until analysis. If the sample contains residual chlorine, add sodium thiosulfate preservative (10 mg/40 mL is sufficient for up to 5 ppm Cl_2) to the empty sample bottle just prior to shipping to the sampling site. EPA Methods 330.4 and 330.5 may be used for measurement of residual chlorine.[8] Field test kits are available for this purpose.

9.2 Grab samples must be collected in glass containers having a total volume of at least 25 mL. Fill the sample bottle just to overflowing in such a manner that no air bubbles pass through the sample as the bottle is being filled. Seal the bottle so that no air bubbles are entrapped in it. If preservative has been added, shake vigorously for 1 min. Maintain the hermetic seal on the sample bottle until time of analysis.

9.3 Experimental evidence indicates that some aromatic compounds, notably benzene, toluene, and ethyl benzene are susceptible to rapid biological degradation under certain environmental conditions.[3] Refrigeration alone may not be adequate to preserve these compounds in wastewaters for more than seven days. For this reason, a separate sample should be collected, acidified, and analyzed when these aromatics are to be determined. Collect about 500 mL of sample in a clean container. Adjust the pH of the sample to about 2 by adding 1+1 HCl while stirring vigorously, Check pH with narrow range (1.4 to 2.8) pH paper. Fill a sample container as described in Section 9.2.

9.4 All samples must be analyzed within 14 days of collection.[3]

10. Daily GC/MS Performance Tests

10.1 At the beginning of each day that analyses are to be performed, the GC/MS system must be checked to see if acceptable performance criteria are achieved for BFB.[9] The performance test must be passed before any samples, blanks, or standards are analyzed, unless the instrument has met the DFTPP test described in Method 625 earlier in the day.[10]

10.2 These performance tests require the following instrumental parameters:

Electron Energy: 70 V (nominal)

Mass Range: 20 to 260 amu

Scan Time: To give at least 5 scans per peak but not to exceed 7 s per scan.

10.3 At the beginning of each day, inject 2 µL of BFB solution directly on the column. Alternatively, add 2 µL of BFB solution to 5.0 mL of reagent water or standard solution and analyze the solution according to section 11. Obtain a background-corrected mass spectrum of BFB and confirm that all the key m/z criteria in Table 2 are achieved. If all the criteria are not achieved, the analyst must retune the mass spectrometer and repeat the test until all criteria are achieved.

11. Sample Purging and Gas Chromatography

11.1 Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are retention times and MDL that can be achieved under these conditions. An example of the separations achieved by this column is shown in Figure 5. Other packed columns or chromatographic conditions may be used if the requirements of Section 8.2 are met.

11.2 After achieving the key m/z abundance criteria in Section 10, calibrate the system daiy as described in Section 7.

11.3 Adjust the purge gas (helium) flow rate to 40 mL/min. Attach the trap inlet to the purging device, and set the purge and trap system to purge (Figure 3). Open the syringe valve located on the purging device sample introduction needle.

11.4 Allow the sample to come to ambient temperature prior to introducing it into the syringe. Remove the plunger from a 5-mL syringe and attach a closed syringe valve. Open the sample bottle (or standard) and carefully pour the sample into the syringe barrel to just short of overflowing. Replace the syringe plunger and compress the sample. Open the syringe valve and vent any residual air while adjusting the sample volume to 5.0 mL. Since this process of taking an aliquot destroys the validity of the sample for future analysis, the analyst should fill a second syringe at this time to protect against possible loss of data. Add 10.0 µL of the surrogate spiking solution (Section 6.7) and 10.0 µL of the internal standard spiking solution (Section 7.3.2) through the valve bore, then close the valve. The surrogate and internal standards may be mixed and added as a single spiking solution.

11.5 Attach the syringe-syringe valve assembly to the syringe valve on the purging device. Open the syringe valves and inject the sample into the purging chamber.

11.6 Close both valves and purge the sample for 11.0±0.1 min at ambient temperature.

11.7 After the 11-min purge time, attach the trap to the chromatograph, adjust the purge and trap system to the desorb mode (Figure 4), and begin to temperature program the gas chromatograph. Introduce the trapped materials to the GC column by rapidly heating the trap to 180 °C while backflushing the trap with an inert gas between 20 and 60 mL/min for 4 min. If rapid heating of the trap cannot be achieved, the GC cloumn must be used as a secondary trap by cooling it to 30 °C (subambient temperature, if problems persist) instead of the initial program temperature of 45 °C.

11.8 While the trap is being desorbed into the gas chromatograph, empty the purging chamber using the sample introduction syringe. Wash the chamber with two 5-mL flushes of reagent water.

11.9 After desorbing the sample for 4 min, recondition the trap by returning the purge and trap system to the purge mode. Wait 15 s then close the syringe valve on the purging device to begin gas flow through the trap. The trap temperature should be maintained at 180 °C. After approximately 7 min, turn off the trap heater and open the syringe valve to stop the gas flow through the trap. When the trap is cool, the next sample can be analyzed.

11.10 If the response for any m/z exceeds the working range of the system, prepare a dilution of the sample with reagent water from the aliquot in the second syringe and reanalyze.

12. Qualitative Identification

12.1 Obtain EICPs for the primary m/z (Table 4) and at least two secondary masses for each parameter of interest. The following criteria must be met to make a qualitative identification:

12.1.1 The characteristic masses of each parameter of interest must maximize in the same or within one scan of each other.

12.1.2 The retention time must fall within ±30 s of the retention time of the authentic compound.

12.1.3 The relative peak heights of the three characteristic masses in the EICPs must fall within ±20% of the relative intensities of these masses in a reference mass spectrum. The reference mass spectrum can be obtained from a standard analyzed in the GC/MS system or from a reference library.

12.2 Structural isomers that have very similar mass spectra and less than 30 s difference in retention time, can be explicitly identified only if the resolution between authentic isomers in a standard mix is acceptable. Acceptable resolution is achieved if the baseline to valley height between the isomers is less than 25% of the sum of the two peak heights. Otherwise, structural isomers are identified as isomeric pairs.

13. Calculations

13.1 When a parameter has been identified, the quantitation of that parameter should be based on the integrated abundance from the EICP of the primary characteristic m/z given in Table 4. If the sample produces an interference for the primary m/z, use a secondary characteristic m/z to quantitate.

Calculate the concentration in the sample using the response factor (RF) determined in Section 7.3.3 and Equation 2.

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(C_{is})}{(A_{is})(RF)}$$

Equation 2

where:

A_S=Area of the characteristic m/z for the parameter or surrogate standard to be measured.

A_{is}=Area of the characteristic m/z for the internal standard.

C_{is}=Concentration of the internal standard.

13.2 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

14. Method Performance

14.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentrations listed in Table 1 were obtained using reagent water.[11] Similar results were achieved using representative wastewaters. The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

14.2 This method was tested by 15 laboratories using reagent water, drinking water, surface water, and industrial wastewaters spiked at six concentrations over the range 5–600 µg/L.[12] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 5.

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11. ''Method Detection Limit for Methods 624 and 625,'' Olynyk, P., Budde, W.L., and Eichelberger, J.W. Unpublished report, May 14, 1980.

12. ''EPA Method Study 29 EPA Method 624—Purgeables,'' EPA 600/4–84–054, National Technical Information Service, PB84–209915, Springfield, Virginia 22161, June 1984.

13.''Method Performance Data for Method 624,'' Memorandum from R. Slater and T. Pressley, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268, January 17, 1984.

TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS

Parameter	Retention time (min)	Method detection limit (µg/L)
Chloromethane	2.3	nd
Bromomethane	3.1	nd
Vinyl chloride	3.8	nd
Chloroethane	4.6	nd
Methylene chloride	6.4	2.8
Trichlorofluoromethane	8.3	nd
1,1-Dichloroethene	9.0	2.8
1,1-Dichloroethane	10.1	4.7
trans-1,2-Dichloroethene	10.8	1.6
Chloroform	11.4	1.6
1,2-Dichloroethane	12.1	2.8
1,1,1-Trichloroethane	13.4	3.8
Carbon tetrachloride	13.7	2.8
Bromodichloromethane	14.3	2.2
1,2-Dichloroproane	15.7	6.0
cis-1,3-Dichloropropene	15.9	5.0
Trichloroethene	16.5	1.9
Benzene	17.0	4.4
Dibromochloromethane	17.1	3.1
1,1,2-Trichloroethane	17.2	5.0
trans-1,3-Dichloropropene	17.2	nd
2-Chloroethylvinlyl ether	18.6	nd
Bromoform	19.8	4.7
1,1,2,2-Tetrachloroethane	22.1	6.9
Tetrachloroethene	22.2	4.1
Toluene	23.5	6.0
Chlorobenzene	24.6	6.0
Ethyl benzene	26.4	7.2
1,3-Dichlorobenzene	33.9	nd
1,2-Dichlorobenzene	35.0	nd

TABLE 1—CHROMATOGRAPHIC CONDITIONS AND METHOD DETECTION LIMITS—Continued

Parameter	Retention time (min)	Method detection limit (µg/L)
1,4-Dichlorobenzene	35.4	nd

Column conditions: Carbopak B (60/80 mesh) coated with 1% SP–1000 packed in a 6 ft by 0.1 in. ID glass column with helium carrier gas at 30 mL/min. flow rate. Column temperature held at 45°C for 3 min., then programmed at 8°C/min. to 220°C and held for 15 min.
nd=not determined.

TABLE 2—BFB KEY m/z ABUNDANCE CRITERIA

Mass	m/z Abundance criteria
50	15 to 40% of mass 95.
75	30 to 60% of mass 95.
95	Base Peak, 100% Relative Abundance.
96	5 to 9% of mass 95.
173	<2% of mass 174.
174	>50% of mass 95.
175	5 to 9% of mass 174.
176	>95% but <101% of mass 174.
177	5 to 9% of mass 176.

TABLE 3—SUGGESTED SURROGATE AND INTERNAL STANDARDS

Compound	Retention time (min)[a]	Primary m/z	Secondary masses
Benzene d-6	17.0	84	
4-Bromofluorobenzene	28.3	95	174, 176
1,2-Dichloroethane d-4	12.1	102	
1,4-Difluorobenzene	19.6	114	63, 88
Ethylbenzene d-5	26.4	111	
Ethylbenzene d-10	26.4	98	
Fluorobenzene	18.4	96	70
Pentafluorobenzene	23.5	168	
Bromochloromethane	9.3	128	49, 130, 51
2-Bromo-1-chloropropane	19.2	77	79, 156
1, 4-Dichlorobutane	25.8	55	90, 92

[a] For chromatographic conditions, see Table 1.

TABLE 4MDASH;CHARACTERISTIC MASSES FOR PURGEABLE ORGANICS

Parameter	Primary	Secondary
Chloromethane	50	52.
Bromomethane	94	96.
Vinyl chloride	62	64.
Chloroethane	64	66.
Methylene chloride	84	49, 51, and 86.
Trichlorofluoromethane	101	103.
1,1-Dichloroethene	96	61 and 98.
1,1-Dichloroethane	63	65, 83, 85, 98, and 100.
trans-1,2-Dichloroethene	96	61 and 98.
Chloroform	83	85.
1,2-Dichloroethane	98	62, 64, and 100.
1,1,1-Trichloroethane	97	99, 117, and 119.
Carbon tetrachloride	117	119 and 121.
Bromodichloromethane	127	83, 85, and 129.
1,2-Dichloropropane	112	63, 65, and 114.
trans-1,3-Dichloropropene	75	77.
Trichloroethene	130	95, 97, and 132.
Benzene	78	
Dibromochloromethane	127	129, 208, and 206.
1,1,2-Trichloroethane	97	83, 85, 99, 132, and 134.
cis-1,3-Dichloropropene	75	77.
2-Chloroethylvinyl ether	106	63 and 65.
Bromoform	173	171, 175, 250, 252, 254, and 256.
1,1,2,2-Tetrachloroethane	168	83, 85, 131, 133, and 166.
Tetrachloroethene	164	129, 131, and 166.
Toluene	92	91.
Chlorobenzene	112	114.
Ethyl benzene	106	91.
1,3-Dichlorobenzene	146	148 and 113.
1,2-Dichlorobenzene	146	148 and 113.
1,4-Dichlorobenzene	146	148 and 113.

TABLE 5—CALIBRATION AND QC ACCEPTANCE CRITERIA—METHOD 624[a]

Parameter	Range for Q (µ/g/L)	Limit for s (µ/g/L)	Range for $\bar{X}$ (µ/g/L)	Range for P, P_s (%)
Benzene	12.8 – 27.2	6.9	15.2 – 26.0	37 – 151
Bromodichloromethane	13.1 – 26.9	6.4	10.1 – 28.0	35 – 155
Bromoform	14.2 – 25.8	5.4	11.4 – 31.1	45 – 169
Bromomethane	2.8 – 37.2	17.9	D – 41.2	D – 242
Carbon tetrachloride	14.6 – 25.4	5.2	17.2 – 23.5	70 – 140
Chlorobenzene	13.2 – 26.8	6.3	16.4 – 27.4	37 – 160
Chloroethane	7.6 – 32.4	11.4	8.4 – 40.4	14 – 230
2-Chloroethylvinyl ether	D – 44.8	25.9	D – 50.4	D – 305
Chloroform	13.5 – 26.5	6.1	13.7 – 24.2	51 – 138
Chloromethane	D – 40.8	19.8	D – 45.9	D – 273
Dibromochloromethane	13.5 – 26.5	6.1	13.8 – 26.6	53 – 149
1,2-Dichlorobenzene	12.6 – 27.4	7.1	11.8 – 34.7	18 – 190
1,3-Dichlorobenzene	14.6 – 25.4	5.5	17.0 – 28.8	59 – 156
1,4-Dichlorobenzene	12.6 – 27.4	7.1	11.8 – 34.7	18 – 190
1,1-Dichloroethane	14.5 – 25.5	5.1	14.2 – 28.5	59 – 155
1,2-Dichloroethane	13.6 – 26.4	6.0	14.3 – 27.4	49 – 155
1,1-Dichlorothene	10.1 – 29.9	9.1	3.7 – 42.3	D – 234
trans-1,2-Dichloroethene	13.9 – 26.1	5.7	13.6 – 28.5	54 – 156

TABLE 5—CALIBRATION AND QC ACCEPTANCE CRITERIA—METHOD 624[a]—Continued

Parameter	Range for Q (μ/g/L)	Limit for s (μ/g/L)	Range for $\bar{X}$ (μ/g/L)	Range for P, P_s (%)
1,2-Dichloropropane	6.8 – 33.2	13.8	3.8 – 36.2	D – 210
cis-1,3-Dichloropropene	4.8 – 35.2	15.8	1.0 – 39.0	D – 227
trans-1,3-Dichloropropene	10.0 – 30.0	10.4	7.6 – 32.4	17 – 183
Ethyl benzene	11.8 – 28.2	7.5	17.4 – 26.7	37 – 162
Methylene chloride	12.1 – 27.9	7.4	D – 41.0	D – 221
1,1,2,2-Tetrachloroethane	12.1 – 27.9	7.4	13.5 – 27.2	46 – 157
Tetrachloroethene	14.7 – 25.3	5.0	17.0 – 26.6	64 – 148
Toluene	14.9 – 25.1	4.8	16.6 – 26.7	47 – 150
1,1,1-Trichloroethane	15.0 – 25.0	4.6	13.7 – 30.1	52 – 162
1,1,2-Trichloroethane	14.2 – 25.8	5.5	14.3 – 27.1	52 – 150
Trichloroethene	13.3 – 26.7	6.6	18.6 – 27.6	71 – 157
Trichlorofluoromethane	9.6 – 30.4	10.0	8.9 – 31.5	17 – 181
Vinyl chloride	0.8 – 39.2	20.0	D – 43.5	D – 251

Q= Concentration measured in QC check sample, in μg/L (Section 7.5.3).
s= Standard deviation of four recovery measurements, in μg/L (Section 8.2.4).
$\bar{X}$= Average recovery of four recovery measurements, in μg/L (Section 8.2.4).
P, P_s= Percent recovery measured, (Section 8.3.2, Section 8.4.2).
D= Detected; result must be greater than zero.
[a] Criteria were calculated assuming a QC check sample concentration of 20 μg/L.

NOTE: These criteria are based directly upon the method performance data in Table 6. Where necessary, the limits for recovery have been broadened to assure applicability of the limits to concentrations below those used to develop Table 6.

TABLE 6—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 624

Parameter	Accuracy, as recovery, $\bar{X}'$ (μg/L)	Single analyst precision, s_r' (μg/L)	Overall precision, S' (μg/L)
Benzene	0.93C+2.00	$0.26\bar{X} - 1.74$	$0.25\bar{X} - 1.33$
Bromodichloromethane	1.03C – 1.58	$0.15\bar{X}+0.59$	$0.20\bar{X}+1.13$
Bromoform	1.18C – 2.35	$0.12\bar{X}+0.36$	$0.17\bar{X}+1.38$
Bromomethane[a]	1.00C	$0.43\bar{X}$	$0.58\bar{X}$
Carbon tetrachloride	1.10C – 1.68	$0.12\bar{X}+0.25$	$0.11\bar{X}+0.37$
Chlorobenzene	0.98C+2.28	$0.16\bar{X} - 0.09$	$0.26\bar{X} - 1.92$
Chloroethane	1.18C+0.81	$0.14\bar{X}+2.78$	$0.29\bar{X}+1.75$
2–Chloroethylvinyl ether[a]	1.00C	$0.62\bar{X}$	$0.84\bar{X}$
Chloroform	0.93C+0.33	$0.16\bar{X}+0.22$	$0.18\bar{X}+0.16$
Chloromethane	1.03C+0.81	$0.37\bar{X}+2.14$	$0.58\bar{X}+0.43$
Dibromochloromethane	1.01C – 0.03	$0.17\bar{X} - 0.18$	$0.17\bar{X}+0.49$
1,2–Dichlorobenzene[b]	0.94C+4.47	$0.22\bar{X} - 1.45$	$0.30\bar{X} - 1.20$
1,3–Dichlorobenzene	1.06C+1.68	$0.14\bar{X} - 0.48$	$0.18\bar{X} - 0.82$
1,4–Dichlorobenzene[b]	0.94C+4.47	$0.22\bar{X} - 1.45$	$0.30\bar{X} - 1.20$
1,1–Dichloroethane	1.05C+0.36	$0.13\bar{X} - 0.05$	$0.16\bar{X}+0.47$
1,2–Dichloroethane	1.02C+0.45	$0.17\bar{X} - 0.32$	$0.21\bar{X} - 0.38$
1,1–Dichloroethene	1.12C+0.61	$0.17\bar{X}+1.06$	$0.43\bar{X} - 0.22$
trans–1,2,–Dichloroethene	1.05C+0.03	$0.14\bar{X}+0.09$	$0.19\bar{X}+0.17$
1,2–Dichloropropane[a]	1.00C	$0.33\bar{X}$	$0.45\bar{X}$
cis–1,3–Dichloropropene[a]	1.00C	$0.38\bar{X}$	$0.52\bar{X}$
trans–1,3–Dichloropropene[a]	1.00C	$0.25\bar{X}$	$0.34\bar{X}$
Ethyl benzene	0.98C+2.48	$0.14\bar{X}+1.00$	$0.26\bar{X} - 1.72$
Methylene chloride	0.87C+1.88	$0.15\bar{X}+1.07$	$0.32\bar{X}+4.00$
1,1,2,2–Tetrachloroethane	0.93C+1.76	$0.16\bar{X}+0.69$	$0.20\bar{X}+0.41$
Tetrachloroethene	1.06C+0.60	$0.13\bar{X} - 0.18$	$0.16\bar{X} - 0.45$
Toluene	0.98C+2.03	$0.15\bar{X} - 0.71$	$0.22\bar{X} - 1.71$
1,1,1–Trichloroethane	1.06C+0.73	$0.12\bar{X} - 0.15$	$0.21\bar{X} - 0.39$
1,1,2–Trichloroethane	0.95C+1.71	$0.14\bar{X}+0.02$	$0.18\bar{X}+0.00$
Trichloroethene	1.04C+2.27	$0.13\bar{X}+0.36$	$0.12\bar{X}+0.59$
Trichloroflouromethane	0.99C+0.39	$0.33\bar{X} - 1.48$	$0.34\bar{X} - 0.39$
Vinyl chloride	1.00C	$0.48\bar{X}$	$0.65\bar{X}$

$\bar{X}'$=Expected recovery for one or more measurements of a sample containing a concentration of C, in μg/L.
S_r'=Expected single analyst standard deviation of measurements at an average concentration found of$\bar{X}$, in μg/L.
S'=Expected interlaboratory standard deviation of measurements at an average concentration found of$\bar{X}$, in μg/L.
C=True value for the concentration, in μg/L.
$\bar{X}$=Average recovery found for measurements of samples containing a concentration of C, in μg/L.
[a] Estimates based upon the performance in a single laboratory.[13]
[b] Due to chromatographic resolution problems, performance statements for these isomers are based upon the sums of their concentrations.

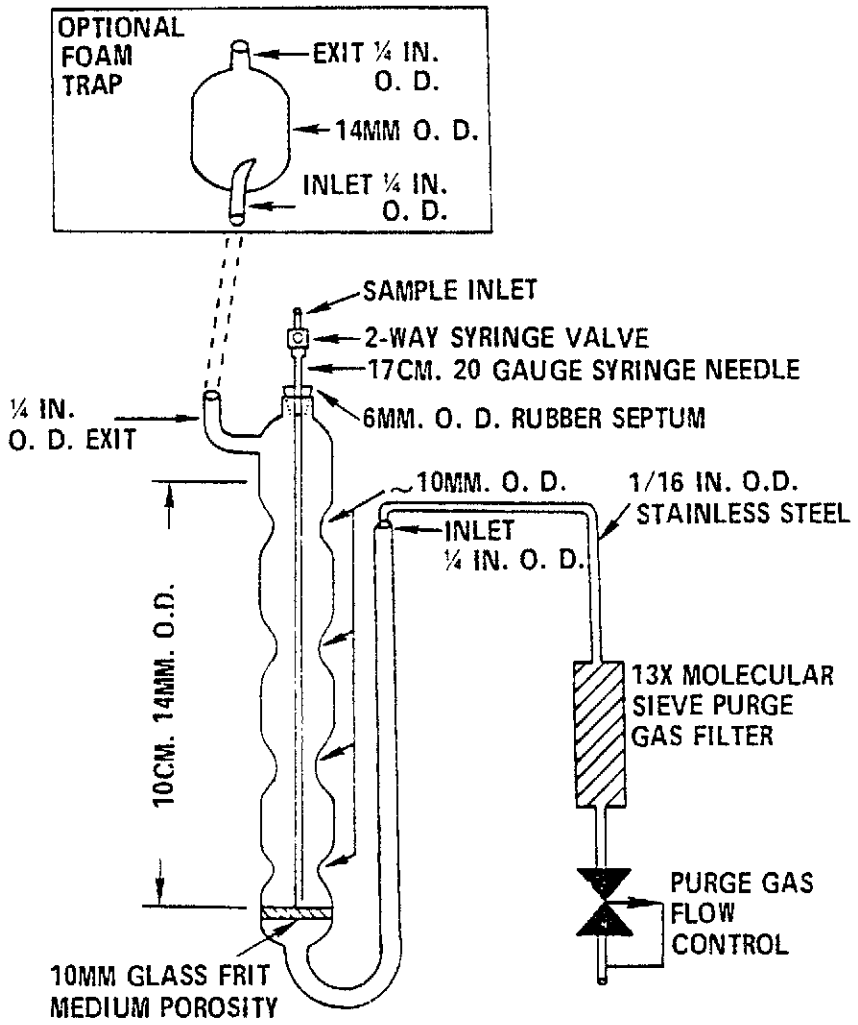

Figure 1. Purging device.

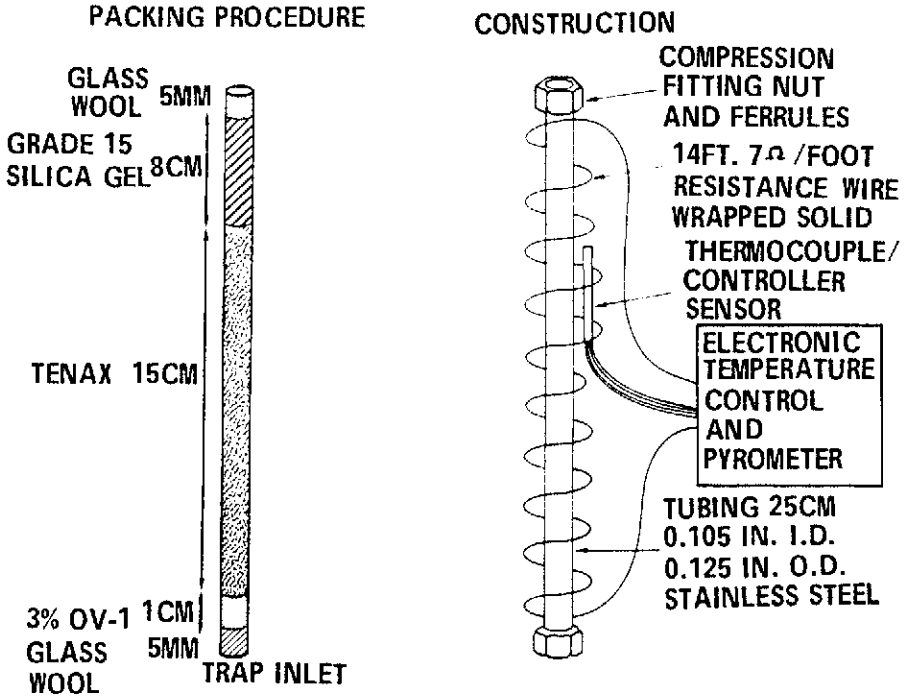

Figure 2. Trap packings and construction to include desorb capability.

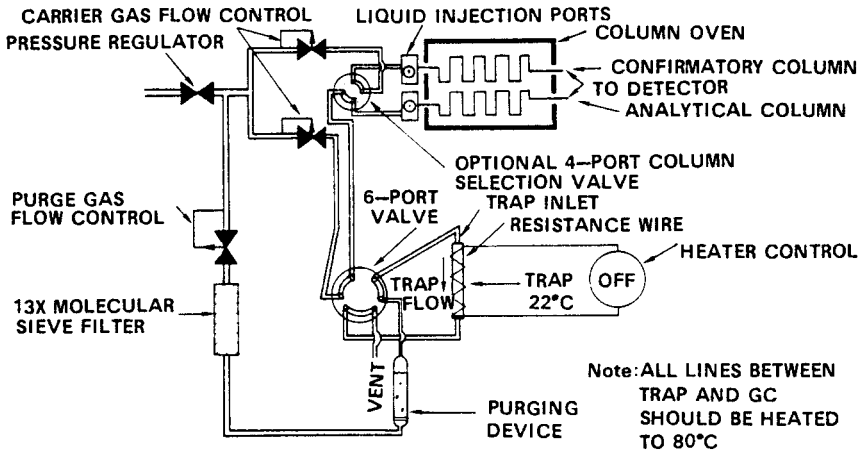

Figure 3. Purge and trap system - purge mode.

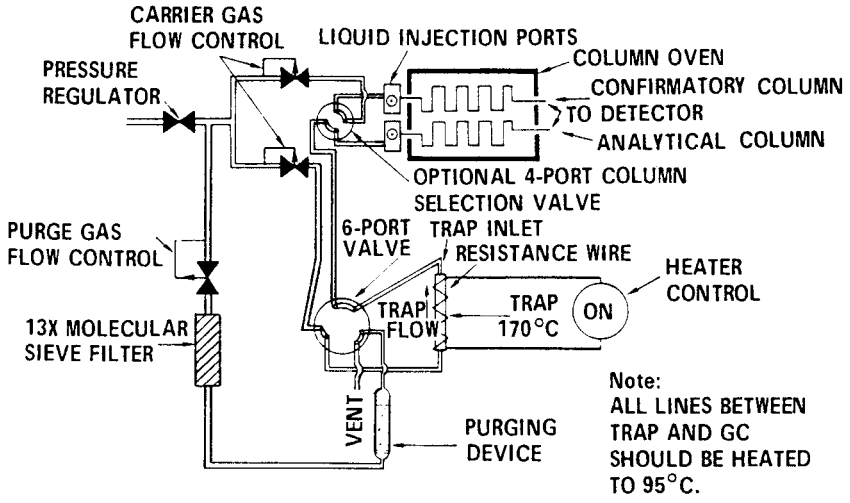

Figure 4. Purge and trap system - desorb mode.

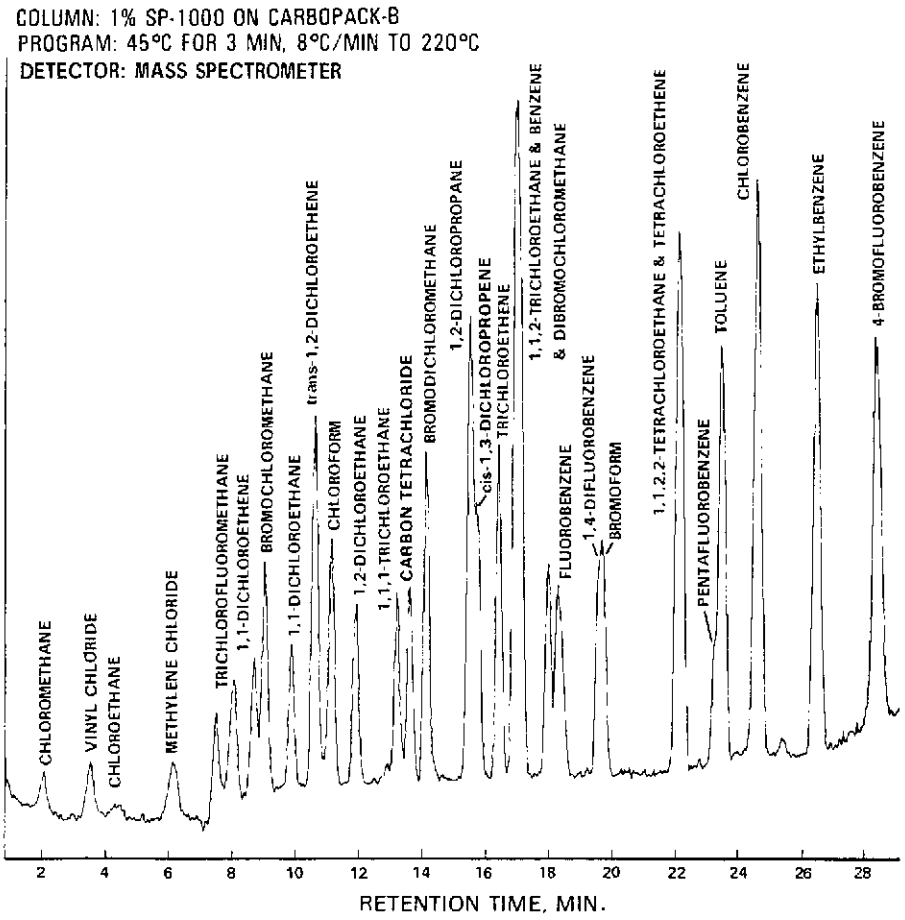

Figure 5. Gas chromatogram of volatile organics.

METHOD 625—BASE/NEUTRALS AND ACIDS

1. Scope and Application

1.1 This method covers the determination of a number of organic compounds that are partitioned into an organic solvent and are amenable to gas chromatography. The parameters listed in Tables 1 and 2 may be qualitatively and quantitatively determined using this method.

1.2 The method may be extended to include the parameters listed in Table 3. Benzidine can be subject to oxidative losses during solvent concentration. Under the alkaline conditions of the extraction step, α–BHC, γ–BHC, endosulfan I and II, and endrin are subject to decomposition. Hexachlorocyclopentadiene is subject to thermal decomposition in the inlet of the gas chromatograph, chemical reaction in acetone solution, and photochemical decomposition. N-nitrosodimethylamine is difficult to separate from the solvent under the chromatographic conditions described. N-nitrosodiphenylamine decomposes in the gas chromatographic inlet and cannot be separated from diphenylamine. The preferred method for each of these parameters is listed in Table 3.

1.3 This is a gas chromatographic/mass spectrometry (GC/MS) method[2,14] applicable to the determination of the compounds listed in Tables 1, 2, and 3 in municipal and industrial discharges as provided under 40 CFR 136.1.

1.4 The method detection limit (MDL, defined in Section 16.1)[1] for each parameter is listed in Tables 4 and 5. The MDL for a specific wastewater may differ from those listed, depending upon the nature of interferences in the sample matrix.

1.5 Any modification to this method, beyond those expressly permitted, shall be considered as a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5. Depending upon the nature of the modification and the extent of intended use, the applicant may be required to demonstrate that the modifications will produce equivalent results when applied to relevant wastewaters.

1.6 This method is restricted to use by or under the supervision of analysts experienced in the use of a gas chromatograph/mass spectrometer and in the interpretation of mass spectra. Each analyst must demonstrate the ability to generate acceptable results with this method using the procedure described in Section 8.2.

2. Summary of Method

2.1 A measured volume of sample, approximately 1–L, is serially extracted with methylene chloride at a pH greater than 11 and again at a pH less than 2 using a separatory funnel or a continuous extractor.[2] The methylene chloride extract is dried, concentrated to a volume of 1 mL, and analyzed by GC/MS. Qualitative identification of the parameters in the extract is performed using the retention time and the relative abundance of three characteristic masses (m/z). Quantitative analysis is performed using internal standard techniques with a single characteristic m/z.

3. Interferences

3.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that lead to discrete artifacts and/or elevated baselines in the total ion current profiles. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running laboratory reagent blanks as described in Section 8.1.3.

3.1.1 Glassware must be scrupulously cleaned.[3] Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. Solvent rinsing should be followed by detergent washing with hot water, and rinses with tap water and distilled water. The glassware should then be drained dry, and heated in a muffle furnace at 400 °C for 15 to 30 min. Some thermally stable materials, such as PCBs, may not be eliminated by this treatment. Solvent rinses with acetone and pesticide quality hexane may be substituted for the muffle furnace heating. Thmrough rinsing with such solvents usually eliminates PCB interference. Volumetric ware should not be heated in a muffle furnace. After drying and cooling, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Store inverted or capped with aluminum foil.

3.1.2 The use of high purity reagents and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

3.2 Matrix interferences may be caused by contaminants that are co-extracted from the sample. The extent of matrix interferences will vary considerably from source to source, depending upon the nature and diversity of the industrial complex or municipality being sampled.

3.3 The base-neutral extraction may cause significantly reduced recovery of phenol, 2-methylphenol, and 2,4-dimethylphenol. The analyst must recognize that results obtained under these conditions are minimum concentrations.

3.4 The packed gas chromatographic columns recommended for the basic fraction may not exhibit sufficient resolution for certain isomeric pairs including the following: anthracene and phenanthrene; chrysene and benzo(a)anthracene; and benzo(b)fluoranthene and benzo(k)fluoranthene. The gas chromatographic retention time and mass spectra for these pairs of compounds are not sufficiently different to make an unambiguous identification. Alternative techniques should be used to identify and quantify these specific compounds, such as Method 610.

3.5 In samples that contain an inordinate number of interferences, the use of chemical ionization (CI) mass spectrometry may make identification easier. Tables 6 and 7 give characteristic CI ions for most of the compounds covered by this method. The use of CI mass spectrometry to support electron ionization (EI) mass spectrometry is encouraged but not required.

4. Safety

4.1 The toxicity or carcinogenicity of each reagent used in this method have not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified[4–6] for the information of the analyst.

4.2 The following parameters covered by this method have been tentatively classified as known or suspected, human or mammalian carcinogens: benzo(a)anthracene, benzidine, 3,3′-dichlorobenzidine, benzo(a)pyrene, α–BHC, β–BHC, δ–BHC, γ–BHC, dibenzo(a,h)anthracene, N-nitrosodimethylamine, 4,4′–DDT, and polychlorinated biphenyls (PCBs). Primary standards of these toxic compounds should be prepared in a hood. A NIOSH/MESA approved toxic gas respirator should be worn when the analyst handles high concentrations of these toxic compounds.

5. Apparatus and Materials

5.1 Sampling equipment, for discrete or composit sampling.

5.1.1 Grab sample bottle—1–L or 1-gt, amber glass, fitted with a screw cap lined with Teflon. Foil may be substituted for Teflon if the sample is not corrosive. If amber bottles are not available, protect samples from light. The bottle and cap liner must be washed, rinsed with acetone or methylene chloride, and dried before use to minimize contamination.

5.1.2 Automatic sampler (optional)—The sampler must incorporate glass sample containers for the collection of a minimum of 250 mL of sample. Sample containers must be kept refrigerated at 4 °C and protected from light during compositing. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used. before use, however, the compressible tubing should be throughly rinsed with methanol, followed by repeated rinsings with distilled water to minimize the potential for contamination of the sample. An integrating flow meter is required to collect flow proportional composites.

5.2 Glassware (All specifications are suggested. Catalog numbers are included for illustration only.):

5.2.1 Separatory funnel—2–L, with Teflon stopcock.

5.2.2 Drying column—Chromatographic column, 19 mm ID, with coarse frit

5.2.3 Concentrator tube, Kuderna-Danish—10-mL, graduated (Kontes K–570050–1025 or equivalent). Calibration must be checked at the volumes employed in the test. Ground glass stopper is used to prevent evaporation of extracts.

5.2.4 Evaporative flask, Kuderna-Danish—500-mL (Kontes K–57001–0500 or equivalent). Attach to concentrator tube with springs.

5.2.5 Snyder column, Kuderna-Danish—Three all macro (Kontes K–503000–0121 or equivalent).

5.2.6 Snyder column, Kuderna-Danish—Two-ball macro (Kontes K–569001–0219 or equivalent).

5.2.7 Vials—10 to 15-mL, amber glass, with Teflon-lined screw cap.

5.2.8 Continuous liquid—liquid extractor—Equipped with Teflon or glass connecting joints and stopcocks requiring no lubrication. (Hershberg-Wolf Extractor, Ace Glass Company, Vineland, N.J., P/N 6841–10 or equivalent.)

5.3 Boiling chips—Approximately 10/40 mesh. Heat to 400 °C for 30 min of Soxhlet extract with methylene chloride.

5.4 Water bath—Heated, with concentric ring cover, capable of temperature control (±2°C). The bath should be used in a hood.

5.5 Balance—Analytical, capable of accurately weighing 0.0001 g.

5.6 GC/MS system:

5.6.1 Gas Chromatograph—An analytical system complete with a temperature programmable gas chromatograph and all required accessores including syringes, analytical columns, and gases. The injection port must be designed for on-column injection when using packed columns and for splitless injection when using capillary columns.

5.6.2 Column for base/neutrals—1.8 m long × 2 mm ID glass, packed with 3% SP–2250 on Supelcoport (100/120 mesh) or equivalent. This column was used to develop the method performance statements in Section 16. Guidelines for the use of alternate column packings are provided in Section 13.1.

5.6.3 Column for acids—1.8 m long × 2 mm ID glass, packed with 1% SP–1240DA on Supelcoport (100/120 mesh) or equivalent. This column was used to develop the method performance statements in Section 16. Guidelines for the use of alternate column packings are given in Section 13.1.

5.6.4 Mass spectrometer—Capable of scanning from 35 to 450 amu every 7 s or less, utilizing a 70 V (nominal) electron energy in the electron impact ionization mode, and producing a mass spectrum which meets all the criteria in Table 9 when 50 ng of decafluorotriphenyl phosphine (DFTPP; bis(perfluorophenyl) phenyl phosphine) is injected through the GC inlet.

5.6.5 GC/MS interface—Any GC to MS interface that gives acceptable calibration points at 50 ng per injection for each of the parameters of interest and achieves all acceptable performance criteria (Section 12) may be used. GC to MS interfaces constructed of all glass or glass-lined materials are recommended. Glass can be deactivated by silanizing with dichlorodimethylsilane.

5.6.6 Data system—A computer system must be interfaced to the mass spectrometer that allows the contiluous acquisition and storage on machine-readable media of all mass spectra obtained throughout the duration of the chromatographic program. The computer must have software that allows searching any GC/MS data file for specific m/z and plotting such m/z abundances versus time or scan number. This type of plot is defined as an Extracted Ion Current Profile (EICP). Software must also be available that

allows integrating the abundance in any EICP between specified time or scan number limits.

6. Reagents

6.1 Reagent water—Reagent water is defined as a water in which an interferent is not observed at the MDL of the parameters of interest.

6.2 Sodium hydroxide solution (10 N)—Dissolve 40 g of NaOH (ACS) in reagent water and dilute to 100 mL.

6.3 Sodium thiosulfate—(ACS) Granular.

6.4 Sulfuric acid (1+1)—Slowly, add 50 mL of H_2SO_4 (ACS, sp. gr. 1.84) to 50 mL of reagent water.

6.5 Acetone, methanol, methlylene chloride—Pesticide quality or equivalent.

6.6 Sodium sulfate—(ACS) Granular, anhydrous. Purify by heating at 400 °C for 4 h in a shallow tray.

6.7 Stock standard solutions (1.00 µg/µL)—standard solutions can be prepared from pure standard materials or purchased as certified solutions.

6.7.1 Prepare stock standard solutions by accurately weighing about 0.0100 g of pure material. Dissolve the material in pesticide quality acetone or other suitable solvent and dilute to volume in a 10-mL volumetric flask. Larger volumes can be used at the convenience of the analyst. When compound purity is assayed to be 96% or greater, the weight may be used without correction to calculate the concentration of the stock standard. Commercially prepared stock standards may be used at any concentration if they are certified by the manufacturer or by an independent source.

6.7.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4 °C and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

6.7.3 Stock standard solutions must be replaced after six months, or sooner if comparison with quality control check samples indicate a problem.

6.8 Surrogate standard spiking solution—Select a minimum of three surrogate compounds from Table 8. Prepare a surrogate standard spiking solution containing each selected surrogate compound at a concentration of 100 µg/mL in acetone. Addition of 1.00 mL of this solution to 1000 mL of sample is equivalent to a concentration of 100 µg/L of each surrogate standard. Store the spiking solution at 4 °C in Teflon-sealed glass container. The solution should be checked frequently for stability. The solution must be replaced after six months, or sooner if comparison with quality control check standards indicates a problem.

6.9 DFTPP standard—Prepare a 25 µg/mL solution of DFTPP in acetone.

6.10 Quality control check sample concentrate—See Section 8.2.1.

7. Calibration

7.1 Establish gas chromatographic operating parameters equivalent to those indicated in Table 4 or 5.

7.2 Internal standard calibration procedure—To use this approach, the analyst must select three or more internal standards that are similar in analytical behavior to the compounds of interest. The analyst must further demonstrate that the measurement of the internal standards is not affected by method or matrix interferences. Some recommended internal standards are listed in Table 8. Use the base peak m/z as the primary m/z for quantification of the standards. If interferences are noted, use one of the next two most intense m/z quantities for quantification.

7.2.1 Prepare calibration standards at a minimum of three concentration levels for each parameter of interest by adding appropriate volumes of one or more stock standards to a volumetric flask. To each calibration standard or standard mixture, add a known constant amount of one or more internal standards, and and dilute to volume with acetone. One of the calibration standards should be at a concentration near, but above, the MDL and the other concentrations should correspond to the expected range of concentrations found in real samples or should define the working range of the GC/MS system.

7.2.2 Using injections of 2 to 5 µL, analyze each calibration standard according to Section 13 and tabulate the area of the primary characteristic m/z (Tables 4 and 5) against concentration for each compound and internal standard. Calculate response factors (RF) for each compound using Equation 1.

$$RF = \frac{(A_s)(C_{is})}{(A_{is})(C_s)}$$

Equation 1

where:

A_s=Area of the characteristic m/z for the parameter to be measured.

A_{is}=Area of the characteristic m/z for the internal standard.

C_{is}=Concentration of the internal standard (µg/L).

C_s=Concentration of the parameter to be measured (µg/L).

If the RF value over the working range is a constant (<35% RSD), the RF can be assumed to be invariant and the average RF can be used for calculations. Alternatively, the results can be used to plot a calibration curve of response ratios, A_s/A_{is}, vs. RF.

7.3 The working calibration curve or RF must be verified on each working day by the

measurement of one or more calibration standards. If the response for any parameter varies from the predicted response by more than ±20%, the test must be repeated uning a fresh calibration standard. Alternatively, a new calibration curve must be prepared for that compound.

8. Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality control program. The minimum requirements of this program consist of an initial demonstration of laboratory capability and an ongoing analysis of spiked samples to evaluate and document data quality. The laboratory must maintain records to document the quality of data that is generated. Ongoing data quality checks are compared with established performance criteria to determine if the results of analyses meet the performance characteristics of the method. When results of sample spikes indicate atypical method performance, a quality control check standard must be analyzed to confirm that the measurements were performed in an in-control mode of operation.

8.1.1 The analyst must make an initial, one-time, demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 In recognition of advances that are occuring in chromatography, the analyst is permitted certain options (detailed in Sections 10.6 and 13.1) to improve the separations or lower the cost of measurements. Each time such a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2.

8.1.3 Before processing any samples, the analyst must analyze a reagent water blank to demonstrate that interferences from the analytical system and glassware are under control. Each time a set of samples is extracted or reagents are changed, a reagent water blank must be processed as a safeguard against laboratory contamination.

8.1.4 The laboratory must, on an ongoing basis, spike and analyze a minimum of 5% of all samples to monitor and evaluate laboratory data quality. This procedure is described in Section 8.3.

8.1.5 The laboratory must, on an ongoing basis, demonstrate through the analyses of quality control check standards that the operation of the measurement system is in control. This procedure is described in Section 8.4. The frequency of the check standard analyses is equivalent to 5% of all samples analyzed but may be reduced if spike recoveries from samples (Section 8.3) meet all specified quality control criteria.

8.1.6 The laboratory must maintain performance records to document the quality of data that is generated. This procedure is described in Section 8.5.

8.2 To establish the ability to generate acceptable accuracy and precision, the analyst must perform the following operations.

8.2.1 A quality control (QC) check sample concentrate is required containing each parameter of interest at a concentration of 100 µg/mL in acetone. Multiple solutions may be required. PCBs and multicomponent pesticides may be omitted from this test. The QC check sample concentrate must be obtained from the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory in Cincinnati, Ohio, if available. If not available from that source, the QC check sample concentrate must be obtained from another external source. If not available from either source above, the QC check sample concentrate must be prepared by the laboratory using stock standards prepared independently from those used for calibration.

8.2.2 Using a pipet, prepare QC check samples at a concentration of 100 µg/L by adding 1.00 mL of QC check sample concentrate to each of four 1–L aliquots of reagent water.

8.2.3 Analyze the well-mixed QC check samples according to the method beginning in Section 10 or 11.

8.2.4 Calculate the average recovery (X) in µg/L, and the standard deviation of the recovery (s) in µg/L, for each parameter using the four results.

8.2.5 For each parameter compare s and X with the corresponding acceptance criteria for precision and accuracy, respectively, found in Table 6. If s and X for all parameters of interest meet the acceptance criteria, the system performance is acceptable and analysis of actual samples can begin. If any individual s exceeds the precision limit or any individual X falls outside the range for accuracy, the system performance is unacceptable for that parameter.

NOTE: The large number of parameters in Table 6 present a substantial probability that one or more will fail at least one of the acceptance criteria when all parameters are analyzed.

8.2.6 When one or more of the parameters tested fail at least one of the acceptance criteria, the analyst must proceed according to Section 8.2.6.1 or 8.2.6.2.

8.2.6.1 Locate and correct the source of the problem and repeat the test for all parameters of interest beginning with Section 8.2.2.

8.2.6.2 Beginning with Section 8.2.2, repeat the test only for those parameters that failed to meet criteria. Repeated failure, however, will confirm a general problem with the measurement system. If this occurs, locate and correct the source of the problem and repeat the test for all compounds of interest beginning with Section 8.2.2.

8.3 The laboratory must, on an ongoing basis, spike at least 5% of the samples from each sample site being monitored to assess

accuracy. For laboratories analyzing 1 to 20 samples per month, at least one spiked sample per month is required.

8.3.1. The concentration of the spike in the sample should be determined as follows:

8.3.1 If, as in compliance monitoring, the concentration of a specific parameter in the sample is being checked against a regulatory concentration limit, the spike should be at that limit or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.2 If the concentration of a specific parameter in the sample is not being checked against a limit specific to that parameter, the spike should be at 100 µg/L or 1 to 5 times higher than the background concentration determined in Section 8.3.2, whichever concentration would be larger.

8.3.1.3 If it is impractical to determine background levels before spiking (e.g., maximum holding times will be exceeded), the spike concentration should be (1) the regulatory concentration limit, if any; or, if none (2) the larger of either 5 times higher than the expected background concentration or 100 µg/L.

8.3.2 Analyze one sample aliquot to determine the background concentration (B) of each parameter. If necessary, prepare a new QC check sample concentrate (Section 8.2.1) appropriate for the background concentrations in the sample. Spike a second sample aliquot with 1.0 mL of the QC check sample concentrate and analyze it to determine the concentration after spiking (A) of each parameter. Calculate each percent recovery (P) as 100(A–B)%/T, where T is the known true value of the spike.

8.3.3 Compare the percent recovery (P) for each parameter with the corresponding QC acceptance criteria found in Table 6. These acceptance criteria were calculated to include an allowance for error in measurement of both the background and spike concentrations, assuming a spike to background ratio of 5:1. This error will be accounted for to the extent that the analyst's spike to background ratio approaches 5:1.[7] If spiking was performed at a concentration lower than 100 µg/L, the analyst must use either the QC acceptance criteria in Table 6, or optional QC acceptance criteria calculated for the specific spike concentration. To calculate optional acceptance criteria for the recovery of a parameter: (1) Calculate accuracy (X′) using the equation in Table 7, substituting the spike concentration (T) for C; (2) calculate overall precision (S′) using the equation in Table 7, substituting X′ for X; (3) calculate the range for recovery at the spike concentration as (100 X′/T)±2.44(100 S′/T)%[7]

8.3.4 If any individual P falls outside the designated range for recovery, that parameter has failed the acceptance criteria. A check standard containing each parameter that failed the criteria must be analyzed as described in Section 8.4.

8.4 If any parameter fails the acceptance criteria for recovery in Section 8.3, a QC check standard containing each parameter that failed must be prepared and analyzed.

NOTE: The frequency for the required analysis of a QC check standard will depend upon the number of parameters being simultaneously tested, the complexity of the sample matrix, and the performance of the laboratory. If the entire list of single-component parameters in Table 6 must be measured in the sample in Section 8.3, the probability that the analysis of a QC check standard will be required is high. In this case the QC check standard should be routinely analyzed with the spike sample.

8.4.1 Prepare the QC check standard by adding 1.0 mL of QC check sample concentrate (Section 8.2.1 or 8.3.2) to 1 L of reagent water. The QC check standard needs only to contain the parameters that failed criteria in the test in Section 8.3.

8.4.2 Analyze the QC check standard to determine the concentration measured (A) of each parameter. Calculate each percent recovery (P_S) as 100 (A/T)%, where T is the true value of the standard concentration.

8.4.3 Compare the percent recovery (P_s) for each parameter with the corresponding QC acceptance criteria found in Table 6. Only parameters that failed the test in Section 8.3 need to be compared with these criteria. If the recovery of any such parameter falls outside the designated range, the laboratory performance for that parameter is judged to be out of control, and the problem must be immediately identified and corrected. The analytical result for that parameter in the unspiked sample is suspect and may not be reported for regulatory compliance purposes.

8.5 As part of the QC program for the laboratory, method accuracy for wastewater samples must be assessed and records must be maintained. After the analysis of five spiked wastewater samples as in Section 8.3, calculate the average percent recovery (P) and the standard deviation of the percent recovery (s_p). Express the accuracy assessment as a percent interval from $P-2s_p$ to $P+2s_p$. If P=90% and s_p=10%, for example, the accuracy interval is expressed as 70−110%. Update the accuracy assessment for each parameter on a regular basis (e.g. after each five to ten new accuracy measurements).

8.6 As a quality control check, the laboratory must spike all samples with the surrogate standard spiking solution as described in Section 10.2, and calculate the percent recovery of each surrogate compound.

8.7 It is recommended that the laboratory adopt additional quality assurance practices for use with this method. The specific practices that are most productive depend upon the needs of the laboratory and the nature of

the samples. Field duplicates may be analyzed to assess the precision of the environmental measurements. Whenever possible, the laboratory should analyze standard reference materials and participate in relevant performance evaluation studies.

9. Sample Collection, Preservation, and Handling

9.1 Grab samples must be collected in glass containers. Conventional sampling practices[8] should be followed, except that the bottle must not be prerinsed with sample before collection. Composite samples should be collected in refrigerated glass containers in accordance with the requirements of the program. Automatic sampling equipment must be as free as possible of Tygon tubing and other potential sources of contamination.

9.2 All sampling must be iced or refrigerated at 4 °C from the time of collection until extraction. Fill the sample bottles and, if residual chlorine is present, add 80 mg of sodium thiosulfate per liter of sample and mix well. EPA Methods 330.4 and 330.5 may be used for measurement of residual chlorine.[9] Field test kits are available for this purpose.

9.3 All samples must be extracted within 7 days of collection and completely analyzed within 40 days of extraction.

10. Separatory Funnel Extraction

10.1 Samples are usually extracted using separatory funnel techniques. If emulsions will prevent achieving acceptable solvent recovery with separatory funnel extractions, continuous extraction (Section 11) may be used. The separatory funnel extraction scheme described below assumes a sample volume of 1 L. When sample volumes of 2 L are to be extracted, use 250, 100, and 100-mL volumes of methylene chloride for the serial extraction of the base/neutrals and 200, 100, and 100-mL volumes of methylene chloride for the acids.

10.2 Mark the water meniscus on the side of the sample bottle for later determination of sample volume. Pour the entire sample into a 2–L separatory funnel. Pipet 1.00 mL of the surrogate standard spiking solution into the separatory funnel and mix well. Check the pH of the sample with wide-range pH paper and adjust to pH>11 with sodium hydroxide solution.

10.3 Add 60 mL of methylene chloride to the sample bottle, seal, and shake for 30 s to rinse the inner surface. Transfer the solvent to the separatory funnel and extract the sample by shaking the funnel for 2 min. with periodic venting to release excess pressure. Allow the organic layer to separate from the water phase for a minimum of 10 min. If the emulsion interface between layers is more than one-third the volume of the solvent layer, the analyst must employ mechanical techniques to complete the phase separation. The optimum technique depends upon the sample, but may include stirring, filtration of the emulsion through glass wool, centrifugation, or other physical methods. Collect the methylene chloride extract in a 250-mL Erlenmeyer flask. If the emulsion cannot be broken (recovery of less than 80% of the methylene chloride, corrected for the water solubility of methylene chloride), transfer the sample, solvent, and emulsion into the extraction chamber of a continuous extractor and proceed as described in Section 11.3.

10.4 Add a second 60-mL volume of methylene chloride to the sample bottle and repeat the extraction procedure a second time, combining the extracts in the Erlenmeyer flask. Perform a third extraction in the same manner. Label the combined extract as the base/neutral fraction.

10.5 Adjust the pH of the aqueous phase to less than 2 using sulfuric acid. Serially extract the acidified aqueous phase three times with 60-mL aliquots of methylene chloride. Collect and combine the extracts in a 250-mL Erlenmeyer flask and label the combined extracts as the acid fraction.

10.6 For each fraction, assemble a Kuderna-Danish (K–D) concentrator by attaching a 10-mL concentrator tube to a 500-mL evaporative flask. Other concentration devices or techniques may be used in place of the K–D concentrator if the requirements of Section 8.2 are met.

10.7 For each fraction, pour the combined extract through a solvent-rinsed drying column containing about 10 cm of anhydrous sodium sulfate, and collect the extract in the K–D concentrator. Rinse the Erlenmeyer flask and column with 20 to 30 mL of methylene chloride to complete the quantitative transfer.

10.8 Add one or two clean boiling chips and attach a three-ball Snyder column to the evaporative flask for each fraction. Prewet each Snyder column by adding about 1 mL of methylene chloride to the top. Place the K–D apparatus on a hot water bath (60 to 65 °C) so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15 to 20 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches 1 mL, remove the K–D apparatus from the water bath and allow it to drain and cool for at least 10 min. Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1 to 2 mL of methylene chloride. A 5-mL syringe is recommended for this operation.

10.9 Add another one or two clean boiling chips to the concentrator tube for each fraction and attach a two-ball micro-Snyder column. Prewet the Snyder column by adding about 0.5 mL of methylene chloride to the top. Place the K–D apparatus on a hot water bath (60 to 65 °C) so that the concentrator tube is partially immersed in hot water. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 5 to 10 min. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches about 0.5 mL, remove the K–D apparatus from the water bath and allow it to drain and cool for at least 10 min. Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with approximately 0.2 mL of acetone or methylene chloride. Adjust the final volume to 1.0 mL with the solvent. Stopper the concentrator tube and store refrigerated if further processing will not be performed immediately. If the extracts will be stored longer than two days, they should be transferred to Teflon-sealed screw-cap vials and labeled base/neutral or acid fraction as appropriate.

10.10 Determine the original sample volume by refilling the sample bottle to the mark and transferring the liquid to a 1000-mL graduated cylinder. Record the sample volume to the nearest 5 mL.

11. Continuous Extraction

11.1 When experience with a sample from a given source indicates that a serious emulsion problem will result or an emulsion is encountered using a separatory funnel in Section 10.3, a continuous extractor should be used.

11.2 Mark the water meniscus on the side of the sample bottle for later determination of sample volume. Check the pH of the sample with wide-range pH paper and adjust to pH >11 with sodium hydroxide solution. Transfer the sample to the continuous extractor and using a pipet, add 1.00 mL of surrogate standard spiking solution and mix well. Add 60 mL of methylene chloride to the sample bottle, seal, and shake for 30 s to rinse the inner surface. Transfer the solvent to the extractor.

11.3 Repeat the sample bottle rinse with an additional 50 to 100-mL portion of methylene chloride and add the rinse to the extractor.

11.4 Add 200 to 500 mL of methylene chloride to the distilling flask, add sufficient reagent water to ensure proper operation, and extract for 24 h. Allow to cool, then detach the distilling flask. Dry, concentrate, and seal the extract as in Sections 10.6 through 10.9.

11.5 Charge a clean distilling flask with 500 mL of methylene chloride and attach it to the continuous extractor. Carefully, while stirring, adjust the pH of the aqueous phase to less than 2 using sulfuric acid. Extract for 24 h. Dry, concentrate, and seal the extract as in Sections 10.6 through 10.9.

12. Daily GC/MS Performance Tests

12.1 At the beginning of each day that analyses are to be performed, the GC/MS system must be checked to see if acceptable performance criteria are achieved for DFTPP.[10] Each day that benzidine is to be determined, the tailing factor criterion described in Section 12.4 must be achieved. Each day that the acids are to be determined, the tailing factor criterion in Section 12.5 must be achieved.

12.2 These performance tests require the following instrumental parameters:

Electron Energy: 70 V (nominal)
Mass Range: 35 to 450 amu
Scan Time: To give at least 5 scans per peak but not to exceed 7 s per scan.

12.3 DFTPP performance test—At the beginning of each day, inject 2 µL (50 ng) of DFTPP standard solution. Obtain a background-corrected mass spectra of DFTPP and confirm that all the key m/z criteria in Table 9 are achieved. If all the criteria are not achieved, the analyst must retune the mass spectrometer and repeat the test until all criteria are achieved. The performance criteria must be achieved before any samples, blanks, or standards are analyzed. The taililg factor tests in Sections 12.4 and 12.5 may be performed simultaneously with the DFTPP test.

12.4 Column performance test for base/neutrals—At the beginning of each day that the base/neutral fraction is to be analyzed for benzidine, the benzidine tailing factor must be calculated. Inject 100 ng of benzidine either separately or as a part of a standard mixture that may contain DFTPP and calculate the tailing factor. The benzidine tailing factor must be less than 3.0. Calculation of the tailing factor is illustrated in Figure 13.[11] Replace the column packing if the tailing factor criterion cannot be achieved.

12.5 Column performance test for acids—At the beginning of each day that the acids are to be determined, inject 50 ng of pentachlorophenol either separately or as a part of a standard mix that may contain DFTPP. The tailing factor for pentachlorophenol must be less than 5. Calculation of the tailing factor is illustrated in Figure 13.[11] Replace the column packing if the tailing factor criterion cannot be achieved.

13. Gas Chromatography/Mass Spectrometry

13.1 Table 4 summarizes the recommended gas chromatographic operating conditions for the base/neutral fraction. Table 5 summarizes the recommended gas chromatographic

operating conditions for the acid fraction. Included in these tables are retention times and MDL that can be achieved under these conditions. Examples of the separations achieved by these columns are shown in Figures 1 through 12. Other packed or capillary (open-tubular) columns or chromatographic conditions may be used if the requirements of Section 8.2 are met.

13.2 After conducting the GC/MS performance tests in Section 12, calibrate the system daily as described in Section 7.

13.3 The internal standard must be added to sample extract and mixed thoroughly immediately before it is injected into the instrument. This procedure minimizes losses due to adsorption, chemical reaction or evaporation.

13.4 Inject 2 to 5 µL of the sample extract or standard into the GC/MS system using the solvent-flush technique.[12] Smaller (1.0 µL) volumes may be injected if automatic devices are employed. Record the volume injected to the nearest 0.05 µL.

13.5 If the response for any m/z exceeds the working range of the GC/MS system, dilute the extract and reanalyze.

13.6 Perform all qualitative and quantitative measurements as described in Sections 14 and 15. When the extracts are not being used for analyses, store them refrigerated at 4°C, protected from light in screw-cap vials equipped with unpierced Teflon-lined septa.

14. Qualitative Identification

14.1 Obtain EICPs for the primary m/z and the two other masses listed in Tables 4 and 5. See Section 7.3 for masses to be used with internal and surrogate standards. The following criteria must be met to make a qualitative identification:

14.1.1 The characteristic masses of each parameter of interest must maximize in the same or within one scan of each other.

14.1.2 The retention time must fall within ±30 s of the retention time of the authentic compound.

14.1.3 The relative peak heights of the three characteristic masses in the EICPs must fall within ±20% of the relative intensities of these masses in a reference mass spectrum. The reference mass spectrum can be obtained from a standard analyzed in the GC/MS system or from a reference library.

14.2 Structural isomers that have very similar mass spectra and less than 30 s difference in retention time, can be explicitly identified only if the resolution between authentic isomers in a standard mix is acceptable. Acceptable resolution is achieved if the baseline to valley height between the isomers is less than 25% of the sum of the two peak heights. Otherwise, structural isomers are identified as isomeric pairs.

15. Calculations

15.1 When a parameter has been identified, the quantitation of that parameter will be based on the integrated abundance from the EICP of the primary characteristic m/z in Tables 4 and 5. Use the base peak m/z for internal and surrogate standards. If the sample produces an interference for the primary m/z, use a secondary characteristic m/z to quantitate.

Calculate the concentration in the sample using the response factor (RF) determined in Section 7.2.2 and Equation 3.

$$\text{Concentration } (\mu g/L) = \frac{(A_s)(I_s)}{(A_{is})(RF)(V_o)}$$

Equation 3

where:

A_s=Area of the characteristic m/z for the parameter or surrogate standard to be measured.

A_{is}=Area of the characteristic m/z for the internal standard.

I_s=Amount of internal standard added to each extract (µg).

V_o=Volume of water extracted (L).

15.2 Report results in µg/L without correction for recovery data. All QC data obtained should be reported with the sample results.

16. Method Performance

16.1 The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero.[1] The MDL concentrations listed in Tables 4 and 5 were obtained using reagent water.[13] The MDL actually achieved in a given analysis will vary depending on instrument sensitivity and matrix effects.

16.2 This method was tested by 15 laboratories using reagent water, drinking water, surface water, and industrial wastewaters spiked at six concentrations over the range 5 to 1300 µg/L.[14] Single operator precision, overall precision, and method accuracy were found to be directly related to the concentration of the parameter and essentially independent of the sample matrix. Linear equations to describe these relationships are presented in Table 7.

17. Screening Procedure for 2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8–TCDD)

17.1 If the sample must be screened for the presence of 2,3,7,8–TCDD, it is recommended that the reference material not be handled in the laboratory unless extensive safety precautions are employed. It is sufficient to analyze the base/neutral extract by selected ion monitoring (SIM) GC/MS techniques, as follows:

17.1.1 Concentrate the base/neutral extract to a final volume of 0.2 ml.

17.1.2 Adjust the temperature of the base/neutral column (Section 5.6.2) to 220 °C.

17.1.3 Operate the mass spectrometer to acquire data in the SIM mode using the ions at m/z 257, 320 and 322 and a dwell time no greater than 333 milliseconds per mass.

17.1.4 Inject 5 to 7 µL of the base/neutral extract. Collect SIM data for a total of 10 min.

17.1.5 The possible presence of 2,3,7,8–TCDD is indicated if all three masses exhibit simultaneous peaks at any point in the selected ion current profiles.

17.1.6 For each occurrence where the possible presence of 2,3,7,8–TCDD is indicated, calculate and retain the relative abundances of each of the three masses.

17.2 False positives to this test may be caused by the presence of single or coeluting combinations of compounds whose mass spectra contain all of these masses.

17.3 Conclusive results of the presence and concentration level of 2,3,7,8–TCDD can be obtained only from a properly equipped laboratory through the use of EPA Method 613 or other approved alternate test procedures.

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TABLE 1—BASE/NEUTRAL EXTRACTABLES

Parameter	STORET No.	CAS No.
Acenaphthene	34205	83–32–9
Acenaphthylene	34200	208–96–8
Anthracene	34220	120–12–7
Aldrin	39330	309–00–2
Benzo(a)anthracene	34526	56–55–3
Benzo(b)fluoranthene	34230	205–99–2
Benzo(k)fluoranthene	34242	207–08–9
Benzo(a)pyrene	34247	50–32–8
Benzo(ghi)perylene	34521	191–24–2
Benzyl butyl phthalate	34292	85–68–7
β-BHC	39338	319–85–7
δ-BHC	34259	319–86–8
Bis(2-chloroethyl) ether	34273	111–44–4
Bis(2-chloroethoxy)methane	34278	111–91–1
Bis(2-ethylhexyl) phthalate	39100	117–81–7
Bis(2-chloroisopropyl) ether[a]	34283	108–60–1
4-Bromophenyl phenyl ether[a]	34636	101–55–3
Chlordane	39350	57–74–9
2-Chloronaphthalele	34581	91–58–7
4-Chlorophenyl phenyl ether	34641	7005–72–3
Chrysene	34320	218–01–9
4,4′-DDD	39310	72–54–8
4,4′-DDE	39320	72–55–9
4,4′-DDT	39300	50–29–3
Dibenzo(a,h)anthracene	34556	53–70–3
Di-n-butylphthalate	39110	84–74–2
1,3-Dichlorobenzene	34566	541–73–1
1,2-Dichlorobenzene	34536	95–50–1
1,4-Dichlorobenzene	34571	106–46–7
3,3′-Dichlorobenzidine	34631	91–94–1
Dieldrin	39380	60–57–1
Diethyl phthalate	34336	84–66–2
Dimethyl phthalate	34341	131–11–3
2,4-Dinitrotoluene	34611	121–14–2
2,6-Dinitrotoluene	34626	606–20–2
Di-n-octylphthalate	34596	117–84–0
Endosulfan sulfate	34351	1031–07–8

TABLE 1—BASE/NEUTRAL EXTRACTABLES—Continued

Parameter	STORET No.	CAS No.
Endrin aldehyde	34366	7421–93–4
Fluoranthene	34376	206–44–0
Fluorene	34381	86–73–7
Heptachlor	39410	76–44–8
Heptchlor epoxide	39420	1024–57–3
Hexachlorobenzene	39700	118–74–1
Hexachlorobutadiene	34391	87–68–3
Hexachloroethane	34396	67–72–1
Indeno(1,2,3-cd)pyrene	34403	193–39–5
Isophorone	34408	78–59–1
Naphthalene	34696	91–20–3
Nitrobenzene	34447	98–95–3
N-Nitrosodi-n-propylamine	34428	621–64–7
PCB-1016	34671	12674–11–2
PCB-1221	39488	11104–28–2
PCB-1232	39492	11141–16–5
PCB-1242	39496	53469–21–9
PCB-1248	39500	12672–29–6
PCB-1254	39504	11097–69–1
PCB-1260	39508	11096–82–5
Phenanthrene	34461	85–01–8
Pyrene	34469	129–00–0
Toxaphene	39400	8001–35–2
1,2,4-Trichlorobenzene	34551	120–82–1

[a] The proper chemical name is 2,2′-oxybis(1-chloropropane).

TABLE 2—ACID EXTRACTABLES

Parameter	STORET No.	CAS No.
4-Chloro-3-methylphenol	34452	59–50–7
2-Chlorophenol	34586	95–57–8
2,4-Dichlorophenol	34601	120–83–2
2,4-Dimethylphenol	34606	105–67–9
2,4-Dinitrophenol	34616	51–28–5
2-Methyl-4,6-dinitrophenol	34657	534–52–1
2-Nitrophenol	34591	88–75–5
4-Nitrophenol	34646	100–02–7
Pentachlorophenol	39032	87–86–5
Phenol	34694	108–95–2
2,4,6-Trichlorophenol	34621	88–06–2

TABLE 3—ADDITIONAL EXTRACTABLE PARAMETERS[a]

Parameter	STORET No.	CAS No.	Method
Benzidine	39120	92–87–5	605
β-BHC	39337	319–84–6	608
δ-BHC	39340	58–89–8	608
Endosulfan I	34361	959–98–8	608
Endosulfan II	34356	33213–65–9	608
Endrin	39390	72–20–8	608
Hexachlorocylopentadiene	34386	77–47–4	612
N-Nitrosodimethylamine	34438	62–75–9	607
N-Nitrosodiphenylamine	34433	86–30–6	607

[a] See Section 1.2.

TABLE 4—CHROMATOGRAPHIC CONDITIONS, METHOD DETECTION LIMITS, AND CHARACTERISTIC MASSES FOR BASE/NEUTRAL EXTRACTABLES

Parameter	Retention time (min)	Method detection limit (μg/L)	Characteristic masses					
			Electron impact			Chemical ionization		
			Primary	Secondary	Secondary	Methane	Methane	Methane
1,3-Dichlorobenzene	7.4	1.9	146	148	113	146	148	150
1,4-Dichlorobenzene	7.8	4.4	146	148	113	146	148	150
Hexachloroethane	8.4	1.6	117	201	199	199	201	203
Bis(2-chloroethyl) ether[a]	8.4	5.7	93	63	95	63	107	109
1,2-Dichlorobenzene	8.4	1.9	146	148	113	146	148	150
Bis(2-chloroisopropyl) ether[a]	9.3	5.7	45	77	79	77	135	137
N-Nitrosodi-n-propylamine	.....	.....	130	42	101	.....	.....	.....
Nitrobenzene	11.1	1.9	77	123	65	124	152	164
Hexachlorobutadiene	11.4	0.9	225	223	227	223	225	227
1,2,4-Trichlorobenzene	11.6	1.9	180	182	145	181	183	209
Isophorone	11.9	2.2	82	95	138	139	167	178
Naphthalene	12.1	1.6	128	129	127	129	157	169
Bis(2-chloroethoxy) methane	12.2	5.3	93	95	123	65	107	137
Hexachlorocyclopentadiene[a]	13.9	.....	237	235	272	235	237	239
2-Chloronaphthalene	15.9	1.9	162	164	127	163	191	203
Acenaphthylene	17.4	3.5	152	151	153	152	153	181
Acenaphthene	17.8	1.9	154	153	152	154	155	183
Dimethyl phthalate	18.3	1.6	163	194	164	151	163	164
2,6-Dinitrotoluene	18.7	1.9	165	89	121	183	211	223
Fluorene	19.5	1.9	166	165	167	166	167	195
4-Chlorophenyl phenyl ether	19.5	4.2	204	206	141	.....	.....	.....
2,4-Dinitrotoluene	19.8	5.7	165	63	182	183	211	223
Diethyl phthalate	20.1	1.9	149	177	150	177	223	251
N-Nitrosodiphenylamine[b]	20.5	1.9	169	168	167	169	170	198
Hexachlorobenzene	21.0	1.9	284	142	249	284	286	288
β-BHC[b]	21.1	.....	183	181	109	.....	.....	.....
4-Bromophenyl phenyl ether	21.2	1.9	248	250	141	249	251	277
δ-BHC[b]	22.4	.....	183	181	109	.....	.....	.....
Phenanthrene	22.8	5.4	178	179	176	178	179	207
Anthracene	22.8	1.9	178	179	176	178	179	207
β-BHC	23.4	4.2	181	183	109	.....	.....	.....

TABLE 4—CHROMATOGRAPHIC CONDITIONS, METHOD DETECTION LIMITS, AND CHARACTERISTIC MASSES FOR BASE/NEUTRAL EXTRACTABLES—Continued

Parameter	Retention time (min)	Method detection limit (μg/L)	Characteristic masses					
			Electron impact			Chemical ionization		
			Primary	Secondary	Secondary	Methane	Methane	Methane
Heptachlor	23.4	1.9	100	272	274	.....	.....	.....
δ-BHC	23.7	3.1	183	109	181	.....	.....	.....
Aldrin	24.0	1.9	66	263	220	.....	.....	.....
Dibutyl phthalate	24.7	2.5	149	150	104	149	205	279
Heptachlor epoxide	25.6	2.2	353	355	351	.....	.....	.....
Endosulfan I[b]	26.4	.....	237	339	341	.....	.....	.....
Fluoranthene	26.5	2.2	202	101	100	203	231	243
Dieldrin	27.2	2.5	79	263	279	.....	.....	.....
4,4′-DDE	27.2	5.6	246	248	176	.....	.....	.....
Pyrene	27.3	1.9	202	101	100	203	231	243
Endrin[b]	27.9	.....	81	263	82	.....	.....	.....
Endosulfan II[b]	28.6	.....	237	339	341	.....	.....	.....
4,4′-DDD	28.6	2.8	235	237	165	.....	.....	.....
Benzidine[b]	28.8	44	184	92	185	185	213	225
4,4′-DDT	29.3	4.7	235	237	165	.....	.....	.....
Endosulfan sulfate	29.8	5.6	272	387	422	.....	.....	.....
Endrin aldehyde	.....	.....	67	345	250	.....	.....	.....
Butyl benzyl phthalate	29.9	2.5	149	91	206	149	299	327
Bis(2-ethylhexyl) phthalate	30.6	2.5	149	167	279	149	.....	.....
Chrysene	31.5	2.5	228	226	229	228	229	257
Benzo(a)anthracene	31.5	7.8	228	229	226	228	229	257
3,3′-Dichlorobenzidine	32.2	16.5	252	254	126	.....	.....	.....
Di-n-octyl phthalate	32.5	2.5	149	.....	.....	.....	.....	.....
Benzo(b)fluoranthene	34.9	4.8	252	253	125	252	253	281
Benzo(k)fluoranthene	34.9	2.5	252	253	125	252	253	281
Benzo(a)pyrene	36.4	2.5	252	253	125	252	253	281
Indeno(1,2,3-cd) pyrene	42.7	3.7	276	138	277	276	277	305
Dibenzo(a,h)anthracene	43.2	2.5	278	139	279	278	279	307
Benzo(ghi)perylene	45.1	4.1	276	138	277	276	277	305
N-Nitrosodimethylamine[b]	.....	.....	42	74	44	.....	.....	.....
Chlordane[c]	19–30	.....	373	375	377	.....	.....	.....
Toxaphene[c]	25–34	.....	159	231	233	.....	.....	.....
PCB 1016[c]	18–30	.....	224	260	294	.....	.....	.....
PCB 1221[c]	15–30	30	190	224	260	.....	.....	.....
PCB 1232[c]	15–32	.....	190	224	260	.....	.....	.....
PCB 1242[c]	15–32	.....	224	260	294	.....	.....	.....
PCB 1248[c]	12–34	.....	294	330	262	.....	.....	.....
PCB 1254[c]	22–34	36	294	330	362	.....	.....	.....
PCB 1260[c]	23–32	.....	330	362	394	.....	.....	.....

[a] The proper chemical name is 2,2′-bisoxy(1-chloropropane).
[b] See Section 1.2.
[c] These compounds are mixtures of various isomers (See Figures 2 through 12). Column conditions: Supelcoport (100/120 mesh) coated with 3% SP–2250 packed in a 1.8 m long × 2 mm ID glass column with helium carrier gas at 30 mL/min. flow rate. Column temperature held isothermal at 50 °C for 4 min., then programmed at 8 °C/min. to 270 °C and held for 30 min.

TABLE 5—CHROMATOGRAPHIC CONDITIONS, METHOD DETECTION LIMITS, AND CHARACTERISTIC MASSES FOR ACID EXTRACTABLES

Parameter	Retention time (min)	Method detection limit (μg/L)	Characteristic masses					
			Electron Impact			Chemical ionization		
			Primary	Secondary	Secondary	Methane	Methane	Methane
2-Chlorophenol	5.9	3.3	128	64	130	129	131	157
2-Nitrophenol	6.5	3.6	139	65	109	140	168	122
Phenol	8.0	1.5	94	65	66	95	123	135
2,4-Dimethylphenol	9.4	2.7	122	107	121	123	151	163
2,4-Dichlorophenol	9.8	2.7	162	164	98	163	165	167
2,4,6-Trichlorophenol	11.8	2.7	196	198	200	197	199	201
4-Chloro-3-methylphenol	13.2	3.0	142	107	144	143	171	183
2,4-Dinitrophenol	15.9	42	184	63	154	185	213	225
2-Methyl-4,6-dinitrophenol	16.2	24	198	182	77	199	227	239
Pentachlorophenol	17.5	3.6	266	264	268	267	265	269

TABLE 5—CHROMATOGRAPHIC CONDITIONS, METHOD DETECTION LIMITS, AND CHARACTERISTIC MASSES FOR ACID EXTRACTABLES—Continued

Parameter	Retention time (min)	Method detection limit (μg/L)	Characteristic masses					
			Electron Impact			Chemical ionization		
			Primary	Secondary	Secondary	Methane	Methane	Methane
4-Nitrophenol	20.3	2.4	65	139	109	140	168	122

Column conditions: Supelcoport (100/120 mesh) coated with 1% SP–1240DA packed in a 1.8 m long × 2mm ID glass column with helium carrier gas at 30 mL/min. flow rate. Column temperature held isothermal at 70 °C for 2 min. then programmed at 8 °C/min. to 200 °C.

TABLE 6—QC ACCEPTANCE CRITERIA—METHOD 625

Parameter	Test concentration (μg/L)	Limits for s (μg/L)	Range for X(μg/L)	Range for P, P_s (Percent)
Acenaphthene	100	27.6	60.1–132.3	47–145
Acenaphthylene	100	40.2	53.5–126.0	33–145
Aldrin	100	39.0	7.2–152.2	D–166
Anthracene	100	32.0	43.4–118.0	27–133
Benzo(a)anthracene	100	27.6	41.8–133.0	33–143
Benzo(b)fluoranthene	100	38.8	42.0–140.4	24–159
Benzo(k)fluoranthene	100	32.3	25.2–145.7	11–162
Benzo(a)pyrene	100	39.0	31.7–148.0	17–163
Benzo(ghi)perylene	100	58.9	D–195.0	D–219
Benzyl butyl phthalate	100	23.4	D–139.9	D–152
β-BHC	100	31.5	41.5–130.6	24–149
δ-BHC	100	21.6	D–100.0	D–110
Bis(2-chloroethyl) ether	100	55.0	42.9–126.0	12–158
Bis(2-chloroethoxy)methane	100	34.5	49.2–164.7	33–184
Bis(2-chloroisopropyl) ether[a]	100	46.3	62.8–138.6	36–166
Bis(2-ethylhexyl) phthalate	100	41.1	28.9–136.8	8–158
4-Bromophenyl phenyl ether	100	23.0	64.9–114.4	53–127
2-Chloronaphthalene	100	13.0	64.5–113.5	60–118
4-Chlorophenyl phenyl ether	100	33.4	38.4–144.7	25–158
Chrysene	100	48.3	44.1–139.9	17–168
4,4′-DDD	100	31.0	D–134.5	D–145
4,4′-DDE	100	32.0	19.2–119.7	4–136
4,4′-DDT	100	61.6	D–170.6	D–203
Dibenzo(a,h)anthracene	100	70.0	D–199.7	D–227
Di-n-butyl phthalate	100	16.7	8.4–111.0	1–118
1,2-Dichlorobenzene	100	30.9	48.6–112.0	32–129
1,3-Dichlorobenzene	100	41.7	16.7–153.9	D–172
1,4,-Dichlorobenzene	100	32.1	37.3–105.7	20–124
3,3′-Dhlorobenzidine	100	71.4	8.2–212.5	D–262
Dieldrin	100	30.7	44.3–119.3	29–136
Diethyl phthalate	100	26.5	D–100.0	D–114
Dimethyl phthalate	100	23.2	D–100.0	D–112
2,4-Dinitrotoluene	100	21.8	47.5–126.9	39–139
2,6-Dinitrotoluene	100	29.6	68.1–136.7	50–158
Di-n-octyl phthalate	100	31.4	18.6–131.8	4–146
Endosulfan sulfate	100	16.7	D–103.5	D–107
Endrin aldehyde	100	32.5	D–188.8	D–209
Fluoranthene	100	32.8	42.9–121.3	26–137
Fluorene	100	20.7	71.6–108.4	59–121
Heptachlor	100	37.2	D–172.2	D–192
Heptachlor epoxide	100	54.7	70.9–109.4	26–155
Hexachlorobenzene	100	24.9	7.8–141.5	D–152
Hexachlorobutadiene	100	26.3	37.8–102.2	24–116
Hexachloroethane	100	24.5	55.2–100.0	40–113
Indeno(1,2,3-cd)pyrene	100	44.6	D–150.9	D–171
Isophorone	100	63.3	46.6–180.2	21–196
Naphthalene	100	30.1	35.6–119.6	21–133
Nitrobenzene	100	39.3	54.3–157.6	35–180
N-Nitrosodi-n-propylamine	100	55.4	13.6–197.9	D–230
PCB-1260	100	54.2	19.3–121.0	D–164
Phenanthrene	100	20.6	65.2–108.7	54–120
Pyrene	100	25.2	69.6–100.0	52–115
1,2,4-Trichlorobenzene	100	28.1	57.3–129.2	44–142
4-Chloro-3-methylphenol	100	37.2	40.8–127.9	22–147
2-Chlorophenol	100	28.7	36.2–120.4	23–134

TABLE 6—QC ACCEPTANCE CRITERIA—METHOD 625—Continued

Parameter	Test conclusion (μg/L)	Limits for s (μg/L)	Range for X(μg/L)	Range for P, P_s (Percent)
2,4-Dichlorophenol	100	26.4	52.5–121.7	39–135
2,4-Dimethylphenol	100	26.1	41.8–109.0	32–119
2,4-Dinitrophenol	100	49.8	D–172.9	D–191
2-Methyl-4,6-dinitrophenol	100	93.2	53.0–100.0	D–181
2-Nitrophenol	100	35.2	45.0–166.7	29–182
4-Nitrophenol	100	47.2	13.0–106.5	D–132
Pentachlorophenol	100	48.9	38.1–151.8	14–176
Phenol	100	22.6	16.6–100.0	5–112
2,4,6-Trichlorophenol	100	31.7	52.4–129.2	37–144

s=Standard deviation for four recovery measurements, in μg/L (Section 8.2.4).
X=Average recovery for four recovery measurements, in μg/L (Section 8.2.4).
P, P_s=Percent recovery measured (Section 8.3.2, Section 8.4.2).
D=Detected; result must be greater than zero.

NOTE: These criteria are based directly upon the method performance data in Table 7. Where necessary, the limits for recovery have been broadened to assure applicability of the limts to concentrations below those used to develop Table 7.

[a] The proper chemical name is 2,2′oxybis(1-chloropropane).

TABLE 7—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 625

Parameter	Accuracy, as recovery, X′ (μg/L)	Single analyst precision, S_r′ (μg/L)	Overall precision, S′ (μg/L)
Acenaphthene	0.96C=0.19	$0.15\bar{X}-0.12$	$0.21\bar{X}-0.67$
Acenaphthylene	0.89C=0.74	$0.24\bar{X}-1.06$	$0.26\bar{X}-0.54$
Aldrin	0.78C=1.66	$0.27\bar{X}-1.28$	$0.43\bar{X}=1.13$
Anthracene	0.80C=0.68	$0.21\bar{X}-0.32$	$0.27\bar{X}-0.64$
Benzo(a)anthracene	0.88C−0.60	$0.15\bar{X}=0.93$	$0.26\bar{X}-0.28$
Benzo(b)fluoranthene	0.93C−1.80	$0.22\bar{X}=0.43$	$0.29\bar{X}=0.96$
Benzo(k)fluoranthene	0.87C−1.56	$0.19\bar{X}=1.03$	$0.35\bar{X}=0.40$
Benzo(a)pyrene	0.90C−0.13	$0.22\bar{X}=0.48$	$0.32\bar{X}=1.35$
Benzo(ghi)perylene	0.98C−0.86	$0.29\bar{X}=2.40$	$0.51\bar{X}-0.44$
Benzyl butyl phthalate	0.66C−1.68	$0.18\bar{X}=0.94$	$0.53\bar{X}=0.92$
β-BHC	0.87C−0.94	$0.20\bar{X}-0.58$	$0.30\bar{X}-1.94$
δ-BHC	0.29C−1.09	$0.34\bar{X}=0.86$	$0.93\bar{X}-0.17$
Bis(2-chloroethyl) ether	0.86C−1.54	$0.35\bar{X}-0.99$	$0.35\bar{X}=0.10$
Bis(2-chloroethoxy)methane	1.12C−5.04	$0.16\bar{X}=1.34$	$0.26\bar{X}=2.01$
Bis(2-chloroisopropyl) ether[a]	1.03C−2.31	$0.24\bar{X}=0.28$	$0.25\bar{X}=1.04$
Bis(2-ethylhexyl) phthalate	0.84C−1.18	$0.26\bar{X}=0.73$	$0.36\bar{X}=0.67$
4-Bromophenyl phenyl ether	0.91C−1.34	$0.13\bar{X}=0.66$	$0.16\bar{X}=0.66$
2-Chloronaphthalene	0.89C=0.01	$0.07\bar{X}=0.52$	$0.13\bar{X}=0.34$
4-Chlorophenyl phenyl ether	0.91C=0.53	$0.20\bar{X}-0.94$	$0.30\bar{X}-0.46$
Chrysene	0.93C−1.00	$0.28\bar{X}=0.13$	$0.33\bar{X}-0.09$
4,4′-DDD	0.56C−0.40	$0.29\bar{X}-0.32$	$0.66\bar{X}-0.96$
4,4′-DDE	0.70C−0.54	$0.26\bar{X}-1.17$	$0.39\bar{X}-1.04$
4,4′-DDT	0.79C−3.28	$0.42\bar{X}=0.19$	$0.65\bar{X}-0.58$
Dibenzo(a,h)anthracene	0.88C=4.72	$0.30\bar{X}=8.51$	$0.59\bar{X}=0.25$
Di-n-butyl phthalate	0.59C=0.71	$0.13\bar{X}=1.16$	$0.39\bar{X}=0.60$
1,2-Dichlorobenzene	0.80C=0.28	$0.20\bar{X}=0.47$	$0.24\bar{X}=0.39$
1,3-Dichlorobenzene	0.86C−0.70	$0.25\bar{X}=0.68$	$0.41\bar{X}=0.11$
1,4-Dichlorobenzene	0.73C−1.47	$0.24\bar{X}=0.23$	$0.29\bar{X}=0.36$
3,3′-Dichlorobenzidine	1.23C−12.65	$0.28\bar{X}=7.33$	$0.47\bar{X}=3.45$
Dieldrin	0.82C−0.16	$0.20\bar{X}-0.16$	$0.26\bar{X}-0.07$
Diethyl phthalate	0.43C=1.00	$0.28\bar{X}=1.44$	$0.52\bar{X}=0.22$
Dimethyl phthalate	0.20C=1.03	$0.54\bar{X}=0.19$	$1.05\bar{X}-0.92$
2,4-Dinitrotoluene	0.92C−4.81	$0.12\bar{X}=1.06$	$0.21\bar{X}=1.50$
2,6-Dinitrotoluene	1.06C−3.60	$0.14\bar{X}=1.26$	$0.19\bar{X}=0.35$
Di-n-octyl phthalate	0.76C−0.79	$0.21\bar{X}=1.19$	$0.37\bar{X}=1.19$
Endosulfan sulfate	0.39C=0.41	$0.12\bar{X}=2.47$	$0.63\bar{X}-1.03$
Endrin aldehyde	0.76C−3.86	$0.18\bar{X}=3.91$	$0.73\bar{X}-0.62$
Fluoranthene	0.81C=1.10	$0.22\bar{X}-0.73$	$0.28\bar{X}-0.60$
Fluorene	0.90C−0.00	$0.12\bar{X}=0.26$	$0.13\bar{X}=0.61$
Heptachlor	0.87C−2.97	$0.24\bar{X}-0.56$	$0.50\bar{X}-0.23$
Heptachlor epoxide	0.92C−1.87	$0.33\bar{X}-0.46$	$0.28\bar{X}=0.64$
Hexachlorobenzene	0.74C=0.66	$0.18\bar{X}-0.10$	$0.43\bar{X}-0.52$
Hexachlorobutadiene	0.71C−1.01	$0.19\bar{X}=0.92$	$0.26\bar{X}=0.49$
Hexachloroethane	0.73C−0.83	$0.17\bar{X}=0.67$	$0.17\bar{X}=0.80$
Indeno(1,2,3-cd)pyrene	0.78C−3.10	$0.29\bar{X}=1.46$	$0.50\bar{X}=0.44$
Isophorone	1.12C=1.41	$0.27\bar{X}=0.77$	$0.33\bar{X}=0.26$
Naphthalene	0.76C=1.58	$0.21\bar{X}-0.41$	$0.30\bar{X}-0.68$

TABLE 7—METHOD ACCURACY AND PRECISION AS FUNCTIONS OF CONCENTRATION—METHOD 625—Continued

Parameter	Accuracy, as recovery, X′ (μg/L)	Single analyst precision, s_r′ (μg/L)	Overall precision, S′ (μg/L)
Nitrobenzene	1.09C − 3.05	0.19$\bar{X}$=0.92	0.27$\bar{X}$=0.21
N-Nitrosodi-n-propylamine	1.12C − 6.22	0.27$\bar{X}$=0.68	0.44$\bar{X}$=0.47
PCB–1260	0.81C − 10.86	0.35$\bar{X}$=3.61	0.43$\bar{X}$=1.82
Phenanthrene	0.87C − 0.06	0.12$\bar{X}$=0.57	0.15$\bar{X}$=0.25
Pyrene	0.84C − 0.16	0.16$\bar{X}$=0.06	0.15$\bar{X}$=0.31
1,2,4-Trichlorobenzene	0.94C − 0.79	0.15$\bar{X}$=0.85	0.21$\bar{X}$=0.39
4-Chloro-3-methylphenol	0.84C=0.35	0.23$\bar{X}$=0.75	0.29$\bar{X}$=1.31
2-Chlorophenol	0.78C=0.29	0.18$\bar{X}$=1.46	0.28$\bar{X}$=0.97
2,4-Dichlorophenol	0.87C=0.13	0.15$\bar{X}$=1.25	0.21$\bar{X}$=1.28
2,4-Dimethylphenol	0.71C=4.41	0.16$\bar{X}$=1.21	0.22$\bar{X}$=1.31
2,4-Dinitrophenol	0.81C − 18.04	0.38$\bar{X}$=2.36	0.42$\bar{X}$=26.29
2-Methyl-4,6-Dinitrophenol	1.04C − 28.04	0.05$\bar{X}$=42.29	0.26$\bar{X}$=23.10
2-Nitrophenol	1.07C − 1.15	0.16$\bar{X}$=1.94	0.27$\bar{X}$=2.60
4-Nitrophenol	0.61C − 1.22	0.38$\bar{X}$=2.57	0.44$\bar{X}$=3.24
Pentachlorophenol	0.93C=1.99	0.24$\bar{X}$=3.03	0.30$\bar{X}$=4.33
Phenol	0.43C=1.26	0.26$\bar{X}$=0.73	0.35$\bar{X}$=0.58
2,4,6-Trichlorophenol	0.91C − 0.18	0.16$\bar{X}$=2.22	0.22$\bar{X}$=1.81

X′=Expected recovery for one or more measurements of a sample containing a concentration of C, in μg/L.
s_r′=Expected single analyst standard deviation of measurements at an average concentration found of $\bar{X}$, in μg/L.
S′= Expected interlaboratory standard deviation of measurements at an average concentration found of X, in μg/L.
C= True value for the concentration, in μg/L.
X= Average recovery found for measurements of samples containing a concentration of C, in μg/L.
[a] The proper chemical name is 2,2′oxybis(1-chloropropane).

TABLE 8—SUGGESTED INTERNAL AND SURROGATE STANDARDS

Base/neutral fraction	Acid fraction
Aniline-d_5	2-Fluorophenol.
Anthracene-d_{10}	Pentafluorophenol.
Benzo(a)anthracene-d_{12}	Phenol-d_5
4,4′-Dibromobiphenyl	2-Perfluoromethyl phenol.
4,4′-Dibromooctafluorobiphenyl.	
Decafluorobiphenyl	
2,2[1]-Difluorobiphenyl	
4-Fluoroaniline	
1-Fluoronaphthalene	
2-Fluoronaphthalene	
Naphthalene-d_8	
Nitrobenzene-d_5	
2,3,4,5,6-Pentafluorobiphenyl	
Phenanthrene-d_{10}	
Pyridine-d_5	

TABLE 9—DFTPP KEY MASSES AND ABUNDANCE CRITERIA

Mass	m/z Abundance criteria
51	30–60 percent of mass 198.
68	Less than 2 percent of mass 69.
70	Less than 2 percent of mass 69.
127	40–60 percent of mass 198.
197	Less than 1 percent of mass 198.
198	Base peak, 100 percent relative abundance.
199	5–9 percent of mass 198.
275	10–30 percent of mass 198.
365	Greater than 1 percent of mass 198.
441	Present but less than mass 443.
442	Greater than 40 percent of mass 198.
443	17–23 percent of mass 442.

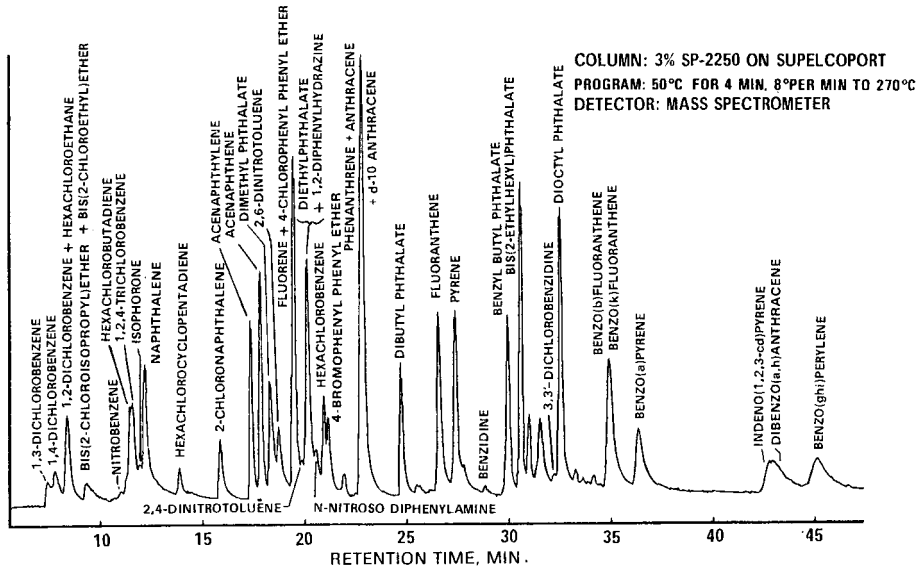


Figure 1. Gas chromatogram of base/neutral fraction.

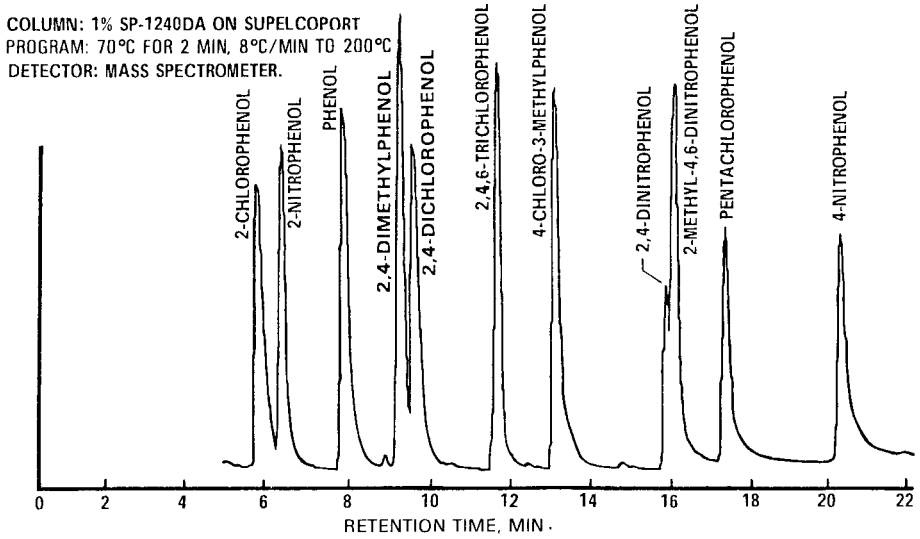


Figure 2. Gas chromatogram of acid fraction.

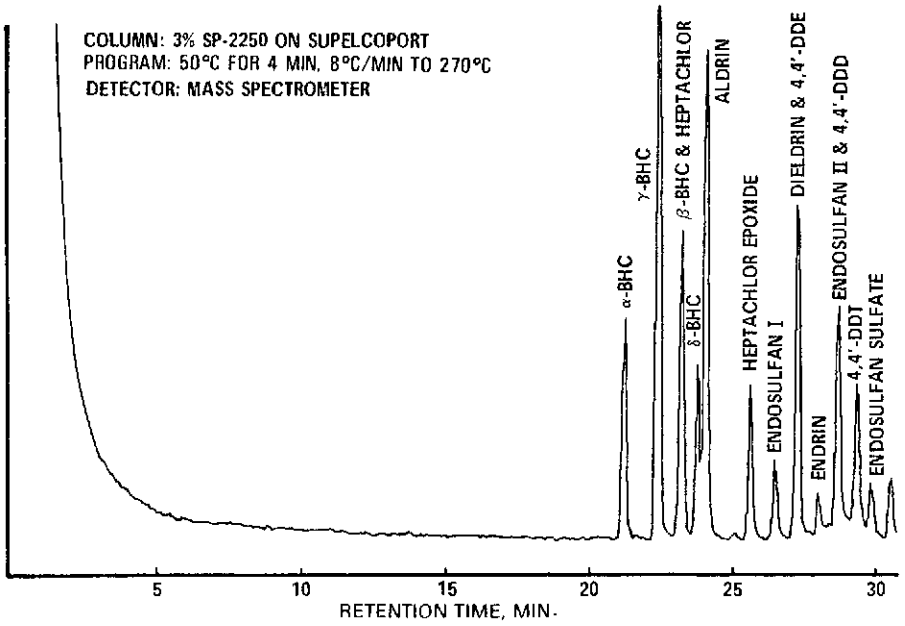


Figure 3. Gas chromatogram of pesticide fraction.

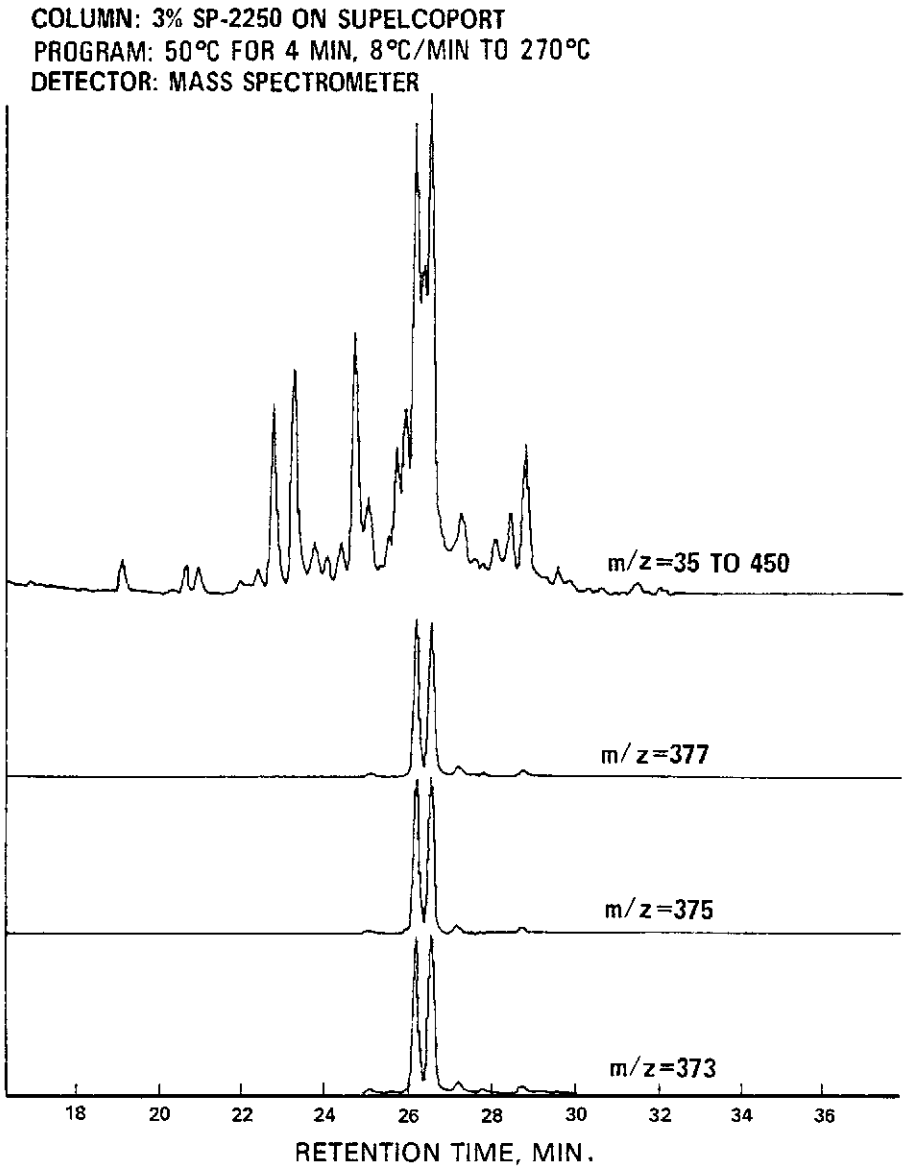


Figure 4. Gas chromatogram of chlordane.

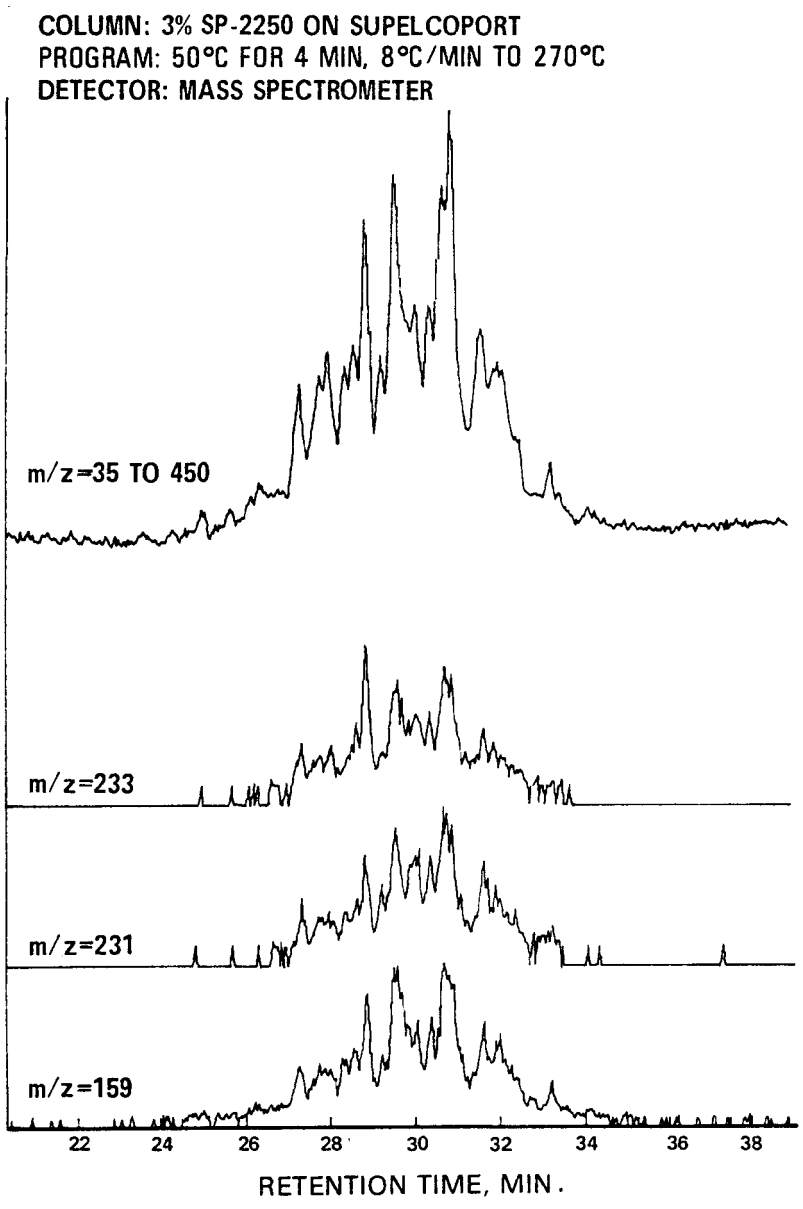


Figure 5. Gas chromatogram of toxaphene.

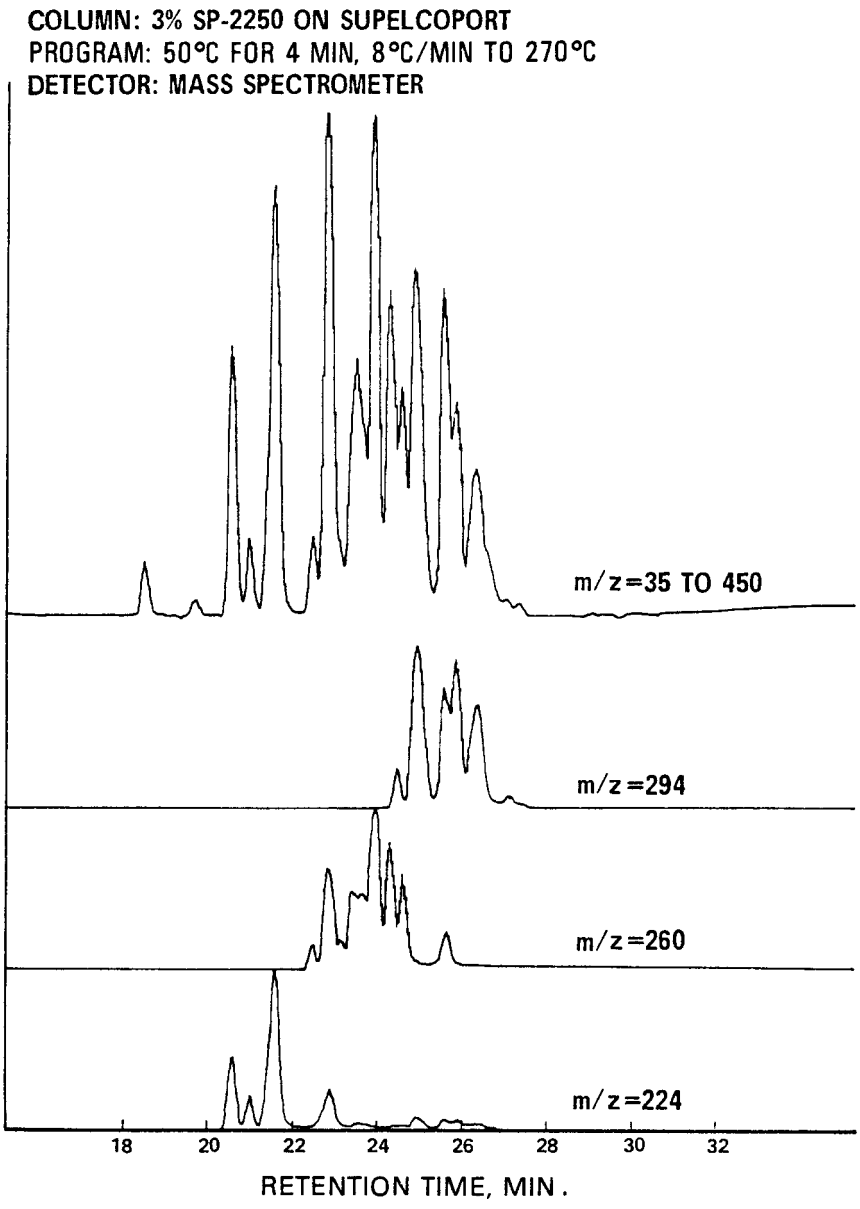


Figure 6. Gas chromatogram of PCB-1016.

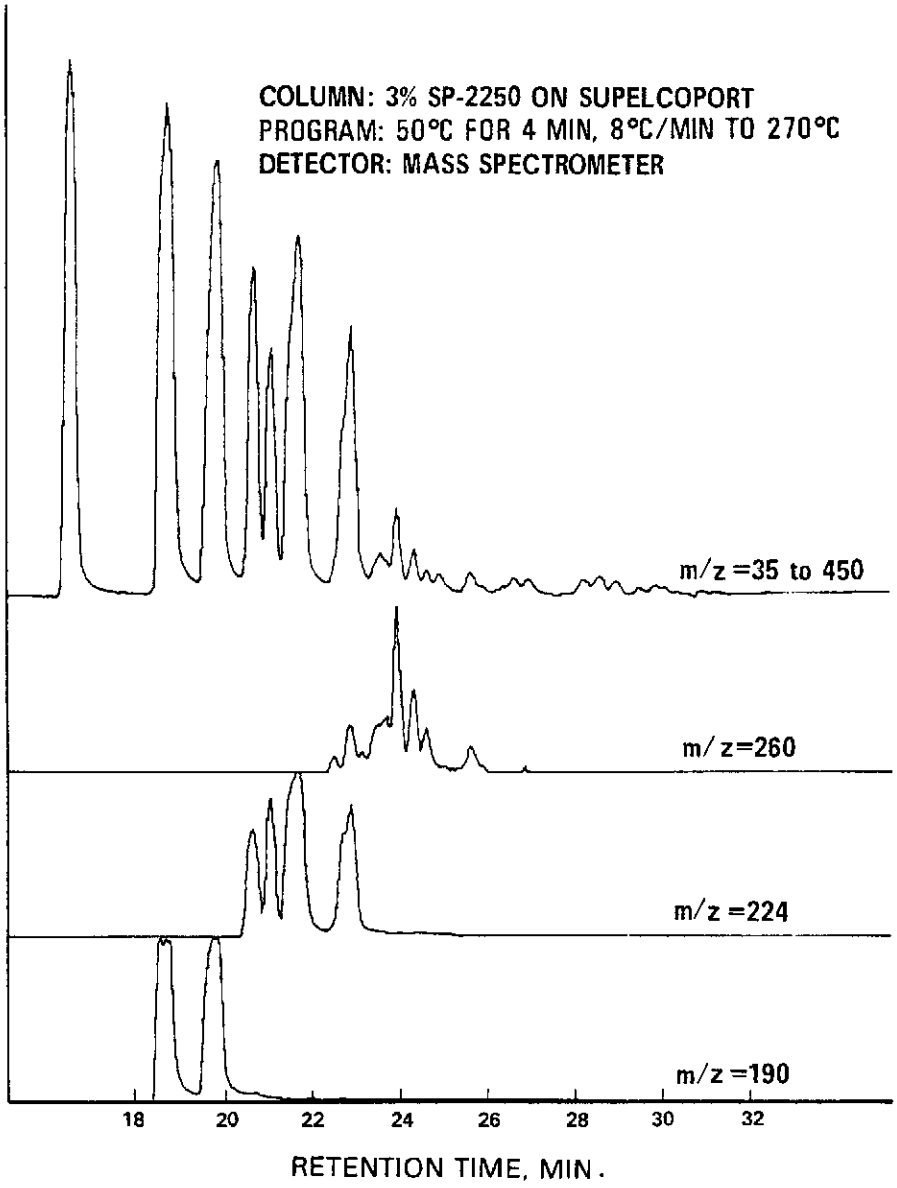


Figure 7. Gas chromatogram of PCB-1221.

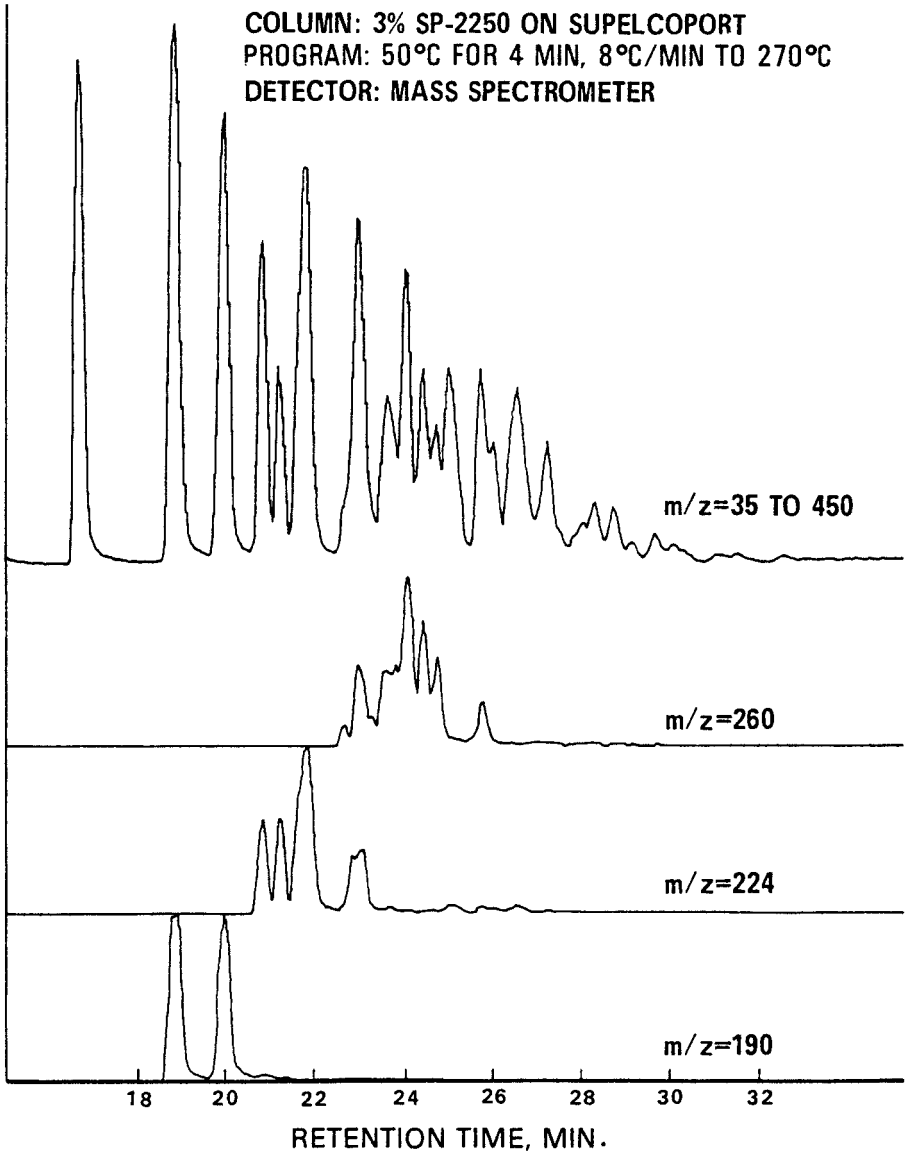


Figure 8. Gas chromatogram of PCB-1232.

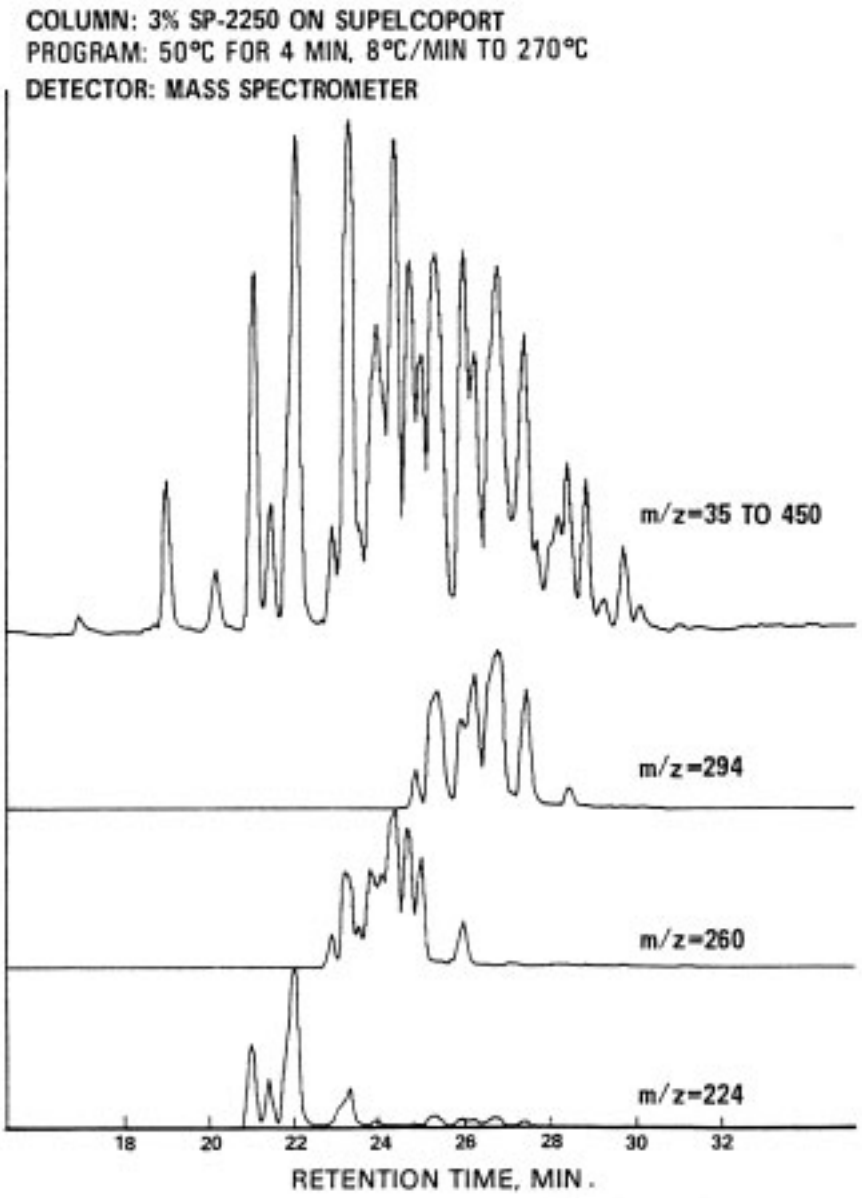


Figure 9. Gas chromatogram of PCB-1242.

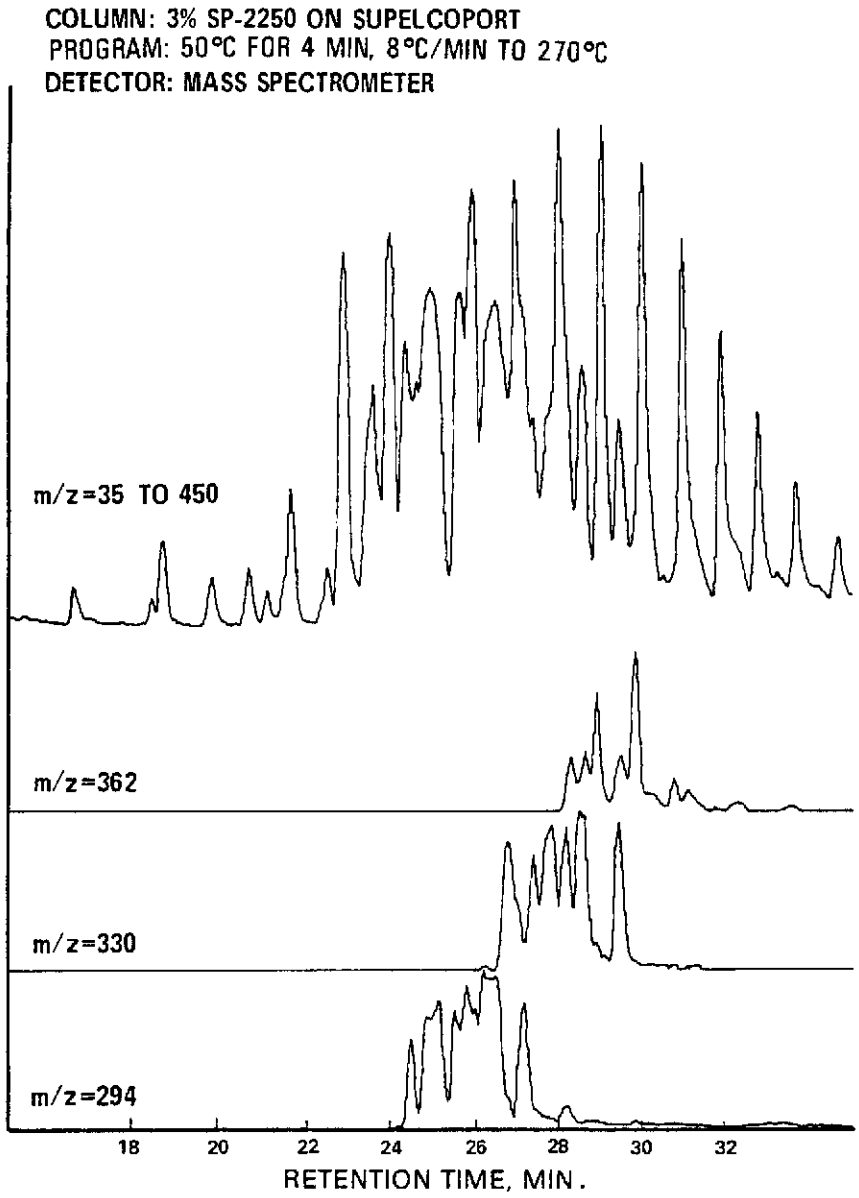


Figure 10. Gas chromatogram of PCB-1248.

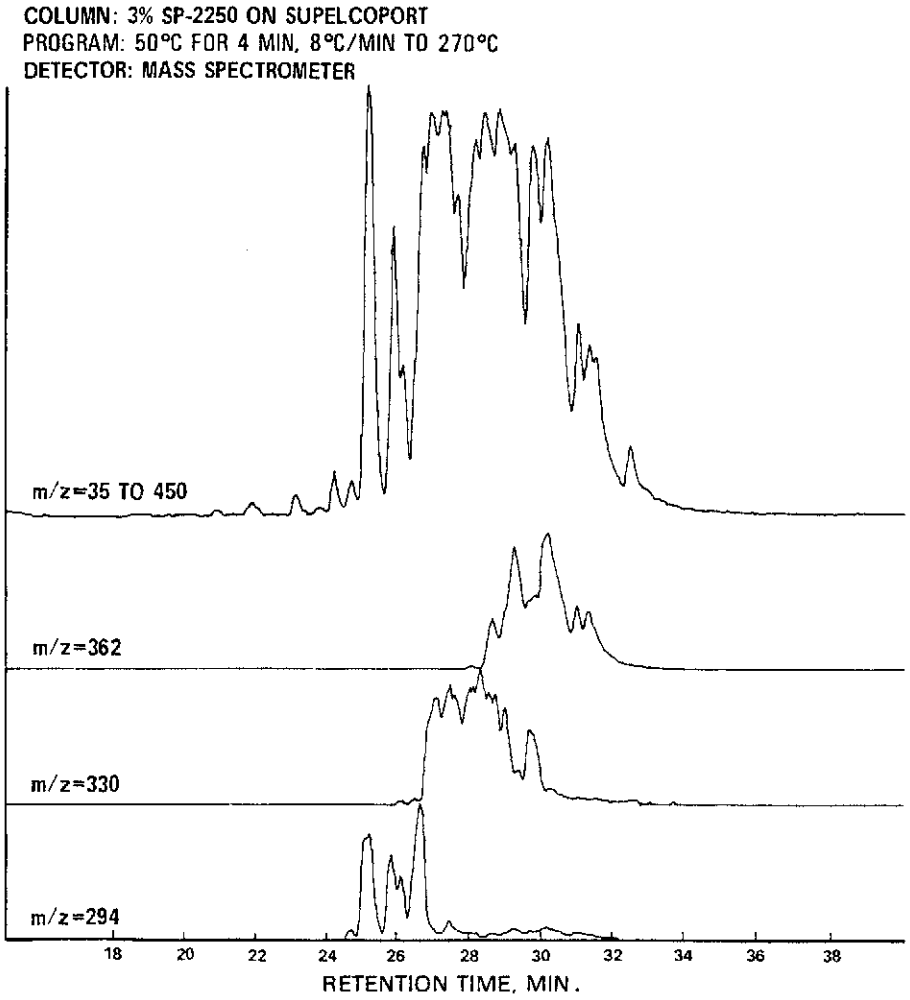


Figure 11. Gas chromatogram of PCB-1254.

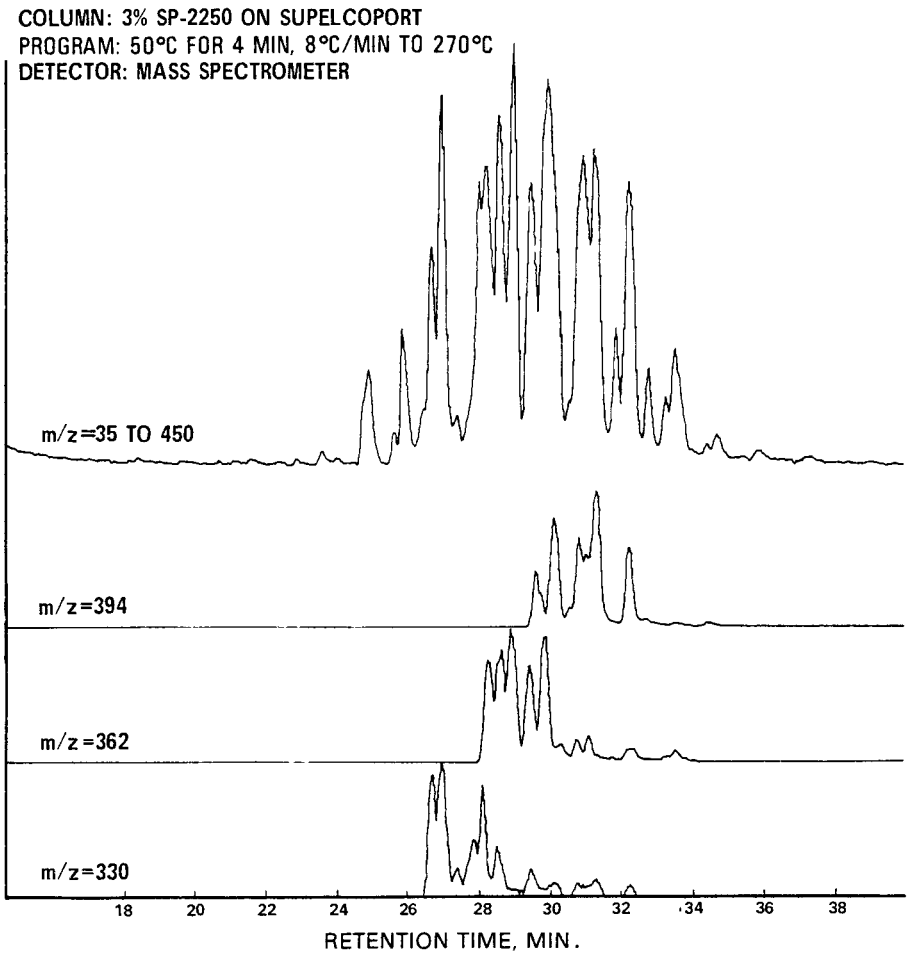
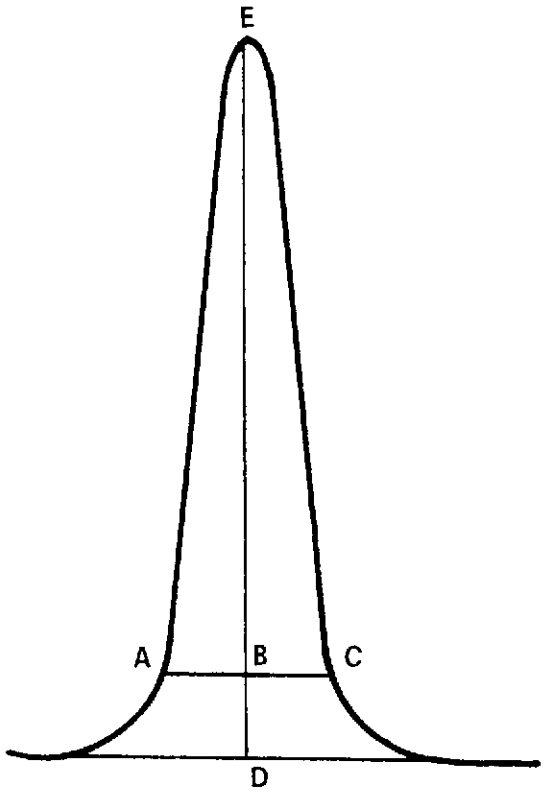


Figure 12. Gas chromatogram of PCB-1260.



Example calculation: Peak Height = DE = 100 mm
10% Peak Height = BD = 10 mm
Peak Width at 10% Peak Height = AC = 23 mm
AB = 11 mm
BC = 12 mm

Therefore: Tailing Factor = $\frac{12}{11}$ = 1.1

Figure 13. Tailing factor calculation.

ATTACHMENT 1 TO METHOD 625

INTRODUCTION

To support measurement of several semivolatile pollutants, EPA has developed this attachment to EPA Method 625.[1] The modifications listed in this attachment are approved only for monitoring wastestreams from the Centralized Waste Treatment Point Source Category (40 CFR Part 437) and the Landfills Point Source Category (40 CFR Part 445). EPA Method 625 (the Method) involves sample extraction with methylene chloride followed by analysis of the extract using either packed or capillary column gas chromatography/mass spectrometry (GC/MS). This attachment addresses the addition of the semivolatile pollutants listed in Tables 1 and 2, to all applicable standard, stock, and spiking solutions utilized for the determination of semivolatile organic compounds by EPA Method 625.

1.0 EPA METHOD 625 MODIFICATION SUMMARY

The additional semivolatile organic compounds listed in Tables 1 and 2 are added to all applicable calibration, spiking, and other solutions utilized in the determination of base/neutral and acid compounds by EPA Method 625. The instrument is to be calibrated with these compounds, using a capillary column, and all procedures and quality control tests stated in the Method must be performed.

2.0 SECTION MODIFICATIONS

NOTE: All section and figure numbers in this Attachment reference section and figure numbers in EPA Method 625 unless noted otherwise. Sections not listed here remain unchanged.

Section 6.7 The stock standard solutions described in this section are modified such that the analytes in Tables 1 and 2 of this attachment are required in addition to those specified in the Method.

Section 7.2 The calibration standards described in this section are modified to include the analytes in Tables 1 and 2 of this attachment.

Section 8.2 The precision and accuracy requirements are modified to include the analytes listed in Tables 1 and 2 of this attachment. Additional performance criteria are supplied in Table 5 of this attachment.

Section 8.3 The matrix spike is modified to include the analytes listed in Tables 1 and 2 of this attachment.

Section 8.4 The QC check standard is modified to include the analytes listed in Tables 1 and 2 of this attachment. Additional performance criteria are supplied in Table 5 of this attachment.

Section 16.0 Additional method performance information is supplied with this attachment.

TABLE 1—BASE/NEUTRAL EXTRACTABLES

Parameter	CAS No.
acetophenone [1]	98–86–2
alpha-terpineol [3]	98–55–5
aniline [2]	62–53–3
carbazole [1]	86–74–8
o-cresol [1]	95–48–7
n-decane [1]	124–18–5
2,3-dichloroaniline [1]	608–27–5
n-octadecane [1]	593–45–3
pyridine [2]	110–86–1

CAS = Chemical Abstracts Registry.
[1] Analysis of this pollutant is approved only for the Centralized Waste Treatment industry.
[2] Analysis of this pollutant is approved only for the Centralized Waste Treatment and Landfills industries.
[3] Analysis of this pollutant is approved only for the Landfills industry.

TABLE 2—ACID EXTRACTABLES

Parameter	CAS No.
p-cresol [1]	106–44–5

CAS = Chemical Abstracts Registry.
[1] Analysis of this pollutant is approved only for the Centralized Waste Treatment and Landfills industries.

TABLE 3—CHROMATOGRAPHIC CONDITIONS,[1] METHOD DETECTION LIMITS (MDLS), AND CHARACTERISTIC M/Z'S FOR BASE/NEUTRAL EXTRACTABLES

Analyte	Retention time (min) [2]	MDL (µg/L)	Characteristic m/z's		
			Electron impact		
			Primary	Secondary	Secondary
pyridine [3]	4.93	4.6	79	52	51
N-Nitro sodimethylamine	4.95	.....	42	74	44
aniline [3]	10.82	3.3	93	66	65
Bis(2-chloroethyl)ether	10.94	.....	93	63	95
n-decane [4]	11.11	5.0	57	.....	.....
1,3-Dichlorobenzene	11.47	.....	146	148	113
1,4-Dichlorobenzene	11.62	.....	146	148	113
1,2-Dichlorobenzene	12.17	.....	146	148	113

[1] EPA Method 625: Base/Neutrals and Acids, 40 CFR Part 136, Appendix A.

TABLE 3—CHROMATOGRAPHIC CONDITIONS,[1] METHOD DETECTION LIMITS (MDLS), AND CHARACTERISTIC M/Z'S FOR BASE/NEUTRAL EXTRACTABLES—Continued

Analyte	Retention time (min)[2]	MDL (µg/L)	Characteristic m/z's		
			Electron impact		
			Primary	Secondary	Secondary
o-creso[1]	12.48	4.7	108	107	79
Bis(2-chloro- isopropyl)ether	12.51	.....	45	77	79
acetophenone[4]	12.88	3.4	105	77	51
N-Nitrosodi-n-propylamine	12.97	.....	130	42	101
Hexachloroethane	13.08	.....	117	201	199
Nitrobenzene	13.40	.....	77	123	65
Isophorone	14.11	.....	82	95	138
Bis (2-chloro ethoxy)methane	14.82	.....	93	95	123
1,2,4-Trichlorobenzene	15.37	.....	180	182	145
alpha-terpineol	15.55	5.0	59	.....	.....
Naphthalene	15.56	.....	128	129	127
Hexachlorobutadiene	16.12	.....	225	223	227
Hexachlorocyclopentadiene	18.47	.....	237	235	272
2,3-dichloroaniline[4]	18.82	2.5	161	163	90
2-Chloronaphthalene	19.35	.....	162	164	127
Dimethyl phthalate	20.48	.....	163	194	164
Acenaphthylene	20.69	.....	152	151	153
2,6-Dinitrotoluene	20.73	.....	165	89	121
Acenaphthene	21.30	.....	154	153	152
2,4-Dinitrotoluene	22.00	.....	165	63	182
Diethylphthalate	22.74	.....	149	177	150
4-Chlorophenyl phenyl ether	22.90	.....	204	206	141
Fluorene	22.92	.....	166	165	167
N-Nitro sodiphenylamine	23.35	.....	169	168	167
4-Bromophenyl phenyl ether	24.44	.....	248	250	141
Hexachlorobenzene	24.93	.....	284	142	249
n-octadecane[4]	25.39	2.0	57	.....	.....
Phenanthrene	25.98	.....	178	179	176
Anthracene	26.12	.....	178	179	176
Carbazole[4]	26.66	4.0	167	.....	.....
Dibutyl phthalate	27.84	.....	149	150	104
Fluoranthene	29.82	.....	202	101	100
Benzidine	30.26	.....	184	92	185
Pyrene	30.56	.....	202	101	100
Butyl benzyl phthalate	32.63	.....	149	91	206
3,3'-Dichlorobenzidine	34.28	.....	252	254	126
Benzo(a)anthracene	34.33	.....	228	229	226
Bis(2-ethyl hexyl)phthalate	34.36	.....	149	167	279
Chrysene	34.44	.....	228	226	229
Di-n-octyl-phthalate	36.17	.....	149	.....	.....
Benzo(b)fluoranthene	37.90	.....	252	253	125
Benzo(k)fluoranthene	37.97	.....	252	253	125
Benzo(a)pyrene	39.17	.....	252	253	125
Dibenzo(a,h) anthracene	44.91	.....	278	139	279
Indeno(1,2,3-c,d)pyrene	45.01	.....	276	138	277
Benzo(ghi)perylene	46.56	.....	276	138	277

[1] The data presented in this table were obtained under the following conditions:

Column—30 ±5 meters × 0.25 ±.02 mm i.d., 94% methyl, 5% phenyl, 1% vinyl, bonded phase fused silica capillary column (DB–5).

Temperature program—Five minutes at 30 °C; 30–280 °C at 8 °C per minute; isothermal at 280 °C until benzo(ghi)perylene elutes.

Gas velocity—30±5 cm/sec at 30 °C.

[2] Retention times are from Method 1625, Revision C, using a capillary column, and are intended to be consistent for all analytes in Tables 4 and 5 of this attachment.

[3] Analysis of this pollutant is approved only for the Centralized Waste Treatment and Landfills industries.

[4] Analysis of this pollutant is approved only for the Centralized Waste Treatment industry.

TABLE 4—CHROMATOGRAPHIC CONDITIONS,[1] METHOD DETECTION LIMITS (MDLS), AND CHARACTERISTIC M/Z'S FOR ACID EXTRACTABLES

Analyte	Retention time[2] (min)	MDL (µg/L)	Characteristic m/z's		
			Electron impact		
			Primary	Secondary	Secondary
Phenol	10.76	.....	94	65	66
2-Chlorophenol	11.08	.....	128	64	130

TABLE 4—CHROMATOGRAPHIC CONDITIONS,[1] METHOD DETECTION LIMITS (MDLS), AND CHARACTERISTIC M/Z'S FOR ACID EXTRACTABLES—Continued

Analyte	Retention time[2] (min)	MDL (µg/L)	Characteristic m/z's		
			Electron impact		
			Primary	Secondary	Secondary
p-cresol[3]	12.92	7.8	108	107	77
2-Nitrophenol	14.38		139	65	109
2,4-Dimethylphenol	14.54		122	107	121
2,4-Dichlorophenol	15.12		162	164	98
4-Chloro-3-methylphenol	16.83		142	107	144
2,4,6-Trichlorophenol	18.80		196	198	200
2,4-Dinitrophenol	21.51		184	63	154
4-Nitrophenol	21.77		65	139	109
2-Methyl-4,6-dinitrophenol	22.83		198	182	77
Pentachlorophenol	25.52		266	264	268

[1] The data presented in this table were obtained under the following conditions:
Column—30 ±5 meters × 0.25 ±.02 mm i.d., 94% methyl, 5% phenyl, 1% vinyl silicone bonded phase fused silica capillary column (DB–5).
Temperature program—Five minutes at 30 °C; 30–280 °C at 8 °C per minute; isothermal at 280 °C until benzo(ghi)perylene elutes.
Gas velocity—30 ±5 cm/sec at 30 °C
[2] Retention times are from EPA Method 1625, Revision C, using a capillary column, and are intended to be consistent for all analytes in Tables 3 and 4 of this attachment.
[3] Analysis of this pollutant is approved only for the Centralized Waste Treatment and Landfills industries.

TABLE 5—QC ACCEPTANCE CRITERIA

Analyte	Test conclusion (µg/L)	Limits for s (µg/L)	Range for X (µg/L)	Range for P, P_s(%)
acetophenone[1]	100	51	23–254	61–144
alpha-terpineol	100	47	46–163	58–156
aniline[2]	100	71	15–278	46–134
carbazole[1]	100	17	79–111	73–131
o-cresol[1]	100	23	30–146	55–126
p-cresol[2]	100	22	11–617	76–107
n-decane[1]	100	70	D–651	D-ns
2,3-dichloroaniline[1]	100	13	40–160	68–134
n-octadecane[1]	100	10	52–147	65–123
pyridine[2]	100	ns	7–392	33–158

s = Standard deviation for four recovery measurements, in µg/L (Section 8.2)
X = Average recovery for four recovery measurements in µg/L (Section 8.2)
P,Ps = Percent recovery measured (Section 8.3, Section 8.4)
D = Detected; result must be greater than zero.
ns = no specification; limit is outside the range that can be measured reliably.
[1] Analysis of this pollutant is approved only for the Centralized Waste Treatment industry.
[2] Analysis of this pollutant is approved only for the Centralized Waste Treatment and Landfills industries.

METHOD 1613, REVISION B

Tetra- Through Octa-Chlorinated Dioxins and Furans by Isotope Dilution HRGC/HRMS

1.0 Scope and Application

1.1 This method is for determination of tetra- through octa-chlorinated dibenzo-p-dioxins (CDDs) and dibenzofurans (CDFs) in water, soil, sediment, sludge, tissue, and other sample matrices by high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS). The method is for use in EPA's data gathering and monitoring programs associated with the Clean Water Act, the Resource Conservation and Recovery Act, the Comprehensive Environmental Response, Compensation and Liability Act, and the Safe Drinking Water Act. The method is based on a compilation of EPA, industry, commercial laboratory, and academic methods (References 1–6).

1.2 The seventeen 2,3,7,8-substituted CDDs/CDFs listed in Table 1 may be determined by this method. Specifications are also provided for separate determination of 2,3,7,8-tetrachloro-dibenzo-p-dioxin (2,3,7,8-TCDD) and 2,3,7,8-tetrachloro-dibenzofuran (2,3,7,8-TCDF).

1.3 The detection limits and quantitation levels in this method are usually dependent on the level of interferences rather than instrumental limitations. The minimum levels (MLs) in Table 2 are the levels at which the CDDs/CDFs can be determined with no interferences present. The Method Detection

Limit (MDL) for 2,3,7,8-TCDD has been determined as 4.4 pg/L (parts-per-quadrillion) using this method.

1.4 The GC/MS portions of this method are for use only by analysts experienced with HRGC/HRMS or under the close supervision of such qualified persons. Each laboratory that uses this method must demonstrate the ability to generate acceptable results using the procedure in Section 9.2.

1.5 This method is ''performance-based''. The analyst is permitted to modify the method to overcome interferences or lower the cost of measurements, provided that all performance criteria in this method are met. The requirements for establishing method equivalency are given in Section 9.1.2.

1.6 Any modification of this method, beyond those expressly permitted, shall be considered a major modification subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

2.0 Summary of Method

Flow charts that summarize procedures for sample preparation, extraction, and analysis are given in Figure 1 for aqueous and solid samples, Figure 2 for multi-phase samples, and Figure 3 for tissue samples.

2.1 Extraction.

2.1.1 Aqueous samples (samples containing less than 1% solids)—Stable isotopically labeled analogs of 15 of the 2,3,7,8-substituted CDDs/CDFs are spiked into a 1 L sample, and the sample is extracted by one of three procedures:

2.1.1.1 Samples containing no visible particles are extracted with methylene chloride in a separatory funnel or by the solid-phase extraction technique summarized in Section 2.1.1.3. The extract is concentrated for cleanup.

2.1.1.2 Samples containing visible particles are vacuum filtered through a glass-fiber filter. The filter is extracted in a Soxhlet/Dean-Stark (SDS) extractor (Reference 7), and the filtrate is extracted with methylene chloride in a separatory funnel. The methylene chloride extract is concentrated and combined with the SDS extract prior to cleanup.

2.1.1.3 The sample is vacuum filtered through a glass-fiber filter on top of a solid-phase extraction (SPE) disk. The filter and disk are extracted in an SDS extractor, and the extract is concentrated for cleanup.

2.1.2 Solid, semi-solid, and multi-phase samples (but not tissue)—The labeled compounds are spiked into a sample containing 10 g (dry weight) of solids. Samples containing multiple phases are pressure filtered and any aqueous liquid is discarded. Coarse solids are ground or homogenized. Any non-aqueous liquid from multi-phase samples is combined with the solids and extracted in an SDS extractor. The extract is concentrated for cleanup.

2.1.3 Fish and other tissue—The sample is extracted by one of two procedures:

2.1.3.1 Soxhlet or SDS extraction—A 20 g aliquot of sample is homogenized, and a 10 g aliquot is spiked with the labeled compounds. The sample is mixed with sodium sulfate, allowed to dry for 12–24 hours, and extracted for 18–24 hours using methylene chloride:hexane (1:1) in a Soxhlet extractor. The extract is evaporated to dryness, and the lipid content is determined.

2.1.3.2 HCl digestion—A 20 g aliquot is homogenized, and a 10 g aliquot is placed in a bottle and spiked with the labeled compounds. After equilibration, 200 mL of hydrochloric acid and 200 mL of methylene chloride:hexane (1:1) are added, and the bottle is agitated for 12–24 hours. The extract is evaporated to dryness, and the lipid content is determined.

2.2 After extraction, $^{37}Cl_4$-labeled 2,3,7,8-TCDD is added to each extract to measure the efficiency of the cleanup process. Sample cleanups may include back-extraction with acid and/or base, and gel permeation, alumina, silica gel, Florisil and activated carbon chromatography. High-performance liquid chromatography (HPLC) can be used for further isolation of the 2,3,7,8-isomers or other specific isomers or congeners. Prior to the cleanup procedures cited above, tissue extracts are cleaned up using an anthropogenic isolation column, a batch silica gel adsorption, or sulfuric acid and base back-extraction, depending on the tissue extraction procedure used.

2.3 After cleanup, the extract is concentrated to near dryness. Immediately prior to injection, internal standards are added to each extract, and an aliquot of the extract is injected into the gas chromatograph. The analytes are separated by the GC and detected by a high-resolution (≥10,000) mass spectrometer. Two exact m/z's are monitored for each analyte.

2.4 An individual CDD/CDF is identified by comparing the GC retention time and ion-abundance ratio of two exact m/z's with the corresponding retention time of an authentic standard and the theoretical or acquired ion-abundance ratio of the two exact m/z's. The non-2,3,7,8 substituted isomers and congeners are identified when retention times and ion-abundance ratios agree within predefined limits. Isomer specificity for 2,3,7,8-TCDD and 2,3,7,8-TCDF is achieved using GC columns that resolve these isomers from the other tetra-isomers.

2.5 Quantitative analysis is performed using selected ion current profile (SICP) areas, in one of three ways:

2.5.1 For the 15 2,3,7,8-substituted CDDs/CDFs with labeled analogs (see Table 1), the GC/MS system is calibrated, and the concentration of each compound is determined using the isotope dilution technique.

2.5.2 For 1,2,3,7,8,9-HxCDD, OCDF, and the labeled compounds, the GC/MS system is calibrated and the concentration of each compound is determined using the internal standard technique.

2.5.3 For non-2,3,7,8-substituted isomers and for all isomers at a given level of chlorination (i.e., total TCDD), concentrations are determined using response factors from calibration of the CDDs/CDFs at the same level of chlorination.

2.6 The quality of the analysis is assured through reproducible calibration and testing of the extraction, cleanup, and GC/MS systems.

3.0 Definitions

Definitions are given in the glossary at the end of this method.

4.0 Contamination and Interferences

4.1 Solvents, reagents, glassware, and other sample processing hardware may yield artifacts and/or elevated baselines causing misinterpretation of chromatograms (References 8–9). Specific selection of reagents and purification of solvents by distillation in all-glass systems may be required. Where possible, reagents are cleaned by extraction or solvent rinse.

4.2 Proper cleaning of glassware is extremely important, because glassware may not only contaminate the samples but may also remove the analytes of interest by adsorption on the glass surface.

4.2.1 Glassware should be rinsed with solvent and washed with a detergent solution as soon after use as is practical. Sonication of glassware containing a detergent solution for approximately 30 seconds may aid in cleaning. Glassware with removable parts, particularly separatory funnels with fluoropolymer stopcocks, must be disassembled prior to detergent washing.

4.2.2 After detergent washing, glassware should be rinsed immediately, first with methanol, then with hot tap water. The tap water rinse is followed by another methanol rinse, then acetone, and then methylene chloride.

4.2.3 Do not bake reusable glassware in an oven as a routine part of cleaning. Baking may be warranted after particularly dirty samples are encountered but should be minimized, as repeated baking of glassware may cause active sites on the glass surface that will irreversibly adsorb CDDs/CDFs.

4.2.4 Immediately prior to use, the Soxhlet apparatus should be pre-extracted with toluene for approximately three hours (see Sections 12.3.1 through 12.3.3). Separatory funnels should be shaken with methylene chloride/toluene (80/20 mixture) for two minutes, drained, and then shaken with pure methylene chloride for two minutes.

4.3 All materials used in the analysis shall be demonstrated to be free from interferences by running reference matrix method blanks initially and with each sample batch (samples started through the extraction process on a given 12-hour shift, to a maximum of 20 samples).

4.3.1 The reference matrix must simulate, as closely as possible, the sample matrix under test. Ideally, the reference matrix should not contain the CDDs/CDFs in detectable amounts, but should contain potential interferents in the concentrations expected to be found in the samples to be analyzed. For example, a reference sample of human adipose tissue containing pentachloronaphthalene can be used to exercise the cleanup systems when samples containing pentachloronaphthalene are expected.

4.3.2 When a reference matrix that simulates the sample matrix under test is not available, reagent water (Section 7.6.1) can be used to simulate water samples; playground sand (Section 7.6.2) or white quartz sand (Section 7.3.2) can be used to simulate soils; filter paper (Section 7.6.3) can be used to simulate papers and similar materials; and corn oil (Section 7.6.4) can be used to simulate tissues.

4.4 Interferences coextracted from samples will vary considerably from source to source, depending on the diversity of the site being sampled. Interfering compounds may be present at concentrations several orders of magnitude higher than the CDDs/CDFs. The most frequently encountered interferences are chlorinated biphenyls, methoxy biphenyls, hydroxydiphenyl ethers, benzylphenyl ethers, polynuclear aromatics, and pesticides. Because very low levels of CDDs/CDFs are measured by this method, the elimination of interferences is essential. The cleanup steps given in Section 13 can be used to reduce or eliminate these interferences and thereby permit reliable determination of the CDDs/CDFs at the levels shown in Table 2.

4.5 Each piece of reusable glassware should be numbered to associate that glassware with the processing of a particular sample. This will assist the laboratory in tracking possible sources of contamination for individual samples, identifying glassware associated with highly contaminated samples that may require extra cleaning, and determining when glassware should be discarded.

4.6 Cleanup of tissue—The natural lipid content of tissue can interfere in the analysis of tissue samples for the CDDs/CDFs. The lipid contents of different species and portions of tissue can vary widely. Lipids are soluble to varying degrees in various organic solvents and may be present in sufficient quantity to overwhelm the column chromatographic cleanup procedures used for cleanup of sample extracts. Lipids must

be removed by the lipid removal procedures in Section 13.7, followed by alumina (Section 13.4) or Florisil (Section 13.8), and carbon (Section 13.5) as minimum additional cleanup steps. If chlorodiphenyl ethers are detected, as indicated by the presence of peaks at the exact m/z's monitored for these interferents, alumina and/or Florisil cleanup must be employed to eliminate these interferences.

5.0 Safety

5.1 The toxicity or carcinogenicity of each compound or reagent used in this method has not been precisely determined; however, each chemical compound should be treated as a potential health hazard. Exposure to these compounds should be reduced to the lowest possible level.

5.1.1 The 2,3,7,8-TCDD isomer has been found to be acnegenic, carcinogenic, and teratogenic in laboratory animal studies. It is soluble in water to approximately 200 ppt and in organic solvents to 0.14%. On the basis of the available toxicological and physical properties of 2,3,7,8-TCDD, all of the CDDs/CDFs should be handled only by highly trained personnel thoroughly familiar with handling and cautionary procedures and the associated risks.

5.1.2 It is recommended that the laboratory purchase dilute standard solutions of the analytes in this method. However, if primary solutions are prepared, they shall be prepared in a hood, and a NIOSH/MESA approved toxic gas respirator shall be worn when high concentrations are handled.

5.2 The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material safety data sheets (MSDSs) should also be made available to all personnel involved in these analyses. It is also suggested that the laboratory perform personal hygiene monitoring of each analyst who uses this method and that the results of this monitoring be made available to the analyst. Additional information on laboratory safety can be found in References 10–13. The references and bibliography at the end of Reference 13 are particularly comprehensive in dealing with the general subject of laboratory safety.

5.3 The CDDs/CDFs and samples suspected to contain these compounds are handled using essentially the same techniques employed in handling radioactive or infectious materials. Well-ventilated, controlled access laboratories are required. Assistance in evaluating the health hazards of particular laboratory conditions may be obtained from certain consulting laboratories and from State Departments of Health or Labor, many of which have an industrial health service. The CDDs/CDFs are extremely toxic to laboratory animals. Each laboratory must develop a strict safety program for handling these compounds. The practices in References 2 and 14 are highly recommended.

5.3.1 Facility—When finely divided samples (dusts, soils, dry chemicals) are handled, all operations (including removal of samples from sample containers, weighing, transferring, and mixing) should be performed in a glove box demonstrated to be leak tight or in a fume hood demonstrated to have adequate air flow. Gross losses to the laboratory ventilation system must not be allowed. Handling of the dilute solutions normally used in analytical and animal work presents no inhalation hazards except in the case of an accident.

5.3.2 Protective equipment—Disposable plastic gloves, apron or lab coat, safety glasses or mask, and a glove box or fume hood adequate for radioactive work should be used. During analytical operations that may give rise to aerosols or dusts, personnel should wear respirators equipped with activated carbon filters. Eye protection equipment (preferably full face shields) must be worn while working with exposed samples or pure analytical standards. Latex gloves are commonly used to reduce exposure of the hands. When handling samples suspected or known to contain high concentrations of the CDDs/CDFs, an additional set of gloves can also be worn beneath the latex gloves.

5.3.3 Training—Workers must be trained in the proper method of removing contaminated gloves and clothing without contacting the exterior surfaces.

5.3.4 Personal hygiene—Hands and forearms should be washed thoroughly after each manipulation and before breaks (coffee, lunch, and shift).

5.3.5 Confinement—Isolated work areas posted with signs, segregated glassware and tools, and plastic absorbent paper on bench tops will aid in confining contamination.

5.3.6 Effluent vapors—The effluents of sample splitters from the gas chromatograph (GC) and from roughing pumps on the mass spectrometer (MS) should pass through either a column of activated charcoal or be bubbled through a trap containing oil or high-boiling alcohols to condense CDD/CDF vapors.

5.3.7 Waste Handling—Good technique includes minimizing contaminated waste. Plastic bag liners should be used in waste cans. Janitors and other personnel must be trained in the safe handling of waste.

5.3.8 Decontamination

5.3.8.1 Decontamination of personnel—Use any mild soap with plenty of scrubbing action.

5.3.8.2 Glassware, tools, and surfaces—Chlorothene NU Solvent is the least toxic solvent shown to be effective. Satisfactory cleaning may be accomplished by rinsing with Chlorothene, then washing with any detergent and water. If glassware is first rinsed

with solvent, then the dish water may be disposed of in the sewer. Given the cost of disposal, it is prudent to minimize solvent wastes.

5.3.9 Laundry—Clothing known to be contaminated should be collected in plastic bags. Persons who convey the bags and launder the clothing should be advised of the hazard and trained in proper handling. The clothing may be put into a washer without contact if the launderer knows of the potential problem. The washer should be run through a cycle before being used again for other clothing.

5.3.10 Wipe tests—A useful method of determining cleanliness of work surfaces and tools is to wipe the surface with a piece of filter paper. Extraction and analysis by GC with an electron capture detector (ECD) can achieve a limit of detection of 0.1 µg per wipe; analysis using this method can achieve an even lower detection limit. Less than 0.1 µg per wipe indicates acceptable cleanliness; anything higher warrants further cleaning. More than 10 µg on a wipe constitutes an acute hazard and requires prompt cleaning before further use of the equipment or work space, and indicates that unacceptable work practices have been employed.

5.3.11 Table or wrist-action shaker—The use of a table or wrist-action shaker for extraction of tissues presents the possibility of breakage of the extraction bottle and spillage of acid and flammable organic solvent. A secondary containment system around the shaker is suggested to prevent the spread of acid and solvents in the event of such a breakage. The speed and intensity of shaking action should also be adjusted to minimize the possibility of breakage.

6.0 Apparatus and Materials

NOTE: Brand names, suppliers, and part numbers are for illustration purposes only and no endorsement is implied. Equivalent performance may be achieved using apparatus and materials other than those specified here. Meeting the performance requirements of this method is the responsibility of the laboratory.

6.1 Sampling Equipment for Discrete or Composite Sampling

6.1.1 Sample bottles and caps

6.1.1.1 Liquid samples (waters, sludges and similar materials containing 5% solids or less)—Sample bottle, amber glass, 1.1 L minimum, with screw cap.

6.1.1.2 Solid samples (soils, sediments, sludges, paper pulps, filter cake, compost, and similar materials that contain more than 5% solids)—Sample bottle, wide mouth, amber glass, 500 mL minimum.

6.1.1.3 If amber bottles are not available, samples shall be protected from light.

6.1.1.4 Bottle caps—Threaded to fit sample bottles. Caps shall be lined with fluoropolymer.

6.1.1.5 Cleaning

6.1.1.5.1 Bottles are detergent water washed, then solvent rinsed before use.

6.1.1.5.2 Liners are detergent water washed, rinsed with reagent water (Section 7.6.1) followed by solvent, and baked at approximately 200 °C for a minimum of 1 hour prior to use.

6.1.2 Compositing equipment—Automatic or manual compositing system incorporating glass containers cleaned per bottle cleaning procedure above. Only glass or fluoropolymer tubing shall be used. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used in the pump only. Before use, the tubing shall be thoroughly rinsed with methanol, followed by repeated rinsing with reagent water to minimize sample contamination. An integrating flow meter is used to collect proportional composite samples.

6.2 Equipment for Glassware Cleaning—Laboratory sink with overhead fume hood.

6.3 Equipment for Sample Preparation

6.3.1 Laboratory fume hood of sufficient size to contain the sample preparation equipment listed below.

6.3.2 Glove box (optional).

6.3.3 Tissue homogenizer—VirTis Model 45 Macro homogenizer (American Scientific Products H–3515, or equivalent) with stainless steel Macro-shaft and Turbo-shear blade.

6.3.4 Meat grinder—Hobart, or equivalent, with 3–5 mm holes in inner plate.

6.3.5 Equipment for determining percent moisture

6.3.5.1 Oven—Capable of maintaining a temperature of 110 ±5 °C.

6.3.5.2 Dessicator.

6.3.6 Balances

6.3.6.1 Analytical—Capable of weighing 0.1 mg.

6.3.6.2 Top loading—Capable of weighing 10 mg.

6.4 Extraction Apparatus

6.4.1 Water samples

6.4.1.1 pH meter, with combination glass electrode.

6.4.1.2 pH paper, wide range (Hydrion Papers, or equivalent).

6.4.1.3 Graduated cylinder, 1 L capacity.

6.4.1.4 Liquid/liquid extraction—Separatory funnels, 250 mL, 500 mL, and 2000 mL, with fluoropolymer stopcocks.

6.4.1.5 Solid-phase extraction

6.4.1.5.1 One liter filtration apparatus, including glass funnel, glass frit support, clamp, adapter, stopper, filtration flask, and vacuum tubing (Figure 4). For wastewater samples, the apparatus should accept 90 or 144 mm disks. For drinking water or other samples containing low solids, smaller disks may be used.

6.4.1.5.2 Vacuum source capable of maintaining 25 in. Hg, equipped with shutoff valve and vacuum gauge.

6.4.1.5.3 Glass-fiber filter—Whatman GMF 150 (or equivalent), 1 micron pore size, to fit filtration apparatus in Section 6.4.1.5.1.

6.4.1.5.4 Solid-phase extraction disk containing octadecyl (C_{18}) bonded silica uniformly enmeshed in an inert matrix—Fisher Scientific 14–378F (or equivalent), to fit filtration apparatus in Section 6.4.1.5.1.

6.4.2 Soxhlet/Dean-Stark (SDS) extractor (Figure 5)—For filters and solid/sludge samples.

6.4.2.1 Soxhlet—50 mm ID, 200 mL capacity with 500 mL flask (Cal-Glass LG–6900, or equivalent, except substitute 500 mL round-bottom flask for 300 mL flat-bottom flask).

6.4.2.2 Thimble—43 × 123 to fit Soxhlet (Cal-Glass LG–6901–122, or equivalent).

6.4.2.3 Moisture trap—Dean Stark or Barret with fluoropolymer stopcock, to fit Soxhlet.

6.4.2.4 Heating mantle—Hemispherical, to fit 500 mL round-bottom flask (Cal-Glass LG–8801–112, or equivalent).

6.4.2.5 Variable transformer—Powerstat (or equivalent), 110 volt, 10 amp.

6.4.3 Apparatus for extraction of tissue.

6.4.3.1 Bottle for extraction (if digestion/extraction using HCl is used)'' 500–600 mL wide-mouth clear glass, with fluoropolymer-lined cap.

6.4.3.2 Bottle for back-extraction—100–200 mL narrow-mouth clear glass with fluoropolymer-lined cap.

6.4.3.3 Mechanical shaker—Wrist-action or platform-type rotary shaker that produces vigorous agitation (Sybron Thermolyne Model LE ''Big Bill'' rotator/shaker, or equivalent).

6.4.3.4 Rack attached to shaker table to permit agitation of four to nine samples simultaneously.

6.4.4 Beakers—400–500 mL.

6.4.5 Spatulas—Stainless steel.

6.5 Filtration Apparatus.

6.5.1 Pyrex glass wool—Solvent-extracted by SDS for three hours minimum.

NOTE: Baking glass wool may cause active sites that will irreversibly adsorb CDDs/CDFs.

6.5.2 Glass funnel—125–250 mL.

6.5.3 Glass-fiber filter paper—Whatman GF/D (or equivalent), to fit glass funnel in Section 6.5.2.

6.5.4 Drying column—15–20 mm ID Pyrex chromatographic column equipped with coarse-glass frit or glass-wool plug.

6.5.5 Buchner funnel—15 cm.

6.5.6 Glass-fiber filter paper—to fit Buchner funnel in Section 6.5.5.

6.5.7 Filtration flasks—1.5–2.0 L, with side arm.

6.5.8 Pressure filtration apparatus—Millipore YT30 142 HW, or equivalent.

6.6 Centrifuge Apparatus.

6.6.1 Centrifuge—Capable of rotating 500 mL centrifuge bottles or 15 mL centrifuge tubes at 5,000 rpm minimum.

6.6.2 Centrifuge bottles—500 mL, with screw-caps, to fit centrifuge.

6.6.3 Centrifuge tubes—12–15 mL, with screw-caps, to fit centrifuge.

6.7 Cleanup Apparatus.

6.7.1 Automated gel permeation chromatograph (Analytical Biochemical Labs, Inc, Columbia, MO, Model GPC Autoprep 1002, or equivalent).

6.7.1.1 Column—600–700 mm long × 25 mm ID, packed with 70 g of SX–3 Bio-beads (Bio-Rad Laboratories, Richmond, CA, or equivalent).

6.7.1.2 Syringe—10 mL, with Luer fitting.

6.7.1.3 Syringe filter holder—stainless steel, and glass-fiber or fluoropolymer filters (Gelman 4310, or equivalent).

6.7.1.4 UV detectors—254 nm, preparative or semi-preparative flow cell (Isco, Inc., Type 6; Schmadzu, 5 mm path length; Beckman-Altex 152W, 8 µL micro-prep flow cell, 2 mm path; Pharmacia UV–1, 3 mm flow cell; LDC Milton-Roy UV–3, monitor #1203; or equivalent).

6.7.2 Reverse-phase high-performance liquid chromatograph.

6.7.2.1 Column oven and detector—Perkin-Elmer Model LC–65T (or equivalent) operated at 0.02 AUFS at 235 nm.

6.7.2.2 Injector—Rheodyne 7120 (or equivalent) with 50 µL sample loop.

6.7.2.3 Column—Two 6.2 mm × 250 mm Zorbax-ODS columns in series (DuPont Instruments Division, Wilmington, DE, or equivalent), operated at 50 °C with 2.0 mL/min methanol isocratic effluent.

6.7.2.4 Pump—Altex 110A (or equivalent).

6.7.3 Pipets.

6.7.3.1 Disposable, pasteur—150 mm long × 5-mm ID (Fisher Scientific 13–678–6A, or equivalent).

6.7.3.2 Disposable, serological—10 mL (6 mm ID).

6.7.4 Glass chromatographic columns.

6.7.4.1 150 mm long × 8-mm ID, (Kontes K–420155, or equivalent) with coarse-glass frit or glass-wool plug and 250 mL reservoir.

6.7.4.2 200 mm long × 15 mm ID, with coarse-glass frit or glass-wool plug and 250 mL reservoir.

6.7.4.3 300 mm long × 25 mm ID, with 300 mL reservoir and glass or fluoropolymer stopcock.

6.7.5 Stirring apparatus for batch silica cleanup of tissue extracts.

6.7.5.1 Mechanical stirrer—Corning Model 320, or equivalent.

6.7.5.2 Bottle—500–600 mL wide-mouth clear glass.

6.7.6 Oven—For baking and storage of adsorbents, capable of maintaining a constant temperature (±5 °C) in the range of 105–250 °C.

6.8 Concentration Apparatus.

6.8.1 Rotary evaporator—Buchi/Brinkman-American Scientific No. E5045–10 or equivalent, equipped with a variable temperature water bath.

6.8.1.1 Vacuum source for rotary evaporator equipped with shutoff valve at the evaporator and vacuum gauge.

6.8.1.2 A recirculating water pump and chiller are recommended, as use of tap water for cooling the evaporator wastes large volumes of water and can lead to inconsistent performance as water temperatures and pressures vary.

6.8.1.3 Round-bottom flask—100 mL and 500 mL or larger, with ground-glass fitting compatible with the rotary evaporator.

6.8.2 Kuderna-Danish (K–D) Concentrator.

6.8.2.1 Concentrator tube—10 mL, graduated (Kontes K–570050–1025, or equivalent) with calibration verified. Ground-glass stopper (size 19/22 joint) is used to prevent evaporation of extracts.

6.8.2.2 Evaporation flask—500 mL (Kontes K–570001–0500, or equivalent), attached to concentrator tube with springs (Kontes K–662750–0012 or equivalent).

6.8.2.3 Snyder column—Three-ball macro (Kontes K–503000–0232, or equivalent).

6.8.2.4 Boiling chips.

6.8.2.4.1 Glass or silicon carbide—Approximately 10/40 mesh, extracted with methylene chloride and baked at 450 °C for one hour minimum.

6.8.2.4.2 Fluoropolymer (optional)—Extracted with methylene chloride.

6.8.2.5 Water bath—Heated, with concentric ring cover, capable of maintaining a temperature within ±2 °C, installed in a fume hood.

6.8.3 Nitrogen blowdown apparatus—Equipped with water bath controlled in the range of 30–60 °C (N-Evap, Organomation Associates, Inc., South Berlin, MA, or equivalent), installed in a fume hood.

6.8.4 Sample vials.

6.8.4.1 Amber glass—2–5 mL with fluoropolymer-lined screw-cap.

6.8.4.2 Glass—0.3 mL, conical, with fluoropolymer-lined screw or crimp cap.

6.9 Gas Chromatograph—Shall have splitless or on-column injection port for capillary column, temperature program with isothermal hold, and shall meet all of the performance specifications in Section 10.

6.9.1 GC column for CDDs/CDFs and for isomer specificity for 2,3,7,8-TCDD—60±5 m long × 0.32±0.02 mm ID; 0.25 µm 5% phenyl, 94% methyl, 1% vinyl silicone bonded-phase fused-silica capillary column (J&W DB–5, or equivalent).

6.9.2 GC column for isomer specificity for 2,3,7,8-TCDF—30±5 m long × 0.32±0.02 mm ID; 0.25 µm bonded-phase fused-silica capillary column (J&W DB–225, or equivalent).

6.10 Mass Spectrometer—28–40 eV electron impact ionization, shall be capable of repetitively selectively monitoring 12 exact m/z's minimum at high resolution (≥10,000) during a period of approximately one second, and shall meet all of the performance specifications in Section 10.

6.11 GC/MS Interface—The mass spectrometer (MS) shall be interfaced to the GC such that the end of the capillary column terminates within 1 cm of the ion source but does not intercept the electron or ion beams.

6.12 Data System—Capable of collecting, recording, and storing MS data.

7.0 Reagents and Standards

7.1 pH Adjustment and Back-Extraction.

7.1.1 Potassium hydroxide—Dissolve 20 g reagent grade KOH in 100 mL reagent water.

7.1.2 Sulfuric acid—Reagent grade (specific gravity 1.84).

7.1.3 Hydrochloric acid—Reagent grade, 6N.

7.1.4 Sodium chloride—Reagent grade, prepare at 5% (w/v) solution in reagent water.

7.2 Solution Drying and Evaporation.

7.2.1 Solution drying—Sodium sulfate, reagent grade, granular, anhydrous (Baker 3375, or equivalent), rinsed with methylene chloride (20 mL/g), baked at 400 °C for one hour minimum, cooled in a dessicator, and stored in a pre-cleaned glass bottle with screw-cap that prevents moisture from entering. If, after heating, the sodium sulfate develops a noticeable grayish cast (due to the presence of carbon in the crystal matrix), that batch of reagent is not suitable for use and should be discarded. Extraction with methylene chloride (as opposed to simple rinsing) and baking at a lower temperature may produce sodium sulfate that is suitable for use.

7.2.2 Tissue drying—Sodium sulfate, reagent grade, powdered, treated and stored as above.

7.2.3 Prepurified nitrogen.

7.3 Extraction.

7.3.1 Solvents—Acetone, toluene, cyclohexane, hexane, methanol, methylene chloride, and nonane; distilled in glass, pesticide quality, lot-certified to be free of interferences.

7.3.2 White quartz sand, 60/70 mesh—For Soxhlet/Dean-Stark extraction (Aldrich Chemical, Cat. No. 27–437–9, or equivalent). Bake at 450 °C for four hours minimum.

7.4 GPC Calibration Solution—Prepare a solution containing 300 mg/mL corn oil, 15 mg/mL bis(2-ethylhexyl) phthalate, 1.4 mg/mL pentachlorophenol, 0.1 mg/mL perylene, and 0.5 mg/mL sulfur.

7.5 Adsorbents for Sample Cleanup.

7.5.1 Silica gel.

7.5.1.1 Activated silica gel—100–200 mesh, Supelco 1–3651 (or equivalent), rinsed with methylene chloride, baked at 180 °C for a minimum of one hour, cooled in a dessicator, and stored in a precleaned glass bottle with

screw-cap that prevents moisture from entering.

7.5.1.2 Acid silica gel (30% w/w)—Thoroughly mix 44.0 g of concentrated sulfuric acid with 100.0 g of activated silica gel in a clean container. Break up aggregates with a stirring rod until a uniform mixture is obtained. Store in a bottle with a fluoropolymer-lined screw-cap.

7.5.1.3 Basic silica gel—Thoroughly mix 30 g of 1N sodium hydroxide with 100 g of activated silica gel in a clean container. Break up aggregates with a stirring rod until a uniform mixture is obtained. Store in a bottle with a fluoropolymer-lined screw-cap.

7.5.1.4 Potassium silicate.

7.5.1.4.1 Dissolve 56 g of high purity potassium hydroxide (Aldrich, or equivalent) in 300 mL of methanol in a 750–1000 mL flat-bottom flask.

7.5.1.4.2 Add 100 g of silica gel and a stirring bar, and stir on a hot plate at 60–70 °C for one to two hours.

7.5.1.4.3 Decant the liquid and rinse the potassium silicate twice with 100 mL portions of methanol, followed by a single rinse with 100 mL of methylene chloride.

7.5.1.4.4 Spread the potassium silicate on solvent-rinsed aluminum foil and dry for two to four hours in a hood.

7.5.1.4.5 Activate overnight at 200–250 °C.

7.5.2 Alumina—Either one of two types of alumina, acid or basic, may be used in the cleanup of sample extracts, provided that the laboratory can meet the performance specifications for the recovery of labeled compounds described in Section 9.3. The same type of alumina must be used for all samples, including those used to demonstrate initial precision and recovery (Section 9.2) and ongoing precision and recovery (Section 15.5).

7.5.2.1 Acid alumina—Supelco 19996–6C (or equivalent). Activate by heating to 130 °C for a minimum of 12 hours.

7.5.2.2 Basic alumina—Supelco 19944–6C (or equivalent). Activate by heating to 600 °C for a minimum of 24 hours. Alternatively, activate by heating in a tube furnace at 650–700 °C under an air flow rate of approximately 400 cc/minute. Do not heat over 700 °C, as this can lead to reduced capacity for retaining the analytes. Store at 130 °C in a covered flask. Use within five days of baking.

7.5.3 Carbon.

7.5.3.1 Carbopak C—(Supelco 1–0258, or equivalent).

7.5.3.2 Celite 545—(Supelco 2–0199, or equivalent).

7.5.3.3 Thoroughly mix 9.0 g Carbopak C and 41.0 g Celite 545 to produce an 18% w/w mixture. Activate the mixture at 130 °C for a minimum of six hours. Store in a dessicator.

7.5.4 Anthropogenic isolation column—Pack the column in Section 6.7.4.3 from bottom to top with the following:

7.5.4.1 2 g silica gel (Section 7.5.1.1).

7.5.4.2 2 g potassium silicate (Section 7.5.1.4).

7.5.4.3 2 g granular anhydrous sodium sulfate (Section 7.2.1).

7.5.4.4 10 g acid silica gel (Section 7.5.1.2).

7.5.4.5 2 g granular anhydrous sodium sulfate.

7.5.5 Florisil column.

7.5.5.1 Florisil—60–100 mesh, Floridin Corp (or equivalent). Soxhlet extract in 500 g portions for 24 hours.

7.5.5.2 Insert a glass wool plug into the tapered end of a graduated serological pipet (Section 6.7.3.2). Pack with 1.5 g (approx 2 mL) of Florisil topped with approx 1 mL of sodium sulfate (Section 7.2.1) and a glass wool plug.

7.5.5.3 Activate in an oven at 130–150 °C for a minimum of 24 hours and cool for 30 minutes. Use within 90 minutes of cooling.

7.6 Reference Matrices—Matrices in which the CDDs/CDFs and interfering compounds are not detected by this method.

7.6.1 Reagent water—Bottled water purchased locally, or prepared by passage through activated carbon.

7.6.2 High-solids reference matrix—Playground sand or similar material. Prepared by extraction with methylene chloride and/or baking at 450 °C for a minimum of four hours.

7.6.3 Paper reference matrix—Glass-fiber filter, Gelman Type A, or equivalent. Cut paper to simulate the surface area of the paper sample being tested.

7.6.4 Tissue reference matrix—Corn or other vegetable oil. May be prepared by extraction with methylene chloride.

7.6.5 Other matrices—This method may be verified on any reference matrix by performing the tests given in Section 9.2. Ideally, the matrix should be free of the CDDs/CDFs, but in no case shall the background level of the CDDs/CDFs in the reference matrix exceed three times the minimum levels in Table 2. If low background levels of the CDDs/CDFs are present in the reference matrix, the spike level of the analytes used in Section 9.2 should be increased to provide a spike-to-background ratio in the range of 1:1 to 5:1 (Reference 15).

7.7 Standard Solutions—Purchased as solutions or mixtures with certification to their purity, concentration, and authenticity, or prepared from materials of known purity and composition. If the chemical purity is 98% or greater, the weight may be used without correction to compute the concentration of the standard. When not being used, standards are stored in the dark at room temperature in screw-capped vials with fluoropolymer-lined caps. A mark is placed on the vial at the level of the solution so that solvent loss by evaporation can be detected. If solvent loss has occurred, the solution should be replaced.

7.8 Stock Solutions.

7.8.1 Preparation—Prepare in nonane per the steps below or purchase as dilute solutions (Cambridge Isotope Laboratories (CIL), Woburn, MA, or equivalent). Observe the safety precautions in Section 5, and the recommendation in Section 5.1.2.

7.8.2 Dissolve an appropriate amount of assayed reference material in solvent. For example, weigh 1–2 mg of 2,3,7,8-TCDD to three significant figures in a 10 mL ground-glass-stoppered volumetric flask and fill to the mark with nonane. After the TCDD is completely dissolved, transfer the solution to a clean 15 mL vial with fluoropolymer-lined cap.

7.8.3 Stock standard solutions should be checked for signs of degradation prior to the preparation of calibration or performance test standards. Reference standards that can be used to determine the accuracy of calibration standards are available from CIL and may be available from other vendors.

7.9 PAR Stock Solution

7.9.1 All CDDs/CDFs—Using the solutions in Section 7.8, prepare the PAR stock solution to contain the CDDs/CDFs at the concentrations shown in Table 3. When diluted, the solution will become the PAR (Section 7.14).

7.9.2 If only 2,3,7,8-TCDD and 2,3,7,8-TCDF are to be determined, prepare the PAR stock solution to contain these compounds only.

7.10 Labeled-Compound Spiking Solution.

7.10.1 All CDDs/CDFs—From stock solutions, or from purchased mixtures, prepare this solution to contain the labeled compounds in nonane at the concentrations shown in Table 3. This solution is diluted with acetone prior to use (Section 7.10.3).

7.10.2 If only 2,3,7,8-TCDD and 2,3,7,8-TCDF are to be determined, prepare the labeled-compound solution to contain these compounds only. This solution is diluted with acetone prior to use (Section 7.10.3).

7.10.3 Dilute a sufficient volume of the labeled compound solution (Section 7.10.1 or 7.10.2) by a factor of 50 with acetone to prepare a diluted spiking solution. Each sample requires 1.0 mL of the diluted solution, but no more solution should be prepared than can be used in one day.

7.11 Cleanup Standard—Prepare $^{37}Cl_4$-2,3,7,8-TCDD in nonane at the concentration shown in Table 3. The cleanup standard is added to all extracts prior to cleanup to measure the efficiency of the cleanup process.

7.12 Internal Standard(s).

7.12.1 All CDDs/CDFs—Prepare the internal standard solution to contain $^{13}C_{12}$-1,2,3,4-TCDD and $^{13}C_2$-1,2,3,7,8,9-HxCDD in nonane at the concentration shown in Table 3.

7.12.2 If only 2,3,7,8-TCDD and 2,3,7,8-TCDF are to be determined, prepare the internal standard solution to contain $^{13}C_{12}$–1,2,3,4-TCDD only.

7.13 Calibration Standards (CS1 through CS5)—Combine the solutions in Sections 7.9 through 7.12 to produce the five calibration solutions shown in Table 4 in nonane. These solutions permit the relative response (labeled to native) and response factor to be measured as a function of concentration. The CS3 standard is used for calibration verification (VER). If only 2,3,7,8-TCDD and 2,3,7,8-TCDF are to be determined, combine the solutions appropriate to these compounds.

7.14 Precision and Recovery (PAR) Standard—Used for determination of initial (Section 9.2) and ongoing (Section 15.5) precision and recovery. Dilute 10 µL of the precision and recovery standard (Section 7.9.1 or 7.9.2) to 2.0 mL with acetone for each sample matrix for each sample batch. One mL each are required for the blank and OPR with each matrix in each batch.

7.15 GC Retention Time Window Defining Solution and Isomer Specificity Test Standard—Used to define the beginning and ending retention times for the dioxin and furan isomers and to demonstrate isomer specificity of the GC columns employed for determination of 2,3,7,8-TCDD and 2,3,7,8-TCDF. The standard must contain the compounds listed in Table 5 (CIL EDF—4006, or equivalent), at a minimum. It is not necessary to monitor the window-defining compounds if only 2,3,7,8-TCDD and 2,3,7,8-TCDF are to be determined. In this case, an isomer-specificity test standard containing the most closely eluted isomers listed in Table 5 (CIL EDF-4033, or equivalent) may be used.

7.16 QC Check Sample—A QC Check Sample should be obtained from a source independent of the calibration standards. Ideally, this check sample would be a certified reference material containing the CDDs/CDFs in known concentrations in a sample matrix similar to the matrix under test.

7.17 Stability of Solutions—Standard solutions used for quantitative purposes (Sections 7.9 through 7.15) should be analyzed periodically, and should be assayed against reference standards (Section 7.8.3) before further use.

8.0 Sample Collection, Preservation, Storage, and Holding Times

8.1 Collect samples in amber glass containers following conventional sampling practices (Reference 16). Aqueous samples that flow freely are collected in refrigerated bottles using automatic sampling equipment. Solid samples are collected as grab samples using wide-mouth jars.

8.2 Maintain aqueous samples in the dark at 0–4 °C from the time of collection until receipt at the laboratory. If residual chlorine is present in aqueous samples, add 80 mg sodium thiosulfate per liter of water. EPA

Methods 330.4 and 330.5 may be used to measure residual chlorine (Reference 17). If sample pH is greater than 9, adjust to pH 7–9 with sulfuric acid.

Maintain solid, semi-solid, oily, and mixed-phase samples in the dark at <4 °C from the time of collection until receipt at the laboratory.

Store aqueous samples in the dark at 0–4 °C. Store solid, semi-solid, oily, mixed-phase, and tissue samples in the dark at <−10 °C.

8.3 Fish and Tissue Samples.

8.3.1 Fish may be cleaned, filleted, or processed in other ways in the field, such that the laboratory may expect to receive whole fish, fish fillets, or other tissues for analysis.

8.3.2 Fish collected in the field should be wrapped in aluminum foil, and must be maintained at a temperature less than 4 °C from the time of collection until receipt at the laboratory.

8.3.3 Samples must be frozen upon receipt at the laboratory and maintained in the dark at <−10 °C until prepared. Maintain unused sample in the dark at <−10 °C.

8.4 Holding Times.

8.4.1 There are no demonstrated maximum holding times associated with CDDs/CDFs in aqueous, solid, semi-solid, tissues, or other sample matrices. If stored in the dark at 0–4 °C and preserved as given above (if required), aqueous samples may be stored for up to one year. Similarly, if stored in the dark at <−10 °C, solid, semi-solid, multiphase, and tissue samples may be stored for up to one year.

8.4.2 Store sample extracts in the dark at <−10 °C until analyzed. If stored in the dark at <−10 °C, sample extracts may be stored for up to one year.

9.0 Quality Assurance/Quality Control

9.1 Each laboratory that uses this method is required to operate a formal quality assurance program (Reference 18). The minimum requirements of this program consist of an initial demonstration of laboratory capability, analysis of samples spiked with labeled compounds to evaluate and document data quality, and analysis of standards and blanks as tests of continued performance. Laboratory performance is compared to established performance criteria to determine if the results of analyses meet the performance characteristics of the method.

If the method is to be applied to sample matrix other than water (e.g., soils, filter cake, compost, tissue) the most appropriate alternate matrix (Sections 7.6.2 through 7.6.5) is substituted for the reagent water matrix (Section 7.6.1) in all performance tests.

9.1.1 The analyst shall make an initial demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 9.2.

9.1.2 In recognition of advances that are occurring in analytical technology, and to allow the analyst to overcome sample matrix interferences, the analyst is permitted certain options to improve separations or lower the costs of measurements. These options include alternate extraction, concentration, cleanup procedures, and changes in columns and detectors. Alternate determinative techniques, such as the substitution of spectroscopic or immuno-assay techniques, and changes that degrade method performance, are not allowed. If an analytical technique other than the techniques specified in this method is used, that technique must have a specificity equal to or better than the specificity of the techniques in this method for the analytes of interest.

9.1.2.1 Each time a modification is made to this method, the analyst is required to repeat the procedure in Section 9.2. If the detection limit of the method will be affected by the change, the laboratory is required to demonstrate that the MDL (40 CFR Part 136, Appendix B) is lower than one-third the regulatory compliance level or one-third the ML in this method, whichever is higher. If calibration will be affected by the change, the analyst must recalibrate the instrument per Section 10.

9.1.2.2 The laboratory is required to maintain records of modifications made to this method. These records include the following, at a minimum:

9.1.2.2.1 The names, titles, addresses, and telephone numbers of the analyst(s) who performed the analyses and modification, and of the quality control officer who witnessed and will verify the analyses and modifications.

9.1.2.2.2 A listing of pollutant(s) measured, by name and CAS Registry number.

9.1.2.2.3 A narrative stating reason(s) for the modifications.

9.1.2.2.4 Results from all quality control (QC) tests comparing the modified method to this method, including:

(a) Calibration (Section 10.5 through 10.7).

(b) Calibration verification (Section 15.3).

(c) Initial precision and recovery (Section 9.2).

(d) Labeled compound recovery (Section 9.3).

(e) Analysis of blanks (Section 9.5).

(f) Accuracy assessment (Section 9.4).

9.1.2.2.5 Data that will allow an independent reviewer to validate each determination by tracing the instrument output (peak height, area, or other signal) to the final result. These data are to include:

(a) Sample numbers and other identifiers.

(b) Extraction dates.

(c) Analysis dates and times.

(d) Analysis sequence/run chronology.

(e) Sample weight or volume (Section 11).

(f) Extract volume prior to each cleanup step (Section 13).

(g) Extract volume after each cleanup step (Section 13).

(h) Final extract volume prior to injection (Section 14).

(i) Injection volume (Section 14.3).

(j) Dilution data, differentiating between dilution of a sample or extract (Section 17.5).

(k) Instrument and operating conditions.

(l) Column (dimensions, liquid phase, solid support, film thickness, etc).

(m) Operating conditions (temperatures, temperature program, flow rates).

(n) Detector (type, operating conditions, etc).

(o) Chromatograms, printer tapes, and other recordings of raw data.

(p) Quantitation reports, data system outputs, and other data to link the raw data to the results reported.

9.1.3 Analyses of method blanks are required to demonstrate freedom from contamination (Section 4.3). The procedures and criteria for analysis of a method blank are described in Sections 9.5 and 15.6.

9.1.4 The laboratory shall spike all samples with labeled compounds to monitor method performance. This test is described in Section 9.3. When results of these spikes indicate atypical method performance for samples, the samples are diluted to bring method performance within acceptable limits. Procedures for dilution are given in Section 17.5.

9.1.5 The laboratory shall, on an ongoing basis, demonstrate through calibration verification and the analysis of the ongoing precision and recovery aliquot that the analytical system is in control. These procedures are described in Sections 15.1 through 15.5.

9.1.6 The laboratory shall maintain records to define the quality of data that is generated. Development of accuracy statements is described in Section 9.4.

9.2 Initial Precision and Recovery (IPR)—To establish the ability to generate acceptable precision and recovery, the analyst shall perform the following operations.

9.2.1 For low solids (aqueous) samples, extract, concentrate, and analyze four 1 L aliquots of reagent water spiked with the diluted labeled compound spiking solution (Section 7.10.3) and the precision and recovery standard (Section 7.14) according to the procedures in Sections 11 through 18. For an alternative sample matrix, four aliquots of the alternative reference matrix (Section 7.6) are used. All sample processing steps that are to be used for processing samples, including preparation (Section 11), extraction (Section 12), and cleanup (Section 13), shall be included in this test.

9.2.2 Using results of the set of four analyses, compute the average concentration (X) of the extracts in ng/mL and the standard deviation of the concentration (s) in ng/mL for each compound, by isotope dilution for CDDs/CDFs with a labeled analog, and by internal standard for 1,2,3,7,8,9-HxCDD, OCDF, and the labeled compounds.

9.2.3 For each CDD/CDF and labeled compound, compare s and X with the corresponding limits for initial precision and recovery in Table 6. If only 2,3,7,8-TCDD and 2,3,7,8-TCDF are to be determined, compare s and X with the corresponding limits for initial precision and recovery in Table 6a. If s and X for all compounds meet the acceptance criteria, system performance is acceptable and analysis of blanks and samples may begin. If, however, any individual s exceeds the precision limit or any individual X falls outside the range for accuracy, system performance is unacceptable for that compound. Correct the problem and repeat the test (Section 9.2).

9.3 The laboratory shall spike all samples with the diluted labeled compound spiking solution (Section 7.10.3) to assess method performance on the sample matrix.

9.3.1 Analyze each sample according to the procedures in Sections 11 through 18.

9.3.2 Compute the percent recovery of the labeled compounds and the cleanup standard using the internal standard method (Section 17.2).

9.3.3 The recovery of each labeled compound must be within the limits in Table 7 when all 2,3,7,8-substituted CDDs/CDFs are determined, and within the limits in Table 7a when only 2,3,7,8-TCDD and 2,3,7,8-TCDF are determined. If the recovery of any compound falls outside of these limits, method performance is unacceptable for that compound in that sample. To overcome such difficulties, water samples are diluted and smaller amounts of soils, sludges, sediments, and other matrices are reanalyzed per Section 18.4.

9.4 Recovery of labeled compounds from samples should be assessed and records should be maintained.

9.4.1 After the analysis of five samples of a given matrix type (water, soil, sludge, pulp, etc.) for which the labeled compounds pass the tests in Section 9.3, compute the average percent recovery (R) and the standard deviation of the percent recovery (SR) for the labeled compounds only. Express the assessment as a percent recovery interval from $R-2S_R$ to $R=2S_R$ for each matrix. For example, if R = 90% and S_R = 10% for five analyses of pulp, the recovery interval is expressed as 70–110%.

9.4.2 Update the accuracy assessment for each labeled compound in each matrix on a regular basis (e.g., after each 5–10 new measurements).

9.5 Method Blanks—Reference matrix method blanks are analyzed to demonstrate freedom from contamination (Section 4.3).

9.5.1 Prepare, extract, clean up, and concentrate a method blank with each sample batch (samples of the same matrix started through the extraction process on the same 12-hour shift, to a maximum of 20 samples). The matrix for the method blank shall be similar to sample matrix for the batch, e.g., a 1 L reagent water blank (Section 7.6.1), high-solids reference matrix blank (Section 7.6.2), paper matrix blank (Section 7.6.3); tissue blank (Section 7.6.4) or alternative reference matrix blank (Section 7.6.5). Analyze the blank immediately after analysis of the OPR (Section 15.5) to demonstrate freedom from contamination.

9.5.2 If any 2,3,7,8-substituted CDD/CDF (Table 1) is found in the blank at greater than the minimum level (Table 2) or one-third the regulatory compliance level, whichever is greater; or if any potentially interfering compound is found in the blank at the minimum level for each level of chlorination given in Table 2 (assuming a response factor of 1 relative to the $^{13}C_{12}$-1,2,3,4-TCDD internal standard for compounds not listed in Table 1), analysis of samples is halted until the blank associated with the sample batch shows no evidence of contamination at this level. All samples must be associated with an uncontaminated method blank before the results for those samples may be reported for regulatory compliance purposes.

9.6 QC Check Sample—Analyze the QC Check Sample (Section 7.16) periodically to assure the accuracy of calibration standards and the overall reliability of the analytical process. It is suggested that the QC Check Sample be analyzed at least quarterly.

9.7 The specifications contained in this method can be met if the apparatus used is calibrated properly and then maintained in a calibrated state. The standards used for calibration (Section 10), calibration verification (Section 15.3), and for initial (Section 9.2) and ongoing (Section 15.5) precision and recovery should be identical, so that the most precise results will be obtained. A GC/MS instrument will provide the most reproducible results if dedicated to the settings and conditions required for the analyses of CDDs/CDFs by this method.

9.8 Depending on specific program requirements, field replicates may be collected to determine the precision of the sampling technique, and spiked samples may be required to determine the accuracy of the analysis when the internal standard method is used.

10.0 Calibration

10.1 Establish the operating conditions necessary to meet the minimum retention times for the internal standards in Section 10.2.4 and the relative retention times for the CDDs/CDFs in Table 2.

10.1.1 Suggested GC operating conditions:

Injector temperature: 270 °C
Interface temperature: 290 °C
Initial temperature: 200 °C
Initial time: Two minutes
Temperature program:
200–220 °C, at 5 °C/minute
220 °C for 16 minutes
220–235 °C, at 5 °C/minute
235 °C for seven minutes
235–330 °C, at 5 °C/minute

NOTE: All portions of the column that connect the GC to the ion source shall remain at or above the interface temperature specified above during analysis to preclude condensation of less volatile compounds.

Optimize GC conditions for compound separation and sensitivity. Once optimized, the same GC conditions must be used for the analysis of all standards, blanks, IPR and OPR aliquots, and samples.

10.1.2 Mass spectrometer (MS) resolution—Obtain a selected ion current profile (SICP) of each analyte in Table 3 at the two exact m/z's specified in Table 8 and at ≥10,000 resolving power by injecting an authentic standard of the CDDs/CDFs either singly or as part of a mixture in which there is no interference between closely eluted components.

10.1.2.1 The analysis time for CDDs/CDFs may exceed the long-term mass stability of the mass spectrometer. Because the instrument is operated in the high-resolution mode, mass drifts of a few ppm (e.g., 5 ppm in mass) can have serious adverse effects on instrument performance. Therefore, a mass-drift correction is mandatory and a lock-mass m/z from PFK is used for drift correction. The lock-mass m/z is dependent on the exact m/z's monitored within each descriptor, as shown in Table 8. The level of PFK metered into the HRMS during analyses should be adjusted so that the amplitude of the most intense selected lock-mass m/z signal (regardless of the descriptor number) does not exceed 10% of the full-scale deflection for a given set of detector parameters. Under those conditions, sensitivity changes that might occur during the analysis can be more effectively monitored.

NOTE: Excessive PFK (or any other reference substance) may cause noise problems and contamination of the ion source necessitating increased frequency of source cleaning.

10.1.2.2 If the HRMS has the capability to monitor resolution during the analysis, it is acceptable to terminate the analysis when the resolution falls below 10,000 to save reanalysis time.

10.1.2.3 Using a PFK molecular leak, tune the instrument to meet the minimum required resolving power of 10,000 (10% valley) at m/z 304.9824 (PFK) or any other reference signal close to m/z 304 (from TCDF). For each

descriptor (Table 8), monitor and record the resolution and exact m/z's of three to five reference peaks covering the mass range of the descriptor. The resolution must be greater than or equal to 10,000, and the deviation between the exact m/z and the theoretical m/z (Table 8) for each exact m/z monitored must be less than 5 ppm.

10.2 Ion Abundance Ratios, Minimum Levels, Signal-to-Noise Ratios, and Absolute Retention Times—Choose an injection volume of either 1 µL or 2 µL, consistent with the capability of the HRGC/HRMS instrument. Inject a 1 µL or 2 µL aliquot of the CS1 calibration solution (Table 4) using the GC conditions from Section 10.1.1. If only 2,3,7,8-TCDD and 2,3,7,8-TCDF are to be determined, the operating conditions and specifications below apply to analysis of those compounds only.

10.2.1 Measure the SICP areas for each analyte, and compute the ion abundance ratios at the exact m/z's specified in Table 8. Compare the computed ratio to the theoretical ratio given in Table 9.

10.2.1.1 The exact m/z's to be monitored in each descriptor are shown in Table 8. Each group or descriptor shall be monitored in succession as a function of GC retention time to ensure that all CDDs/CDFs are detected. Additional m/z's may be monitored in each descriptor, and the m/z's may be divided among more than the five descriptors listed in Table 8, provided that the laboratory is able to monitor the m/z's of all the CDDs/CDFs that may elute from the GC in a given retention-time window. If only 2,3,7,8-TCDD and 2,3,7,8-TCDF are to be determined, the descriptors may be modified to include only the exact m/z's for the tetra-and penta-isomers, the diphenyl ethers, and the lock m/z's.

10.2.1.2 The mass spectrometer shall be operated in a mass-drift correction mode, using perfluorokerosene (PFK) to provide lock m/z's. The lock-mass for each group of m/z's is shown in Table 8. Each lock mass shall be monitored and shall not vary by more than ±20% throughout its respective retention time window. Variations of the lock mass by more than 20% indicate the presence of coeluting interferences that may significantly reduce the sensitivity of the mass spectrometer. Reinjection of another aliquot of the sample extract will not resolve the problem. Additional cleanup of the extract may be required to remove the interferences.

10.2.2 All CDDs/CDFs and labeled compounds in the CS1 standard shall be within the QC limits in Table 9 for their respective ion abundance ratios; otherwise, the mass spectrometer shall be adjusted and this test repeated until the m/z ratios fall within the limits specified. If the adjustment alters the resolution of the mass spectrometer, resolution shall be verified (Section 10.1.2) prior to repeat of the test.

10.2.3 Verify that the HRGC/HRMS instrument meets the minimum levels in Table 2. The peaks representing the CDDs/CDFs and labeled compounds in the CS1 calibration standard must have signal-to-noise ratios (S/N) greater than or equal to 10.0. Otherwise, the mass spectrometer shall be adjusted and this test repeated until the minimum levels in Table 2 are met.

10.2.4 The absolute retention time of $^{13}C_{12}$-1,2,3,4–TCDD (Section 7.12) shall exceed 25.0 minutes on the DB–5 column, and the retention time of $^{13}C_{12}$-1,2,3,4–TCDD shall exceed 15.0 minutes on the DB–225 column; otherwise, the GC temperature program shall be adjusted and this test repeated until the above-stated minimum retention time criteria are met.

2010.3 Retention-Time Windows—Analyze the window defining mixtures (Section 7.15) using the optimized temperature program in Section 10.1. Table 5 gives the elution order (first/last) of the window-defining compounds. If 2,3,7,8-TCDD and 2,3,7,8-TCDF only are to be analyzed, this test is not required.

10.4 Isomer Specificity.

10.4.1 Analyze the isomer specificity test standards (Section 7.15) using the procedure in Section 14 and the optimized conditions for sample analysis (Section 10.1.1).

10.4.2 Compute the percent valley between the GC peaks that elute most closely to the 2,3,7,8-TCDD and TCDF isomers, on their respective columns, per Figures 6 and 7.

10.4.3 Verify that the height of the valley between the most closely eluted isomers and the 2,3,7,8-substituted isomers is less than 25% (computed as 100 x/y in Figures 6 and 7). If the valley exceeds 25%, adjust the analytical conditions and repeat the test or replace the GC column and recalibrate (Sections 10.1.2 through 10.7).

10.5 Calibration by Isotope Dilution—Isotope dilution calibration is used for the 15 2,3,7,8-substituted CDDs/CDFs for which labeled compounds are added to samples prior to extraction. The reference compound for each CDD/CDF compound is shown in Table 2.

10.5.1 A calibration curve encompassing the concentration range is prepared for each compound to be determined. The relative response (RR) (labeled to native) vs. concentration in standard solutions is plotted or computed using a linear regression. Relative response is determined according to the procedures described below. Five calibration points are employed.

10.5.2 The response of each CDD/CDF relative to its labeled analog is determined using the area responses of both the primary and secondary exact m/z's specified in Table 8, for each calibration standard, as follows:

$$RR = \frac{(A1_n + A2_n)C_l}{(A1_l + A2_l)C_n}$$

where:

$A1_n$ and $A2_n$ = The areas of the primary and secondary m/z's for the CDD/CDF.

$A1_l$ and $A2_l$ = The areas of the primary and secondary m/z's for the labeled compound.

C_l = The concentration of the labeled compound in the calibration standard (Table 4).

C_n = The concentration of the native compound in the calibration standard (Table 4).

10.5.3 To calibrate the analytical system by isotope dilution, inject a volume of calibration standards CS1 through CS5 (Section 7.13 and Table 4) identical to the volume chosen in Section 10.2, using the procedure in Section 14 and the conditions in Section 10.1.1 and Table 2. Compute the relative response (RR) at each concentration.

10.5.4 Linearity—If the relative response for any compound is constant (less than 20% coefficient of variation) over the five-point calibration range, an averaged relative response may be used for that compound; otherwise, the complete calibration curve for that compound shall be used over the five-point calibration range.

10.6 Calibration by Internal Standard—The internal standard method is applied to determination of 1,2,3,7,8,9-HxCDD (Section 17.1.2), OCDF (Section 17.1.1), the non 2,3,7,8-substituted compounds, and to the determination of labeled compounds for intralaboratory statistics (Sections 9.4 and 15.5.4).

10.6.1 Response factors—Calibration requires the determination of response factors (RF) defined by the following equation:

$$RF = \frac{(A1_s + A2_s)C_{is}}{(A1_{is} + A2_{is})C_s}$$

where:

$A1_s$ and $A2_s$ = The areas of the primary and secondary m/z's for the CDD/CDF.

$A1_{is}$ and $A2_{is}$ = The areas of the primary and secondary m/z's for the internal standard.

C_{is} = The concentration of the internal standard (Table 4).

C_s = The concentration of the compound in the calibration standard (Table 4).

NOTE: There is only one m/z for $^{37}Cl_4$-2,3,7,8-TCDD. See Table 8.

10.6.2 To calibrate the analytical system by internal standard, inject 1.0 µL or 2.0 µL of calibration standards CS1 through CS5 (Section 7.13 and Table 4) using the procedure in Section 14 and the conditions in Section 10.1.1 and Table 2. Compute the response factor (RF) at each concentration.

10.6.3 Linearity—If the response factor (RF) for any compound is constant (less than 35% coefficient of variation) over the five-point calibration range, an averaged response factor may be used for that compound; otherwise, the complete calibration curve for that compound shall be used over the five-point range.

10.7 Combined Calibration—By using calibration solutions (Section 7.13 and Table 4) containing the CDDs/CDFs and labeled compounds and the internal standards, a single set of analyses can be used to produce calibration curves for the isotope dilution and internal standard methods. These curves are verified each shift (Section 15.3) by analyzing the calibration verification standard (VER, Table 4). Recalibration is required if any of the calibration verification criteria (Section 15.3) cannot be met.

10.8 Data Storage—MS data shall be collected, recorded, and stored.

10.8.1 Data acquisition—The signal at each exact m/z shall be collected repetitively throughout the monitoring period and stored on a mass storage device.

10.8.2 Response factors and multipoint calibrations—The data system shall be used to record and maintain lists of response factors (response ratios for isotope dilution) and multipoint calibration curves. Computations of relative standard deviation (coefficient of variation) shall be used to test calibration linearity. Statistics on initial performance (Section 9.2) and ongoing performance (Section 15.5) should be computed and maintained, either on the instrument data system, or on a separate computer system.

11.0 Sample Preparation

11.1 Sample preparation involves modifying the physical form of the sample so that the CDDs/CDFs can be extracted efficiently. In general, the samples must be in a liquid form or in the form of finely divided solids in order for efficient extraction to take place. Table 10 lists the phases and suggested quantities for extraction of various sample matrices.

For samples known or expected to contain high levels of the CDDs/CDFs, the smallest sample size representative of the entire sample should be used (see Section 17.5).

For all samples, the blank and IPR/OPR aliquots must be processed through the same steps as the sample to check for contamination and losses in the preparation processes.

11.1.1 For samples that contain particles, percent solids and particle size are determined using the procedures in Sections 11.2 and 11.3, respectively.

11.1.2 Aqueous samples—Because CDDs/CDFs may be bound to suspended particles, the preparation of aqueous samples is dependent on the solids content of the sample.

11.1.2.1 Aqueous samples visibly absent particles are prepared per Section 11.4 and extracted directly using the separatory funnel or SPE techniques in Sections 12.1 or 12.2, respectively.

11.1.2.2 Aqueous samples containing visible particles and containing one percent suspended solids or less are prepared using the procedure in Section 11.4. After preparation, the sample is extracted directly using the SPE technique in 12.2 or filtered per Section 11.4.3. After filtration, the particles and filter are extracted using the SDS procedure in Section 12.3 and the filtrate is extracted using the separatory funnel procedure in Section 12.1.

11.1.2.3 For aqueous samples containing greater than one percent solids, a sample aliquot sufficient to provide 10 g of dry solids is used, as described in Section 11.5.

11.1.3 Solid samples are prepared using the procedure described in Section 11.5 followed by extraction via the SDS procedure in Section 12.3.

11.1.4 Multiphase samples—The phase(s) containing the CDDs/CDFs is separated from the non-CDD/CDF phase using pressure filtration and centrifugation, as described in Section 11.6. The CDDs/CDFs will be in the organic phase in a multiphase sample in which an organic phase exists.

11.1.5 Procedures for grinding, homogenization, and blending of various sample phases are given in Section 11.7.

11.1.6 Tissue samples—Preparation procedures for fish and other tissues are given in Section 11.8.

11.2 Determination of Percent Suspended Solids.

NOTE: This aliquot is used for determining the solids content of the sample, not for determination of CDDs/CDFs.

11.2.1 Aqueous liquids and multi-phase samples consisting of mainly an aqueous phase.

11.2.1.1 Dessicate and weigh a GF/D filter (Section 6.5.3) to three significant figures.

11.2.1.2 Filter 10.0±0.02 mL of well-mixed sample through the filter.

11.2.1.3 Dry the filter a minimum of 12 hours at 110±5 °C and cool in a dessicator.

11.2.1.4 Calculate percent solids as follows:

$$\%\ \text{solids} = \frac{\text{weight of sample aliquot after drying (g)} - \text{weight of filter (g)}}{10\ \text{g}} \times 100$$

11.2.2 Non-aqueous liquids, solids, semi-solid samples, and multi-phase samples in which the main phase is not aqueous; but not tissues.

11.2.2.1 Weigh 5–10 g of sample to three significant figures in a tared beaker.

11.2.2.2 Dry a minimum of 12 hours at 110±5 °C, and cool in a dessicator.

11.2.2.3 Calculate percent solids as follows:

$$\%\ \text{solids} = \frac{\text{weight of sample aliquot after drying}}{\text{weight of sample aliquot before drying}} \times 100$$

11.3 Determination of Particle Size.

11.3.1 Spread the dried sample from Section 11.2.2.2 on a piece of filter paper or aluminum foil in a fume hood or glove box.

11.3.2 Estimate the size of the particles in the sample. If the size of the largest particles is greater than 1 mm, the particle size must be reduced to 1 mm or less prior to extraction using the procedures in Section 11.7.

11.4 Preparation of Aqueous Samples Containing 1% Suspended Solids or Less.

11.4.1 Aqueous samples visibly absent particles are prepared per the procedure below and extracted directly using the separatory funnel or SPE techniques in Sections 12.1 or 12.2, respectively. Aqueous samples containing visible particles and one percent suspended solids or less are prepared using the procedure below and extracted using either the SPE technique in Section 12.2 or further prepared using the filtration procedure in Section 11.4.3. The filtration procedure is followed by SDS extraction of the filter and particles (Section 12.3) and separatory funnel extraction of the filtrate (Section 12.1). The SPE procedure is followed by SDS extraction of the filter and disk.

11.4.2 Preparation of sample and QC aliquots.

11.4.2.1 Mark the original level of the sample on the sample bottle for reference. Weigh the sample plus bottle to ± 1.

11.4.2.2 Spike 1.0 mL of the diluted labeled-compound spiking solution (Section 7.10.3) into the sample bottle. Cap the bottle and mix the sample by careful shaking. Allow the sample to equilibrate for one to two hours, with occasional shaking.

11.4.2.3 For each sample or sample batch (to a maximum of 20 samples) to be extracted during the same 12-hour shift, place two 1.0 L aliquots of reagent water in clean sample bottles or flasks.

11.4.2.4 Spike 1.0 mL of the diluted labeled-compound spiking solution (Section 7.10.3) into both reagent water aliquots. One of these aliquots will serve as the method blank.

11.4.2.5 Spike 1.0 mL of the PAR standard (Section 7.14) into the remaining reagent water aliquot. This aliquot will serve as the OPR (Section 15.5).

11.4.2.6 If SPE is to be used, add 5 mL of methanol to the sample, cap and shake the sample to mix thoroughly, and proceed to Section 12.2 for extraction. If SPE is not to be used, and the sample is visibly absent particles, proceed to Section 12.1 for extraction. If SPE is not to be used and the sample contains visible particles, proceed to the following section for filtration of particles.

11.4.3 Filtration of particles.

11.4.3.1 Assemble a Buchner funnel (Section 6.5.5) on top of a clean filtration flask. Apply vacuum to the flask, and pour the entire contents of the sample bottle through a glass-fiber filter (Section 6.5.6) in the Buchner funnel, swirling the sample remaining in the bottle to suspend any particles.

11.4.3.2 Rinse the sample bottle twice with approximately 5 mL portions of reagent water to transfer any remaining particles onto the filter.

11.4.3.3 Rinse any particles off the sides of the Buchner funnel with small quantities of reagent water.

11.4.3.4 Weigh the empty sample bottle to ±1 g. Determine the weight of the sample by difference. Save the bottle for further use.

11.4.3.5 Extract the filtrate using the separatory funnel procedure in Section 12.1.

11.4.3.6 Extract the filter containing the particles using the SDS procedure in Section 12.3.

11.5 Preparation of Samples Containing Greater Than 1% Solids.

11.5.1 Weigh a well-mixed aliquot of each sample (of the same matrix type) sufficient to provide 10 g of dry solids (based on the solids determination in Section 11.2) into a clean beaker or glass jar.

11.5.2 Spike 1.0 mL of the diluted labeled compound spiking solution (Section 7.10.3) into the sample.

11.5.3 For each sample or sample batch (to a maximum of 20 samples) to be extracted during the same 12-hour shift, weigh two 10 g aliquots of the appropriate reference matrix (Section 7.6) into clean beakers or glass jars.

11.5.4 Spike 1.0 mL of the diluted labeled compound spiking solution (Section 7.10.3) into each reference matrix aliquot. One aliquot will serve as the method blank. Spike 1.0 mL of the PAR standard (Section 7.14) into the other reference matrix aliquot. This aliquot will serve as the OPR (Section 15.5).

11.5.5 Stir or tumble and equilibrate the aliquots for one to two hours.

11.5.6 Decant excess water. If necessary to remove water, filter the sample through a glass-fiber filter and discard the aqueous liquid.

11.5.7 If particles >1mm are present in the sample (as determined in Section 11.3.2), spread the sample on clean aluminum foil in a hood. After the sample is dry, grind to reduce the particle size (Section 11.7).

11.5.8 Extract the sample and QC aliquots using the SDS procedure in Section 12.3.

11.6 Multiphase Samples.

11.6.1 Using the percent solids determined in Section 11.2.1 or 11.2.2, determine the volume of sample that will provide 10 g of solids, up to 1 L of sample.

11.6.2 Pressure filter the amount of sample determined in Section 11.6.1 through Whatman GF/D glass-fiber filter paper (Section 6.5.3). Pressure filter the blank and OPR aliquots through GF/D papers also. If necessary to separate the phases and/or settle the solids, centrifuge these aliquots prior to filtration.

11.6.3 Discard any aqueous phase (if present). Remove any non-aqueous liquid present and reserve the maximum amount filtered from the sample (Section 11.6.1) or 10 g, whichever is less, for combination with the solid phase (Section 12.3.5).

11.6.4 If particles >1mm are present in the sample (as determined in Section 11.3.2) and the sample is capable of being dried, spread the sample and QC aliquots on clean aluminum foil in a hood. After the aliquots are dry or if the sample cannot be dried, reduce the particle size using the procedures in Section 11.7 and extract the reduced particles using the SDS procedure in Section 12.3. If particles >1mm are not present, extract the particles and filter in the sample and QC aliquots directly using the SDS procedure in Section 12.3.

11.7 Sample grinding, homogenization, or blending—Samples with particle sizes greater than 1 mm (as determined in Section 11.3.2) are subjected to grinding, homogenization, or blending. The method of reducing particle size to less than 1 mm is matrix-dependent. In general, hard particles can be reduced by grinding with a mortar and pestle. Softer particles can be reduced by grinding in a Wiley mill or meat grinder, by homogenization, or in a blender.

11.7.1 Each size-reducing preparation procedure on each matrix shall be verified by running the tests in Section 9.2 before the procedure is employed routinely.

11.7.2 The grinding, homogenization, or blending procedures shall be carried out in a glove box or fume hood to prevent particles from contaminating the work environment.

11.7.3 Grinding—Certain papers and pulps, slurries, and amorphous solids can be ground in a Wiley mill or heavy duty meat grinder. In some cases, reducing the temperature of the sample to freezing or to dry ice or liquid nitrogen temperatures can aid in the grinding process. Grind the sample aliquots from Section 11.5.7 or 11.6.4 in a clean grinder. Do not allow the sample temperature to exceed 50 °C. Grind the blank and reference matrix aliquots using a clean grinder.

11.7.4 Homogenization or blending—Particles that are not ground effectively, or particles greater than 1 mm in size after grinding, can often be reduced in size by high speed homogenization or blending. Homogenize and/or blend the particles or filter from Section 11.5.7 or 11.6.4 for the sample, blank, and OPR aliquots.

11.7.5 Extract the aliquots using the SDS procedure in Section 12.3.

11.8 Fish and Other Tissues—Prior to processing tissue samples, the laboratory must determine the exact tissue to be analyzed. Common requests for analysis of fish tissue include whole fish—skin on, whole fish—skin removed, edible fish fillets (filleted in the field or by the laboratory), specific organs, and other portions. Once the appropriate tissue has been determined, the sample must be homogenized.

11.8.1 Homogenization.

11.8.1.1 Samples are homogenized while still frozen, where practical. If the laboratory must dissect the whole fish to obtain the appropriate tissue for analysis, the unused tissues may be rapidly refrozen and stored in a clean glass jar for subsequent use.

11.8.1.2 Each analysis requires 10 g of tissue (wet weight). Therefore, the laboratory should homogenize at least 20 g of tissue to allow for re-extraction of a second aliquot of the same homogenized sample, if re-analysis is required. When whole fish analysis is necessary, the entire fish is homogenized.

11.8.1.3 Homogenize the sample in a tissue homogenizer (Section 6.3.3) or grind in a meat grinder (Section 6.3.4). Cut tissue too large to feed into the grinder into smaller pieces. To assure homogeneity, grind three times.

11.8.1.4 Transfer approximately 10 g (wet weight) of homogenized tissue to a clean, tared, 400–500 mL beaker. For the alternate HCl digestion/extraction, transfer the tissue to a clean, tared 500–600 mL wide-mouth bottle. Record the weight to the nearest 10 mg.

11.8.1.5 Transfer the remaining homogenized tissue to a clean jar with a fluoropolymer-lined lid. Seal the jar and store the tissue at <-10 °C. Return any tissue that was not homogenized to its original container and store at <-10 °C.

11.8.2 QC aliquots.

11.8.2.1 Prepare a method blank by adding approximately 10 g of the oily liquid reference matrix (Section 7.6.4) to a 400–500 mL beaker. For the alternate HCl digestion/extraction, add the reference matrix to a 500–600 mL wide-mouth bottle. Record the weight to the nearest 10 mg.

11.8.2.2 Prepare a precision and recovery aliquot by adding approximately 10 g of the oily liquid reference matrix (Section 7.6.4) to a separate 400–500 mL beaker or wide-mouth bottle, depending on the extraction procedure to be used. Record the weight to the nearest 10 mg. If the initial precision and recovery test is to be performed, use four aliquots; if the ongoing precision and recovery test is to be performed, use a single aliquot.

11.8.3 Spiking

11.8.3.1 Spike 1.0 mL of the labeled compound spiking solution (Section 7.10.3) into the sample, blank, and OPR aliquot.

11.8.3.2 Spike 1.0 mL of the PAR standard (Section 7.14) into the OPR aliquot.

11.8.4 Extract the aliquots using the procedures in Section 12.4.

12.0 Extraction and Concentration

Extraction procedures include separatory funnel (Section 12.1) and solid phase (Section 12.2) for aqueous liquids; Soxhlet/Dean-Stark (Section 12.3) for solids, filters, and SPE disks; and Soxhlet extraction (Section 12.4.1) and HCl digestion (Section 12.4.2) for tissues. Acid/base back-extraction (Section 12.5) is used for initial cleanup of extracts.

Macro-concentration procedures include rotary evaporation (Section 12.6.1), heating mantle (Section 12.6.2), and Kuderna-Danish (K–D) evaporation (Section 12.6.3). Micro-concentration uses nitrogen blowdown (Section 12.7).

12.1 Separatory funnel extraction of filtrates and of aqueous samples visibly absent particles.

12.1.1 Pour the spiked sample (Section 11.4.2.2) or filtrate (Section 11.4.3.5) into a 2 L separatory funnel. Rinse the bottle or flask twice with 5 mL of reagent water and add these rinses to the separatory funnel.

12.1.2 Add 60 mL methylene chloride to the empty sample bottle (Section 12.1.1), seal, and shake 60 seconds to rinse the inner surface. Transfer the solvent to the separatory funnel, and extract the sample by shaking the funnel for two minutes with periodic venting. Allow the organic layer to separate from the aqueous phase for a minimum of 10 minutes. If an emulsion forms and is more than one-third the volume of the solvent layer, employ mechanical techniques to complete the phase separation (see note below). Drain the methylene chloride extract

through a solvent-rinsed glass funnel approximately one-half full of granular anhydrous sodium sulfate (Section 7.2.1) supported on clean glass-fiber paper into a solvent-rinsed concentration device (Section 12.6).

NOTE: If an emulsion forms, the analyst must employ mechanical techniques to complete the phase separation. The optimum technique depends upon the sample, but may include stirring, filtration through glass wool, use of phase separation paper, centrifugation, use of an ultrasonic bath with ice, addition of NaCl, or other physical methods. Alternatively, solid-phase or other extraction techniques may be used to prevent emulsion formation. Any alternative technique is acceptable so long as the requirements in Section 9 are met.

Experience with aqueous samples high in dissolved organic materials (e.g., paper mill effluents) has shown that acidification of the sample prior to extraction may reduce the formation of emulsions. Paper industry methods suggest that the addition of up to 400 mL of ethanol to a 1 L effluent sample may also reduce emulsion formation. However, studies by EPA suggest that the effect may be a result of sample dilution, and that the addition of reagent water may serve the same function. Mechanical techniques may still be necessary to complete the phase separation. If either acidification or addition of ethanol is utilized, the laboratory must perform the startup tests described in Section 9.2 using the same techniques.

12.1.3 Extract the water sample two more times with 60 mL portions of methylene chloride. Drain each portion through the sodium sulfate into the concentrator. After the third extraction, rinse the separatory funnel with at least 20 mL of methylene chloride, and drain this rinse through the sodium sulfate into the concentrator. Repeat this rinse at least twice. Set aside the funnel with sodium sulfate if the extract is to be combined with the extract from the particles.

12.1.4 Concentrate the extract using one of the macro-concentration procedures in Section 12.6.

12.1.4.1 If the extract is from a sample visibly absent particles (Section 11.1.2.1), adjust the final volume of the concentrated extract to approximately 10 mL with hexane, transfer to a 250 mL separatory funnel, and back-extract using the procedure in Section 12.5.

12.1.4.2 If the extract is from the aqueous filtrate (Section 11.4.3.5), set aside the concentration apparatus for addition of the SDS extract from the particles (Section 12.3.9.1.2).

12.2 SPE of Samples Containing Less Than 1% Solids (References 19–20).

12.2.1 Disk preparation.

12.2.1.1 Place an SPE disk on the base of the filter holder (Figure 4) and wet with toluene. While holding a GMF 150 filter above the SPE disk with tweezers, wet the filter with toluene and lay the filter on the SPE disk, making sure that air is not trapped between the filter and disk. Clamp the filter and SPE disk between the 1 L glass reservoir and the vacuum filtration flask.

12.2.1.2 Rinse the sides of the filtration flask with approx 15 mL of toluene using a squeeze bottle or syringe. Apply vacuum momentarily until a few drops appear at the drip tip. Release the vacuum and allow the filter/disk to soak for approx one minute. Apply vacuum and draw all of the toluene through the filter/disk. Repeat the wash step with approx 15 mL of acetone and allow the filter/disk to air dry.

12.2.1.3 Re-wet the filter/disk with approximately 15 mL of methanol, allowing the filter/disk to soak for approximately one minute. Pull the methanol through the filter/disk using the vacuum, but retain a layer of methanol approximately 1 mm thick on the filter. Do not allow the disk to go dry from this point until the end of the extraction.

12.2.1.4 Rinse the filter/disk with two 50-mL portions of reagent water by adding the water to the reservoir and pulling most through, leaving a layer of water on the surface of the filter.

12.2.2 Extraction.

12.2.2.1 Pour the spiked sample (Section 11.4.2.2), blank (Section 11.4.2.4), or IPR/OPR aliquot (Section 11.4.2.5) into the reservoir and turn on the vacuum to begin the extraction. Adjust the vacuum to complete the extraction in no less than 10 minutes. For samples containing a high concentration of particles (suspended solids), filtration times may be eight hours or longer.

12.2.2.2 Before all of the sample has been pulled through the filter/disk, rinse the sample bottle with approximately 50 mL of reagent water to remove any solids, and pour into the reservoir. Pull through the filter/disk. Use additional reagent water rinses until all visible solids are removed.

12.2.2.3 Before all of the sample and rinses have been pulled through the filter/disk, rinse the sides of the reservoir with small portions of reagent water.

12.2.2.4 Allow the filter/disk to dry, then remove the filter and disk and place in a glass Petri dish. Extract the filter and disk per Section 12.3.

12.3 SDS Extraction of Samples Containing Particles, and of Filters and/or Disks.

12.3.1 Charge a clean extraction thimble (Section 6.4.2.2) with 5.0 g of 100/200 mesh silica (Section 7.5.1.1) topped with 100 g of quartz sand (Section 7.3.2).

NOTE: Do not disturb the silica layer throughout the extraction process.

12.3.2 Place the thimble in a clean extractor. Place 30–40 mL of toluene in the receiver and 200–250 mL of toluene in the flask.

12.3.3 Pre-extract the glassware by heating the flask until the toluene is boiling. When properly adjusted, one to two drops of toluene will fall per second from the condenser tip into the receiver. Extract the apparatus for a minimum of three hours.

12.3.4 After pre-extraction, cool and disassemble the apparatus. Rinse the thimble with toluene and allow to air dry.

12.3.5 Load the wet sample, filter, and/or disk from Section 11.4.3.6, 11.5.8, 11.6.4, 11.7.3, 11.7.4, or 12.2.2.4 and any nonaqueous liquid from Section 11.6.3 into the thimble and manually mix into the sand layer with a clean metal spatula, carefully breaking up any large lumps of sample.

12.3.6 Reassemble the pre-extracted SDS apparatus, and add a fresh charge of toluene to the receiver and reflux flask. Apply power to the heating mantle to begin refluxing. Adjust the reflux rate to match the rate of percolation through the sand and silica beds until water removal lessens the restriction to toluene flow. Frequently check the apparatus for foaming during the first two hours of extraction. If foaming occurs, reduce the reflux rate until foaming subsides.

12.3.7 Drain the water from the receiver at one to two hours and eight to nine hours, or sooner if the receiver fills with water. Reflux the sample for a total of 16–24 hours. Cool and disassemble the apparatus. Record the total volume of water collected.

12.3.8 Remove the distilling flask. Drain the water from the Dean-Stark receiver and add any toluene in the receiver to the extract in the flask.

12.3.9 Concentrate the extract using one of the macro-concentration procedures in Section 12.6 per the following:

12.3.9.1 Extracts from the particles in an aqueous sample containing less than 1% solids (Section 11.4.3.6).

12.3.9.1.1 Concentrate the extract to approximately 5 mL using the rotary evaporator or heating mantle procedures in Section 12.6.1 or 12.6.2.

12.3.9.1.2 Quantitatively transfer the extract through the sodium sulfate (Section 12.1.3) into the apparatus that was set aside (Section 12.1.4.2) and reconcentrate to the level of the toluene.

12.3.9.1.3 Adjust to approximately 10 mL with hexane, transfer to a 250 mL separatory funnel, and proceed with back-extraction (Section 12.5).

12.3.9.2 Extracts from particles (Sections 11.5 through 11.6) or from the SPE filter and disk (Section 12.2.2.4)—Concentrate to approximately 10 mL using the rotary evaporator or heating mantle (Section 12.6.1 or 12.6.2), transfer to a 250 mL separatory funnel, and proceed with back-extraction (Section 12.5).

12.4 Extraction of Tissue—Two procedures are provided for tissue extraction.

12.4.1 Soxhlet extraction (Reference 21).

12.4.1.1 Add 30–40 g of powdered anhydrous sodium sulfate to each of the beakers (Section 11.8.4) and mix thoroughly. Cover the beakers with aluminum foil and allow to equilibrate for 12–24 hours. Remix prior to extraction to prevent clumping.

12.4.1.2 Assemble and pre-extract the Soxhlet apparatus per Sections 12.3.1 through 12.3.4, except use the methylene chloride:hexane (1:1) mixture for the pre-extraction and rinsing and omit the quartz sand. The Dean-Stark moisture trap may also be omitted, if desired.

12.4.1.3 Reassemble the pre-extracted Soxhlet apparatus and add a fresh charge of methylene chloride:hexane to the reflux flask.

12.4.1.4 Transfer the sample/sodium sulfate mixture (Section 12.4.1.1) to the Soxhlet thimble, and install the thimble in the Soxhlet apparatus.

12.4.1.5 Rinse the beaker with several portions of solvent mixture and add to the thimble. Fill the thimble/receiver with solvent. Extract for 18–24 hours.

12.4.1.6 After extraction, cool and disassemble the apparatus.

12.4.1.7 Quantitatively transfer the extract to a macro-concentration device (Section 12.6), and concentrate to near dryness. Set aside the concentration apparatus for reuse.

12.4.1.8 Complete the removal of the solvent using the nitrogen blowdown procedure (Section 12.7) and a water bath temperature of 60 °C. Weigh the receiver, record the weight, and return the receiver to the blowdown apparatus, concentrating the residue until a constant weight is obtained.

12.4.1.9 Percent lipid determination—The lipid content is determined by extraction of tissue with the same solvent system (methylene chloride:hexane) that was used in EPA's National Dioxin Study (Reference 22) so that lipid contents are consistent with that study.

12.4.1.9.1 Redissolve the residue in the receiver in hexane and spike 1.0 mL of the cleanup standard (Section 7.11) into the solution.

12.4.1.9.2 Transfer the residue/hexane to the anthropogenic isolation column (Section 13.7.1) or bottle for the acidified silica gel batch cleanup (Section 13.7.2), retaining the boiling chips in the concentration apparatus. Use several rinses to assure that all material is transferred. If necessary, sonicate or heat the receiver slightly to assure that all material is re-dissolved. Allow the receiver to dry. Weigh the receiver and boiling chips.

12.4.1.9.3 Calculate the lipid content to the nearest three significant figures as follows:

$$\text{Percent lipid} = \frac{\text{Weight of residue (g)}}{\text{Weight of tissue (g)}} \times 100$$

12.4.1.9.4 It is not necessary to determine the lipid content of the blank, IPR, or OPR aliquots.

12.4.2 HCl digestion/extraction and concentration (References 23–26).

12.4.2.1 Add 200 mL of 6 N HCl and 200 mL of methylene chloride:hexane (1:1) to the sample and QC aliquots (Section 11.8.4).

12.4.2.2 Cap and shake each bottle one to three times. Loosen the cap in a hood to vent excess pressure. Shake each bottle for 10–30 seconds and vent.

12.4.2.3 Tightly cap and place on shaker. Adjust the shaker action and speed so that the acid, solvent, and tissue are in constant motion. However, take care to avoid such violent action that the bottle may be dislodged from the shaker. Shake for 12–24 hours.

12.4.2.4 After digestion, remove the bottles from the shaker. Allow the bottles to stand so that the solvent and acid layers separate.

12.4.2.5 Decant the solvent through a glass funnel with glass-fiber filter (Sections 6.5.2 through 6.5.3) containing approximately 10 g of granular anhydrous sodium sulfate (Section 7.2.1) into a macro-concentration apparatus (Section 12.6). Rinse the contents of the bottle with two 25 mL portions of hexane and pour through the sodium sulfate into the apparatus.

12.4.2.6 Concentrate the solvent to near dryness using a macro-concentration procedure (Section 12.6).

12.4.2.7 Complete the removal of the solvent using the nitrogen blowdown apparatus (Section 12.7) and a water bath temperature of 60 °C. Weigh the receiver, record the weight, and return the receiver to the blowdown apparatus, concentrating the residue until a constant weight is obtained.

12.4.2.8 Percent lipid determination—The lipid content is determined in the same solvent system [methylene chloride:hexane (1:1)] that was used in EPA's National Dioxin Study (Reference 22) so that lipid contents are consistent with that study.

12.4.2.8.1 Redissolve the residue in the receiver in hexane and spike 1.0 mL of the cleanup standard (Section 7.11) into the solution.

12.4.2.8.2 Transfer the residue/hexane to the narrow-mouth 100–200 mL bottle retaining the boiling chips in the receiver. Use several rinses to assure that all material is transferred, to a maximum hexane volume of approximately 70 mL. Allow the receiver to dry. Weigh the receiver and boiling chips.

12.4.2.8.3 Calculate the percent lipid per Section 12.4.1.9.3. It is not necessary to determine the lipid content of the blank, IPR, or OPR aliquots.

12.4.2.9 Clean up the extract per Section 13.7.3.

12.5 Back-Extraction with Base and Acid.

12.5.1 Spike 1.0 mL of the cleanup standard (Section 7.11) into the separatory funnels containing the sample and QC extracts from Section 12.1.4.1, 12.3.9.1.3, or 12.3.9.2.

12.5.2 Partition the extract against 50 mL of potassium hydroxide solution (Section 7.1.1). Shake for two minutes with periodic venting into a hood. Remove and discard the aqueous layer. Repeat the base washing until no color is visible in the aqueous layer, to a maximum of four washings. Minimize contact time between the extract and the base to prevent degradation of the CDDs/CDFs. Stronger potassium hydroxide solutions may be employed for back-extraction, provided that the laboratory meets the specifications for labeled compound recovery and demonstrates acceptable performance using the procedure in Section 9.2.

12.5.3 Partition the extract against 50 mL of sodium chloride solution (Section 7.1.4) in the same way as with base. Discard the aqueous layer.

12.5.4 Partition the extract against 50 mL of sulfuric acid (Section 7.1.2) in the same way as with base. Repeat the acid washing until no color is visible in the aqueous layer, to a maximum of four washings.

12.5.5 Repeat the partitioning against sodium chloride solution and discard the aqueous layer.

12.5.6 Pour each extract through a drying column containing 7–10 cm of granular anhydrous sodium sulfate (Section 7.2.1). Rinse the separatory funnel with 30–50 mL of solvent, and pour through the drying column. Collect each extract in a round-bottom flask. Re-concentrate the sample and QC aliquots per Sections 12.6 through 12.7, and clean up the samples and QC aliquots per Section 13.

12.6 Macro-Concentration—Extracts in toluene are concentrated using a rotary evaporator or a heating mantle; extracts in methylene chloride or hexane are concentrated using a rotary evaporator, heating mantle, or Kuderna-Danish apparatus.

12.6.1 Rotary evaporation—Concentrate the extracts in separate round-bottom flasks.

12.6.1.1 Assemble the rotary evaporator according to manufacturer's instructions, and warm the water bath to 45 °C. On a daily basis, preclean the rotary evaporator by concentrating 100 mL of clean extraction solvent through the system. Archive both the concentrated solvent and the solvent in the catch flask for a contamination check if necessary. Between samples, three 2–3 mL aliquots of solvent should be rinsed down the feed tube into a waste beaker.

12.6.1.2 Attach the round-bottom flask containing the sample extract to the rotary evaporator. Slowly apply vacuum to the system, and begin rotating the sample flask.

12.6.1.3 Lower the flask into the water bath, and adjust the speed of rotation and the temperature as required to complete concentration in 15–20 minutes. At the proper rate of concentration, the flow of solvent into the receiving flask will be steady, but no bumping or visible boiling of the extract will occur.

NOTE: If the rate of concentration is too fast, analyte loss may occur.

12.6.1.4 When the liquid in the concentration flask has reached an apparent volume of approximately 2 mL, remove the flask from the water bath and stop the rotation. Slowly and carefully admit air into the system. Be sure not to open the valve so quickly that the sample is blown out of the flask. Rinse the feed tube with approximately 2 mL of solvent.

12.6.1.5 Proceed to Section 12.6.4 for preparation for back-extraction or micro-concentration and solvent exchange.

12.6.2 Heating mantle—Concentrate the extracts in separate round-bottom flasks.

12.6.2.1 Add one or two clean boiling chips to the round-bottom flask, and attach a three-ball macro Snyder column. Prewet the column by adding approximately 1 mL of solvent through the top. Place the round-bottom flask in a heating mantle, and apply heat as required to complete the concentration in 15–20 minutes. At the proper rate of distillation, the balls of the column will actively chatter, but the chambers will not flood.

12.6.2.2 When the liquid has reached an apparent volume of approximately 10 mL, remove the round-bottom flask from the heating mantle and allow the solvent to drain and cool for at least 10 minutes. Remove the Snyder column and rinse the glass joint into the receiver with small portions of solvent.

12.6.2.3 Proceed to Section 12.6.4 for preparation for back-extraction or micro-concentration and solvent exchange.

12.6.3 Kuderna-Danish (K–D)—Concentrate the extracts in separate 500 mL K–D flasks equipped with 10 mL concentrator tubes. The K–D technique is used for solvents such as methylene chloride and hexane. Toluene is difficult to concentrate using the K–D technique unless a water bath fed by a steam generator is used.

12.6.3.1 Add one to two clean boiling chips to the receiver. Attach a three-ball macro Snyder column. Prewet the column by adding approximately 1 mL of solvent through the top. Place the K–D apparatus in a hot water bath so that the entire lower rounded surface of the flask is bathed with steam.

12.6.3.2 Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15–20 minutes. At the proper rate of distillation, the balls of the column will actively chatter but the chambers will not flood.

12.6.3.3 When the liquid has reached an apparent volume of 1 mL, remove the K–D apparatus from the bath and allow the solvent to drain and cool for at least 10 minutes. Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1–2 mL of solvent. A 5 mL syringe is recommended for this operation.

12.6.3.4 Remove the three-ball Snyder column, add a fresh boiling chip, and attach a two-ball micro Snyder column to the concentrator tube. Prewet the column by adding approximately 0.5 mL of solvent through the top. Place the apparatus in the hot water bath.

12.6.3.5 Adjust the vertical position and the water temperature as required to complete the concentration in 5–10 minutes. At the proper rate of distillation, the balls of the column will actively chatter but the chambers will not flood.

12.6.3.6 When the liquid reaches an apparent volume of 0.5 mL, remove the apparatus from the water bath and allow to drain and cool for at least 10 minutes.

12.6.3.7 Proceed to 12.6.4 for preparation for back-extraction or micro-concentration and solvent exchange.

12.6.4 Preparation for back-extraction or micro-concentration and solvent exchange.

12.6.4.1 For back-extraction (Section 12.5), transfer the extract to a 250 mL separatory funnel. Rinse the concentration vessel with small portions of hexane, adjust the hexane volume in the separatory funnel to 10–20 mL, and proceed to back-extraction (Section 12.5).

12.6.4.2 For determination of the weight of residue in the extract, or for clean-up procedures other than back-extraction, transfer the extract to a blowdown vial using two to three rinses of solvent. Proceed with micro-concentration and solvent exchange (Section 12.7).

12.7 Micro-Concentration and Solvent Exchange.

12.7.1 Extracts to be subjected to GPC or HPLC cleanup are exchanged into methylene chloride. Extracts to be cleaned up using silica gel, alumina, carbon, and/or Florisil are exchanged into hexane.

12.7.2 Transfer the vial containing the sample extract to a nitrogen blowdown device. Adjust the flow of nitrogen so that the surface of the solvent is just visibly disturbed.

NOTE: A large vortex in the solvent may cause analyte loss.

12.7.3 Lower the vial into a 45 °C water bath and continue concentrating.

12.7.3.1 If the extract is to be concentrated to dryness for weight determination (Sections 12.4.1.8, 12.4.2.7, and 13.7.1.4), blow dry until a constant weight is obtained.

12.7.3.2 If the extract is to be concentrated for injection into the GC/MS or the

solvent is to be exchanged for extract cleanup, proceed as follows:

12.7.4 When the volume of the liquid is approximately 100 L, add 2–3 mL of the desired solvent (methylene chloride for GPC and HPLC, or hexane for the other cleanups) and continue concentration to approximately 100 µL. Repeat the addition of solvent and concentrate once more.

12.7.5 If the extract is to be cleaned up by GPC, adjust the volume of the extract to 5.0 mL with methylene chloride. If the extract is to be cleaned up by HPLC, further concentrate the extract to 30 µL. Proceed with GPC or HPLC cleanup (Section 13.2 or 13.6, respectively).

12.7.6 If the extract is to be cleaned up by column chromatography (alumina, silica gel, Carbopak/Celite, or Florisil), bring the final volume to 1.0 mL with hexane. Proceed with column cleanups (Sections 13.3 through 13.5 and 13.8).

12.7.7 If the extract is to be concentrated for injection into the GC/MS (Section 14), quantitatively transfer the extract to a 0.3 mL conical vial for final concentration, rinsing the larger vial with hexane and adding the rinse to the conical vial. Reduce the volume to approximately 100 µL. Add 10 µL of nonane to the vial, and evaporate the solvent to the level of the nonane. Seal the vial and label with the sample number. Store in the dark at room temperature until ready for GC/MS analysis. If GC/MS analysis will not be performed on the same day, store the vial at < -10 °C.

13.0 Extract Cleanup

13.1 Cleanup may not be necessary for relatively clean samples (e.g., treated effluents, groundwater, drinking water). If particular circumstances require the use of a cleanup procedure, the analyst may use any or all of the procedures below or any other appropriate procedure. Before using a cleanup procedure, the analyst must demonstrate that the requirements of Section 9.2 can be met using the cleanup procedure. If only 2,3,7,8-TCDD and 2,3,7,8-TCDF are to be determined, the cleanup procedures may be optimized for isolation of these two compounds.

13.1.1 Gel permeation chromatography (Section 13.2) removes high molecular weight interferences that cause GC column performance to degrade. It should be used for all soil and sediment extracts and may be used for water extracts that are expected to contain high molecular weight organic compounds (e.g., polymeric materials, humic acids).

13.1.2 Acid, neutral, and basic silica gel (Section 13.3), alumina (Section 13.4), and Florisil (Section 13.8) are used to remove nonpolar and polar interferences. Alumina and Florisil are used to remove chlorodiphenyl ethers.

13.1.3 Carbopak/Celite (Section 13.5) is used to remove nonpolar interferences.

13.1.4 HPLC (Section 13.6) is used to provide specificity for the 2,3,7,8-substituted and other CDD and CDF isomers.

13.1.5 The anthropogenic isolation column (Section 13.7.1), acidified silica gel batch adsorption procedure (Section 13.7.2), and sulfuric acid and base back-extraction (Section 13.7.3) are used for removal of lipids from tissue samples.

13.2 Gel Permeation Chromatography (GPC).

13.2.1 Column packing.

13.2.1.1 Place 70–75 g of SX–3 Bio-beads (Section 6.7.1.1) in a 400–500 mL beaker.

13.2.1.2 Cover the beads with methylene chloride and allow to swell overnight (a minimum of 12 hours).

13.2.1.3 Transfer the swelled beads to the column (Section 6.7.1.1) and pump solvent through the column, from bottom to top, at 4.5–5.5 mL/minute prior to connecting the column to the detector.

13.2.1.4 After purging the column with solvent for one to two hours, adjust the column head pressure to 7–10 psig and purge for four to five hours to remove air. Maintain a head pressure of 7–10 psig. Connect the column to the detector (Section 6.7.1.4).

13.2.2 Column calibration.

13.2.2.1 Load 5 mL of the calibration solution (Section 7.4) into the sample loop.

13.2.2.2 Inject the calibration solution and record the signal from the detector. The elution pattern will be corn oil, bis(2-ethyl hexyl)phthalate, pentachlorophenol, perylene, and sulfur.

13.2.2.3 Set the ''dump time'' to allow >85% removal of the corn oil and >85% collection of the phthalate.

13.2.2.4 Set the ''collect time'' to the peak minimum between perylene and sulfur.

13.2.2.5 Verify the calibration with the calibration solution after every 20 extracts. Calibration is verified if the recovery of the pentachlorophenol is greater than 85%. If calibration is not verified, the system shall be recalibrated using the calibration solution, and the previous 20 samples shall be reextracted and cleaned up using the calibrated GPC system.

13.2.3 Extract cleanup—GPC requires that the column not be overloaded. The column specified in this method is designed to handle a maximum of 0.5 g of high molecular weight material in a 5 mL extract. If the extract is known or expected to contain more than 0.5 g, the extract is split into aliquots for GPC, and the aliquots are combined after elution from the column. The residue content of the extract may be obtained gravimetrically by evaporating the solvent from a 50 µL aliquot.

13.2.3.1 Filter the extract or load through the filter holder (Section 6.7.1.3) to remove the particles. Load the 5.0 mL extract onto the column.

13.2.3.2 Elute the extract using the calibration data determined in Section 13.2.2. Collect the eluate in a clean 400–500 mL beaker.

13.2.3.3 Rinse the sample loading tube thoroughly with methylene chloride between extracts to prepare for the next sample.

13.2.3.4 If a particularly dirty extract is encountered, a 5.0 mL methylene chloride blank shall be run through the system to check for carry-over.

13.2.3.5 Concentrate the eluate per Sections 12.6 and 12.7 for further cleanup or injection into the GC/MS.

13.3 Silica Gel Cleanup.

13.3.1 Place a glass-wool plug in a 15 mm ID chromatography column (Section 6.7.4.2). Pack the column bottom to top with: 1 g silica gel (Section 7.5.1.1), 4 g basic silica gel (Section 7.5.1.3), 1 g silica gel, 8 g acid silica gel (Section 7.5.1.2), 2 g silica gel, and 4 g granular anhydrous sodium sulfate (Section 7.2.1). Tap the column to settle the adsorbents.

13.3.2 Pre-elute the column with 50–100 mL of hexane. Close the stopcock when the hexane is within 1 mm of the sodium sulfate. Discard the eluate. Check the column for channeling. If channeling is present, discard the column and prepare another.

13.3.3 Apply the concentrated extract to the column. Open the stopcock until the extract is within 1 mm of the sodium sulfate.

13.3.4 Rinse the receiver twice with 1 mL portions of hexane, and apply separately to the column. Elute the CDDs/CDFs with 100 mL hexane, and collect the eluate.

13.3.5 Concentrate the eluate per Sections 12.6 and 12.7 for further cleanup or injection into the HPLC or GC/MS.

13.3.6 For extracts of samples known to contain large quantities of other organic compounds (such as paper mill effluents), it may be advisable to increase the capacity of the silica gel column. This may be accomplished by increasing the strengths of the acid and basic silica gels. The acid silica gel (Section 7.5.1.2) may be increased in strength to as much as 44% w/w (7.9 g sulfuric acid added to 10 g silica gel). The basic silica gel (Section 7.5.1.3) may be increased in strength to as much as 33% w/w (50 mL 1N NaOH added to 100 g silica gel), or the potassium silicate (Section 7.5.1.4) may be used.

NOTE: The use of stronger acid silica gel (44% w/w) may lead to charring of organic compounds in some extracts. The charred material may retain some of the analytes and lead to lower recoveries of CDDs/CDFs. Increasing the strengths of the acid and basic silica gel may also require different volumes of hexane than those specified above to elute the analytes off the column. Therefore, the performance of the method after such modifications must be verified by the procedure in Section 9.2.

13.4 Alumina Cleanup.

13.4.1 Place a glass-wool plug in a 15 mm ID chromatography column (Section 6.7.4.2).

13.4.2 If using acid alumina, pack the column by adding 6 g acid alumina (Section 7.5.2.1). If using basic alumina, substitute 6 g basic alumina (Section 7.5.2.2). Tap the column to settle the adsorbents.

13.4.3 Pre-elute the column with 50–100 mL of hexane. Close the stopcock when the hexane is within 1 mm of the alumina.

13.4.4 Discard the eluate. Check the column for channeling. If channeling is present, discard the column and prepare another.

13.4.5 Apply the concentrated extract to the column. Open the stopcock until the extract is within 1 mm of the alumina.

13.4.6 Rinse the receiver twice with 1 mL portions of hexane and apply separately to the column. Elute the interfering compounds with 100 mL hexane and discard the eluate.

13.4.7 The choice of eluting solvents will depend on the choice of alumina (acid or basic) made in Section 13.4.2.

13.4.7.1 If using acid alumina, elute the CDDs/CDFs from the column with 20 mL methylene chloride:hexane (20:80 v/v). Collect the eluate.

13.4.7.2 If using basic alumina, elute the CDDs/CDFs from the column with 20 mL methylene chloride:hexane (50:50 v/v). Collect the eluate.

13.4.8 Concentrate the eluate per Sections 12.6 and 12.7 for further cleanup or injection into the HPLC or GC/MS.

13.5 Carbon Column.

13.5.1 Cut both ends from a 10 mL disposable serological pipet (Section 6.7.3.2) to produce a 10 cm column. Fire-polish both ends and flare both ends if desired. Insert a glass-wool plug at one end, and pack the column with 0.55 g of Carbopak/Celite (Section 7.5.3.3) to form an adsorbent bed approximately 2 cm long. Insert a glass-wool plug on top of the bed to hold the adsorbent in place.

13.5.2 Pre-elute the column with 5 mL of toluene followed by 2 mL of methylene chloride: methanol:toluene (15:4:1 v/v), 1 mL of methylene chloride:cyclohexane (1:1 v/v), and 5 mL of hexane. If the flow rate of eluate exceeds 0.5 mL/minute, discard the column.

13.5.3 When the solvent is within 1 mm of the column packing, apply the sample extract to the column. Rinse the sample container twice with 1 mL portions of hexane and apply separately to the column. Apply 2 mL of hexane to complete the transfer.

13.5.4 Elute the interfering compounds with two 3 mL portions of hexane, 2 mL of methylene chloride:cyclohexane (1:1 v/v), and 2 mL of methylene chloride:methanol:toluene (15:4:1 v/v). Discard the eluate.

13.5.5 Invert the column, and elute the CDDs/CDFs with 20 mL of toluene. If carbon particles are present in the eluate, filter through glass-fiber filter paper.

13.5.6 Concentrate the eluate per Sections 12.6 and 12.7 for further cleanup or injection into the HPLC or GC/MS.

13.6 HPLC (Reference 6).

13.6.1 Column calibration.

13.6.1.1 Prepare a calibration standard containing the 2,3,7,8-substituted isomers and/or other isomers of interest at a concentration of approximately 500 pg/µL in methylene chloride.

13.6.1.2 Inject 30 µL of the calibration solution into the HPLC and record the signal from the detector. Collect the eluant for reuse. The elution order will be the tetra- through octa-isomers.

13.6.1.3 Establish the collection time for the tetra-isomers and for the other isomers of interest. Following calibration, flush the injection system with copious quantities of methylene chloride, including a minimum of five 50 µL injections while the detector is monitored, to ensure that residual CDDs/CDFs are removed from the system.

13.6.1.4 Verify the calibration with the calibration solution after every 20 extracts. Calibration is verified if the recovery of the CDDs/CDFs from the calibration standard (Section 13.6.1.1) is 75–125% compared to the calibration (Section 13.6.1.2). If calibration is not verified, the system shall be recalibrated using the calibration solution, and the previous 20 samples shall be re-extracted and cleaned up using the calibrated system.

13.6.2 Extract cleanup—HPLC requires that the column not be overloaded. The column specified in this method is designed to handle a maximum of 30 µL of extract. If the extract cannot be concentrated to less than 30 µL, it is split into fractions and the fractions are combined after elution from the column.

13.6.2.1 Rinse the sides of the vial twice with 30 µL of methylene chloride and reduce to 30 µL with the evaporation apparatus (Section 12.7).

13.6.2.2 Inject the 30 µL extract into the HPLC.

13.6.2.3 Elute the extract using the calibration data determined in Section 13.6.1. Collect the fraction(s) in a clean 20 mL concentrator tube containing 5 mL of hexane:acetone (1:1 v/v).

13.6.2.4 If an extract containing greater than 100 ng/mL of total CDD or CDF is encountered, a 30 µL methylene chloride blank shall be run through the system to check for carry-over.

13.6.2.5 Concentrate the eluate per Section 12.7 for injection into the GC/MS.

13.7 Cleanup of Tissue Lipids—Lipids are removed from the Soxhlet extract using either the anthropogenic isolation column (Section 13.7.1) or acidified silica gel (Section 13.7.2), or are removed from the HCl digested extract using sulfuric acid and base back-extraction (Section 13.7.3).

13.7.1 Anthropogenic isolation column (References 22 and 27)—Used for removal of lipids from the Soxhlet/SDS extraction (Section 12.4.1).

13.7.1.1 Prepare the column as given in Section 7.5.4.

13.7.1.2 Pre-elute the column with 100 mL of hexane. Drain the hexane layer to the top of the column, but do not expose the sodium sulfate.

13.7.1.3 Load the sample and rinses (Section 12.4.1.9.2) onto the column by draining each portion to the top of the bed. Elute the CDDs/CDFs from the column into the apparatus used for concentration (Section 12.4.1.7) using 200 mL of hexane.

13.7.1.4 Concentrate the cleaned up extract (Sections 12.6 through 12.7) to constant weight per Section 12.7.3.1. If more than 500 mg of material remains, repeat the cleanup using a fresh anthropogenic isolation column.

13.7.1.5 Redissolve the extract in a solvent suitable for the additional cleanups to be used (Sections 13.2 through 13.6 and 13.8).

13.7.1.6 Spike 1.0 mL of the cleanup standard (Section 7.11) into the residue/solvent.

13.7.1.7 Clean up the extract using the procedures in Sections 13.2 through 13.6 and 13.8. Alumina (Section 13.4) or Florisil (Section 13.8) and carbon (Section 13.5) are recommended as minimum additional cleanup steps.

13.7.1.8 Following cleanup, concentrate the extract to 10 µL as described in Section 12.7 and proceed with the analysis in Section 14.

13.7.2 Acidified silica gel (Reference 28)—Procedure alternate to the anthropogenic isolation column (Section 13.7.1) that is used for removal of lipids from the Soxhlet/SDS extraction (Section 12.4.1).

13.7.2.1 Adjust the volume of hexane in the bottle (Section 12.4.1.9.2) to approximately 200 mL.

13.7.2.2 Spike 1.0 mL of the cleanup standard (Section 7.11) into the residue/solvent.

13.7.2.3 Drop the stirring bar into the bottle, place the bottle on the stirring plate, and begin stirring.

13.7.2.4 Add 30–100 g of acid silica gel (Section 7.5.1.2) to the bottle while stirring, keeping the silica gel in motion. Stir for two to three hours.

NOTE: 30 grams of silica gel should be adequate for most samples and will minimize contamination from this source.

13.7.2.5 After stirring, pour the extract through approximately 10 g of granular anhydrous sodium sulfate (Section 7.2.1) contained in a funnel with glass-fiber filter into a macro contration device (Section 12.6). Rinse the bottle and sodium sulfate with hexane to complete the transfer.

13.7.2.6 Concentrate the extract per Sections 12.6 through 12.7 and clean up the extract using the procedures in Sections 13.2 through 13.6 and 13.8. Alumina (Section 13.4) or Florisil (Section 13.8) and carbon (Section 13.5) are recommended as minimum additional cleanup steps.

13.7.3 Sulfuric acid and base back-extraction'Used with HCl digested extracts (Section 12.4.2).

13.7.3.1 Spike 1.0 mL of the cleanup standard (Section 7.11) into the residue/solvent (Section 12.4.2.8.2).

13.7.3.2 Add 10 mL of concentrated sulfuric acid to the bottle. Immediately cap and shake one to three times. Loosen cap in a hood to vent excess pressure. Cap and shake the bottle so that the residue/solvent is exposed to the acid for a total time of approximately 45 seconds.

13.7.3.3 Decant the hexane into a 250 mL separatory funnel making sure that no acid is transferred. Complete the quantitative transfer with several hexane rinses.

13.7.3.4 Back extract the solvent/residue with 50 mL of potassium hydroxide solution per Section 12.5.2, followed by two reagent water rinses.

13.7.3.5 Drain the extract through a filter funnel containing approximately 10 g of granular anhydrous sodium sulfate in a glass-fiber filter into a macro concentration device (Section 12.6).

13.7.3.6 Concentrate the cleaned up extract to a volume suitable for the additional cleanups given in Sections 13.2 through 13.6 and 13.8. Gel permeation chromatography (Section 13.2), alumina (Section 13.4) or Florisil (Section 13.8), and Carbopak/Celite (Section 13.5) are recommended as minimum additional cleanup steps.

13.7.3.7 Following cleanup, concentrate the extract to 10 L as described in Section 12.7 and proceed with analysis per Section 14.

13.8 Florisil Cleanup (Reference 29).

13.8.1 Pre-elute the activated Florisil column (Section 7.5.3) with 10 mL of methylene chloride followed by 10 mL of hexane:methylene chloride (98:2 v/v) and discard the solvents.

13.8.2 When the solvent is within 1 mm of the packing, apply the sample extract (in hexane) to the column. Rinse the sample container twice with 1 mL portions of hexane and apply to the column.

13.8.3 Elute the interfering compounds with 20 mL of hexane:methylene chloride (98:2) and discard the eluate.

13.8.4 Elute the CDDs/CDFs with 35 mL of methylene chloride and collect the eluate. Concentrate the eluate per Sections 12.6 through 12.7 for further cleanup or for injection into the HPLC or GC/MS.

14.0 HRGC/HRMS Analysis

14.1 Establish the operating conditions given in Section 10.1.

14.2 Add 10 uL of the appropriate internal standard solution (Section 7.12) to the sample extract immediately prior to injection to minimize the possibility of loss by evaporation, adsorption, or reaction. If an extract is to be reanalyzed and evaporation has occurred, do not add more instrument internal standard solution. Rather, bring the extract back to its previous volume (e.g., 19 L) with pure nonane only (18 L if 2 L injections are used).

14.3 Inject 1.0 µL or 2.0 µL of the concentrated extract containing the internal standard solution, using on-column or splitless injection. The volume injected must be identical to the volume used for calibration (Section 10). Start the GC column initial isothermal hold upon injection. Start MS data collection after the solvent peak elutes. Stop data collection after the OCDD and OCDF have eluted. If only 2,3,7,8-TCDD and 2,3,7,8-TCDF are to be determined, stop data collection after elution of these compounds. Return the column to the initial temperature for analysis of the next extract or standard.

15.0 System and Laboratory Performance

15.1 At the beginning of each 12-hour shift during which analyses are performed, GC/MS system performance and calibration are verified for all CDDs/CDFs and labeled compounds. For these tests, analysis of the CS3 calibration verification (VER) standard (Section 7.13 and Table 4) and the isomer specificity test standards (Section 7.15 and Table 5) shall be used to verify all performance criteria. Adjustment and/or recalibration (Section 10) shall be performed until all performance criteria are met. Only after all performance criteria are met may samples, blanks, IPRs, and OPRs be analyzed.

15.2 MS Resolution—A static resolving power of at least 10,000 (10% valley definition) must be demonstrated at the appropriate m/z before any analysis is performed. Static resolving power checks must be performed at the beginning and at the end of each 12-hour shift according to procedures in Section 10.1.2. Corrective actions must be implemented whenever the resolving power does not meet the requirement.

15.3 Calibration Verification.

15.3.1 Inject the VER standard using the procedure in Section 14.

15.3.2 The m/z abundance ratios for all CDDs/CDFs shall be within the limits in Table 9; otherwise, the mass spectrometer shall be adjusted until the m/z abundance ratios fall within the limits specified, and the verification test shall be repeated. If the adjustment alters the resolution of the mass spectrometer, resolution shall be verified (Section 10.1.2) prior to repeat of the verification test.

15.3.3 The peaks representing each CDD/CDF and labeled compound in the VER

standard must be present with S/N of at least 10; otherwise, the mass spectrometer shall be adjusted and the verification test repeated.

15.3.4 Compute the concentration of each CDD/CDF compound by isotope dilution (Section 10.5) for those compounds that have labeled analogs (Table 1). Compute the concentration of the labeled compounds by the internal standard method (Section 10.6). These concentrations are computed based on the calibration data in Section 10.

15.3.5 For each compound, compare the concentration with the calibration verification limit in Table 6. If only 2,3,7,8-TCDD and 2,3,7,8-TCDF are to be determined, compare the concentration to the limit in Table 6a. If all compounds meet the acceptance criteria, calibration has been verified and analysis of standards and sample extracts may proceed. If, however, any compound fails its respective limit, the measurement system is not performing properly for that compound. In this event, prepare a fresh calibration standard or correct the problem causing the failure and repeat the resolution (Section 15.2) and verification (Section 15.3) tests, or recalibrate (Section 10).

15.4 Retention Times and GC Resolution.

15.4.1 Retention times.

15.4.1.1 Absolute—The absolute retention times of the $^{13}C_{12}$-1,2,3,4–TCDD and $^{13}C_{12}$-1,2,3,7,8,9-HxCDD GCMS internal standards in the verification test (Section 15.3) shall be within ±15 seconds of the retention times obtained during calibration (Sections 10.2.1 and 10.2.4).

15.4.1.2 Relative—The relative retention times of CDDs/CDFs and labeled compounds in the verification test (Section 15.3) shall be within the limits given in Table 2.

15.4.2 GC resolution.

15.4.2.1 Inject the isomer specificity standards (Section 7.15) on their respective columns.

15.4.2.2 The valley height between 2,3,7,8-TCDD and the other tetra-dioxin isomers at m/z 319.8965, and between 2,3,7,8-TCDF and the other tetra-furan isomers at m/z 303.9016 shall not exceed 25% on their respective columns (Figures 6 and 7).

15.4.3 If the absolute retention time of any compound is not within the limits specified or if the 2,3,7,8-isomers are not resolved, the GC is not performing properly. In this event, adjust the GC and repeat the verification test (Section 15.3) or recalibrate (Section 10), or replace the GC column and either verify calibration or recalibrate.

15.5 Ongoing Precision and Recovery.

15.5.1 Analyze the extract of the ongoing precision and recovery (OPR) aliquot (Section 11.4.2.5, 11.5.4, 11.6.2, 11.7.4, or 11.8.3.2) prior to analysis of samples from the same batch.

15.5.2 Compute the concentration of each CDD/CDF by isotope dilution for those compounds that have labeled analogs (Section 10.5). Compute the concentration of 1,2,3,7,8,9-HxCDD, OCDF, and each labeled compound by the internal standard method (Section 10.6).

15.5.3 For each CDD/CDF and labeled compound, compare the concentration to the OPR limits given in Table 6. If only 2,3,7,8-TCDD and 2,3,7,8-TCDF are to be determined, compare the concentration to the limits in Table 6a. If all compounds meet the acceptance criteria, system performance is acceptable and analysis of blanks and samples may proceed. If, however, any individual concentration falls outside of the range given, the extraction/concentration processes are not being performed properly for that compound. In this event, correct the problem, reprepare, extract, and clean up the sample batch and repeat the ongoing precision and recovery test (Section 15.5).

15.5.4 Add results that pass the specifications in Section 15.5.3 to initial and previous ongoing data for each compound in each matrix. Update QC charts to form a graphic representation of continued laboratory performance. Develop a statement of laboratory accuracy for each CDD/CDF in each matrix type by calculating the average percent recovery (R) and the standard deviation of percent recovery (S_R). Express the accuracy as a recovery interval from $R-2S_R$ to $R=2S_R$. For example, if R=95% and S_R=5%, the accuracy is 85–105%.

15.6 Blank—Analyze the method blank extracted with each sample batch immediately following analysis of the OPR aliquot to demonstrate freedom from contamination and freedom from carryover from the OPR analysis. The results of the analysis of the blank must meet the specifications in Section 9.5.2 before sample analyses may proceed.

16.0 Qualitative Determination

A CDD, CDF, or labeled compound is identified in a standard, blank, or sample when all of the criteria in Sections 16.1 through 16.4 are met.

16.1 The signals for the two exact m/z's in Table 8 must be present and must maximize within the same two seconds.

16.2 The signal-to-noise ratio (S/N) for the GC peak at each exact m/z must be greater than or equal to 2.5 for each CDD or CDF detected in a sample extract, and greater than or equal to 10 for all CDDs/CDFs in the calibration standard (Sections 10.2.3 and 15.3.3).

16.3 The ratio of the integrated areas of the two exact m/z's specified in Table 8 must be within the limit in Table 9, or within ±10% of the ratio in the midpoint (CS3) calibration or calibration verification (VER), whichever is most recent.

16.4 The relative retention time of the peak for a 2,3,7,8-substituted CDD or CDF must be within the limit in Table 2. The retention time of peaks representing non-

2,3,7,8-substituted CDDs/CDFs must be within the retention time windows established in Section 10.3.

16.5 Confirmatory Analysis—Isomer specificity for 2,3,7,8-TCDF cannot be achieved on the DB–5 column. Therefore, any sample in which 2,3,7,8-TCDF is identified by analysis on a DB–5 column must have a confirmatory analysis performed on a DB–225, SP–2330, or equivalent GC column. The operating conditions in Section 10.1.1 may be adjusted to optimize the analysis on the second GC column, but the GC/MS must meet the mass resolution and calibration specifications in Section 10.

16.6 If the criteria for identification in Sections 16.1 through 16.5 are not met, the CDD or CDF has not been identified and the results may not be reported for regulatory compliance purposes. If interferences preclude identification, a new aliquot of sample must be extracted, further cleaned up, and analyzed.

17.0 Quantitative Determination

17.1 Isotope Dilution Quantitation—By adding a known amount of a labeled compound to every sample prior to extraction, correction for recovery of the CDD/CDF can be made because the CDD/CDF and its labeled analog exhibit similar effects upon extraction, concentration, and gas chromatography. Relative response (RR) values are used in conjunction with the initial calibration data described in Section 10.5 to determine concentrations directly, so long as labeled compound spiking levels are constant, using the following equation:

$$C_{ex}\ (ng/mL) = \frac{(A1_n + A2_n)\,C_l}{(A1_l + A2_l)\,RR}$$

where:

C_{ex} = The concentration of the CDD/CDF in the extract, and the other terms are as defined in Section 10.5.2.

17.1.1 Because of a potential interference, the labeled analog of OCDF is not added to the sample. Therefore, OCDF is quantitated against labeled OCDD. As a result, the concentration of OCDF is corrected for the recovery of the labeled OCDD. In instances where OCDD and OCDF behave differently during sample extraction, concentration, and cleanup procedures, this may decrease the accuracy of the OCDF results. However, given the low toxicity of this compound relative to the other dioxins and furans, the potential decrease in accuracy is not considered significant.

17.1.2 Because $^{13}C_{12}$-1,2,3,7,8,9-HxCDD is used as an instrument internal standard (i.e., not added before extraction of the sample), it cannot be used to quantitate the 1,2,3,7,8,9-HxCDD by strict isotope dilution procedures. Therefore, 1,2,3,7,8,9-HxCDD is quantitated using the averaged response of the labeled analogs of the other two 2,3,7,8-substituted HxCDD's: 1,2,3,4,7,8-HxCDD and 1,2,3,6,7,8-HxCDD. As a result, the concentration of 1,2,3,7,8,9-HxCDD is corrected for the average recovery of the other two HxCDD's.

17.1.3 Any peaks representing non-2,3,7,8-substituted CDDs/CDFs are quantitated using an average of the response factors from all of the labeled 2,3,7,8-isomers at the same level of chlorination.

17.2 Internal Standard Quantitation and Labeled Compound Recovery.

17.2.1 Compute the concentrations of 1,2,3,7,8,9-–HxCDD, OCDF, the ^{13}C-labeled analogs and the ^{37}C-labeled cleanup standard in the extract using the response factors determined from the initial calibration data (Section 10.6) and the following equation:

$$C_{ex}\ (ng/mL) = \frac{(A1_s + A2_s)\,C_{is}}{(A1_{is} + A2_{is})\,RF}$$

where:

C_{ex} = The concentration of the CDD/CDF in the extract, and the other terms are as defined in Section 10.6.1.

NOTE: There is only one m/z for the ^{37}Cl-labeled standard.

17.2.2 Using the concentration in the extract determined above, compute the percent recovery of the ^{13}C-labeled compounds and the ^{37}C-labeled cleanup standard using the following equation:

$$\text{Recovery (\%)} = \frac{\text{Concentration found (}\mu\text{g/mL)}}{\text{Concentration spiked (}\mu\text{g/mL)}} \times 100$$

17.3 The concentration of a CDD/CDF in the solid phase of the sample is computed using the concentration of the compound in the extract and the weight of the solids (Section 11.5.1), as follows:

$$\text{Concentration in solid (ng/kg)} = \frac{\left(C_{ex} \times V_{ex}\right)}{W_s}$$

where:

C_{ex} = The concentration of the compound in the extract.
V_{ex} = The extract volume in mL.
W_s = The sample weight (dry weight) in kg.

17.4 The concentration of a CDD/CDF in the aqueous phase of the sample is computed using the concentration of the compound in the extract and the volume of water extracted (Section 11.4 or 11.5), as follows:

$$\text{Concentration in aqueous phase (pg/L)} = \frac{\left(C_{ex} \times V_{ex}\right)}{V_s}$$

where:

C_{ex} = The concentration of the compound in the extract.
V_{ex} = The extract volume in mL.
V_s = The sample volume in liters.

17.5 If the SICP area at either quantitation m/z for any compound exceeds the calibration range of the system, a smaller sample aliquot is extracted.

17.5.1 For aqueous samples containing 1% solids or less, dilute 100 mL, 10 mL, etc., of sample to 1 L with reagent water and re-prepare, extract, clean up, and analyze per Sections 11 through 14.

17.5.2 For samples containing greater than 1% solids, extract an amount of sample equal to $^{1/10}$, $^{1/100}$, etc., of the amount used in Section 11.5.1. Re-prepare, extract, clean up, and analyze per Sections 11 through 14.

17.5.3 If a smaller sample size will not be representative of the entire sample, dilute the sample extract by a factor of 10, adjust the concentration of the instrument internal standard to 100 pg/μL in the extract, and analyze an aliquot of this diluted extract by the internal standard method.

17.6 Results are reported to three significant figures for the CDDs/CDFs and labeled compounds found in all standards, blanks, and samples.

17.6.1 Reporting units and levels.

17.6.1.1 Aqueous samples—Report results in pg/L (parts-per-quadrillion).

17.6.1.2 Samples containing greater than 1% solids (soils, sediments, filter cake, compost)—Report results in ng/kg based on the dry weight of the sample. Report the percent solids so that the result may be corrected.

17.6.1.3 Tissues—Report results in ng/kg of wet tissue, not on the basis of the lipid content of the sample. Report the percent lipid content, so that the data user can calculate the concentration on a lipid basis if desired.

17.6.1.4 Reporting level.

17.6.1.4.1 Standards (VER, IPR, OPR) and samples—Report results at or above the minimum level (Table 2). Report results below the minimum level as not detected or as required by the regulatory authority.

17.6.1.4.2 Blanks—Report results above one-third the ML.

17.6.2 Results for CDDs/CDFs in samples that have been diluted are reported at the least dilute level at which the areas at the quantitation m/z's are within the calibration range (Section 17.5).

17.6.3 For CDDs/CDFs having a labeled analog, results are reported at the least dilute level at which the area at the quantitation m/z is within the calibration range (Section 17.5) and the labeled compound recovery is within the normal range for the method (Section 9.3 and Tables 6, 6a, 7, and 7a).

17.6.4 Additionally, if requested, the total concentration of all isomers in an individual level of chlorination (i.e., total TCDD, total TCDF, total Paced, etc.) may be reported by summing the concentrations of all isomers identified in that level of chlorination, including both 2,3,7,8-substituted and non-2,3,7,8-substituted isomers.

18.0 Analysis of Complex Samples

18.1 Some samples may contain high levels (>10 ng/L; >1000 ng/kg) of the compounds of interest, interfering compounds, and/or polymeric materials. Some extracts will not concentrate to 10 μL (Section 12.7); others may overload the GC column and/or mass spectrometer.

18.2 Analyze a smaller aliquot of the sample (Section 17.5) when the extract will not concentrate to 10 μL after all cleanup procedures have been exhausted.

18.3 Chlorodiphenyl Ethers—If chromatographic peaks are detected at the retention time of any CDDs/CDFs in any of the m/z channels being monitored for the

chlorodiphenyl ethers (Table 8), cleanup procedures must be employed until these interferences are removed. Alumina (Section 13.4) and Florisil (Section 13.8) are recommended for removal of chlorodiphenyl ethers.

18.4 Recovery of Labeled Compounds—In most samples, recoveries of the labeled compounds will be similar to those from reagent water or from the alternate matrix (Section 7.6).

18.4.1 If the recovery of any of the labeled compounds is outside of the normal range (Table 7), a diluted sample shall be analyzed (Section 17.5).

18.4.2 If the recovery of any of the labeled compounds in the diluted sample is outside of normal range, the calibration verification standard (Section 7.13) shall be analyzed and calibration verified (Section 15.3).

18.4.3 If the calibration cannot be verified, a new calibration must be performed and the original sample extract reanalyzed.

18.4.4 If the calibration is verified and the diluted sample does not meet the limits for labeled compound recovery, the method does not apply to the sample being analyzed and the result may not be reported for regulatory compliance purposes. In this case, alternate extraction and cleanup procedures in this method must be employed to resolve the interference. If all cleanup procedures in this method have been employed and labeled compound recovery remains outside of the normal range, extraction and/or cleanup procedures that are beyond this scope of this method will be required to analyze these samples.

19.0 Pollution Prevention

19.1 The solvents used in this method pose little threat to the environment when managed properly. The solvent evaporation techniques used in this method are amenable to solvent recovery, and it is recommended that the laboratory recover solvents wherever feasible.

19.2 Standards should be prepared in volumes consistent with laboratory use to minimize disposal of standards.

20.0 Waste Management

20.1 It is the laboratory's responsibility to comply with all federal, state, and local regulations governing waste management, particularly the hazardous waste identification rules and land disposal restrictions, and to protect the air, water, and land by minimizing and controlling all releases from fume hoods and bench operations. Compliance is also required with any sewage discharge permits and regulations.

20.2 Samples containing HCl to pH <2 are hazardous and must be neutralized before being poured down a drain or must be handled as hazardous waste.

20.3 The CDDs/CDFs decompose above 800 °C. Low-level waste such as absorbent paper, tissues, animal remains, and plastic gloves may be burned in an appropriate incinerator. Gross quantities (milligrams) should be packaged securely and disposed of through commercial or governmental channels that are capable of handling extremely toxic wastes.

20.4 Liquid or soluble waste should be dissolved in methanol or ethanol and irradiated with ultraviolet light with a wavelength shorter than 290 nm for several days. Use F40 BL or equivalent lamps. Analyze liquid wastes, and dispose of the solutions when the CDDs/CDFs can no longer be detected.

20.5 For further information on waste management, consult ''The Waste Management Manual for Laboratory Personnel'' and ''Less is Better—Laboratory Chemical Management for Waste Reduction,'' available from the American Chemical Society's Department of Government Relations and Science Policy, 1155 16th Street N.W., Washington, D.C. 20036.

21.0 Method Performance

Method performance was validated and performance specifications were developed using data from EPA's international interlaboratory validation study (References 30–31) and the EPA/paper industry Long-Term Variability Study of discharges from the pulp and paper industry (58 FR 66078).

22.0 References

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23.0 Tables and Figures

TABLE 1—CHLORINATED DIBENZO-P-DIOXINS AND FURANS DETERMINED BY ISOTOPE DILUTION AND INTERNAL STANDARD HIGH RESOLUTION GAS CHROMATOGRAPHY (HRGC)/HIGH RESOLUTION MASS SPECTROMETRY (HRMS)

CDDs/CDFs [1]	CAS registry	Labeled analog	CAS registry
2,3,7,8-TCDD	1746–01–6	$^{13}C_{12}$-2,3,7,8-TCDD	76523–40–5
		$^{37}Cl_4$-2,3,7,8-TCDD	85508–50–5
Total TCDD	41903–57–5		
2,3,7,8-TCDF	51207–31–9	$^{13}C_{12}$-2,3,7,8-TCDF	89059–46–1
Total-TCDF	55722–27–5		
1,2,3,7,8-PeCDD	40321–76–4	$^{13}C_{12}$-1,2,3,7,8-PeCDD	109719–79–1
Total-PeCDD	36088–22–9		
1,2,3,7,8-PeCDF	57117–41–6	$^{13}C_{12}$-1,2,3,7,8-PeCDF	109719–77–9
2,3,4,7,8-PeCDF	57117–31–4	$^{13}C_{12}$-2,3,4,7,8-PeCDF	116843–02–8
Total-PeCDF	30402–15–4		
1,2,3,4,7,8-HxCDD	39227–28–6	$^{13}C_{12}$-1,2,3,4,7,8-HxCDD	109719–80–4
1,2,3,6,7,8-HxCDD	57653–85–7	$^{13}C_{12}$-1,2,3,6,7,8-HxCDD	109719–81–5
1,2,3,7,8,9-HxCDD	19408–74–3	$^{13}C_{12}$-1,2,3,7,8,9-HxCDD	109719–82–6
Total-HxCDD	34465–46–8		
1,2,3,4,7,8-HxCDF	70648–26–9	$^{13}C_{12}$-1,2,3,4,7,8-HxCDF	114423–98–2
1,2,3,6,7,8-HxCDF	57117–44–9	$^{13}C_{12}$-1,2,3,6,7,8-HxCDF	116843–03–9
1,2,3,7,8,9-HxCDF	72918–21–9	$^{13}C_{12}$-1,2,3,7,8,9-HxCDF	116843–04–0
2,3,4,6,7,8-HxCDF	60851–34–5	$^{13}C_{12}$-2,3,4,6,7,8-HxCDF	116843–05–1
Total-HxCDF	55684–94–1		
1,2,3,4,6,7,8-HpCDD	35822–46–9	$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDD	109719–83–7
Total-HpCDD	37871–00–4		
1,2,3,4,6,7,8-HpCDF	67562–39–4	$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDF	109719–84–8
1,2,3,4,7,8,9-HpCDF	55673–89–7	$^{13}C_{12}$-1,2,3,4,7,8,9-HpCDF	109719–94–0
Total-HpCDF	38998–75–3		
OCDD	3268–87–9	$^{13}C_{12}$-OCDD	114423–97–1
OCDF	39001–02–0	Not used.	

[1] Chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans.
TCDD = Tetrachlorodibenzo-p-dioxin.
TCDF = Tetrachlorodibenzofuran.
PeCDD = Pentachlorodibenzo-p-dioxin.
PeCDF = Pentachlorodibenzofuran.
HxCDD = Hexachlorodibenzo-p-dioxin.
HxCDF = Hexachlorodibenzofuran.
HpCDD = Heptachlorodibenzo-p-dioxin.
HpCDF = Heptachlorodibenzofuran.
OCDD = Octachlorodibenzo-p-dioxin.
OCDF = Octachlorodibenzofuran.

TABLE 2—RETENTION TIME REFERENCES, QUANTITATION REFERENCES, RELATIVE RETENTION TIMES, AND MINIMUM LEVELS FOR CDDS AND DCFS

CDD/CDF	Retention time and quantitation reference	Relative retention time	Minimum level [1]		
			Water (pg/L; ppq)	Solid (ng/kg; ppt)	Extract (pg/µL; ppb)
Compounds using ^{13}C12–1,2,3,4-TCDD as the Injection Internal Standard					
2,3,7,8-TCDF	$^{13}C_{12}$-2,3,7,8-TCDF	0.999–1.003	10	1	0.5
2,3,7,8-TCDD	$^{13}C_{12}$-2,3,7,8-TCDD	0.999–1.002	10	1	0.5
1,2,3,7,8-Pe	$^{13}C_{12}$-1,2,3,7,8-PeCDF	0.999–1.002	50	5	2.5
2,3,4,7,8-PeCDF	$^{13}C_{12}$-2,3,4,7,8-PeCDF	0.999–1.002	50	5	2.5
1,2,3,7,8-PeCDD	$^{13}C_{12}$-1,2,3,7,8-PeCDD	0.999–1.002	50	5	2.5
$^{13}C_{12}$-2,3,7,8-TCDF	$^{13}C_{12}$-1,2,3,4-TCDD	0.923–1.103	.....	.....	.....
$^{13}C_{12}$-2,3,7,8-TCDD	$^{13}C_{12}$-1,2,3,4-TCDD	0.976–1.043	.....	.....	.....
$^{13}C_{12}$-2,3,7,8-TCDD	$^{13}C_{12}$-1,2,3,4-TCDD	0.989–1.052	.....	.....	.....
$^{13}C_{12}$-1,2,3,7,8-PeCDF	$^{13}C_{12}$-1,2,3,4-TCDD	1.000–1.425	.....	.....	.....
$^{13}C_{12}$-2,3,4,7,8-PeCDF	$^{13}C_{12}$-1,2,3,4-TCDD	1.001–1.526	.....	.....	.....
$^{13}C_{12}$-1,2,3,7,8-PeCDF	$^{13}C_{12}$-1,2,3,4-TCDD	1.000–1.567	.....	.....	.....
Compounds using ^{13}C12–1,2,3,7,8,9-HxCDD as the Injection Internal Standard					
1,2,3,4,7,8-HxCDF	$^{13}C_{12}$-1,2,3,4,7,8-HxCDF	0.999–1.001	50	5	2.5
1,2,3,6,7,8-HxCDF	$^{13}C_{12}$-1,2,3,6,7,8-HxCDF	0.997–1.005	50	5	2.5
1,2,3,7,8,9-HxCDF	$^{13}C_{12}$-1,2,3,7,8,9-HxCDF	0.999–1.001	50	5	2.5
2,3,4,6,7,8-HxCDF	$^{13}C_{12}$-2,3,4,6,7,8-HxCDF	0.999–1.001	50	5	2.5
1,2,3,4,7,8-HxCDD	$^{13}C_{12}$-1,2,3,4,7,8-HxCDD	0.999–1.001	50	5	2.5

TABLE 2—RETENTION TIME REFERENCES, QUANTITATION REFERENCES, RELATIVE RETENTION TIMES, AND MINIMUM LEVELS FOR CDDS AND DCFS—Continued

CDD/CDF	Retention time and quantitation reference	Relative retention time	Minimum level[1]		
			Water (pg/L; ppq)	Solid (ng/kg; ppt)	Extract (pg/μL; ppb)
1,2,3,6,7,8-HxCDD	$^{13}C_{12}$-1,2,3,6,7,8-HxCDD	0.998–1.004	50	5	2.5
1,2,3,7,8,9-HxCDD	([2])	1.000–1.019	50	5	2.5
1,2,3,4,6,7,8-HpCDF	$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDF	0.999–1.001	50	5	2.5
1,2,3,4,7,8,9-HpCDF	$^{13}C_{12}$-1,2,3,4,7,8,9-HpCDF	0.999–1.001	50	5	2.5
1,2,3,4,6,7,8-HpCDD	$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDD	0.999–1.001	50	5	2.5
OCDF	$^{13}C_{12}$-OCDD	0.999–1.001	100	10	5.0
OCDD	$^{13}C_{12}$-OCDD	0.999–1.001	100	10	5.0
1,2,3,4,6,7,8,-HxCDF	$^{13}C_{12}$-1,2,3,7,8,9-HpCDD	0.949–0.975			
$^{13}C_{12}$1,2,3,7,8,9-HxCDF	$^{13}C_{12}$-1,2,3,7,8,9-HpCDD	0.977–1.047			
$^{13}C_{12}$2,3,4,6,7,8,-HxCDF	$^{13}C_{12}$-1,2,3,7,8,9-HpCDD	0.959–1.021			
$^{13}C_{12}$1,2,3,4,7,8,-HxCDF	$^{13}C_{12}$-1,2,3,7,8,9-HpCDD	0.977–1.000			
$^{13}C_{12}$1,2,3,6,7,8,-HxCDF	$^{13}C_{12}$-1,2,3,7,8,9-HpCDD	0.981–1.003			
$^{13}C_{12}$1,2,3,4,6,7,8-HxCDF	$^{13}C_{12}$-1,2,3,7,8,9-HpCDD	1.043–1.085			
$^{13}C_{12}$1,2,3,4,7,8,9-HxCDF	$^{13}C_{12}$-1,2,3,7,8,9-HpCDD	1.057–1.151			
$^{13}C_{12}$1,2,3,4,6,7,8-HxCDF	$^{13}C_{12}$-1,2,3,7,8,9-HpCDD	1.086–1.110			
$^{13}C_{12}$OCDD	$^{13}C_{12}$-1,2,3,7,8,9-HpCDD	1.032–1.311			

[1] The Minimum Level (ML) for each analyte is defined as the level at which the entire analytical system must give a recognizable signal and acceptable calibration point. It is equivalent to the concentration of the lowest calibration standard, assuming that all method-specified sample weights, volumes, and cleanup procedures have been employed.

[2] The retention time reference for 1,2,3,7,8,9-HxCDD is $^{13}C_{12}$-1,2,3,6,7,8-HxCDD, and 1,2,3,7,8,9-HxCDD is quantified using the averaged responses for $^{13}C_{12}$-1,2,3,4,7,8-HxCDD and $^{13}C_{12}$-1,2,3,6,7,8-HxCDD.

TABLE 3—CONCENTRATION OF STOCK AND SPIKING SOLUTIONS CONTAINING CDDS/CDFS AND LABELED COMPOUNDS

CDD/CDF	Labeled compound stock solution[1] (ng/mL)	Labeled compound spiking solution[2] (ng/mL)	PAR stock solution[3] (ng/mL)	PAR spiking solution[4] (ng/mL)
2,3,7,8-TCDD			40	0.8
2,3,7,8-TCDF			40	0.8
1,2,3,7,8-PeCDD			200	4
1,2,3,7,8-PeCDF			200	4
2,3,4,7,8-PeCDF			200	4
1,2,3,4,7,8-HxCDD			200	4
1,2,3,6,7,8-HxCDD			200	4
1,2,3,7,8,9-HxCDD			200	4
1,2,3,4,7,8-HxCDF			200	4
1,2,3,6,7,8-HxCDF			200	4
1,2,3,7,8,9-HxCDF			200	4
2,3,4,6,7,8-HxCDF			200	4
1,2,3,4,6,7,8-HpCDD			200	4
1,2,3,4,6,7,8-HpCDF			200	4
1,2,3,4,7,8,9-HpCDF			200	4
OCDD			400	8
OCDF			400	8
$^{13}C_{12}$-2,3,7,8-TCDD	100	2		
$^{13}C_{12}$-2,3,7,8-TCDF	100	2		
$^{13}C_{12}$-1,2,3,7,8-PeCDD	100	2		
$^{13}C_{12}$-1,2,3,7,8-PeCDF	100	2		
$^{13}C_{12}$-2,3,4,7,8-PeCDF	100	2		
$^{13}C_{12}$-1,2,3,4,7,8-HxCDD	100	2		
$^{13}C_{12}$-1,2,3,6,7,8-HxCDD	100	2		
$^{13}C_{12}$-1,2,3,4,7,8-HxCDF	100	2		
$^{13}C_{12}$-1,2,3,6,7,8-HxCDF	100	2		
$^{13}C_{12}$-1,2,3,7,8,9-HxCDF	100	2		
$^{13}C_{12}$-2,3,4,6,7,8-HxCDF	100	2		
$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDD	100	2		
$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDF	100	2		
$^{13}C_{12}$-1,2,3,4,7,8,9-HpCDF	100	2		
$^{13}C_{12}$-OCDD	200	4		
Cleanup Standard[5]				
$^{37}Cl_4$-2,3,7,8-TCDD	0.8			
Internal Standards[6]				
$^{13}C_{12}$-1,2,3,4-TCDD	200			

TABLE 3—CONCENTRATION OF STOCK AND SPIKING SOLUTIONS CONTAINING CDDS/CDFS AND LABELED COMPOUNDS—Continued

CDD/CDF	Labeled compound stock solution [1] (ng/mL)	Labeled compound spiking solution [2] (ng/mL)	PAR stock solution [3] (ng/mL)	PAR spiking solution [4] (ng/mL)
$^{13}C_{12}$-1,2,3,7,8,9-HxCDD	200	.....	.....	.....

[1] Section 7.10—prepared in nonane and diluted to prepare spiking solution.
[2] Section 7.10.3—prepared in acetone from stock solution daily.
[3] Section 7.9—prepared in nonane and diluted to prepare spiking solution.
[4] Section 7.14—prepared in acetone from stock solution daily.
[5] Section 7.11—prepared in nonane and added to extract prior to cleanup.
[6] Section 7.12—prepared in nonane and added to the concentrated extract immediately prior to injection into the GC (Section 14.2).

TABLE 4—CONCENTRATION OF CDDS/CDFS IN CALIBRATION AND CALIBRATION VERIFICATION SOLUTIONS [1] (SECTION 15.3)

	CDD/CDF	CS2 (ng/mL)	CS3 (ng/mL)	CS4 (ng/mL)	CS5 (ng/mL)
2,3,7,8-TCDD	0.5	2	10	40	200
2,3,7,8-TCDF	0.5	2	10	40	200
1,2,3,7,8-PeCDD	2.5	10	50	200	1000
1,2,3,7,8-PeCDF	2.5	10	50	200	1000
2,3,4,7,8-PeCDF	2.5	10	50	200	1000
1,2,3,4,7,8-HxCDD	2.5	10	50	200	1000
1,2,3,6,7,8-HxCDD	2.5	10	50	200	1000
1,2,3,7,8,9-HxCDD	2.5	10	50	200	1000
1,2,3,4,7,8-HxCDF	2.5	10	50	200	1000
1,2,3,6,7,8-HxCDF	2.5	10	50	200	1000
1,2,3,7,8,9-HxCDF	2.5	10	50	200	1000
2,3,4,6,7,8-HxCDF	2.5	10	50	200	1000
1,2,3,4,6,7,8-HpCDD	2.5	10	50	200	1000
1,2,3,4,6,7,8-HpCDF	2.5	10	50	200	1000
1,2,3,4,7,8,9-HpCDF	2.5	10	50	200	1000
OCDD	5.0	20	100	400	2000
OCDF	5.0	20	100	400	2000
$^{13}C_{12}$-2,3,7,8-TCDD	100	100	100	100	100
$^{13}C_{12}$-2,3,7,8-TCDF	100	100	100	100	100
$^{13}C_{12}$-1,2,3,7,8-PeCDD	100	100	100	100	100
$^{13}C_{12}$-PeCDF	100	100	100	100	100
$^{13}C_{12}$-2,3,4,7,8-PeCDF	100	100	100	100	100
$^{13}C_{12}$-1,2,3,4,7,8-HxCDD	100	100	100	100	100
$^{13}C_{12}$-1,2,3,6,7,8-HxCDD	100	100	100	100	100
$^{13}C_{12}$-1,2,3,4,7,8-HxCDF	100	100	100	100	100
$^{13}C_{12}$-1,2,3,6,7,8-HxCDF	100	100	100	100	100
$^{13}C_{12}$-1,2,3,7,8,9-HxCDF	100	100	100	100	100
$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDD	100	100	100	100	100
$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDF	100	100	100	100	100
$^{13}C_{12}$-1,2,3,4,7,8,9-Hp CDF	100	100	100	100	100
$^{13}C_{12}$-OCDD	200	200	200	200	200
Cleanup Standard:					
$^{37}C1_4$-2,3,7,8-TCDD	0.5	2	10	40	200
Internal Standards:					
$^{13}C_{12}$-1,2,3,4-TCDD	100	100	100	100	100
$^{13}C_{12}$-1,2,3,7,8,9-HxCDD	100	100	100	100	100

TABLE 5—GC RETENTION TIME WINDOW DEFINING SOLUTION AND ISOMER SPECIFICITY TEST STANDARD (SECTION 7.15)

DB–5 column GC retention-time window defining solution		
CDD/CDF	First eluted	Last eluted
TCDF	1,3,6,8-	1,2,8,9-
TCDD	1,3,6,8-	1,2,8,9-
PeCDF	1,3,4,6,8-	1,2,3,8,9-
PeCDD	1,2,4,7,9-	1,2,3,8,9-
HxCDF	1,2,3,4,6,8-	1,2,3,4,8,9-
HxCDD	1,2,4,6,7,9-	1,2,3,4,6,7-
HpCDF	1,2,3,4,6,7,8-	1,2,3,4,7,8,9-

TABLE 5—GC RETENTION TIME WINDOW DEFINING SOLUTION AND ISOMER SPECIFICITY TEST STANDARD (SECTION 7.15)—Continued

DB–5 column GC retention-time window defining solution		
CDD/CDF	First eluted	Last eluted
HpCDD	1,2,3,4,6,7,9-	1,2,3,4,6,7,8-

DB–5 Column TCDD Specificity Test Standard

1,2,3,7=1,2,3,8-TCDD
2,3,7,8-TCDD
1,2,3,9-TCDD

DB–225 Column TCDF Isomer Specificity Test Standard

2,3,4,7-TCDF
2,3,7,8-TCDF
1,2,3,9-TCDF

TABLE 6—ACCEPTANCE CRITERIA FOR PERFORMANCE TESTS WHEN ALL CDDS/CDFS ARE TESTED [1]

CDD/CDF	Test conc. (ng/mL)	IPR [2 3]		OPR (ng/mL)	VER (ng/mL)
		s (ng/mL)	X (ng/mL)		
2,3,7,8-TCDD	10	2.8	8.3–12.9	6.7–15.8	7.8–12.9
2,3,7,8-TCDF	10	2.0	8.7–13.7	7.5–15.8	8.4–12.0
1,2,3,7,8-PeCDD	50	7.5	38–66	35–71	39–65
1,2,3,7,8-PeCDF	50	7.5	43–62	40–67	41–60
2,3,4,7,8-PeCDF	50	8.6	36–75	34–80	41–61
1,2,3,4,7,8-HxCDD	50	9.4	39–76	35–82	39–64
1,2,3,6,7,8-HxCDD	50	7.7	42–62	38–67	39–64
1,2,3,7,8,9-HxCDD	50	11.1	37–71	32–81	41–61
1,2,3,4,7,8-HxCDF	50	8.7	41–59	36–67	45–56
1,2,3,6,7,8-HxCDF	50	6.7	46–60	42–65	44–57
1,2,3,7,8,9-HxCDF	50	6.4	42–61	39–65	45–56
2,3,4,6,7,8-HxCDF	50	7.4	37–74	35–78	44–57
1,2,3,4,6,7,8-HpCDD	50	7.7	38–65	35–70	43–58
1,2,3,4,6,7,8-HpCDF	50	6.3	45–56	41–61	45–55
1,2,3,4,7,8,9-HpCDF	50	8.1	43–63	39–69	43–58
OCDD	100	19	89–127	78–144	79–126
OCDF	100	27	74–146	63–170	63–159
$^{13}C_{12}$-2,3,7,8-TCDD	100	37	28–134	20–175	82–121
$^{13}C_{12}$-2,3,7,8-TCDF	100	35	31–113	22–152	71–140
$^{13}C_{12}$-1,2,3,7,8-PeCDD	100	39	27–184	21–227	62–160
$^{13}C_{12}$-1,2,3,7,8-PeCDF	100	34	27–156	21–192	76–130
$^{13}C_{12}$-2,3,4,7,8-PeCDF	100	38	16–279	13–328	77–130
$^{13}C_{12}$-1,2,3,4,7,8-HxCDD	100	41	29–147	21–193	85–117
$^{13}C_{12}$-1,2,3,6,7,8-HxCDD	100	38	34–122	25–163	85–118
$^{13}C_{12}$-1,2,3,4,7,8-HxCDF	100	43	27–152	19–202	76–131
$^{13}C_{12}$-1,2,3,6,7,8-HxCDF	100	35	30–122	21–159	70–143
$^{13}C_{12}$-1,2,3,7,8,9-HxCDF	100	40	24–157	17–205	74–135
$^{13}C_{12}$-2,3,4,6,7,8,-HxCDF	100	37	29–136	22–176	73–137
$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDD	100	35	34–129	26–166	72–138
$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDF	100	41	32–110	21–158	78–129
$^{13}C_{12}$-1,2,3,4,7,8,9-HpCDF	100	40	28–141	20–186	77–129
$^{13}C_{12}$-OCDD	200	95	41–276	26–397	96–415
$^{37}Cl_4$-2,3,7,8-TCDD	10	3.6	3.9–15.4	3.1–19.1	7.9–12.7

[1] All specifications are given as concentration in the final extract, assuming a 20 μL volume.
[2] s = standard deviation of the concentration.
[3] X = average concentration.

TABLE 6A—ACCEPTANCE CRITERIA FOR PERFORMANCE TESTS WHEN ONLY TETRA COMPOUNDS ARE TESTED [1]

CDD/CDF	Test Conc. (ng/mL)	IPR [2 3]		OPR (ng/mL)	VER (ng/mL)
		s (ng/mL)	X (ng/mL)		
2,3,7,8-TCDD	10	2.7	8.7–12.4	7.314.6	8.2–12.3
2,3,7,8-TCDF	10	2.0	9.1–13.1	8.0–14.7	8.6–11.6
$^{13}C_{12}$-2,3,7,8-TCDD	100	35	32–115	25–141	85–117
$^{13}C_{12}$-2,3,7,8-TCDF	100	34	35–99	26–126	76–131

TABLE 6A—ACCEPTANCE CRITERIA FOR PERFORMANCE TESTS WHEN ONLY TETRA COMPOUNDS ARE TESTED [1]—Continued

CDD/CDF	Test Conc. (ng/mL)	IPR [2 3]		OPR (ng/mL)	VER (ng/mL)
		s (ng/mL)	X (ng/mL)		
$^{37}Cl_4$-2,3,7,8-TCDD	10	3.4	4.5–13.4	3.7–15.8	8.3–12.1

[1] All specifications are given as concentration in the final extract, assuming a 20 μL volume.
[2] s = standard deviation of the concentration.
[3] X = average concentration.

TABLE 7—LABELED COMPOUNDS RECOVERY IN SAMPLES WHEN ALL CDDS/CDFS ARE TESTED

Compound	Test conc. (ng/mL)	Labeled compound recovery	
		(ng/mL) [1]	(%)
$^{13}C_{12}$-2,3,7,8-TCDD	100	25–164	25–164
$^{13}C_{12}$-2,3,7,8-TCDF	100	24–169	24–169
$^{13}C_{12}$-1,2,3,7,8-PeCDD	100	25–181	25–181
$^{13}C_{12}$-1,2,3,7,8-PeCDF	100	24–185	24–185
$^{13}C_{12}$-2,3,4,7,8-PeCDF	100	21–178	21–178
$^{13}C_{12}$-1,2,3,4,7,8-HxCDD	100	32–141	32–141
$^{13}C_{12}$-1,2,3,6,7,8-HxCDD	100	28–130	28–130
$^{13}C_{12}$-1,2,3,4,7,8-HxCDF	100	26–152	26–152
$^{13}C_{12}$-1,2,3,6,7,8-HxCDF	100	26–123	26–123
$^{13}C_{12}$-1,2,3,7,8,9-HxCDF	100	29–147	29–147
$^{13}C_{12}$-2,3,4,6,7,8-HxCDF	100	28–136	28–136
$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDD	100	23–140	23–140
$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDF	100	28–143	28–143
$^{13}C_{12}$-1,2,3,4,7,8,9-HpCDF	100	26–138	26–138
$^{13}C_{12}$-OCDD	200	34-313	17–157
$^{37}Cl_4$-2,3,7,8-TCDD	10	3.5–19.7	35–197

[1] Specification given as concentration in the final extract, assuming a 20-μL volume.

TABLE 7A—LABELED COMPOUND RECOVERY IN SAMPLES WHEN ONLY TETRA COMPOUNDS ARE TESTED

Compound	Test conc. (ng/mL)	Labeled compound recovery	
		(ng/mL) [1]	(%)
$^{13}C_{12}$-2,3,7,8-TCDD	100	31–137	31–137
$^{13}C_{12}$-2,3,7,8-TCDF	100	29–140	29–140
$^{37}Cl_4$-2,3,7,8-TCDD	10	4.2–16.4	42–164

[1] Specification given as concentration in the final extract, assuming a 20 μL volume.

TABLE 8—DESCRIPTORS, EXACT M/Z'S, M/Z TYPES, AND ELEMENTAL COMPOSITIONS OF THE CDDS AND CDFS

Descriptor	Exact M/Z [1]	M/Z type	Elemental composition	Substance [2]
1	292.9825	Lock	C_7F_{11}	PFK
	303.9016	M	$C_{12}H_4{}^{35}Cl_4O$	TCDF
	305.8987	M=2	$C_{12}H_4{}^{35}Cl_3{}^{37}ClO$	TCDF
	315.9419	M	$^{13}C_{12}H_4{}^{35}Cl_4O$	TCDF [3]
	317.9389	M=2	$^{13}C_{12}H_4{}^{35}Cl_3{}^{37}ClO$	TCDF [3]
	319.8965	M	$C_{12}H_4{}^{35}Cl_4O_2$	TCDD
	321.8936	M=2	$C_{12}H_4{}^{35}Cl_3{}^{37}ClO_2$	TCDD
	327.8847	M	$C_{12}H_4{}^{37}Cl_4O_2$	TCDD [4]
	330.9792	QC	C_7F_{13}	PFK
	331.9368	M	$^{13}C_{12}H_4{}^{35}Cl_4O_2$	TCDD [3]
	333.9339	M=2	$^{13}C_{12}H_4{}^{35}Cl_3{}^{37}ClO_2$	TCDD [3]
	375.8364	M=2	$C_{12}H_4{}^{35}Cl_5{}^{37}ClO$	HxCDPE
2	339.8597	M=2	$C_{12}H_3{}^{35}Cl_4{}^{37}ClO$	PeCDF
	341.8567	M=4	$C_{12}H_3{}^{35}Cl_3{}^{37}Cl_2O$	PeCDF
	351.9000	M=2	$^{13}C_{12}H_3{}^{35}Cl_4{}^{37}ClO$	PeCDF
	353.8970	M=4	$^{13}C_{12}H_3{}^{35}Cl_3{}^{37}Cl_2O$	PeCDF [3]
	354.9792	Lock	C_9F_{13}	PFK
	355.8546	M=2	$C_{12}H_3{}^{35}Cl_4{}^{37}ClO_2$	PeCDD
	357.8516	M=4	$C_{12}H_3{}^{35}Cl_3{}^{37}Cl_2O_2$	PeCDD

TABLE 8—DESCRIPTORS, EXACT M/Z'S, M/Z TYPES, AND ELEMENTAL COMPOSITIONS OF THE CDDS AND CDFS—Continued

Descriptor	Exact M/Z [1]	M/Z type	Elemental composition	Substance [2]
	367.8949	M=2	$^{13}C_{12}H_3{}^{35}Cl_4{}^{37}ClO_2$	PeCDD [3]
	369.8919	M=4	$^{13}C_{12}H_3{}^{35}Cl_3{}^{37}Cl_2O_2$	PeCDD [3]
	409.7974	M=2	$C_{12}H_3{}^{35}Cl_6{}^{37}ClO$	HpCDPE
3	373.8208	M=2	$C_{12}H_2{}^{35}Cl_5{}^{37}ClO$	HxCDF
	375.8178	M=4	$C_{12}H_2{}^{35}Cl_4{}^{37}Cl_2O$	HxCDF
	383.8639	M	$^{13}C_{12}H_2{}^{35}Cl_6O$	HxCDF [3]
	385.8610	M=2	$^{13}C_{12}H_2{}^{35}Cl_5{}^{37}ClO$	HxCDF [3]
	389.8157	M=2	$C_{12}H_2{}^{35}Cl_5{}^{37}ClO_2$	HxCDD
	391.8127	M=4	$C_{12}H_2{}^{35}Cl_4{}^{37}Cl_2O_2$	HxCDD
	392.9760	Lock	C_9F_{15}	PFK
	401.8559	M=2	$^{13}C_{12}H_2{}^{35}Cl_5{}^{37}ClO_2$	HxCDD [3]
	403.8529	M=4	$^{13}C_{12}H_2{}^{35}Cl_4{}^{37}Cl_2O_2$	HxCDD [3]
	430.9729	QC	C_9F_{17}	PFK
	445.7555	M=4	$C_{12}H_2{}^{35}Cl_6{}^{37}Cl_2O$	OCDPE
4	407.7818	M=2	$C_{12}H^{35}Cl_6{}^{37}ClO$	HpCDF
	409.7789	M=4	$C_{12}H^{35}Cl_5{}^{37}Cl_2O$	HpCDF
	417.8253	M	$^{13}C_{12}H^{35}Cl_7O$	HpCDF [3]
	419.8220	M=2	$^{13}C_{12}H^{35}Cl_6{}^{37}ClO$	HpCDF [3]
	423.7766	M=2	$C_{12}H^{35}Cl_6{}^{37}ClO_2$	HpCDD
	425.7737	M=4	$C_{12}H^{35}Cl_5{}^{37}Cl_2O_2$	HpCDD
	430.9729	Lock	C_9F_{17}	PFK
	435.8169	M=2	$^{13}C_{12}H^{35}Cl_6{}^{37}ClO_2$	HpCDD [3]
	437.8140	M=4	$^{13}C_{12}H^{35}Cl_5{}^{37}Cl_2O_2$	HpCDD [3]
	479.7165	M=4	$C_{12}H^{35}Cl_7{}^{37}Cl_2O$	NCDPE
5	441.7428	M=2	$C_{12}{}^{35}Cl_7{}^{37}ClO$	OCDF
	442.9728	Lock	$C_{10}F_{17}$	PFK
	443.7399	M=4	$C_{12}{}^{35}Cl_6{}^{37}Cl_2O$	OCDF
	457.7377	M=2	$C_{12}{}^{35}Cl_7{}^{37}ClO_2$	OCDD
	459.7348	M=4	$C_{12}{}^{35}Cl_6{}^{37}Cl_2O_2$	OCDD
	469.7779	M=2	$^{13}C_{12}{}^{35}Cl_7{}^{37}ClO_2$	OCDD [3]
	471.7750	M=4	$^{13}C_{12}{}^{35}Cl_6{}^{37}Cl_2O_2$	OCDD [3]
	513.6775	M=4	$C_{12}{}^{35}Cl_8{}^{37}Cl_2O$	DCDPE

[1] Nuclidic masses used:
H = 1.007825.
O = 15.994915.
C = 12.00000.
^{35}Cl = 34.968853.
^{13}C = 13.003355.
^{37}Cl = 36.965903.
F = 18.9984.

[2] TCDD = Tetrachlorodibenzo-p-dioxin.
PeCDD = Pentachlorodibenzo-p-dioxin.
HxCDD = Hexachlorodibenzo-p-dioxin.
HpCDD = Heptachlorodibenzo-p-dioxin.
OCDD = Octachlorodibenzo-p-dioxin.
HxCDPE = Hexachlorodiphenyl ether.
OCDPE = Octachlorodiphenyl ether.
DCDPE = Decachlorodiphenyl ether.
TCDF = Tetrachlorodibenzofuran.
PeCDF = Pentachlorodibenzofuran.
HxCDF = Hexachlorodibenzofuran.
HpCDF = Heptachlorodibenzofuran.
OCDF = Octachlorodibenzofuran.
HpCDPE = Heptachlorodiphenyl ether.
NCDPE = Nonachlorodiphenyl ether.
PFK = Perfluorokerosene.

[3] Labeled compound.

[4] There is only one m/z for $^{37}Cl_4$-2,3,7,8,-TCDD (cleanup standard).

TABLE 9—THEORETICAL ION ABUNDANCE RATIOS AND QC LIMITS

Number of chlorine atoms	M/Z's forming ratio	Theoretical ratio	QC limit [1]	
			Lower	Upper
4 [2]	M/(M=2)	0.77	0.65	0.89
5	(M=2)/(M=4)	1.55	1.32	1.78
6	(M=2)/(M=4)	1.24	1.05	1.43
6 [3]	M/(M=2)	0.51	0.43	0.59
7	(M=2)/(M=4)	1.05	0.88	1.20
7 [4]	M/(M=2)	0.44	0.37	0.51
8	(M=2)/(M=4)	0.89	0.76	1.02

[1] QC limits represent ±15% windows around the theoretical ion abundance ratios.

[2] Does not apply to $^{37}Cl_4$-2,3,7,8-TCDD (cleanup standard).
[3] Used for $^{13}C_{12}$-HxCDF only.
[4] Used for $^{13}C_{12}$-HpCDF only.

TABLE 10—SUGGESTED SAMPLE QUANTITIES TO BE EXTRACTED FOR VARIOUS MATRICES [1]

Sample Matrix [2]	Example	Percent solids	Phase	Quantity extracted
Single-phase:				
Aqueous	Drinking water	<1	([3])	1000 mL.
	Groundwater			
	Treated wastewater			
Solid	Dry soil	>20	Solid	10 g.
	Compost			
	Ash			
Organic	Waste solvent	<1	Organic	10 g.
	Waste oil			
	Organic polymer			
Tissue	Fish		Organic	10 g.
	Human adipose			
Multi-phase:				
Liquid/Solid:				
Aqueous/Solid	Wet soil	1–30	Solid	10 g.
	Untreated effluent.			
	Digested municipal sludge.			
	Filter cake.			
	Paper pulp.			
Organic/solid	Industrial sludge	1–100	Both	10 g.
	Oily waste			
Liquid/Liquid:				
Aqueous/organic	In-process effluent	<1	Organic	10 g.
	Untreated effluent			
	Drum waste			
Aqueous/organic/solid.	Untreated effluent	>1	Organic and solid	10 g.
	Drum waste			

[1] The quantity of sample to be extracted is adjusted to provide 10 g of solids (dry weight). One liter of aqueous samples containing 1% solids will contain 10 g of solids. For aqueous samples containing greater than 1% solids, a lesser volume is used so that 10 g of solids (dry weight) will be extracted.
[2] The sample matrix may be amorphous for some samples. In general, when the CDDs/CDFs are in contact with a multiphase system in which one of the phases is water, they will be preferentially dispersed in or adsorbed on the alternate phase because of their low solubility in water.
[3] Aqueous samples are filtered after spiking with the labeled compounds. The filtrate and the materials trapped on the filter are extracted separately, and the extracts are combined for cleanup and analysis.

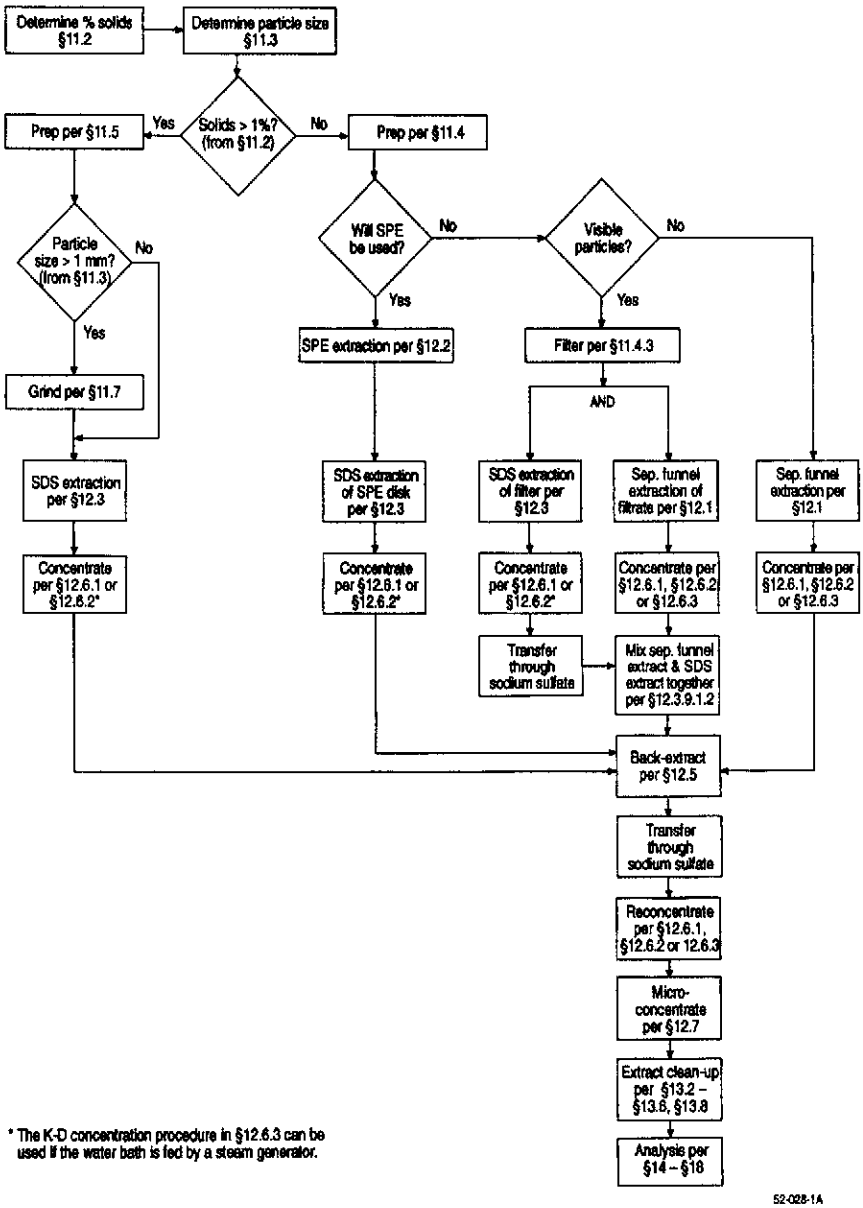

Figure 1. Flow Chart for Analysis of Aqueous and Solid Samples

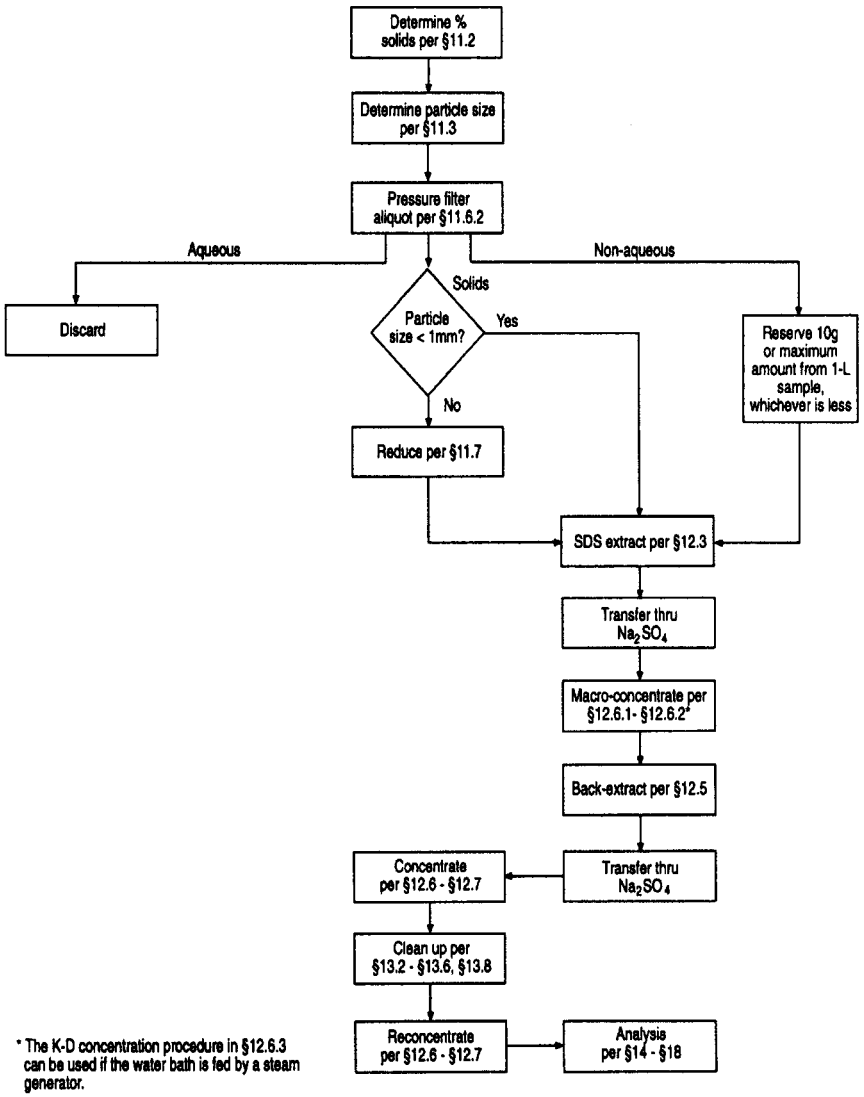

Figure 2. Flow Chart for Analysis of Multi-Phase Samples

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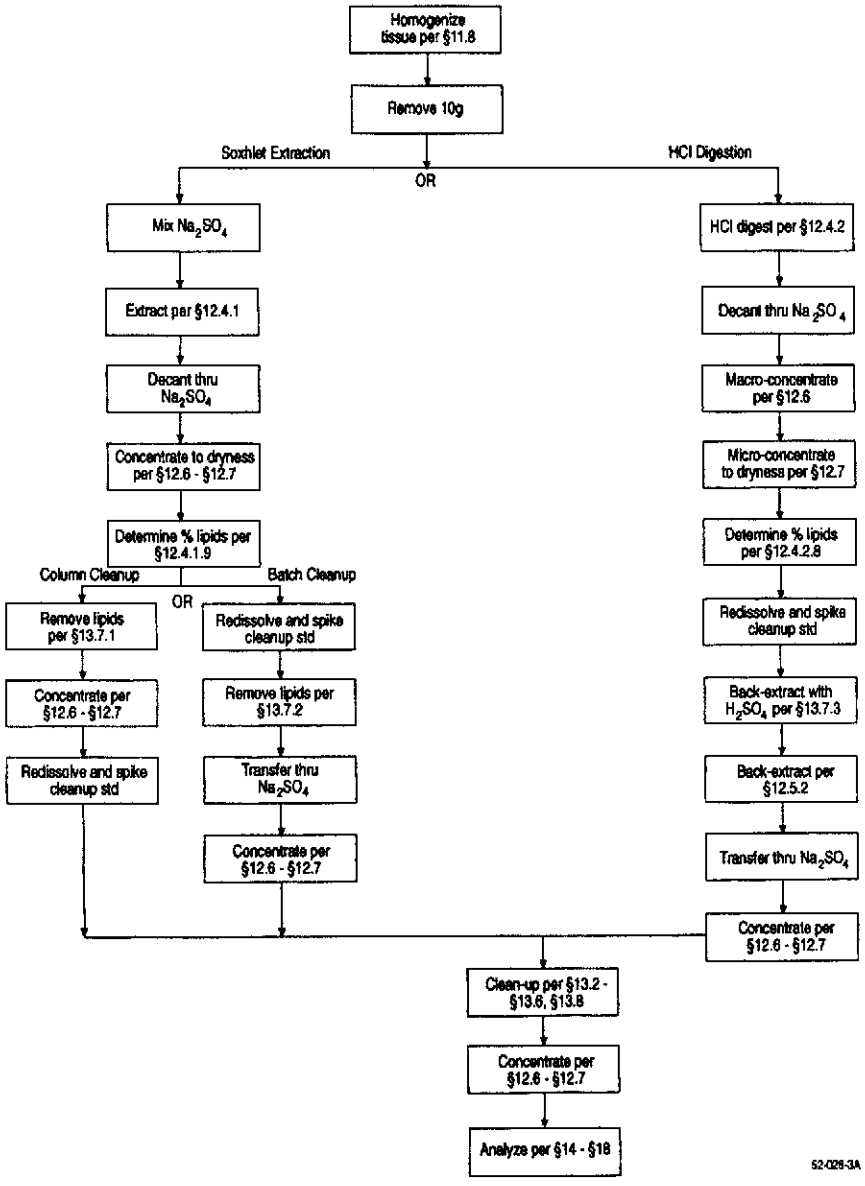

Figure 3. Flow Chart for Analysis of Tissue Samples

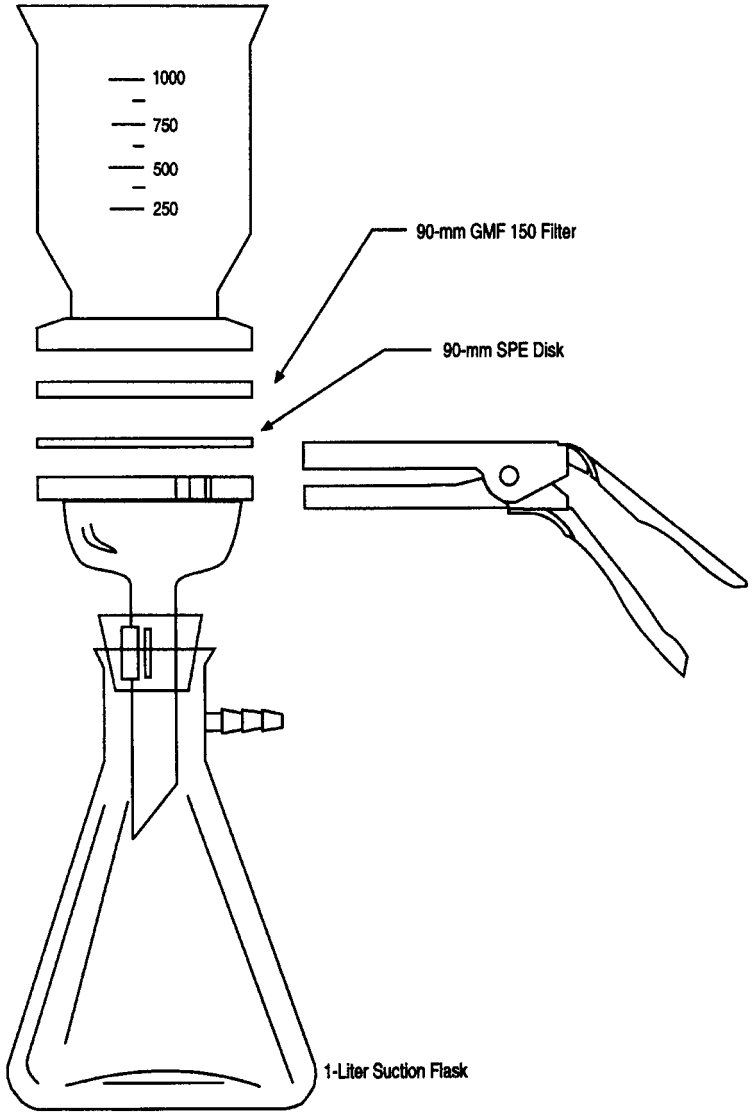

Figure 4. Solid-Phase Extraction Apparatus

52-027-1A

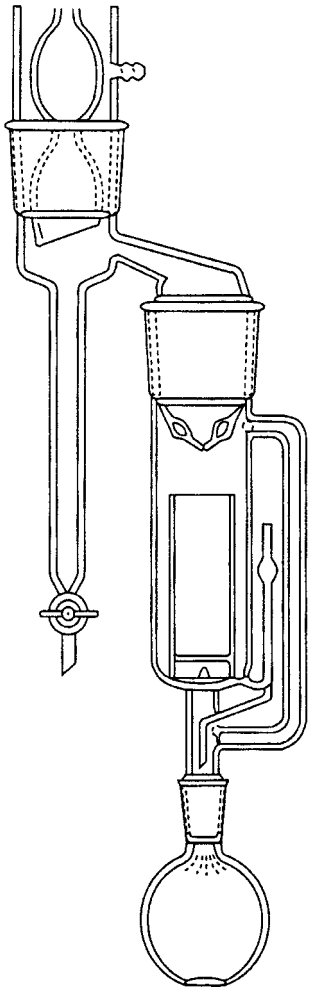

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Figure 5. Soxhlet/Dean-Stark Extractor

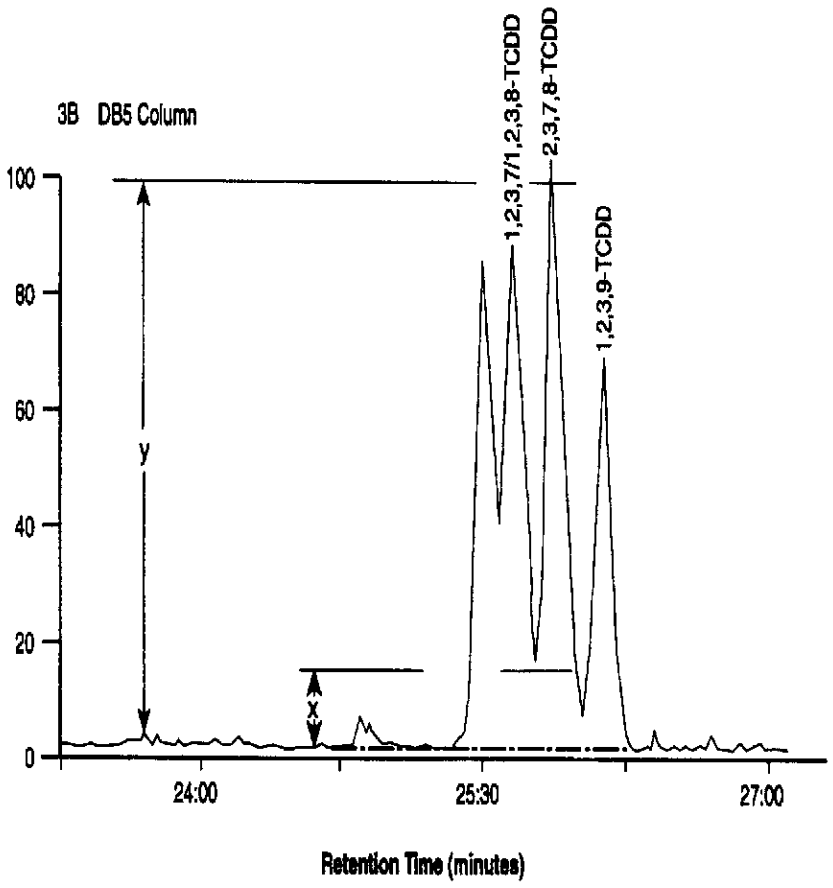

Figure 6. Isomer-Specific Separation of 2,3,7,8-TCDD on DB-5 Column

52-027-03

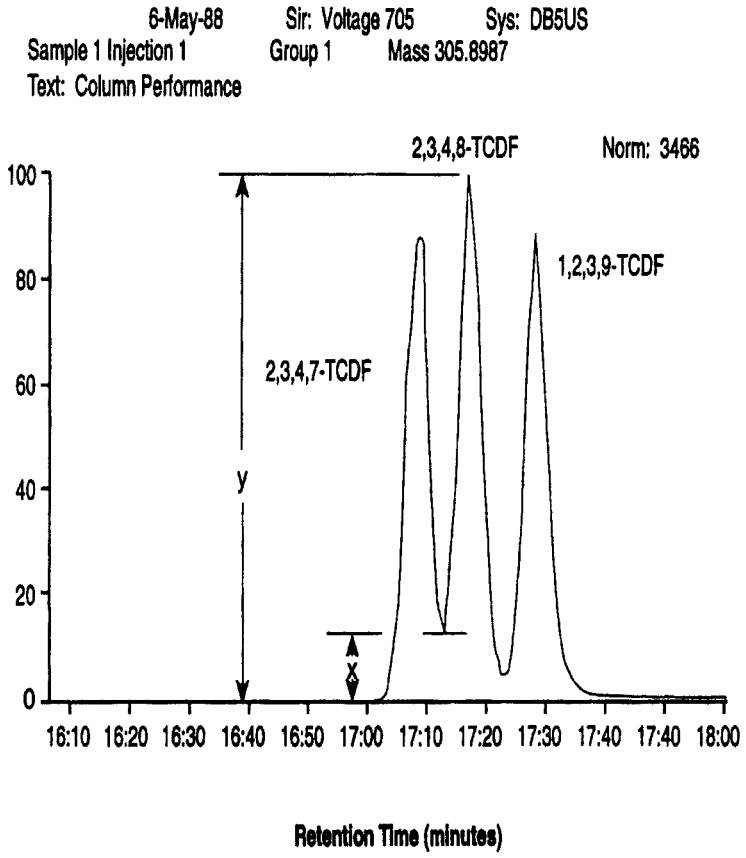

Figure 7. Isomer-Specific Separation of 2,3,7,8-TCDF on DB-5 Column

52-027-4A

24.0 Glossary of Definitions and Purposes

These definitions and purposes are specific to this method but have been conformed to common usage as much as possible.

24.1 Units of weight and Measure and Their Abbreviations.

24.1.1 Symbols:

°C—degrees Celsius
µL—microliter
µm—micrometer
<—less than
>—greater than
%—percent

24.1.2 Alphabetical abbreviations:

amp—ampere
cm—centimeter
g—gram
h—hour
D—inside diameter
in.—inch
L—liter
M—Molecular ion
m—meter
mg—milligram
min—minute
mL—milliliter
mm—millimeter
m/z—mass-to-charge ratio

N—normal; gram molecular weight of solute divided by hydrogen equivalent of solute, per liter of solution
OD—outside diameter
pg—picogram
ppb—part-per-billion
ppm—part-per-million
ppq—part-per-quadrillion
ppt—part-per-trillion
psig—pounds-per-square inch gauge
v/v—volume per unit volume
w/v—weight per unit volume

24.2 Definitions and Acronyms (in Alphabetical Order).

Analyte—A CDD or CDF tested for by this method. The analytes are listed in Table 1.

Calibration Standard (CAL)—A solution prepared from a secondary standard and/or stock solutions and used to calibrate the response of the instrument with respect to analyte concentration.

Calibration Verification Standard (VER)—The mid-point calibration standard (CS3) that is used in to verify calibration. See Table 4.

CDD—Chlorinated Dibenzo-p-ioxin—The isomers and congeners of tetra-through octachlorodibenzo-p-dioxin.

CDF—Chlorinated Dibenzofuran—The isomers and congeners of tetra-through octachlorodibenzofuran.

CS1, CS2, CS3, CS4, CS5—See Calibration standards and Table 4.

Field Blank—An aliquot of reagent water or other reference matrix that is placed in a sample container in the laboratory or the field, and treated as a sample in all respects, including exposure to sampling site conditions, storage, preservation, and all analytical procedures. The purpose of the field blank is to determine if the field or sample transporting procedures and environments have contaminated the sample.

GC—Gas chromatograph or gas chromatography.

GPC—Gel permeation chromatograph or gel permeation chromatography.

HPLC—High performance liquid chromatograph or high performance liquid chromatography.

HRGC—High resolution GC.

HRMS—High resolution MS.

IPR—Initial precision and recovery; four aliquots of the diluted PAR standard analyzed to establish the ability to generate acceptable precision and accuracy. An IPR is performed prior to the first time this method is used and any time the method or instrumentation is modified.

K–D—Kuderna-Danish concentrator; a device used to concentrate the analytes in a solvent.

Laboratory Blank—See method blank.

Laboratory Control sample (LCS)—See ongoing precision and recovery standard (OPR).

Laboratory Reagent Blank—See method blank.

May—This action, activity, or procedural step is neither required nor prohibited.

May Not—This action, activity, or procedural step is prohibited.

Method Blank—An aliquot of reagent water that is treated exactly as a sample including exposure to all glassware, equipment, solvents, reagents, internal standards, and surrogates that are used with samples. The method blank is used to determine if analytes or interferences are present in the laboratory environment, the reagents, or the apparatus.

Minimum Level (ML)—The level at which the entire analytical system must give a recognizable signal and acceptable calibration point for the analyte. It is equivalent to the concentration of the lowest calibration standard, assuming that all method-specified sample weights, volumes, and cleanup procedures have been employed.

MS—Mass spectrometer or mass spectrometry.

Must—This action, activity, or procedural step is required.

OPR—Ongoing precision and recovery standard (OPR); a laboratory blank spiked with known quantities of analytes. The OPR is analyzed exactly like a sample. Its purpose is to assure that the results produced by the laboratory remain within the limits specified in this method for precision and recovery.

PAR—Precision and recovery standard; secondary standard that is diluted and spiked to form the IPR and OPR.

PFK—Perfluorokerosene; the mixture of compounds used to calibrate the exact m/z scale in the HRMS.

Preparation Blank—See method blank.

Primary Dilution Standard—A solution containing the specified analytes that is purchased or prepared from stock solutions and diluted as needed to prepare calibration solutions and other solutions.

Quality Control Check Sample (QCS)—A sample containing all or a subset of the analytes at known concentrations. The QCS is obtained from a source external to the laboratory or is prepared from a source of standards different from the source of calibration standards. It is used to check laboratory performance with test materials prepared external to the normal preparation process.

Reagent Water—Water demonstrated to be free from the analytes of interest and potentially interfering substances at the method detection limit for the analyte.

Relative Standard Deviation (RSD)—The standard deviation times 100 divided by the mean. Also termed ''coefficient of variation.''

RF—Response factor. See Section 10.6.1.

RR—Relative response. See Section 10.5.2.

RSD—See relative standard deviation.

SDS—Soxhlet/Dean-Stark extractor; an extraction device applied to the extraction of solid and semi-solid materials (Reference 7).

Should—This action, activity, or procedural step is suggested but not required.

SICP—Selected ion current profile; the line described by the signal at an exact m/z.

SPE—Solid-phase extraction; an extraction technique in which an analyte is extracted from an aqueous sample by passage over or through a material capable of reversibly adsorbing the analyte. Also termed liquid-solid extraction.

Stock Solution—A solution containing an analyte that is prepared using a reference material traceable to EPA, the National Institute of Science and Technology (NIST), or a source that will attest to the purity and authenticity of the reference material.

TCDD—Tetrachlorodibenzo-p-dioxin.

TCDF—Tetrachlorodibenzofuran.

VER—See calibration verification standard.

METHOD 1624 REVISION B—VOLATILE ORGANIC COMPOUNDS BY ISOTOPE DILUTION GC/MS

1. Scope and Application

1.1 This method is designed to determine the volatile toxic organic pollutants associated with the 1976 Consent Decree and additional compounds amenable to purge and trap gas chromatography-mass spectrometry (GC/MS).

1.2 The chemical compounds listed in table 1 may be determined in municipal and industrial discharges by this method. The methmd is designed to meet the survey requirements of Effluent Guidelines Division (EGD) and the National Pollutants Discharge Elimination System (NPDES) under 40 CFR 136.1 and 136.5. Any modifications of this method, beyond those expressly permitted, shall be considered as major modifications subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.3 The detection limit of this method is usually dependent on the level of interferences rather than instrumental limitations. The limits in table 2 represent the minimum quantity that can be detected with no interferences present.

1.4 The GC/MS portions of this method are for use only by analysts experienced with GC/MS or under the close supervision of such qualified persons. Laboratories unfamiliar with the analyses of environmental samples by GC/MS should run the performance tests in reference 1 before beginning.

2. Summary of Method

2.1 Stable isotopically labeled analogs of the compounds of interest are added to a 5 mL water sample. The sample is purged at 20–25 °C with an inert gas in a specially designed chamber. The volatile organic compounds are transferred from the aqueous phase into the gaseous phase where they are passed into a sorbent column and trapped. After purging is completed, the trap is backflushed and heated rapidly to desorb the compounds into a gas chromatograph (GC). The compounds are separated by the GC and detected by a mass spectrometer (MS) (references 2 and 3). The labeled compounds serve to correct the variability of the analytical technique.

2.2 Identification of a compound (qualitative analysis) is performed by comparing the GC retention time and the background corrected characteristic spectral masses with those of authentic standards.

2.3 Quantitative analysis is performed by GC/MS using extracted ion current profile (EICP) areas. Isotope dilution is used when labeled compounds are available; otherwise, an internal standard method is used.

2.4 Quality is assured through reproducible calibration and testing of the purge and trap and GC/MS systems.

3. Contamination and Interferences

3.1 Impurities in the purge gas, organic compounds out-gassing from the plumbing upstream of the trap, and solvent vapors in the laboratory account for the majority of contamination problems. The analytical system is demonstrated to be free from interferences under conditions of the analysis by analyzing blanks initially and with each sample lot (samples analyzed on the same 8 hr shift), as described in Section 8.5.

3.2 Samples can be contaminated by diffusion of volatile organic compounds (particularly methylene chloride) through the bottle seal during shipment and storage. A field blank prepared from reagent water and carried through the sampling and handling protocol serves as a check on such contamination.

3.3 Contamination by carry-over can occur when high level and low level samples are analyzed sequentially. To reduce carry-over, the purging device and sample syringe are rinsed between samples with reagent water. When an unusually concentrated sample is encountered, it is followed by analysis of a reagent water blank to check for carry-over. For samples containing large amounts of water soluble materials, suspended solids, high boiling compounds, or high levels or purgeable compounds, the purge device is washed with soap solution, rinsed with tap and distilled water, and dried in an oven at 100–125 °C. The trap and other parts of the system are also subject to contamination; therefore, frequent bakeout and purging of the entire system may be required.

3.4 Interferences resulting from samples will vary considerably from source to source, depending on the diversity of the industrial complex or municipality being sampled.

4. Safety

4.1 The toxicity or carcinogenicity of each compound or reagent used in this method has not been precisely determined; however, each chemical compound should be treated as a potential health hazard. Exposure to these compounds should be reduced to the lowest possible level. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of data handling sheets should also be made available to all personnel involved in these analyses. Additional information on laboratory safety can be found in references 4–6.

4.2 The following compounds covered by this method have been tentatively classified as known or suspected human or mammalian carcinogens: benzene, carbon tetrachloride, chloroform, and vinyl chloride. Primary standards of these toxic compounds should be prepared in a hood, and a NIOSH/MESA approved toxic gas respirator should be worn when high concentrations are handled.

5. Apparatus and Materials

5.1 Sample bottles for discrete sampling.

5.1.1 Bottle—25 to 40 mL with screw cap (Pierce 13075, or equivalent). Detergent wash, rinse with tap and distilled water, and dry at >105 °C for one hr minimum before use.

5.1.2 Septum—Teflon-faced silicone (Pierce 12722, or equivalent), cleaned as above and baked at 100–200 °C, for one hour minimum.

5.2 Purge and trap device—consists of purging device, trap, and desorber. Complete devices are commercially available.

5.2.1 Purging device—designed to accept 5 mL samples with water column at least 3 cm deep. The volume of the gaseous head space between the water and trap shall be less than 15 mL. The purge gas shall be introduced less than 5 mm from the base of the water column and shall pass through the water as bubbles with a diameter less than 3 mm. The purging device shown in Figure 1 meets these criteria.

5.2.2 Trap—25 to 30 cm × 2.5 mm i.d. minimum, containing the following:

5.2.2.1 Methyl silicone packing—one ±0.2 cm, 3 percent OV–1 on 60/80 mesh Chromosorb W, or equivalent.

5.2.2.2 Porous polymer—15 ±1.0 cm, Tenax GC (2,6-diphenylene oxide polymer), 60/80 mesh, chromatographic grade, or equivalent.

5.2.2.3 Silica gel—8 ±1.0 cm, Davison Chemical, 35/60 mesh, grade 15, or equivalent. The trap shown in Figure 2 meets these specifications.

5.2.3 Desorber—shall heat the trap to 175 ±5 °C in 45 seconds or less. The polymer section of the trap shall not exceed 180 °C, and the remaining sections shall not exceed 220 °C. The desorber shown in Figure 2 meets these specifications.

5.2.4 The purge and trap device may be a separate unit or coupled to a GC as shown in Figures 3 and 4.

5.3 Gas chromatograph—shall be linearly temperature programmable with initial and final holds, shall contain a glass jet separator as the MS interface, and shall produce results which meet the calibration (Section 7), quality assurance (Section 8), and performance tests (Section 11) of this method.

5.3.1 Column—2.8 ±0.4 m × 2 ±0.5 mm i. d. glass, packekd with one percent SP–1000 on Carbopak B, 60/80 mesh, or equivalent.

5.4 Mass spectrometer—70 eV electron impact ionization; shall repetitively scan from 20 to 250 amu every 2–3 seconds, and produce a unit resolution (valleys between m/z 174–176 less than 10 percent of the height of the m/z 175 peak), background corrected mass spectrum from 50 ng 4-bromo-fluorobenzene (BFB) injected into the GC. The BFB spectrum shall meet the mass-intensity criteria in Table 3. All portions of the GC column, transfer lines, and separator which connect the GC column to the ion source shall remain at or above the column temperature during analysis to preclude condensation of less volatile compounds.

5.5 Data system—shall collect and record MS data, store mass intensity data in spectral libraries, process GC/MS data and generate reports, and shall calculate and record response factors.

5.5.1 Data acquisition—mass spectra shall be collected continuously throughout the analysis and stored on a mass storage device.

5.5.2 Mass spectral libraries—user created libraries containing mass spectra obtained from analysis of authentic standards shall be employed to reverse search GC/MS runs for the compounds of interest (Section 7.2).

5.5.3 Data processing—the data system shall be used to search, locate, identify, and quantify the compounds of interest in each GC/MS analysis. Software routines shall be employed to compute retention times and EICP areas. Displays of spectra, mass chromatograms, and library comparisons are required to verify results.

5.5.4 Response factors and multipoint calibrations—the data system shall be used to record and maintain lists of response factors (response ratios for isotope dilution) and generate multi-point calibration curves (Section 7). Computations of relative standard deviation (coefficient of variation) are useful for testing calibration linearity. Statistics on initial and on-going performance shall be maintained (Sections 8 and 11).

5.6 Syringes—5 mL glass hypodermic, with Luer-lok tips.

5.7 Micro syringes—10, 25, and 100 uL.

5.8 Syringe valves—2-way, with Luer ends (Telfon or Kel-F).

5.9 Syringe—5 mL, gas-tight, with shut-off valve.

5.10 Bottles—15 mL., screw-cap with Telfon liner.

5.11 Balance—analytical, capable of weighing 0.1 mg.

6. Reagents and Standards

6.1 Reagent water—water in which the compounds of interest and interfering compounds are not detected by this method (Section 11.7). It may be generated by any of the following methods:

6.1.1 Activated carbon—pass tap water through a carbon bed (Calgon Filtrasorb-300, or equivalent).

6.1.2 Water purifier—pass tap water through a purifier (Millipore Super Q, or equivalent).

6.1.3 Boil and purge—heat tap water to 90–100 °C and bubble contaminant free inert gas through it for approx one hour. While still hot, transfer the water to screw-cap bottles and seal with a Teflon-lined cap.

6.2 Sodium thiosulfate—ACS granular.

6.3 Methanol—pesticide quality or equivalent.

6.4 Standard solutions—purchased as solution or mixtures with certification to their purity, concentration, and authenticity, or prepared from materials of known purity and composition. If compound purity is 96 percent or greater, the weight may be used without correction to calculate the concentration of the standard.

6.5 Preparation of stock solutions—prepare in methanol using liquid or gaseous standards per the steps below. Observe the safety precautions given in Section 4.

6.5.1 Place approx 9.8 mL of methanol in a 10 mL ground glass stoppered volumetric flask. Allow the flask to stand unstoppered for approximately 10 minutes or until all methanol wetted surfaces have dried. In each case, weigh the flask, immediately add the compound, then immediately reweigh to prevent evaporation losses from affecting the measurement.

6.5.1.1 Liquids—using a 100 µL syringe, permit 2 drops of liquid to fall into the methanol without contacting the leck of the flask. Alternatively, inject a known volume of the compound into the methanol in the flask using a micro-syringe.

6.5.1.2 Gases (chloromethane, bromomethane, chloroethane, vinyl chloride)—fill a valved 5 mL gas-tight syringe with the compound. Lower the needle to approximately 5 mm above the methanol meniscus. Slowly introduce the compound above the surface of the meniscus. The gas will dissolve rapidly in the methanol.

6.5.2 Fill the flask to volume, stopper, then mix by inverting several times. Calculate the concentration in mg/mL (µg/µL) from the weight gain (or density if a known volume was injected).

6.5.3 Transfer the stock solution to a Teflon sealed screw-cap–bottle. Store, with minimal headspace, in the dark at −10 to −20 °C.

6.5.4 Prepare fresh standards weekly for the gases and 2-chloroethylvinyl ether. All other standards are replaced after one month, or sooner if comparison with check standards indicate a change in concentration. Quality control check standards that can be used to determine the accuracy of calibration standards are available from the US Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.

6.6 Labeled compound spiking solution—from stock standard solutions prepared as above, or from mixtures, prepare the spiking solution to contain a concentration such that a 5–10 µL spike into each 5 mL sample, blank, or aqueous standard analyzed will result in a concentration of 20 µg/L of each labeled compound. For the gases and for the water soluble compounds (acrolein, acrylonitrile, acetone, diethyl ether, and MEK), a concentration of 100 µg/L may be used. Include the internal standards (Section 7.5) in this solution so that a concentration of 20 µg/L in each sample, blank, or aqueous standard will be produced.

6.7 Secondary standards—using stock solutions, prepare a secondary standard in methanol to contain each pollutant at a concentration of 500 µg/mL For the gases and water soluble compounds (Section 6.6), a concentration of 2.5 mg/mL may be used.

6.7.1 Aqueous calibration standards—using a 25 µL syringe, add 20 µL of the secondary standard (Section 6.7) to 50, 100, 200, 500, and 1000 mL of reagent water to produce concentrations of 200, 100, 50, 20, and 10 µg/L, respectively. If the higher concentration standard for the gases and water soluble compounds was chosen (Section 6.6), these compounds will be at concentrations of 1000, 500, 250, 100, and 50 µg/L in the aqueous calibration standards.

6.7.2 Aqueous performance standard—an aqueous standard containing all pollutants, internal standards, labeled compounds, and BFB is prepared daily, and analyzed each shift to demonstrate performance (Section 11). This standard shall contain either 20 or 100 µg/L of the labeled and pollutant gases and water soluble compounds, 10 µg/L BFB, and 20 µg/L of all other pollutants, labeled compounds, and internal standards. It may be the nominal 20 µg/L aqueous calibration standard (Section 6.7.1).

6.7.3 A methanolic standard containing all pollutants and internal standards is prepared to demonstrate recovery of these compounds when syringe injection and purge and trap analyses are compared. This standard shall contain either 100 µg/mL or 500 µg/mL of the gases and water soluble compounds, and 100 µg/mL of the remaining pollutants

and internal standards (consistent with the amounts in the aqueous performance standard in 6.7.2).

6.7.4 Other standards which may be needed are those for test of BFB performance (Section 7.1) and for collection of mass spectra for storage in spectral libraries (Section 7.2).

7. Calibration

7.1 Assemble the gas chromatographic apparatus and establish operating conditions given in table 2. By injecting standards into the GC, demonstrate that the analytical system meets the detection limits in table 2 and the mass-intensity criteria in table 3 for 50 ng BFB.

7.2 Mass spectral libraries—detection and identification of the compound of interest are dependent upon the spectra stored in user created libraries.

7.2.1 Obtain a mass spectrum of each pollutant and labeled compound and each internal standard by analyzing an authentic standard either singly or as part of a mixture in which there is no interference between closely eluted components. That only a single compound is present is determined by examination of the spectrum. Fragments not attributable to the compound under study indicate the presence of an interfering compound. Adjust the analytical conditions and scan rate (for this test only) to produce an undistorted spectrum at the GC peak maximum. An undistorted spectrum will usually be obtained if five complete spectra are collected across the upper half of the GC peak. Software algorithms designed to ''enhance'' the spectrum may eliminate distortion, but may also eliminate authentic m/z's or introduce other distortion.

7.2.3 The authentic reference spectrum is obtained under BFB tuning conditions (Section 7.1 and table 3) to normalize it to spectra from other instruments.

7.2.4 The spectrum is edited by saving the 5 most intense mass spectral peaks and all other mass spectral peaks greater than 10 percent of the base peak. This spectrum is stored for reverse search and for compound confirmation.

7.3 Assemble the purge and trap device. Pack the trap as shown in Figure 2 and condition overnight at 170–180 °C by backflushing with an inert gas at a flow rate of 20–30 mL/min. Condition traps daily for a minimum of 10 minutes prior to use.

7.3.1 Analyze the aqueous performance standard (Section 6.7.2) according to the purge and trap procedure in Section 10. Compute the area at the primary m/z (table 4) for each compound. Compare these areas to those obtained by injecting one µL of the methanolic standard (Section 6.7.3) to determine compound recovery. The recovery shall be greater than 20 percent for the water soluble compounds, and 60–110 percent for all other compounds. This recovery is demonstrated initially for each purge and trap GC/MS system. The test is repeated only if the purge and trap or GC/MS systems are modified in any way that might result in a change in recovery.

7.3.2 Demonstrate that 100 ng toluene (or toluene-d8) produces an area at m/z 91 (or 99) approx one-tenth that required to exceed the linear range of the system. The exact value must be determined by experience for each instrument. It is used to match the calibration range of the instrument to the analytical range and detection limits required.

7.4 Calibration by isotope dilution—the isotope dilution approach is used for the purgeable organic compounds when appropriate labeled compounds are available and when interferences do not preclude the analysis. If labeled compounds are not available, or interferences are present, internal standard methods (Section 7.5 or 7.6) are used. A calibration curve encompassing the concentration range of interest is prepared for each compound determined. The relative response (RR) vs concentration (µg/L) is plotted or computed using a linear regression. An example of a calibration curve for toluene using toluene-d8 is given in figure 5. Also shown are the ±10 percent error limits (dotted lines). Relative response is determined according to the procedures described below. A minimum of five data points are required for calibration (Section 7.4.4).

7.4.1 The relative response (RR) of pollutant to labeled compound is determined from isotope ratio values calculated from acquired data. Three isotope ratios are used in this process:

R_x=the isotope ratio measured in the pure pollutant (figure 6A).

R_y=the isotope ratio of pure labeled compound (figure 6B).

R_m=the isotope ratio measured in the analytical mixture of the pollutant and labeled compounds (figure 6C).

The correct way to calculate RR is: $RR=(R_y-R_m)\ (R_x+1)/(R_m-R_x)(R_y+1)$ If R_m is not between $2R_y$ and $0.5R_x$, the method does not apply and the sample is analyzed by internal or external standard methods (Section 7.5 or 7.6).

7.4.2 In most cases, the retention times of the pollutant and labeled compound are the same and isotope ratios (R's) can be calculated from the EICP areas, where: R=(area at m_1/z)/(area at m_2/z) If either of the areas is zero, it is assigned a value of one in the calculations; that is, if: area of m_1/z=50721, and area of m_2/z=0, then R=50721/1=50720. The m/z's are always selected such that $R_x>R_y$. When there is a difference in retention times (RT) between the pollutant and labeled compounds, special precautions are required to determine the isotope ratios.

R_x, R_y, and R_m are defined as follows:

R_x=[area m_1/z (at RT_1)]/1

R_y=1/[area m_2/z (at RT_2)]

R_m=[area m_1/z (at RT_1)]/[area m_2/z (at RT_2)]

7.4.3 An example of the above calculations can be taken from the data plotted in figure 6 for toluene and toluene-d8. For these data, R_x=168920/1=168900, R_y=1/60960=0.00001640, and R_m=96868/82508=1.174. The RR for the above data is then calculated using the equation given in Section 7.4.1. For the example, RR=1.174.

NOTE: Not all labeled compounds elute before their pollutant analogs.

7.4.4 To calibrate the analytical system by isotope dilution, analyze a 5 mL aliquot of each of the aqueous calibration standards (Section 6.7.1) spiked with an appropriate constant amount of the labeled compound spiking solution (Section 6.6), using the purge and trap procedure in section 10. Compute the RR at each concentration.

7.4.5 Linearity—if the ratio of relative response to concentration for any compound is constant (less than 20 percent coefficient of variation) over the 5 point calibration range, an averaged relative response/concentration ratio may be used for that compound; otherwise, the complete calibration curve for that compound shall be used over the 5 point calibration range.

7.5 Calibration by internal standard—used when criteria for isotope dilution (Section 7.4) cannot be met. The method is applied to pollutants having no labeled analog and to the labeled compounds. The internal standards used for volatiles analyses are bromochloromethane, 2-bromo-1-chloropropane, and 1,4-dichlorobutane. Concentrations of the labeled compounds and pollutants without labeled analogs are computed relative to the nearest eluted internal standard, as shown in table 2.

7.5.1 Response factors—calibration requires the determination of response factors (RF) which are defined by the following equation:

$RF=(A_s x C_{is})/(A_{is} x C_s)$, where A_s is the EICP area at the characteristic m/z for the compound in the daily standard. A_{is} is the EICP area at the characteristic m/z for the internal standard.

C_{is} is the concentration (ug/L) of the internal standard

C_s is the concentration of the pollutant in the daily standard.

7.5.2 The response factor is determined at 10, 20, 50, 100, and 200 ug/L for the pollutants (optionally at five times these concentrations for gases and water soluble pollutants—see Section 6.7), in a way analogous to that for calibration by isotope dilution (Section 7.4.4). The RF is plotted against concentration for each compound in the standard (C_s) to produce a calibration curve.

7.5.3 Linearity—if the response factor (RF) for any compound is constant (less than 35 percent coefficient of variation) over the 5 point calibration range, an averaged response factor may be used for that compound; otherwise, the complete calibration curve for that compound shall be used over the 5 point range.

7.6 Combined calibration—by adding the isotopically labeled compounds and internal standards (Section 6.6) to the aqueous calibration standards (Section 6.7.1), a single set of analyses can be used to produce calibration curves for the isotope dilution and internal standard methods. These curves are verified each shift (Section 11.5) by purging the aqueous performance standard (Section 6.7.2). Recalibration is required only if calibration and on-going performance (Section 11.5) criteria cannot be met.

8. Quality Assurance/Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality assurance program. The minimum requirements of this program consist of an initial demonstration of laboratory capability, analysis of samples spiked with labeled compounds to evaluate and document data quality, and analysis of standards and blanks as tests of continued performance. Laboratory performance is compared to established performance criteria to determine if the results of analyses meet the performance characteristics of the method.

8.1.1 The analyst shall make an initial demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 The analyst is permitted to modify this method to improve separations or lower the costs of measurements, provided all performance specifications are met. Each time a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2 to demonstrate method performance.

8.1.3 Analyses of blanks are required to demonstrate freedom from contamination and that the compounds of interest and interfering compounds have not been carried over from a previous analysis (Section 3). The procedures and criteria for analysis of a blank are described in Sections 8.5 and 11.7.

8.1.4 The laboratory shall spike all samples with labeled compounds to monitor method performance. This test is described in Section 8.3. When results of these spikes indicate atypical method performance for samples, the samples are diluted to bring method performance within acceptable limits (Section 14.2).

8.1.5 The laboratory shall, on an on-going basis, demonstrate through the analysis of the aqueous performance standard (Section 6.7.2) that the analysis system is in control. This procedure is described in Sections 11.1 and 11.5.

8.1.6 The laboratory shall maintain records to define the quality of data that is generated. Development of accuracy statements is described in Sections 8.4 and 11.5.2.

8.2 Initial precision and accuracy—to establish the ability to generate acceptable precision and accuracy, the analyst shall perform the following operations:

8.2.1 Analyze two sets of four 5–mL aliquots (8 aliquots total) of the aqueous performance standard (Section 6.7.2) according to the method beginning in Section 10.

8.2.2 Using results of the first set of four analyses in Section 8.2.1, compute the average recovery (X) in µg/L and the standard deviation of the recovery (s) in µg/L for each compound, by isotope dilution for pollutants with a labeled analog, and by internal standard for labeled compounds and pollutants with no labeled analog.

8.2.3 For each compound, compare s and $\bar{X}$ with the corresponding limits for initial precision and accuracy found in table 5. If s and $\bar{X}$ for all compounds meet the acceptance criteria, system performance is acceptable and analysis of blanks and samples may begin. If individual $\bar{X}$ falls outside the range for accuracy, system performance is unacceptable for that compound.

NOTE: The large number of compounds in table 5 present a substantial probability that one or more will fail one of the acceptance criteria when all compoulds are analyzed. To determine if the analytical system is out of control, or if the failure can be attributed to probability, proceed as follows:

8.2.4 Using the results of the second set of four analyses, compute s and $\bar{X}$ for only those compounds which failed the test of the first set of four analyses (Section 8.2.3). If these compounds now pass, system performance is acceptable for all compounds and analysis of blanks and samples may begin. If, however, any of the same compounds fail again, the analysis system is not performing properly for the compound(s) in question. In this event, correct the problem and repeat the entire test (Section 8.2.1).

8.3 The laboratory shall spike all samples with labeled compounds to assess method performance on the sample matrix.

8.3.1 Spike and analyze each sample according to the method beginning in Section 10.

8.3.2 Compute the percent recovery (P) of the labeled compounds using the internal standard method (Section 7.5).

8.3.3 Compare the percent recovery for each compound with the corresponding labeled compound recovery limit in table 5. If the recovery of any compound falls outside its warning limit, method performance is unacceptable for that compound in that sample. Therefore, the sample matrix is complex and the sample is to be diluted and reanalyzed, per Section 14.2.

8.4 As part of the QA program for the laboratory, method accuracy for wastewater samples shall be assessed and records shall be maintained. After the analysis of five wastewater samples for which the labeled compounds pass the tests in Section 8.3.3, compute the average percent recovery (P) and the standard deviation of the percent recovery (s_p) for the labeled compounds only. Express the accuracy assessment as a percent recovery interval from $P-2s_p$ to $P+2s_p$. For example, if P=90% and s_p=10%, the accuracy interval is expressed as 70–110%. Update the accuracy assessment for each compound on a regular basis (e.g. after each 5–10 new accuracy measurements).

8.5 Blanks—reagent water blanks are analyzed to demonstrate freedom from carryover (Section 3) and contamination.

8.5.1 The level at which the purge and trap system will carry greater than 5 µg/L of a pollutant of interest (table 1) into a succeeding blank shall be determined by analyzing successively larger concentrations of these compounds. When a sample contains this concentration or more, a blank shall be analyzed immediately following this sample to demonstrate no carry-over at the 5 µg/L level.

8.5.2 With each sample lot (samples analyzed on the same 8 hr shift), a blank shall be analyzed immediately after analysis of the aqueous performance standard (Section 11.1) to demonstrate freedom from contamination. If any of the compounds of interest (table 1) or any potentially interfering compound is found in a blank at greater than 10 µg/L (assuming a response factor of 1 relative to the nearest eluted internal standard for compounds not listed in table 1), analysis of samples is halted until the source of contamination is eliminated and a blank shows no evidence of contamination at this level.

8.6 The specifications contained in this method can be met if the apparatus used is calibrated properly, then maintained in a calibrated state.

The standards used for calibration (Section 7), calibration verification (Section 11.5) and for initial (Section 8.2) and on-going (Section 11.5) precision and accuracy should be identical, so that the most precise results will be obtained. The GC/MS instrument in particular will provide the most reproducible results if dedicated to the settings and conditions required for the analyses of volatiles by this method.

8.7 Depending on specific program requirements, field replicates may be collected to determine the precision of the sampling technique, and spiked samples may be required to determine the accuracy of the analysis when internal or external standard methods are used.

9. Sample Collection, Preservation, and Handling

9.1 Grab samples are collected in glass containers having a total volume greater than 20 mL. Fill sample bottles so that no air bubbles pass through the sample as the bottle is filled. Seal each bottle so that no air bubbles are entrapped. Maintain the hermetic seal on the sample bottle until time of analysis.

9.2 Samples are maintained at 0–4 °C from the time of collection until analysis. If the sample contains residual chlorine, add sodium thiosulfate preservative (10 mg/40 mL) to the empty sample bottles just prior to shipment to the sample site. EPA Methods 330.4 and 330.5 may be used for measurement of residual chlorine (Reference 8). If preservative has been added, shake bottle vigorously for one minute immediately after filling.

9.3 Experimental evidence indicates that some aromatic compounds, notably benzene, toluene, and ethyl benzene are susceptible to rapid biological degradation under certain environmental conditions. Refrigeration alone may not be adequate to preserve these compounds in wastewaters for more than seven days. For this reason, a separate sample should be collected, acidified, and analyzed when these aromatics are to be determined. Collect about 500 mL of sample in a clean container.

Adjust the pH of the sample to about 2 by adding HCl (1+1) while stirring. Check pH with narrow range (1.4 to 2.8) pH paper. Fill a sample container as described in Section 9.1. If residual chlorine is present, add sodium thiosulfate to a separate sample container and fill as in Section 9.1.

9.4 All samples shall be analyzed within 14 days of collection.

10. Purge, Trap, and GC/MS Analysis

10.1 Remove standards and samples from cold storage and bring to 20–25 °.

10.2 Adjust the purge gas flow rate to 40 ±4 mL/min. Attach the trap inlet to the purging device and set the valve to the purge mode (figure 3). Open the syringe valve located on the purging device sample introduction needle (figure 1).

10.3 Remove the plunger from a 5–mL syringe and attach a closed syringe valve. Open the sample bottle and carefully pour the sample into the syringe barrel until it overflows. Replace the plunger and compress the sample. Open the syringe valve and vent any residual air while adjusting the sample volume to 5.0 mL. Because this process of taking an aliquot destroys the validity of the sample for future analysis, fill a second syringe at this time to protect against possible loss of data. Add an appropriate amount of the labeled compound spiking solution (Section 6.6) through the valve bore, then close the valve.

10.4 Attach the syringe valve assembly to the syringe valve on the purging device. Open both syringe valves and inject the sample into the purging chamber.

10.5 Close both valves and purge the sample for 11.0 ±0.1 minutes at 20–25 °C.

10.6 After the 11 minute purge time, attach the trap to the chromatograph and set the purge and trap apparatus to the desorb mode (figure 4). Desorb the trapped compounds into the GC column by heating the trap to 170–180 °C while backflushing with carrier gas at 20–60 mL/min for four minutes. Start MS data acquisition upon start of the desorb cycle, and start the GC column temperature program 3 minutes later. Table 1 summarizes the recommended operating conditions for the gas chromatograph. Included in this table are retention times and detection limits that were achieved under these conditions. Other columns may be used provided the requirements in Section 8 can be met. If the priority pollutant gases produce GC peaks so broad that the precision and recovery specifications (Section 8.2) cannot be met, the column may be cooled to ambient or sub-ambient temperatures to sharpen these peaks.

10.7 While analysis of the desorbed compounds proceeds, empty the purging chamber using the sample introduction syringe. Wash the chamber with two 5-mL portions of reagent water. After the purging device has been emptied, allow the purge gas to vent through the chamber until the frit is dry, so that it is ready for the next sample.

10.8 After desorbing the sample for four minutes, recondition the trap by returning to the purge mode. Wait 15 seconds, then close the syringe valve on the purging device to begin gas flow through the trap. Maintain the trap temperature at 170–180 °C. After approximately seven minutes, turn off the trap heater and open the syringe valve to stop the gas flow through the trap. When cool, the trap is ready for the next sample.

11. System Performance

11.1 At the beginning of each 8 hr shift during which analyses are performed, system calibration and performance shall be verified for all pollutants and labeled compounds. For these tests, analysis of the aqueous performance standard (Section 6.7.2) shall be used to verify all performance criteria. Adjustment and/or recalibration (per Section 7) shall be performed until all performance criteria are met. Only after all performance criteria are met may blanks and samples be analyzed.

11.2 BFB spectrum validity—the criteria in table 3 shall be met.

11.3 Retention times—the absolute retention times of all compounds shall approximate those given in Table 2.

11.4 GC resolution—the valley height between toluene and toluene-d8 (at m/z 91 and 99 plotted on the same graph) shall be less than 10 percent of the taller of the two peaks.

11.5 Calibration verification and on-going precision and accuracy—compute the concentration of each polutant (Table 1) by isotope dilution (Section 7.4) for those compmunds which have labeled analogs. Compute the concentration of each pollutant (Table 1) which has no labeled analog by the internal standard method (Section 7.5). Compute the concentration of the labeled compounds by the internal standard method. These concentrations are computed based on the calibration data determined in Section 7.

11.5.1 For each pollutant and labeled compound, compare the concentration with the corresponding limit for on-going accuracy in Table 5. If all compmunds meet the acceptance criteria, system performance is acceptable and analysis of blanks and samples may continue. If any individual value falls outside the range given, system performance is unacceptable for that compound.

NOTE: The large number of compounds in Table 5 present a substantial probability that one or more will fail the acceptance criteria when all compounds are analyzed. To determine if the analytical system is out of control, or if the failure may be attributed to probability, proceed as follows:

11.5.1.1 Analyze a second aliquot of the aqueous performance standard (Section 6.7.2).

11.5.1.2 Compute the concentration for only those compounds which failed the first test (Section 11.5.1). If these compounds now pass, system performance is acceptable for all compounds and analyses of blanks and samples may proceed. If, however, any of the compounds fail again, the measurement system is not performing properly for these compounds. In this event, locate and correct the problem or recalibrate the system (Section 7), and repeat the entire test (Section 11.1) for all compounds.

11.5.2 Add results which pass the specification in 11.5.1.2 to initial (Section 8.2) and previous on-going data. Update QC charts to form a graphic representation of laboratory performance (Figure 7). Develop a statement of accuracy for each pollutant and labeled compound by calculating the average percentage recovery (R) and the standard deviation of percent recovery (s_r). Express the accuracy as a recovery interval from $R-2s_r$ to $R+2s_r$. For example, if R=95% and s_r=5%, the accuracy is 85–105 percent.

12. Qualitative Determination—Accomplished by Comparison of Data from Analysis of a Sample or Blank with Data from Analysis of the Shift Standard (Section 11.1). Identification is Confirmed When Spectra and Retention Times Agree Per the Criteria Below

12.1 Labeled compounds and pollutants having no labeled analog:

12.1.1 The signals for all characteristic masses stored in the spectral library (Section 7.2.4) shall be present and shall maximize within the same two consecutive scans.

12.1.2 Either (1) the background corrected EICP areas, or (2) the corrected relative intensities of the mass spectral peaks at the GC peak maximum shall agree within a factor of two (0.5 to 2 times) for all masses stored in the library.

12.1.3 The retention time relative to the nearest eluted internal standard shall be within ±7 scans or ±20 seconds, whichever is greater.

12.2 Pollutants having a labeled analog:

12.2.1 The signals for all characteristic masses stored in the spectral library (Section 7.2.4) shall be present and shall maximize within the same two consecutive scans.

12.2.2 Either (1) the background corrected EICP areas, or (2) the corrected relative intensities of the mass spectral peaks at the GC peak maximum shall agree within a factor of two for all masses stored in the spectral library.

12.2.3 The retention time difference between the pollutant and its labeled analog shall agree within ±2 scans or ±6 seconds (whichever is greater) of this difference in the shift standard (Section 11.1).

12.3 Masses present in the experimental mass spectrum that are not present in the reference mass spectrum shall be accounted for by contaminant or background ions. If the experimental mass spectrum is contaminated, an experienced spectrometrist (Section 1.4) is to determine the presence or absence of the compound.

13. Quantitative Determination

13.1 Isotope dilution—by adding a known amount of a labeled compound to every sample prior to purging, correction for recovery of the pollutant can be made because the pollutant and its labeled analog exhibit the same effects upon purging, desorption, and gas chromatography. Relative response (RR) values for sample mixtures are used in conjunction with calibration curves described in Section 7.4 to determine concentrations directly, so long as labeled compound spiking levels are constant. For the toluene example given in Figure 6 (Section 7.4.3), RR would be equal to 1.174. For this RR value, the toluene

calibration curve given in Figure 5 indicates a concentration of 31.8 µg/L.

13.2 Internal standard—calculate the concentration using the response factor determined from calibration data (Section 7.5) and the following equation:

Concentration $=(A_s \times C_{is})/(A_{is} \times RF)$ where the terms are as defined in Section 7.5.1.

13.3 If the EICP area at the quantitation mass for any compound exceeds the calibration range of the system, the sample is diluted by successive factors of 10 and these dilutions are analyzed until the area is within the calibration range.

13.4 Report results for all pollutants and labeled compounds (Table 1) found in all standards, blanks, and samples, in µg/L to three significant figures. Results for samples which have been diluted are reported at the least dilute level at which the area at the quantitation mass is within the calibration range (Section 13.3) and the labeled compound recovery is within the normal range for the Method (Section 14.2).

14. Analysis of Complex Samples

14.1 Untreated effluents and other samples frequently contain high levels (>1000 µg/L) of the compounds of interest and of interfering compounds. Some samples will foam excessively when purged; others will overload the trap/or GC column.

14.2 Dilute 0.5 mL of sample with 4.5 mL of reagent water and analyze this diluted sample when labeled compound recovery is outside the range given in Table 5. If the recovery remains outside of the range for this diluted sample, the aqueous performance standard shall be analyzed (Section 11) and calibration verified (Section 11.5). If the recovery for the labeled compmund in the aqueous performance standard is outside the range given in Table 5, the analytical system is out of control. In this case, the instrumelt shall be repaired, the performance specifications in Section 11 shall be met, and the analysis of the undiluted sample shall be repeated. If the recovery for the aqueous performance standard is within the range given in Table 5, the method does not work on the sample being analyzed and the result may not be reported for regulatory compliance purposes.

14.3 Reverse search computer programs can misinterpret the spectrum of chromatographically unresolved pollutant and labeled compound pairs with overlapping spectra when a high level of the pollutant is present. Examine each chromatogram for peaks greater than the height of the internal standard peaks. These peaks can obscure the compounds of interest.

15. Method Performance

15.1 The specifications for this method were taken from the inter-laboratory validation of EPA Method 624 (reference 9). Method 1624 has been shown to yield slightly better performance on treated effluents than Method 624. Additional method performance data can be found in Reference 10.

References

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TABLE 1—VOLATILE ORGANIC COMPOUNDS ANALYZED BY ISOTOPE DILUTION GC/MS

Compound	Storet	CAS registry	EPA–EGD	NPDES
Acetone	81552	67–64–1	516 V	.....
Acrolein	34210	107–02–8	002 V	001 V
Acrylonitrile	34215	107–13–1	003 V	002 V
Benzene	34030	71–43–2	004 V	003 V

TABLE 1—VOLATILE ORGANIC COMPOUNDS ANALYZED BY ISOTOPE DILUTION GC/MS—Continued

Compound	Storet	CAS registry	EPA–EGD	NPDES
Bromodichloromethane	32101	75–27–4	048 V	012 V
Bromoform	32104	75–25–2	047 V	005 V
Bromomethane	34413	74–83–9	046 V	020 V
Carbon tetrachloride	32102	56–23–5	006 V	006 V
Chlorobenzene	34301	108–90–7	007 V	007 V
Chloroethane	34311	75–00–3	016 V	009 V
2-chloroethylvinyl ether	34576	110–75–8	019 V	010 V
Chloroform	32106	67–66–1	023 V	011 V
Chloromethane	34418	74–87–3	045 V	021 V
Dibromochloromethane	32105	124–48–1	051 V	008 V
1,1-dichloroethane	34496	75–34–3	013 V	014 V
1,2-dichloroethane	34536	107–06–2	010 V	015 V
1,1-dichloroethene	34501	75–35–4	029 V	016 V
Trans-1,2-dichloroethane	34546	156–60–5	030 V	026 V
1,2-dichloropropane	34541	78–87–5	032 V	017 V
Cis-1,3-dichloropropene	34704	10061–01–5	.....	.....
Trans-1,3-dichloropropene	34699	10061–02–6	033 V	.....
Diethyl ether	81576	60–29–7	515 V	.....
P-dioxane	81582	123–91–1	527 V	.....
Ethylbenzene	34371	100–41–4	038 V	019 V
Methylene chloride	34423	75–09–2	044 V	022 V
Methyl ethyl ketone	81595	78–93–3	514 V	.....
1,1,2,2-tetrachloroethane	34516	79–34–5	015 V	023 V
Tetrachlorethene	34475	127–18–4	085 V	024 V
Toluene	34010	108–88–3	086 V	025 V
1,1,1-trichloroethane	34506	71–55–6	011 V	027 V
1,1,2-trichloroethane	34511	79–00–5	014 V	028 V
Trichloroethene	39180	79–01–6	087 V	029 V
Vinyl chloride	39175	75–01–4	088 V	031 V

TABLE 2—GAS CHROMATOGRAPHY OF PURGEABLE ORGANIC COMPOUNDS BY ISOTOPE DILUTION GC/MS

EGD No. (1)	Compound	Ref EGD No.	Mean retention time (sec)	Minimum level (2) (µg/L)
181	Bromochloromethane (I.S.)	181	730	10
245	Chloromethane-d3	181	147	50
345	Chloromethane	245	148	50
246	Bromomethane-d3	181	243	50
346	Bromomethane	246	246	50
288	Vinyl chloride-d3	181	301	50
388	Vinyl chloride	288	304	10
216	Chloroethane-d5	181	378	50
316	Chloroethane	216	386	50
244	Methylene chloride-d2	181	512	10
344	Methylene chloride	244	517	10
616	Acetone-d6	181	554	50
716	Acetone	616	565	50
002	Acrolein	181	566	50
203	Acrylonitrile-d3	181	606	50
303	Acrylonitrile	203	612	50
229	1,1-dichloroethene-d2	181	696	10
329	1,1-dichloroethene	229	696	10
213	1,1-dichloroethane-d3	181	778	10
313	1,1-dichloroethane	213	786	10
615	Diethyl ether-d10	181	804	50
715	Diethyl ether	615	820	50
230	Trans-1,2-dichloroethene-d2	181	821	10
330	Trans-1,2-dichloroethene	230	821	10
614	Methyl ethyl ketone-d3	181	840	50
714	Methyl ethyl ketone	614	848	50
223	Chloroform-13C1	181	861	10
323	Chloroform	223	861	10
210	1,2-dichloroethane-d4	181	901	10

TABLE 2—GAS CHROMATOGRAPHY OF PURGEABLE ORGANIC COMPOUNDS BY ISOTOPE DILUTION GC/MS—Continued

EGD No. (1)	Compound	Ref EGD No.	Mean retention time (sec)	Minimum level (2) (µg/L)
310	1,2-dichloroethane	210	910	10
211	1,1,1-trichloroethane-13C2	181	989	10
311	1,1,1-trichloroethane	211	999	10
527	p-dioxane	181	1001	10
206	Carbon tetrachloride-13C1	182	1018	10
306	Carbon tetrachloride	206	1018	10
248	Bromodichloromethane-13C1	182	1045	10
348	Bromodichloromethane	248	1045	10
232	1,2-dichloropropane-d6	182	1123	10
332	1.2-dichloropropane	232	1134	10
233	Trans-1,3-dichloropropene-d4	182	1138	10
333	Trans-1,3-dichloropropene	233	1138	10
287	Trichloroethene-13C1	182	1172	10
387	Trichloroethene	287	1187	10
204	Benzene-d6	182	1200	10
304	Benzene	204	1212	10
251	Chlorodibromemethane-13C1	182	1222	10
351	Chlorodibromomethane	251	1222	10
214	1,1,2-trichloroethane-13C2	182	1224	10
314	1,1,2-trichloroethane	214	1224	10
019	2-chloroethylvinyl ether	182	1278	10
182	2-bromo-1-chloropropane (I.S.)	182	1306	10
247	Bromoform-13C1	182	1386	10
347	Bromoform	247	1386	10
215	1,1,2,2-tetrachloroethane-d2	183	1525	10
315	1,1,2,2-tetrachloroethane	215	1525	10
285	Tetrachloroethene-13C2	183	1528	10
385	Tetrachloroethene	285	1528	10
183	1,4-dichlorobutale (int std)	183	1555	10

TABLE 2—GAS CHROMATOGRAPHY OF PURGEABLE ORGANIC COMPOUNDS BY ISOTOPE DILUTION GC/MS—Continued

EGD No. (1)	Compound	Ref EGD No.	Mean retention time (sec)	Minimum level (2) (µg/L)
286	Toluene-d8	183	1603	10
386	Toluene	286	1619	10
207	Chlorobenzene-d5	183	1679	10
307	Chlorobenzene	207	1679	10
238	Ethylbenzene-d10	183	1802	10
338	Ethylbenzene	238	1820	10
185	Bromofluorobenzene	183	1985	10

(1) Reference numbers beginning with 0, 1 or 5 indicate a pollutant quantified by the internal standard method; reference numbers beginning with 2 or 6 indicate a labeled compound quantified by the internal standard method; reference numbers beginning with 3 or 7 indicate a pollutant quantified by isotope dilution.

(2) This is a minimum level at which the analytical system shall give recognizable mass spectra (background corrected) and acceptable calibration points. Column: 2.4m (8 ft) × 2 mm i.d. glass, packed with one percent SP–1000 coated on 60/80 Carbopak B. Carrier gas: helium at 40 mL/min. Temperature program: 3 min at 45 °C, 8 °C per min to 240 °C, hold at 240 °C for 15 minutes.

NOTE: The specifications in this table were developed from data collected from three wastewater laboratories.

TABLE 3—BFB MASS-INTENSITY SPECIFICATIONS

Mass	Intensity required
50	15 to 40 percent of mass 95.
75	30 to 60 percent of mass 95.
95	base peak, 100 percent.
96	5 to 9 percent of mass 95.
173	<2 percent of mass 174.
174	>50 percent of mass 95.
175	5 to 9 percent of mass 174
176	95 to 101 percent of mass 174
177	5 to 9 percent of mass 176.

TABLE 4—VOLATILE ORGANIC COMPOUND CHARACTERISTIC MASSES

Labeled compound	Analog	Primary m/z's
Acetone	d6	58/64
Acrolein	d2	56/58
Acrylonitrile	d3	53/56
Benzene	d6	78/84
Bromodichloromethane	13C	83/86
Bromoform	13C	173/176
Bromomethale	d3	96/99
Carbon tetrachloride	13C	47/48
Chlorobenzene	d5	112/117
Chloroethane	d5	64/71
2-chloroethylvinyl ether	d7	106/113
Chloroform	13C	85/86
Chloromethane	d3	50/53
Dibromochloromethane	13C	129/130
1,1-dichloroethane	d3	63/66
1,2-dichloroethane	d4	62/67
1,1-dichloroethene	d2	61/65
Trans-1,2-dichloroethene	d2	61/65
1,2-dichloropropane	d6	63/67
Cis-1,3-dichloropropene	d4	75/79
Trans-1,3-dichloropropene	d4	75/79
Diethyl ether	d10	74/84
p-dioxane	d8	88/96
Ethylbenzene	d10	106/116
Methylene chloride	d2	84/88
Methyl ethyl ketone	d3	72/75
1,1,2,2-tetrachloroethane	d2	83/84
Tetrachloroethene	13C2	166/172
Toluene	d8	92/99
1,1,1-trichloroethane	d3	97/102
1,1,2-trichloroethane	13C2	83/84
Trichloroethene	13C	95/133
Vinyl chloride	d3	62/65

TABLE 5—ACCEPTANCE CRITERIA FOR PERFORMANCE TESTS

Compound	Acceptance criteria at 20 µg/L			
	Initial precision and accuracy section 8.2.3		Labeled compound recovery sec. 8.3 and 14.2	On-going accuracy sec. 11.5
	s (µg/L)	$\bar{X}$ (µg/L)	P (percent)	R (µg/L)
Acetone		Note 1		
Acrolein		Note 2		
Acrylonitrile		Note 2		
Benzene	9.0	13.0–28.2	ns–196	4–33
Bromodichloromethane	8.2	6.5–31.5	ns–199	4–34
Bromoform	7.0	7.4–35.1	ns–214	6–36
Bromomethane	25.0	d–54.3	ns–414	d–61
Carbon tetrachloride	6.9	15.9–24.8	42–165	12–30
Chlorobenzene	8.2	14.2–29.6	ns–205	4–35
Chloroethane	14.8	2.1–46.7	ns–308	d–51
2–chloroethylvinyl ether	36.0	d–69.8	ns–554	d–79
Chloroform	7.9	11.6–26.3	18–172	8–30
Chloromethane	26.0	d–55.5	ns–410	d–64
Dibromochloromethane	7.9	11.2–29.1	16–185	8–32
1,1-dichloroethane	6.7	11.4–31.4	23–191	9–33
1,2-dichloroethane	7.7	11.6–30.1	12–192	8–33
1,1-dichloroethene	11.7	d–49.8	ns–315	d–52

TABLE 5—ACCEPTANCE CRITERIA FOR PERFORMANCE TESTS—Continued

Compound	Acceptance criteria at 20 μg/L			
	Initial precision and accuracy section 8.2.3		Labeled compound recovery sec. 8.3 and 14.2	On-going accuracy sec. 11.5
	s (μg/L)	$\bar{X}$ (μg/L)	P (percent)	R (μg/L)
Trans-1,2–dichloroethene	7.4	10.5–31.5	15–195	8–34
1,2-dichloropropane	19.2	d–46.8	ns–343	d–51
Cis–1,3–dichloropropene	22.1	d–51.0	ns–381	d–56
Trans–1,3–dichloropropene	14.5	d–40.2	ns–284	d–44
Diethyl ether		Note 1		
P–dioxane		Note 1		
Ethyl benzene	9.6	15.6–28.5	ns–203	5–35
Methylene chloride	9.7	d–49.8	ns–316	d–50
Methyl ethyl ketone		Note 1		
1,1,2,2-tetrachloroethane	9.6	10.7–30.0	5–199	7–34
Tetrachloroethene	6.6	15.1–28.5	31–181	11–32
Toluene	6.3	14.5–28.7	4–193	6–33
1,1,1-trichloroethane	5.9	10.5–33.4	12–200	8–35
1,1,2-trichloroethane	7.1	11.8–29.7	21–184	9–32
Trichloroethene	8.9	16.6–29.5	35–196	12–34
Vinyl chloride	27.9	d–58.5	ns–452	d–65

d = detected; result must be greater than zero.
ns = no specification; limit would be below detection limit.

NOTE 1: Specifications not available for these compounds at time of release of this method.
NOTE 2: Specifications not developed for these compounds; use method 603.

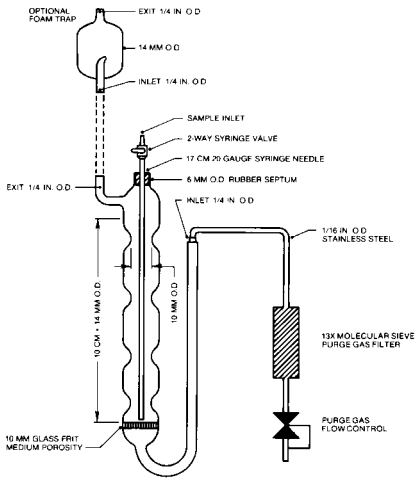

FIGURE 1 Purging Device.

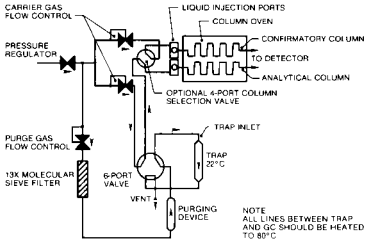

FIGURE 3 Schematic of Purge and Trap Device—Purge Mode.

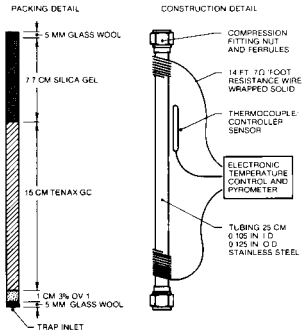

FIGURE 2 Trap Packings and Construction to Include Desorb Capability.

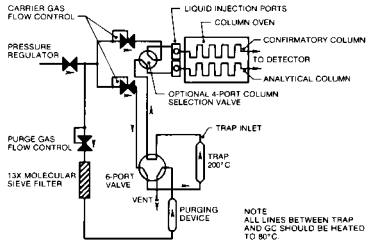

FIGURE 4 Schematic of Purge and Trap Device—Desorb Mode.

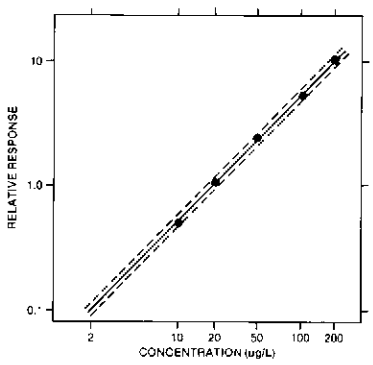

FIGURE 5 Relative Response Calibration Curve for Toluene. The Dotted Lines Enclose a ±10 Percent Error Window.

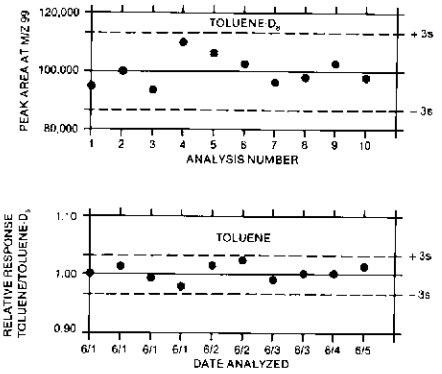

FIGURE 7 Quality Control Charts Showing Area (top graph) and Relative Response of Toluene to Toluene-d_8 (lower graph) Plotted as a Function of Time or Analysis Number.

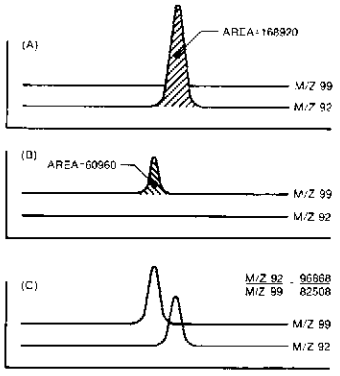

FIGURE 6 Extracted Ion Current Profiles for (A) Toluene, (B) Toluene-d_8, and a Mixture of Toluene and Toluene-d_8.

METHOD 1625 REVISION B—SEMIVOLATILE ORGANIC COMPOUNDS BY ISOTOPE DILUTION GC/MS

1. Scope and Application

1.1 This method is designed to determine the semivolatile toxic organic pollutants associated with the 1976 Consent Decree and additional compounds amenable to extraction and analysis by capillary column gas chromatography-mass spectrometry (GC/MS).

1.2 The chemical compounds listed in Tables 1 and 2 may be determined in municipal and industrial discharges by this method. The method is designed to meet the survey

requirements of Effluent Guidelines Division (EGD) and the National Pollutants Discharge Elimination System (NPDES) under 40 CFR 136.1. Any modifications of this method, beyond those expressly permitted, shall be considered as major modifications subject to application and approval of alternate test procedures under 40 CFR 136.4 and 136.5.

1.3 The detection limit of this method is usually dependent on the level of interferences rather than instrumental limitations. The limits listed in Tables 3 and 4 represent the minimum quantity that can be detected with no interferences present.

1.4 The GC/MS portions of this method are for use only by analysts experienced with GC/MS or under the close supervision of such qualified persons. Laboratories unfamiliar with analyses of environmental samples by GC/MS should run the performance tests in reference 1 before beginning.

2. Summary of Method

2.1 Stable isotopically labeled analogs of the compounds of interest are added to a one liter wastewater sample. The sample is extracted at pH 12–13, then at pH <2 with methylene chloride using continuous extraction techniques. The extract is dried over sodium sulfate and concentrated to a volume of one mL. An internal standard is added to the extract, and the extract is injected into the gas chromatograph (GC). The compounds are separated by GC and detected by a mass spectrometer (MS). The labeled compounds serve to correct the variability of the analytical technique.

2.2 Identification of a compound (qualitative analysis) is performed by comparing the GC retention time and background corrected characteristic spectral masses with those of authentic standards.

2.3 Quantitative analysis is performed by GC/MS using extracted ion current profile (EICP) areas. Isotope dilution is used when labeled compounds are available; otherwise, an internal standard method is used.

2.4 Quality is assured through reproducible calibration and testing of the extraction and GC/MS systems.

3. Contamination and Interferences

3.1 Solvents, reagents, glassware, and other sample processing hardware may yield artifacts and/or elevated baselines causing misinterpretation of chromatograms and spectra. All materials shall be demonstrated to be free from interferences under the conditions of analysis by running method blanks initially and with each sample lot (samples started through the extraction process on a given 8 hr shift, to a maximum of 20). Specific selection of reagents and purification of solvents by distillation in all-glass systems may be required. Glassware and, where possible, reagents are cleaned by solvent rinse and baking at 450 °C for one hour minimum.

3.2 Interferences coextracted from samples will vary considerably from source to source, depending on the diversity of the industrial complex or municipality being samples.

4. Safety

4.1 The toxicity or carcinogenicity of each compound or reagent used in this method has not been precisely determined; however, each chemical compound should be treated as a potential health hazard. Exposure to these compounds should be reduced to the lowest possible level. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of data handling sheets should also be made available to all personnel involved in these analyses. Additional information on laboratory safety can be found in references 2–4.

4.2 The following compounds covered by this method have been tentatively classified as known or suspected human or mammalian carcinogens: benzidine benzo(a)anthracene, 3,3′-dichlorobenzidine, benzo(a)pyrene, dibenzo(a,h)anthracene, N-nitrosodimethylamine, and β-naphtylamine. Primary standards of these compounds shall be prepared in a hood, and a NIOSH/MESA approved toxic gas respirator should be worn when high concentrations are handled.

5. Apparatus and Materials

5.1 Sampling equipment for discrete or composite sampling.

5.1.1 Sample bottle, amber glass, 1.1 liters minimum. If amber bottles are not available, samples shall be protected from light. Bottles are detergent water washed, then solvent rinsed or baked at 450 °C for one hour minimum before use.

5.1.2 Bottle caps—threaded to fit sample bottles. Caps are lined with Teflon. Aluminum foil may be substituted if the sample is not corrosive. Liners are detergent water washed, then reagent water (Section 6.5) and solvent rinsed, and baked at approximately 200 °C for one hour minimum before use.

5.1.3 Compositing equipment—automatic or manual compositing system incorporating glass containers for collection of a minimum 1.1 liters. Sample containers are kept at 0 to 4 °C during sampling. Glass or Teflon tubing only shall be used. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used in the pump only. Before use, the tubing is thoroughly rinsed with methanol, followed by repeated rinsings with reagent water (Section 6.5) to minimize sample contamination. An integrating flow meter is used to collect proportional composite samples.

5.2 Continuous liquid-liquid extractor—Teflon or glass conncecting joints and stopcocks without lubrication (Hershberg-Wolf Extractor) one liter capacity, Ace Glass 6841–10, or equivalent.

5.3 Drying column—15 to 20 mm i.d. Pyrex chromatographic column equipped with coarse glass frit or glass wool plug.

5.4 Kuderna-Danish (K–D) apparatus

5.4.1 Concentrator tube—10mL, graduated (Kontes K–570050–1025, or equivalent) with calibration verified. Ground glass stopper (size 19/22 joint) is used to prevent evaporation of extracts.

5.4.2 Evaporation flask—500 mL (Kontes K–570001–0500, or equivalent), attached to concentrator tube with springs (Kontes K–662750–0012).

5.4.3 Snyder column—three ball macro (Kontes K–503000–0232, or equivalent).

5.4.4 Snyder column—two ball micro (Kontes K–469002–0219, or equivalent).

5.4.5 Boiling chips—approx 10/40 mesh, extracted with methylene chloride and baked at 450 °C for one hr minimum.

5.5 Water bath—heated, with concentric ring cover, capable of temperature control ±2 °C, installed in a fume hood.

5.6 Sample vials—amber glass, 2–5 mL with Teflon-lined screw cap.

5.7 Analytical balance—capable of weighing 0.1 mg.

5.8 Gas chromatograph—shall have splitless or on-column injection port for capillary column, temperature program with 30 °C hold, and shall meet all of the performance specifications in Section 12.

5.8.1 Column—30±5 m×0.25±0.02 mm i.d. 5% phenyl, 94% methyl, 1% vinyl silicone bonded phase fused silica capillary column (J & W DB–5, or equivalent).

5.9 Mass spectrometer—70 eV electron impact ionization, shall repetitively scan from 35 to 450 amu in 0.95 to 1.00 second, and shall produce a unit resolution (valleys between m/z 441–442 less than 10 percent of the height of the 441 peak), backgound corrected mass spectrum from 50 ng decafluorotriphenylphosphine (DFTPP) introduced through the GC inlet. The spectrum shall meet the mass-intensity criteria in Table 5 (reference 5). The mass spectrometer shall be interfaced to the GC such that the end of the capillary column terminates within one centimeter of the ion source but does not intercept the electron or ion beams. All portions of the column which connect the GC to the ion source shall remain at or above the column temperature during analysis to preclude condensation of less volatile compounds.

5.10 Data system—shall collect and record MS data, store mass-intensity data in spectral libraries, process GC/MS data, generate reports, and shall compute and record response factors.

5.10.1 Data acquisition—mass spectra shall be collected continuously throughout the analysis and stored on a mass storage device.

5.10.2 Mass spectral libraries—user created libraries containing mass spectra obtained from analysis of authentic standards shall be employed to reverse search GC/MS runs for the compounds of interest (Section 7.2).

5.10.3 Data processing—the data system shall be used to search, locate, identify, and quantify the compounds of interest in each GC/MS analysis. Software routines shall be employed to compute retention times and peak areas. Displays of spectra, mass chromatograms, and library comparisons are required to verify results.

5.10.4 Response factors and multipoint calibrations—the data system shall be used to record and maintain lists of response factors (response ratios for isotope dilution) and multipoint calibration curves (Section 7). Computations of relative standard deviation (coefficient of variation) are useful for testing calibration linearity. Statistics on initial (Section 8.2) and on-going (Section 12.7) performance shall be computed and maintained.

6. Reagents and Standards

6.1 Sodium hydroxide—reagent grade, 6N in reagent water.

6.2 Sulfuric acid—reagent grade, 6N in reagent water.

6.3 Sodium sulfate—reagent grade, granular anhydrous, rinsed with methylene chloride (20 mL/g) and conditioned at 450 °C for one hour minimum.

6.4 Methylene chloride—distilled in glass (Burdick and Jackson, or equivalent).

6.5 Reagent water—water in which the compounds of interest and interfering compounds are not detected by this method.

6.6 Standard solutions—purchased as solutions or mixtures with certification to their purity, concentration, and authenticity, or prepared from materials of known purity and composition. If compound purity is 96 percent or greater, the weight may be used without correction to compute the concentration of the standard. When not being used, standards are stored in the dark at −20 to −10 °C in screw-capped vials with Teflon-lined lids. A mark is placed on the vial at the level of the solution so that solvent evaporation loss can be detected. The vials are brought to room temperature prior to use. Any precipitate is redissolved and solvent is added if solvent loss has occurred.

6.7 Preparation of stock solutions—prepare in methylene chloride, benzene, p-dioxane, or a mixture of these solvents per the steps below. Observe the safety precautions in Section 4. The large number of labeled and unlabeled acid, base/neutral, and Appendix C compounds used for combined calibration (Section 7) and calibration verification (12.5) require high

concentratimns (approx 40 mg/mL) when individual stock solutions are prepared, so that dilutions of mixtures will permit calibration with all compounds in a single set of solutions. The working range for most compounds is 10–200 µg/mL. Compounds with a reduced MS response may be prepared at higher concentrations.

6.7.1 Dissolve an appropriate amount of assayed reference material in a suitable solvent. For example, weigh 400 mg naphthalene in a 10 mL ground glass stoppered volumetric flask and fill to the mark with benzene. After the naphthalene is completely dissolved, transfer the solution to a 15 mL vial with Teflon-lined cap.

6.7.2 Stock standard solutions should be checked for signs of degradation prior to the preparation of calibration or performance test standards. Quality control check samples that can be used to determine the accuracy of calibration standards are available from the US Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268.

6.7.3 Stock standard solutions shall be replaced after six months, or sooner if comparison with quality control check samples indicates a change in concentration.

6.8 Labeled compound spiking solution—from stock standard solutions prepared as above, or from mixtures, prepare the spiking solution at a concentration of 200 µg/mL, or at a concentration appropriate to the MS response of each compound.

6.9 Secondary standard—using stock solutions (Section 6.7), prepare a secondary standard containing all of the compounds in Tables 1 and 2 at a concentration of 400 µg/mL, or higher concentration appropriate to the MS response of the compound.

6.10 Internal standard solution—prepare 2,2′-difluorobiphenyl (DFB) at a concentration of 10 mg/mL in benzene.

6.11 DFTPP solution—prepare at 50 µg/mL in acetone.

6.12 Solutions for obtaining authentic mass spectra (Section 7.2)—prepare mixtures of compounds at concentrations which will assure authentic spectra are obtained for storage in libraries.

6.13 Calibration solutions—combine 0.5 mL of the solution in Section 6.8 with 25, 50, 125, 250, and 500 uL of the solution in section 6.9 and bring to 1.00 mL total volume each. This will produce calibration solutions of nominal 10, 20, 50, 100, and 200 µg/mL of the pollutants and a constant nominal 100 µg/mL of the labeled compounds. Spike each solution with 10 µL of the internal standard solution (Section 6.10). These solutions permit the relative response (labeled to unlabeled) to be measured as a function of concentration (Section 7.4).

6.14 Precision and recovery standard—used for determination of initial (Section 8.2) and on-going (Section 12.7) precision and recovery. This solution shall contain the pollutants and labeled compounds at a nominal concentration of 100 µg/mL.

6.15 Stability of solutions—all standard solutions (Sections 6.8–6.14) shall be analyzed within 48 hours of preparation and on a monthly basis thereafter for signs of degradation. Standards will remain acceptable if the peak area at the quantitation mass relative to the DFB internal standard remains within ±15 percent of the area obtained in the initial analysis of the standard.

7. Calibration

7.1 Assemble the GC/MS and establish the operating conditions in Table 3. Analyze standards per the procedure in Section 11 to demonstrate that the analytical system meets the detection limits in Tables 3 and 4, and the mass-intensity criteria in Table 5 for 50 ng DFTPP.

7.2 Mass spectral libraries—detection and identification of compounds of interest are dependent upon spectra stored in user created libraries.

7.2.1 Obtain a mass spectrum of each pollutant, labeled compound, and the internal standard by analyzing an authentic standard either singly or as part of a mixture in which there is no interference between closely eluted components. That only a single compound is present is determined by examination of the spectrum. Fragments not attributable to the compound under study indicate the presence of an interfering compound.

7.2.2 Adjust the analytical conditions and scan rate (for this test only) to produce an undistorted spectrum at the GC peak maximum. An undistorted spectrum will usually be obtained if five complete spectra are collected across the upper half of the GC peak. Software algorithms designed to ''enhance'' the spectrum may eliminate distortion, but may also eliminate authentic masses or introduce other distortion.

7.2.3 The authentic reference spectrum is obtained under DFTPP tuning conditions (Section 7.1 and Table 5) to normalize it to spectra from other instruments.

7.2.4 The spectrum is edited by saving the 5 most intense mass spectral peaks and all other mass spectral peaks greater than 10 percent of the base peak. This edited spectrum is stored for reverse search and for compound confirmation.

7.3 Analytical range—demonstrate that 20 ng anthracene or phenanthrene produces an area at m/z 178 approx one-tenth that required to exceed the linear range of the system. The exact value must be determined by experience for each instrument. It is used to match the calibration range of the instrument to the analytical range and detection limits required, and to diagnose instrument sensitivity problems (Section 15.4). The 20 ug/mL calibration standard (Section 6.13) can be used to demonstrate this performance.

7.3.1 Polar compound detection—demonstrate that unlabeled pentachlorophenol and benzidine are detectable at the 50 µg/mL level (per all criteria in Section 13). The 50 µg/mL calibration standard (Section 6.13) can be used to demonstrate this performance.

7.4 Calibration with isotope dilution—isotope dilution is used when (1) labeled compounds are available, (2) interferences do not preclude its use, and (3) the quantitation mass extracted ion current profile (EICP) area for the compound is in the calibration range. If any of these conditions preclude isotope dilution, internal standard methods (Section 7.5 or 7.6) are used.

7.4.1 A calibration curve encompassing the concentration range is prepared for each compound to be determined. The relative response (pollutant to labeled) vs concentration in standard solutions is plotted or computed using a linear regression. The example in Figure 1 shows a calibration curve for phenol using phenol-d5 as the isotopic diluent. Also shown are the ± 10 percent error limits (dotted lines). Relative Reponse (RR) is determined according to the procedures described below. A minimum of five data points are employed for calibration.

7.4.2 The relative response of a pollutant to its labeled analog is determined from isotope ratio values computed from acquired data. Three isotope ratios are used in this process:

R_x = the isotope ratio measured for the pure pollutant.

R_y = the isotope ratio measured for the labeled compound.

R_m = the isotope ratio of an analytical mixture of pollutant and labeled compounds.

The m/z's are selected such that $R_x > R_y$. If R_m is not between $2R_y$ and $0.5R_x$, the method does not apply and the sample is analyzed by internal or external standard methods.

7.4.3 Capillary columns usually separate the pollutant-labeled pair, with the labeled compound eluted first (Figure 2). For this case, R_x = [area m_1/z]/1, at the retention time of the pollutant (RT_2). R_y = 1/[area m_2/z, at the retention time of the labeled compound RT_1). R_m = [area at m_1/z (at RT_2)]/[area at RT_1)], as measured in the mixture of the pollutant and labeled compounds (Figure 2), and $RR = R_m$.

7.4.4 Special precautions are taken when the pollutant-labeled pair is not separated, or when another labeled compound with interfering spectral masses overlaps the pollutant (a case which can occur with isomeric compounds). In this case, it is necessary to determine the respective contributions of the pollutant and labeled compounds to the respective EICP areas. If the peaks are separated well enough to permit the data system or operator to remove the contributions of the compounds to each other, the equations in Section 7.4.3 apply. This usually occurs when the height of the valley between the two GC peaks at the same m/z is less than 10 percent of the height of the shorter of the two peaks. If significant GC and spectral overlap occur, RR is computed using the following equation:

$RR = (R_y - R_m)(R_x + 1)/(R_m - R_x)(R_y + 1)$, where R_x is measured as shown in Figure 3A, R_y is measured as shown in Figure 3B, and R_m is measured as shown in Figure 3C. For example, R_x = 46100/4780 = 9.644, R_y = 2650/43600 = 0.0608, R_m = 49200/48300 = 1.019. amd RR = 1.114.

7.4.5 To calibrate the analytical system by isotope dilution, analyze a 1.0 µL aliquot of each of the calibration standards (Section 6.13) using the procedure in Section 11. Compute the RR at each concentration.

7.4.6 Linearity—if the ratio of relative response to concentration for any compound is constant (less than 20 percent coefficient of variation) over the 5 point calibration range, and averaged relative response/concentration ratio may be used for that compound; otherwise, the complete calibration curve for that compound shall be used over the 5 point calibration range.

7.5 Calibration by internal standard—used when criteria for istope dilution (Section 7.4) cannot be met. The internal standard to be used for both acid and base/neutral analyses is 2,2'–difluorobiphenyl. The internal standard method is also applied to determination of compounds having no labeled analog, and to measurement of labeled compounds for intra-laboratory statistics (Sections 8.4 and 12.7.4).

7.5.1 Response factors—calibration requires the determination of response factors (RF) which are defined by the following equation:

$RF = (A_s \times C_{is})/(A_{is} \times C_s)$, where

A_s is the area of the characteristic mass for the compmund in the daily standard

A_{is} is the area of the characteristic mass for the internal standard

C_{is} is the concentration of the internal standard (µg/mL)

C_s is the concentration of the compound in the daily standard (µg/mL)

7.5.1.1 The response factor is determined for at least five concentrations appropriate to the response of each compound (Section 6.13); nominally, 10, 20, 50, 100, and 200 µg/mL. The amount of internal standard added to each extract is the same (100 µg/mL) so that C_{is} remains constant. The RF is plotted vs concentration for each compound in the standard (C_s) to produce a calibration curve.

7.5.1.2 Linearity—if the response factor (RF) for any compound is constant (less than 35 percent coefficient of variation) over the 5 point calibration range, an averaged response factor may be used for that compound; otherwise, the complete calibration

curve for that compound shall be used over the 5 point range.

7.6 Combined calibration—by using calibration solutions (Section 6.13) containing the pollutants, labeled compounds, and the internal standard, a single set of analyses can be used to produce calibration curves for the isotope dilution and internal standard methods. These curves are verified each shift (Section 12.5) by analyzing the 100 θg/mL calibration standard (Section 6.13). Recalibration is required only if calibration verification (Section 12.5) criteria cannot be met.

8. Quality Assurance/Quality Control

8.1 Each laboratory that uses this method is required to operate a formal quality assurance program. The minimum requirements of this program consist of an initial demonstration of laboratory capability, analysis of samples spiked with labeled compounds to evaluate and document data quality, and analysis of standards and blanks as tests of continued performance. Laboratory performance is compared to established performance criteria to determine if the results of analyses meet the performance characteristics of the method.

8.1.1 The analyst shall make an initial demonstration of the ability to generate acceptable accuracy and precision with this method. This ability is established as described in Section 8.2.

8.1.2 The analyst is permitted to modify this method to improve separations or lower the costs of measurements, provided all performance specifications are met. Each time a modification is made to the method, the analyst is required to repeat the procedure in Section 8.2 to demonstrate method performance.

8.1.3 Analyses of blanks are required to demonstrate freedom from contamination. The procedures and criteria for analysis of a blank are described in Section 8.5.

8.1.4 The laboratory shall spike all samples with labeled compounds to monitor method performance. This test is described in Section 8.3. When results of these spikes indicate atypical method performance for samples, the samples are diluted to bring method performance within acceptable limits (Section 15).

8.1.5 The laboratory shall, on an on-going basis, demonstrate through calibration verification and the analysis of the precision and recovery standard (Section 6.14) that the analysis system is in control. These procedures are described in Sections 12.1, 12.5, and 12.7.

8.1.6 The laboratory shall maintain records to define the quality of data that is generated. Development of accuracy statements is described in Section 8.4.

8.2 Initial precision and accuracy—to establish the ability to generate acceptable precision and accuracy, the analyst shall perform the following operations:

8.2.1 Extract, concentrate, and analyze two sets of four one-liter aliquots (8 aliquots total) of the precision and recovery standard (Section 6.14) according to the procedure in Section 10.

8.2.2 Using results of the first set of four analyses, compute the average recovery ($\bar{X}$) in μg/mL and the standard deviation of the recovery (s) in θg/μL for each compound, by isotope dilution for pollutants with a labeled analog, and by internal standard for labeled compounds and pollutants with no labeled analog.

8.2.3 For each compound, compare s and $\bar{X}$ with the corresponding limits for initial precision and accuracy in Table 8. If s and $\bar{X}$ for all compounds meet the acceptance criteria, system performance is acceptable and analysis of blanks and samples may begin. If, however, any individual s exceeds the precision limit or any individual X falls outside the range for accuracy, system performance is unacceptable for that compound.

NOTE: The large number of compounds in Table 8 present a substantial probability that one or more will fail the acceptance criteria when all compounds are analyzed. To determine if the analytical system is out of control, or if the failure can be attributed to probability, proceed as follows:

8.2.4 Using the results of the second set of four analyses, compute s and $\bar{X}$ for only those compounds which failed the test of the first set of four analyses (Section 8.2.3). If these compounds now pass, system performance is acceptable for all compounds and analysis of blanks and samples may begin. If, however, any of the same compoulds fail again, the analysis system is not performing properly for these compounds. In this event, correct the problem and repeat the entire test (Section 8.2.1).

8.3 The laboratory shall spike all samples with labeled compounds to assess method performance on the sample matrix.

8.3.1 Analyze each sample according to the method in Section 10.

8.3.2 Compute the percent recovery (P) of the labeled compounds using the internal standard methmd (Section 7.5).

8.3.3 Compare the labeled compound recovery for each compound with the corresponding limits in Table 8. If the recovery of any compounds falls outside its warning limit, method performance is unacceptable for that compound in that sample, Therefore, the sample is complex and is to be diluted and reanalyzed per Section 15.4.

8.4 As part of the QA program for the laboratory, method accuracy for wastewater samples shall be assessed and records shall be maintained. After the analysis of five wastewater samples for which the labeled compounds pass the tests in Section 8.3, compute the average percent recovery (P)

and the standard deviation of the percent recovery (s_p) for the labeled compounds only. Express the accuracy assessment as a percent recovery interval from P—2 $_{sp}$ to P+2$_{sp}$. For example, if P=90% and s_p=10%, the accuracy interval is expressed as 70–100%. Update the accuracy assessment for each compound on a regular basis (e.g. after each 5–10 new accuracy measurements).

8.5 Blanks—reagent water blanks are analyzed to demonstrate freedom from contamination.

8.5.1 Extract and concentrate a blank with each sample lot (samples started through the extraction process on the same 8 hr shift, to a maximum of 20 samples). Analyze the blank immediately after analysis of the precision and recovery standard (Section 6.14) to demonstrate freedom from contamination.

8.5.2 If any of the compounds of interest (Tables 1 and 2) or any potentially interfering compound is found in a blank at greater than 10 µg/L (assuming a response factor of 1 relative to the internal standard for compounds not listed in Tables 1 and 2), analysis of samples is halted until the source of contamination is eliminated and a blank shows no evidence of contamination at this level.

8.6 The specifications contained in this method can be met if the apparatus used is calibrated properly, then maintained in a calibrated state. The standards used for calibration (Section 7), calibration verification (Section 12.5), and for initial (Section 8.2) and on-going (Section 12.7) precision and recovery should be identical, so that the most precise results will be obtained. The GC/MS instrument in particular will provide the most reproducible results if dedicated to the settings and conditions required for the analysis of semi-volatiles by this method.

8.7 Depending on specific program requirements, field replicates may be collected to determine the precision of the sampling technique, and spiked samples may be required to determine the accuracy of the analysis when internal or external standard methods are used.

9. Sample Collection, Preservation, and Handling

9.1 Collect samples in glass containers following conventional sampling practices (Reference 7). Composite samples are collected in refrigerated glass containers (Section 5.1.3) in accordance with the requirements of the sampling program.

9.2 Maintain samples at 0–4 °C from the time collectimn until extraction. If residual chlorine is present, add 80 mg sodium thiosulfate per liter of water. EPA Methods 330.4 and 330.5 may be used to measure residual chlorine (Reference 8).

9.3 Begin sample extraction within seven days of collection, and analyze all extracts within 40 days of extraction.

10. Sample Extraction and Concentration (See Figure 4)

10.1 Labeled compound spiking—measure 1.00 ± 0.01 liter of sample into a glass container. For untreated effluents, and samples which are expected to be difficult to extract and/or concentrate, measure an additional 10.0 ± 0.1 mL and dilute to a final volume of 1.00 ± 0.01 liter with reagent water in a glass container.

10.1.1 For each sample or sample lot (to a maximum of 20) to be extracted at the same time, place three 1.00 ± 0.10 liter aliquots of reagent water in glass containers.

10.1.2 Spike 0.5 mL of the labeled compound spiking solution (Section 6.8) into all samples and one reagant water aliquot.

10.1.3 Spike 1.0 mL of the precision and recovery standard (Section 6.14) into the two remaining reagent water aliquots.

10.1.4 Stir and equilibrate all solutions for 1–2 hr.

10.2 Base/neutral extraction—place 100–150 mL methylene chloride in each continuous extractor and 200–300 in each distilling flask.

10.2.1 Pour the sample(s), blank, and standard aliquots into the extractors. Rinse the glass containers with 50–100 mL methylene chloride and add to the respective extractor.

10.2.2 Adjust the pH of the waters in the extractors to 12–13 with 6N NaOH while monitoring with a pH meter. Begin the extraction by heating the flask until the methylene chloride is boiling. When properly adjusted, 1–2 drops of methylene chloride per second will fall from the condensor tip into the water. After 1–2 hours of extraction, test the pH and readjust to 12–13 if required. Extract for 18–24 hours.

10.2.3 Remove the distilling flask, estimate and record the volume of extract (to the nearest 100 mL), and pour the contents through a drying column containing 7 to 10 cm anhydrous sodium sulfate. Rinse the distilling flask with 30–50 mL of methylene chloride and pour through the drying column. Collect the solution in a 500 mL K–D evaporator flask equipped with a 10 mL concentrator tube. Seal, label as the base/neutral fraction, and concentrate per Sections 10.4 to 10.5.

10.3 Acid extraction—adjust the pH of the waters in the extractors to 2 or less using 6N sulfuric acid. Charge clean distilling flasks with 300–400 mL of methylene chloride. Test and adjust the pH of the waters after the first 1–2 hr of extraction. Extract for 18–24 hours.

10.3.1 Repeat Section 10.2.3, except label as the acid fraction.

10.4 Concentration—concentrate the extracts in separate 500 mL K–D flasks equipped with 10 mL concentrator tubes.

10.4.1 Add 1 to 2 clean boiling chips to the flask and attach a three-ball macro Snyder column. Prewet the column by adding approximately one mL of methylene chloride through the top. Place the K–D apparatus in a hot water bath so that the entire lower rounded surface of the flask is bathed with steam. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in 15 to 20 minutes. At the proper rate of distillation, the balls of the column will actively chatter but the chambers will not flood. When the liquid has reached an apparent volume of 1 mL, remove the K–D apparatus from the bath and allow the solvent to drain and cool for at least 10 minutes. Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 1–2 mL of methylene chloride. A 5-mL syringe is recommended for this operation.

10.4.2 For performance standards (Sections 8.2 and 12.7) and for blanks (Section 8.5), combine the acid and base/neutral extracts for each at this point. Do not combine the acid and base/neutral extracts for samples.

10.5 Add a clean boiling chip and attach a two ball micro Snyder column to the concentrator tube. Prewet the column by adding approx 0.5 mL methylene chloride through the top. Place the apparatus in the hot water bath. Adjust the vertical position and the water temperature as required to complete the concentration in 5–10 minutes. At the proper rate of distillation, the balls of the column will actively chatter but the chambers will not flood. When the liquid reaches an apparent volume of approx 0.5 mL, remove the apparatus from the water bath and allow to drain and cool for at least 10 minutes. Remove the micro Snyder column and rinse its lower joint into the concentrator tube with approx 0.2 mL of methylene chloride. Adjust the final volume to 1.0 mL.

10.6 Transfer the concentrated extract to a clean screw-cap vial. Seal the vial with a Teflon-lined lid, and mark the level on the vial. Label with the sample number and fraction, and store in the dark at −20 to −10 °C until ready for analysis.

11. GC/MS Analysis

11.1 Establish the operating conditions given in Table 3 or 4 for analysis of the base/neutral or acid extracts, respectively. For analysis of combined extracts (Section 10.4.2), use the operating conditions in Table 3.

11.2 Bring the concentrated extract (Section 10.6) or standard (Sections 6.13 through 6.14) to room temperature and verify that any precipitate has redissolved. Verify the level on the extract (Sections 6.6 and 10.6) and bring to the mark with solvent if required.

11.3 Add the internal standard solution (Section 6.10) to the extract (use 1.0 uL of solution per 0.1 mL of extract) immediately prior to injection to minimize the possibility of loss by evaporation, adsorption, or reaction. Mix thoroughly.

11.4 Inject a volume of the standard solution or extract such that 100 ng of the internal standard will be injected, using on-column or splitless injection. For 1 mL extracts, this volume will be 1.0 uL. Start the GC column initial isothermal hold upon injection. Start MS data collection after the solvent peak elutes. Stop data collection after the benzo (ghi) perylene or pentachlorophenol peak elutes for the base/neutral or acid fraction, respectively. Return the column to the initial temperature for analysis of the next sample.

12. System and Laboratory Performance

12.1 At the beginning of each 8 hr shift during which analyses are performed, GC/MS system performance and calibration are verified for all pollutants and labeled compounds. For these tests, analysis of the 100 µg/mL calibration standard (Section 6.13) shall be used to verify all performance criteria. Adjustment and/or recalibration (per Section 7) shall be performed until all performance criteria are met. Only after all performance criteria are met may samples, blanks, and precision and recovery standards be analyzed.

12.2 DFTPP spectrum validity—inject 1 µL of the DFTPP solution (Section 6.11) either separately or within a few seconds of injection of the standard (Section 12.1) analyzed at the beginning of each shift. The criteria in Table 5 shall be met.

12.3 Retention times—the absolute retention time of 2,2′-difluorobiphenyl shall be within the range of 1078 to 1248 seconds and the relative retention times of all pollutants and labeled compounds shall fall within the limits given in Tables 3 and 4.

12.4 GC resolution—the valley height between anthracene and phenanthrene at m/z 178 (or the analogs at m/z 188) shall not exceed 10 percent of the taller of the two peaks.

12.5 Calibration verification—compute the concentration of each pollutant (Tables 1 and 2) by isotope dilution (Section 7.4) for those compounds which have labeled analogs. Compute the concentration of each pollutant which has no labeled analog by the internal standard method (Section 7.5). Compute the concentration of the labeled compounds by the internal standard method. These concentrations are computed based on the calibration data determined in Section 7.

12.5.1 For each pollutant and labeled compound being tested, compare the concentration with the calibration verification limit

in Table 8. If all compounds meet the acceptance criteria, calibration has been verified and analysis of blanks, samples, and precision and recovery standards may proceed. If, however, any compound fails, the measurement system is not performing properly for that compound. In this event, prepare a fresh calibration standard or correct the problem causing the failure and repeat the test (Section 12.1), or recalibrate (Section 7).

12.6 Multiple peaks—each compound injected shall give a single, distinct GC peak.

12.7 On-going precision and accuracy.

12.7.1 Analyze the extract of one of the pair of precision and recovery standards (Section 10.1.3) prior to analysis of samples from the same lot.

12.7.2 Compute the concentration of each pollutant (Tables 1 and 2) by isotope dilution (Section 7.4) for those compounds which have labeled analogs. Compute the concentration of each pollutant which has no labeled analog by the internal standard method (Section 7.5). Compute the concentration of the labeled compounds by the internal standard method.

12.7.3 For each pollutant and labeled compound, compare the concentration with the limits for on-going accuracy in Table 8. If all compounds meet the acceptance criteria, system performance is acceptable and analysis of blanks and samples may proceed. If, however, any individual concentration falls outside of the range given, system performance is unacceptable for that compound.

NOTE: The large number of compounds in Table 8 present a substantial probability that one or more will fail when all compounds are analyzed. To determine if the extraction/concentration system is out of control or if the failure is caused by probability, proceed as follows:

12.7.3.1 Analyze the second aliquot of the pair of precision and recovery standard (Section 10.1.3).

12.7.3.2 Compute the concentration of only those pollutants or labeled compounds that failed the previous test (Section 12.7.3). If these compounds now pass, the extraction/concentration processes are in control and analysis of blanks and samples may proceed. If, however, any of the same compounds fail again, the extraction/concentration processes are not being performed properly for these compounds. In this event, correct the problem, re-extract the sample lot (Section 10) and repeat the on-going precision and recovery test (Section 12.7).

12.7.4 Add results which pass the specifications in Section 12.7.2 to initial and previous on-going data. Update QC charts to perform a graphic representation of continued laboratory performance (Figure 5). Develop a statement of laboratory accuracy for each pollutant and labeled compound by calculating the average percent recovery (R) and the standard deviation of percent recovery (s_r). Express the accuracy as a recovery interval from $R-2s_r$ to $R+2s_r$. For example, if $R=95\%$ and $s_r=5\%$, the accuracy is $85-105\%$.

13. Qualitative Determination

13.1 Qualititative determination is accomplished by comparison of data from analysis of a sample or blank with data from analysis of the shift standard (Section 12.1) and with data stored in the spectral libraries (Section 7.2.4). Identification is confirmed when spectra and retention times agree per the criteria below.

13.2 Labeled compounds and pollutants having no labeled analog:

13.2.1 The signals for all characteristic masses stored in the spectral library (Section 7.2.4) shall be present and shall maximize within the same two consecutive scans.

13.2.2 Either (1) the background corrected EICP areas, or (2) the corrected relative intensities of the mass spectral peaks at the GC peak maximum shall agree within a factor of two (0.5 to 2 times) for all masses stored in the library.

13.2.3 The retention time relative to the nearest eluted internal standard shall be within ±15 scans or ±15 seconds, whichever is greater of this difference in the shift standard (Section 12.1).

13.3 Pollutants having a labled analog:

13.3.1 The signals for all characteristic masses stored in the spectral library (Section 7.2.4) shall be present and shall maximize within the same two consecutive scans.

13.3.2. Either (1) the background corrected EICP areas, or (2) the corrected relative intensities of the mass spectral peaks at the GC peak maximum shall agree within a factor of two for all masses stored in the spectral library.

13.3.3. The retention time difference between the pollutant and its labeled analog shall agree within ± 6 scans or ± 6 seconds (whichever is greater) of this difference in the shift standard (Section 12.1).

13.4 Masses present in the experimental mass spectrum that are not present in the reference mass spectrum shall be accounted for by contaminant or background ions. If the experimental mass spectrum is contaminated, an experienced spectrometrist (Section 1.4) is to determine the presence or absence of the cmmpound.

14. Quantitative Determination

14.1 Isotope dilution—by adding a known amount of a labeled compound to every sample prior to extraction, correction for recovery of the pollutant can be made because the pollutant and its labeled analog exhibit the same effects upon extraction, concentration, and gas chromatography. Relative response (RR) values for mixtures are used in conjunction with calibration curves described in

Section 7.4 to determine concentrations directly, so long as labeled compound spiking levels are constant. For the phenml example given in Figure 1 (Section 7.4.1), RR would be equal to 1.114. For this RR value, the phenol calibration curve given in Figure 1 indicates a concentration of 27 µg/mL in the sample extract (C_{ex}).

14.2 Internal standard—compute the concentration in the extract using the response factor determined from calibration data (Section 7.5) and the following equation: $C_{ex}(\mu g/mL)=(A_s \times C_{is}/(A_{is} \times RF)$ where C_{ex} is the concentration of the compound in the extract, and the other terms are as defined in Section 7.5.1.

14.3 The concentration of the pollutant in water is computed using the volumes of the original water sample (Section 10.1) and the final extract volume (Section 10.5), as follows: Concentration in water $(\mu g/L)=(C_{ex} \times V_{ex})/V_s$ where V_{ex} is the extract volume in mL, and V_s is the sample volume in liters.

14.4 If the EICP area at the quantitiation mass for any compound exceeds the calibration range of the system, the extract of the dilute aliquot (Section 10.1) is analyzed by isotope dilution; otherwise, the extract is diluted by a factor of 10, 9 µL of internal standard solution (Section 6.10) are added to a 1.0 mL aliquot, and this diluted extract is analyzed by the internal standard method (Section 14.2). Quantify each compound at the highest concentration level within the calibration range.

14.5 Report results for all pollutants and labeled compounds (Tables 1 and 2) found in all standards, blanks, and samples in µg/L, to three significant figures. Results for samples which have been diluted are reported at the least dilute level at which the area at the quantitation mass is within the calibration range (Section 14.4) and the labeled compound recovery is within the normal range for the method (Section 15.4).

15. Analysis of Complex Samples

15.1 Untreated effluents and other samples frequently contain high levels (>1000 µg/L) of the compounds of interest, interfering compounds, and/or polymeric materials. Some samples will not concentrate to one mL (Section 10.5); others will overload the GC column and/or mass spectrometer.

15.2 Analyze the dilute aliquot (Section 10.1) when the sample will not concentrate to 1.0 mL. If a dilute aliquot was not extracted, and the sample holding time (Section 9.3) has not been exceeded, dilute an aliquot of the sample with reagent water and re-extract (Section 10.1); otherwise, dilute the extract (Section 14.4) and analyze by the internal standard method (Section 14.2).

15.3 Recovery of internal standard— the EICP area of the internal standard should be within a factor of two of the area in the shift standard (Section 12.1). If the absolute areas of the labeled compounds are within a factor of two of the respective areas in the shift standard, and the internal standard area is less than one-half of its respective area, then internal standard loss in the extract has occurred. In this case, use one of the labeled compounds (perferably a polynuclear aromatic hydrocarbon) to compute the concentration of a pollutant with no labeled analog.

15.4 Recovery of labeled compounds— in most samples, labeled compound recoveries will be similar to those from reagent water (Section 12.7). If the labeled compound recovery is outside the limits given in Table 8, the dilute extract (Section 10.1) is analyzed as in Section 14.4. If the recoveries of all labeled compounds and the internal staldard are low (per the criteria above), then a loss in instrument sensitivity is the most likely cause. In this case, the 100 µg/mL calibration standard (Section 12.1) shall be analyzed and calibration verified (Section 12.5). If a loss in sensitivity has occurred, the instrument shall be repaired, the performance specifications in Section 12 shall be met, and the extract reanalyzed. If a loss in instrument sensitivity has not occurred, the method does not work on the sample being analyzed and the result may not be reported for regulatory compliance purposes.

16. Method Performance

16.1 Interlaboratory performance for this method is detailed in references 9 and 10.

16.2 A chromatogram of the 100 µg/mL acid/base/neutral calibration standard (Section 6.13) is shown in Figure 6.

References

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4. ''Safety in Academic Chemistry Laboratories, '' ACS Committee on Chemical Safety (1979).

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6. ''Handbook of Analytical Quality Control in Water and Wastewater Laboratories,'' USEPA, EMSL/Cincinnati, OH 45268, EPA–600/4–79–019 (March 1979).

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8. ''Methods 330.4 and 330.5 for Total Residual Chlorine,'' USEPA, EMSL/ Cincinnati, OH 45268, EPA 600/4–70–020 (March 1979).

9. Colby, B.N., Beimer, R.G., Rushneck, D.R., and Telliard, W.A., ''Isotope Dilution Gas Chromatography-Mass Spectrometry for the determination of Priority Pollutants in Industrial Effluents.'' USEPA, Effluent Guidelines Division, Washington, DC 20460 (1980).

10. ''Inter-laboratory Validation of US Environmental Protection Agency Method 1625,'' USEPA, Effluent Guidelines Division, Washington, DC 20460 (June 15, 1984).

TABLE 1—BASE/NEUTRAL EXTRACTABLE COMPOUNDS

Compound	STORET	CAS registry	EPA-EGD	NPDES
Acenaphthene	34205	83–32–9	001 B	001 B
Acenaphthylene	34200	208–96–8	077 B	002 B
Anthracene	34220	120–12–7	078 B	003 B
Benzidine	39120	92–87–5	005 B	004 B
Benzo(a)anthracene	34526	56–55–3	072 B	005 B
Benzo(b)fluoranthene	34230	205–99–2	074 B	007 B
Benzo(k)fluoranthene	34242	207–08–9	075 B	009 B
Benzo(a)pyrene	34247	50–32–8	073 B	006 B
Benzo(ghi)perylene	34521	191–24–2	079 B	008 B
Biphenyl (Appendix C)	81513	92–52–4	512 B	.....
Bis(2-chloroethyl) ether	34273	111–44–4	018 B	011 B
Bis(2-chloroethyoxy)methane	34278	111–91–1	043 B	010 B
Bis(2-chloroisopropyl) ether	34283	108–60–1	042 B	012 B
Bis(2-ethylhexyl) phthalate	39100	117–81–7	066 B	013 B
4-bromophenyl phenyl ether	34636	101–55–3	041 B	014 B
Butyl benzyl phthalate	34292	85–68–7	067 B	015 B
n-C10 (Appendix C)	77427	124–18–5	517 B	.....
n-C12 (Appendix C)	77588	112–40–2	506 B	.....
n-C14 (Appendix C)	77691	629–59–4	518 B	.....
n-C16 (Appendix C)	77757	544–76–3	519 B	.....
n-C18 (Appendix C)	77804	593–45–3	520 B	.....
n-C20 (Appendix C)	77830	112–95–8	521 B	.....
n-C22 (Appendix C)	77859	629–97–0	522 B	.....
n-C24 (Appendix C)	77886	646–31–1	523 B	.....
n-C26 (Appendix C)	77901	630–01–3	524 B	.....
n-C28 (Appendix C)	78116	630–02–4	525 B	.....
n-C30 (Appendix C)	78117	638–68–6	526 B	.....
Carbazole (4c)	77571	86–74–8	528 B	.....
2-chloronaphthalene	34581	91–58–7	020 B	016 B
4-chlorophenyl phenyl ether	34641	7005–72–3	040 B	017 B
Chrysene	34320	218–01–9	076 B	018 B
P-cymene (Appendix C)	77356	99–87–6	513 B	.....
Dibenzo(a,h)anthracene	34556	53–70–3	082 B	019 B
Dibenzofuran (Appendix C and 4c)	81302	132–64–9	505 B	.....
Dibenzothiophene (Synfuel)	77639	132–65–0	504 B	.....
Di-n-butyl phthalate	39110	84–74–2	068 B	026 B
1,2-dichlorobenzene	34536	95–50–1	025 B	020 B
1,3-dichlorobenzene	34566	541–73–1	026 B	021 B
1,4-dichlorobenzene	34571	106–46–7	027 B	022 B
3,3′-dichlorobenzidine	34631	91–94–1	028 B	023 B
Diethyl phthalate	34336	84–66–2	070 B	024 B
2,4-dimethylphenol	34606	105–67–9	034 A	003 A
Dimethyl phthalate	34341	131–11–3	071 B	025 B
2,4-dinitrotoluene	34611	121–14–2	035 B	027 B
2,6-dinitrotoluene	34626	606–20–2	036 B	028 B
Di-n-octyl phthalate	34596	117–84–0	069 B	029 B
Diphenylamine (Appendix C)	77579	122–39–4	507 B	.....
Diphenyl ether (Appendix C)	77587	101–84–8	508 B	.....
1,2-diphenylhydrazine	34346	122–66–7	037 B	030 B
Fluoranthene	34376	206–44–0	039 B	031 B
Fluorene	34381	86–73–7	080 B	032 B
Hexachlorobenzene	39700	118–74–1	009 B	033 B
Hexachlorobutadiene	34391	87–68–3	052 B	034 B
Hexachloroethane	34396	67–72–1	012 B	036 B
Hexachlorocyclopentadiene	34386	77–47–4	053 B	035 B
Indeno(1,2,3-cd)pyrene	34403	193–39–5	083 B	037 B
Isophorone	34408	78–59–1	054 B	038 B
Naphthalene	34696	91–20–3	055 B	039 B
B-naphthylamine (Appendix C)	82553	91–59–8	502 B	.....
Nitrobenzene	34447	98–95–3	056 B	040 B
N-nitrosodimethylamine	34438	62–75–9	061 B	041 B
N-nitrosodi-n-propylamine	34428	621–64–7	063 B	042 B
N-nitrosodiphenylamine	34433	86–30–3	062 B	043 B

TABLE 1—BASE/NEUTRAL EXTRACTABLE COMPOUNDS—Continued

Compound	STORET	CAS registry	EPA-EGD	NPDES
Phenanthrene	34461	85–01–8	081 B	044 B
Phenol	34694	108–95–2	065 A	010 A
a-Picoline (Synfuel)	77088	109–06–89	503 B	.....
Pyrene	34469	129–00–0	084 B	045 B
styrene (Appendix C)	77128	100–42–5	510 B	.....
a-terpineol (Appendix C)	77493	98–55–5	509 B	.....
1,2,3-trichlorobenzene (4c)	77613	87–61–6	529 B	.....
1,2,4-trichlorobenzene	34551	120–82–1	008 B	046 B

TABLE 2—ACID EXTRACTABLE COMPOUNDS

Compound	STORET	CAS registry	EPA-EGD	NPDES
4-chloro-3-methylphenol	34452	59–50–7	022 A	008 A
2-chlorophenol	34586	95–57–8	024 A	001 A
2,4-dichlorophenol	34601	120–83–2	031 A	002 A
2,4-dinitrophenol	34616	51–28–5	059 A	005 A
2-methyl-4,6-dinitrophenol	34657	534–52–1	060 A	004 A
2-nitrophenol	34591	88–75–5	057 A	006 A
4-nitrophenol	34646	100–02–7	058 A	007 A
Pentachlorophenol	39032	87–86–5	064 A	009 A
2,3,6-trichlorophenol (4c)	77688	93–37–55	530 A	.....
2,4,5-trichlorophenol (4c)	.....	95–95–4	531 A	.....
2,4,6-trichlorophenol	34621	88–06–2	021 A	011 A

TABLE 3—GAS CHROMATOGRAPHY OF BASE/NEUTRAL EXTRACTABLE COMPOUNDS

EGD No.[1]	Compound	Retention time			Detection limit[2] (µg/L)
		Mean (sec)	EGD Ref	Relative	
164	2,2′-difluorobiphenyl (int std)	1163	164	1.000–1.000	10
061	N-nitrosodimethylamine	385	164	ns	50
603	alpha picoline-d7	417	164	0.326–0.393	50
703	alpha picoline	426	603	1.006–1.028	50
610	styrene-d5	546	164	0.450–0.488	10
710	styrene	549	610	1.002–1.009	10
613	p-cymene-d14	742	164	0.624–0.652	10
713	p-cymene	755	613	1.008–1.023	10
265	phenol-d5	696	164	0.584–0.613	10
365	phenol	700	265	0.995–1.010	10
218	bis(2-chloroethyl) ether-d8	696	164	0.584–0.607	10
318	bis(2-chloroethyl) ether	704	218	1.007–1.016	10
617	n-decane-d22	698	164	0.585–0.615	10
717	n-decane	720	617	1.022–1.038	10
226	1,3-dichlorobenzene-d4	722	164	0.605–0.636	10
326	1,3-dichlorobenzene	724	226	0.998–1.008	10
227	1,4-dichlorobenzene-d4	737	164	0.601–0.666	10
327	1,4-dichlorobenzene	740	227	0.997–1.009	10
225	1,2-dichlorobenzene-d4	758	164	0.632–0.667	10
325	1,2-dichlorobenzene	760	225	0.995–1.008	10
242	bis(2-chloroisopropyl) ether-d12	788	164	0.664–0.691	10
342	bis(2-chloroisopropyl) ether	799	242	1.010–1.016	10
212	hexachloroethane-13C	819	164	0.690–0.717	10
312	hexachloroethane	823	212	0.999–1.001	10
063	N-nitrosodi-n-propylamine	830	164	ns	20
256	nitrobenzene-d5	845	164	0.706–0.727	10
356	nitrobenzene	849	256	1.002–1.007	10
254	isophorone-d8	881	164	0.747–0.767	10
354	isophorone	889	254	0.999–1.017	10
234	2,4-dimethyl phenol-d3	921	164	0.781–0.803	10
334	2,4-dimethylphenol	924	234	0.999–1.003	10
043	bis(2-chloroethoxy) methane	939	164	ns	10
208	1,2,4-trichlorobenzene-d3	955	164	0.813–0.830	10
308	1,2,4-trichlorobenzene	958	208	1.000–1.005	10
255	naphthalene-d8	963	164	0.819–0.836	10
355	naphthalene	967	255	1.001–1.006	10
609	alpha-terpineol-d3	973	164	0.829–0.844	10

TABLE 3—GAS CHROMATOGRAPHY OF BASE/NEUTRAL EXTRACTABLE COMPOUNDS—Continued

EGD No.[1]	Compound	Retention time			Detection limit[2] (µg/L)
		Mean (sec)	EGD Ref	Relative	
709	alpha-terpineol	975	609	0.998–1.008	10
606	n-dodecane-d26	953	164	0.730–0.908	10
706	n-dodecane	981	606	0.986–1.051	10
529	1,2,3-trichlorobenzene	1003	164	ns	10
252	hexachlorobutadiene-13C4	1005	164	0.856–0.871	10
352	hexachlorobutadiene	1006	252	0.999–1.002	10
253	hexachlorocyclopentadiene-13C4	1147	164	0.976–0.986	10
353	hexachlorocyclopentadiene	1142	253	0.999–1.001	10
220	2-chloronaphthalene-d7	1185	164	1.014–1.024	10
320	2-chloronaphthalene	1200	220	0.997–1.007	10
518	n-tetradecane	1203	164	ns	10
612	Biphenyl-d10	1205	164	1.016–1.027	10
712	Biphenyl	1195	612	1.001–1.006	10
608	Diphenyl ether-d10	1211	164	1.036–1.047	10
708	Diphenyl ether	1216	608	0.997–1.009	10
277	Acenaphthylene-d8	1265	164	1.080–1.095	10
377	Acenaphthylene	1247	277	1.000–1.004	10
271	Dimethyl phthalate-d4	1269	164	1.083–1.102	10
371	Dimethyl phthalate	1273	271	0.998–1.005	10
236	2,6-dinitrotoluene-d3	1283	164	1.090–1.112	10
336	2,6-dinitrotoluene	1300	236	1.001–1.005	10
201	Acenaphthene-d10	1298	164	1.107–1.125	10
301	Acenaphthene	1304	201	0.999–1.009	10
605	Dibenzofuran-d8	1331	164	1.134–1.155	10
705	Dibenzofuran	1335	605	0.998–1.007	10
602	Beta-naphthylamine-d7	1368	164	1.163–1.189	50
702	Beta-naphthylamine	1371	602	0.996–1.007	50
280	Fluorene-d10	1395	164	1.185–1.214	10
380	Fluorene	1401	281	0.999–1.008	10
240	4-chlorophenyl phenyl ether-d5	1406	164	1.194–1.223	10
340	4-chlorophenyl phenyl ether	1409	240	0.990–1.015	10
270	Diethyl phthalate-d4	1409	164	1.197–1.229	10
370	Diethyl phthalate	1414	270	0.996–1.006	10
619	n-hexadecane-d34	1447	164	1.010–1.478	10
719	n-hexadecane	1469	619	1.013–1.020	10
235	2,4-dinitrotoluene-d3	1359	164	1.152–1.181	10
335	2,4-dinitrotoluene	1344	235	1.000–1.002	10
237	1,2-diphenylhydrazine-d8	1433	164	1.216–1.248	20
337	1,2-diphenylhydrazine ([3])	1439	237	0.999–1.009	20
607	Diphenylamine–d10	1437	164	1.213–1.249	20
707	Diphenylamine	1439	607	1.000–1.007	20
262	N-nitrosodiphenylamine-d6	1447	164	1.225–1.252	20
362	N-nitrosodiphenylamine ([4])	1464	262	1.000–1.002	20
041	4-bromophenyl phenyl ether	1498	164	1.271–1.307	10
209	Hexachlorobenzene-13C6	1521	164	1.288–1.327	10
309	Hexachlorobenzene	1522	209	0.999–1.001	10
281	Phenanthrene-d10	1578	164	1.334–1.380	10
520	n-octadecane	1580	164	ns	10
381	Phenanthrene	1583	281	1.000–1.005	10
278	Anthracene-d10	1588	164	1.342–1.388	10
378	Anthracene	1592	278	0.998–1.006	10
604	Dibenzothiophene-d8	1559	164	1.314–1.361	10
704	Dibenzothiophene	1564	604	1.000–1.006	10
528	Carbazole	1650	164	ns	20
621	n-eicosane-d42	1655	164	1.184–1.662	10
721	n-eicosane	1677	621	1.010–1.021	10
268	Di-n-butyl phthalate-d4	1719	164	1.446–1.510	10
368	Di-n-butyl phthalate	1723	268	1.000–1.003	10
239	Fluoranthene-d10	1813	164	1.522–1.596	10
339	Fluoranthene	1817	239	1.000–1.004	10
284	Pyrene-d10	1844	164	1.523–1.644	10
384	Pyrene	1852	284	1.001–1.003	10
205	Benzidine-d8	1854	164	1.549–1.632	50
305	Benzidine	1853	205	1.000–1.002	50
522	n-docosane	1889	164	ns	10
623	n-tetracosane-d50	1997	164	1.671–1.764	10
723	n-tetracosane	2025	612	1.012–1.015	10
067	Butylbenzyl phthalate	2060	164	ns	10
276	Chrysene-d12	2081	164	1.743–1.837	10
376	Chrysene	2083	276	1.000–1.004	10

TABLE 3—GAS CHROMATOGRAPHY OF BASE/NEUTRAL EXTRACTABLE COMPOUNDS—Continued

EGD No.[1]	Compound	Retention time			Detection limit[2] (µg/L)
		Mean (sec)	EGD Ref	Relative	
272	Benzo(a)anthracene-d12	2082	164	1.735–1.846	10
372	Benzo(a)anthracene	2090	272	0.999–1.007	10
228	3,3′-dichlorobenzidine-d6	2088	164	1.744–1.848	50
328	3,3′-dichlorobenzidine	2086	228	1.000–1.001	50
266	Bis(2-ethylhexyl) phthalate-d4	2123	164	1.771–1.880	10
366	Bis(2-ethylhexyl) phthalate	2124	266	1.000–1.002	10
524	n-hexacosane	2147	164	ns	10
269	di-n-octyl phthalate-d4	2239	164	1.867–1.982	10
369	di-n-octyl phthalate	2240	269	1.000–1.002	10
525	n-octacosane	2272	164	ns	10
274	Benzo(b)fluoranthene-d12	2281	164	1.902–2.025	10
354	Benzo(b)fluoranthene	2293	274	1.000–1.005	10
275	Benzo(k)fluoranthene-d12	2287	164	1.906–2.033	10
375	Benzo(k)fluoranthene	2293	275	1.000–1.005	10
273	Benzo(a)pyrene-d12	2351	164	1.954–2.088	10
373	Benzo(a)pyrene	2350	273	1.000–1.004	10
626	N-triacontane-d62	2384	164	1.972–2.127	10
726	N-triacontane	2429	626	1.011–1.028	10
083	Indeno(1,2,3-cd)pyrene	2650	164	ns	20
082	Dibenzo(a,h)anthracene	2660	164	ns	20
279	Benzo(ghi)perylene-d12	2741	164	2.187–2.524	20
379	Benzo(ghi)perylene	2750	279	1.001–1.006	20

[1] Reference numbers beginning with 0, 1 or 5 indicate a pollutant quantified by the internal standard method; reference numbers beginning with 2 or 6 indicate a labeled compound quantified by the internal standard method; reference numbers beginning with 3 or 7 indicate a pollutant quantified by isotope dilution.

[2] This is a minimum level at which the entire GC/MS system must give recognizable mass spectra (background corrected) and acceptable calibration points.

[3] Detected as azobenzene.

[4] Detected as diphenylamine.

ns = specification not available at time of release of method.

Column: 30 ±2 m × 0.25 ±0.02 mm i.d. 94% methyl, 4% phenyl, 1% vinyl bonded phase fused silica capillary.

Temperature program: 5 min at 30 °C; 30 – 280 °C at 8 °C per min; isothermal at 280 °C until benzo(ghi)perylene elutes.

Gas velocity: 30 ±5 cm/sec.

TABLE 4—GAS CHROMATOGRAPHY OF ACID EXTRACTABLE COMPOUNDS

EGD No. [1]	Compound	Retention time			Detection limit [2] (µg/L)
		Mean (sec)	EGD Ref	Relative	
164	2,2′-difluorobiphenyl (int std)	1163	164	1.000–1.000	10
224	2-chlorophenol-d4	701	164	0.587–0.618	10
324	2-chlorophenol	705	224	0.997–1.010	10
257	2-nitrophenol-d4	898	164	0.761–0.783	20
357	2-nitrophenol	900	257	0.994–1.009	20
231	2,4-dichlorophenol-d3	944	164	0.802–0.822	10
331	2,4-dichlorophenol	947	231	0.997–1.006	10
222	4-chloro-3-methylphenol-d2	1086	164	0.930–0.943	10
322	4-chloro-3-methylphenol	1091	222	0.998–1.003	10
221	2,4,6-trichlorophenol-d2	1162	164	0.994–1.005	10
321	2,4,6-trichlorophenol	1165	221	0.998–1.004	10
531	2,4,5-trichlorophenol	1170	164	ns	10
530	2,3,6-trichlorophenol	1195	164	ns	10
259	2,4-dinitrophenol-d3	1323	164	1.127–1.149	50
359	2,4-dinitrophenol	1325	259	1.000–1.005	50
258	4-nitrophenol-d4	1349	164	1.147–1.175	50
358	4-nitrophenol	1354	258	0.997–1.006	50
260	2-methyl-4,6-dinitrophenol-d2	1433	164	1.216–1.249	20
360	2-methyl-4,6-dinitrophenol	1435	260	1.000–1.002	20
264	Pentachlorophenol-13C6	1559	164	1.320–1.363	50
364	Pentachlorophenol	1561	264	0.998–1.002	50

[1] Reference numbers beginning with 0, 1 or 5 indicate a pollutant quantified by the internal standard method; reference numbers beginning with 2 or 6 indicate a labeled compound quantified by the internal standard method; reference numbers beginning with 3 or 7 indicate a pollutant quantified by isotope dilution.

[2] This is a minimum level at which the entire GC/MS system must give recognizable mass spectra (background corrected) and acceptable calibration points.

ns=specification not available at time of release of method.

Column: 30 ±2m×0.25 ±0.02mm i.d. 94% methyl, 4% phenyl, 1% vinyl bonded phase fused silica capillary.

Temperature program: 5 min at 30 °C; 8 °C/min. to 250°C or until pentachlorophenol elutes.

Gas velocity: 30± 5 cm/sec.

TABLE 5—DFTPP MASS INTENSITY SPECIFICATIONS

Mass	Intensity required
51	30–60 percent of mass 198.
68	Less than 2 percent of mass 69.
70	Less than 2 percent of mass 69.
127	40–60 percent of mass 198.
197	Less than 1 percent of mass 198.
199	5–9 percent of mass 198.
275	10–30 percent of mass 198.
365	greater than 1 percent of mass 198
441	present and less than mass 443
442	40–100 percent of mass 198.
443	17–23 percent of mass 442.

TABLE 6—BASE/NEUTRAL EXTRACTABLE COMPOUND CHARACTERISTIC MASSES

Compound	Labeled analog	Primary m/z
Acenaphthene	d10	154/164
Acenaphthylene	d8	152/160
Anthracene	d10	178/188
Benzidine	d8	184/192
Benzo(a)anthracene	d12	228/240
Benzo(b)fluoranthene	d12	252/264
Benzo(k)fluoranthene	d12	252/264
Benzo(a)pyrene	d12	252/264
Benzo(ghi)perylene	d12	276/288
Biphenyl	d10	154/164
Bis(2-chloroethyl) ether	d8	93/101
Bis(2-chloroethoxy)methane	.....	93
Bis(2-chloroisopropyl) ether	d12	121/131
Bis(2-ethylhexyl) phthalate	d4	149/153
4-bromophenyl phenyl ether	.....	248
Butyl benzyl phthalate	.....	149
n-C10	d22	55/66
n-C12	d26	55/66
n-C14	.....	55
n-C16	d34	55/66
n-C18	.....	55
n-C20	d42	55/66
n-C22	.....	55
n-C24	d50	55/66
n-C26	.....	55
n-C28	.....	55
n-C30	d62	55/66
Carbazole	d8	167/175
2-chloronaphthalene	d7	162/169
4-chlorophenyl phenyl ether	d5	204/209
Chrysene	d12	228/240
p-cymene	d14	114/130
Dibenzo(a,h)anthracene	.....	278
Dibenzofuran	d8	168/176
Dibenzothiophene	d8	184/192
Di-n-butyl phthalate	d4	149/153
1,2-dichlorobenzene	d4	146/152
1,3-dichlorobenzene	d4	146/152

TABLE 6—BASE/NEUTRAL EXTRACTABLE COMPOUND CHARACTERISTIC MASSES—Continued

Compound	Labeled analog	Primary m/z
1,4-dichlorobenzene	d4	146/152
3,3′-dichlorobenzidine	d6	252/258
Diethyl phthalate	d4	149/153
2,4-dimethylphenol	d3	122/125
Dimethyl phthalate	d4	163/167
2,4-dinitrotoluene	d3	164/168
2,6-dinitrotoluene	d3	165/167
Di-n-octyl phthalate	d4	149/153
Diphenylamine	d10	169/179
Diphenyl ether	d10	170/180
1,2-diphenylhydrazine[1]	d10	77/82
Fluoranthene	d10	202/212
Fluorene	d10	166/176
Hexachlorobenzene	13C6	284/292
Hexachlorobutadiene	13C4	225/231
Hexachloroethane	13C	201/204
Hexachlorocyclopentadiene	13C4	237/241
Ideno(1,2,3-cd)pyrene	.....	276
Isophorone	d8	82/88
Naphthalene	d8	128/136
B-naphthylamine	d7	143/150
Nitrobenzene	d5	123/128
N-nitrosodimethylamine	.....	74
N-nitrosodi-n-propylamine	.....	70
N-nitrosodiphenylamile[2]	d6	169/175
Phenanthrene	d10	178/188
Phenol	d5	94/71
a-picoline	d7	93/100
Pyrene	d10	202/212
Styrene	d5	104/109
a-terpineol	d3	59/62
1,2,3-trichlorobenzene	d3	180/183
1,2,4-trichlorobenzene	d3	180/183

[1] Detected as azobenzene.
[2] Detected as diphenylamine.

TABLE 77—ACID EXTRACTABLE COMPOUND CHARACTERISTIC MASSES

Compound	Labeled analog	Primary m/z
4-chloro-3-methylphenol	d2	107/109
2-chlorophenol	d4	128/132
2,4-dichlorophenol	d3	162/167
2,4-dinitrophenol	d3	184/187
2-methyl-4,6-dinitrophenol	d2	198/200
2-nitrophenol	d4	139/143
4-nitrophenol	d4	139/143
Pentachlorophenol	13C6	266/272
2,3,6-trichlorophenol	d2	196/200
2,4,5-trichlorophenol	d2	196/200
2,4,6-trichlorophenol	d2	196/200

TABLE 8—ACCEPTANCE CRITERIA FOR PERFORMANCE TESTS

EGD No.[1]	Compound	Acceptance criteria				
		Initial precision and accuracy section 8.2.3 (µg/L)		Labeled compound recovery sec. 8.3 and 14.2 P (percent)	Calibration verification sec. 12.5 (µg/mL)	On-going accuracy sec. 11.6 R (µg/L)
		s	X			
301	Acenaphthene	21	79–134	.....	80–125	72–144
201	Acenaphthene-d10	38	38–147	20–270	71–141	30–180
377	Acenaphtylene	38	69–186	.....	60–166	61–207
277	Acenaphthylene-d8	31	38–146	23–239	66–152	33–168

TABLE 8—ACCEPTANCE CRITERIA FOR PERFORMANCE TESTS—Continued

EGD No.[1]	Compound	Acceptance criteria				
		Initial precision and accuracy section 8.2.3 (μg/L)		Labeled compound recovery sec. 8.3 and 14.2 P (percent)	Calibration verification sec. 12.5 (μg/mL)	On-going accuracy sec. 11.6 R (μg/L)
		s	X			
378	Anthracene	41	58–174	.....	60–168	50–199
278	Anthracene-d10	49	31–194	14–419	58–171	23–242
305	Benzidine	119	16–518	.....	34–296	11–672
205	Benzidine-d8	269	ns–ns	ns–ns	ns–ns	ns–ns
372	Benzo(a)anthracene	20	65–168	.....	70–142	62–176
272	Benzo(a)anthracene-d12	41	25–298	12–605	28–357	22–329
374	Benzo(b)fluoranthene	183	32–545	.....	61–164	20–ns
274	Benzo(b)fluoranthene-d12	168	11–577	ns–ns	14–ns	ns–ns
375	Benzo(k)fluoranthene	26	59–143	.....	13–ns	53–155
275	Benzo(k)fluoranthene-d12	114	15–514	ns–ns	13–ns	ns–685
373	Benzo(a)pyrene	26	62–195	.....	78–129	59–206
273	Benzo(a)pyrene-d12	24	35–181	21–290	12–ns	32–194
379	Benzo(ghi)perylene	21	72–160	.....	69–145	58–168
279	Benzo(ghi)perylene-d12	45	29–268	14–529	13–ns	25–303
712	Biphenyl (Appendix C)	41	75–148	.....	58–171	62–176
612	Biphenyl-d12	43	28–165	ns–ns	52–192	17–267
318	Bis(2-chloroethyl) ether	34	55–196	.....	61–164	50–213
218	Bis(2-chloroethyl) ether-d8	33	29–196	15–372	52–194	25–222
043	Bis(2-chloroethoxy)methane*	27	43–153	.....	44–228	39–166
342	Bis(2-chloroisopropyl) ether	17	81–138	.....	67–148	77–145
242	Bis(2-chloroisopropyl)ether-d12	27	35–149	20–260	44–229	30–169
366	Bis(2-ethylhexyl) phthalate	31	69–220	.....	76–131	64–232
266	Bis(2-ethylhexyl) phthalate-d4	29	32–205	18–364	43–232	28–224
041	4-bromophenyl phenyl ether*	44	44–140	.....	52–193	35–172
067	Butyl benzyl phthalate*	31	19–233	.....	22–450	35–170
717	n-C10 (Appendix C)	51	24–195	.....	42–235	19–237
617	n-C10-d22	70	ns–298	ns–ns	44–227	ns–504
706	n-C12 (Appendix C)	74	35–369	.....	60–166	29–424
606	n-C12-d26	53	ns–331	ns–ns	41–242	ns–408
518	n-C14 (Appendix C)*	109	ns–985	.....	37–268	ns–ns
719	n-C16 (Appendix C)	33	80–162	.....	72–138	71–181
619	n-C16-d34	46	37–162	18–308	54–186	28–202
520	n-C18 (Appendix C)*	39	42–131	.....	40–249	35–167
721	n-C20 (Appendix C)	59	53–263	.....	54–184	46–301
621	n-C20-d42	34	34–172	19–306	62–162	29–198
522	n-C22 (Appendix C)*	31	45–152	.....	40–249	39–195
723	n-C24 (Appendix C)	11	80–139	.....	65–154	78–142
623	n-C24-d50	28	27–211	15–376	50–199	25–229
524	n-C26 (Appendix C)*	35	35–193	.....	26–392	31–212
525	n-C28 (Appendix C)*	35	35–193	.....	26–392	31–212
726	n-C30 (Appendix C)	32	61–200	.....	66–152	56–215
626	n-C30-d62	41	27–242	13–479	24–423	23–274
528	Carbazole (4c)*	38	36–165	.....	44–227	31–188
320	2-chloronaphthalene	100	46–357	.....	58–171	35–442
220	2-chloronaphthalene-d7	41	30–168	15–324	72–139	24–204
322	4-chloro-3-methylphenol	37	76–131	.....	85–115	62–159
222	4-chloro-3-methylphenol-d2	111	30–174	ns–613	68–147	14–314
324	2-chlorophenol	13	79–135	.....	78–129	76–138
224	2-chlorophenol-d4	24	36–162	23–255	55–180	33–176
340	4-chlorophenyl phenyl ether	42	75–166	.....	71–142	63–194
240	4-chlorophenyl phenyl ether-d5	52	40–161	19–325	57–175	29–212
376	Chrysene	51	59–186	.....	70–142	48–221
276	Chrysene-d12	69	33–219	13–512	24–411	23–290
713	p-cymene (Appendix C)	18	76–140	.....	79–127	72–147
613	p-cymene-d14	67	ns–359	ns–ns	66–152	ns–468
082	Dibenzo(a,h)anthracene*	55	23–299	.....	13–761	19–340
705	Dibenzofuran (Appendix C)	20	85–136	.....	73–136	79–146
605	Dibenzofuran-d8	31	47–136	28–220	66–150	39–160
704	Dibenzothiophene (Synfuel)	31	79–150	.....	72–140	70–168
604	Dibenzothiophene-d8	31	48–130	29–215	69–145	40–156
368	Di-n-butyl phthalate	15	76–165	.....	71–142	74–169
268	Di-n-butyl phthalate-d4	23	23–195	13–346	52–192	22–209
325	1,2-dichlorobenzene	17	73–146	.....	74–135	70–152
225	1,2-dichlorobenzene-d4	35	14–212	ns–494	61–164	11–247
326	1,3-dichlorobenzene	43	63–201	.....	65–154	55–225
226	1,3-dichlorobenzene-d4	48	13–203	ns–550	52–192	ns–260
327	1,4-dichlorobenzene	42	61–194	.....	62–161	53–219

TABLE 8—ACCEPTANCE CRITERIA FOR PERFORMANCE TESTS—Continued

EGD No.[1]	Compound	Acceptance criteria				
		Initial precision and accuracy section 8.2.3 (µg/L)		Labeled compound recovery sec. 8.3 and 14.2 P (percent)	Calibration verification sec. 12.5 (µg/mL)	On-going accuracy sec. 11.6 R (µg/L)
		s	X			
227	1,4-dichlorobenzene-d4	48	15–193	ns–474	65–153	11–245
328	3,3′-dichlorobenzidine	26	68–174	.....	77–130	64–185
228	3,3′-dichlorobenzidine-d6	80	ns–562	ns–ns	18–558	ns–ns
331	2,4-dichlorophenol	12	85–131	.....	67–149	83–135
231	2,4-dichlorophenol-d3	28	38–164	24–260	64–157	34–182
370	Diethyl phthalate	44	75–196	.....	74–135	65–222
270	Diethyl phthalate-d4	78	ns–260	ns–ns	47–211	ns–ns
334	2,4-dimethylphenol	13	62–153	.....	67–150	60–156
234	2,4-dimethylphenol-d3	22	15–228	ns–449	58–172	14–242
371	Dimethyl phthalate	36	74–188	.....	73–137	67–207
271	Dimethyl phthalate-d4	108	ns–640	ns–ns	50–201	ns–ns
359	2,4-dinitrophenol	18	72–134	.....	75–133	68–141
259	2,4-dinitrophenol-d3	66	22–308	ns–ns	39–256	17–378
335	2,4-dinitrotoluene	18	75–158	.....	79–127	72–164
235	2,4-dinitrotoluene-d3	37	22–245	10–514	53–187	19–275
336	2,6-dinitrotoluene	30	80–141	.....	55–183	70–159
236	2,6-dinitrotoluene-d3	59	44–184	17–442	36–278	31–250
369	Di-n-octyl phthalate	16	77–161	.....	71–140	74–166
269	Di-n-octyl phthalate-d4	46	12–383	ns–ns	21–467	10–433
707	Diphenylamine (Appendix C)	45	58–205	.....	57–176	51–231
607	Diphenylamine-d10	42	27–206	11–488	59–169	21–249
708	Diphenyl ether (Appendix C)	19	82–136	.....	83–120	77–144
608	Diphenyl ether-d10	37	36–155	19–281	77–129	29–186
337	1,2-diphenylhydrazine	73	49–308	.....	75–134	40–360
237	1,2-diphenylhydrazine-d10	35	31–173	17–316	58–174	26–200
339	Fluoranthene	33	71–177	.....	67–149	64–194
239	Fluoranthene-d10	35	36–161	20–278	47–215	30–187
380	Fluorene	29	81–132	.....	74–135	70–151
280	Fluorene-d10	43	51–131	27–238	61–164	38–172
309	Hexachlorobenzene	16	90–124	.....	78–128	85–132
209	Hexachlorobenzene-13C6	81	36–228	13–595	38–265	23–321
352	hexachlorobutadiene	56	51–251	.....	74–135	43–287
252	hexachlorobutadiene-13C4	63	ns–316	ns–ns	68–148	ns–413
312	hexachloroethane	227	21–ns	.....	71–141	13–ns
212	hexachloroethane-13C1	77	ns–400	ns–ns	47–212	ns–563
353	hexachlorocyclopentadiene	15	69–144	.....	77–129	67–148
253	hexachlorocyclopentadiene-13C4	60	ns–ns	ns–ns	47–211	ns–ns
083	ideno(1,2,3-cd)pyrene*	55	23–299	.....	13–761	19–340
354	isophorone	25	76–156	.....	70–142	70–168
254	isophorone-d8	23	49–133	33–193	52–194	44–147
360	2-methyl-4,6-dinitrophenol	19	77–133	.....	69–145	72–142
260	2-methyl-4,6-dinitrophenol-d2	64	36–247	16–527	56–177	28–307
355	naphthalene	20	80–139	.....	73–137	75–149
255	naphthalene-d8	39	28–157	14–305	71–141	22–192
702	B-naphthylamine (Appendix C)	49	10–ns	.....	39–256	ns–ns
602	B-naphthylamine-d7	33	ns–ns	ns–ns	44–230	ns–ns
356	nitrobenzene	25	69–161	.....	85–115	65–169
256	nitrobenzene-d5	28	18–265	ns–ns	46–219	15–314
357	2-nitrophenol	15	78–140	.....	77–129	75–145
257	2-nitrophenol-d4	23	41–145	27–217	61–163	37–158
358	4-nitrophenol	42	62–146	.....	55–183	51–175
258	4-nitrophenol-d4	188	14–398	ns–ns	35–287	ns–ns
061	N-nitrosodimethylamile*	198	21–472	.....	40–249	12–807
063	N-nitrosodi-n-proplyamine*	198	21–472	.....	40–249	12–807
362	N-nitrosodiphenylamine	45	65–142	.....	68–148	53–173
262	N-nitrosodiphenylamine-d6	37	54–126	26–256	59–170	40–166
364	pentachlorophenol	21	76–140	.....	77–130	71–150
264	pentachlorophenol-13C6	49	37–212	18–412	42–237	29–254
381	phenanthrene	13	93–119	.....	75–133	87–126
281	phenanthrene-d10	40	45–130	24–241	67–149	34–168
365	phenol	36	77–127	.....	65–155	62–154
265	phenol-d5	161	21–210	ns–ns	48–208	ns–ns
703	a-picoline (Synfuel)	38	59–149	.....	60–165	50–174
603	a-picoline-d7	138	11–380	ns–ns	31–324	ns–608
384	pyrene	19	76–152	.....	76–132	72–159
284	pyrene-d10	29	32–176	18–303	48–210	28–196
710	styrene (Appendix C)	42	53–221	.....	65–153	48–244

TABLE 8—ACCEPTANCE CRITERIA FOR PERFORMANCE TESTS—Continued

EGD No.[1]	Compound	Acceptance criteria				
		Initial precision and accuracy section 8.2.3 (µg/L)		Labeled compound recovery sec. 8.3 and 14.2 P (percent)	Calibration verification sec. 12.5 (µg/mL)	On-going accuracy sec. 11.6 R (µg/L)
		s	X			
610	styrene-d5	49	ns–281	ns–ns	44–228	ns–348
709	a-terpineol (Appendix C)	44	42–234	.....	54–186	38–258
609	a-terpineol-d3	48	22–292	ns–672	20–502	18–339
529	1,2,3-trichlorobenzene (4c)*	69	15–229	.....	60–167	11–297
308	1,2,4-trichlorobenzene	19	82–136	.....	78–128	77–144
208	1,2,4-trichlorobenzene-d3	57	15–212	ns–592	61–163	10–282
530	2,3,6-trichlorophenol (4c)*	30	58–137	.....	56–180	51–153
531	2,4,5-trichlorophenol (4c)*	30	58–137	.....	56–180	51–153
321	2,4,6-trichlorophenol	57	59–205	.....	81–123	48–244
221	2,4,6-trichlorophenol-d2	47	43–183	21–363	69–144	34–226

[1] Reference numbers beginning with 0, 1 or 5 indicate a pollutant quantified by the internal standard method; reference numbers beginning with 2 or 6 indicate a labeled compound quantified by the internal standard method; reference numbers beginning with 3 or 7 indicate a pollutant quantified by isotope dilution.

* Measured by internal standard; specification derived from related compound.

ns=no specification; limit is outside the range that can be measured reliably.

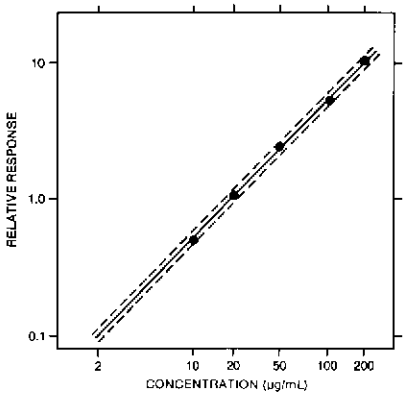

FIGURE 1 Relative Response Calibration Curve for Phenol. The Dotted Lines Enclose a ±10 Percent Error Window.

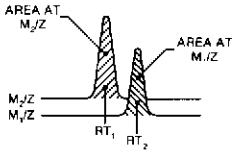

FIGURE 2 Extracted Ion Current Profiles for Chromatographically Resolved Labeled (m_2/z) and Unlabeled (m_1/z) Pairs.

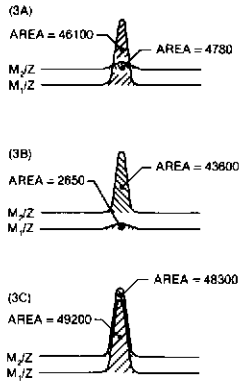

FIGURE 3 Extracted Ion Current Profiles for (3A) Unlabeled Compound, (3B) Labeled Compound, and (3C) Equal Mixture of Unlabeled and Labeled Compounds.

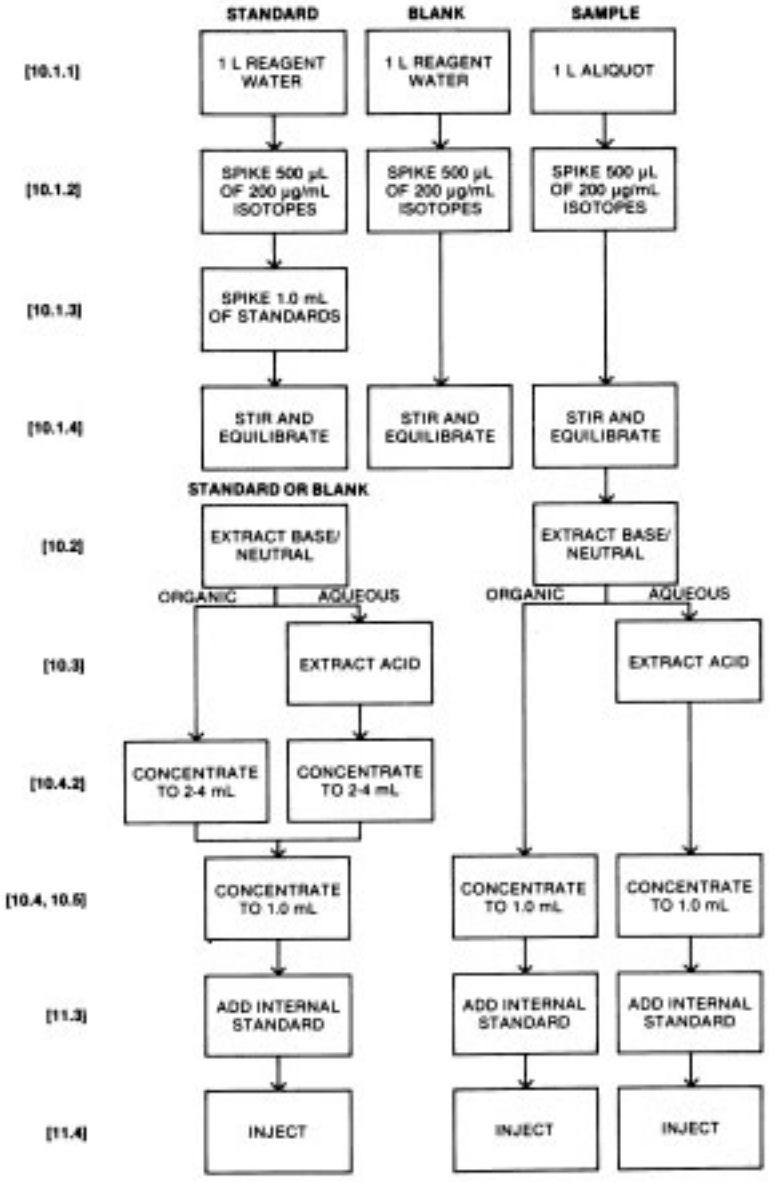

FIGURE 4 Flow Chart for Extraction/Concentration of Precision and Recovery Standard, Blank, and Sample by Method 1625. Numbers in Brackets [ ] Refer to Section Numbers in the Method.

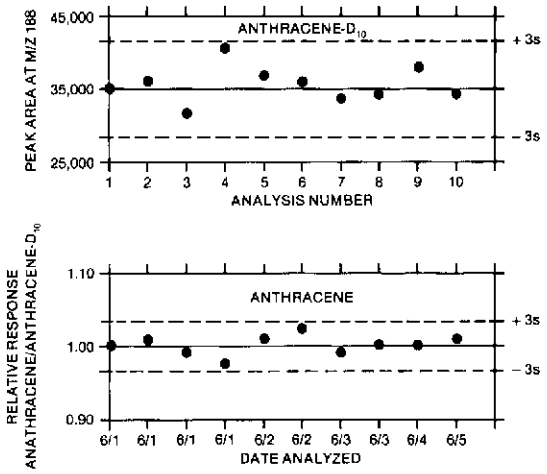

FIGURE 5 Quality Control Charts Showing Area (top graph) and Relative Response of Anthracene to Anthracene-d_{10} (lower graph) Plotted as a Function of Time or Analysis Number.

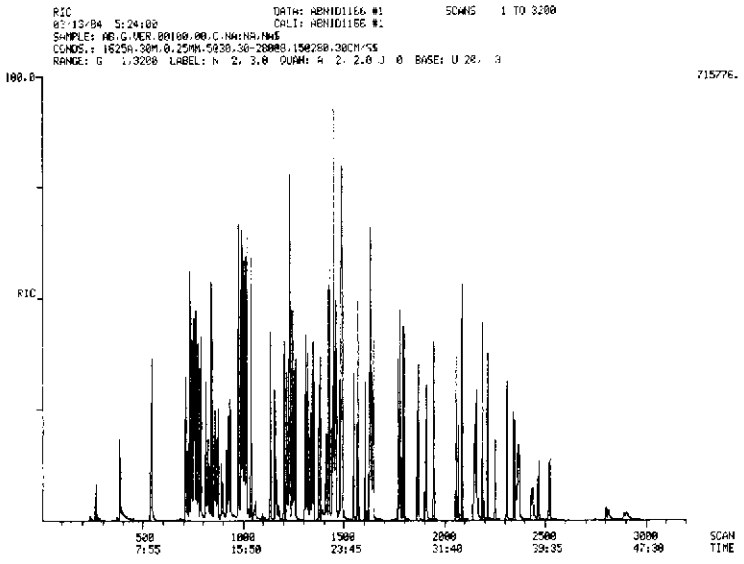

FIGURE 6 Chromatogram of Combined Acid/base/neutral Standard.

ATTACHMENT 1 TO METHOD 1625

INTRODUCTION

To support measurement of several semivolatile pollutants, EPA has developed this attachment to EPA Method 1625B.[1] The modifications listed in this attachment are approved only for monitoring wastestreams from the Centralized Waste Treatment Point Source Category (40 CFR Part 437) and the Landfills Point Source Category (40 CFR Part 445). EPA Method 1625B (the Method) employs sample extraction with methylene chloride followed by analysis of the extract using capillary column gas chromatography-mass spectrometry (GC/MS). This attachment addresses the addition of the semivolatile pollutants listed in Tables 1 and 2 to all applicable standard, stock, and spiking solutions utilized for the determination of semivolatile organic compounds by EPA Method 1625B.

1.0 EPA METHOD 1625 REVISION B MODIFICATION SUMMARY

The additional semivolatile organic compounds listed in Tables 1 and 2 are added to all applicable calibration, spiking, and other solutions utilized in the determination of semivolatile compounds by EPA Method 1625. The instrument is to be calibrated with these compounds, and all procedures and quality control tests described in the Method must be performed.

2.0 SECTION MODIFICATIONS

NOTE: All section and figure numbers in this Attachment reference section and figure numbers in EPA Method 1625 Revision B unless noted otherwise. Sections not listed here remain unchanged.

Section 6.7 The stock standard solutions described in this section are modified such that the analytes in Tables 1 and 2 of this attachment are required in addition to those specified in the Method.

Section 6.8 The labeled compound spiking solution in this section is modified to include the labeled compounds listed in Tables 5 and 6 of this attachment.

Section 6.9 The secondary standard is modified to include the additional analytes listed in Tables 1 and 2 of this attachment.

Section 6.12 The solutions for obtaining authentic mass spectra are to include all additional analytes listed in Tables 1 and 2 of this attachment.

Section 6.13 The calibration solutions are modified to include the analytes listed in Tables 1 and 2 and the labeled compounds listed in Tables 5 and 6 of this attachment.

Section 6.14 The precision and recovery standard is modified to include the analytes listed in Tables 1 and 2 and the labeled compounds listed in Tables 5 and 6 of this attachment.

Section 6.15 The solutions containing the additional analytes listed in Tables 1 and 2 of this attachment are to be analyzed for stability.

Section 7.2.1 This section is modified to include the analytes listed in Tables 1 and 2 and the labeled compounds listed in Tables 5 and 6 of this attachment.

Section 7.4.5 This section is modified to include the analytes listed in Tables 1 and 2 and the labeled compounds listed in Tables 5 and 6 in the calibration.

Section 8.2 The initial precision and recovery (IPR) requirements are modified to include the analytes listed in Tables 1 and 2 and the labeled compounds listed in Tables 5 and 6 of this attachment. Additional IPR performance criteria are supplied in Table 7 of this attachment.

Section 8.3 The labeled compounds listed in Tables 3 and 4 of this attachment are to be included in the method performance tests. Additional method performance criteria are supplied in Table 7 of this attachment.

Section 8.5.2 The acceptance criteria for blanks includes the analytes listed in Tables 1 and 2 of this attachment.

Section 10.1.2 The labeled compound solution must include the labeled compounds listed in Tables 5 and 6 of this attachment.

Section 10.1.3 The precision and recovery standard must include the analytes listed in Tables 1 and 2 and the labeled compounds listed in Tables 5 and 6 of this attachment.

Section 12.5 Additional QC requirements for calibration verification are supplied in Table 7 of this attachment.

Section 12.7 Additional QC requirements for ongoing precision and recovery are supplied in Table 7 of this attachment.

[1] EPA Method 1625 Revision B, Semivolatile Organic Compounds by Isotope Dilution GC/MS, 40 CFR Part 136, Appendix A.

TABLE 1—BASE/NEUTRAL EXTRACTABLE COMPOUNDS

Compound	Pollutant	
	CAS Registry	EPA–EGD
acetophenone [1]	98–86–2	758
aniline [2]	62–53–3	757
-2,3-dichloroaniline [1]	608–27–5	578
-o-cresol [1]	95–48–7	771
pyridine [2]	110–86–1	1330

CAS = Chemical Abstracts Registry.
EGD = Effluent Guidelines Division.
[1] Analysis of this pollutant is approved only for the Centralized Waste Treatment industry.
[2] Analysis of this pollutant is approved only for the Centralized Waste Treatment and Landfills industries.

TABLE 2—ACID EXTRACTABLE COMPOUNDS

Compound	Pollutant	
	CAS Registry	EPA–EGD
p-cresol [1]	106–44–5	1744

CAS = Chemical Abstracts Registry.
EGD = Effluent Guidelines Division.
[1] Analysis of this pollutant is approved only for the Centralized Waste Treatment and Landfills industries.

TABLE 3—GAS CHROMATOGRAPHY [1] OF BASE/NEUTRAL EXTRACTABLE COMPOUNDS

EGD No.	Compound	Retention time [2]			Minimum level [3] (μg/L)
		Mean (sec)	EGD Ref	Relative	
758	acetophenone [4]	818	658	1.003–1.005	10
757	aniline [5]	694	657	0.994–1.023	10
578	2,3-dichloroaniline [4]	1160	164	1.003–1.007	10
771	o-cresol [4]	814	671	1.005–1.009	10
1330	pyridine [5]	378	1230	1.005–1.011	10

EGD = Effluent Guidelines Division.
[1] The data presented in this table were obtained under the chromatographic conditions given in the footnote to Table 3 of EPA Method 1625B.
[2] Retention times are approximate and are intended to be consistent with the retention times for the analytes in EPA Method 1625B.
[3] See the definition in footnote 2 to Table 3 of EPA Method 1625B.
[4] Analysis of this pollutant is approved only for the Centralized Waste Treatment industry.
[5] Analysis of this pollutant is approved only for the Centralized Waste Treatment and Landfills industries.

TABLE 4—GAS CHROMATOGRAPHY [1] OF ACID EXTRACTABLE COMPOUNDS

EGD No.	Compound	Retention time [2]			Minimum level (μ/L) [3]
		Mean (sec)	EGD Ref	Relative	
1744	p-cresol [4]	834	1644	1.004–1.008	20

EGD = Effluent Guidelines Division.
[1] The data presented in this table were obtained under the chromatographic conditions given in the footnote to Table 4 of EPA Method 1625B.
[2] Retention times are approximate and are intended to be consistent with the retention times for the analytes in EPA Method 1625B.
[3] See the definition in footnote 2 to Table 4 of EPA Method 1625B.
[4] Analysis of this pollutant is approved only for the Centralized Waste Treatment and Landfills industries.

TABLE 5—BASE/NEUTRAL EXTRACTABLE COMPOUND CHARACTERISTIC M/Z'S

Compound	Labeled Analog	Primary m/z [1]
acetophenone [2]	d_5	105/110
aniline [3]	d_7	93/100
o-cresol [2]	d_7	108/116
2,3-dichloroaniline [2]	n/a	161
pyridine [3]	d_5	79/84

m/z = mass to charge ratio.

[1] Native/labeled.
[2] Analysis of this pollutant is approved only for the Centralized Waste Treatment industry.
[3] Analysis of this pollutant is approved only for the Centralized Waste Treatment and Landfills industries.

TABLE 6—ACID EXTRACTABLE COMPOUND CHARACTERISTIC M/Z'S

Compound	Labeled Analog	Primary m/z [1]
p-cresol [2]	d_7	108/116

m/z = mass to charge ratio.
[1] Native/labeled.
[2] Analysis of this pollutant is approved only for the Centralized Waste Treatment and Landfills industries.

TABLE 7—ACCEPTANCE CRITERIA FOR PERFORMANCE TESTS

EGD No.	Compound	Acceptance criteria			Calibration verification sec. 12.5 µg/mL)	On-going accuracy sec. 12.7 R (µg/L)
		Initial precision and accuracy section 8.2 (µg/L)		Labeled compound recovery sec. 8.3 and 14.2 P (percent)		
		s (µg/L)	X			
758	acetophenone [1]	34	44–167	.....	85–115	45–162
658	acetophenone-d_5 [1]	51	23–254	45–162	85–115	22–264
757	aniline [2]	32	30–171	.....	85–115	33–154
657	aniline-d_7 [2]	71	15–278	33–154	85–115	12–344
771	o-cresol [1]	40	31–226	.....	85–115	35–196
671	o-cresol-d_7 [1]	23	30–146	35–196	85–115	31–142
1744	p-cresol [2]	59	54–140	.....	85–115	37–203
1644	p-cresol-d_7 [2]	22	11–618	37–203	85–115	16–415
578	2,3-dichloroaniline [1]	13	40–160	.....	85–115	44–144
1330	pyridine [2]	28	10–421	.....	83–117	18–238
1230	pyridine-d_5 [2]	ns	7–392	19–238	85–115	4–621

s = Standard deviation of four recovery measurements.
X = Average recovery for four recovery measurements.
EGD = Effluent Guidelines Division.
ns = no specification; limit is outside the range that can be measured reliably.
[1] Analysis of this pollutant is approved only for the Centralized Waste Treatment industry.
[2] Analysis of this pollutant is approved only for the Centralized Waste Treatment and Landfills industries.

[49 FR 43261, Oct. 26, 1984; 50 FR 692, 695, Jan. 4, 1985, as amended at 51 FR 23702, June 30, 1986; 62 FR 48405, Sept. 15, 1997; 65 FR 3044, Jan. 19, 2000; 65 FR 81295, 81298, Dec. 22, 2000]

APPENDIX B TO PART 136—DEFINITION AND PROCEDURE FOR THE DETERMINATION OF THE METHOD DETECTION LIMIT—REVISION 1.11

Definition

The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero and is determined from analysis of a sample in a given matrix containing the analyte.

Scope and Application

This procedure is designed for applicability to a wide variety of sample types ranging from reagent (blank) water containing analyte to wastewater containing analyte. The MDL for an analytical procedure may vary as a function of sample type. The procedure requires a complete, specific, and well defined analytical method. It is essential that all sample processing steps of the analytical method be included in the determination of the method detection limit.

The MDL obtained by this procedure is used to judge the significance of a single measurement of a future sample.

The MDL procedure was designed for applicability to a broad variety of physical and chemical methods. To accomplish this, the procedure was made device- or instrument-independent.

Procedure

1. Make an estimate of the detection limit using one of the following:

(a) The concentration value that corresponds to an instrument signal/noise in the range of 2.5 to 5.

(b) The concentration equivalent of three times the standard deviation of replicate instrumental measurements of the analyte in reagent water.

(c) That region of the standard curve where there is a significant change in sensitivity, i.e., a break in the slope of the standard curve.

(d) Instrumental limitations.

It is recognized that the experience of the analyst is important to this process. However, the analyst must include the above considerations in the initial estimate of the detection limit.

2. Prepare reagent (blank) water that is as free of analyte as possible. Reagent or interference free water is defined as a water sample in which analyte and interferent concentrations are not detected at the method detection limit of each analyte of interest. Interferences are defined as systematic errors in the measured analytical signal of an established procedure caused by the presence of interfering species (interferent). The interferent concentration is presupposed to be normally distributed in representative samples of a given matrix.

3. (a) If the MDL is to be determined in reagent (blank) water, prepare a laboratory standard (analyte in reagent water) at a concentration which is at least equal to or in the same concentration range as the estimated method detection limit. (Recommend between 1 and 5 times the estimated method detection limit.) Proceed to Step 4.

(b) If the MDL is to be determined in another sample matrix, analyze the sample. If the measured level of the analyte is in the recommended range of one to five times the estimated detection limit, proceed to Step 4.

If the measured level of analyte is less than the estimated detection limit, add a known amount of analyte to bring the level of analyte between one and five times the estimated detection limit.

If the measured level of analyte is greater than five times the estimated detection limit, there are two options.

(1) Obtain another sample with a lower level of analyte in the same matrix if possible.

(2) The sample may be used as is for determining the method detection limit if the analyte level does not exceed 10 times the MDL of the analyte in reagent water. The variance of the analytical method changes as the analyte concentration increases from the MDL, hence the MDL determined under these circumstances may not truly reflect method variance at lower analyte concentrations.

4. (a) Take a minimum of seven aliquots of the sample to be used to calculate the method detection limit and process each through the entire analytical method. Make all computations according to the defined method with final results in the method reporting units. If a blank measurement is required to calculate the measured level of analyte, obtain a separate blank measurement for each sample aliquot analyzed. The average blank measurement is subtracted from the respective sample measurements.

(b) It may be economically and technically desirable to evaluate the estimated method detection limit before proceeding with 4a. This will: (1) Prevent repeating this entire procedure when the costs of analyses are high and (2) insure that the procedure is being conducted at the correct concentration. It is quite possible that an inflated MDL will be calculated from data obtained at many times the real MDL even though the level of analyte is less than five times the calculated method detection limit. To insure that the estimate of the method detection limit is a good estimate, it is necessary to determine that a lower concentration of analyte will not result in a significantly lower method detection limit. Take two aliquots of the sample to be used to calculate the method detection limit and process each through the entire method, including blank measurements as described above in 4a. Evaluate these data:

(1) If these measurements indicate the sample is in desirable range for determination of the MDL, take five additional aliquots and proceed. Use all seven measurements for calculation of the MDL.

(2) If these measurements indicate the sample is not in correct range, reestimate the MDL, obtain new sample as in 3 and repeat either 4a or 4b.

5. Calculate the variance (S^2) and standard deviation (S) of the replicate measurements, as follows:

$$S^2 = \frac{1}{n-1}\left[\sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} X_i\right)^2}{n}\right]$$

$$S = \left(S^2\right)^{\frac{1}{2}}$$

where:

X_i; i=1 to n, are the analytical results in the final method reporting units obtained from

the n sample aliquots and Σ refers to the sum of the X values from i=l to n.

6. (a) Compute the MDL as follows:

$$MDL = T_{(n-1,1-\alpha=0.99)} \quad (S)$$

where:

MDL = the method detection limit

$t_{(n-1,1-\alpha=.99)}$ = the students' t value appropriate for a 99% confidence level and a standard deviation estimate with n-1 degrees of freedom. See Table.

S = standard deviation of the replicate analyses.

(b) The 95% confidence interval estimates for the MDL derived in 6a are computed according to the following equations derived from percentiles of the chi square over degrees of freedom distribution (χ^2/df).

LCL = 0.64 MDL

UCL = 2.20 MDL

where: LCL and UCL are the lower and upper 95% confidence limits respectively based on seven aliquots.

7. Optional iterative procedure to verify the reasonableness of the estimate of the MDL and subsequent MDL determinations.

(a) If this is the initial attempt to compute MDL based on the estimate of MDL formulated in Step 1, take the MDL as calculated in Step 6, spike the matrix at this calculated MDL and proceed through the procedure starting with Step 4.

(b) If this is the second or later iteration of the MDL calculation, use S^2 from the current MDL calculation and S^2 from the previous MDL calculation to compute the F-ratio. The F-ratio is calculated by substituting the larger S^2 into the numerator S^2_A and the other into the denominator S^2_B. The computed F-ratio is then compared with the F-ratio found in the table which is 3.05 as follows: if $S^2_A/S^2_B<3.05$, then compute the pooled standard deviation by the following equation:

$$S_{pooled} = \left[\frac{6S_A^2 + 6S_B^2}{12}\right]^{\frac{1}{2}}$$

if $S^2_A/S^2_B>3.05$, respike at the most recent calculated MDL and process the samples through the procedure starting with Step 4. If the most recent calculated MDL does not permit qualitative identification when samples are spiked at that level, report the MDL as a concentration between the current and previous MDL which permits qualitative identification.

(c) Use the S_{pooled} as calculated in 7b to compute The final MDL according to the following equation:

$$MDL=2.681\ (S_{pooled})$$

where 2.681 is equal to $t_{(12,1-\alpha=.99)}$.

(d) The 95% confidence limits for MDL derived in 7c are computed according to the following equations derived from precentiles of the chi squared over degrees of freedom distribution.

LCL=0.72 MDL

UCL=1.65 MDL

where LCL and UCL are the lower and upper 95% confidence limits respectively based on 14 aliquots.

TABLES OF STUDENTS' T VALUES AT THE 99 PERCENT CONFIDENCE LEVEL

Number of replicates	Degrees of freedom (n-1)	$t_{cn-1,.99}$)
7	6	3.143
8	7	2.998
9	8	2.896
10	9	2.821
11	10	2.764
16	15	2.602
21	20	2.528
26	25	2.485
31	30	2.457
61	60	2.390
00	00	2.326

Reporting

The analytical method used must be specifically identified by number or title ald the MDL for each analyte expressed in the appropriate method reporting units. If the analytical method permits options which affect the method detection limit, these conditions must be specified with the MDL value. The sample matrix used to determine the MDL must also be identified with MDL value. Report the mean analyte level with the MDL and indicate if the MDL procedure was iterated. If a laboratory standard or a sample that contained a known amount analyte was used for this determination, also report the mean recovery.

If the level of analyte in the sample was below the determined MDL or exceeds 10 times the MDL of the analyte in reagent water, do not report a value for the MDL.

[49 FR 43430, Oct. 26, 1984; 50 FR 694, 696, Jan. 4, 1985, as amended at 51 FR 23703, June 30, 1986]

APPENDIX C TO PART 136—INDUCTIVELY COUPLED PLASMA—ATOMIC EMISSION SPECTROMETRIC METHOD FOR TRACE ELEMENT ANALYSIS OF WATER AND WASTES METHOD 200.7

1. Scope and Application

1.1 This method may be used for the determination of dissolved, suspended, or total elements in drinking water, surface water, and domestic and industrial wastewaters.

1.2 Dissolved elements are determined in filtered and acidified samples. Appropriate steps must be taken in all analyses to ensure that potential interferences are taken into account. This is especially true when dissolved solids exceed 1500 mg/L. (See Section 5.)

1.3 Total elements are determined after appropriate digestion procedures are performed. Since digestion techniques increase the dissolved solids content of the samples, appropriate steps must be taken to correct for potential interference effects. (See Section 5.)

1.4 Table 1 lists elements for which this method applies along with recommended wavelengths and typical estimated instrumental detection limits using conventional pneumatic nebulization. Actual working detection limits are sample dependent and as the sample matrix varies, these concentrations may also vary. In time, other elements may be added as more information becomes available and as required.

1.5 Because of the differences between various makes and models of satisfactory instruments, no detailed instrumental operating instructions can be provided. Instead, the analyst is referred to the instruction provided by the manufacturer of the particular instrument.

2. Summary of Method

2.1 The method describes a technique for the simultaneous or sequential multielement determination of trace elements in solution. The basis of the method is the measurement of atomic emission by an optical spectroscopic technique. Samples are nebulized and the aerosol that is produced is transported to the plasma torch where excitation occurs. Characteristic atomic-line emission spectra are produced by a radio-frequency inductively coupled plasma (ICP). The spectra are dispersed by a grating spectrometer and the intensities of the lines are monitored by photomultiplier tubes. The photocurrents from the photomultiplier tubes are processed and controlled by a computer system. A background correction technique is required to compensate for variable background contribution to the determination of trace elements. Background must be measured adjacent to analyte lines on samples during analysis. The position selected for the background intensity measurement, on either or both sides of the analytical line, will be determined by the complexity of the spectrum adjacent to the analyte line. The position used must be free of spectral interference and reflect the same change in background intensity as occurs at the analyte wavelength measured. Background correction is not required in cases of line broadening where a background correction measurement would actually degrade the analytical result. The possibility of additional interferences named in 5.1 (and tests for their presence as described in 5.2) should also be recognized and appropriate corrections made.

3. Definitions

3.1 *Dissolved*—Those elements which will pass through a 0.45 µm membrane filter.

3.2 *Suspended*—Those elements which are retained by a 0.45 µm membrane filter.

3.3 *Total*—The concentration determined on an unfiltered sample following vigorous digestion (Section 9.3), or the sum of the dissolved plus suspended concentrations. (Section 9.1 plus 9.2).

3.4 *Total recoverable*—The concentration determined on an unfiltered sample following treatment with hot, dilute mineral acid (Section 9.4).

3.5 *Instrumental detection limit*—The concentration equivalent to a signal, due to the analyte, which is equal to three times the standard deviation of a series of ten replicate measurements of a reagent blank signal at the same wavelength.

3.6 *Sensitivity*—The slope of the analytical curve, i.e. functional relationship between emission intensity and concentration.

3.7 *Instrument check standard*—A multielement standard of known concentrations prepared by the analyst to monitor and verify instrument performance on a daily basis. (See 7.6.1)

3.8 *Interference check sample*—A solution containing both interfering and analyte elemelts of known concentration that can be used to verify background and interelement correction factors. (See 7.6.2.)

3.9 *Quality control sample*—A solution obtained from an outside source having known, concentration values to be used to verify the calibration standards. (See 7.6.3)

3.10 *Calibration standards*—A series of known standard solutions used by the analyst for calibration of the instrument (i.e., preparation of the analytical curve). (See 7.4)

3.11 *Linear dynamic range*—The concentration range over which the analytical curve remains linear.

3.12 *Reagent blank*—A volume of deionized, distilled water containing the same acid matrix as the calibration standards carried through the entire analytical scheme. (See 7.5.2)

3.13 *Calibration blank*—A volume of deionized, distilled water acidified with HNO_3 and HCl. (See 7.5.1)

3.14 *Methmd of standard addition*— The standard addition technique involves the use of the unknown and the unknown plus a known amount of standard. (See 10.6.1.)

4. Safety

4.1 The toxicity of carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is repsonsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material data handling sheets should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified [14.7,14.8and14.9] for the information of the analyst.

5. Interferences

5.1 Several types of interference effects may contribute to inaccuracies in the determination of trace elements. They can be summarized as follows:

5.1.1 *Spectral interferences* can be categorized as (1) overlap of a spectral line from another element; (2) unresolved overlap of molecular band spectra; (3) background contribution from continuous or recombination phenomena; and (4) background contribution from stray light from the line emission of high concentration elements. The first of these effects can be compensated by utilizing a computer correction of the raw data, requiring the monitoring and measurement of the interfering element. The second effect may require selection of an alternate wavelength. The third and fourth effects can usually be compensated by a background correction adjacent to the analyte line. In addition, users of simultaneous multi-element instrumentation must assume the responsibility of verifying the absence of spectral interference from an element that could occur in a sample but for which there is no channel in the instrument array. Listed in Table 2 are some interference effects for the recommended wavelengths given in Table 1. The data in Table 2 are intended for use only as a rudimentary guide for the indication of potential spectral interferences. For this purpose, linear relations between concentration and intensity for the analytes and the interferents can be assumed. The Interference information, which was collected at the Ames Laboratory,[1] is expressed as analyte concentration equivalents (i.e. false analyte concentrations) arising from 100 mg/L of the interferent element. The suggested use of this information is as follows: Assume that arsenic (at 193.696 nm) is to be determined in a sample containing approximately 10 mg/L of aluminum. According to Table 2, 100 mg/L of aluminum would yield a false signal for arsenic equivalent to approximately 1.3 mg/L. Therefore, 10 mg/L of aluminum would result in a false signal for arsenic equivalent to approximately 0.13 mg/L. The reader is cautioned that other analytical systems may exhibit somewhat different levels of interference than those shown in Table 2, and that the interference effects must be evaluated for each individual system.

Only those interferents listed were investigated and the blank spaces in Table 2 indicate that measurable interferences were not observed for the interferent concentrations listed in Table 3. Generally, interferences were discernible if they produced peaks or background shifts corresponding to 2–5% of the peaks generated by the analyte concentrations also listed in Table 3.

At present, information on the listed silver and potassium wavelengths are not available but it has been reported that second order energy from the magnesium 383.231 nm wavelength interferes with the listed potassium line at 766.491 nm.

5.1.2 *Physical interferences* are generally considered to be effects associated with the sample nebulization and transport processes. Such properties as change in viscosity and surface tension can cause significant inaccuracies especially in samples which may contain high dissolved solids and/or acid concentrations. The use of a peristaltic pump may lessen these interferences. If these types of interferences are operative, they must be reduced by dilution of the sample and/or utilization of standard addition techniques. Another problem which can occur from high dissolved solids is salt buildup at the tip of the nebulizer. This affects aersol flow rate causing instrumental drift. Wetting the argon prior to nebulization, the use of a tip washer, or sample dilution have been used to control this problem. Also, it has been reported that better control of the argon flow rate improves instrument performance. This is accomplished with the use of mass flow controllers.

[1] Ames Laboratory, USDOE, Iowa State University, Ames Iowa 50011.

5.1.3 *Chemical Interferences* are characterized by molecular compound formation, ionization effects and solute vaporization effects. Normally these effects are not pronounced with the ICP technique, however, if observed they can be minimized by careful selection of operating conditions (that is, incident power, observation position, and so forth), by buffering of the sample, by matrix matching, and by standard addition procedures. These types of interferences can be highly dependent on matrix type and the specific analyte element.

5.2 It is recommended that whenever a new or unusual sample matrix is encountered, a series of tests be performed prior to reporting concentration data for analyte elements. These tests, as outlined in 5.2.1 through 5.2.4, will ensure the analyst that neither positive nor negative interference effects are operative on any of the analyte elements thereby distorting the accuracy of the reported values.

5.2.1 *Serial dilution*. If the analyte concentration is sufficiently high (minimally a factor of 10 above the instrumental detection limit after dilution), an analysis of a dilution should agree within 5 percent of the original determination (or within some acceptable control limit (14.3) that has been established for that matrix.). If not, a chemical or physical interference effect should be suspected.

5.2.2 *Spike addition*. The recovery of a spike addition added at a minimum level of 10X the instrumental detection limit (maximum 100X) to the original determination should be recovered to within 90 to 110 percent or within the established control limit for that matrix. If not, a matrix effect should be suspected. The use of a standard addition analysis procedure can usually compensate for this effect.

Caution: The standard addition technique does not detect coincident spectral overlap. If suspected, use of computerized compensation, an alternate wavelength, or comparison with an alternate method is recommended (See 5.2.3).

5.2.3 *Comparison with alternate method of analysis.* When investigating a new sample matrix, comparison tests may be performed with other analytical techniques such as atomic absorption spectrometry, or other approved methodology.

5.2.4 *Wavelength scanning of analyte line region.* If the appropriate equipment is available, wavelength scanning can be performed to detect potential spectral interferences.

6. Apparatus

6.1 Inductively Coupled Plasma-Atomic Emission Spectrometer.

6.1.1 Computer controlled atomic emission spectrometer with background correction.

6.1.2 Radiofrequency generator.

6.1.3 Argon gas supply, welding grade or better.

6.2 Operating conditions—Because of the differences between various makes and models of satisfactory instruments, no detailed operating instructions can be provided. Instead, the analyst should follow the instructions provided by the manufacturer of the particular instrument. Sensitivity, instrumental detection limit, precision, linear dynamic range, and interference effects must be investigated and established for each individual analyte line on that particular instrument. It is the responsibility of the analyst to verify that the instrument configuration and operating conditions used satisfy the analytical requirements and to maintain quality control data confirming instrument performance and analytical results.

7. Reagents and Standards

7.1 Acids used in the preparation of standards and for sample processing must be ultra-high purity grade or equivalent. Redistilled acids are acceptable.

7.1.1 *Acetic acid*, conc. (sp gr 1.06).

7.1.2 *Hydrochloric acid*, conc. (sp gr 1.19).

7.1.3 *Hydrochloric acid*, (1+1): Add 500 mL conc. HCl (sp gr 1.19) to 400 mL deionized, distilled water and dilute to 1 liter.

7.1.4 *Nitric acid*, conc. (sp gr 1.41).

7.1.5 *Nitric acid*, (1+1): Add 500 mL conc. HNO_3 (sp gr 1.41) to 400 mL deionized, distilled water and dilute to 1 liter.

7.2 *Deionized, distilled water:* Prepare by passing distilled water through a mixed bed of cation and anion exchange resins. Use deionized, distilled water for the preparation of all reagents, calibration standards and as dilution water. The purity of this water must be equivalent to ASTM Type II reagent water of Specification D 1193 (14.6).

7.3 *Standard stock solutions* may be purchased or prepared from ultra high purity grade chemicals or metals. All salts must be dried for 1 h at 105 °C unless otherwise specified.

(CAUTION: Many metal salts are extremely toxic and may be fatal if swallowed. Wash hands thoroughly after handling.)

Typical stock solution preparation procedures follow:

7.3.1 *Aluminum solution, stock*, 1 mL=100μg Al: Dissolve 0.100 g of aluminum metal in an acid mixture of 4 mL of (1+1) HCl and 1 mL of conc. HNO_3 in a beaker. Warm gently to effect solution. When solution is complete, transfer quantitatively to a liter flask add an additional 10 mL of (1+1) HCl and dilute to 1,000 mL with deionized, distilled water.

7.3.2 *Antimony solution stock*, 1 mL=100 μg Sb: Dissolve 0.2669 g $K(SbO)C_4H_4O_6$ in deionized distilled water, add 10 mL (1+1) HCl and dilute to 1,000 mL with deionized, distilled water.

7.3.3 *Arsenic solution, stock,* 1 mL=100 µg As: Dissolve 0.1320 g of As_2O_3 in 100 mL of deionized, distilled water containing 0.4 g NaOH. Acidify the solution with 2 mL conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.4 *Barium solution, stock,* 1 mL=100 µg Ba: Dissolve 0.1516 g $BaCl_2$ (dried at 250 °C for 2 hrs) in 10 mL deionized, distilled water with 1 mL (1+1) HCl. Add 10.0 mL (1+1) HCl and dilute to 1,000 with mL deionized, distilled water.

7.3.5 *Beryllium solution, stock,* 1 mL=100 µg Be: *Do not dry.* Dissolve 1.966 g $BeSO_4 \cdot 4H_2O$, in deionized, distilled water, add 10.0 mL conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.6 *Boron solution, stock,* 1 mL=100µg B: *Do not dry.* Dissolve 0.5716 g anhydrous H_3BO_3 in deionized, distilled water and dilute to 1,000 mL. Use a reagent meeting ACS specifications, keep the bottle tightly stoppered and store in a desiccator to prevent the entrance of atmospheric moisture.

7.3.7 *Cadmium solution, stock,* 1 mL=100 µg Cd: Dissolve 0.1142 g CdO in a minimum amount of (1+1) HNO_3. Heat to increase rate of dissolution. Add 10.0 mL conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.8 *Calcium solution, stock,* 1 mL=100 µg Ca: Suspend 0.2498 g $CaCO_3$ dried at 180 °C for 1 h before weighing in deionized, distilled water and dissolve cautiously with a minimum amount of (1+1) HNO_3. Add 10.0 mL conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.9 *Chromium solution, stock,* 1 mL=100 µg Cr: Dissolve 0.1923 g of CrO_3 in deionized, distilled water. When solution is complete, acidify with 10 mL conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.10 *Cobalt solution, stock,* 1 mL=100 µg Co: Dissolve 0.1000 g of cobalt metal in a minimum amount of (1+1) HNO_3. Add 10.0 mL (1+1) HCl and dilute to 1,000 mL with deionized, distilled water.

7.3.11 *Copper solution, stock,* 1 mL=100 µg Cu: Dissolve 0.1252 g CuO in a minimum amount of (1+1) HNO_3. Add 10.0 mL conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.12 *Iron solution, stock,* 1 mL=100 µg Fe: Dissolve 0.1430 g Fe_2O_3 in a warm mixture of 20 mL (1+1) HCl and 2 mL of conc. HNO_3. Cool, add an additional 5 mL of conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.13 *Lead solution, stock,* 1 mL=100 µg Pb: Dissolve 0.1599 g $Pb(NO_3)_2$ in a minimum amount of (1+1) HNO_3. Add 10.0 mL conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.14 *Magnesium solution, stock,* 1 mL=100 µg Mg: Dissolve 0.1658 g MgO in a minimum amount of (1+1) HNO_3. Add 10.0 mL conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.15 *Manganese solution, stock,* 1 mL=100 µg Mn: Dissolve 0.1000 g of manganese metal in the acid mixture 10 mL conc. HCl and 1 mL conc. HNO_3, and dilute to 1,000 mL with deionized, distilled water.

7.3.16 *Molybdenum solution, stock,* 1 mL=100 µg Mo: Dissolve 0.2043 g $(NH_4)_2$ MoO_4 in deionized, distilled water and dilute to 1,000 mL.

7.3.17 *Nickel solution, stock,* 1 mL=100 µg Ni: Dissolve 0.1000 g of nickel metal in 10 mL hot conc. HNO_3, cool and dilute to 1,000 mL with deionized, distilled water.

7.3.18 *Potassium solution, stock,* 1 mL=100 µg K: Dissolve 0.1907 g KCl, dried at 110 °C, in deionized, distilled water and dilute to 1,000 mL.

7.3.19 *Selenium solution, stock,* 1 mL=100 µg Se: *Do not dry.* Dissolve 0.1727 g H_2SeO_3 (actual assay 94.6%) in deionized, distilled water and dilute to 1,000 mL.

7.3.20 *Silica solution, stock,* 1 mL=100 µg SiO_2≤ *Do not dry.* Dissolve 0.4730 g $Na_2SiO_3 \cdot 9H_2O$ in deionized, distilled water. Add 10.0 mL conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.21 *Silver solution, stock,* 1 mL=100 µg Ag: Dissolve 0.1575 g $AgNO_3$ in 100 mL of deionized, distilled water and 10 mL conc. HNO_3. Dilute to 1,000 mL with deionized, distilled water.

7.3.22 *Sodium solution, stock,* 1 mL=100 µg Na: Dissolve 0.2542 g NaCl in deionized, distilled water. Add 10.0 mL conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.23 *Thallium solution, stock,* 1 mL=100 µg Tl: Dissolve 0.1303 g $TlNO_3$ in deionized, distilled water. Add 10.0 mL conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.24 *Vanadium solution, stock,* 1 mL=100 µg V: Dissolve 0.2297 NH_4 VO_3 in a minimum amount of conc. HNO_3. Heat to increase rate of dissolution. Add 10.0 mL conc. HNO_3 and dilute to 1,000 mL with deionized, distilled water.

7.3.25 *Zinc solution, stock,* 1 mL=100 µg Zn: Dissolve 0.1245 g ZnO in a minimum amount of dilute HNO_3. Add 10.0 mL conc. HNO_3 and dilute to 1,000 mL deionized, distilled water.

7.4 *Mixed calibration standard solutions*—Prepare mixed calibration standard solutions by combining appropriate volumes of the stock solutions in volumetric flasks. (See 7.4.1 thru 7.4.5) Add 2 mL of (1+1) HNO_3 and 10 mL of (1+1) HC1 and dilute to 100 mL with deionized, distilled water. (See Notes 1 and 6.) Prior to preparing the mixed standards, each stock solution should be analyzed separately to determine possible spectral interference or the presence of impurities. Care should be taken when preparing the

mixed standards that the elemelts are compatible and stable. Transfer the mixed standard solutions to a FEP fluorocarbon or unused polyethylene bottle for storage. Fresh mixed standards should be prepared as needed with the realization that concentration can change on aging. Calibration standards must be initially verified using a quality control sample and monitored weekly for stability (See 7.6.3). Although not specifically required, some typical calibration standard combinations follow when using those specific wavelengths listed in Table 1.

7.4.1 *Mixed standard solution I*—Manganese, beryllium, cadmium, lead, and zinc.

7.4.2 *Mixed standard solution II*—Barium, copper, iron, vanadium, and cobalt.

7.4.3 *Mixed standard solution III*—Molybdenum, silica, arsenic, and selenium.

7.4.4 *Mixed standard solution IV*—Calcium, sodium, potassium, aluminum, chromium and nickel.

7.4.5 *Mixed standard solution V*— Antimony, boron, magnesium, silver, and thallium.

NOTE: 1. If the addition of silver to the recommended acid combination results in an initial precipitation, add 15 mL of deionized distilled water and warm the flask until the solution clears. Cool and dilute to 100 mL with deionized, distilled water. For this acid combination the silver concentration should be limited to 2 mg/L. Silver under these conditions is stable in a tap water matrix for 30 days. Higher concentrations of silver require additional HCl.

7.5 Two types of blanks are required for the analysis. The calibration blank (3.13) is used in establishing the analytical curve while the reagent blank (3.12) is used to correct for possible contamination resulting from varying amounts of the acids used in the sample processing.

7.5.1 *The calibration blank* is prepared by diluting 2 mL of (1+1) HNO_3 and 10 mL of (1+1) HCl to 100 mL with deionized, distilled water. (See Note 6.) Prepare a sufficient quantity to be used to flush the system between standards and samples.

7.5.2 *The reagent blank* must contain all the reagents and in the same volumes as used in the processing of the samples. The reagent blank must be carried through the complete procedure and contain the same acid concentration in the final solution as the sample solution used for analysis.

7.6 In addition to the calibration standards, an instrument check standard (3.7), an interference check sample (3.8) and a quality control sample (3.9) are also required for the analyses.

7.6.1 The *instrument check standard* is prepared by the analyst by combining compatible elements at a concentration equivalent to the midpoint of their respective calibration curves. (See 12.1.1.)

7.6.2 The *interference check sample* is prepared by the analyst in the following manner. Select a representative sample which contains minimal concentrations of the analytes of interest but known concentration of interfering elements that will provide an adequate test of the correction factors. Spike the sample with the elements of interest at the approximate concentration of either 100 µg/L or 5 times the estimated detection limits given in Table 1. (For effluent samples of expected high concentrations, spike at an appropriate level.) If the type of samples analyzed are varied, a synthetically prepared sample may be used if the above criteria and intent are met.

7.6.3 The *quality control sample* should be prepared in the same acid matrix as the calibration standards at a concentration near 1 mg/L and in accordance with the instructions provided by the supplier. The Quality Assurance Branch of EMSL-Cincinnati will either supply a quality control sample or information where one of equal quality can be procured. (See 12.1.3.)

8. Sample Handling and Preservation

8.1 For the determination of trace elements, contamination and loss are of prime concern. Dust in the laboratory environment, impurities in reagents and impurities on laboratory apparatus which the sample contacts are all sources of potential contamination. Sample containers can introduce either positive or negative errors in the measurement of trace elements by (a) contributing contaminants through leaching or surface desorption and (b) by depleting concentrations through adsorption. Thus the collection and treatment of the sample prior to analysis requires particular attention. Laboratory glassware including the sample bottle (whether polyethylene, polyproplyene or FEP-fluorocarbon) should be thoroughly washed with detergent and tap water; rinsed with (1+1) nitric acid, tap water, (1+1) hydrochloric acid, tap and finally deionized, distilled water in that order (See Notes 2 and 3).

NOTE: 2. Chromic acid may be useful to remove organic deposits from glassware; however, the analyst should be cautioned that the glassware must be thoroughly rinsed with water to remove the last traces of chromium. This is especially important if chromium is to be included in the analytical scheme. A commercial product, NOCHROMIX, available from Godax Laboratories, 6 Varick St., New York, NY 10013, may be used in place of chromic acid. Chromic acid should not be used with plastic bottles.

NOTE: 3. If it can be documented through an active analytical quality control program using spiked samples and reagent blanks, that certain steps in the cleaning procedure are not required for routine samples, those steps may be eliminated from the procedure.

8.2 Before collection of the sample a decision must be made as to the type of data desired, that is dissolved, suspended or total, so that the appropriate preservation and pretreatment steps may be accomplished. Filtration, acid preservation, etc., are to be performed at the time the sample is collected or as soon as possible thereafter.

8.2.1 For the determination of dissolved elements the sample must be filtered through a 0.45-μm membrane filter as soon as practical after collection. (Glass or plastic filtering apparatus are recommended to avoid possible contamination.) Use the first 50–100 mL to rinse the filter flask. Discard this portion and collect the required volume of filtrate. Acidify the filtrate with (1+1) HNO_3 to a pH of 2 or less. Normally, 3 mL of (1+1) acid per liter should be sufficient to preserve the sample.

8.2.2 For the determination of suspended elements a measured volume of unpreserved sample must be filtered through a 0.45-μm membrane filter as soon as practical after collection. The filter plus suspended material should be transferred to a suitable container for storage and/or shipment. No preservative is required.

8.2.3 For the determination of total or total recoverable elements, the sample is acidified with (1+1) HNO_3 to pH 2 or less as soon as possible, preferably at the time of collection. The sample is not filtered before processing.

9. Sample Preparation

9.1 For the determinations of dissolved elements, the filtered, preserved sample may often be analyzed as received. The acid matrix and concentration of the samples and calibration standards must be the same. (See Note 6.) If a precipitate formed upon acidification of the sample or during transit or storage, it must be redissolved before the analysis by adding additional acid and/or by heat as described in 9.3.

9.2 For the determination of suspended elements, transfer the membrane filter containing the insoluble material to a 150-mL Griffin beaker and add 4 mL conc. HNO_3. Cover the beaker with a watch glass and heat gently. The warm acid will soon dissolve the membrane. Increase the temperature of the hot plate and digest the material. When the acid has nearly evaporated, cool the beaker and watch glass and add another 3 mL of conc. HNO_3. Cover and continue heating until the digestion is complete, generally indicated by a light colored digestate. Evaporate to near dryness (2 mL), cool, and 10 mL HCl (1+1) and 15 mL deionized, distilled water per 100 mL dilution and warm the beaker gently for 15 min. to dissolve any precipitated or residue material. Allow to cool, wash down the watch glass and beaker walls with deionized distilled water and filter the sample to remove insoluble material that could clog the nebulizer. (See Note 4.) Adjust the volume based on the expected concentrations of elements present. This volume will vary depending on the elements to be determined (See Note 6). The sample is now ready for analysis. Concentrations so determined shall be reported as ''suspended.''

NOTE: 4. In place of filtering, the sample after diluting and mixing may be centrifuged or allowed to settle by gravity overnight to remove insoluble material.

9.3 For the determination of total elements, choose a measured volume of the well mixed acid preserved sample appropriate for the expected level of elements and transfer to a Griffin beaker. (See Note 5.) Add 3 mL of conc. HNO_3. Place the beaker on a hot plate and evaporate to near dryness cautiously, making certain that the sample does not boil and that no area of the bottom of the beaker is allowed to go dry. Cool the beaker and add another 5 mL portion of conc. HNO_3. Cover the beaker with a watch glass and return to the hot plate. Increase the temperature of the hot plate so that a gently reflux action occurs. Continue heating, adding additional acid as necessary, until the digestion is complete (generally indicated when the digestate is light in color or does not change in appearance with continued refluxing.) Again, evaporate to near dryness and cool the beaker. Add 10 mL of 1+1 HCl and 15 mL of deionized, distilled water per 100 mL of final solution and warm the beaker gently for 15 min. to dissolve any precipitate or residue resulting from evaporation. Allow to cool, wash down the beaker walls and watch glass with deionized distilled water and filter the sample to remove insoluble material that could clog the nebulizer. (See Note 4.) Adjust the sample to a predetermined volume based on the expected concentrations of elements present. The sample is now ready for analysis (See Note 6). Concentrations so determined shall be reported as ''total.''

NOTE: 5. If low determinations of boron are critical, quartz glassware should be used.

NOTE: 6. If the sample analysis solution has a different acid concentration from that given in 9.4, but does not introduce a physical interference or affect the analytical result, the same calibration standards may be used.

9.4 For the determination of total recoverable elements, choose a measured volume of a well mixed, acid preserved sample appropriate for the expected level of elements and transfer to a Griffin beaker. (See Note 5.) Add 2 mL of (1+1) HNO_3 and 10 mL of (1+1) HCl to the sample and heat on a steam bath or hot plate until the volume has been reduced to near 25 mL making certain the sample does not boil. After this treatment, cool the sample and filter to remove insoluble material that could clog the nebulizer. (See Note 4.) Adjust the volume to 100 mL and

mix. The sample is now ready for analysis. Concentrations so determined shall be reported as ''total.''

10. Procedure

10.1 Set up instrument with proper operating parameters established in Section 6.2. The instrument must be allowed to become thermally stable before beginning. This usually requires at least 30 min. of operation prior to calibration.

10.2 Initiate appropriate operating configuration of computer.

10.3 Profile and calibrate instrument according to instrument manufacturer's recommended procedures, using the typical mixed calibration standard solutions described in Section 7.4. Flush the system with the calibration blank (7.5.1) between each standard. (See Note 7.) (The use of the average intensity of multiple exposures for both standardization and sample analysis has been found to reduce random error.)

NOTE: 7. For boron concentrations greater than 500 µg/L extended flush times of 1 to 2 minutes may be required.

10.4 Before beginning the sample run, reanalyze the highest mixed calibration standard as if it were a sample. Concentration values obtained should not deviate from the actual values by more than ±5 percent (or the established control limits whichever is lower). If they do, follow the recommendations of the instrument manufacturer to correct for this condition.

10.5 Begin the sample run flushing the system with the calibration blank solution (7.5.1) between each sample. (See Note 7.) Analyze the instrument check standard (7.6.1) and the calibration blank (7.5.1) each 10 samples.

10.6 If it has been found that methods of standard addition are required, the following procedure is recommended.

10.6.1 The standard addition technique (14.2) involves preparing new standards in the sample matrix by adding known amounts of standard to one or more aliquots of the processed sample solution. This technique compensates for a sample constitutent that enhances or depresses the analyte signal thus producing a different slope from that of the calibration standards. It will not correct for additive interference which causes a baseline shift. The simplest version of this technique is the single-addition method. The procedure is as follows. Two identical aliquots of the sample solution, each of volume V_x, are taken. To the first (labeled A) is added a small volume V_s of a standard analyte solution of concentration c_s. To the second (labeled B) is added the same volume V_s of the solvent. The analytical signals of A and B are measured and corrected for nonanalyte signals. The unknown sample concentration c_x is calculated:

$$c_x = \frac{S_B V_s c_s}{(S_A - S_B) V_x}$$

where S_A and S_B are the analytical signals (corrected for the blank) of solutions A and B, respectively. V_s and c_s should be chosen so that S_A is roughly twice S_B on the average. It is best if V_s is made much less than V_x, and thus c_s is much greater than c_x, to avoid excess dilution of the sample matrix. If a separation or concentration step is used, the additions are best made first and carried through the entire procedure. For the results from this technique to be valid, the following limitations must be taken into consideration:

1. The analytical curve must be linear.
2. The chemical form of the analyte added must respond the same as the analyte in the sample.
3. The interference effect must be constant over the working range of concern.
4. The signal must be corrected for any additive interference.

11. Calculation

11.1 Reagent blanks (7.5.2) should be subtracted from all samples. This is particularly important for digested samples requiring large quantities of acids to complete the digestion.

11.2 If dilutions were performed, the appropriate factor must be applied to sample values.

11.3 Data should be rounded to the thousandth place and all results should be reported in mg/L up to three significant figures.

12. Quality Control (Instrumental)

12.1 Check the instrument standardization by analyzing appropriate quality control check standards as follow:

12.1.1 Analyze and appropriate instrument check standard (7.6.1) containing the elements of interest at a frequency of 10%. This check standard is used to determine instrument drift. If agreement is not within ±5% of the expected values or within the established control limits, whichever is lower, the analysis is out of control. The analysis should be terminated, the problem corrected, and the instrument recalibrated.

Analyze the calibration blank (7.5.1) at a frequency of 10%. The result should be within the established control limits of 2 standard deviations of the meal value. If not, repeat the analysis two more times and average the three results. If the average is not wihin the control limit, terminate the analysis, correct the problem and recalibrate the instrument.

12.1.2 To verify interelement and background correction factors analyze the interference check sample (7.6.2) at the beginning,

end, and at periodic intervals throughout the sample run. Results should fall within the established control limits of 1.5 times the standard deviation of the mean value. If not, terminate the analysis, correct the problem and recalibrate the instrument.

12.1.3 A quality control sample (7.6.3) obtained from an outside source must first be used for the initial verification of the calibration standards. A fresh dilution of this sample shall be analyzed every week thereafter to monitor their stability. If the results are not within ±5% of the true value listed for the control sample, prepare a new calibration standard and recalibrate the instrument. If this does not correct the problem, prepare a new stock standard and a new calibration standard and repeat the calibration.

13. Precision and Accuracy

13.1 An interlaboratory study of metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of the twenty-five elements listed in Table 4 were added to reagent water, surface water, drinking water and three effluents. These samples were digested by both the total digestion procedure (9.3) and the total recoverable procedure (9.4). Results for both digestions for the twenty-five elements in reagent water are given in Table 4; results for the other matrices can be found in Reference 14.10.

14. References

14.1 Winge, R.K., V.J. Peterson, and V.A. Fassel, ''Inductively Coupled Plasma-Atomic Emission Spectroscopy: Prominent Lines, EPA–600/4–79–017.

14.2 Winefordner, J.D., ''Trace Analysis: Spectroscopic Methods for Elements,'' *Chemical Analysis,* Vol, *46,* pp. 41–42.

14.3 Handbook for Analytical Quality Control in Water and Wastewater Laboratories, EPA–600/4–79–019.

14.4 Garbarino, J.R. and Taylor, H.E., ''An Inductively-Coupled Plasma Atomic Emission Spectrometric Method for Routine Water Quality Testing,'' Applied Spectroscopy *33,* No. 3 (1979).

14.5 ''Methods for Chemical Analysis of Water and Wastes,'' EPA–600/4–79–020.

14.6 Annual Book of ASTM Standards, Part 31.

14.7 ''Carcinogens—Working With Carcinogens,'' Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, Publication No. 77–206, August 1977.

14.8 ''OSHA Safety and Health Standards, General Industry,'' (29 CFR Part 1910), Occupational Safety and Health Administration, OSHA 2206, (Revised, January 1976).

14.9 ''Safety in Academic Chemistry Laboratories, American Chemical Society Publication, Committee on Chemical Safety, 3rd Edition, 1979.

14.10 Maxfield R. and Minak B., ''EPA Method Study 27, Method 200.7 Trace Metals by ICP,'' National Technical Information Service, Order No. PB 85–248–656, November 1983.

TABLE 1—RECOMMENDED WAVELENGTHS [1] AND ESTIMATED INSTRUMENTAL DETECTION LIMITS

Element	Wavelength, nm	Estimated detection limit, µg/L [2]
Aluminum	308.215	45
Arsenic	193.696	53
Antimony	206.833	32
Barium	455.403	2
Beryllium	313.042	0.3
Boron	249.773	5
Cadmium	226.502	4
Calcium	317.933	10
Chromium	267.716	7
Cobalt	228.616	7
Copper	324.754	6
Iron	259.940	7
Lead	220.353	42
Magnesium	279.079	30
Manganese	257.610	2
Molybdenum	202.030	8
Nickel	231.604	15
Potassium	766.491	[3]
Selenium	196.026	75
Silica (SiO_2)	288.158	58
Silver	328.068	7
Sodium	588.995	29
Thallium	190.864	40
Vanadium	292.402	8
Zinc	213.856	2

[1] The wavelengths listed are recommended because of their sensitivity and overall acceptance. Other wavelengths may be substituted if they can provide the needed sensitivity and are treated with the same corrective techniques for spectral interference. (See 5.1.1).

[2] The estimated instrumental detection limits as shown are taken from ''Inductively Coupled Plasma-Atomic Emission Spectroscopy-Prominent Lines,'' EPA–600/4–79–017. They are given as a guide for an instrumental limit. The actual method detection limits are sample dependent and may vary as the sample matrix varies.

[3] Highly dependent on operating conditions and plasma position.

TABLE 1—ANALYTE CONCENTRATION EQUIVALENTS (MG/L) ARISING FROM INTERFERENTS AT THE 100 MG/L LEVEL

Analyte	Wavelength, nm	Interferent—									
		A1	Ca	Cr	Cu	Fe	Mg	Mn	Ni	Ti	V
Aluminum	308.214	.....	.....	.....	.....	.....	.....	0.21	.....	.....	1.4

TABLE 1—ANALYTE CONCENTRATION EQUIVALENTS (MG/L) ARISING FROM INTERFERENTS AT THE 100 MG/L LEVEL—Continued

Analyte	Wavelength, nm	Interferent—									
		A1	Ca	Cr	Cu	Fe	Mg	Mn	Ni	Ti	V
Antimony	206.833	0.47	.....	2.9	.....	0.08	.....	.....	.....	0.25	0.45
Arsenic	193.696	1.3	.....	0.44	.....	.....	.....	.....	.....	.....	1.1
Barium	455.403	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Beryllium	313.042	.....	.....	.....	.....	.....	.....	.....	.....	0.04	0.05
Boron	249.773	0.04	.....	.....	.....	0.32	.....	.....	.....	.....	.....
Cadmium	226.502	.....	.....	.....	.....	0.03	.....	.....	0.02	.....	.....
Calcium	317.933	.....	.....	0.08	.....	0.01	0.01	0.04	.....	0.03	0.03
Chromium	267.716	.....	.....	.....	.....	0.003	.....	0.04	.....	.....	0.04
Cobalt	228.616	.....	.....	0.03	.....	0.005	.....	.....	0.03	0.15	.....
Copper	324.754	.....	.....	.....	.....	0.003	.....	.....	.....	0.05	0.02
Iron	259.940	.....	.....	.....	.....	.....	.....	0.12	.....	.....	.....
Lead	220.353	0.17	.....	.....	.....	.....	.....	.....	.....	.....	.....
Magnesium	279.079	.....	0.02	0.11	.....	0.13	.....	0.25	.....	0.07	0.12
Manganese	257.610	0.005	.....	0.01	.....	0.002	0.002	.....	.....	.....	.....
Molybdenum	202.030	0.05	.....	.....	.....	0.03	.....	.....	.....	.....	.....
Nickel	231.604	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Selenium	196.026	0.23	.....	.....	.....	0.09	.....	.....	.....	.....	.....
Silicon	288.158	.....	.....	0.07	.....	.....	.....	.....	.....	.....	0.01
Sodium	588.995	.....	.....	.....	.....	.....	.....	.....	.....	0.08	.....
Thallium	190.864	0.30	.....	.....	.....	.....	.....	.....	.....	.....	.....
Vanadium	292.402	.....	.....	0.05	.....	0.005	.....	.....	.....	0.02	.....
Zinc	213.856	.....	.....	.....	0.14	.....	.....	.....	0.29	.....	.....

TABLE 3—INTERFERENT AND ANALYTE ELEMENTAL CONCENTRATIONS USED FOR INTERFERENCE MEASUREMELTS IN TABLE 2

Analytes	(mg/L)		Interferents	(mg/L)	
Al	10		Al	1,000	
AS	10		Ca	1,000	
B	10		Cr	200	
Ba	1		Cu	200	
Be	1		Fe	1,000	
Ca	1		Mg	1,000	
Cd	10		Mn	200	
Co	1		Ni	200	
Cr	1		Ti	200	
Cu	1		V	200	
Fe	1				
Mg	1				
Mn	1				
Mo	10				
Na	10				
Ni	10				
Pb	10				
Sb	10				
Se	10				
Si	1				
Tl	10				
V	1				
Zn	10				

TABLE 4—ICP PRECISION AND RECOVERY DATA

Analyte	Concentration µg/L	Total digestion (9.3) µg/L	Recoverable digestion (9.4) µg/L
Aluminum	69–4792	X=0.9273(C)+3.6 S=0.0559(X)+18.6 SR=0.0507(X)+3.5	X=0.9380(C)+22.1 S=0.0873(X)+31.7 SR=0.0481(X)+18.8
Antimony	77–1406	X=0.7940(C) − 17.0 S=0.1556(X) − 0.6 SR=0.1081(X)+3.9	X=0.8908(C)+0.9 S=0.0982(X)+8.3 SR=0.0682(X)+2.5
Arsenic	69–1887	X=1.0437(C) − 12.2 S=0.1239(X)+2.4 SR=0.0874(X)+6.4	X=1.0175(C)+3.9 S=0.1288(X)+6.1 SR=0.0643(X)+10.3
Barium	9–377	X=0.7683(C)+0.47	X=0.8380(C)+1.68

TABLE 4—ICP PRECISION AND RECOVERY DATA—Continued

Analyte	Concentration µg/L	Total digestion (9.3) µg/L	Recoverable digestion (9.4) µg/L
		S=0.1819(X)+2.78	S=0.2540(X)+0.30
		SR=0.1285(X)+2.55	SR=0.0826(X)+3.54
Beryllium	3–1906	X=0.9629(C)+0.05	X=1.0177(C)−0.55
		S=0.0136(X)+0.95	S=0.0359(X)+0.90
		SR=0.0203(X)−0.07	SR=0.0445(X)−0.10
Boron	19–5189	X=0.8807(C)+9.0	X=0.9676(C)+18.7
		S=0.1150(X)+14.1	S=0.1320(X)+16.0
		SR=0.0742(X)+23.2	SR=0.0743(X)+21.1
Cadmium	9–1943	X=0.9874(C)−0.18	X=1.0137(C)−0.65
		S=0.557(X)+2.02	S=0.0585(X)+1.15
		SR=0.0300(X)+0.94	SR=0.332(X)+0.90
Calcium	17–47170	X=0.9182(C)−2.6	X=0.9658(C)+0.8
		S=0.1228(X)+10.1	S=0.0917(X)+6.9
		SR=0.0189(X)+3.7	SR=0.0327(X)+10.1
Chromium	13–1406	X=0.9544(C)+3.1	X=1.0049(C)−1.2
		S=0.0499(X)+4.4	S=0.0698(X)+2.8
		SR=0.0009(X)+7.9	SR=0.0571(X)+1.0
Cobalt	17–2340	X=0.9209(C)−4.5	X=0.9278(C)−1.5
		S=0.0436(X)+3.8	S=0.0498(X)+2.6
		SR=0.0428(X)+0.5	SR=0.0407(X)+0.4
Copper	8–1887	X=0.9297(C)−0.30	X=0.9647(C)−3.64
		S=0.0442(X)+2.85	S=0.0497(X)+2.28
		SR=0.0128(X)+2.53	SR=0.0406(X)+0.96
Iron	13–9359	X=0.8829(C)+7.0	X=0.9830(C)+5.7
		S=0.0683(X)+11.5	S=0.1024(X)+13.0
		SR=0.0046(X)+10.0	SR=0.0790(X)+11.5
Lead	42–4717	X=0.9699(C)−2.2	X=1.0056(C)+4.1
		S=0.0558(X)+7.0	S=0.0779(X)+4.6
		SR=0.0353(X)+3.6	SR=0.0448(X)+3.5
Magnesium	34–13868	X=0.9881(C)−1.1	X=0.9879(C)+2.2
		S=0.0607(C)+11.6	S=0.0564(X)+13.2
		SR=0.0298(X)+0.6	SR=0.0268(X)+8.1
Manganese	4–1887	X=0.9417(C)+0.13	X=0.9725(C)+0.07
		S=0.0324(X)+0.88	S=0.0557(X)+0.76
		SR=0.0153(X)+0.91	SR=0.0400(X)+0.82
Molybdenum	17–1830	X=0.9682(C)+0.1	X=0.9707(C)−2.3
		S=0.0618(X)+1.6	S=0.0811(X)+3.8
		SR=0.0371(X)+2.2	SR=0.0529(X)+2.1
Nickel	17–47170	X=0.9508(C)+0.4	X=0.9869(C)+1.5
		S=0.0604(X)+4.4	S=0.0526(X)+5.5
		SR=0.0425(X)+3.6	SR=0.0393(X)+2.2
Potassium	347–14151	X=0.8669(C)−36.4	X=0.9355(C)−183.1
		S=0.0934(X)+77.8	S=0.0481(X)+177.2
		SR=0.0099(X)+144.2	SR=0.0329(X)+60.9
Selenium	69–1415	X=0.9363(C)−2.5	X=0.9737(C)−1.0
		S=0.0855(X)+17.8	S=0.1523(X)+7.8
		SR=0.0284(X)+9.3	SR=0.0443(X)+6.6
Silicon	189–9434	X=0.5742(C)−35.6	X=0.9737(C)−60.8
		S=0.4160(X)+37.8	S=0.3288(X)+46.0
		SR=0.1987(X)+8.4	SR=0.2133(X)+22.6
Silver	8–189	X=0.4466(C)+5.07	X=0.3987(C)+8.25
		S=0.5055(X)−3.05	S=0.5478(X)−3.93
		SR=0.2086(X)−1.74	SR=0.1836(X)−0.27
Sodium	35–47170	X=0.9581(C)+39.6	X=1.0526(C)+26.7
		S=0.2097(X)+33.0	S=0.1473(X)+27.4
		SR=0.0280(X)+105.8	SR=0.0884(X)+50.5
Thallium	79–1434	X=0.9020(C)−7.3	X=0.9238(C)+5.5
		S=0.1004(X)+18.3	S=0.2156(X)+5.7
		SR=0.0364(X)+11.5	SR=0.0106(X)+48.0
Vanadium	13–4698	X=0.9615(C)−2.0	X=0.9551(C)+0.4
		S=0.0618(X)+1.7	S=0.0927(X)+1.6
		SR=0.0220(X)+0.7	SR=0.0472(X)+0.5
Zinc	7–7076	X=0.9356(C)−0.30	X=0.9500(C)+1.82
		S=0.0914(X)+3.75	S=0.0597(X)+6.50
		SR=0.0130(X)+10.7	SR=0.0153(X)+7.78

AAAAAX=Mean Recovery, µg/L
AAAAAC=True Value for the Concentration, µg/L
AAAAAS=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

[49 FR 43431, Oct. 26, 1984; 50 FR 695, 696, Jan. 4, 1985, as amended at 51 FR 23703, June 30, 1986; 55 FR 33440, Aug. 15, 1990]

APPENDIX D TO PART 136—PRECISION AND RECOVERY STATEMENTS FOR METHODS FOR MEASURING METALS

Twenty-eight selected methods from ''Methods for Chemical Analysis of Water and Wastes,'' EPA–600/4–79–020 (1979) have been subjected to interlaboratory method validation studies. The following precision and recovery statements are presented in this appendix and incorporated into part 136:

Method 202.1

For Aluminum, Method 202.1 (Atomic Absorption, Direct Aspiration) replace the Precision and Accuracy Section with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water and a natural water or effluent of the analyst's choice. The digestion procedure was not specified. Results for the reagent water are given below. Results for other water types and study details are found in ''USEPA Method Study 7, Analyses for Trace Methods in water by Atomic Absorption Spectroscopy (Direction Aspiration) and Colorimetry'', National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB86–208709/AS, Winter, J.A. and Britton, P.W., June, 1986.

For a concentration range of 500–1200 µg/L

$X=0.979(C)+6.16$
$S=0.066(X)+125$
$SR=0.086(X)+40.5$

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 206.4

For Arsenic, Method 206.4 (Spectrophotometric-SDDC) add the following to the Precision and Accuracy Section:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water and a natural water or effluent of the analyst's choice. Results for the reagent water are given below. Results for other water types and study details are found in ''USEPA Method Study 7, Analyses for Trace Methods in Water by Atomic Absorption Spectroscopy (Direct Aspiration) and Colorimetry'', National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB86–208709/AS, Winter, J.A. and Britton, P.W., June, 1986.

For a concentration range of 20–292 µg/L

$X=0.850(C)-0.25$
$S=0.198(X)+5.93$
$SR=0.122(X)+3.10$

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 213.1

For Cadmium, Method 213.1 (Atomic Absorption, Direct Aspiration) replace the Precision and Accuracy Section with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water and a natural water or effluent of the analyst's choice. The digestion procedure was not specified. Results for the reagent water are given below. Results for other water types and study details are found in ''USEPA Method Study 7, Analyses for Trace Methods in Water by Atomic Absorption Spectroscopy (Direct Aspiration) and Colorimetry'', National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB86–208709/AS, Winter, J.A. and Britton, P.W., June, 1986.

For a concentration range of 14–78 µg/L

$X=0.919(C)+2.97$
$S=0.108(X)+5.08$
$SR=0.120(X)+0.89$

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 218.1

For Chromium, Method 218.1 (Atomic Absorption, Direct Aspiration) replace the Precision and Accuracy Section with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water and a natural water or effluent of the analyst's choice. The digestion procedure was not specified. Results for the reagent water are given below. Results for other water types and study details are found in ''USEPA Method Study 7, Analyses for Trace Methods in Water by Atomic Absorption Spectroscopy (Direct Aspiration) and Colorimetry'', National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB86–208709/AS, Winter, J.A. and Britton, P.W., June 1986.

For a concentration range of 74–407 µg/L

X=0.976(C)+3.94
S=0.131(X)+4.26
SR=0.052(X)+3.01

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 220.1

For Copper, Method 220.1 (Atomic Absorption, Direct Aspiration) replace the Precision and Accuracy Section with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water and a natural water or effluent of the analyst's choice. The digestion procedure was not specified. Results for the reagent water are given below. Results for other water types and study details are found in ''USEPA Method Study 7, Analyses for Trace Methods in Water by Atomic Absorption Spectroscopy (Direct Aspiration) and Colorimetry'', National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB86–208709/AS, Winter, J.A. and Britton, P.W., June, 1986.

For concentration range 60–332 µg/L

X=0.963(C)+3.49
S=0.047(X)+12.3
SR=0.042(X)+4.60

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 236.1

For Iron, Method 236.1 (Atomic Absorption, Direct Aspiration) replace the Precision and Accuracy Section with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water and a natural water or effluent of the analyst's choice. The digestion procedure was not specified. Results for the reagent water are given below. Results for other water types and study details are found in ''USEPA Method Study 7, Analyses for Trade Methods in Water by Atomic Absorption Spectroscopy (Direct Aspiration) and Colorimetry'', National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB86–208709/AS, Winter, J.A. and Britton, P.W., June, 1986.

For concentration range 350–840 µg/L

X=0.999(C)−2.21
S=0.022(X)+41.0
SR=0.019(X)+21.2

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-Laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 239.1

For Lead, Method 239.1 (Atomic Absorption, Direct Aspiration) replace Precision and Accuracy Section with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water and a natural water or effluent of the analyst's choice. The digestion procedure was not specified. Results for the reagent water are given below. Results for other water types and study details are found in ''USEPA Method Study 7 Analyses for Trace Methods in Water by Atomic Absorption Spectroscopy

(Direct Aspiration) and Colorimetry''; National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB86–208709/AS, Winter, J.A. and Britton, P.W., June, 1986.

For concentration range of 84–367 µg/L

X=0.961(C)+13.8
S=0.028(C)+33.9
SR=0.011(X)+16.1

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 243.1

For Manganese, Method 243.1 (Atomic Absorption, Direct Aspiration) replace Precision and Accuracy Section with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water and a natural water or effluent of the analyst's choice. The digestion procedure was not specified. Results for the reagent water are given below. Results for other water types and study details are found in ''USEPA Method Study 7, Analyses for Trace Methods in Water by Atomic Absorption Spectroscopy (Direct Aspiration) and Colorimetry'', National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB86–208709/AS, Winter, J.A. and Britton, P.W., June, 1986.

For concentration range 84–469 µg/L

X=0.987(C)−1.27
S=0.042(X)+8.95
SR=0.023(X)+4.90

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 289.1

For Zinc, Method 289.1 (Atomic Absorption, Direct Aspiration) replace the Precision and Accuracy Section with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory-Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water and a natural water or effluent of the analyst's choice. The digestion procedure was not specified. Results for the reagent water are given below. Results for other water types and study details are found in ''USEPA Method Study 7, Analyses for Trace Methods in Water by Atomic Absorption Spectroscopy (Direct Aspiration) and Colorimetry'', National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB86–208709/AS, Winter, J. A. and Britton, P. W., June, 1986.

For concentration range 56–310 µg/L

X=0.999(C)+0.033
S=0.078(X)+10.8
SR=0.049(X)+1.10

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 202.2

For Aluminum, Method 202.2 (Atomic Absorption, Furnace Technique) replace the Precision and Accuracy Section statement with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory-Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques), ''National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 0.46−125 µg/L

X=1.1579(C)−0.121
S=0.4286(X)−0.124
SR=0.2908(X)−0.082

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 204.2

For Antimony, Method 204.2 (Atomic Absorption, Furnace Technique) replace the Precision and Accuracy Section statement with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory-Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual as modified by this method. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 10.50−240 µg/L
X=0.7219(C)−0.986
S=0.3732(X)+0.854
SR=0.1874(X)−0.461

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 206.2

For Arsenic, Method 206.2 (Atomic Absorption, Furnace Technique) add the following to the existing Precision and Accuracy statement:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory-Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 9.78−237 µg/L
X=0.9652(C)+2.112
S=0.1411(X)+1.873
SR=0.0464(X)+2.109

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 208.2

For Barium, Method 208.2 (Atomic Absorption, Furnace Technique) add the following to the existing Precision and Accuracy information:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 56.50–437 µg/L
X=0.8268(C)+59.459
S=0.2466(X)+6.436
SR=0.1393(X)−0.428

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 210.2

For Beryllium, Method 210.2 (Atomic Absorption, Furnace Technique) replace the existing Precision and Accuracy statement with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31,

Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 0.45–11.4 µg/L
X=1.0682(C)−0.158
S=0.2167(X)+0.090
SR=0.1096(X)+0.061

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 213.2

For Cadmium, Method 213.2 (Atomic Absorption, Furnace Technique) add the following to the existing Precision and Accuracy information:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring System Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 0.43–12.5 µg/L
X=0.9826(C)+0.171
S=0.2300(X)+0.045
SR=0.1031(X)+0.116

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Devision, µg/L

Method 218.2

For Chromium, Method 218.2 (Atomic Absorption, Furnace Technique) add the following to the existing Precision and Accuracy Section:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 9.87–246 µg/L
X=0.9120(C)+0.234
S=0.1684(X)+0.852
SR=0.1469(X)+0.315

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Devision, µg/L

Method 219.2

For Cobalt, Method 219.2 (Atomic Absorption, Furnace Technique), replace the Precision and Accuracy Section statement with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 21.10−461 µg/L
X=0.8875(C)+0.859
S=0.2481(X)−2.541
SR=0.0969(X)+0.134

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 220.2

For Copper, Method 220.2 (Atomic Absorption, Furnace Technique) replace the Precision and Accuracy Section statement with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 0.30−245 µg/L
X=0.9253(C)+0.010
S=0.2735(X)−0.058
SR=0.2197(X)−0.050

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 236.2

For Iron, Method 236.2 (Atomic Absorption, Furnace Technique) replace the Precision and Accuracy Section statement with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 0.37−455 µg/L
X=1.4494(C)−0.229
S=0.3611(X)−0.079
SR=0.3715(X)−0.161

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 239.2

For Lead, Method 239.2 (Atomic Absorption, Furnace Technique) add the following to the existing Precisions and Accuracy Section:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 10.40−254 µg/L
X=0.9430(C)−0.504
S=0.2224(X)+0.507
SR=0.1931(X)−0.378

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 243.2

For Manganese, Method 243.2 (Atomic Absorption, Furnace Technique) replace the Precision and Accuracy Section statement with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL—CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents.

These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 0.42–666 µg/L
X=1.0480(C)+1.404
S=0.2001(X)+1.042
SR=0.1333(X)+0.680

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 249.2

For Nickel, Method 249.2 (Atomic Absorption, Furnace Technique) replace the Precision and Accuracy Section statement with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL—CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 26.20–482 µg/L
X=0.8812(C)+2.426
S=0.2475(X)+1.896
SR=0.1935(X)+1.315

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 270.2

For Selenium, Method 270.2 (Atomic Absorption, Furnace Technique) add the following to the existing Precision and Accuracy Section:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL—CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 10.00–246 µg/L
X=0.9564(C)+0.476
S=0.1584(X)+0.878
SR=0.0772(X)+0.547

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 272.2

For Silver, Method 272.2 (Atomic Absorption, Furnace Technique) add the following to the existing Precision and Accuracy Section:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory—Cincinnati (EMSL—CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 0.45–56.5 µg/L
X=0.9470(C)+0.181
S=0.1805(X)+0.153
SR=0.1417(X)+0.039

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L

SR=Single-analyst Standard Deviation, µg/L

Method 279.2

For Thalliu, Method 279.2 (Atomic Absorption, Furnace Technique) replace the Precision and Accuracy Section statement with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory–Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 10.00–252 µg/L.
X=0.8781(C)−0.715
S=0.1112(X)+0.669
SR=0.1005(X)+0.241

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 286.2

For Vanadium, Method 286.2 (Atomic Absorption, Furnace Technique) replace the Precision and Accuracy Section statement with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory–Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 1.36–982 µg/L.
X=0.8486(C)+0.252
S=0.3323(X)−0.428
SR=0.1195(X)−0.121

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

Method 289.2

For Zinc, Method 289.2 (Atomic Absorption, Furnace Technique) replace the Precision and Accuracy Section statement with the following:

Precision and Accuracy

An interlaboratory study on metal analyses by this method was conducted by the Quality Assurance Branch (QAB) of the Environmental Monitoring Systems Laboratory–Cincinnati (EMSL–CI). Synthetic concentrates containing various levels of this element were added to reagent water, surface water, drinking water and three effluents. These samples were digested by the total digestion procedure, 4.1.3 in this manual. Results for the reagent water are given below. Results for other water types and study details are found in ''EPA Method Study 31, Trace Metals by Atomic Absorption (Furnace Techniques),'' National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 Order No. PB 86–121 704/AS, by Copeland, F.R. and Maney, J.P., January 1986.

For a concentration range of 0.51–189 µg/L.
X=1.6710(C)+1.485
S=0.6740(X)−0.342
SR=0.3895(X)−0.384

where:

C=True Value for the Concentration, µg/L
X=Mean Recovery, µg/L
S=Multi-laboratory Standard Deviation, µg/L
SR=Single-analyst Standard Deviation, µg/L

[55 FR 33442, Aug. 15, 1990]

PART 140—MARINE SANITATION DEVICE STANDARD

Sec.
140.1 Definitions.
140.2 Scope of standard.
140.3 Standard.
140.4 Complete prohibition.
140.5 Analytical procedures.

AUTHORITY: 33 U.S.C. 1322, as amended.

CHAPTER 10

RADIATION RISK ASSESSMENT GUIDANCE

There are many sites contaminated with radioactive substances that are included on the National Priorities List (NPL), and additional sites are expected in future NPL updates. This chapter provides supplemental baseline risk assessment guidance for use at these sites. This guidance is intended as an overview of key differences in chemical and radionuclide assessments, and not as a comprehensive, stand-alone approach for assessing the risks posed by radiation.

The reader should be familiar with the guidance provided in Chapters 2 through 9 before proceeding further in Chapter 10. Although the discussions in the previous chapters focus primarily on chemically contaminated sites, much of the information presented is also applicable to the evaluation of radioactively contaminated Superfund sites. For consistency and completeness, the topics discussed in each section of this chapter parallel the topics covered in each of the previous chapters.

After a brief introduction to some of the basic principles and concepts of radiation protection (Section 10.1), seven additional areas are addressed:

(1) Regulation of Radioactively Contaminated Sites (Section 10.2);

(2) Data Collection (Section 10.3);

(3) Data Evaluation (Section 10.4);

(4) Exposure and Dose Assessment (Section 10.5);

ACRONYMS, SYMBOLS, AND UNITS FOR CHAPTER 10

A(t) = Activity at Time t
Bq = Becquerel
Ci = Curie
CLP = Contract Laboratory Program
D = Absorbed Dose
DCF = Dose Conversion Factor Per Unit Intake
H_E = Effective Dose Equivalent
H_T = Dose Equivalent Averaged Over Tissue or Organ T
$H_{E,50}$ = Committed Effective Dose Equivalent Per Unit Intake
$H_{T,50}$ = Committed Dose Equivalent Averaged Over Tissue T
LET = Linear Energy Transfer
LLD = Lower Limit of Detection
MeV = Million Electron Volts
N = Modifying Factor in the Definition of Dose Equivalent
pCi = PicoCurie (10^{-12} Ci)
Q = Quality Factor in Definition of Dose Equivalent
RBE = Relative Biological Effectiveness
SI = International System of Units
Sv = Sievert
T = Tissue or Target Organs
w_T = Weighting Factor in the Definition of Effective Dose Equivalent and Committed Effective Dose Equivalent

(5) Toxicity Assessment (Section 10.6);

(6) Risk Characterization (Section 10.7); and

(7) Documentation, Review, and Management Tools for the Risk Assessor, Reviewer, and Manager (Section 10.8).

DEFINITIONS FOR CHAPTER 10

Absorbed Dose (D). The mean energy imparted by ionizing radiation to matter per unit mass. The special SI unit of absorbed dose is the gray (Gy); the conventional unit is the rad (1 rad = 0.01 Gy).

Becquerel (Bq). One nuclear disintegration per second; the name for the SI unit of activity. 1 Bq = 2.7 x 10^{-11} Ci.

Committed Dose Equivalent ($H_{T,50}$). The total dose equivalent (averaged over tissue T) deposited over the 50-year period following the intake of a radionuclide.

Committed Effective Dose Equivalent ($H_{E,50}$). The weighted sum of committed dose equivalents to specified organs and tissues, in analogy to the effective dose equivalent.

Curie (Ci). 3.7 x 10^{10} nuclear disintegrations per second, the name for the conventional unit of activity. 1 Ci = 3.7 x 10^{10}Bq.

Decay Product(s). A radionuclide or a series of radionuclides formed by the nuclear transformation of another radionuclide which, in this context, is referred to as the parent.

Dose Conversion Factor (DCF). The dose equivalent per unit intake of radionuclide.

Dose Equivalent (H). The product of the absorbed dose (D), the quality factor (Q), and any other modifying factors (N). The SI unit of dose equivalent is the sievert (Sv); the conventional unit is the rem (1 rem = 0.01 Sv).

Effective Dose Equivalent (H_E). The sum over specified tissues of the products of the dose equivalent in a tissue or organ (T) and the weighting factor for that tissue.

External Radiation. Radiations incident upon the body from an external source.

Gray (Gy). The SI unit of absorbed dose. 1Gy = 1 Joule kg^{-1} = 100 rad.

Half-Life (physical, biological, or effective). The time for a quantity of radionuclide, i.e., its activity, to diminish by a factor of a half (because of nuclear decay events, biological elimination of the material, or both.).

Internal Radiation. Radiation emitted from radionuclides distributed within the body.

Ionizing Radiation. Any radiation capable of displacing electrons from atoms or molecules, thereby producing ions.

Linear Energy Transfer (LET). A measure of the rate of energy absorption, defined as the average energy imparted to the absorbing medium by a charged particle per unit distance (KeV per um).

Nuclear Transformation. The spontaneous transformation of one radionuclide into a different nuclide or into a different energy state of the same nuclide.

Quality Factor (Q). The principal modifying factor that is employed in deriving dose equivalent, H, from absorbed dose, D; chosen to account for the relative biological effectiveness (RBE) of the radiation in question, but to be independent of the tissue or organ under consideration, and of the biological endpoint. For radiation protection purposes, the quality factor is determined by the linear energy transfer (LET) of the radiation.

Rad. The conventional unit for absorbed dose of ionizing radiation; the corresponding SI unit is the gray (Gy); 1 rad = 0.01 Gy = 0.01 Joule/kg.

Rem. An acronym of radiation equivalent man, the conventional unit of dose equivalent; the corresponding SI unit is the Sievert; 1 Sv = 100 rem.

Sievert (Sv). The special name for the SI unit of dose equivalent. 1 Sv = 100 rem.

Slope Factor. The age-averaged lifetime excess cancer incidence rate per unit intake (or unit exposure for external exposure pathways) of a radionuclide.

Weighting Factor (w_T). Factor indicating the relative risk of cancer induction or hereditary defects from irradiation of a given tissue or organ; used in calculation of effective dose equivalent and committed effective dose equivalent.

There are special hazards associated with handling radioactive waste and EPA strongly recommends that a health physicist experienced in radiation measurement and protection be consulted prior to initiating any activities at a site suspected of being contaminated with radioactive substances. EPA also recommends that the remedial project manager (RPM) or on-scene coordinator (OSC) should designate both a chemical risk assessor and a radiation risk assessor. These individuals should work closely with each other and the RPM to coordinate remedial activities (e.g., site scoping, health and safety planning, sampling and analysis) and exchange information common to both chemical and radionuclide assessments, including data on the physical characteristics of the site, potentially impacted populations, pathways of concern, and fate and transport models used. At the conclusion of the remedial investigation/feasibility study (RI/FS) process, the RPM should issue a single report that summarizes and integrates the results from both the chemical and the radiation risk assessments.

A two-phase evaluation is described for the radiation risk assessment. As discussed in Section 10.5, procedures established by the International Commission on Radiological Protection (ICRP 1979) and adopted by EPA in *Federal Guidance Report No. 11* (EPA 1988) are used to estimate the radiation dose equivalent to humans from potential exposures to radionuclides through all pertinent exposure pathways at a site. Those estimates of dose equivalent may be used for comparison with established radiation protection standards and criteria. However, this methodology was developed for regulation of occupational radiation exposures for adults and is not completely applicable for estimating health risk to the general population at a Superfund site. Therefore, a separate methodology is presented in Section 10.7.2 for estimating health risk, based on the age-averaged lifetime excess cancer incidence per unit intake (and per unit external exposure) for radionuclides of concern. Radiation risk assessments for Superfund sites should include estimates of both the dose equivalent computed as described in Section 10.5, and the health risk attributable to radionuclide exposures computed using the approach described in Section 10.7.

Only summary-level information is presented in this chapter, and references are provided to a number of supporting technical documents for further information. In particular, the reader is encouraged to consult Volume 1 of the *Background Information Document for the Draft Environmental Impact Statement for Proposed NESHAPS for Radionuclides* (EPA 1989a) for a more comprehensive discussion of EPA's current risk assessment methodology for radionuclides.

For additional radiation risk assessment information and guidance, RPMs and other interested individuals can contact the Office of Radiation Programs (ORP) within EPA headquarters at 202-475-9630 (FTS 475-9630). Interested individuals also can contact the Regional Radiation Program Managers within each of the EPA regional offices for guidance and health physics support.

10.1 RADIATION PROTECTION PRINCIPLES AND CONCEPTS

Radioactive atoms undergo spontaneous nuclear transformations and release excess energy in the form of ionizing radiation. Such transformations are referred to as radioactive decay. As a result of the radioactive decay process, one element is transformed into another; the newly formed element, called a decay product, will possess physical and chemical properties different from those of its parent, and may also be radioactive. A radioactive species of a particular element is referred to as a radionuclide or radioisotope. The exact mode of radioactive transformation for a particular radionuclide depends solely upon its nuclear characteristics, and is independent of the nuclide's chemical characteristics or physical state. A fundamental and unique characteristic of each radionuclide is its radioactive half-life, defined as the time required for one half of the atoms in a given quantity of the radionuclide to decay. Over 1,600 different radionuclides have been identified to date, with half-lives ranging from fractions of a second to millions of years. Selected radionuclides of potential importance at Superfund sites are listed in Exhibit 10-1.

Radiation emitted by radioactive substances can transfer sufficient localized energy to atoms to remove electrons from the electric field of their nucleus (ionization). In living tissue this energy transfer can destroy cellular constituents and produce electrically charged molecules (i.e., free radicals). Extensive biological damage can lead to adverse health effects. The type of ionizing radiation emitted by a particular radionuclide depends upon the exact nature of the nuclear transformation, and may include emission of alpha particles, electrons (beta particles or positrons), and neutrons; each of these transformations may be accompanied by emission of photons (gamma radiation or x-rays). Each type of radiation differs in its physical characteristics and in its ability to inflict damage to biological tissue. These characteristics and effects are summarized in the box on this page.

Quantities of radionuclides are typically expressed in terms of activity at a given time t (A(t)). The SI unit of activity is the becquerel (Bq), which is defined as the quantity of a given radionuclide in which one atom is transformed per second (i.e., one decay per second). The conventional unit of activity is the curie (Ci), which is defined as the quantity of a given radionuclide in which $3.7x10^{10}$ atoms undergo nuclear transformation each second; one curie is approximately equivalent to the decay rate of one gram of Ra-226. A more convenient unit of activity for expressing environmental concentrations of radionuclides is the picoCurie (pCi), which is equal to 10^{-12} Ci. Occasionally, activity is expressed incorrectly in terms of counts per second (cps) or counts per minute (cpm): these refer to the number of transformations per unit time measured by a particular radiation detector and do not represent the true decay rate of the radionuclide. To derive activity values, count rate measurements are multiplied by radioisotope-specific detector calibration factors.

PRINCIPAL TYPES OF IONIZING RADIATION

Alpha particles are doubly charged cations, composed of two protons and two neutrons, which are ejected monoenergetically from the nucleus of an atom when the neutron to proton ratio is too low. Because of their relatively large mass and charge, alpha particles tend to ionize nearby atoms quite readily, expending their energy in short distances. Alpha particles will usually not penetrate an ordinary sheet of paper or the outer layer of skin. Consequently, alpha particles represent a significant hazard only when taken into the body, where their energy is completely absorbed by small volumes of tissues.

Beta particles are electrons ejected at high speeds from the nucleus of an unstable atom when a neutron spontaneously converts to a proton and an electron. Unlike alpha particles, beta particles are not emitted with discrete energies but are ejected from the nucleus over a continuous energy spectrum. Beta particles are smaller than alpha particles, carry a single negative charge, and possess a lower specific ionization potential. Unshielded beta sources can constitute external hazards if the beta radiation is within a few centimeters of exposed skin surfaces and if the beta energy is greater than 70 keV. Beta sources shielded with certain metallic materials may produce bremsstrahlung (low energy x-ray) radiation which may also contribute to the external radiation exposure. Internally, beta particles have a much greater range than alpha particles in tissue. However, because they cause fewer ionizations per unit path length, beta particles deposit much less energy to small volumes of tissue and, consequently, inflict must less damage than alpha particles.

Positrons are identical to beta particles except that they have a positive charge. A positron is emitted from the nucleus of a neutron-deficient atom when a proton spontaneously transforms into a neutron. Alternatively, in cases where positron emission is not energetically possible, the neutron deficiency may be overcome by electron capture, whereby one of the orbital electrons is captured by the nucleus and united with a proton to form a neutron, or by annihilation radiation, whereby the combined mass of a positron and electron is converted into photon energy. The damage inflicted by positrons to small volumes of tissue is similar to that of beta particles.

Gamma radiations are photons emitted from the nucleus of a radioactive atom. X-rays, which are extra-nuclear in origin, are identical in form to gamma rays, but have slightly lower energy ranges. There are three main ways in which x- and gamma rays interact with matter: the photoelectric effect, the Compton effect, and pair production. All three processes yield electrons which then ionize or excite other atoms of the substance. Because of their high penetration ability, x- and gamma radiations are of most concern as external hazards.

Neutrons are emitted during nuclear fission reactions, along with two smaller nuclei, called fission fragments, and beta and gamma radiation. For radionuclides likely to be encountered at Superfund sites, the rate of spontaneous fission is minute and no significant neutron radiation is expected.

EXHIBIT 10-1

RADIOLOGICAL CHARACTERISTICS OF SELECTED RADIONUCLIDES FOUND AT SUPERFUND SITES[a]

Nuclide	Half-life[c]	Average Radiation Energies (MeV/decay)[b]		
		Alpha	Beta, Electron	x, Gamma
Am-241	4.32×10^{2} y	5.57×10^{0}	5.21×10^{-2}	3.25×10^{-2}
Am-243	7.38×10^{3} y	5.36×10^{0}	2.17×10^{-2}	5.61×10^{-2}
Ba-137m	2.55×10^{0} h	--	6.37×10^{-2}	5.98×10^{-1}
C-14	5.73×10^{3} y	--	4.95×10^{-2}	--
Ce-144	2.84×10^{2} d	--	9.22×10^{-2}	2.07×10^{-2}
Cm-243	2.85×10^{1} y	5.89×10^{0}	1.38×10^{-1}	1.35×10^{-1}
Cm-244	1.81×10^{1} y	5.89×10^{0}	8.59×10^{-3}	1.70×10^{-3}
Co-60	5.27×10^{0} y	--	9.65×10^{-2}	2.50×10^{0}
Cr-51	2.77×10^{1} d	--	3.86×10^{-3}	3.26×10^{-2}
Cs-134	2.06×10^{0} y	--	1.64×10^{-1}	1.55×10^{0}
Cs-135	2.30×10^{6} y	--	6.73×10^{-2}	--
Cs-137	3.00×10^{1} y	--	1.87×10^{-1}	--
Fe-59	4.45×10^{1} d	--	1.17×10^{-1}	1.19×10^{0}
H-3	1.23×10^{1} y	--	5.68×10^{-3}	--
I-129	1.57×10^{7} y	--	6.38×10^{-2}	2.46×10^{-2}
I-131	8.04×10^{0} d	--	1.92×10^{-1}	3.81×10^{-1}
K-40	1.28×10^{9} y	--	5.23×10^{-1}	1.56×10^{-1}
Mn-54	3.13×10^{2} d	--	4.22×10^{-3}	8.36×10^{-1}
Mo-99	6.60×10^{1} h	--	3.93×10^{-1}	1.50×10^{-1}
Nb-94	2.03×10^{4} y	--	1.68×10^{-1}	1.57×10^{0}
Np-237	2.14×10^{6} y	4.85×10^{0}	7.01×10^{-2}	3.46×10^{-2}
P-32	1.43×10^{1} d	--	6.95×10^{-1}	--
Pb-210	2.23×10^{1} y	--	3.80×10^{-2}	4.81×10^{-3}
Po-210	1.38×10^{2} d	5.40×10^{0}	8.19×10^{-8}	8.51×10^{-6}
Pu-238	8.77×10^{1} y	5.59×10^{0}	1.06×10^{-2}	1.81×10^{-3}
Pu-239	2.41×10^{4} y	5.24×10^{0}	6.74×10^{-3}	8.07×10^{-4}
Pu-240	6.54×10^{3} y	5.24×10^{0}	1.06×10^{-2}	1.73×10^{-3}
Pu-241	1.44×10^{1} y	1.22×10^{-4}	5.25×10^{-3}	2.55×10^{-6}
Pu-242	3.76×10^{5} y	4.97×10^{0}	8.73×10^{-3}	1.44×10^{-3}
Ra-226	1.60×10^{3} y	4.86×10^{0}	3.59×10^{-3}	6.75×10^{-3}
Ra-228	5.75×10^{0} y	--	1.69×10^{-2}	4.14×10^{-9}
Ru-106	3.68×10^{2} d	--	1.00×10^{-2}	--
S-35	8.74×10^{1} d	--	4.88×10^{-2}	--
Sr-89	5.05×10^{1} d	--	5.83×10^{-1}	8.45×10^{-5}
Sr-90	2.91×10^{1} y	--	1.96×10^{-1}	--
Tc-99	2.13×10^{5} y	--	1.01×10^{-1}	--
Tc-99m	6.02×10^{0} h	--	1.62×10^{-2}	1.26×10^{-1}
Th-230	7.70×10^{4} y	4.75×10^{0}	1.42×10^{-2}	1.55×10^{-3}
Th-232	1.41×10^{10} y	4.07×10^{0}	1.25×10^{-2}	1.33×10^{-3}
U-234	2.44×10^{5} y	4.84×10^{0}	1.32×10^{-2}	1.73×10^{-3}
U-235	7.04×10^{8} y	4.47×10^{0}	4.92×10^{-2}	1.56×10^{-1}
U-238	4.47×10^{9} y	4.26×10^{0}	1.00×10^{-2}	1.36×10^{-3}

[a] Source: ICRP 1983 (except Ba-137m data from Kocher 1981).
[b] Computed as the sum of the products of the energies and yields of individual radiations.
[c] Half-life expressed in years (y), days (d), and hours (h).

The activity per unit mass of a given radionuclide is called the specific activity, and is usually expressed in units of becquerels per gram (Bq/g) or curies per gram (Ci/g). The shorter the half-life of the radionuclide, the greater is its specific activity. For example, Co-60 has a radioactive half-life of about 5 years and a specific activity of $4x10^{13}$ Bq/g, whereas Np-237 has a half-life of 2 million years and a specific activity of $3x10^{7}$ Bq/g.

Several terms are used by health physicists to describe the physical interactions of different types of radiations with biological tissue, and to define the effects of these interactions on human health. One of the first terms developed was radiation exposure, which refers to the transfer of energy from a radiation field of x- or gamma rays to a unit mass of air. The unit for this definition of exposure is the roentgen (R), expressed as coulombs of charge per kilogram of air (1 R = $2.58x10^{-4}$ C/kg).

The term exposure is also defined as the physical contact of the human body with radiation. Internal exposure refers to an exposure that occurs when human tissues are subjected to radiations from radionuclides that have entered the body via inhalation, ingestion, injection, or other routes. External exposure refers to the irradiation of human tissues by radiations emitted by radionuclides located outside the body either dispersed in the air or water, on skin surfaces, or deposited on ground surfaces. All types of radiation may contribute to internal exposure, whereas only photon, beta, and neutron radiations contribute significantly to external exposure.

Ionizing radiation can cause deleterious effects on biological tissues only when the energy released during radioactive decay is absorbed in tissue. The absorbed dose (D) is defined as the mean energy imparted by ionizing radiation per unit mass of tissue. The SI unit of absorbed dose is the joule per kilogram, also assigned the special name the gray (1 Gy = 1 joule/kg). The conventional unit of absorbed dose is the rad (1 rad = 100 ergs per gram = 0.01 Gy).

For radiation protection purposes, it is desirable to compare doses of different types of radiation. The absorbed dose of any radiation divided by the absorbed dose of a reference radiation (traditionally 250 kVp x-rays) that produces the same biological endpoint is called the Relative Biological Effectiveness or RBE. For regulatory purposes, an arbitrary consensus RBE estimate called the Quality Factor or Q is often used. The dose equivalent (H) was developed to normalize the unequal biological effects produced from equal absorbed doses of different types of radiation. The dose equivalent is defined as:

$$H = DQN$$

where D is the absorbed dose, Q is a quality factor that accounts for the RBE of the type of radiation emitted, and N is the product of any additional modifying factors. Quality factors currently assigned by the International Commission on Radiological Protection (ICRP) include values of Q=20 for alpha particles, Q=10 for neutrons and protons, and Q=1 for beta particles, positrons, x-rays, and gamma rays (ICRP 1984). These factors may be interpreted as follows: on average, if an equal amount of energy is absorbed, an alpha particle will inflict approximately 20 times more damage to biological tissue than a beta particle or gamma ray, and twice as much damage as a neutron. The modifying factor is currently assigned a value of unity (N=1) for all radiations. The SI unit of dose equivalent is the sievert (Sv), and the conventional unit is the rem (1 rem = 0.01 Sv).

GENERAL HEALTH PHYSICS REFERENCES

Introduction to Health Physics (Cember 1983)

Atoms, Radiation, and Radiation Protection (Turner 1986)

Environmental Radioactivity (Eisenbud 1987)

The Health Physics and Radiological Health Handbook (Shleien and Terpilak 1984)

EFFECTIVE DOSE EQUIVALENT

The effective dose equivalent, H_E , is a weighted sum of dose equivalents to all organs and tissues (ICRP 1977, ICRP 1979), defined as:

$$H_E = \sum_T w_T H_T$$

where w_T is the weighting factor for organ or tissue T and H_T is the mean dose equivalent to organ or tissue T. The factor w_T, which is normalized so that the summation of all the organ weighting factors is equal to one, corresponds to the fractional contribution of organ or tissue T to the total risk of stochastic health effects when the body is uniformly irradiated. Similarly, the committed effective dose equivalent, $H_{E,50}$, is defined as the weighted sum of committed dose equivalents to all irradiated organs and tissues, as follows:

$$H_{E,50} = \sum_T w_T H_{T,50}$$

H_E and $H_{E,50}$ thus reflect both the distribution of dose among the various organs and tissues of the body and their assumed relative sensitivities to stochastic effects. The organ and tissue weighting factor values w_T are as follows: Gonads, 0.25; Breast, 0.15; Red Marrow, 0.12; Lungs, 0.12; Thyroid, 0.03; Bone Surface, 0.03; and Remainder, 0.30 (i.e., a value of $w_T = 0.06$ is applicable to each of the five remaining organs or tissues receiving the highest doses).

The dose delivered to tissues from radiations external to the body occurs only while the radiation field is present. However, the dose delivered to body tissues due to radiations from systemically incorporated radionuclides may continue long after intake of the nuclide has ceased. Therefore, internal doses to specific tissues and organs are typically reported in terms of the committed dose equivalent ($H_{T,50}$), which is defined as the integral of the dose equivalent in a particular tissue T for 50 years after intake (corresponding to a working lifetime).

When subjected to equal doses of radiation, organs and tissues in the human body will exhibit different cancer induction rates. To account for these differences and to normalize radiation doses and effects on a whole body basis for regulation of occupational exposure, the ICRP developed the concept of the effective dose equivalent (H_E) and committed effective dose equivalent ($H_{E,50}$), which are defined as weighted sums of the organ-specific dose equivalents (i.e., $\Sigma\ w_T H_T$) and organ-specific committed dose equivalents (i.e., $\Sigma w_T H_{T,50}$), respectively. Weighting factors, w_T, are based on selected stochastic risk factors specified by the ICRP and are used to average organ-specific dose equivalents (ICRP 1977, 1979). The effective dose equivalent is equal to that dose equivalent, delivered at a uniform whole-body rate, that corresponds to the same number (but possibly a dissimilar distribution) of fatal stochastic health effects as the particular combination of committed organ dose equivalents (see the box on this page).

A special unit, the working level (WL), is used to describe exposure to the short-lived radioactive decay products of radon (Rn-222). Radon is a naturally occurring radionuclide that is of particular concern because it is ubiquitous, it is very mobile in the environment, and it decays through a series of short-lived decay products that can deliver a significant dose to the lung when inhaled. The WL is defined as any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of alpha energy. The working level month (WLM) is defined as the exposure to 1 WL for 170 hours (1 working month).

Radiation protection philosophy encourages the reduction of all radiation exposures as low as reasonably achievable (ALARA), in consideration of technical, economic, and social factors. Further, no practice involving radiation exposure should be adopted unless it provides a positive net benefit. In addition to these general guidelines, specific upper limits on radiation exposures and doses have been established by regulatory authorities as described in the following section.

Additional discussion on the measurement of radioactivity is provided in Sections 10.3 and 10.4, and the evaluation of radiation exposure and dose is discussed further in Section 10.5. Discussion of potential health impacts from ionizing radiation is presented in Section 10.6.

10.2 REGULATION OF RADIOACTIVELY CONTAMINATED SITES

Chapter 2 briefly describes the statutes, regulations, guidance, and studies related to the human health evaluation process for chemical contaminants. The discussion describes CERCLA, as amended by SARA, and the RI/FS process. Since radionuclides are classified as hazardous substances under CERCLA, this information is also applicable to radioactively contaminated sites. Chapter 2 also introduces the concept of compliance with applicable or relevant and appropriate requirements (ARARs) in federal and state environmental laws as required by SARA. Guidance on potential ARARs for the remediation of radioactively contaminated sites under CERCLA is available in the *CERCLA Compliance with Other Laws Manual* (EPA 1989c). Only a brief summary of regulatory authorities is presented here.

The primary agencies with regulatory authority for the cleanup of radioactively contaminated sites include EPA, the Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), and state agencies. Other federal agencies, including the Department of Transportation (DOT) and Department of Defense (DOD), also have regulatory programs (but more limited) for radioactive materials. Also, national and international scientific advisory organizations provide recommendations related to radiation protection and radioactive waste management, but have no regulatory authority. The following is a brief description of the main functions and areas of jurisdiction of these agencies and organizations.

- EPA's authority to protect public health and the environment from adverse effects of radiation exposure is derived from several statutes, including the Atomic Energy Act, the Clean Air Act, the Uranium Mill Tailings Radiation Control Act (UMTRCA), the Nuclear Waste Policy Act, the Resource Conservation and Recovery Act (RCRA), and CERCLA. EPA's major responsibilities with regard to radiation include the development of federal guidance and standards, assessment of new technologies, and surveillance of radiation in the environment. EPA also has lead responsibility in the federal government for advising all federal agencies on radiation standards. EPA's radiation standards apply to many different types of activities involving all types of radioactive material (i.e., source, byproduct, special nuclear, and naturally occurring and accelerator produced radioactive material [NARM]). For some of the EPA standards, implementation and enforcement responsibilities are vested in other agencies, such as NRC and DOE.

- NRC licenses the possession and use of certain types of radioactive material at certain types of facilities. Specifically, the NRC is authorized to license source, byproduct, and special nuclear material. The NRC is not authorized to license NARM, although NARM may be partially subject to NRC regulation when it is associated with material licensed by the NRC. Most of DOE's operations are exempt from NRC's licensing and regulatory requirements, as are certain DOD activities involving nuclear weapons and the use of nuclear reactors for military purposes.

- DOE is responsible for conducting or overseeing radioactive material operations at numerous government-owned/contractor-operated facilities. DOE is also responsible for managing several inactive sites that contain radioactive waste, such as sites associated with the Formerly Utilized Sites Remedial Action Program (FUSRAP), the Uranium Mill Tailings Remedial Action Program (UMTRAP), the Grand Junction Remedial

MAJOR FEDERAL LAWS FOR RADIATION PROTECTION

- Atomic Energy Act of 1954, Public Law 83-703 - established the Atomic Energy Commission as the basic regulatory authority for ionizing radiation.
- Energy Reorganization Act of 1974, Public Law 93-438 - amended the Atomic Energy Act, and established the Nuclear Regulatory Commission to regulate nondefense nuclear activities.
- Marine Protection, Research, and Sanctuaries Act of 1972, Public Law 92-532 - established controls for ocean disposal of radioactive waste.
- Safe Drinking Water Act, Public Law 93-523 - mandated regulation of radionuclides in drinking water.
- Clean Air Act Amendments of 1977, Public Law 95-95 - extended coverage of the Act's provisions to include radionuclides.
- Uranium Mill Tailings Radiation Control Act of 1978, Public Law 96-415 - required stabilization and control of byproduct materials (primarily mill tailings) at licensed commercial uranium and thorium processing sites.
- Low-Level Radioactive Waste Policy Act of 1980, Public Law 96-573 - made states responsible for disposal of LLRW generated within their borders and encouraged formation of inter-state compacts.
- Nuclear Waste Policy Act of 1982, Public Law 97-425 - mandated the development of repositories for the disposal of high-level radioactive waste and spent nuclear fuel.
- Low-Level Radioactive Waste Policy Act Amendments of 1985, Public Law 99-240 - amended LLRWPA requirements and

Action Program (GJRAP), and the Surplus Facilities Management Program (SFMP). DOE is authorized to control all types of radioactive materials at sites within its jurisdiction.

- Other federal agencies with regulatory programs applicable to radioactive waste include DOT and DOD. DOT has issued regulations that set forth packaging, labeling, record keeping, and reporting requirements for the transport of radioactive material (see 49 CFR Parts 171 through 179). Most of DOD's radioactive waste management activities are regulated by NRC and/or EPA. However, DOD has its own program for controlling wastes generated for certain nuclear weapon and reactor operations for military purposes. Other agencies, such as the Federal Emergency Management Agency (FEMA) and the Department of the Interior (DOI), may also play a role in radioactive waste cleanups in certain cases.
- States have their own authority and regulations for managing radioactive material and waste. In addition, 29 states (Agreement States) have entered into agreements with the NRC, whereby the Commission has relinquished to the states its regulatory authority over source, byproduct, and small quantities of special nuclear material. Both Agreement States and Nonagreement States can also regulate NARM. Such state-implemented regulations are potential ARARs.
- The National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP) provide recommendations on human radiation protection. The NCRP was chartered by Congress to collect, analyze, develop, and disseminate information and recommendations about radiation protection and measurements. The ICRP's function is basically the same, but on an international level. Although neither the NCRP nor the ICRP have regulatory authority, their recommendations serve as the basis for many of the general (i.e., not

source-specific) regulations on radiation protection developed at state and federal levels.

The standards, advisories, and guidance of these various groups are designed primarily to be consistent with each other, often overlapping in scope and purpose. Nevertheless, there are important differences between agencies and programs in some cases. It is important that these differences be well understood so that when more than one set of standards is potentially applicable to or relevant and appropriate for the same CERCLA site, RPMs will be able to evaluate which standards to follow. In general, determination of an ARAR for a site contaminated with radioactive materials requires consideration of the radioactive constituents present and the functional operations that generated the site, whose regulatory jurisdiction the site falls under, and which regulation is most protective, or if relevant and appropriate, most appropriate given site conditions.

For further information on radiation standards, advisories, and guidance, RPMs should consult the detailed ARARs guidance document (EPA 1989c), as well as EPA's ORP and/or Regional Radiation Program Managers.

10.3 DATA COLLECTION

Data collection needs and procedures for sites contaminated with radioactive substances are very similar to those described in Chapter 4 for chemically contaminated sites. There are, however, some basic differences that simplify data collection for radionuclides, including the relative ease and accuracy with which natural background radiation and radionuclide contaminants can be detected in the environment when compared with chemical contaminants.

The pathways of exposure and the mathematical models used to evaluate the potential health risks associated with radionuclides in the environment are similar to those used for evaluating chemical contaminants. Many of the radionuclides found at Superfund sites behave in the environment like trace metals. Consequently, the types of data needed for a radiation risk assessment are very similar to those required for a chemical contaminant risk assessment. For example, the environmental, land use, and demographic data needed and the procedures used to gather the data required to model fate and effect are virtually identical. The primary differences lie in the procedures used to characterize the radionuclide contaminants. In the sections that follow, emphasis is placed on the procedures used to characterize the radionuclide contaminants and not the environmental setting that affects their fate and effects, since the latter has been thoroughly covered in Chapter 4.

10.3.1 RADIATION DETECTION METHODS

Field and laboratory methods used to identify and quantify concentrations of radionuclides in the environment are, in many cases, more exact, less costly, and more easily implemented than those employed for chemical analyses. Selection of a radiometric method depends upon the number of radionuclides of interest, their activities and types of radiations emitted, as well as on the level of sensitivity required and the sample size available. In some cases, the selection process requires prior knowledge of the nature and extent of radioactive contamination present onsite. See the references provided in the box on page 10-12 for detailed guidance on sample collection and preparation, radiochemical procedures, and radiation counters and measurement techniques. The following discussion provides an overview of a few of the radiation detection techniques and instruments currently used to characterize sites contaminated with radioactive materials.

Field methods utilize instrumental techniques rather than radiochemical procedures to determine in-situ identities and concentrations of radionuclides, contamination profiles, and external beta/gamma exposure rates. Field instruments designed for radiation detection (see Exhibit 10-2) are portable, rugged, and relatively insensitive to wide fluctuations in temperature and humidity. At the same time, they are sensitive enough to discriminate between variable levels of background radiation from naturally occurring radionuclides and excess radiation due to radioactive waste. Because of the harsh conditions in which they are sometimes

EXHIBIT 10-2

TYPES OF FIELD RADIATION DETECTION INSTRUMENTS

Instruments	Range of Counting Rate and Other Characteristics	Typical Uses	Remarks
Beta-Gamma Surface Monitors[a]			
Portable Count Rate Meter (Thin Walled or Thin Window G-M Counter)	0-1,000; 0-10,000; 0-100,000 count/min	Surfaces, hands, clothing	Simple, reliable, battery powered
Alpha Surface Monitors			
Portable Air Proportional Counter with Probe	0-100,000 count/min over 100 cm^2	Surfaces, hands, clothing	Not accurate in high humidity; battery powered; fragile window
Portable Gas Flow Counter with Probe	0-100,000 count/min over 100 cm^2	Surfaces, hands, clothing	Not affected by the humidity; battery powered; fragile window
Portable Scintillation Counter with Probe	0-100,000 count/min over 100 cm^2	Surfaces, hands, clothing	Not affected by the humidity; battery powered; fragile window
Air Monitors			
Particle Samplers			
Filter Paper (High-volume)	40 ft^3/min (1.1 m^3/min)	For quick grab samples	Used intermittently; requires separate counter
Filter Paper (Low-volume)	0.1 to 10 ft^3/min (0.003-0.3 m^3/min)	For continuous room air breathing zone monitoring	Used continuously; requires separate counter
Electrostatic Precipitator	3 ft^3/min (0.09 m^3/min)	For continuous monitoring	Sample deposited on cyclindrical shell; requires separate counter
Impinger	20 to 40 ft^3/min (0.6-1.1 m^3/min)	Alpha contamination	Special uses; requires separate counter
Tritium Monitors			
Flow ionization chambers	0.10 pCi/ m^3/min	Continuous monitoring	May be sensitive to other sources of ionization

[a] None of these surface monitors is suitable for tritium detection.

Source: NCRP Report No. 57 (NCRP 1978).

RADIONUCLIDE MEASUREMENT PROCEDURES

Environmental Radiation Measurements (NCRP 1976)

Instrumentation and Monitoring Methods for Radiation Protection (NCRP 1978)

Radiochemical Analytical Procedures for Analysis of Environmental Samples (EPA 1979a)

Eastern Environmental Radiation Facility Radiochemistry Procedures Manual (EPA 1984a)

A Handbook of Radioactivity Measurement Procedures (NCRP 1985a)

operated, and because their detection efficiency varies with photon energy, all field instruments should be properly calibrated in the laboratory against National Bureau of Standards (NBS) radionuclide sources prior to use in the field. Detector response should also be tested periodically in the field against NBS check-sources of known activity.

Commonly used gamma-ray survey meters include Geiger-Muller (G-M) probes, sodium iodide (NaI(Tl)) crystals, and solid-state germanium diodes (Ge(Li)) coupled to ratemeters, scalers, or multichannel analyzers (MCAs). These instruments provide measurements of overall exposure rates in counts per minute, or microRoentgens or microrem per hour. However, only NaI and Ge(Li) detectors with MCAs provide energy spectra of the gamma rays detected and can therefore verify the identity of specific radionuclides. Thin window G-M detectors and Pancake (ionization) probes are used to detect beta particles. Alpha-particle surface monitors include portable air proportional, gas proportional, and zinc sulfide (ZnS) scintillation detectors, which all have very thin and fragile windows. The references in the box on this page provide additional information on several other survey techniques and instruments, such as aerial gamma surveillance used to map gamma exposure rate contours over large areas.

Laboratory methods involve both chemical and instrumental techniques to quantify low-levels of radionuclides in sample media. The preparation of samples prior to counting is an important consideration, especially for samples containing alpha- and beta-emitting radionuclides that either do not emit gamma rays or emit gamma rays of low abundance. Sample preparation is a multistep process that achieves the following three objectives: (1) the destruction of the sample matrix (primarily organic material) to reduce alpha- and beta-particle self-absorption; (2) the separation and concentration of radionuclides of interest to increase resolution and sensitivity; and (3) the preparation of the sample in a suitable form for counting. Appropriate radioactive tracers (i.e., isotopes of the radionuclides of interest that are not present in the sample initially, but are added to the sample to serve as yield determinants) must be selected and added to the sample before a radiochemical procedure is initiated.

For alpha counting, samples are prepared as thin-layer (low mass) sources on membrane filters by coprecipitation with stable carriers or on metal discs by electrodeposition. These sample filters and discs are then loaded into gas proportional counters, scintillation detectors, or alpha spectrometry systems for measurement (see Exhibit 10-3). In a proportional counter, the sample is immersed in a counting gas, usually methane and argon, and subjected to a high voltage field: alpha emissions dissociate the counting gas creating an ionization current proportional to the source strength, which is then measured by the system electronics. In a scintillation detector, the sample is placed in contact with a ZnS phosphor against the window of a photomultiplier (PM) tube: alpha particles induce flashes of light in the phosphor that are converted to an electrical current in the PM tube and measured. Using alpha spectrometry, the sample is placed in a holder in an evacuated chamber facing a solid-state, surface-barrier detector: alpha particles strike the detector and cause electrical impulses, which are sorted by strength into electronic bins and counted. All three systems yield results in counts per minute, which are then converted into activity units using detector- and radionuclide-specific calibration

EXHIBIT 10-3

TYPES OF LABORATORY RADIATION DETECTION INSTRUMENTS [a]

Type of Instrument	Typical Activity Range (mCi)	Typical Sample Form	Data Acquisition and Display
Gas Proportional Counters	10^{-7} to 10^{-3}	Film disc mount, gas	Ratemeter or scaler
Liquid-Scintillation Counters	10^{-7} to 10^{-3}	Up to 20 ml of liquid gel	Accessories for background subtraction, quench correction, internal standard, sample comparison
NaI (T1) Cylindrical or Well Crystals	10^{-6} to 10^{-3}	Liquid, solid, or contained gas, < 4 ml	Ratemeter
			Discriminators for measuring various energy regions
			Multichannel analyzer, or computer plus analog-to-digital converter
			Computational accessories for full-energy-peak identification, quantification, and spectrum stripping
Ionization Chambers	10^{-2} to 10^{3}	Liquid, solid, or contained gas, (can be large in size)	Ionization-current measurement; digital (mCi) readout, as in dose calibrators
Solid-state Detectors	10^{-2} to 10	Various	Multichannel analyzer or computer with various readout options

[a] Source: NCRP Report No. 58 (NCRP 1985a).

values. Alpha spectrometry is the only system, however, that can be used to identify specific alpha-emitting radionuclides.

For beta counting, samples are prepared both as thin-sources and as solutions mixed with scintillation fluid, similar in function to a phosphor. Beta-emitting sources are counted in gas proportional counters at higher voltages than those applied for alpha counting or in scintillation detectors using phosphors specifically constructed for beta-particle detection. Beta-emitters mixed with scintillation fluid are counted in 20 ml vials in beta-scintillation counters: beta-particle interactions with the fluid produce detectable light flashes. Like alpha detectors, beta detectors provide measurements in counts per minute, which are converted to activity units using calibration factors. It should be noted, however, that few detection systems are available for determining the identity of individual beta-emitting radionuclides, because beta particles are emitted as a continuous spectrum of energy that is difficult to characterize and ascribe to any specific nuclide.

It is advisable to count all samples intact in a known geometry on a NaI or Ge(Li) detector system prior to radiochemical analysis, because many radionuclides that emit gamma rays in sufficient abundance and energy can be detected and measured by this process. Even complex gamma-ray spectra emitted by multiple radionuclide sources can be resolved using Ge(Li) detectors, MCAs, and software packages, and specific radionuclide concentrations can be determined. If the sample activity is low or if gamma rays are feeble, then more rigorous alpha or beta analyses are advised.

10.3.2 REVIEWING AVAILABLE SITE INFORMATION

In Chapter 4, reference is made to reviewing the site data for chemical contaminants in accordance with Stage 1 of the Data Quality Objectives (DQO) process (see box on Page 4-4). This process also applies to radionuclides. For further guidance on the applicability of DQOs to radioactively contaminated sites, consult EPA's Office of Radiation Programs.

10.3.3 ADDRESSING MODELING PARAMETER NEEDS

Exhibits 4-1 and 4-2 describe the elements of a conceptual model and the types of information that may be obtained during a site sampling investigation. These exhibits apply to radioactively contaminated sites with only minor modifications. For example, additional exposure pathways for direct external exposure from immersion in contaminated air or water or from contaminated ground surfaces may need to be addressed for certain radionuclides; these exposure pathways are discussed further in subsequent sections. In addition, several of the parameters identified in these exhibits are not as important or necessary for radiological surveys. For example, the parameters that are related primarily to the modeling of organic contaminants, such as the lipid content of organisms, are typically not needed for radiological assessments.

10.3.4 DEFINING BACKGROUND RADIATION SAMPLING NEEDS

As is the case with a chemically contaminated site, the background characteristics of a radioactively contaminated site must be defined reliably in order to distinguish natural background radiation and fallout from the onsite sources of radioactive waste. With the possible exception of indoor sources of Rn-222, it is often possible to make these distinctions because the radiation detection equipment and analytical techniques used are very precise and sensitive. At a chemically contaminated site, there can be many potential and difficult-to-pinpoint offsite sources for the contamination found onsite, confounding the interpretation of field measurements. With a radioactively contaminated site, however, this is not usually a problem because sources of radionuclides are, in general, easier to isolate and identify. In fact, some radionuclides are so specifically associated with particular industries that the presence of a certain radioactive contaminant sometimes acts as a "fingerprint" to identify its source. Additional information on the sources of natural background and man-made radiation in the environment may be found in the references listed in the box on the next page.

NATURAL BACKGROUND RADIATION

Tritium in the Environment (NCRP 1979)

Ionizing Radiation: Sources and Effects (UNSCEAR 1982)

Exposure from the Uranium Series with Emphasis on Radon and its Daughters (NCRP 1984b)

Carbon-14 in the Environment (NCRP 1985c)

Environmental Radioactivity (Eisenbud 1987)

Population Exposure to External Natural Radiation Background in the United States (EPA 1987a)

Ionizing Radiation Exposure of the Population of the United States (NCRP 1987a)

Exposure of the Population of the United States and Canada from Natural Background Radiation (NCRP 1987b)

10.3.5 PRELIMINARY IDENTIFICATION OF POTENTIAL EXPOSURE

Identification of environmental media of concern, the types of radionuclides expected at a site, areas of concern (sampling locations), and potential routes of radionuclide transport through the environment is an important part of the radiological risk assessment process. Potential media of concern include soil, ground water, surface water, air, and biota, as discussed in Chapter 4. Additional considerations for radioactively contaminated sites are listed below.

- Usually a very limited number of radionuclides at a site contribute significantly to the risk. During the site scoping meeting, it is appropriate to consult with a health physicist not only to develop a conceptual model of the facility, but also to identify the anticipated critical radionuclides and pathways.

- In addition to the environmental media identified for chemically contaminated sites, radioactively contaminated sites should be examined for the potential presence of external radiation fields. Many radionuclides emit both beta and gamma radiation, which can create significant external exposures.

- There are other components in the environment that may or may not be critical exposure pathways for the public, but that are very useful indicators of the extent and type of contamination at a site. These components include sediment, aquatic plants, and fish, which may concentrate and integrate the radionuclide contaminants that may be (or have been) present in the aquatic environment at a site. Accordingly, though some components of the environment may or may not be important direct routes of exposure to man, they can serve as indicators of contamination.

10.3.6 DEVELOPING A STRATEGY FOR SAMPLE COLLECTION

The discussions in Chapter 4 regarding sample location, size, type, and frequency apply as well to radioactively contaminated sites with the following additions and qualifications. First, the resolution and sensitivity of radioanalytical techniques permit detection in the environment of most radionuclides at levels that are well below those that are considered potentially harmful. Analytical techniques for nonradioactive chemicals are usually not this sensitive.

For radionuclides, continuous monitoring of the site environment is important, in addition to the sampling and monitoring programs described in Chapter 4. Many field devices that measure external gamma radiation, such as continuous radon monitors and high pressure ionization chambers, provide a real time continuous record of radiation exposure levels and radionuclide concentrations. Such devices are useful for determining the temporal variation of radiation levels at a contaminated site and for comparing these results to the variability observed at background locations. Continuous measure-ments

provide an added level of resolution for quantifying and characterizing radiological risk.

Additional factors that affect the frequency of sampling for radionuclides, besides those discussed in Chapter 4, include the half-lives and the decay products of the radionuclides. Radionuclides with short half-lives, such as Fe-59 (half-life = 44.5 days), have to be sampled more frequently because relatively high levels of contamination can be missed between longer sampling intervals. The decay products of the radionuclides must also be considered, because their presence can interfere with the detection of the parent nuclides of interest, and because they also may be important contributors to risks.

10.3.7 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC) MEASURES

The QA/QC concepts described in Chapter 4 also apply to sampling and analysis programs for radionuclides, although the procedures differ. Guidance regarding sampling and measurement of radionuclides and QA/QC protocols for their analyses are provided in the publications listed in the box on this page.

The QA/QC protocols used for radionuclide analysis were not developed to meet the evidential needs of the Superfund program; however, it is likely that many of the current radiological QA/QC guidance would meet the intent of Superfund requirements. Some areas where radiological QA/QC guidance may not meet the intent of Superfund are listed below.

- The degree of standardization for radiochemical procedures may be less rigorous in the QA/QC protocols than that required for chemical labs under the Contract Laboratory Program (CLP). In radiochemical laboratories, several different techniques may be used to analyze for a specific radionuclide in a given matrix with comparable results. The CLP requires all participating chemical laboratories to use standardized techniques.
- The required number and type of QC blanks are fewer for radionuclide samples. For example, a "trip" blank is not generally used because radionuclide samples are less likely to be contaminated from direct exposure to air than are samples of volatile organics.

Limited guidance is available that specifies field QA/QC procedures (see the box on this page). These and other issues related to QA/QC guidance for radiological analyses are discussed further in the Section 10.4.

RADIONUCLIDE MEASUREMENT QA/QC PROCEDURES

Quality Control for Environmental Measurements Using Gamma-Ray Spectrometry (EPA 1977b)

Quality Assurance Monitoring Programs (Normal Operation) - Effluent Streams and the Environment (NRC 1979)

Upgrading Environmental Radiation Data (EPA 1980)

Handbook of Analytical Quality Control in Radioanalytical Laboratories (EPA 1987b)

QA Procedures for Health Labs Radiochemistry (American Public Health Association 1987)

10.4 DATA EVALUATION

Chapter 5 describes the procedures for organizing and evaluating data collected during a site sampling investigation for use in risk assessment. The ten-step process outlined for chemical data evaluation is generally applicable to the evaluation of radioactive contaminants, although many of the details must be modified to accommodate differences in sampling and analytical methods.

10.4.1 COMBINING DATA FROM AVAILABLE SITE INVESTIGATIONS

All available data for the site should be gathered for evaluation and sorted by environmental medium sampled, analytical methods, and sampling periods. Decisions should be made, using the process described in Section 5.1, to combine, evaluate individually, or eliminate specific data for use in the quantitative risk assessment.

10.4.2 EVALUATING ANALYTICAL METHODS

As with chemical data, radiological data should be grouped according to the types of analyses performed to determine which data are appropriate for use in quantitative risk assessment. Analytical methods for measuring radioactive contaminants differ from those for measuring organic and inorganic chemicals. Standard laboratory procedures for radionuclide analyses are presented in references, such as those listed in the box on page 10-12. Analytical methods include alpha, beta, and gamma spectrometry, liquid scintillation counting, proportional counting, and chemical separation followed by spectrometry, depending on the specific radionuclides of interest.

Laboratory accreditation procedures for the analysis of radionuclides also differ. Radionuclide analyses are not currently conducted as part of the Routine Analytical Services (RAS) under the Superfund CLP. However, these analyses may be included under Special Analytical Services (SAS). The EPA Environmental Radioactivity Intercomparison Program, coordinated by the Nuclear Radiation Assessment Division of the Environmental Monitoring Systems Laboratory in Las Vegas (EMSL-LV), provides quality assurance oversight for participating radiation measurement laboratories (EPA 1989b). Over 300 federal, state, and private laboratories participate in some phase of the program, which includes analyses for a variety of radionuclides in media (e.g., water, air, milk, and food) with activity concentrations that approximate levels that may be encountered in the environment. Similar intercomparison programs for analysis of thermoluminescent dosimeters (TLDs) for external radiation exposure rate measurements are conducted by the DOE Environmental Measurements Laboratory (EML) and the DOE Radiological and Environmental Services Laboratory (RESL).

In both cases, these intercomparison programs are less comprehensive than the CLP in terms of facility requirements other than analysis of performance evaluation samples, such as laboratory space and procedural requirements, instrumentation, training, and quality control. However, until such time as radiation measurements become fully incorporated in the CLP, use of laboratories that successfully participate in these intercomparison studies may be the best available alternative for ensuring high-quality analytical data. Regardless of laboratory accreditation, all analytical results should be carefully scrutinized and not accepted at face value.

As discussed in Chapter 5 for chemical analyses, radioanalytical results that are not specific for a particular radionuclide (e.g., gross alpha, gross beta) may have limited usefulness for quantitative risk assessment. They can be useful as a screening tool, however. External gamma exposure rate data, although thought of as a screening measurement, can be directly applied as input data for a quantitative risk assessment.

10.4.3 EVALUATING QUANTITATION LIMITS

Lower limits of detection (LLDs), or quantitation limits, for standard techniques for most radionuclide analyses are sufficiently low to ensure the detection of nuclides at activity concentrations well below levels of concern. There are exceptions, however: some radionuclides with very low specific activities, long half-lives, and/or low-energy decay emissions (e.g., I-129, C-14) are difficult to detect precisely using standard techniques. To achieve lower LLDs, a laboratory may: (1) use more sensitive measurement techniques and/or chemical extraction procedures; (2) analyze larger sample sizes; or (3) increase the counting time of the sample. A laboratory may also choose to apply all three options to increase detection capabilities. Exhibit 10-4 presents examples of typical LLDs using standard analytical techniques. The same special considerations noted for chemical analyses

EXHIBIT 10-4

EXAMPLES OF LOWER LIMITS OF DETECTION (LLD) FOR SELECTED RADIONUCLIDES USING STANDARD ANALYTICAL METHODS[a]

Isotope	Sample Media[b]	LLD pCi	LLD Bq	Methodology
Co-60	-Water	10	0.4	Gamma Spectrometry
	-Soil (dry wt.)	0.1	0.004	Gamma Spectrometry
	-Biota (wet wt.)[c]	0.1	0.004	Gamma Spectrometry
	-Air[d]	25	0.9	Gamma Spectrometry
Sr-90	-Water	1	0.04	Radiochemistry
Cs-137	-Water	10	0.4	Gamma Spectrometry
		0.3	0.01	Radiochemistry
	-Soil (dry wt.)	1	0.04	Gamma Spectrometry
		0.3	0.01	Radiochemistry
	-Biota (wet wt.)	1	0.04	Gamma Spectrometry
		0.3	0.01	Radiochemistry
	-Air	30	1	Gamma Spectrometry
Pb-210	-Water	0.2	0.007	Radiochemistry
	-Soil (dry wt.)	0.2	0.007	Radiochemistry
	-Biota (wet wt.)	0.2	0.007	Radiochemistry
	-Air	5	0.2	Radiochemistry
Ra-226	-Water	100	4	Gamma Spectrometry
		0.1	0.004	Radiochemistry
		0.1	0.004	Radon Daughter Emanation
	-Soil (dry wt.)	0.1	0.004	Radon Daughter Emanation
	-Biota (wet wt.)	0.1	0.004	Radon Daughter Emanation
	-Air	1	0.04	Alpha Spectrometry
Th-232	-Water	0.02	0.0007	Alpha Spectrometry
	-Soil (dry wt.)	0.2	0.007	Radiochemistry
	-Biota (wet wt.)	0.02	0.0007	Alpha Spectrometry
	-Air	0.3	0.01	Alpha Proportional Counter
U-234	-Water	0.02	0.0007	Alpha Spectrometry
U-235	-Soil (dry wt.)	0.1	0.004	Alpha Spectrometry
U-238	-Biota (wet wt.)	0.01	0.0004	Alpha Spectrometry
	-Air	0.2	0.007	Alpha Spectrometry

(continued)

EXHIBIT 10-4 (continued)

EXAMPLES OF LOWER LIMITS OF DETECTION (LLD)
FOR SELECTED RADIONUCLIDES USING STANDARD ANALYTICAL METHODS[a]

Isotope	Sample Media[b]	LLD pCi	LLD Bq	Methodology
Pu-238	-Water	0.02	0.0007	Alpha Spectrometry
Pu-239	-Soil (dry wt.)	0.1	0.004	Alpha Spectrometry
Pu-240	-Biota (wet wt.)	0.01	0.0004	Alpha Spectrometry
	-Air	0.2	0.007	Alpha Spectrometry

[a] Source: U.S. Environmental Protection Agency Eastern Environmental Radiation Facility (EPA-EERF), Department of Energy Environmental Measurements Laboratory (DOE-EML), and commercial laboratories. Note that LLDs are radionuclide-, media-, sample size-, and laboratory-specific: higher and lower LLDs than those reported above are possible. The risk assessor should request and report the LLDs supplied by the laboratory performing the analyses.

[b] Nominal sample sizes: water (1 liter), soil (1 kg dry wt.), biota (1 kg wet wt.), and air (1 filter sample).

[c] Biota includes vegetation, fish, and meat.

[d] Air refers to a sample of 300 m^3 of air collected on a filter, which is analyzed for the radionuclide of interest.

would also apply for radionuclides that are not detected in any samples from a particular medium, but are suspected to be present at a site. In these cases, three options may be applied: (1) re-analyze the sample using more sensitive methods; (2) use the LLD value as a "proxy" concentration to evaluate the potential risks at the detection limit; or (3) evaluate the possible risk implication of the radionuclide qualitatively. An experienced health physicist should decide which of these three options would be most appropriate.

When multiple radionuclides are present in a sample, various interferences can occur that may reduce the analytical sensitivity for a particular radionuclide. Also, in some areas of high background radioactivity from naturally occurring radionuclides, it may be difficult to differentiate background contributions from incremental site contamination. It may be possible to eliminate such interferences by radiochemical separation or special instrumental techniques.

A sample with activity that is nondetectable should be reported as less than the appropriate sample and radionuclide-specific LLD value. However, particular caution should be exercised when applying this approach to radionuclides that are difficult to measure and possess unusually high detection limits, as discussed previously. In most cases where a potentially important radionuclide contaminant is suspected, but not detected, in a sample, the sample should be reanalyzed using more rigorous radiochemical procedures and more sophisticated detection techniques.

If radionuclide sample data for a site are reported without sample-specific radionuclide quantitation limits, the laboratory conducting the analyses should be contacted to determine the appropriate LLD values for the analytical techniques and sample media.

10.4.4 EVALUATING QUALIFIED AND CODED DATA

Various data qualifiers and codes may be attached to problem data from inorganic and organic chemical analyses conducted under the CLP as shown in Exhibits 5-4 and 5-5. These include laboratory qualifiers assigned by the laboratory conducting the analysis and data validation qualifiers assigned by personnel involved in data validation. These qualifiers pertain to QA/QC problems and generally indicate questions concerning chemical identity, chemical concentration, or both. No corresponding system of qualifiers has been developed for radioanalytical data, although certain of the CLP data qualifiers might be adopted for use in reporting radioanalytical data. The health physicist should define and evaluate any qualifiers attached to data for radionuclide analyses. Based on the discussions in Chapter 5, the references on methods listed above, and professional judgment, the health physicist should eliminate inappropriate data from use in the risk assessment.

10.4.5 COMPARING CONCENTRATIONS DETECTED IN BLANKS WITH CONCENTRATIONS DETECTED IN SAMPLES

The analysis of blank samples (e.g., laboratory or reagent blanks, field blanks, calibration blanks) is an important component of a proper radioanalytical program. Analysis of blanks provides a measure of contamination introduced into a sample during sampling or analysis activities.

The CLP provides guidance for inorganic and organic chemicals that are not common laboratory contaminants. According to this guidance, if a blank contains detectable levels of any uncommon laboratory chemical, site sample results should be considered positive only if the measured concentration in the sample exceeds five times the maximum amount detected in any blank. Samples containing less than five times the blank concentration should be classified as nondetects, and the maximum blank-related concentration should be specified as the quantitation limit for that chemical in the sample. Though they are not considered to be common laboratory contaminants, radionuclides should not be classified as nondetects using the above CLP guidance. Instead, the health physicist should evaluate all active sample preparation and analytical procedures for possible sources of contamination.

10.4.6 EVALUATING TENTATIVELY IDENTIFIED RADIONUCLIDES

Because radionuclides are not included on the Target Compound List (TCL), they may be classified as tentatively identified compounds (TICs) under CLP protocols. In reality, however, radioanalytical techniques are sufficiently sensitive that the identity and quantity of radionuclides of potential concern at a site can be determined with a high degree of confidence. In some cases, spectral or matrix interferences may introduce uncertainties, but these problems usually can be overcome using special radiochemical and/or instrumental methods. In cases where a radionuclide's identity is not sufficiently well-defined by the available data set: (1) further analyses may be performed using more sensitive methods, or (2) the tentatively identified radionuclide may be included in the risk assessment as a contaminant of potential concern with notation of the uncertainty in its identity and concentration.

10.4.7 COMPARING SAMPLES WITH BACKGROUND

It is imperative to select, collect, and analyze an appropriate number of background samples to be able to distinguish between onsite sources of radionuclide contaminants from radionuclides expected normally in the environment. Background measurements of direct radiation and radionuclide concentrations in all media of concern should be determined at sampling locations geologically similar to the site, but beyond the influence of the site. Screening measurements (e.g., gross alpha, beta, and gamma) should be used to determine whether more sensitive radionuclide-specific analyses are warranted. Professional judgment should be used by the health physicist to select appropriate background sampling locations and analytical techniques. The health physicist should also determine which naturally occurring radionuclides (e.g., uranium, radium, or thorium) detected onsite should be eliminated from the quantitative risk assessment. All man-made radionuclides detected in samples collected should, however, be retained for further consideration.

10.4.8 DEVELOPING A SET OF RADIONUCLIDE DATA AND INFORMATION FOR USE IN A RISK ASSESSMENT

The process described in Section 5.8 for selection of chemical data for inclusion in the quantitative risk assessment generally applies for radionuclides as well. One exception is the lack of CLP qualifiers for radionuclides, as discussed previously. Radionuclides of concern should include those that are positively detected in at least one sample in a given medium, at levels significantly above levels detected in blank samples and significantly above local background levels. As discussed previously, the decision to include radionuclides not detected in samples from any medium but suspected at the site based on historical information should be made by a qualified health physicist.

10.4.9 GROUPING RADIONUCLIDES BY CLASS

Grouping radionuclides for consideration in the quantitative risk assessment is generally unnecessary and inappropriate. Radiation dose and resulting health risk is highly dependent on the specific properties of each radionuclide. In some cases, however, it may be acceptable to group different radioisotopes of the same element that have similar radiological characteristics (e.g., Pu-238/239/240, U-235/238) or belong to the same decay series. Such groupings should be determined very selectively and seldom offer any significant advantage.

10.4.10 FURTHER REDUCTION IN THE NUMBER OF RADIONUCLIDES

For sites with a large number of radionuclides detected in samples from one or more media, the risk assessment should focus on a select group of radionuclides that dominate the radiation dose and health risk to the critical receptors. For example, when considering transport through ground water to distant receptors, transit times may be very long; consequently, only radionuclides with long half-lives or radioactive progeny that are formed during transport may be of concern for that exposure pathway. For direct external exposures, high-energy gamma emitters are of principal concern, whereas

alpha-emitters may dominate doses from the inhalation and ingestion pathways. The important radionuclides may differ for each exposure pathway and must be determined on their relative concentrations, half-lives, environmental mobility, and dose conversion factors (see Section 10.5 for discussion of dose conversion factors) for each exposure pathway of interest.

The total activity inventory and individual concentrations of radionuclides at a Superfund site will change with time as some nuclides decay away and others "grow in" as a result of radioactive decay processes. Consequently, it may be important to evaluate different time scales in the risk assessment. For example, at a site where Ra-226 (half-life = 1600 years) is the only contaminant of concern in soil at some initial time, the Pb-210 (half-life = 22.3 years) and Po-210 (half-life = 138 days) progeny will also become dominant contributors to the activity onsite over a period of several hundred years.

10.4.11 SUMMARIZING AND PRESENTING DATA

Presentation of results of the data collection and evaluation process will be generally the same for radionuclides and chemical contaminants. The sample table formats presented in Exhibits 5-6 and 5-7 are equally applicable to radionuclide data, except that direct radiation measurement data should be added, if appropriate for the radionuclides and exposure pathways identified at the site.

10.5 EXPOSURE AND DOSE ASSESSMENT

This section describes a methodology for estimating the radiation dose equivalent to humans from potential exposures to radionuclides through all pertinent exposure pathways at a remedial site. These estimates of dose equivalent may be used for comparison with radiation protection standards and criteria. However, this methodology has been developed for regulation of occupational radiation exposures for adults and is not completely applicable for estimating health risk to the general population. Section 10.7.2, therefore, describes a separate methodology for estimating health risk.

Chapter 6 describes the procedures for conducting an exposure assessment for chemical contaminants as part of the baseline risk assessment for Superfund sites. Though many aspects of the discussion apply to radionuclides, the term "exposure" is used in a fundamentally different way for radionuclides as compared to chemicals. For chemicals, exposure generally refers to the intake (e.g., inhalation, ingestion, dermal exposure) of the toxic chemical, expressed in units of mg/kg-day. These units are convenient because the toxicity values for chemicals are generally expressed in these terms. For example, the toxicity value used to assess carcinogenic effects is the slope factor, expressed in units of risk of lifetime excess cancers per mg/kg-day. As a result, the product of the intake estimate with the slope factor yields the risk of cancer (with proper adjustments made for absorption, if necessary).

Intakes by inhalation, ingestion, and absorption are also potentially important exposure pathways for radionuclides, although radionuclide intake is typically expressed in units of activity (i.e., Bq or Ci) rather than mass. Radionuclides that enter through these internal exposure pathways may become systemically incorporated and emit alpha, beta, or gamma radiation within tissues or organs. Unlike chemical assessments, an exposure assessment for radioactive contaminants can include an explicit estimation of the radiation dose equivalent. As discussed previously in Section 10.1, the dose equivalent is an expression that takes into consideration both the amount of energy deposited in a unit mass of a specific organ or tissue as a result of the radioactive decay of a specific radionuclide, as well as the relative biological effectiveness of the radiations emitted by that nuclide. (Note that the term dose has a different meaning for radionuclides [dose = energy imparted to a unit mass of tissue] than that used in Chapter 6 for chemicals [dose, or absorbed dose = mass penetrating into an organism].)

Unlike chemicals, radionuclides can have deleterious effects on humans without being taken into or brought in contact with the body. This is because high energy beta particles and photons from radionuclides in contaminated air, water, or soil can travel long distances with only minimum attenuation in these media before depositing their energy in human tissues. External radiation exposures can

result from either exposure to radionuclides at the site area or to radionuclides that have been transported from the site to other locations in the environment. Gamma and x-rays are the most penetrating of the emitted radiations, and comprise the primary contribution to the radiation dose from external exposures. Alpha particles are not sufficiently energetic to penetrate the outer layer of skin and do not contribute significantly to the external dose. External exposure to beta particles primarily imparts a dose to the outer layer skin cells, although high-energy beta radiation can penetrate into the human body.

The quantification of the amount of energy deposited in living tissue due to internal and external exposures to radiation is termed radiation dosimetry. The amount of energy deposited in living tissue is of concern because the potential adverse effects of radiation are proportional to energy deposition. The energy deposited in tissues is proportional to the decay rate of a radionuclide, and not its mass. Therefore, radionuclide quantities and concentrations are expressed in units of activity (e.g., Bq or Ci), rather than in units of mass.

Despite the fundamental difference between the way exposures are expressed for radionuclides and chemicals, the approach to exposure assessment presented in Chapter 6 for chemical contaminants largely applies to radionuclide contaminants. Specifically, the three steps of an exposure assessment for chemicals also apply to radionuclides: (1) characterization of the exposure setting; (2) identification of the exposure pathways; and (3) quantification of exposure. However, some of the methods by which these three steps are carried out are different for radionuclides.

10.5.1 CHARACTERIZING THE EXPOSURE SETTING

Initial characterization of the exposure setting for radioactively contaminated sites is virtually identical to that described in Chapter 6. One additional consideration is that, at sites suspected of having radionuclide contamination, a survey should be conducted to determine external radiation fields using any one of a number of field survey instruments (preferably, G-M tubes and NaI(Tl) field detectors) (see Exhibit 10-2). Health and safety plans should be implemented to reduce the possibility of radiation exposures that are in excess of allowable limits.

REFERENCES ON EXPOSURE ASSESSMENT FOR RADIONUCLIDES

Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents (NRC 1977)

Radiological Assessment: A Textbook on Environmental Dose Analysis (Till and Meyer 1983)

Models and Parameters for Environmental Radiological Assessments (Miller 1984)

Radiological Assessment: Predicting the Transport, Bioaccumulation, and Uptake by Man of Radionuclides Released to the Environment (NCRP 1984a)

Background Information Document, Draft EIS for Proposed NESHAPS for Radionuclides, Volume I, Risk Assessment Methodology (EPA 1989a)

Screening Techniques for Determining Compliance with Environmental Standards (NCRP 1989)

10.5.2 IDENTIFYING EXPOSURE PATHWAYS

The identification of exposure pathways for radioactively contaminated sites is very similar to that described in Chapter 6 for chemically contaminated sites, with the following additional guidance.

- In addition to the various ingestion, inhalation, and direct contact pathways described in Chapter 6, external exposure to penetrating radiation should also be considered. Potential external exposure pathways to be considered include immersion in contaminated air, immersion in contaminated water, and radiation

exposure from ground surfaces contaminated with beta- and photon-emitting radionuclides.

- As with nonradioactive chemicals, environmentally dispersed radionuclides are subject to the same chemical processes that may accelerate or retard their transfer rates and may increase or decrease their bioaccumulation potentials. These transformation processes must be taken into consideration during the exposure assessment.

- Radionuclides undergo radioactive decay that, in some respects, is similar to the chemical or biological degradation of organic compounds. Both processes reduce the quantity of the hazardous substance in the environment and produce other substances. (Note, however, that biological and chemical transformations can never alter, i.e., either increase or decrease, the radioactivity of a radionuclide.) Radioactive decay products can also contribute significantly to the radiation exposure and must be considered in the assessment.

- Chapter 6 presents a series of equations (Exhibits 6-11 through 6-19) for quantification of chemical exposures. These equations and suggested default variable values may be used to estimate radionuclide intakes as a first approximation, if the equations are modified by deleting the body weight and averaging time from the denominator. However, depending upon the characteristics of the radionuclides of concern, consideration of radioactive decay and ingrowth of radioactive decay products may be important additions, as well as the external exposure pathways.

- Chapter 6 also refers to a number of computer models that are used to predict the behavior and fate of chemicals in the environment. While those models may be suitable for evaluations of radioactive contaminants in some cases, numerous models have been developed specifically for evaluating the transport of radionuclides in the environment and predicting the doses and risks to exposed individuals. In general, models developed specifically for radiological assessments should be used. Such models include, for example, explicit consideration of radioactive decay and ingrowth of radioactive decay products. (Contact ORP for additional guidance on the fate and transport models recommended by EPA.)

10.5.3 QUANTIFYING EXPOSURE: GENERAL CONSIDERATIONS

One of the primary objectives of an exposure assessment is to make a reasonable estimate of the maximum exposure to individuals and critical population groups. The equation presented in Exhibit 6-9 to calculate intake for chemicals may be considered to be applicable to exposure assessment for radionuclides, except that the body weight and averaging time terms in the denominator should be omitted. However, as discussed previously, exposures to radionuclides include both internal and external exposure pathways. In addition, radiation exposure assessments do not end with the calculation of intake, but take the calculation an additional step in order to estimate radiation dose equivalent.

The radiation dose equivalent to specified organs and the effective dose equivalent due to intakes of radionuclides by inhalation or ingestion are estimated by multiplying the amount of each radionuclide inhaled or ingested times appropriate dose conversion factors (DCFs), which represent the dose equivalent per unit intake. As noted previously, the effective dose equivalent is a weighted sum of the dose equivalents to all irradiated organs and tissues, and represents a measure of the overall detriment. *Federal Guidance Report No. 11* (EPA 1988) provides DCFs for each of over 700 radionuclides for both inhalation and ingestion exposures. It is important to note, however, that these DCFs were developed for regulation of occupational exposures to radiation and may not be appropriate for the general population.

Radionuclide intake by inhalation and ingestion is calculated in the same manner as chemical intake

except that it is not divided by body weight or averaging time. For radionuclides, a reference body weight is already incorporated into the DCFs, and the dose is an expression of energy deposited per gram of tissue.

If intake of a radionuclide is defined for a specific time period (e.g., Bq/year), the dose equivalent will be expressed in corresponding terms (e.g., Sv/year). Because systemically incorporated radionuclides can remain within the body for long periods of time, internal dose is best expressed in terms of the committed effective dose equivalent, which is equal to the effective dose equivalent over the 50-year period following intake.

External exposures may be determined by monitoring and sampling of the radionuclide concentrations in environmental media, direct measurement of radiation fields using portable instrumentation, or by mathematical modeling. Portable survey instruments that have been properly calibrated can display dose rates (e.g., Sv/hr), and dose equivalents can be estimated by multiplying by the duration of exposure to the radiation field. Alternatively, measured or predicted concentrations in environmental media may be multiplied by DCFs, which relate radionuclide concentrations on the ground, in air, or in water to external dose rates (e.g., Sv/hr per Bq/m^2 for ground contamination or Sv/hr per Bq/m^3 for air or water immersion).

The dose equivalents associated with external and internal exposures are expressed in identical units (e.g., Sv), so that contributions from all pathways can be summed to estimate the total effective dose equivalent value and prioritize risk from different sources.

In general, radiation exposure assessments need not consider acute toxicity effects. Acute exposures are of less concern for radionuclides than for chemicals because the quantities of radionuclides required to cause adverse effects from acute exposure are extremely large and such levels are not normally encountered at Superfund sites. Toxic effects from acute radiation exposures are possible when humans are exposed to the radiation from large amounts of radioactive materials released during a major nuclear plant accident, such as Chernobyl, or during above-ground weapons detonations. Consequently, the exposure and risk assessment guidance for radionuclides presented in this chapter is limited to situations causing chronic exposures to low levels of radioactive contaminants.

10.5.4 QUANTIFYING EXPOSURE: DETERMINING EXPOSURE POINT CONCENTRATIONS

The preferred method for estimating the concentration of chemical or radioactive contaminants at those places where members of the public may come into contact with them is by direct measurement. However, this will not be possible in many circumstances and it may be necessary, therefore, to use environmental fate and transport models to predict contaminant concentrations. Such modeling would be necessary, for example: (1) when it is not possible to obtain representative samples for all radionuclides of concern; (2) when the contaminant has not yet reached the potential exposure points; and (3) when the contaminants are below the limits of detection but, if present, can still represent a significant risk to the public.

Numerous fate and transport models have been developed to estimate contaminant concentrations in ground water, soil, air, surface water, sediments, and food chains. Models developed for chemical contaminants, such as those discussed in Chapter 6, may also be applied to radionuclides with allowance for radioactive decay and ingrowth of decay products. There are also a number of models that have been developed specifically for radionuclides. These models are similar to the models used for toxic chemicals but have features that make them convenient to use for radionuclide pathway analysis, such as explicit consideration of radioactive decay and daughter ingrowth. Available models for use in radiation risk assessments range in complexity from a series of hand calculations to major computer codes. For example, NRC Regulatory Guide 1.109 presents a methodology that may be used to manually estimate dose equivalents from a variety of exposure pathways (NRC 1977). Examples of computerized radiological assessment models include the AIRDOS-EPA code and the EPA-PRESTO family of codes, which are used extensively by EPA to estimate exposures and doses to populations following atmospheric releases of radionuclides and releases from a low-level waste

disposal facility, respectively. Guidance on selection and use of the various models can be obtained from the EPA Office of Radiation Programs.

Exhibit 6-10, Example of Table Format for Summarizing Exposure Concentrations, may be used for radionuclide contaminants, except that radionuclide concentrations are expressed in terms of activity per unit mass or volume of the environmental medium (e.g., Bq/kg, Bq/L) rather than mass.

10.5.5 QUANTIFYING EXPOSURE: ESTIMATING INTAKE AND DOSE EQUIVALENT

Section 6.6 presents a description of the methods used to estimate intake rates of contaminants from the various exposure pathways. Exhibits 6-11 to 6-19 present the equations and input assumptions recommended for use in intake calculations. In concept, those equations and assumptions also apply generally to radionuclides, except that the body weight and averaging time terms in the denominators should be omitted. However, as discussed previously, the product of these calculations for radionuclides is an estimate of the radionuclide intake, expressed in units of activity (e.g., Bq), as opposed to mg/kg-day. In addition, the endpoint of a radiation exposure assessment is radiation dose, which is calculated using DCFs as explained below. As explained previously, dose equivalents calculated in the following manner should be used to compare with radiation protection standards and criteria, not to estimate risk.

Internal Exposure. Exhibits 6-11, 6-12, 6-14, 6-17, 6-18, and 6-19 present simplified models for the ingestion of water, food, and soil as pathways for the intake of environmental contaminants. The recommended assumptions for ingestion rates and exposure durations are applicable to radionuclide exposures and may be used to estimate the intake rates of radionuclides by these pathways. As noted previously, however, these intake estimates for radionuclides should not be divided by the body weight or averaging time. These intake rates must be multiplied by appropriate DCF values in order to obtain committed effective dose equivalent values. The more rigorous and complex radionuclide pathway models noted previously typically require much more extensive input data and may include default parameter values that differ somewhat from the values recommended in these exhibits.

Exhibit 6-16 presents the equation and assumptions used to estimate the contaminant intake from air. For radionuclides, the dose from inhalation of contaminated air is determined as the product of the radionuclide concentration in air (Bq/m^3), the breathing rate (m^3 per day or year), exposure duration (day or year), and the inhalation DCF (Sv per Bq inhaled). The result of this calculation is the committed effective dose equivalent, in units of Sv.

Chapter 6 points out that dermal absorption of airborne chemicals is not an important route of uptake. This point is also true for most radionuclides, except airborne tritiated water vapor, which is efficiently taken into the body through dermal absorption. In order to account for this route of uptake, the inhalation DCF for tritium includes an adjustment factor to account for dermal absorption.

External Exposure. Immersion in air containing certain beta-emitting and/or photon-emitting radioactive contaminants can also result in external exposures. Effective dose equivalents from external exposure are calculated as the product of the airborne radionuclide concentration (Bq/m^3), the external DCF for air immersion (Sv/hr per Bq/m^3), and the duration of exposure (hours).

Exhibits 6-13 and 6-15 illustrate the dermal uptake of contaminants resulting from immersion in water or contact with soil. This route of uptake can be important for many organic chemicals; however, dermal uptake is generally not an important route of uptake for radionuclides, which have small dermal permeability constants. External radiation exposure due to submersion in water contaminated with radionuclides is possible and is similar to external exposure due to immersion in air. However, because of the shielding effects of water and the generally short durations of such exposures, immersion in water is typically of lesser significance. The product of the radionuclide concentration in water (Bq/m^3), the relevant DCF (Sv/hr per Bq/m^3), and the duration of exposure (hours) yields effective dose equivalent.

The third external exposure pathway of potential significance is irradiation from radionuclides deposited on the ground surface. Effective dose equivalents resulting from this pathway may be estimated as the product of the soil surface concentration (Bq/m^2) of photon-emitting radionuclides of concern, the external DCF for ground surface exposure (Sv/hr per Bq/m^2), and the duration of exposure (hours).

10.5.6 COMBINING INTAKES AND DOSES ACROSS PATHWAYS

The calculations described previously result in estimates of committed effective dose equivalents (Sv) from individual radionuclides via a large number of possible exposure pathways. Because a given population may be subject to multiple exposure pathways, the results of the exposure assessment should be organized by grouping all applicable exposure pathways for each exposed population. Risks from various exposure pathways and contaminants then can be integrated during the risk characterization step (see Section 10.7).

10.5.7 EVALUATING UNCERTAINTY

The radiation exposure assessment should include a discussion of uncertainty, that, at a minimum, should include: (1) a tabular summary of the values used to estimate exposures and doses and the range of these values; and (2) a summary of the major assumptions of the exposure assessment, including the uncertainty associated with each assumption and how it might affect the exposure and dose estimates. Sources of uncertainty that must be addressed include: (1) how well the monitoring data represent actual site conditions; (2) the exposure models, assumptions, and input variables used to estimate exposure point concentrations; and (3) the values of the variables used to estimate intakes and external exposures. More comprehensive discussions of uncertainty associated with radiological risk assessment are provided in the *Background Information Document for the Draft EIS for Proposed NESHAPS for Radionuclides* (EPA 1989a), *Radiological Assessment* (Till and Meyer 1983), and NCRP Report No. 76 (NCRP 1984a).

10.5.8 SUMMARIZING AND PRESENTING EXPOSURE ASSESSMENT RESULTS

Exhibit 6-22 presents a sample format for summarizing the results of the exposure assessment. The format may also be used for radionuclide contaminants except that the entries should be specified as committed effective dose equivalents (Sv) and the annual estimated intakes (Bq) for each radionuclide of concern. The intakes and dose estimates should be tabulated for each exposure pathway so that the most important radionuclides and pathways contributing to the total health risk may be identified.

The information should be organized by exposure pathway, population exposed, and current and future use assumptions. For radionuclides, however, it may not be necessary to summarize short-term and long-term exposures separately as specified for chemical contaminants.

10.6 TOXICITY ASSESSMENT

Chapter 7 describes the two-step process employed to assess the potential toxicity of a given chemical contaminant. The first step, hazard identification, is used to determine whether exposure to a contaminant can increase the incidence of an adverse health effect. The second step, dose-response assessment, is used to quantitatively evaluate the toxicity information and characterize the relationship between the dose of the contaminant administered or received and the incidence of adverse health effects in the exposed population.

There are certain fundamental differences between radionuclides and chemicals that somewhat simplify toxicity assessment for radionuclides. As discussed in the previous sections, the adverse effects of exposure to radiation are due to the energy deposited in sensitive tissue, which is referred to as the radiation dose. In theory, any dose of radiation has the potential to produce an adverse effect. Accordingly, exposure to any radioactive substances is, by definition, hazardous.

Dose-response assessment for radionuclides is also more straightforward. The type of effects and

the likelihood of occurrence of any one of a number of possible adverse effects from radiation exposure depends on the radiation dose. The relationship between dose and effect is relatively well characterized (at high doses) for most types of radiations. As a result, the toxicity assessment, within the context that it is used in this manual, need not be explicitly addressed in detail for individual radionuclides at each contaminated site.

The sections that follow provide a brief summary of the human and experimental animal studies that establish the hazard and dose-response relationship for radiation exposure. More detailed discussions of radiation toxicity are provided in publications of the National Academy of Sciences Committee on Biological Effects of Ionizing Radiation (BEIR), the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR), NRC, NCRP, and ICRP listed in the box on this page.

REFERENCES ON HEALTH EFFECTS OF RADIATION EXPOSURE

Recommendations of the ICRP (ICRP 1977)

Limits for Intake of Radionuclides by Workers (ICRP 1979)

Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations (NCRP 1980)

The Effects on Populations of Exposure to Low Levels of Ionizing Radiation (NAS 1980)

Induction of Thyroid Cancer by Ionizing Radiation (NCRP 1985b)

Lung Cancer Risk from Indoor Exposures to Radon Daughters (ICRP 1987)

Health Risks of Radon and Other Internally Deposited Alpha-Emitters (National Academy of Sciences 1988)

Ionizing Radiation: Sources, Effects, and Risks (UNSCEAR 1988)

Health Effects Models for Nuclear Power Plant Accident Consequence Analysis: Low-LET Radiation (NRC 1989)

10.6.1 HAZARD IDENTIFICATION

The principal adverse biological effects associated with ionizing radiation exposures from radioactive substances in the environment are carcinogenicity, mutagenicity, and teratogenicity. Carcinogenicity is the ability to produce cancer. Mutagenicity is the property of being able to induce genetic mutation, which may be in the nucleus of either somatic (body) or germ (reproductive) cells. Mutations in germ cells lead to genetic or inherited defects. Teratogenicity refers to the ability of an agent to induce or increase the incidence of congenital malformations as a result of permanent structural or functional deviations produced during the growth and development of an embryo (more commonly referred to as birth defects). Radiation may induce other deleterious effects at acute doses above about 1 Sv, but doses of this magnitude are not normally associated with radioactive contamination in the environment.

As discussed in Section 10.1, ionizing radiation causes injury by breaking molecules into electrically charged fragments (i.e., free radicals), thereby producing chemical rearrangements that may lead to permanent cellular damage. The degree of biolog--ical damage caused by various types of radiation varies according to how spatially close together the ionizations occur. Some ionizing radiations (e.g., alpha particles) produce high density regions of ionization. For this reason, they are called high-LET (linear energy transfer) particles. Other types of radiation (e.g., x-rays, gamma rays, and beta particles) are called low-LET radiations because of the low density pattern of ionization they produce. In equal doses, the carcinogenicity and mutagenicity of high-LET radiations may be an order of magnitude or more greater than those of low-LET radiations, depending on the endpoint being evaluated. The variability in biological effectiveness is accounted for by the quality factor used to calculate the dose equivalent (see Section 10.1).

Carcinogenesis. An extensive body of literature exists on radiation carcinogenesis in man and animals. This literature has been reviewed most recently by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiations (NAS-BEIR Committee) (UNSCEAR

1977, 1982, 1988; NAS 1972, 1980, 1988). Estimates of the average risk of fatal cancer from low-LET radiation from these studies range from approximately 0.007 to 0.07 fatal cancers per sievert.

An increase in cancer incidence or mortality with increasing radiation dose has been demonstrated for many types of cancer in both human populations and laboratory animals (UNSCEAR 1982, 1988; NAS 1980, 1988). Studies of humans exposed to internal or external sources of ionizing radiation have shown that the incidence of cancer increases with increased radiation exposure. This increased incidence, however, is usually associated with appreciably greater doses and exposure frequencies than those encountered in the environment. Therefore, risk estimates from small doses obtained over long periods of time are determined by extrapolating the effects observed at high, acute doses. Malignant tumors in various organs most often appear long after the radiation exposure, usually 10 to 35 years later (NAS 1980, 1988; UNSCEAR 1982, 1988). Radionuclide metabolism can result in the selective deposition of certain radionuclides in specific organs or tissues, which, in turn, can result in larger radiation doses and higher-than-normal cancer risk in these organs.

Ionizing radiation can be considered pancarcinogenic, i.e., it acts as a complete carcinogen in that it serves as both initiator and promoter, and it can induce cancers in nearly any tissue or organ. Radiation-induced cancers in humans have been reported in the thyroid, female breast, lung, bone marrow (leukemia), stomach, liver, large intestine, brain, salivary glands, bone, esophagus, small intestine, urinary bladder, pancreas, rectum, lymphatic tissues, skin, pharynx, uterus, ovary, mucosa of cranial sinuses, and kidney (UNSCEAR 1977, 1982, 1988; NAS 1972, 1980, 1988). These data are taken primarily from studies of human populations exposed to high levels of radiation, including atomic bomb survivors, underground miners, radium dial painters, patients injected with thorotrast or radium, and patients who received high x-ray doses during various treatment programs. Extrapolation of these data to much lower doses is the major source of uncertainty in determining low-level radiation risks (see EPA 1989a). It is assumed that no lower threshold exists for radiation carcinogenesis.

On average, approximately 50 percent of all of the cancers induced by radiation are lethal. The fraction of fatal cancers is different for each type of cancer, ranging from about 10 percent in the case of thyroid cancer to 100 percent in the case of liver cancer (NAS 1980, 1988). Females have approximately 2 times as many total cancers as fatal cancers following radiation exposure, and males have approximately 1.5 times as many (NAS 1980).

Mutagenesis. Very few quantitative data are available on radiogenic mutations in humans, particularly from low-dose exposures. Some mutations are so mild they are not noticeable, while other mutagenic effects that do occur are similar to nonmutagenic effects and are therefore not necessarily recorded as mutations. The bulk of data supporting the mutagenic character of ionizing radiation comes from extensive studies of experimental animals (UNSCEAR 1977, 1982, 1988; NAS 1972, 1980, 1988). These studies have demonstrated all forms of radiation mutagenesis, including lethal mutations, translocations, inversions, nondisjunction, and point mutations. Mutation rates calculated from these studies are extrapolated to humans and form the basis for estimating the genetic impact of ionizing radiation on humans (NAS 1980, 1988; UNSCEAR 1982, 1988). The vast majority of the demonstrated mutations in human germ cells contribute to both increased mortality and illness (NAS 1980; UNSCEAR 1982). Moreover, the radiation protection community is generally in agreement that the probability of inducing genetic changes increases linearly with dose and that no "threshold" dose is required to initiate heritable damage to germ cells.

The incidence of serious genetic disease due to mutations and chromosome aberrations induced by radiation is referred to as genetic detriment. Serious genetic disease includes inherited ill health, handicaps, or disabilities. Genetic disease may be manifest at birth or may not become evident until some time in adulthood. Radiation-induced genetic detriment includes impairment of life, shortened life span, and increased hospitalization. The frequency of radiation-induced genetic impairment is relatively small in comparison with the magnitude of detriment associated with spontaneously arising genetic diseases (UNSCEAR 1982, 1988).

Teratogenesis. Radiation is a well-known teratogenic agent. The developing fetus is much more sensitive to radiation than the mother. The age of the fetus at the time of exposure is the most important factor in determining the extent and type of damage from radiation. The malformations produced in the embryo depend on which cells, tissues, or organs in the fetus are most actively differentiating at the time of radiation exposure. Embryos are relatively resistant to radiation-induced teratogenic effects during the later stages of their development and are most sensitive from just after implantation until the end of organogenesis (about two weeks to eight weeks after conception) (UNSCEAR 1986; Brent 1980). Effects on nervous system, skeletal system, eyes, genitalia, and skin have been noted (Brent 1980). The brain appears to be most sensitive during development of the neuroblast (these cells eventually become the nerve cells). The greatest risk of brain damage for the human fetus occurs at 8 to 15 weeks, which is the time the nervous system is undergoing the most rapid differentiation and proliferation of cells (Otake 1984).

10.6.2 DOSE-RESPONSE RELATIONSHIPS

This section describes the relationship of the risk of fatal cancer, serious genetic effects, and other detrimental health effects to exposure to low levels of ionizing radiation. Most important from the standpoint of the total societal risk from exposures to low-level ionizing radiation are the risks of cancer and genetic mutations. Consistent with our current understanding of their origins in terms of DNA damage, these effects are believed to be stochastic; that is, the probability (risk) of these effects increases with the dose of radiation, but the severity of the effects is independent of dose. For neither induction of cancer nor genetic effects, moreover, is there any convincing evidence for a "threshold" (i.e., some dose level below which the risk is zero). Hence, so far as is known, any dose of ionizing radiation, no matter how small, might give rise to a cancer or to a genetic effect in future generations. Conversely, there is no way to be certain that a given dose of radiation, no matter how large, has caused an observed cancer in an individual or will cause one in the future.

Exhibit 10-5 summarizes EPA's current estimates of the risk of adverse effects associated with human exposure to ionizing radiation (EPA 1989a). Important points from this summary table are provided below.

- Very large doses (>1 Sv) of radiation are required to induce acute and irreversible adverse effects. It is unlikely that such exposures would occur in the environmental setting associated with a potential Superfund site.

- The risks of serious noncarcinogenic effects associated with chronic exposure to radiation include genetic and teratogenic effects. Radiation-induced genetic effects have not been observed in human populations, and extrapolation from animal data reveals risks per unit exposure that are smaller than, or comparable to, the risk of cancer. In addition, the genetic risks are spread over several generations. The risks per unit exposure of serious teratogenic effects are greater than the risks of cancer. However, there is a possibility of a threshold, and the exposures must occur over a specific period of time during gestation to cause the effect. Teratogenic effects can be induced only during the nine months of pregnancy. Genetic effects are induced during the 30-year reproductive generation and cancer can be induced at any point during the lifetime. If a radiation source is not controlled, therefore, the cumulative risk of cancer may be many times greater than the risk of genetic or teratogenic effects due to the potentially longer period of exposure.

EXHIBIT 10-5

SUMMARY OF EPA'S RADIATION RISK FACTORS[a]

Risk	Significant Exposure Period	Risk Factor Range
Low LET (Gy^{-1})		
Teratogenic:[b]		
Severe mental retardation	Weeks 8 to 15 of gestation	0.25-0.55
Genetic:		
Severe hereditary defects, all generations	30-year reproductive generation	0.006-0.11
Somatic:		
Fatal cancers	Lifetime	0.012-0.12
	In utero	0.029-0.10
All cancers	Lifetime	0.019-0.19
High LET (Gy^{-1})		
Genetic:		
Severe hereditary defects, all generations	30-year reproductive generation	0.016-0.29
Somatic:		
Fatal cancers	Lifetime	0.096-0.96
All cancers	Lifetime	0.15-1.5
Radon Decay Products (10^{-6} WLM^{-1})		
Fatal lung cancer	Lifetime	140-720

[a] In addition to the stochastic risks indicated, acute toxicity may occur at a mean lethal dose of 3-5 Sv with a threshold in excess of 1 Sv.

[b] The range assumes a linear, non-threshold dose-response. However, it is plausible that a threshold may exist for this effect.

Based on these observations, it appears that the risk of cancer is limiting and may be used as the sole basis for assessing the radiation-related human health risks of a site contaminated with radionuclides.

For situations where the risk of cancer induction in a specific target organ is of primary interest, the committed dose equivalent to that organ may be multiplied by an organ-specific risk factor. The relative radiosensitivity of various organs (i.e., the cancer induction rate per unit dose) differs markedly for different organs and varies as a function of the age and sex of the exposed individual. Tabulations of such risk factors as a function of age and sex are provided in the *Background Information Document for the Draft Environmental Impact Statement for Proposed NESHAPS for Radionuclides* (EPA 1989a) for cancer mortality and cancer incidence.

10.7 RISK CHARACTERIZATION

The final step in the risk assessment process is risk characterization. This is an integration step in which the risks from individual radionuclides and pathways are quantified and combined where appropriate. Uncertainties also are examined and discussed in this step.

10.7.1 REVIEWING OUTPUTS FROM THE TOXICITY AND EXPOSURE ASSESSMENTS

The exposure assessment results should be expressed as estimates of radionuclide intakes by inhalation and ingestion, exposure rates and duration for external exposure pathways, and committed effective dose equivalents to individuals from all relevant radionuclides and pathways. The risk assessor should compile the supporting documentation to ensure that it is sufficient to support the analysis and to allow an independent duplication of the results. The review should also confirm that the analysis is reasonably complete in terms of the radionuclides and pathways addressed.

In addition, the review should evaluate the degree to which the assumptions inherent in the analysis apply to the site and conditions being addressed. The mathematical models used to calculate dose use a large number of environmental transfer factors and dose conversion factors that may not always be entirely applicable to the conditions being analyzed. For example, the standard dose conversion factors are based on certain generic assumptions regarding the characteristics of the exposed individual and the chemical and physical properties of the radionuclides. Also, as is the case for chemical contaminants, the environmental transfer factors used in the models may not apply to all settings.

Though the risk assessment models may include a large number of radionuclides and pathways, the important radionuclides and pathways are usually few in number. As a result, it is often feasible to check the computer output using hand calculations. This type of review can be performed by health physicists familiar with the models and their limitations. Guidance on conducting such calculations is provided in numerous references, including Till and Meyer (1983) and NCRP Report No. 76 (NCRP 1984a).

10.7.2 QUANTIFYING RISKS

Given that the results of the exposure assessment are virtually complete, correct, and applicable to the conditions being considered, the next step in the process is to calculate and combine risks. As discussed previously, the risk assessment for radionuclides is somewhat simplified because only radiation carcinogenesis needs to be considered.

Section 10.5 presents a methodology for estimating committed effective dose equivalents that may be compared with radiation protection standards and criteria. Although the product of these dose equivalents (Sv) and an appropriate risk factor (risk per Sv) yields an estimate of risk, the health risk estimate derived in such a manner is not completely applicable for members of the general public. A better estimate of risk may be computed using age- and sex-specific coefficients for individual organs receiving significant radiation doses. This information may be used along with organ-specific dose conversion factors to derive slope factors that represent the age-averaged lifetime excess cancer incidence per unit intake for the radionuclides of concern. The Integrated Risk Information System (IRIS) contains slope factor values for radionuclides of concern at remedial sites for each of the four

major exposure pathways (inhalation, ingestion, air immersion, and ground-surface irradiation), along with supporting documentation for the derivation of these values (see Chapter 7 for more detail on IRIS).

The slope factors from the IRIS data base for the inhalation pathway should be multiplied by the estimated inhaled activity (derived using the methods presented in Section 6.6.3 and Exhibit 6-16, without division of the body weight and averaging time) for each radionuclide of concern to estimate risks from the inhalation pathway. Similarly, risks from the ingestion pathway should be estimated by multiplying the ingestion slope factors by the activity ingested for each radionuclide of concern (derived using the methods presented in Exhibits 6-11, 6-12, 6-14, 6-17, 6-18, and 6-19, without division by the body weight and averaging time). Estimates of the risk from the air immersion pathway should be computed by multiplying the appropriate slope factors by the airborne radionuclide concentration (Bq/m^3) and the duration of exposure. Risk from the ground surface pathway should be computed as the product of the slope factor, the soil concentration (Bq/m^2), and the duration of exposure for each radionuclide of concern.

The sum of the risks from all radionuclides and pathways yields the lifetime risk from the overall exposure. As discussed in Chapter 8, professional judgment must be used in combining the risks from various pathways, as it may not be physically possible for one person to be exposed to the maximum radionuclide concentrations for all pathways.

10.7.3 COMBINING RADIONUCLIDE AND CHEMICAL CANCER RISKS

Estimates of the lifetime risk of cancer to exposed individuals resulting from radiological and chemical risk assessments may be summed in order to determine the overall potential human health hazard associated with a site. Certain precautions should be taken, however, before summing these risks. First, the risk assessor should evaluate whether it is reasonable to assume that the same individual can receive the maximum radiological and chemical dose. It is possible for this to occur in some cases because many of the environmental transport processes and routes of exposure are the same for radionuclides and chemicals.

In cases where different environmental fate and transport models have been used to predict chemical and radionuclide exposure, the mathematical models may incorporate somewhat different assumptions. These differences can result in incompatibilities in the two estimates of risk. One important difference of this nature is how the cancer toxicity values (i.e., slope factors) were developed. For both radionuclides and chemicals, cancer toxicity values are obtained by extrapolation from experimental and epidemiological data. For radionuclides, however, human epidemiological data form the basis of the extrapolation, while for many chemical carcinogens, laboratory experiments are the primary basis for the extrapolation. Another even more fundamental difference between the two is that slope factors for chemical carcinogens generally represent an upper bound or 95th percent confidence limit value, while radionuclide slope factors are best estimate values.

In light of these limitations, the two sets of risk estimates should be tabulated separately in the final baseline risk assessment.

10.7.4 ASSESSING AND PRESENTING UNCERTAINTIES

Uncertainties in the risk assessment must be evaluated and discussed, including uncertainties in the physical setting definition for the site, in the models used, in the exposure parameters, and in the toxicity assessment. Monte Carlo uncertainty analyses are frequently performed as part of the uncertainty and sensitivity analysis for radiological risk assessments. A summary of the use of uncertainty analyses in support of radiological risk assessments is provided in NCRP Report No. 76 (NCRP 1984a), *Radiological Assessment* (Till and Meyer 1983), and in the *Background Information Document for the Draft EIS for Proposed NESHAPs for Radionuclides* (EPA 1989a).

10.7.5 SUMMARIZING AND PRESENTING THE BASELINE RISK CHARACTERIZATION RESULTS

The results of the baseline risk characterization should be summarized and presented in an effective manner to assist in decision-making. The estimates of risk should be summarized in the context of the specific site conditions. Information should include the identity and concentrations of radionuclides, types and magnitudes of health risks predicted, uncertainties in the exposure estimates and toxicity information, and characteristics of the site and potentially exposed populations. A summary table should be provided in a format similar to that shown in Exhibit 6-22, as well as graphical presentations of the predicted health risks (see Exhibit 8-7).

10.8 DOCUMENTATION, REVIEW, AND MANAGEMENT TOOLS FOR THE RISK ASSESSOR, REVIEWER, AND MANAGER

The discussion provided in Chapter 9 also applies to radioactively contaminated sites. The suggested outline provided in Exhibit 9-1 may also be used for radioactively contaminated sites with only minor modifications. For example, the portions that uniquely pertain to the CLP program and noncarcinogenic risks are not needed. In addition, because radionuclide hazard and toxicity have been addressed adequately on a generic basis, there is no need for an extensive discussion of toxicity in the report.

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USEPA CONTRACT LABORATORY PROGRAM

VOLATILE ORGANICS ANALYSIS OF AMBIENT AIR IN CANISTERS

VCAAO 1.0

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USEPA CONTRACT LABORATORY PROGRAM

VOLATILE ORGANICS ANALYSIS OF AMBIENT AIR IN CANISTERS

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VOLATILE ORGANICS ANALYSIS OF
AMBIENT AIR IN CANISTERS

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PREFACE

The purpose of this contract is to provide the U.S. Environmental Protection Agency (EPA) with chemical analytical services, quality control procedures, and an analysis structure which will generate data of known and documented quality. This document was developed with the guidance of the Air Toxics Workgroup to ensure that the needs of regional, state, and local air pollution programs are addressed.

The samples to be analyzed are of ambient air collected in canisters at or in the vicinity of known or suspected hazardous waste sites and may contain potentially hazardous organic in significant concentrations. The Contractor should be aware of the potential hazards associated with the handling and analyses of these samples. It is the Contractor's responsibility to take all necessary measures and precautions to ensure the health and safety of its employees. The Contractor is responsible for providing a safe working environment and making its employees aware of the potential hazards of working with and analyzing these samples.

Procedures specified herein shall be used in the preparation of canisters and analysis of air samples in canisters for the presence and quantitation of certain volatile organic compounds. The Contractor shall employ safe handling procedures and generally accepted laboratory practices in the performance of contract requirements and shall follow the quality assurance and quality control (QA/QC) program specified herein.

The data obtained under this contract will be used by EPA to determine the existence and extent of risk posed by hazardous waste disposal sites to the public, to individuals involved in Superfund site cleanups, and to the environment. The data may be used in civil and/or criminal litigation which requires the strictest adherence to chain-of-custody protocol, document control, and quality assurance procedures.

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EXHIBIT A

SUMMARY OF REQUIREMENTS FOR VOLATILE ORGANICS ANALYSIS OF AMBIENT AIR IN CANISTERS

December, 1991

EXHIBIT A

SUMMARY OF REQUIREMENTS FOR
VOLATILE ORGANICS ANALYSIS OF AMBIENT AIR IN CANISTERS

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SECTION 1

GENERAL REQUIREMENTS

1.1 The Contractor shall employ procedures specified in this contract in the preparation and analysis of the ambient air samples for the presence and quantitation of the organic compounds listed in Exhibit C.

1.2 The Contractor shall use proven techniques to identify and measure the organic parameters presented in the Target Compound List (TCL) as specified in Exhibit C. The Contractor shall perform sample preparation and analysis procedures as prescribed in Exhibit D, and meet specified sample preservation and holding time requirements.

1.3 For all samples analyzed under this contract, the Contractor shall adhere to the QA/QC protocols specified in Exhibit E and abide by the evidentiary protocols specified in Exhibit F.

1.4 Following sample analysis, the Contractor shall perform data reduction and shall report analytical activities, sample data, and quality control documentation as designated in Exhibit B. Exhibit B contains all reporting and deliverables requirements for this contract, including copies of the data reporting forms and form instructions guide.

1.5 To ensure proper understanding of the language in this contract, Exhibit G contains a glossary of terms. When a term is used in the text without explanation, the glossary meaning shall be applicable. Glossary definitions do not replace or take precedence over specific information included in the document text.

1.6 The samples to be analyzed by the Contractor are from known or suspected hazardous waste sites and may contain hazardous organic and/or inorganic materials at high concentration levels. The Contractor should be aware of the potential hazards associated with the handling and analysis of these samples. It is the Contractor's responsibility to take all necessary measures to ensure the health and safety of its employees. It is also the Contractor's responsibility to follow appropriate disposal procedures according to state and federal regulations.

1.7 In addition, the Contractor must be aware of the importance of maintaining the integrity of the data generated under this contract, as it may be used to make major decisions regarding public health and environmental welfare. In addition, data generated under this contract may be used in litigation against potentially responsible parties in the enforcement of Superfund legislation.

SECTION 2

SPECIFIC REQUIREMENTS

For each sample, the Contractor shall perform the following tasks:

2.1 TASK I: RECEIVE AMBIENT AIR SAMPLES IN CANISTERS

2.1.1 The Contractor shall receive and handle samples under the chain-of-custody and document control procedures described in Exhibit F.

2.1.2 The Contractor shall provide the required analytical expertise and instrumentation for analyses of the TCL analytes equal to or lower than the quantitation limits specified in Exhibit C. In Exhibit D, EPA provides the Contractor with an appropriate set of analytical procedures that shall be used.

2.1.3 The Contractor shall analyze samples within the maximum holding times specified in Exhibit D, even if these times are less than the maximum data submission time allowed in this contract.

2.1.4 The Contractor is advised that the samples received under this contract are usually from known or suspected hazardous waste sites and may contain high levels of organic materials of a potentially hazardous nature and of unknown structure and concentration, and should be handled throughout the preparation and analysis with appropriate caution. The Contractor shall be responsible for all necessary measures and precautions to ensure the health and safety of laboratory employees.

2.2 TASK II: ANALYZE SAMPLES FOR THE IDENTIFICATION AND QUANTITATION OF SPECIFIC PARAMETERS

2.2.1 For each sample received, the Contractor shall be required to perform the analyses described in Exhibit D. The documentation that accompanies the sample(s) to the Contractor facility shall indicate specific analytical requirements for that sample or set of samples.

2.2.2 Exhibit D specifies the analytical procedures that shall be used. Exhibit D contains instructions and references for the analysis of ambient air samples containing low-to-medium concentrations of volatile organics for GC/MS analysis. GC/MS may use automated computer programs to facilitate the identification of organic compounds.

2.2.3 All samples must initially be run undiluted. When an analyte concentration exceeds the calibrated or linear range, appropriate dilution (but not below the contract required quantitation limit (CRQL)) and reanalysis of the sample is required, as specified in Exhibit D.

2.2.4 For the purpose of this contract, a full sample analysis is defined as analysis for all of the TCL constituents identified in Exhibit C in accordance with the methods in Exhibit D and performance of related QA/QC as specified in Exhibit D and Exhibit E. Laboratory Control Samples (LCS) analyses shall be considered a separate full sample analysis. All other QA/QC requirements are considered an inherent part of this contract and are included in the contract sample unit price.

2.2.5 The volatile compounds analyzed by GC/MS techniques and initially identified shall be verified by an analyst competent in the interpretation of mass spectra by comparison of the suspect mass spectra to the mass spectrum of a standard of the suspected compound. This procedure requires the use of multiple internal standards. Two criteria must be satisfied to verify the identifications:

2.2.5.1 Elution of the sample component at the same GC relative retention time as the standard component.

2.2.5.2 Correspondence of the sample component and standard component mass spectra.

2.2.6 For each sample analysis, the Contractor shall conduct mass spectral library searches of non-target compound sample components to determine tentative compound identifications as follows:

2.2.6.1 For each volatile organics analysis, the Contractor shall conduct a search to determine the possible identity of up to 10 organic compounds of greatest concentration which are not internal standards and not listed in Exhibit C.

2.2.6.2 In performing searches, the most recent release of the National Institute of Standards and Technology (NIST)/EPA/MSDC mass spectral library must be used.

NOTE: Substances with responses of less than 10 percent of the nearest internal standard are not required to be searched in this fashion.

2.2.6.3 Only after visual comparison of sample spectra with the spectra from the library searches will the mass spectral interpretation specialist assign a tentative identification. If the compound does not meet the identification criteria, it shall be reported as unknown. The mass spectral specialist should give additional classification of the unknown compound, if possible (e.g., unknown aromatic, unknown hydrocarbon, unknown acid type, unknown chlorinated compound). If probable molecular weights can be distinguished, they also should be included.

2.3 TASK III: PERFORM REQUIRED QUALITY ASSURANCE AND QUALITY CONTROL PROCEDURES

2.3.1 All specific QA/QC procedures prescribed in Exhibits D and E shall be strictly adhered to by the Contractor. Records documenting the use of the protocol shall be maintained in accordance with the document control procedures prescribed in Exhibit F, and shall be reported in accordance with Exhibit B requirements.

2.3.2 The Contractor shall establish and use on a continuing basis QA/QC procedures including the daily or (as required) more frequent use of standard reference solutions from EPA, NIST, or secondary standards traceable thereto, where available at appropriate concentrations (i.e., standard solutions designed to ensure that operating parameters of equipment and procedures, from sample receipt through identification and quantitation, produce reliable data). Exhibits D and E provide specific QA/QC requirements.

2.3.3 Additional QA/QC shall be required quarterly or more frequently, i.e., with each Case or Sample Delivery Group (SDG), in the form of Laboratory Control Samples (LCS) and Performance Evaluation (PE) samples for volatile organics submitted to EPA for Contractor analysis, and in the form of verification of instrument parameters, as described in Exhibit E.

2.3.3.1 EPA has provided to the Contractor formats for the reporting of data (Exhibit B). The Contractor shall be responsible for completing and returning analysis data sheets in the format specified in this contract and within the time specified in the Contract Performance/Delivery Schedule.

2.3.3.2 Use of formats other than those designated by EPA will be deemed as noncompliant. Such data are unacceptable. Resubmission in the specified format at no additional cost to the Government will be required.

2.3.3.3 Computer generated forms may be submitted in the hardcopy data package(s) provided that the forms are in exact EPA format. This means that the order of data elements is the same as on each EPA required form, including form numbers and titles, page numbers and header information, columns, and lines.

2.3.4 The Contractor shall provide analytical equipment and technical expertise for this contract as specified by the following:

2.3.4.1 Gas chromatograph/mass spectrometer (GC/MS) data system capable of meeting all the terms and conditions of the Contract with the following requirements:

2.3.4.1.1 The computer shall be interfaced by hardware to the mass spectrometer and be capable of acquiring continuous mass scans for the duration of the chromatographic program.

2.3.4.1.2 The computer shall be equipped with mass storage devices for saving all data from the GC/MS runs.

2.3.4.1.3 Computer software shall be available to allow searching GC/MS runs for specific ions and plotting the intensity of the ions with respect to time or scan number.

2.3.4.1.4 A computer data system must be interfaced to the MS that allows the continuous acquisition and storage, on machine-readable media, of all mass spectra obtained throughout the duration of the chromatographic program. The computer must have software that allows searching any GC/MS data file for ions of a specified mass and plotting such ion abundances versus time or scan number. This type of plot is defined as an Extracted Ion Current Profile (EICP) or Selected Ion Current Profile (SICP). Software must also be available that allows intergrating the abundance in any EICP between specified time or scan number limits. Also, for the non-target compounds, software must be available that allows for the comparison of sample spectra against reference library spectra. The most recent release of the NIST/EPA/MSDC mass spectral library shall be used as the reference library. The data system must be capable of flagging all data files that have been edited manually by laboratory personnel.

2.3.4.1.5 The GC/MS shall be equipped with a GC to MS interface capable of extending a fused silica capillary column into the ion source. The column is to be 50 meters long by 0.25 to 0.53 mm I.D. 100% methyl silicone or 5% phenyl, 95% methyl silicone capillary column, or equivalent.

2.3.4.2 The Contractor shall use a magnetic tape storage device capable of recording data and suitable for long-term, off-line storage. The Contractor shall retain all raw GC/MS data acquired under this contract on magnetic tape in appropriate instrument manufacturer's format. The Contractor is required to retain the magnetic tapes with associated hardcopy tape logbook identifying tape contents (see Exhibit B) for 365 days after data submission. During that time, the Contractor shall submit tapes and logbook within seven days of request, as specified in the Contract Performance/Delivery Schedule.

2.3.4.3 The Contractor shall have a computerized MS library search system capable of providing a forward comparison, using the

standard spectra contained in the mass spectral library. The 1985 (or most recent) release of the NIST library (containing 42,261 spectra) must be used.

2.3.4.4 The system shall provide a numerical ranking of the standard spectra most closely corresponding to the sample spectra examined, and the data system shall have software capable of removing background signals from spectra.

2.3.4.5 The Contractor shall have, in-house and operable, a device capable of analyzing volatile organics as described in Exhibit D.

2.3.4.6 The Contractor shall have, in-house, the appropriate standards for all target compounds listed in Exhibit C prior to accepting any samples from the Sample Management Office (SMO). Standards provided by EPA for use in the Preaward Performance Evaluation may not contain all the target compounds and thus shall not be used for routine analyses unless or until they have been supplemented with commercially-available standard materials.

2.3.5 The minimum functional requirements necessary to meet the terms and conditions of this contract are listed below. The Contractor shall designate and use qualified key personnel to perform these functions. The EPA reserves the right to review personnel qualifications and experience.

2.3.5.1 Project Manager

2.3.5.2 GC/MS Laboratory Supervisor

2.3.5.3 Quality Assurance Officer

2.3.5.4 Systems Manager

2.3.5.5 Programmer Analyst

2.3.5.6 GC/MS Operators

2.3.5.7 Mass Spectral Interpreter

2.3.5.8 Chemist (back-up)

NOTE: The Contractor shall designate a Sample Custodian and a Document Control Officer.

2.3.6 The Contractor shall respond within 10 days to requests from data recipients for additional information or explanations that result from the Government's inspection activities.

2.3.7 The Contractor is required to retain unused sample volumes and used sample containers for a period of 60 days after data submission unless otherwise instructed in Exhibit B or Exhibit D.

2.3.8 The Contractor shall adhere to the chain-of-custody and document control procedures described in Exhibit F. Documentation, as described therein, shall be required to show that all procedures are being strictly followed. This documentation shall be reported in the Complete Case File Purge (Exhibit B).

2.3.9 Sample shipments to the Contractor's facility will be scheduled and coordinated by SMO, acting on behalf of the Administrative Project Officer (APO). The Contractor shall communicate with SMO personnel by telephone as necessary throughout the process of sample scheduling, shipment, analysis, and data reporting, to ensure that samples are properly processed.

2.3.10 If there are problems with the samples (e.g., mixed media, containers broken) or sample documentation/paperwork (e.g., Traffic Reports not with shipment, or sample and Traffic Report numbers do not correspond), the Contractor shall immediately contact SMO for resolution. The Contractor shall immediately notify SMO regarding any problems and laboratory conditions that affect the timeliness of analyses and data reporting. In particular, the Contractor shall notify SMO personnel in advance regarding sample data that will be delivered late and shall specify the estimated delivery date.

2.3.11 Sample analyses will be scheduled by groups of samples, each defined as a Case and identified by a unique EPA Case number assigned by SMO. A Case signifies a group of samples collected at one site or geographical area over a finite time period, and will include one or more field samples with associated blanks. Samples may be shipped to the Contractor in a single shipment or multiple shipments over a period of time, depending on the size of the Case. A Case consists of one or more SDG(s). An SDG is defined by the following:

2.3.11.1 Each Case of field samples received; or

2.3.11.2 Each 20 field samples within a Case; or

2.3.11.3 Each seven calendar day period during which field samples in a Case are received (said period beginning with the receipt of the first sample in the SDG).

2.3.12 Data for all samples in an SDG must be submitted together (in one package) in the order specified in Exhibit B. The SDG number is the EPA number of the first sample received in the SDG. When several samples are received together in the first SDG shipment, the SDG number is the lowest sample number (considering both alpha and numeric

designations) in the first group of samples received under the SDG. The SDG number is reported on all data reporting forms. The SDG Receipt Date is the day that the last sample in the SDG is received.

2.3.13 The Contractor is responsible for identifying each SDG as samples are received, through proper sample documentation (see Exhibit B) and communication with SMO personnel.

2.3.14 Each sample received by the Contractor will be labeled with an EPA sample number, and accompanied by a Traffic Report (TR) form bearing the sample number and descriptive information regarding the sample. The Contractor shall complete and sign the TR, recording the date of sample receipt and sample condition on receipt for each sample container.

2.3.15 The Contractor shall submit signed copies of TRs for all samples in an SDG to SMO within three calendar days following receipt of the last sample in the SDG. TRs shall be submitted in SDG sets (i.e., all TRs for a SDG shall be clipped together) with an SDG Cover Sheet containing information regarding the SDG, as specified in Exhibit B.

2.3.16 EPA Case numbers (including SDG numbers) and EPA sample numbers shall be used by the Contractor in identifying samples received under this contract both verbally and in reports/correspondence.

2.3.17 Samples will be routinely shipped directly to the Contractor through a delivery service. The Contractor shall be available to receive sample shipments at any time the delivery service is operating, including Saturdays and holidays. As necessary, the Contractor shall be responsible for any handling or processing required for the receipt of sample shipments, including pick-up of samples at the nearest servicing airport, bus station, or other carrier service within the Contractor's geographical area.

2.3.18 The Contractor shall accept all samples scheduled by SMO, provided that the total number of samples received in any calendar month does not exceed the monthly limitation expressed in the contract. Should the Contractor elect to accept additional samples, the Contractor shall remain bound by all contract requirements for analysis of those samples accepted.

SECTION 3

DETAILED TECHNICAL & MANAGEMENT REQUIREMENTS

The Contractor shall have the following technical and management capabilities:

3.1 PERSONNEL

3.1.1 Project Manager

3.1.1.1 Responsible for all technical efforts of the laboratory to meet all terms and conditions of the contract.

3.1.1.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.1.3 Experience: Minimum of three years of laboratory experience, including at least one year in a supervisory position.

3.1.2 GC/MS Laboratory Supervisor

3.1.2.1 Responsible for all technical efforts of the GC/MS laboratory to meet all terms and conditions of the contract.

3.1.2.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.2.3 Experience: Minimum of three years of laboratory experience in operating a GC/MS, including at least one year in a supervisory position.

3.1.3 Quality Assurance Officer

3.1.3.1 Responsible for overseeing the quality assurance aspects of data generation and reporting directly to upper management.

3.1.3.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.3.3 Experience: Minimum of three years of laboratory experience, including at least one year of applied experience with QA principles and practices in an analytical laboratory.

3.1.4 Systems Manager

3.1.4.1 Responsible for the management and quality control of

all computing systems (hardware, software, documentation, and procedures), generating, updating, and performing quality control on automated deliverables.

3.1.4.2 Education: Minimum of Bachelor's degree with four or more intermediate courses in programming, information management, database management systems, or systems requirements analysis.

3.1.4.3 Experience: Minimum of three years experience in data or systems management or programming including one year experience with software used for data management and generation of deliverables.

3.1.5 **Program Analyst**

3.1.5.1 Responsible for the installation, operation, and maintenance of software and programs; generating, updating, and performing quality control procedures on analytical databases and automated deliverables.

3.1.5.2 Education: Minimum of Bachelor's degree with four or more intermediate courses in programming, information management, information systems, or systems requirements analysis.

3.1.5.3 Experience: Minimum of two years experience in systems or applications programming including one year of experience with software used for data management and generation of deliverables.

3.1.6 **Gas Chromatography/Mass Spectrometer (GC/MS) Operator**

3.1.6.1 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.6.2 Experience: Minimum of one year of experience in operating and maintaining GC/MS instruments in conjunction with the education requirement; or in lieu of education requirement, three additional years of experience in operating and maintaining GC/MS instrumentation.

3.1.7 **Mass Spectral Interpreter**

3.1.7.1 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline with specialized training in GC/MS.

3.1.7.2 Experience: Minimum of two years of applied experience with GC/MS analysis of environmental samples.

3.1.8 Technical Staff Redundancy

3.1.8.1 In order to ensure continuous operations to accomplish the required work as specified by the contract, the bidder shall have a minimum of one chemist available at all times as a back-up technical person with the following qualifications.

3.1.8.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.8.3 Experience: Minimum of one year of experience in each of the following areas: GC/MS operation and maintenance.

3.2 FACILITIES

The adequacy of the facilities and equipment is as important as the technical staff for accomplishing the required work as specified by the EPA contract.

3.2.1 Sample Receipt Area

Adequate, contamination-free, well-ventilated work space with chemical resistant bench top shall be available for receipt and safe handling of EPA samples.

3.2.2 Storage Area

Sufficient refrigerator space to maintain unused EPA sample volume for up to 60 days after data submission shall be provided. Volatile samples must be stored in a refrigerator used only for storage of volatile samples from this contract. Samples must be stored in an atmosphere demonstrated to be free from all potential contaminants. Samples and standards must be stored separately.

3.2.3 Sample/Standard Preparation Area

Adequate, contamination-free, well-ventilated work space shall be provided with:

3.2.3.1 Benches with chemical resistant tops;

3.2.3.2 Exhaust hoods;

3.2.3.3 Glove box or isolated area in which to prepare standard materials;

3.2.3.4 Source of distilled or demineralized organic-free water; and

3.2.3.5 Analytical balance(s) located away from draft and rapid change in temperature.

3.3 INSTRUMENTATION

At a minimum, the Contractor shall have the following instruments operative at the time of the Preaward Site Evaluation and committed for the full duration of the contract.

3.3.1 100 Samples/Month Capacity Requirements

No. of Instrument(s)	Type of Instrument
1	GC/MS

NOTE: The Contractor shall have 1 complete GC/MS system available (operational) at all times as a back-up system. These instruments must be included in the bidder's inventory of equipment. In addition, the Contractor shall have an in-house stock of instrument parts and circuit boards to ensure continuous operation to meet contract-specified holding and turnaround times.

3.3.2 200 Samples/Month Capacity Requirements

No. of Instrument(s)	Type of Instrument
2	GC/MS

NOTE: These instruments must be included in the bidder's inventory of equipment. In addition, the Contractor shall have an in-house stock of instrument parts and circuit boards to ensure continuous operation to meet contract-specified holding and turnaround times.

3.3.3 Instrument Specifications

Further information on instrument specifications and required ancillary equipment may be found in Exhibit D and other Exhibits in this contract.

3.4 DATA HANDLING AND PACKAGING

The Contractor shall be able to submit reports and data packages as specified in Exhibit B. To complete this task, the Contractor shall be required to:

3.4.1 Provide space, tables, and copy machines to meet the contract requirements; and

3.4.2 Designate personnel responsible for report preparations and submission.

3.5 LABORATORY MANAGEMENT CAPABILITY

The Contractor shall have an organization with well-defined responsibilities for each individual in the management system to ensure sufficient resources for EPA contract(s) and to maintain a successful operation. To establish this capability, the Contractor shall designate personnel to carry out the following responsibilities for the EPA contract. Functions include, but are not limited to, the following:

3.5.1 Technical Staff

Responsible for all technical efforts for the EPA contract such as sample analysis, sample validation, and trouble-shooting of all instruments.

3.5.2 Project Manager

Responsible for overall aspects of EPA contract(s) (from sample receipt through data delivery) and shall be the primary contact for EPA Headquarters APO and Regional Technical Project Officers (TPO).

3.5.3 Sample Custodian

Responsible for receiving the EPA samples (logging, handling, and storage).

3.5.4 Quality Assurance Officer

Responsible for overseeing the quality assurance aspects of the data and reporting directly to upper management.

3.5.5 Document Control Officer

Responsible for ensuring that all documents generated are placed in the Complete SDG File for inventory and are delivered to the appropriate EPA Region or other receiver as designated by EPA.

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EXHIBIT B

REPORTING

AND

DELIVERABLES REQUIREMENTS

December, 1991

EXHIBIT B

REPORTING AND DELIVERABLES REQUIREMENTS

PAGE NO.

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SECTION 1

CONTRACT REPORTS/DELIVERABLES DISTRIBUTION

1.1 The following table summarizes the contract reporting and deliverables requirements specified in the Contract Schedule and includes the distribution of each deliverable. **NOTE**: Specific recipient names and addresses are subject to change during the term of the contract. The EPA APO or SMO will notify the Contractor in writing of such changes when they occur.

Item	No. of Copies	Schedule and Delivery	Distribution		
			(1)	(2)	(3)
Updated Standard Operating Procedures (SOPs)	2	45 days after contract award.		X	X
*Sample Traffic Reports	1	***3 days after receipt of last sample in Sample Delivery Group (SDG).	X		
**Sample Data Summary Package	1	14 days after receipt of last sample in SDG.	X		
**Sample Data Package including the Performance Evaluation (PE) Sample	3	35 days after receipt of last sample in SDG	X	X	X
Results of Intercomparison Study/Preaward Performance Evaluation (PPE) Sample	2	35 days after receipt of last sample in SDG	X	X	
Complete SDG File	1	35 days after data receipt of last sample in SDG.		X	
GC/MS Tapes	Lot	Retain for 365 days after data submission, or submit within 7 days after receipt of written request by APO.	As Directed		
****Quality Assurance Plan	1	Submit copy within 7 days by written request by APO.	As Directed		

Distribution

(1) Sample Management Office
(2) Environmental Monitoring Systems Laboratory-Las Vegas
(3) USEPA Region

* Also required in each Sample Data Package.

** Concurrent delivery of these items to all recipients is required.

*** An SDG is a group of samples within a Case, received over a period of seven days or less and not exceeding 20 samples. Data for all samples in the SDG are due concurrently. (See Exhibit A, Task III, for further description).

**** See Exhibit E for description.

NOTE: As specified in the Contract Schedule in the IFB (Government Furnished Supplies and Materials), unless otherwise instructed by SMO, the Contractor shall dispose of unused sample volume and used sample bottles/containers no earlier than 60 days following submission of analytical data.

Address

(1) USEPA Contract Laboratory Program
Sample Management Office
P.O. Box 818
Alexandria, VA 22313

For overnight delivery service, use street address:

300 North Lee Street
Alexandria, VA 22313

(2) USEPA Environmental Monitoring Systems Laboratory
P.O. Box 93478
Las Vegas, NV 89193-3478
ATTN: Data Audit Staff

For overnight delivery service, use street address:

944 E. Harmon, Executive Center
Las Vegas, NV 89109
ATTN: Data Audit Staff

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(3) USEPA REGIONS:

SMO, acting on behalf of the EPA APO, will provide the Contractor with the list of addresses for the 10 EPA Regions. SMO will provide the Contractor with updated Regional name/address lists as necessary throughout the period of the contract and identify other client recipients on a case-by-case basis.

NOTE: Specific recipient names and addresses are subject to change during the term of the contract. The APO will notify the Contractor in writing of such changes when they occur.

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SECTION 2

REPORT DESCRIPTIONS AND ORDER OF DATA DELIVERABLES

2.1 The Contractor shall provide reports and other deliverables according to the schedule specified in Section F of the IFB, "SCHEDULE INFORMATION." The required content and form of each deliverable is described in this Exhibit.

2.1.1 All reports and documentation shall be:

2.1.1.1 Legible;

2.1.1.2 Clearly labeled and completed in accordance with instructions in this Exhibit;

2.1.1.3 Arranged in the order specified in this section;

2.1.1.4 Paginated; and

2.1.1.5 Single-sided.

2.1.2 If submitted documentation does not conform to the above criteria, the Contractor will be required to resubmit such documentation with deficiency(ies) corrected, at no additional cost to the Government.

2.1.3 Whenever the Contractor is required to submit or resubmit data as a result of an on-site laboratory evaluation or through an APO/TPO action, the data shall be clearly marked as "ADDITIONAL DATA" and shall be sent to all three contractual data recipients (SMO, EMSL-LV, and Region). A cover letter shall be included that describes which data are being delivered, to which EPA Case(s) the data pertain, and who requested the data.

2.1.4 Section 3 of this Exhibit contains instructions to the Contractor for properly completing all data reporting forms to provide the EPA with the required documentation and contains the required data forms in EPA-specified format.

2.1.5 Descriptions of the requirements for each deliverable item cited in the Contract Performance/Delivery Schedule (see Section F of the IFB "SCHEDULE INFORMATION") are specified in this Section. Items submitted concurrently must be arranged in the order listed. Additionally, the components of each item must be arranged in the order presented herein.

2.2 UPDATED STANDARD OPERATING PROCEDURES

2.2.1 The Contractor shall submit updated copies of all required Standard Operating Procedures (SOPs) that were submitted with the Prebid Performance

Evaluation (PPE) sample results. The updated SOPs must address any and all issues of laboratory performance and operation identified by the Contractor in the review of the PPE sample data and the evaluation of Bidder-Supplied Documentation.

2.2.2 The Contractor must supply SOPs for the following.

2.2.2.1 Evidentiary SOPs.

2.2.2.2 Sample receipt and logging.

2.2.2.3 Sample and extract storage area.

2.2.2.4 Preventing sample contamination.

2.2.2.5 Security for laboratory and samples.

2.2.2.6 Traceability/equivalency of standards.

2.2.2.7 Maintaining instrument records and bound logbooks.

2.2.2.8 Glassware cleaning.

2.2.2.9 Technical and managerial review of laboratory operation and data package preparation.

2.2.2.10 Internal review of contractually-required QA/QC data for each individual data package.

2.2.2.11 Sample analysis, data handling, and data reporting.

2.2.2.12 Chain-of-custody and document control, including case file preparation.

2.2.2.13 Sample data validation/self-inspection system, including:

- Data flow and chain-of-command for data review;
- Procedures for measuring precision and accuracy;
- Evaluation parameters for identifying systematic errors;
- Procedures to ensure that hardcopy data are complete and compliant with the requirements in Exhibit B;
- Demonstration of internal QA inspection procedure (demonstrated by supervisory sign-off on personal notebooks, internal PE

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samples, etc.);

- Frequency and type of internal audits (e.g., random, quarterly, spot checks, perceived trouble areas);
- Demonstration of problem identification, corrective actions, and resumption of analytical processing resulting from internal audit (i.e., QA feedback); and
- Documentation of audit reports (internal and external), response, corrective action, etc.

2.2.2.14 Data Handling.

2.2.2.14.1 Data Management procedures are defined as written procedures that are clearly defined for all databases and files used to generate or re-submit deliverables specifying the acquisition or entry, update, correction, deletion, storage, and security of computer-readable data and files. Key areas of concern include: system organization including personnel and security, demonstration, operations, traceability, and quality control.

2.2.2.14.2 Data manually entered from hardcopy must be subjected to quality control procedures and error rates estimated.

2.2.2.14.3 The record of changes in the form of corrections and updates to data originally generated, submitted, and/or resubmitted must be documented to allow traceability of updates. Documentation must include the following information for each change:

- Justification or rationale for the change;
- Initials of the person making the changes or changes. Data changes must be identified when generating the deliverables;
- Changed documentation must be retained according to the schedule of the original deliverable;
- Resubmitted deliverables must be reinspected as a part of the laboratory's internal inspection process prior to submission. The entire deliverable and not just the changes must be reinspected;
- The laboratory manager must approve changes to originally submitted deliverables; and
- Documentation of data changes may be requested by laboratory

auditors.

2.2.2.14.4 Life cycle management procedures must be applied to computer systems used to generate and edit contract deliverables. Such systems must be thoroughly tested and documented prior to utilization.

2.2.2.14.5 A software test and acceptance plan including test requirements, test results, and acceptance criteria must be developed, followed, and available in written form.

2.2.2.14.6 System changes shall not be made directly to production systems generating deliverables. Changes must be made first to a development system and tested prior to implementation.

2.2.2.14.7 Each version of the production system will be given an identification number, date of installation, date of last operation, and archived.

2.2.2.14.8 System and operations documentation shall be developed and maintained for each system. Documentation must include a user's manual and an operations and maintenance manual.

2.2.2.14.9 Individual(s) responsible for the following functions shall be identified:

- System operation and maintenance including documentation and training; and
- Database integrity including data entry, data updating and QC.

2.2.2.14.10 Data and system security, backup, and archiving.

2.3 SAMPLE TRAFFIC REPORTS

2.3.1 The original sample TR page marked "Lab Copy for Return to SMO" shall be submitted to SMO with laboratory receipt information and signed in original Contractor signature, for each sample in the SDG.

2.3.2 TRs shall be submitted in SDG sets (i.e., TRs for all samples in an SDG shall be clipped together), with an SDG Cover Sheet attached.

2.3.3 The SDG Cover Sheet shall contain the following items:

2.3.3.1 Laboratory name.

2.3.3.2 Contract number.

2.3.3.3 Sample analysis price - full sample price from contract.

2.3.3.4 Case number.

2.3.3.5 List of EPA sample numbers of all samples in the SDG, identifying the first and last samples received, and their dates of receipt.

NOTE: When more than one sample is received in the first or last SDG shipment, the "first" sample received would be the lowest sample number (considering both alpha and numeric designations), and the "last" sample received would be the highest sample number (considering both alpha and numeric designations).

2.3.4 Each TR shall be clearly marked with the SDG Number and the EPA sample number of the first sample in the SDG. This information shall be entered below the laboratory receipt date on the TR. The TR for the last sample received in the SDG shall be clearly marked "SDG - FINAL SAMPLE."

2.3.5 If samples are received at the laboratory with multi-sample TRs, all the samples on one multi-sample TR may not necessarily be in the same SDG. In this instance, the laboratory shall make the appropriate number of photocopies of the TR, and submit one copy with each SDG cover sheet.

2.4 SAMPLE DATA SUMMARY PACKAGE

2.4.1 As specified in the Delivery Schedule, one Sample Data Summary Package shall be delivered to SMO concurrently with delivery of other required sample data. The Sample Data Summary Package shall be submitted separately (i.e., separated by rubber bands, clips or other means) directly preceding the Sample Data Package.

2.4.2 The Sample Data Summary Package shall contain data for samples in one SDG of the Case, as follows:

2.4.2.1 Cover Page.

2.4.2.2 By sample, tabulated target compound results (FORM I-AAVC) and tentatively identified compounds (FORM I-AAVC-TIC).

2.4.2.3 Laboratory Control Sample results (FORM III-AAVC).

2.4.2.4 Blank summary (FORM II-AAVC) and tabulated results (FORM I) including tentatively identified compounds (FORM I-AAVC-TIC).

2.4.2.5 Internal standard area and retention time data (FORM VII-AAVC).

2.5 SAMPLE DATA PACKAGE

2.5.1 The sample data package shall be complete, consecutively paginated, and shall include data for analysis of all samples in an SDG such as field samples, blanks, and laboratory control samples.

2.5.2 The sample data package is divided into five units as follows:

2.5.2.1 Cover page.

2.5.2.1.1 This document shall be clearly labeled "Cover Page." The Cover Page shall contain: laboratory name; laboratory code; contract number; Case Number; SDG Number; SOW number (appears on cover page of SOW); EPA sample numbers in alphanumeric order, showing EPA sample number cross-referenced with laboratory ID numbers; and comments, describing in detail any problems encountered in processing the samples in the data package.

2.5.2.1.2 The Cover Page shall contain the following statement, verbatim:

"I certify that this data package is in compliance with the terms and conditions of the contract, both technically and for completeness, for other than the conditions detailed above. Release of the data contained in this hardcopy data package has been authorized by the Laboratory Manager or the Manager's designee, as verified by the following signature."

2.5.2.1.3 This statement shall be directly followed by the signature of the Laboratory Manager or his designee with a typed line below it containing the signer's name and title, and the date of signature.

2.5.2.1.4 In the event that the Laboratory Manager cannot validate all data reported for each sample, he/she must provide a detailed description of the problems associated with the sample(s) on the Cover Page.

2.5.2.2 Sample data (Results).

2.5.2.2.1 Sample data shall be arranged in packets with the Analysis Data Sheet (FORM I-AAVC, including FORM I AAVC-TIC), followed by the raw data for volatile samples. These sample packets should then be placed in increasing EPA sample number

order, considering both letters and numbers.

NOTE: FORM I AAVC-TIC is the tabulated list of the highest probable match for up to 10 organic compounds that are not surrogates and internal standards and are not listed in Exhibit C (TCL). It includes the Chemical Abstracts Service (CAS) Registry Number, tentative identification, and estimated concentration.

2.5.2.2.1.1 Reconstructed total ion chromatograms (RIC) for each sample or sample extract.

2.5.2.2.1.2 RICs must be normalized to the largest nonsolvent component, and must contain the following header information:

- EPA sample number;
- Date and time of analysis;
- GC/MS instrument ID; and
- Laboratory file ID.

2.5.2.2.1.3 Internal standards are to be labeled with the names of compounds, either directly out from the peak, or on a print-out of retention times if retention times are printed over the peak.

2.5.2.2.1.4 Quantitation Report: The complete data system report must be included in all sample data packages, in addition to the reconstructed ion chromatogram for preliminary identification and/or quantitation using either the automated or manual data system procedures. The complete data system report shall include all of the information listed below:

- EPA sample number;
- Date and time of analysis;
- RT or scan number of identified target compounds;
- Ion used for quantitation with measured area;
- Copy of area table from data system;
- GC/MS instrument ID; and
- Laboratory file ID.

2.5.2.2.1.5 In all instances where the data system report has been edited, or where manual integration or quantitation has been performed, the GC/MS operator shall identify such edits or manual procedures by initialing and dating the changes made to the report.

2.5.2.2.1.6 Target Compound Mass Spectra: For each sample, by each compound identified, copies of the raw spectra and copies of background subtracted mass spectra of target compounds listed in Exhibit C that are identified in the sample and corresponding background subtracted target compound standard mass spectra shall be included in the data package. Spectra must be labeled with EPA sample number, laboratory file ID, date and time of analysis, and GC/MS instrument ID; compound names must be clearly marked on all spectra.

2.5.2.2.1.7 Tentatively Identified Compound Mass Spectra and Library Matches: For each sample, by each compound identified, copies of mass spectra of organic compounds not listed in Exhibit C, Tentatively Identified Compounds, with associated best-match spectra (three best matches), labeled as above shall be included in the data package.

2.5.2.2.2 Volatile Standard Data:

2.5.2.2.2.1 Initial Calibration: All initial calibration data must be included for all analyses associated with the SDG. When more than one initial calibration is performed, the reconstructed ion chromatograms and quantitation reports and each type of form must be put in chronological order, by instrument as follows:

- Initial Calibration Data Sheet (FORM V-AAVC);
- Internal Standard Area and Retention Time Summary (FORM VII-AAVC); and
- Volatile standard(s) reconstructed ion chromatograms and quantitation reports (or legible facsimiles) for the initial (five point) calibration are labeled according to 2.5.2.2.1.2 and 2.5.2.2.1.4. Spectra are not required.

2.5.2.2.2.2 Continuing Calibration: When more than one continuing calibration is performed, the reconstructed ion chromatograms and quantitation reports and each type of form must be put in chronological order, by instrument if more than one instrument is used as follows:

- Continuing Calibration Data Sheet (FORM VI-AAVC);
- Internal Standard Area and Retention Time Summary (FORM VII-AAVC); and
- Volatile standard(s) reconstructed ion chromatograms and quantitation reports (or legible facsimiles) for the initial (five point) calibration are labeled according to 2.5.2.2.1.2 and 2.5.2.2.1.4. Spectra are not required.

2.5.2.3 Quality control summary.

2.5.2.3.1 The quality control summary shall contain the following forms:

NOTE: If more than one form is necessary, duplicate forms must be arranged in chronological order by date of analysis or instrument.

- Blank Summary (FORM Ii-AAVC);
- GC/MS Instrument Performance Check (FORM IV-AAVC); and
- Internal Standard Area and RT Summary (FORM VII-AAVC).

2.5.2.3.2 The quality control summary shall also contain the following:

NOTE: If more than one form is necessary, duplicate forms must be arranged in chronological order by date of analysis or instrument.

- GC/MS Tuning Data
  - GC/MS Tuning - BFB data, for each 12-hour period, shall be arranged in chronological order by instrument for each GC/MS system utilized;
  - GC/MS Tuning and Mass Calibration - BFB (FORM IV-AAVC);
  - Bar graph spectrum, labeled as in 2.5.2.2.1.2 and 2.5.2.2.1.4; and
  - Mass listing, labeled as in 2.5.2.2.1.2. and 2.5.2.2.1.4.
- Blank data shall be arranged in chronological order by instrument. The blank data shall be arranged in packets with both of the Organic Analysis Data Sheets (FORM I VOA and FORM I VOA-TIC), followed by the raw data for volatile samples.

- Laboratory Control Sample Data

  - Laboratory Control Sample Data Sheet (FORM III-AAVC); and

  - Reconstructed ion chromatograms and quantitation reports or legible facsimile (GC/MS), labeled according to 2.5.2.2.1.2 and 2.5.2.2.1.4. Spectra are not required.

2.5.2.4 Raw data.

2.5.2.4.1 For each reported value, the Contractor shall include all raw data from the instrument used to obtain the sample values (except for raw data for quarterly verifications of instrument parameters). Raw data shall contain all instrument readouts used for the sample results, including those readouts that may fall below the method quantitation limit. All GC/MS instruments must provide legible hard copy of the direct real-time instrument readout (i.e., stripcharts, printer tapes, etc.). A photocopy of the direct sequential instrument readout must be included.

2.5.2.4.2 All raw data shall include concentration units for GC/MS.

2.5.2.4.3 Organic raw data must be labeled with EPA sample number and appropriate codes as shown in Tables B-1 and B-2 respectively, to identify unequivocally the following:

- Initial and continuing calibration standards;

- Blanks;

- Diluted and undiluted samples (by EPA sample number) and all values used to obtain the reported values. If the dilutions are consistent for all samples in a given SDG, a general statement outlining these parameters is sufficient;

- Duplicates;

- Instrument used, any instrument adjustments, data corrections or other apparent anomalies on the measurement record, including all data voided or data not used to obtain reported values and a brief written explanation;

- Data and EPA sample number for GC/MS analyses clearly and sequentially identified on the raw data;

- All calculations for sample data, including percent recovery,

coefficient of variation, slope and y-intercept of linear fit; and

- Time and date of each analysis. Instrument run logs can be submitted if they contain this information. If the instrument does not automatically provide time of analysis, these must be manually entered on all raw data for initial and continuing calibration verification and blanks, as well as interference check samples and linear range analysis standards.

2.5.2.5 Preparation logs.

These logs must include the following:

- Date;
- Standard weights and/or volumes;
- Sample canister pressures;
- Sufficient information to identify unequivocally which QC samples (e.g., laboratory control sample, blank) correspond to each batch prepared; and
- Comments describing any significant sample changes or reactions which occur during preparation.

2.5.2.6 Sample TRs.

A legible copy of the sample TRs and SDG Cover Sheet shall be submitted as described in part 2.3 of this Exhibit for all of the samples in the SDG. The TRs shall be arranged in increasing EPA sample number order, considering both alpha and numeric designations.

2.6 RESULTS OF INTERCOMPARISON/PERFORMANCE EVALUATION SAMPLE ANALYSES

The reporting of analytical results for Intercomparison Study/Preaward Performance Evaluation (PPE) sample analyses includes all requirements specified in part 2.4 for reporting of sample data. The PPE sample shall be carried through the exact same process as an analytical and field samples.

2.7 COMPLETE CASE FILE PURGE

2.7.1 The Complete SDG File package includes all laboratory records

received or generated for a specific Case that have not been previously submitted to EPA as a deliverable. These items shall be submitted to EPA as a deliverable. These items shall be submitted along with their Document Inventory Sheet FORM AADC-2 (see Exhibit E for description of document numbering and inventory procedure). These items include, but are not limited to, sample tags, custody records, sample tracking records, analysts' logbook pages, bench sheets, instrument readout records, computer printouts, raw data summaries, instrument logbook pages (including instrument conditions), correspondence, and the document inventory.

2.7.2 Shipment of the Complete SDG File package by first class mail, overnight courier, priority mail, or equivalent, is acceptable. Custody seals, which are provided by EPA, shall be placed on shipping containers and a document inventory and transmittal letter included. The Contractor is not required to maintain any documents for a sample Case after submission of the Complete SDG File package; however, the Contractor should maintain a copy of the document inventory and transmittal letter.

2.8 GC/MS TAPES

2.8.1 The Contractor must store all raw and processed GC/MS data on magnetic tape, in appropriate instrument manufacturer's format. This tape must include data for samples, blanks, laboratory control samples, initial calibrations, continuing calibrations, and BFB, as well as all laboratory generated spectral libraries and quantitation reports required to generate the data package. The Contractor shall maintain a written reference logbook of tape files to EPA sample number, calibration data, standards, blanks, and laboratory control samples. The logbook should include EPA sample numbers and standard and blank IDs, identified by Case and SDG.

2.8.2 The Contractor is required to retain the GC/MS tapes for 365 days after data submission. During that time, the Contractor shall submit tapes and associated logbook pages within seven days after receipt of a written request from the APO.

2.9 QUALITY ASSURANCE PLAN (QAP)

2.9.1 The Contractor shall prepare a written Quality Assurance Plan (QAP) which describes the procedures that are implemented to achieve the following: maintain data integrity, validity, and useability; ensure that analytical measurement systems are maintained in an acceptable state of stability and reproducibility; detect problems through data assessment and established corrective action procedures which keep the analytical process reliable; and document all aspects of the measurement process in order to provide data which are technically sound and legally defensible.

2.9.2 The QAP must present, in specific terms, the policies, organization,

objectives, functional guidelines, and specific QA/QC activities designed to achieve the data quality requirements in this contract. Where applicable, SOPs pertaining to each parameter shall be included or referenced as part of the QAP. The QAP must be available during on-site laboratory evaluation and upon written request by the APO.

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Table B-1
Codes for Labeling Organic Data

Sample	XXXXX
Reanalyzed Sample	XXXXXRE
Sample Analyzed at a Dilution	XXXXXDL
Laboratory Control Sample Number	VCLCS##
Laboratory Method Blank	VCBLK##
Standards	VCSTD###

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SECTION 3

FORM INSTRUCTIONS GUIDE/DATA REPORTING FORMS

3.1 Form Instructions Guide

3.1.1 This section includes specific instructions for the completion of all required forms for volatile organics analysis utilizing canister. Each of the forms is specific to a given function. These instructions are arranged in the following order:

3.1.1.1 General Information and Header Information

3.1.1.2 Cover Page [COVER PAGE - AAVC]

3.1.1.3 Analysis Data Sheet [FORM I - AAVC]

3.1.1.4 Tentatively Identified Compounds [FORM I - AAVC-TIC]

3.1.1.5 Blank Summary [FORM II - AAVC]

3.1.1.6 Laboratory Control Sample Data Sheet [FORM III - AAVC]

3.1.1.7 GC/MS Instrument Performance Check and Mass Calibration [FORM IV - AAVC]

3.1.1.8 Initial Calibration Data Sheet [FORM V - AAVC]

3.1.1.9 Continuing Calibration Data Sheet [FORM VI - AAVC]

3.1.1.10 Internal Standard Area and Retention Times Summary [FORM VII - AAVC]

3.1.1.11 Canister Certification [FORM VIII - AAVC]

3.1.1.12 Analytical Sequence [FORM IX - AAVC]

3.1.1.13 Sample Receipt/Log-In Sheet [FORM AADC-1]

3.1.1.14 Complete SDG File (CSF) Document Inventory Sheet [FORM AADC-2]

3.1.2 General Information and Header Information

3.1.2.1 Values must be reported on the hardcopy forms according to the individual form instructions in this Section. For example, results for concentrations of volatile organic target compounds must be reported to three significant figures if the value is greater than

or equal to 10, and to two significant figures for values less than 10.

3.1.2.2 All characters which appear on the data reporting forms presented in the contract must be reproduced by the Contractor when submitting data, and the format of the forms submitted must be identical to that shown in the contract. No information may be added, deleted, or moved from its specified position without prior written approval of the EPA APO. The names of the various fields and compounds (i.e., "Lab Code," "Chloromethane") must appear as they do on the forms in the contract.

3.1.2.3 Alphabetic entries made onto the forms by the Contractor shall be in ALL UPPERCASE letters (i.e., "LOW", not "Low" or "low").

3.1.2.4 Six (6) pieces of information are common to the header sections of each data reporting form. They are Lab Name, Lab Code, Contract No., Case No., SDG No., and SAS No. These pieces of information must be entered on every form and must match on every form.

3.1.2.4.1 The "Lab Name" shall be the name chosen by the Contractor to identify the laboratory. It may not exceed 25 characters.

3.1.2.4.2 The "Lab Code" is an alphabetical abbreviation of up to 6 letters, assigned by the EPA, to identify the laboratory and aid in data processing. This code shall be assigned by the EPA at the time a contract is awarded, and shall not be modified by the Contractor, except at the direction of the EPA. If a change of name or ownership occurs at the laboratory, the Lab Code will remain the same until the contractor is directed by the EPA to use another Lab Code assigned by the EPA.

3.1.2.4.3 The "Contract No." is the number of the EPA contract under which the analyses were performed. In the case of multiple laboratories operating under a corporate-wide contract, the contract number entered shall be that of the corporate contract, regardless of the facility performing the analyses (see Lab Code).

3.1.2.4.4 The "Case No." is the EPA-assigned case number associated with the sample, and reported on the Traffic Report.

3.1.2.4.5 The "SDG No." is the Sample Delivery Group (SDG) number. The SDG No. is the EPA Sample Number of the first sample received in the SDG. When several samples are received together in the first SDG shipment, the SDG number shall be the lowest sample number (considering both alpha and numeric designations) in the first group of samples received under the SDG.

3.1.2.4.6 The "SAS No." is the EPA-assigned number for analyses performed under Special Analytical Services (SAS). If samples are to be analyzed under SAS only and reported on these forms, then enter SAS No. and leave Case No. blank. If samples are analyzed according to the "Routine Analytical Services" (IFB) protocols and have additional SAS requirements, list both Case No. and SAS No. on all forms. If the analyses have no SAS requirements, leave "SAS No." blank. Note that some samples in an SDG may have a SAS No. while others do not.

3.1.2.5 The "EPA Sample No." is the other information common to most of the forms. This number appears either in the upper right corner of the form, or as the left column of a table summarizing data from a number of samples. When the "EPA Sample No." is entered into the triple-spaced box in the upper right corner, it should be entered on the middle line of the three lines that comprise the box.

3.1.2.5.1 All samples, spikes, blanks, and standards shall be identified with an EPA Sample Number. For field samples, the EPA Sample Number is the unique identifying number given in the Traffic Report that accompanied that sample.

3.1.2.5.2 In order to facilitate data assessment, the following sample suffixes must be used:

XXXXX	-	EPA sample number
XXXXXRE	-	Reanalyzed sample
XXXXXDL	-	Sample analyzed at a secondary dilution

3.1.2.5.3 VOC standards prepared in canisters shall be identified as VCSTD###, where ### is the concentration in ppbv of volatile standards in canister (i.e., 002, 005, 010, 020, and 050).

3.1.2.5.4 As for the blank identifiers, these designations will have to be combined with other information to uniquely identify each standard. Blanks shall be identified as VCBLK##. The "EPA Sample No." must be unique for each blank analysis within an SDG. The laboratory must achieve this by replacing the two-character "##" terminator of the identifier with one or two characters or numbers, or a combination of both. For example, possible identifiers for volatiles-canister blanks would be VCBLK01, VCBLK02, etc.

3.1.2.5.5 LCSs shall be identified as VCLCS##. The "EPA Sample No." must be unique for each LCS analysis within an SDG. The laboratory must achieve this by replacing the two-character "##"

terminator of the identifier with one or two characters or numbers, or a combination of both. For example, possible identifiers for volatiles-canister LCSs would be VCLCS01, VCLCS02, etc.

3.1.2.6 Several other pieces of information are common to many of the Data Reporting Forms. These include Lab Sample ID, Lab File ID, Date Received, etc. Following is a brief description of each of these entries.

3.1.2.6.1 "Lab Sample ID" is an optional laboratory-generated internal identifier. Up to 12 alpha-numeric characters may be reported here. If the contractor does not have a Lab Sample ID, this field may be left blank.

3.1.2.6.2 "Lab File ID" is the laboratory-generated name of the GC/MS data system file containing information pertaining to a particular analysis. Up to 14 alpha-numeric characters may be used here.

3.1.2.6.3 "Date Received" is the date of sample receipt at the laboratory, as noted on the Traffic Report (i.e., the VTSR). It should be entered as MM/DD/YY.

3.1.2.6.4 "Date Analyzed" should be entered in a similar fashion. The date of sample receipt will be compared with the analysis dates to ensure that contract holding times were not exceeded.

3.1.2.6.5 "Instrument ID" is common to many of the forms, particularly those containing calibration data. The identifier used by the laboratory must include some indication of the manufacturer and/or model of the instrument, and contain additional characters that differentiate between all instrument of the same type in the laboratory.

3.1.2.6.6 "GC Column ID" or "Column ID" is common to various other forms. This field is used to identify the GC column.

3.1.2.7 For rounding off numbers to the appropriate level of precision, observe the following common rules. If the figure following those to be retained is less than 5, drop it (round down). If the figure is greater than 5, drop it and increase the last digit to be retained by 1 (round up). If the figure following the last digit to be retained equals 5, round up if the digit to be retained is odd, and round down if that digit is even.

3.1.2.8 All results must be transcribed to the forms in the raw data with the specified number of decimal places that are described in

Exhibit B. The raw data result is to be rounded only when the number of figures in the raw data result exceeds the maximum number of figures specified for that result entry for that form. If there are not enough figures in the raw data result to enter in the specified space for that result, then zeros must be used for decimal places to the specified number of reporting decimals for that result for a specific form. The following examples are provided:

Raw Data Result	Specified Format	Correct Entry
5.9	6.3	5.900
5.99653	6.3	5.997
95.99653	6.3	95.997
995.99653	6.3	995.997
9995.996	6.3	9996.00
99995.9	6.3	99995.9
999995.9	6.3	invalid

NOTE: 6.3 stands for a maximum of six significant figures and up to three decimal places.

3.1.3 **Cover Page [COVER PAGE - ~~AAVC~~]**

3.1.3.1 This form is used to list all billable samples analyzed within an SDG, and to provide certain analytical information and general comments. It is also the document which is signed by the Laboratory Manager to authorize and release all data and deliverables associated with the SDG.

3.1.3.2 Under the "EPA Sample No." column, enter up to 7 characters for the EPA sample number (including blanks and duplicates) for each required analysis within the SDG. Duplicates must contain a "D" suffix. These sample numbers must be listed on the form in ascending alphanumeric order using the Extended Binary Coded Decimal Interchange Code convention. Thus, if MAB123A is the lowest (considering both alpha and numeric characters) EPA Sample No. within the SDG, it would be entered in the first EPA Sample No. field. Samples listed below it would be ~~in ascending~~ sequence - MAB124A, MAB124B, MAB125A, MAC111A, MA1111A, MA1111AD, etc.

3.1.3.3 All EPA sample numbers must be listed in ascending alphanumeric order, continuing to the following Cover Page if applicable.

3.1.3.4 Under "Lab Sample ID", a Lab Sample ID (up to 10 characters) may be entered for each associated EPA Sample No. If a Lab Sample ID is entered, it must be entered identically (for each EPA Sample No.) on all associated data.

3.1.3.5 Under "Comments", enter any problems encountered, both technical and administrative, the corrective action taken, and resolution performed for all of the samples in the SDG.

3.1.3.6 Each Cover Page must be signed, in original, by the Laboratory Manager or the Manager's designee, and dated to authorize the release and verify the contents of all data and deliverables associated with an SDG.

3.1.4 Analysis Data Sheet [FORM I - AAVC]

3.1.4.1 This form is used for tabulating and reporting results for analysis of canister samples for the compounds in a Target Compound List for Volatiles as given in Exhibit C.

3.1.4.2 This form is used for reporting the detected concentrations of the target compounds in the field samples, blanks, laboratory control samples, and performance evaluation samples.

3.1.4.3 Complete the header information on each page of Form I-AAVC according to the instructions in section 3.1.2.

3.1.4.4 The use of a Nafion dryer invalidates all results for polar compounds. Indicate by checking the appropriate item whether or not a Nafion dryer was used.

3.1.4.5 Fill in the pressure readings and injection volume (trapped sample volume) in the appropriate blanks. Determine the dilution factor, if any, according to Exhibit D, section 4.5 and fill in the appropriate blank.

3.1.4.6 For each positively identified target compound, the Contractor shall multiply the detected concentration in ppbv by the dilution factor, and if this value is greater than or equal to the quantitation limit, report the resulting true concentration uncorrected for blank contaminants. Report analytical results to two significant figure if the value is less than 10, and three significant figures if the value is greater than or equal to 10.

3.1.4.7 Under the column labeled "Q" for qualifier, flag each result with the specific Data Reporting Qualifiers listed below. The Contractor is encouraged to use additional flags or footnotes. The definition of such flags must be explicit and must be included in the SDG Narrative.

3.1.4.8 For reporting results to the Agency, the following contract specific qualifiers are to be used. The seven qualifiers defined below are not subject to modification by the laboratory. Up to five qualifiers may be reported on Form I-AAVC for each compound. The

seven EPA-defined qualifiers to be used are as follows:

U - Indicates compound was analyzed for but not detected. The sample quantitation limit must be corrected for dilution.

J - Indicates an estimated value. This flag is used either when estimating a concentration for tentatively identified compounds where a 1:1 response is assumed, or when the mass spectral data indicate the presence of a compound that meets the identification criteria but the result is less than the sample quantitation limit but greater than zero. For example, if the sample quantitation limit is 2 ppbv, but a concentration of 1 ppbv is calculated, report it as "1J". The sample quantitation limit must be adjusted for dilution.

N - Indicates presumptive evidence of a compound. This flag is only used for tentatively identified compounds, where the identification is based on a mass spectral library search. It is applied to all TIC results.

B - This flag is used when the analyte is found in the associated blank as well as in the sample. It indicates possible/probable blank contamination and warns the data user to take appropriate action. This flag must be used for a TIC as well as for a positively identified target compound.

E - This flag identifies compounds whose concentrations exceed the calibration range of the GC/MS instrument for that specific analysis. If one or more compounds have a response greater than full scale, except as noted in Exhibit D, the sample must be diluted and reanalyzed according to the specifications in Exhibit D. All such compounds with a response greater than full scale should have the concentration flagged with an "E" on the Form I-AAVC for the original analysis. If the dilution of the sample causes any compounds identified in the first analysis to be below the calibration range in the second analysis, then the results of both analyses shall be reported on separate copies of Form I-AAVC. The Form I-AAVC for the diluted sample shall have the "DL" suffix appended to the sample number.

D - This flag identifies all compounds identified in an analysis at a secondary dilution factor. If a sample is reanalyzed at a higher dilution factor, as in the "E" flag above, the "DL" suffix is appended to the sample number on the Form I-AAVC for the diluted sample, and all concentration values reported on that Form I-AAVC are flagged with the "D" flag. This flag alerts data users that any discrepancies between the concentrations reported may be due to dilution of the sample.

X - Other specific flags may be required to properly define the results. If used, they must be fully described, and such description attached to the Sample Data Summary Package and the SDG Narrative. Begin by using "X". If more than one flag is required, use "Y" and "Z" as needed. If more than five qualifiers are required for a sample result, use the "X" flag to combine several flags, as needed. For instance, the "X" flag might combine the "B", and "D" flags for some sample. The laboratory-defined flags are limited to the letters "X", "Y", and "Z".

NOTE: The combination of flags "BU" or "UB" is expressly prohibited. Blank contaminants are flagged "B" only when they are detected in the sample.

3.1.5 Tentatively Identified Compounds [FORM I - AAVC-TIC]

3.1.5.1 Fill in all header information as above.

3.1.5.2 Report Tentatively Identified Compounds (TICs) including CAS number, compound name, retention time (RT), and the estimated concentration (criteria for reporting TICs are given in Exhibit D). Retention time must be reported in minutes and decimal minutes, not seconds or minutes:seconds.

3.1.5.3 If, in the opinion of the mass spectral interpretation specialist, no valid tentative identification can be made, the compound shall be reported as unknown.

3.1.5.4 Include a Form I-AAVC-TIC for every sample and blank analyzed, even if no TICs are found. Total the number of TICs found, and enter this number in the "No. of TICs found." If none were found, enter "0" (zero). Form I-AAVC-TIC must be provided for every analysis, including required dilutions and reanalyses, even if no TICs are found.

3.1.6 Blank Summary [FORM II - AAVC]

3.1.6.1 This form summarizes the samples associated with each field and laboratory blank analysis. A copy of the appropriate Form II-AAVC is required for each blank reported on a Form I-AAVC.

3.1.6.2 Complete the header information on Form II-AAVC as described in section 3.1.2. The "EPA Sample No." entered in the box at the top of Form II-AAVC shall be the same number entered on the Form I-AAVC when reporting results for the blank itself.

3.1.6.3 On the numbered lines, enter the EPA sample numbers associated with the blank, along with the other information which

identifies the EPA samples. The Canister ID for each sample must be provided under the "Canister" column, if available.

3.1.7 Laboratory Control Sample Data Sheet [FORM III - AAVC]

3.1.7.1 Form III-AAVC is used to report the recovery of the spiked analytes in the laboratory control samples (LCS).

3.1.7.2 Complete the header information according to the instructions in section 3.1.2.

3.1.7.3 Enter the date and time the LCS was analyzed.

3.1.7.4 In the table under "Spiked," enter the spiked concentration in ppbv of each LCS compound. Under "Reported," enter the concentration obtained in ppbv calculated from the analysis of the LCS. Calculate the percent recovery of each LCS compound to the nearest whole percent and enter in the column under "% Recovery". At the bottom of the table are the QC limits for LCS percent recoveries. Flag all values outside of the limits with an "*" in the column under the "Q" symbol.

3.1.7.5 Summarize the values outside the QC limits at the lower part of the form.

3.1.7.6 Enter any comments pertinent to the analysis of the LCS.

3.1.8 GC/MS Instrument Performance Check and Mass Calibration [FORM IV - AAVC]

3.1.8.1 This form is used to report the results of GC/MS instrument performance check (also known as "tuning") and to summarize the date and time of analysis of samples, standards, and blanks associated with each analysis of the instrument performance check solution.

3.1.8.2 Complete the header information as in section 3.1.2. Enter the "Lab File ID" for the injection containing the instrument performance check mixture of BFB. Enter the date and time (military time) of injection of the instrument performance check mixture.

3.1.8.3 For each ion listed on the form, enter the percent relative abundance in the right column. Report relative abundances to the number of significant figures given for each ion in the ion abundance criteria column.

3.1.8.4 Under "to m/e 95", all ion abundances are to be normalized to the nominal base peak listed on Form IV-AAVC. For some of the ions, determine the percentage of the ion abundance to the specified mass and report under "to specified mass". For example, if the relative

ion abundance of mass 96 and mass 174 ions are 4 and 80 (under the "to m/e 95" column), respectively, then enter "5.0" (under the "to specified mass" column) as the ion abundance of mass 96 relative to mass 174.

3.1.8.5 All relative abundances must be reported as a number. If zero, enter "0", not a dash or other non-numeric character.

3.1.8.6 In the lower half of the form, list all samples and standards analyzed under that instrument performance check in chronological order, by time of analysis (in military time). Refer to section 3.1.2 for specific instructions for identifying standards and blanks. Enter "EPA Sample No.", "Lab Sample ID", "Lab File ID", "Date Analyzed", and "Time Analyzed" for all standards, samples, and blanks.

3.1.8.7 The GC/MS instrument performance check must be analyzed again twelve hours from the time of injection of the instrument performance check solution of BFB listed at the top of the form. In order to meet these requirements, samples, standards, or blanks must be injected within twelve hours of the injection of the instrument performance check solution.

3.1.9 Initial Calibration Data Sheet [FORM V - AAVC]

3.1.9.1 Each time the GC/MS system undergoes a five-point calibration to initialize subsequent quantitation of VOCs in sample and blank analysis, the laboratory must complete and submit a Form V-AAVC.

3.1.9.2 Complete all header information as in section 3.1.2.

3.1.9.3 Enter the "Case No." and "SDG No." for the current data package, regardless of the original case for which the initial calibration was performed. Enter "Instrument ID", "GC Column ID", and "Injection Volume".

3.1.9.4 Check the appropriate standard preparation method used to calibrate the GC/MS system. The following define the acronyms provided on the form:

DD(Direct)	-	Dynamic Dilution Direct Injection
DD(Canister)	-	Dynamic Dilution via Canister
SDB	-	Static Dilution Bottle Technique
HPC	-	High Pressure Cylinder
WPT	-	Water Purge and Trap Method

3.1.9.5 Enter the injection dates and times of each of the calibration standards analyzed under "Date injected" and "Time injected", respectively.

3.1.9.6 Enter the "EPA Sample No." and "Lab File ID" for each of the five calibration standards.

3.1.9.7 Complete the relative response factor (RRF) calculation for the five calibration points, and then calculate and report the average relative response factor ($\overline{RRF}$) and %RSD of the RRF values for each target compound in the space provided.

3.1.10 Continuing Calibration Data Sheet [FORM VI - AAVC]

3.1.10.1 Each time the GC/MS system undergoes a continuing calibration to check for the validity of the initial calibration, the laboratory must complete and submit a Form VI-AAVC.

3.1.10.2 Complete all header information as in section 3.1.2. Enter the "Case No." and "SDG No." for the current data package, regardless of the original Case for which the initial calibration was performed. Enter "Instrument ID", "GC Column ID", and the date(s) of the most recent initial calibration. If the calendar date changes during the calibration procedure, the inclusive dates should be given on Form VI.

3.1.10.3 Enter the date and time of injection of the continuing calibration standard.

3.1.10.4 Complete the relative response factor (RRF) calculation for each target compound in the space provided.

3.1.10.5 Under the column "IC mean RRF", enter the mean relative response factor for each target compound as determined in the most recent valid initial calibration.

3.1.10.6 A value of percent difference (%D) is calculated as part of a continuing calibration check in which only the calibration standard with a concentration of 10 ppbv is analyzed. A RRF is calculated for this concentration and compared to the mean RRF value in the most recent valid initial calibration.

3.1.11 Internal Standard Area and Retention Time Summary [FORM VII - AAVC]

3.1.11.1 This form is used to summarize the peak areas and retention times of the internal standards added to all samples and blanks. The data are used to determine when changes in internal standard responses will adversely affect quantification of target compounds. This form must be completed each time an initial or continuing calibration is performed for each GC/MS system.

3.1.11.2 Complete the header information according to section 3.1.2.

3.1.11.3 Enter the Lab File ID of the 12-hour calibration standard, as well as the date and time of analysis of the calibration standard. If samples are analyzed immediately following an initial calibration, before another instrument performance check and a continuing calibration, a Form VI-AAVC shall be completed on the basis of the internal standard areas of the mid level (10 ppbv) initial calibration sequence standard. Use the date and time of analysis of this standard, and its Lab File ID and areas in place of those of a continuing calibration standard.

3.1.11.4 From the results of the analysis of the 12-hour calibration standard, enter the area measured for each internal standard and its retention time (in decimal minutes) under the appropriate column. For each internal standard, calculate the upper limit of the area as the area of the particular standard plus 40 percent of its area (i.e., 1.4 times the area in the 12 HOUR STD box), and the lower limit of the area as the area of the internal standard minus 40% of its area (i.e., 0.6 times the area in the 12 HOUR STD box). Report these values in the boxes labeled "UPPER LIMIT" and "LOWER LIMIT", respectively.

3.1.11.5 Calculate the upper limit of the retention time as the retention of the internal standard plus 0.33 minutes (20 seconds), and the lower limit of the retention time as the retention time in the standard minus 0.33 minutes (20 seconds).

3.1.11.6 For each sample and blank under a given 12-hour analytical sequence, enter the EPA Sample Number and the area measured for each internal standard and its retention time. If the internal standard area is outside the upper or lower limits calculated above, flag that area with an asterisk (*) placed in the far right-hand space of the box for each internal standard area, directly under the "#" symbol. Similarly, flag the retention time of any internal standard that is outside the limits with an asterisk.

3.1.12 Canister Certification [FORM VIII - AAVC]

3.1.12.1 This form is used to document the certification of canisters prior to use.

3.1.12.2 Complete the header information on each page of Form VII-AAVC according to the instructions in section 3.1.2.

3.1.12.3 Enter the results of the leak test procedure in the appropriate spaces provided.

3.1.12.4 Enter in Column 1, the results of the analysis of an unspiked certified clean canister. For target compounds that are not detected, enter the CRQL of the compound followed by a "U". If the detected level is less than the CRQL, enter the value followed by a

"J".

3.1.12.5 Enter in Column 2, under the "Initial" spiked concentration, the results of the initial analysis of a canister spiked with the target compounds.

3.1.12.6 Enter in Column 3, under the "Final" spiked concentration, the results of the analysis of the spiked canister after ageing for seven days.

3.1.12.7 For each standard, enter the percent difference (%D) in Column 4 using the formula given in Exhibit D, section 3.3.4.2. If this value is within ±30 percent, the canister is certified.

3.1.13 **Analytical Sequence [FORM IX - AAVC]**

3.1.13.1 A Form IX-AAVC is required for each analytical sequence for each GC/MS system used to perform VOA on canister samples in an SDG.

3.1.13.2 Complete the header information on each page of Form VII-AAVC according to the instructions in section 3.1.2.

3.1.13.3 On the numbered lines, enter the EPA sample numbers along with the other information which identifies the samples, blanks, and standards. The first item in the table must be the BFB since the 12-hour time period starts at the injection of the instrument performance check standard. Arrange the items in chronological order for each GC/MS system.

3.1.14 **Sample Receipt/Log-In Sheet [FORM AADC-1]**

3.1.14.1 This form is used to document the receipt and inspection of sample containers and samples. One original of Form AADC-1 is required for each sample shipping container. If the samples in a single sample shipping container must be assigned to more than one Sample Delivery Group, the original Form AADC-1 shall be placed with the deliverables for the Sample Delivery Group of the lowest Arabic number and a copy of Form AADC-1 must be placed with the deliverables for the other Sample Delivery Group(s). The copies should be identified as "copy(ies)," and the location of the original should be noted on the copies.

3.1.14.2 Sign and date the airbill (if present). Examine the shipping container and record the presence/absence of custody seals and their condition (i.e., intact, broken) in item 1 on Form AADC-1. Record the custody seal numbers in item 2.

3.1.14.3 Open the container, remove the enclosed sample documentation, and record the presence/absence of chain-of-custody

record(s), SMO forms (i.e., Traffic Reports, Packing Lists), and airbills or airbill stickers in items 3-5 on Form AADC-1. Specify if there is an airbill present or an airbill sticker in item 5 on Form AADC-1. Record the airbill or sticker number, if present.

3.1.14.4 Remove the samples from the shipping container(s), examine the samples and the sample tags (if present), and record the condition of the canister (i.e., intact, dent, leaking) and presence of absence of sample tags in items 6 and 7 on Form AADC-1.

3.1.14.5 Review the sample shipping documents and complete the header information described in section 3.1.2. Compare the information recorded on all the documents and samples and circle the appropriate answer in item 8 on Form AADC-1.

3.1.14.6 If there are no problems observed during receipt, sign and date (include time) Form AADC-1, the chain-of-custody record, and Traffic Report, and write the sample numbers on Form AADC-1. Record the appropriate sample tags and assigned laboratory numbers, if applicable. The log-in date should be recorded at the top of Form AADC-1 and the date and time of sample receipt at the laboratory should be recorded in items 9 and 10. Record the fraction designation (if appropriate) and the specific area designation (e.g., refrigerator number) in the Sample Transfer block located in the bottom left corner of Form AADC-1. Sign and date the Sample Transfer block. Cross out unused columns and spaces.

3.1.14.7 If there are problems observed during receipt or an answer marked with an asterisk (i.e., "absent*") was circled, contact SMO and document the contact as well as resolution of the problem on a CLP Communication Log. Following resolution, sign and date the forms as specified in the preceding paragraph and note, where appropriate, the resolution of the problem.

3.1.15 Complete SDG File (CSF) Document Inventory Sheet [FORM AADC-2]

3.1.15.1 This form is used to record the inventory of the SDG File Purge documents and count of documents in the original Sample Data Package which is sent to the Region.

3.1.15.2 Organize all EPA-CSF documents as described in Exhibit B, Section 1. Assemble the documents in the order specified on Form AADC-2, and stamp each page with a consecutive number. (Do not number the AADC-2 form). Inventory the CSF by reviewing the document numbers and recording page numbers ranges in the columns provided in the Form AADC-2. If there are no documents for a specific document type, enter an "NA" in the empty space.

3.1.15.3 Certain laboratory specific documents related to the CSF may

not fit into a clearly defined category. The laboratory should review AADC-2 to determine if it is most appropriate to place them under No. 17, 18, 19, or 20. Category 20 should be used if there is no appropriate previous category. These types of documents should be described or listed in the blanks under each appropriate category.

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3.2 **Data Reporting Forms**

3.2.1 Cover Page [COVER PAGE - AAVC]

3.2.2 Analysis Data Sheet [FORM I - AAVC]

3.2.3 Tentatively Identified Compounds [FORM I - AAVC-TIC]

3.2.4 Blank Summary [FORM II - AAVC]

3.2.5 Laboratory Control Sample Data Sheet [FORM III - AAVC]

3.2.6 GC/MS Instrument Performance Check and Mass Calibration [FORM IV - AAVC]

3.2.7 Initial Calibration Data Sheet [FORM V - AAVC]

3.2.8 Continuing Calibration Data Sheet [FORM VI - AAVC]

3.2.9 Internal Standard Area and Retention Times Summary [FORM VII - AAVC]

3.2.10 Canister Certification [FORM VIII - AAVC]

3.2.11 Analytical Sequence [FORM IX - AAVC]

3.2.12 Sample Receipt/Log-In Sheet [FORM AADC-1]

3.2.13 Complete SDG File (CSF) Document Inventory Sheet [FORM AADC-2]

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COVER PAGE

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____

	EPA Sample No.	Lab Sample ID
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

Comments:

I certify that this data package is in compliance with the terms and conditions of the contract, both technically and for completeness, for other than the conditions detailed above. Release of the data contained in this hardcopy data package and in the computer-readable data (if submitted) on floppy diskette has been authorized by the Laboratory Manager's designee, as verified by the following signature:

Signature:_____ Name:_____
Date:_____ Title:_____

U. S. ENVIRONMENTAL PROTECTION AGENCY
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SAMPLE RECEIPT/LOG–IN SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____

ITEM	REMARKS	EPA Sample No.	Sample Tag No.	Assigned Lab No.	Spl Vol (m^3)	REMARKS: Conditions of Sample Shipment,etc.
1. Custody Seal(s)	Present/Absent/Intact/Broken*					
2. Custody Seal No(s).						
3. Chain–of–Custody records	Present/Absent*					
4. Traffic Reports or	Present/Absent*					
Packing List						
5. Airbill	Sticker/Present/Absent*					
Airbill No(s).						
6. Sample Tags	Present/Absent*					
Sample Tag No(s):	Listed/Not Listed on COC					
7. Sample Condition	Intact/Broken/Leaking*					
8. Do informations on custody						
records, traffic reports, and						
sample tags agree?	Yes/No*					
9. Date Received at Lab:						
10. Time Received at Lab:						
Sample Transfer						
Area #:						
By:						
On:						

* If circled, contact SMO and attach record of resolution.

Received by:
Signature:_____ Log–in Date:_____
Print Name:_____

Reviewed by:
Signature:_____ Date:_____
Logbook No.:_____ Logbook Page No.:_____

FORM AADC–1

U. S. ENVIRONMENTAL PROTECTION AGENCY
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COMPLETE SDG FILE (CSF) DOCUMENT INVENTORY SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No:_____ SDG No.:_____

DOCUMENT	Page Nos.		Please Check	
	From	To	Lab	Reg
1. Cover Page (Cover Page – AAVC)				
2. Sample Receipt/Log–In Sheet (FORM AADC–1)				
3. CSF Document Inventory Sheet (FORM AADC–2)				
4. Analysis Data Sheet (FORM I – AAVC)				
5. Tentatively Identified Compounds (FORM I – AAVC–TIC)				
6. Blank Summary Form (FORM II – AAVC)				
7. Laboratory Control Sample Data Sheet (FORM III – AAVC)				
8. GC/MS Tuning with BFB (FORM IV – AAVC)				
9. Initial Calibration Data Sheet (FORM V – AAVC)				
10. Continuing Calibration Data Sheet (FORM VI – AAVC)				
13. Internal Standard Area and RT Summary (FORM VII – AAVC)				
14. Canister Certification Data Sheet (FORM VIII – AAVC)				
15. Analytical Sequence (FORM IX – AAVC)				
16. EPA Shipping/Receiving Documents				
Airbill (No. of shipments:___)				
Chain–of–Custody Records				
Sample Tags				
Sample Log–In Sheet (Lab & AADC–1)				
17. Misc. Shipping/Receiving Records (list individual records)				
Telephone Logs				
18. Internal Lab Sample Transfer Records				
19. Internal Original Sample Preparation and Analysis Records				
20. Other Records (describe or list)				

Comments:_____

Completed by (CLP Lab):
Signature:_____ Date:_____
Printed Name/Title:_____
Audited by (EPA):
Signature:_____ Date:_____
Printed Name/Title:_____

FORM AADC–2

U. S. ENVIRONMENTAL PROTECTION AGENCY
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Volatile Organics in Ambient Air – Canister

ANALYSIS DATA SHEET

EPA Sample No. _____

Lab Name: _____ Contract No.: _____
Lab Code: _____ Case No.: _____
SAS No.: _____ SDG No.: _____ Nafion Dryer: ( )Y (/)N
Lab Sample ID: _____ Date Received: _____ Instrument ID: _____
Lab File ID: _____ Date Analyzed: _____ Column ID: _____
Canister pressure on tag (units): _____( ) Injection volume (cm^3): _____
Canister pressure as received (units): _____( ) Dilution factor: _____

CAS RN	COMPOUND NAME	Concentration (ppbv)	Q
67-64-1	Acetone		
75-05-8	Acetonitrile		
107-02-8	Acrolein		
107-13-1	Acrylonitrile		
71-43-2	Benzene		
100-44-7	Benzyl chloride		
75-27-4	Bromodichloromethane		
74-83-9	Bromomethane		
106-99-0	1,3-Butadiene		
78-93-3	2-Butanone		
56-23-5	Carbon tetrachloride		
108-90-7	Chlorobenzene		
75-45-6	Chlorodifluoromethane		
75-00-3	Chloroethane		
67-66-3	Chloroform		
74-87-3	Chloromethane		
107-05-1	3-Chloro-1-propene		
124-48-1	Dibromochloromethane		
106-93-4	1,2-Dibromoethane		
95-50-1	1,2-Dichlorobenzene		
541-73-1	1,3-Dichlorobenzene		
106-46-7	1,4-Dichlorobenzene		
75-71-8	Dichlorodifluoromethane		
75-34-3	1,1-Dichloroethane		
107-06-2	1,2-Dichloroethane		
75-35-4	1,1-Dichloroethene		
156-59-2	cis-1,2-Dichloroethene		
156-60-5	trans-1,2-Dichloroethene		
78-87-5	1,2-Dichloropropane		
10061-01-5	cis-1,3-Dichloropropene		

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ANALYSIS DATA SHEET

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____ Nafion Dryer: ( )Y ( )N
Lab Sample ID:_____ Date Received:_____ Instrument ID:_____
Lab File ID:_____ Date Analyzed:_____ Column ID:_____
Canister pressure on tag (units):_____( ) Injection volume (cm^3):_____
Canister pressure as received (units):_____( ) Dilution factor:_____

CAS RN	COMPOUND NAME	Concentration (ppbv)	Q
10061-02-6	trans-1,3-Dichloropropene		
1320-37-2	1,2-Dichloro-1,1,2,2-tetrafluoroethane		
100-41-4	Ethylbenzene		
142-82-5	Heptane		
87-68-3	Hexachlorobutadiene		
110-54-3	Hexane		
167-56-1	Methanol		
75-09-2	Methylene chloride		
80-62-6	Methyl methacrylate		
108-10-1	4-Methyl-2-pentanone		
98-83-9	alpha-Methyl styrene		
111-65-9	Octane		
109-66-0	n-Pentane		
115-07-1	Propylene		
100-42-5	Styrene		
79-43-5	1,1,2,2-Tetrachloroethane		
127-18-4	Tetrachloroethylene		
108-88-3	Toluene		
120-82-1	1,2,4-Trichlorobenzene		
71-55-6	1,1,1-Trichloroethane		
79-06-5	1,1,2-Trichloroethane		
79-01-6	Trichloroethylene		
75-69-4	Trichlorofluoromethane		
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane		
95-63-6	1,2,4-Trimethylbenzene		
108-67-8	1,3,5-Trimethylbenzene		
108-05-4	Vinyl acetate		
75-01-4	Vinyl chloride		
1330-20-7	Xylenes, m- & p-		
95-47-6	Xylene, o-		

U. S. ENVIRONMENTAL PROTECTION AGENCY
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TENTATIVELY IDENTIFIED COMPOUNDS

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
Lab Sample ID:_____ Lab File ID:_____
SAS No.:_____ Date Received:_____
SDG No:_____ Date Analyzed:_____
GC Column ID:_____ Instrument ID:_____
No. of TICs Found:_____

	CAS RN	COMPOUND NAME	Estimated Concentration (ppbv)	RT (minutes)	Q
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

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BLANK SUMMARY

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Lab Sample ID:_____ Date Analyzed:_____ Instrument ID:_____
Lab File ID:_____ Time Analyzed:_____ Column ID:_____

THIS BLANK APPLIES TO THE FOLLOWING SAMPLES:

	EPA Sample No.	Laboratory ID			Analysis	
		Sample	File	Canister	Date	Time
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
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21						
22						
23						
24						
25						
26						
27						
28						
29						
30						

Comments:

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LABORATORY CONTROL SAMPLE DATA SHEET

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Lab Sample ID:_____ Date Analyzed:_____ Instrument ID:_____
Lab File ID:_____ Time Analyzed:_____ Column ID:_____
Injection Volume (cm^3):_____

		Concentration (ppbv)		%	
CAS RN	COMPOUND NAME	Spiked	Reported	Recovery	Q
71–43–2	Benzene				
56–23–5	Carbon tetrachloride				
106–93–4	1,2–Dibromoethane				
106–46–7	1,4–Dichlorobenzene				
107–06–2	1,2–Dichloroethane				
78–87–5	1,2–Dichloropropane				
10061–02–6	trans–1,3–Dichloropropene				
127–18–4	Tetrachloroethylene				
79–06–5	1,1,2–Trichloroethane				
79–01–6	Trichloroethylene				
75–01–4	Vinyl chloride				

%Recovery QC Limits: 60–140%

LCS Recovery: _____ outside limits out of _____ total.

Comments:

U. S. ENVIRONMENTAL PROTECTION AGENCY
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Volatile Organics in Ambient Air – Canister

GC/MS INSTRUMENT PERFORMANCE CHECK AND MASS CALIBRATION

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Lab Sample ID:_____ Date Injected:_____ Instrument ID:_____
Lab File ID:_____ Time Injected:_____ GC Column ID:_____
Injection Volume (cm^3):_____ Mass BFB Injected (ng):_____

m/e	ION ABUNDANCE CRITERIA	% Relative Abundance	
		to m/e 95	to specified mass
50	8.0 – 40.0% of m/e 95		
75	30.0 – 66.0 of m/e 95		
95	Base peak, 100% relative abundance		
96	5.0 – 9.0% of m/e 174		
173	Less than 2.0% of m/e 174		
174	50.0 – 120.0% of m/e 95		
175	4.0 – 9.0% of m/e 174		
176	93.0 – 101.0% of m/e 174		
177	5.0 – 9.0% of m/e 176		

THIS TUNE APPLIES TO THE FOLLOWING:

	EPA Sample No.	Lab Sample ID	Lab File ID	Date Analyzed	Time Analyzed
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

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INITIAL CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Instrument ID:_____ GC Column ID:_____ Injection Volume (cm^3):_____
Standard Preparation Method: ___DD(Direct) ___DD(Canister) ___SDB ___HPC ___WPT

STANDARD	2	5	10	20	50
EPA Sample No.					
Lab File ID					
Date injected					
Time injected					

COMPOUND NAME	Relative Response Factor (RRF) 2	5	10	20	50	mean RRF	%RSD
Acetone							
Acetonitrile							
Acrolein							
Acrylonitrile							
Benzene							
Benzyl chloride							
Bromodichloromethane							
Bromomethane							
1,3–Butadiene							
2–Butanone							
Carbon tetrachloride							
Chlorobenzene							
Chlorodifluoromethane							
Chloroethane							
Chloroform							
Chloromethane							
3–Chloro–1–propene							
Dibromochloromethane							
1,2–Dibromoethane							
1,2–Dichlorobenzene							
1,3–Dichlorobenzene							
1,4–Dichlorobenzene							
Dichlorodifluoromethane							
1,1–Dichloroethane							
1,2–Dichloroethane							
1,1–Dichloroethene							
cis–1,2–Dichloroethene							
trans–1,2–Dichloroethene							
1,2–Dichloropropane							
cis–1,3–Dichloropropene							

U. S. ENVIRONMENTAL PROTECTION AGENCY
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INITIAL CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Instrument ID:_____ GC Column ID:_____ Injection Volume (cm^3):_____
Standard Preparation Method: ___DD(Direct) ___DD(Canister) ___SDB ___HPC ___WPT

STANDARD	2	5	10	20	50
EPA Sample No.					
Lab File ID					
Date injected					
Time injected					

COMPOUND NAME	Relative Response Factor (RRF) 2	5	10	20	50	mean RRF	%RS
trans-1,3-Dichloropropene							
1,2-Dichloro-1,1,2,2-tetrafluoroethane							
Ethylbenzene							
Heptane							
Hexachlorobutadiene							
Hexane							
Methanol							
Methylene chloride							
Methyl methacrylate							
4-Methyl-2-pentanone							
alpha-Methyl styrene							
Octane							
n-Pentane							
Propylene							
Styrene							
Tetrachloroethylene							
1,1,2,2-Tetrachloroethane							
Toluene							
1,2,4-Trichlorobenzene							
1,1,1-Trichloroethane							
1,1,2-Trichloroethane							
Trichloroethylene							
Trichlorofluoromethane							
1,1,2-Trichloro-1,2,2-trifluoroethane							
1,2,4-Trimethylbenzene							
1,3,5-Trimethylbenzene							
Vinyl acetate							
Vinyl chloride							
Xylenes, m- & p-							
Xylene, o-							

U. S. ENVIRONMENTAL PROTECTION AGENCY
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CONTINUING CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
EPA Sample No.:_____ Lab File ID:_____
Instrument ID:_____ GC Column ID:_____
Date Injected:_____ Time Injected:_____
Injection Volume (cm^3):_____ Date of Init. Cal.:_____

COMPOUND NAME	IC mean RRF	RRF	%D
Acetone			
Acetonitrile			
Acrolein			
Acrylonitrile			
Benzene			
Benzyl chloride			
Bromodichloromethane			
Bromomethane			
1,3–Butadiene			
2–Butanone			
Carbon tetrachloride			
Chlorobenzene			
Chlorodifluoromethane			
Chloroethane			
Chloroform			
Chloromethane			
3–Chloro–1–propene			
Dibromochloromethane			
1,2–Dibromoethane			
1,2–Dichlorobenzene			
1,3–Dichlorobenzene			
1,4–Dichlorobenzene			
Dichlorodifluoromethane			
1,1–Dichloroethane			
1.2–Dichloroethane			
1,1–Dichloroethene			
cis–1,2–Dichloroethene			
trans–1,2–Dichloroethene			
1,2–Dichloropropane			
cis–1.3–Dichloropropene			

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CONTINUING CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
EPA Sample No.:_____ Lab File ID:_____
Instrument ID:_____ GC Column ID:_____
Date Injected:_____ Time Injected:_____
Injection Volume (cm^3):_____ Date of Init. Cal.:_____

COMPOUND NAME	IC mean RRF	RRF	%D
trans–1,3–Dichloropropene			
1,2–Dichloro–1,1,2,2–tetrafluoroethane			
Ethylbenzene			
Heptane			
Hexachlorobutadiene			
Hexane			
Methanol			
Methylene chloride			
Methyl methacrylate			
4–Methyl–2–pentanone			
alpha–Methyl styrene			
Octane			
n–Pentane			
Propylene			
Styrene			
1,1,2,2–Tetrachloroethane			
Tetrachloroethylene			
Toluene			
1,2,4–Trichlorobenzene			
1,1,1–Trichloroethane			
1,1,2–Trichloroethane			
Trichloroethylene			
Trichlorofluoromethane			
1,1,2–Trichloro–1,2,2–trifluoroethane			
1,2,4–Trimethylbenzene			
1,3,5–Trimethylbenzene			
Vinyl acetate			
Vinyl chloride			
Xylenes, m– & p–			
Xylene, o–			

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Canister

INTERNAL STANDARD AREA AND RT SUMMARY

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____

	Chlorobenzene–d_5				Bromochloromethane				1,4–Difluorobenzene			
	Area	#	RT	#	Area	#	RT	#	Area	#	RT	#
12–HOUR STANDARD												
Upper Limit												
Lower Limit												
EPA Sample No.												
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												

AREA: Upper Limit: +40% of internal standard area. RT: Upper Limit: +0.33 minutes of internal standard RT.
Lower Limit: –40% of internal standard area. Lower Limit: –0.33 minutes of internal standard RT.

All values outside of the QC limits must be followed by an "*" under the "#" column.

FORM VII – AAVC

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Canister

CANISTER CERTIFICATION

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No:_____
Case No.:_____ SDG No.:_____
Canister ID:_____ SAS No.:_____
Leak Test (psi/kPa):Initial Pressure:_____ Initial Vacuum:_____
Final Pressure:_____ Final Vacuum:_____

	COMPOUND NAME	1	2	3	4
		Unspiked Concentration	Spiked Concentration		%D (2 and 3)
			Initial	Final	
1	Acetone				
2	Acetonitrile				
3	Acrolein				
4	Acrylonitrile				
5	Benzene				
6	Benzyl chloride				
7	Bromodichloromethane				
8	Bromomethane				
9	1,3–Butadiene				
10	2–Butanone				
11	Carbon tetrachloride				
12	Chlorobenzene				
13	Chlorodifluoromethane				
14	Chloroethane				
15	Chloroform				
16	Chloromethane				
17	3–Chloro–1–propene				
18	Dibromochloromethane				
19	1,2–Dibromoethane				
20	1,2–Dichlorobenzene				
21	1,3–Dichlorobenzene				
22	1,4–Dichlorobenzene				
23	Dichlorodifluoromethane				

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Volatile Organics in Ambient Air – Canister

CANISTER CERTIFICATION

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No:_____
Case No.:_____ SDG No.:_____
Canister ID:_____ SAS No.:_____
Leak Test (psi/kPa):Initial Pressure:_____ Initial Vacuum:_____
Final Pressure:_____ Final Vacuum:_____

	COMPOUND NAME	1	2	3	4
		Unspiked Concentration	Spiked Concentration Initial	Final	%D (2 and 3)
24	1,1–Dichloroethane				
25	1,2–Dichloroethane				
26	1,1–Dichloroethene				
27	cis–1,2–Dichloroethene				
28	trans–1,2–Dichloroethene				
29	1,2–Dichloropropane				
30	cis–1,3–Dichloropropene				
31	trans–1,3–Dichloropropene				
32	1,2–Dichloro–1,1,2,2–tetrafluoroethane				
33	Ethylbenzene				
34	Heptane				
35	Hexachlorobutadiene				
36	Hexane				
37	Methanol				
38	Methylene chloride				
39	Methyl methacrylate				
40	4–Methyl–2–pentanone				
41	alpha–Methyl styrene				
42	Octane				
43	n–Pentane				
44	Propylene				
45	Styrene				
46	1,1,2,2–Tetrachloroethane				

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Canister

CANISTER CERTIFICATION

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No:_____
Case No.:_____ SDG No.:_____
Canister ID:_____ SAS No.:_____
Leak Test (psi/kPa):Initial Pressure:_____ Initial Vacuum:_____
Final Pressure:_____ Final Vacuum:_____

	COMPOUND NAME	1	2	3	4
		Unspiked Concentration	Spiked Concentration		%D
			Initial	Final	(2 and 3)
47	Tetrachloroethylene				
48	Toluene				
49	1,2,4–Trichlorobenzene				
50	1,1,1–Trichloroethane				
51	1,1,2–Trichloroethane				
52	Trichloroethylene				
53	Trichlorofluoromethane				
54	1,1,2-Trichloro-1,2,2-trifluoroethane				
55	1,2,4–Trimethylbenzene				
56	1,3,5–Trimethylbenzene				
57	Vinyl acetate				
58	Vinyl chloride				
59	Xylenes, m– & p–				
60	Xylene, o–				
	OTHERS				
1					
2					
3					
4					
5					
6					
7					
8					

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Canister

ANALYTICAL SEQUENCE

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Instrument ID:_____ GC Column ID:_____

	EPA Sample No.	Lab Sample ID	Analysis Time	Analysis Date
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
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23				
24				
25				
26				
27				
28				
29				
30				

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EXHIBIT C

TARGET COMPOUND LIST

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TABLE 1

VOA OF AMBIENT AIR IN CANISTERS TARGET COMPOUND LIST (TCL) AND CONTRACT REQUIRED QUANTITATION LIMITS (CRQL)

Target Compound	CAS RN	CRQL, ppbv*
Acetone	67-64-1	5
Acetonitrile	75-05-8	5
Acrolein	107-02-8	5
Acrylonitrile	107-13-1	5
Benzene	71-43-2	2
Benzyl chloride	100-44-7	5
Bromodichloromethane	75-27-4	2
Bromomethane	74-83-9	5
1,3-Butadiene	106-99-0	5
2-Butanone	78-93-3	5
Chloromethane	74-87-3	2
Carbon tetrachloride	56-23-5	2
Chlorobenzene	108-90-7	2
Chlorodifluoromethane	75-45-6	2
Chloroethane	75-00-3	2
Chloroform	67-66-3	2
3-Chloro-1-propene	107-05-1	2
Dibromochloromethane	124-48-1	2
1,2-Dibromoethane	106-93-4	2
1,2-Dichlorobenzene	95-50-1	2
1,3-Dichlorobenzene	541-73-1	5
1,4-Dichlorobenzene	106-46-7	5
Dichlorodifluoromethane	75-71-8	2
1,1-Dichloroethane	75-34-3	2
1,2-Dichloroethane	107-06-2	2
1,1-Dichloroethene	75-35-4	5
cis-1,2-Dichloroethylene	156-59-2	2
trans-1,2-Dichloroethylene	156-60-5	2
1,2-Dichloropropane	78-87-5	2
cis-1,3-Dichloropropene	10061-01-5	2
trans-1,3-Dichloropropene	10061-02-6	2
1,2-Dichloro-1,1,2,2-tetrafluoroethane	1320-37-2	2
Ethylbenzene	100-41-4	2
Heptane	142-82-5	2
Hexachlorobutadiene	87-68-3	5
Hexane	110-54-3	2

* ppbv referenced to 25°C and 760 mm Hg.

TABLE 1

VOA OF AMBIENT AIR IN CANISTERS
TARGET COMPOUND LIST (TCL) AND
CONTRACT REQUIRED QUANTITATION LIMITS (CRQL)
(continued)

Target Compound	CAS RN	CRQL, ppbv*
Methanol	67-56-1	5
Methylene chloride	75-09-2	5
Methyl methacrylate	80-62-6	2
4-Methyl-2-pentanone	108-10-1	5
alpha-Methyl styrene	98-83-9	5
Octane	111-65-9	2
n-Pentane	109-66-0	2
Propylene	115-07-1	5
Styrene	100-42-5	5
1,1,2,2-Tetrachloroethane	79-43-5	2
Tetrachloroethylene	127-18-4	5
Toluene	108-88-3	5
1,2,4-Trichlorobenzene	120-82-1	2
1,1,1-Trichloroethane	71-55-6	5
1,1,2-Trichloroethane	79-06-5	5
Trichloroethylene	79-01-6	2
Trichlorofluoromethane	75-69-4	2
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	2
1,2,4-Trimethylbenzene	95-63-6	2
1,3,5-Trimethylbenzene	108-67-8	2
Vinyl acetate	108-05-4	5
Vinyl chloride	75-01-4	2
Xylenes, m- and p-	1330-20-7	5
Xylene, o-	95-47-6	5

NOTE: The values in Table 1 are Contract Required Quantitation Limits (CRQL), not absolute detection limits. The quantitation limits in these tables are set at or slightly above the concentrations in the sample equivalent to the concentration of the lowest calibration standard analyzed for each analyte.

* ppbv referenced to 25°C and 760 mm Hg.

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TABLE 2

VOLATILE ORGANIC COMPOUNDS FOR TENTATIVE IDENTIFICATION AND DEVELOPMENT OF CRQL DATA*

Target Compound	CAS RN
Carbon disulfide	75-15-0
Pyridine	110-86-1
1,2-Dibromo-3-chloropropane	96-12-8
2-Chloro-1,3-butadiene	126-99-8
trans-1,4-Dichlorobutene	110-57-6
Propanal	123-38-6
2-Hexanone	591-78-6
Cyclohexanone	108-94-1
1-Bromobutane	109-65-9
2-Methylnaphthalene	91-57-6
1,3,4-Trimethylbenzene	95-63-6
2,2-Dichloropropane	594-20-7
1,1-Dichloropropene	563-58-6
n-Propylbenzene	103-65-1
tert-Butylbenzene	98-06-6
sec-Butylbenzene	135-98-8
1,2,3-Trichlorobenzene	87-61-6

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This table lists additional compounds for which the method has not been validated, but which were ranked as air toxics of concern or identified as compounds of Regional interest during the development of this document. Data developed during method validation and subsequent analysis under SAS may lead to validation of the VOC methods in this document for some or all of these compounds.

EXHIBIT D

ANALYTICAL METHOD FOR THE DETERMINATION OF VOLATILE ORGANIC COMPOUNDS (VOCs) IN AIR COLLECTED IN SUMMA® CANISTERS AND ANALYZED BY GAS CHROMATOGRAPHY/MASS SPECTROMETRY (GC/MS)

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December, 1991

EXHIBIT D

ANALYTICAL METHOD FOR THE DETERMINATION OF VOLATILE ORGANIC COMPOUNDS (VOCs) IN AIR COLLECTED IN SUMMA® CANISTERS AND ANALYZED BY GAS CHROMATOGRAPHY/MASS SPECTROMETRY (GC/MS)

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EXHIBIT D

ANALYTICAL METHOD FOR THE DETERMINATION OF VOLATILE ORGANIC COMPOUNDS (VOCs) IN AIR COLLECTED IN SUMMA® CANISTERS AND ANALYZED BY GAS CHROMATOGRAPHY/MASS SPECTROMETRY (GC/MS)

1 INTRODUCTION

1.1 SCOPE AND APPLICATION

1.1.1 The analytical methods that follow are designed to analyze whole air samples collected in SUMMA® polished, stainless steel canisters for the volatile organic compounds on the Target Compound List for Volatiles in Exhibit C. The compounds to be identified and quantified from canister samples are those listed in Table D/VC-1 with the Contract Required Quantitation Limits shown therein. The methods are based on EPA Compendium Method TO-14, "The Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using SUMMA® Passivated Canister Sampling and Gas Chromatographic Analysis," with appropriate modifications. The modifications include a more generic description of the method for preconcentration of target compounds and for generation of standards. One result of the modifications is that many systems currently in use for VOC analysis can be adapted to these analytical methods. Any reasonable analytical system can be used provided the system produces results equivalent to the results specified in Section 5.

1.1.2 This method is divided into the following sections: sample storage and holding times; canister cleaning and certification; optional sample screening; GC/MS analysis; and analytical performance requirements. As described in the screening section, a portion of the sample may be analyzed by GC/FID to determine the concentration level of the volatiles and the possible need for sample dilution. The GC/MS analysis section contains a description of the full scan MS analysis after gas chromatographic separation. The sample preconcentration technique is included in the analysis section because GC/MS operation and the preconcentration technique are interrelated. The section on performance requirements discusses detection limits, audit accuracy, and replicate precision that have been achieved in EPA-sponsored network operations, and which the laboratory must meet when performing analyses under this document.

1.1.3 This method is applicable to specific VOCs that have been tested and determined to be stable when stored in SUMMA® polished canisters. The volatile organic compounds that have been collected in pressurized canisters and successfully analyzed by this method are listed in Table D/VC-1 along with target compounds for which storage stability in

canisters has not been fully documented. These compounds have been successfully measured at the parts per billion by volume (ppbv) level.

1.2 SUMMARY OF METHOD

1.2.1 In the field, a sample of air is drawn through a sampling train comprised of components that regulate the rate and duration of sampling into a pre-evacuated SUMMA® passivated canister. After the air sample is collected, the canister valve is closed, an identification tag is attached to the canister, and the canister is transported to a predetermined laboratory for analysis.

1.2.2 During analysis, water vapor may be reduced in the gas stream by a Nafion® dryer (if applicable), although the use of the dryer invalidates all analysis results of polar compounds. The VOCs are then concentrated by collection in a cryogenically-cooled trap. The cryogen is then removed and the temperature of the trap is raised. The VOCs originally collected in the trap are revolatilized, separated on a GC column, then detected by mass spectrometry.

1.3 INTERFERENCES

1.3.1 Chloromethane, vinyl chloride, bromomethane, and chloroethane can display peak broadening if the compounds are not delivered to the GC column in a tight band.

1.3.2 Polar compounds such as methanol, ethanol, butanol, acetonitrile, and methyl ethyl ketone have been found to be less stable than the more nonpolar VOCs when stored in canisters over seven-day periods.

1.3.3 In cases where Nafion® tubing is used to dry the sample stream, polar compounds are not reported.

1.3.4 Interferences in canister samples may result from contamination of the canisters due to poor manufacturing practices, contamination of the canister cleaning apparatus, contamination of the sampling system or analytical system, and improper use or storage. Attention to the following details will help to minimize the possibility of contamination of canisters.

1.3.5 Canisters should be manufactured using high quality welding and cleaning techniques, and new canisters should be filled with humidified zero air which is then analyzed to determine cleanliness. The cleaning apparatus, sampling system, and analytical system should be assembled of clean, high quality components and each system should be shown to be free of contamination.

1.3.6 Canisters should be stored in a contaminant-free location and should be capped tightly during shipment and when not in use to prevent

leakage of ambient air into or out of the canister in the event that a leak develops in the valve.

1.3.7 Impurities in the dilution gas (if applicable) and carrier gas, organic compounds out-gassing from the plumbing ahead of the trap, and solvent vapors in the laboratory account for the majority of contamination problems. The analytical system must be demonstrated to be free from contamination under the conditions of the analysis by running humid zero air blanks. The use of tubing other than chromatographic grade stainless steel, non-TFE thread sealants, or flow controllers with rubber components must be avoided.

1.3.8 Significant contamination of the analytical equipment can occur whenever analysis of samples containing high VOC concentrations are analyzed. This in turn can result in carryover contamination in subsequent analyses. Whenever an unusually concentrated sample is encountered, it should be followed by an analysis of humid zero air to check for cross-contamination.

1.3.9 The laboratory where analysis of volatiles is performed should be completely free of solvents.

1.4 DEFINITIONS

NOTE: Definitions used in this document and any user-prepared standard operating procedures (SOPs) should be consistent with ASTM Methods D1356, E260, and E355. All pertinent abbreviations and symbols are defined within this document at point of use.

1.4.1 Absolute canister pressure = Pg + Pa, where Pg = gauge pressure in the canister (kPa, psi) and Pa = barometric pressure.

1.4.2 Absolute pressure: Pressure measured with reference to absolute zero pressure (as opposed to atmospheric pressure), usually expressed as kPa, mm Hg, or psia.

1.4.3 Cryogen: A refrigerant used to obtain very low temperatures in the cryogenic trap of the analytical system. A typical cryogen is liquid nitrogen (bp -195.8) or liquid argon (bp -185.7°C).

1.4.4 Dynamic calibration: Calibration of an analytical system using calibration gas standard concentrations in a form identical or very similar to the samples to be analyzed and by introducing such standards into the inlet of the sampling or analytical system in a manner very similar to the normal sampling or analytical process.

1.4.5 Dynamic dilution: Means of preparing calibration mixtures in which standard gas(es) from pressurized cylinders are continually blended with humidified zero air in a manifold so that a flowing stream of

calibration mixture is available at the inlet of the analytical system.

1.4.6 Gauge pressure: Pressure measured above ambient atmospheric pressure (as opposed to absolute pressure). Zero gauge pressure is equal to ambient atmospheric (barometric) pressure.

1.4.7 MS-SCAN: The GC is coupled to a MS programmed in the SCAN mode to scan a range of ions repeatedly during the GC run. As used in the current context, this procedure serves as a qualitative identification and characterization of the sample.

1.4.8 Megabore® column: Chromatographic column having an internal diameter (I.D.) greater than 0.50 mm. The Megabore® column is a trademark of the J&W Scientific Co. For purposes of this method, Megabore® refers to chromatographic columns with 0.53 mm I.D.

1.4.9 Qualitative accuracy: The ability of an analytical system to correctly identify compounds.

1.4.10 Quantitative accuracy: The ability of an analytical system to correctly measure the concentration of an identified compound.

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2 SAMPLE STORAGE AND HOLDING TIMES

2.1 CANISTER RECEIPT

2.1.1 Receipt of each canister is recorded in a laboratory notebook dedicated to this use. The overall condition of each sample canister is observed and noted in the dedicated laboratory notebook. Each canister should be received with an attached sample identification tag. Note on the identification tag the date received and initials of recipient.

2.1.2 The pressure of the canister is checked by attaching a pressure gauge to the canister inlet. The canister valve is opened briefly and the gauge pressure (kPa, psig) is recorded.

2.1.3 If gauge pressure is <83 kPa (<12 psig), the user may wish to pressurize the canisters, as an option, with humid zero air up to a gauge pressure of approximately 137 kPa (20 psig) to ensure that enough sample is available for analysis.

NOTE: Pressurizing the canister can introduce additional error, increase the method detection limit (MDL), and consume time. The user should weigh these limitations as part of his program objectives before pressurizing.

2.1.4 If the pressure is significantly different (greater than 10 percent) from the original pressure recorded on the canister ID tag, the integrity of the sample is suspect and the data must be flagged with a "P".

2.2 PROCEDURES FOR SAMPLE STORAGE

2.2.1 The samples must be retained from the validated time of sample receipt (VTSR) until 45 days after delivery of a complete sample data package to the Agency. After 45 days, the samples may be disposed of in a manner that complies with all applicable regulations. Disposal is expected to occur during the process of canister recleaning.

2.2.2 The samples must be stored in an atmosphere demonstrated to be free of all potential contaminants. The canisters should not be stored at elevated temperatures. High temperatures may precipitate leaks and may lead to thermal alteration of target compounds.

2.2.3 Samples and standards must be stored separately.

2.3 CONTRACT REQUIRED HOLDING TIMES

Analysis of air samples in canisters must be completed within 14 days of the VTSR.

3 CANISTER PREPARATION AND CERTIFICATION

3.1 CANISTER PREPARATION

3.1.1 Summary

3.1.2 The SUMMA© polished stainless steel canisters are cleaned by alternate pressurization and evacuation. Two methods of cleaning techniques are described in this section. In the alternate cleaning procedure, the canisters are placed in an oven.

3.1.3 After cleaning, prior to field sampling, canisters are tested to ensure that the canister seals are leak-tight by determining the change, if any, in canister pressure after 24 hours from a pressurized and an evacuated state.

3.1.4 Apparatus and Materials

3.1.4.1 Canisters: Stainless steel vessels (e.g., 6-L, 15-L) which are polished internally by the SUMMA® process and fitted with a stainless steel, high temperature, packless, leak-tight bellows valve capped with a ¼ inch stainless steel fitting.

3.1.4.2 Vacuum pump: Capable of evacuating sample canister(s) to an absolute pressure of <0.05 mm Hg.

3.1.4.3 Manifold: Stainless steel manifold with connections for simultaneously cleaning several canisters.

3.1.4.4 Shut-off valve(s): On-off toggle valves.

3.1.4.5 Thermocouple vacuum gauge: Capable of measuring vacuum in the manifold to an absolute pressure of 0.05 mm Hg or less.

3.1.4.6 Cryogenic trap (2 required): Stainless steel U-shaped open tubular trap cooled with liquid argon or liquid nitrogen to prevent contamination from back diffusion of oil from vacuum pump and to provide clean zero air to sample canister(s).

3.1.4.7 Stainless steel pressure gauges (2): 0-345 kPa (0-50 psig) to monitor zero air pressure.

3.1.4.8 Stainless steel flow control valve: To regulate flow of zero air into canister(s).

3.1.4.9 Humidifier: Pressurizable water bubbler or other system capable of providing moisture to the zero air supply.

3.1.4.10 Isothermal oven (optional): For heating canisters.

3.1.5 Reagents

3.1.5.1 Deionized water: High performance liquid chromatography (HPLC) grade for humidified zero air stream.

3.1.5.2 Cryogen: Liquid argon or liquid nitrogen.

3.1.6 Cleaning Procedure

3.1.6.1 A canister cleaning system may be assembled, as illustrated in Figure D/VC-1, where cryogen is added to both the vacuum pump and zero air supply traps. Figure D/VC-5 provides a flow diagram of the canister cleaning process by this method.

3.1.6.2 Connect the canister(s) to the manifold. Open the vent shut-off valve and the canister valve(s) to release any remaining pressure in the canister(s). Start the vacuum pump, close the vent shut-off valve, and then open the vacuum shut-off valve. Evacuate the canister(s) to <0.05 mm Hg and hold at this vacuum for at least one hour.

NOTE: On a daily basis or more often if necessary, purge the cryogenic traps with zero air to remove any trapped water from previous canister cleaning cycles.

3.1.6.3 Close the vacuum and vacuum/pressure gauge shut-off valves and open the zero air shut-off valve to pressurize the canister(s) with humid zero air to a gauge pressure of approximately 206 kPa (30 psig). If a zero gas generator system is used, the flow rate may need to be limited to maintain the zero air quality.

3.1.6.4 Close the zero air shut-off valve and allow the canister(s) to vent down to atmospheric pressure through the vent shut-off valve. Close the vent shut-off valve. Repeat this procedure two (2) additional times for a total of three (3) evacuation/pressurization cycles for each set of canisters.

3.1.6.5 At the end of the evacuation/pressurization cycle, re-evacuate to <0.05 mm Hg. The evacuated canister is now ready for a leak test and/or certification analyses.

3.1.7 Alternate Cleaning Procedure

3.1.7.1 An alternate canister cleaning system is shown in Figure D/VC-2 and the cleaning procedure is described below.

3.1.7.2 Initially, the system valve and manifold valves are in the closed position and the pump is on. Place canisters, which have been vented to atmospheric pressure in the oven, and attach to the

manifold. Close the canister valves. Bring the oven temperature to 100°C.

3.1.7.3 Place liquid nitrogen in the Dewar flask to immerse the cold trap and replenish as needed during the cleanup cycle. Open the system valve and evacuate the system lines to <0.05 mm Hg. If the system lines will not pump down, the trap may be blocked. To correct this, remove the cryogen and warm the trap with a heat gun while air is pulled through the lines into the pump.

NOTE: Care should be taken to always keep the system valve closed unless the cold trap is immersed in cryogen or air is being pulled through the lines to the pump. This will ensure that pump oil does not backstream into the line between the trap and canisters.

3.1.7.4 Once the system line is evacuated, open the manifold valve and evacuate the manifold tubing to <0.05 mm Hg. This will indicate whether or not the canister/manifold connections are leak-tight. Open the canister valves, and evacuate the canisters to <0.05 mm Hg and hold at this vacuum for a minimum of one hour. Close the canister valves, close the manifold valve, and disconnect the canisters from the manifold. Open the manifold valve slightly so that air is flowing to the pump, and then remove the cryogen from the trap. Allow the trap to warm to room temperature and close the system valve.

3.1.7.5 This cleaning method may be enhanced by adding a cycle in which the canisters are pressurized with humidified zero air and then re-evacuated to <0.05 mm Hg. The evacuated canister is now ready for a leak test and/or certification analyses.

3.2 LEAK TEST PROCEDURE

3.2.1 Summary

The canisters are tested to ensure that the valves and seams are leak-free. Leak testing involves a pressurized and an evacuated state.

3.2.2 Frequency

All canisters are leak tested prior to each sampling use.

3.2.3 Procedure

3.2.3.1 Test all canisters by pressurizing them to a gauge pressure of approximately 206 kPa (30 psig) with zero air. Measure and record the initial pressure and close the canister valve. After 24 hours, open the valve, and measure and record the pressure.

3.2.3.2 Evacuate each canister to <0.05 mm Hg, record the vacuum reading, close the canister valve, and setting the canister aside for 24 hours. After 24 hours, open the canister valve and record the vacuum.

3.2.4 **Technical Acceptance Criteria**

3.2.4.1 In the pressurized test, if leak-tight, the canister pressure should not decrease by more than 0.2 kPa (0.029 psi) over the 24-hour period.

3.2.4.2 The vacuum reading in the canisters in the evacuation tests should be within 0.02 mm Hg of the initial vacuum.

3.2.5 **Corrective Action**

Any significant change from the initial pressure or initial vacuum may indicate that compounds are off-gassing from the canister walls or that the valve or weld seam are not leak-tight. Any problem must be resolved after which the canister shall undergo a leak test and be subject to the same criteria for leak-tightness. If the results are still not within the limits, the canister must be set aside.

3.2.6 **Documentation**

Results of the leak tests shall be reported on Form VIII-AAVC.

3.3 **CANISTER CERTIFICATION**

3.3.1 **Summary**

Canister certification involves two procedures: blank analysis and spiked analysis. The purpose of the blank analysis is to determine the cleanliness of the canister, and the spiked analysis determines the condition of the interior of the canister as indicated by the stability of the spiked target compounds in the canister over a one week period.

3.3.2 **Frequency**

Initially, all canisters must be checked after cleaning to establish the percentage that pass the cleanliness criteria. A total of forty individual canisters should be analyzed in ten batches to check for individual canister contamination and for batch contamination by the cleaning apparatus. If and when only two or less individual canisters are contaminated and no batch contamination is evident, the laboratory may reduce the number of canisters tested for cleanliness after cleaning, but must continue to check 10 percent

of the canisters or one canister from each cleaning run, whichever is greater.

3.3.3 **Procedure**

3.3.3.1 Calibrate the GC/FID or the GC/MS system that has met all the tuning criteria, using a single injection of the 10 ppbv level of standard containing all the target compounds in Table D/VC-1 for volatile organics, prepared according to one of the calibration standard preparation procedures described in section 5.4.

3.3.3.2 For the blank (unspiked) analysis, analyze an aliquot of the contents of a clean canister, pressurized (206 kPa or 30 psig) with humid zero air following the preconcentration procedure in 5.12.3.

3.3.3.3 For the spiked analysis, the same canister used for the blank analysis or another clean canister may be used. Spike the canister with the target compounds then pressurize with humid zero air to 206 kPa or 30 psig. The canister should contain each target compound at a nominal level of 10 ppbv. Immediately analyze an aliquot of the canister contents following the preconcentration procedure in section 5.12.3.

3.3.3.4 Allow the spiked canister to sit at room temperature (ageing) for 7 days, then reanalyze the canister and compare the results with the results of the initial analysis.

3.3.3.5 After analysis, re-evacuate the unspiked canister to <0.05 mm Hg. If clean, the evacuated canister is now ready for storage and/or collection of air sample from the field.

3.3.3.6 The spiked canister must undergo the full canister cleaning cycles as a used canister prior to field use.

3.3.3.7 The certified canisters are considered clean for a period of one month after cleaning. If a canister is stored for a period of one month or more after being successfully cleaned, it must be recleaned by going through one cycle of pressurization and evacuation; however, no subsequent analytical confirmation of cleanliness is required before using.

3.3.4 **Calculation**

3.3.4.1 For the blank analysis, target compound concentrations are determined using the external standard quantitation method. Use the following equation to determine target compound concentration levels:

$$Concentration,\ ppbv = \frac{(A_x)\,(C_s)\,(V_s)}{(A_s)\,(V_x)} \qquad \text{Eq. D/VC-1}$$

where: A_x = peak response of target analyte in the sample aliquot;
A_s = peak response of target analyte in the calibration standard;
V_x = volume of sample aliquot injected, cm^3;
V_s = volume of calibration standard aliquot injected, cm^3; and
C_s = concentration of target analyte in the calibration standard, ppbv.

3.3.4.2 For the spiked analysis, calculate the percent difference (%D) for each target compound between the peak responses at the initial day and the seventh day using the following equation:

$$\%D = \frac{A_0 - A_7}{A_0} \times 100 \qquad \text{Eq. D/VC-2}$$

where: A_0 = peak response of target analyte at initial analysis; and
A_7 = peak response of target analyte after 7 days.

3.3.4.3 For non-target compounds, use the peak response of the target analyte in the calibration standard with the closest retention time to that of the non-target analyte peak in the sample.

3.3.5 Technical acceptance Criteria

3.3.5.1 No target compound shall be present in the unspiked canister at a level higher than its CRQL. The total concentration of compounds in the canister (target and non-target) shall not exceed 10 ppbv.

3.3.5.2 For the spiked canister, the acceptable percent difference for any target compound at a nominal 10 ppbv concentration in humidified zero air is ±30 percent.

3.3.6 Corrective Action

3.3.6.1 Any unspiked canister with a target analyte concentration greater than the its CRQL or a total concentration greater than 10 ppbv (target and non-target) shall be recleaned and reanalyzed subject to the same criteria for cleanliness, or be set aside.

3.3.6.2 For the spiked analysis, a percent difference greater than ±30 percent indicates a problem with the canister, e.g., leak at seams and active sites inside the canister. Any problem must be resolved after which the canister shall undergo a spiked analysis and be subject to the same criteria for cleanliness. If after reanalysis, the percent difference is still not within the limits, the

canister must be set aside.

3.3.7 Documentation

Results of the certification of the canisters shall be reported on Form VIII-AAVC.

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4 OPTIONAL GC/FID SCREENING OF SAMPLES IN CANISTERS

4.1 SUMMARY

The air sample is screened by GC/FID to determine the approximate range of concentrations of VOCs in the sample and to determine whether a dilution of the sample will be required prior to GC/MS analysis. Since FID identifications are based on retention time alone, an FID screening analysis is useful only in establishing tentative identifications and concentrations of the components in a sample, and in determining whether a dilution of the sample will be required prior to GC/MS analysis.

4.2 APPARATUS AND MATERIALS

4.2.1 Gas chromatograph: An analytical system complete with gas chromatograph suitable for on-column injection and all required accessories including analytical columns, gases, flame ionization detector, and integrator. A data system is recommended for measuring peak areas. Sub-ambient oven control and oven temperature programming are required.

4.2.2 Chromatographic column: 30 m x 0.53 mm fused silica column such as DB-1, DB-5, or DB-624, or equivalent.

NOTE: The wider Megabore® column is less susceptible to plugging as a result of trapped water, thus reducing the need for a Nafion® dryer in the analytical system. However, greater retention time variability has been observed when the Nafion® dryer is not used to remove water vapor from the sample stream, and the analyst, therefore, must be careful to consider any retention time shifts when identifications are made. The Megabore® column has sample capacity approaching that of a packed column, while retaining much of the peak resolution traits of narrower columns. GC operating parameters are to be optimized by the analyst.

4.2.3 Six-port gas chromatographic valve.

4.2.4 Cryogenic trap with temperature control assembly.

4.2.5 Electronic mass flow controllers: Capable of maintaining a constant flow (for carrier gas, sample gas and canister sample flow) and to provide analog output to monitor flow anomalies (two 0-100 cm^3/min units for air and one 0-10 cm^3/min unit for helium, or equivalent).

4.2.6 Vacuum pump: General purpose laboratory pump, capable of reducing the downstream pressure of the flow controller to provide the minimum pressure differential necessary to maintain controlled flow rates.

4.2.7 Chromatographic grade stainless steel tubing and stainless steel plumbing fittings.

4.2.8 Vacuum/pressure gauges: Stainless steel gauges, capable of measuring vacuum and pressure.

4.2.9 Stainless steel cylinder pressure regulators: Standard, two-stage cylinder regulators with pressure gauges for helium, air, nitrogen, and hydrogen gas cylinders.

4.2.10 Gas purifiers: Used to remove organic impurities and moisture from gas streams.

4.2.11 Calibration system and manifold described in section 5.2.3.

4.3 **REAGENTS**

4.3.1 Gases: Cylinders of helium, hydrogen, nitrogen, and air, ultrahigh purity grade.

4.3.2 Liquid nitrogen: For cooling GC oven and cryogenic trap.

4.3.3 Deionized water: HPLC grade, for humidifying gas streams.

4.4 **PROCEDURE**

4.4.1 Prepare working calibration standards as described in section 5.4, and calibrate the GC at three of the five concentrations (2, 10, and 20 ppbv) to determine the instrument linearity and sensitivity. Once the FID linearity range has been established, the GC/FID may be calibrated using a single-point (10 ppbv) calibration during each 12-hour period.

4.4.2 Analyze the sample with the procedure described in section 5.12.3. Use the retention times of the target compounds in the calibration standard to tentatively identify target compounds in the sample.

4.4.3 Based on the concentrations of tentatively identified target compounds in the sample, determine whether the sample must be diluted or whether the target compounds are within the range of the GC/MS calibration.

4.4.4 If target compounds are all within the range of the GC/MS calibration, proceed to Section 5.

4.4.5 If target compounds are present at concentrations higher than the calibration range of the GC/MS, then the sample must be diluted as described in the following section prior to GC/MS analysis.

4.5 **DILUTION**

The GC/FID screening procedure, if used, will have shown the approximate concentrations of sample components. If a dilution of the

sample was indicated, first determine the dilution factor needed to bring the concentration into the upper half of the GC/MS calibration, then use one of the following procedures to dilute the sample.

4.5.1 Estimate the final pressure of the canister needed to achieve the dilution. Pressurize the canister with humid zero air which has been demonstrated to be free of contaminants. Measure the final canister pressure and calculate the actual dilution factor using the following equation:

$$DF = \frac{Y_a}{X_a} \qquad \text{Eq. D/VC-3}$$

where: DF = dilution factor;
X_a = canister pressure absolute before dilution; and
Y_a = canister pressure absolute after dilution.

NOTE: (X_a and Y_a must be in same units).

4.5.2 Using a gastight syringe, transfer an aliquot of sample from the original canister to a clean, evacuated canister. Pressurize the dilution canister with humid zero air which has been demonstrated to be free of contaminants. Calculate the dilution factor from the volume of original sample injected and the volume of dilution gas which was added using the following equation.

$$DF = \frac{Volume_{original\ sample}}{Volume_{dilution\ gas}} \qquad \text{Eq. D/VC-4}$$

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5 GC/MS ANALYSIS OF VOLATILES FROM CANISTERS

5.1 SUMMARY

In this analytical procedure, a whole air sample is passed through a preconcentrator where the VOCs are condensed on a reduced temperature surface (cold trap). Subsequently the condensed gases are thermally desorbed and backflushed from the trap with an inert gas onto a gas chromatographic column. The preconcentration technique discussed here is similar to that discussed in EPA Compendium Method TO-14, "The Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using SUMMA® Passivated Canister Sampling and Gas Chromatographic Analysis". Other preconcentration techniques (e.g, those using solid sorbents) may be employed if equivalency is established for the analysis procedure of which it is a part. The gas chromatograph (GC) is temperature-programmed to separate the individual VOCs, which are then detected with a mass spectrometer operated in a full scan mode. The steps of the analytical method are diagrammed in Figure D/VC-3.

5.2 APPARATUS AND MATERIALS

5.2.1 Sampling/Preconcentrator system

5.2.1.1 Electronic mass flow controllers: used to maintain constant flow (for carrier gas and sample gas) and to provide an analog output to monitor flow anomalies.

5.2.1.2 Vacuum pump: general purpose laboratory pump, capable of reducing the downstream pressure of the flow controller to provide the minimum pressure differential necessary to maintain controlled flow rates.

5.2.1.3 Stainless steel tubing and stainless steel fittings: chromatographic grade.

5.2.1.4 Stainless steel cylinder pressure regulators: standard, two-stage cylinder regulators with pressure gauges.

5.2.1.5 Gas purifiers: used to remove organic impurities and moisture from gas streams.

5.2.1.6 Nafion® dryer (optional): consisting of Nafion® tubing coaxially mounted within larger tubing, used to remove water vapor from the sample stream if the MS in use does not have sufficient pumping capacity to handle water vapor.

5.2.1.7 Six-port gas chromatographic valve: for routing sample and carrier gas flows.

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5.2.1.8 Cryogenic preconcentrator: complete units are commercially available from several sources.

5.2.1.8.1 The cooling unit is comprised of a 0.32 cm outside diameter (O.D.) nickel tubing loop packed with 60-80 mesh Pyrex beads with glass wool plugs at each end. The nickel tubing loop is wound onto a cylindrically formed tube heater (250 watt). A cartridge heater (25 watt) is sandwiched between pieces of aluminum plate at the trap inlet and outlet to provide additional heat to eliminate cold spots in the transfer tubing.

NOTE: During operation, the trap is inside a two-section stainless steel shell which is well insulated. Rapid heating (-150 to +100°C in 55 sec.) is accomplished by direct thermal contact between the heater and the trap tubing. Cooling is achieved by vaporization of the cryogen. In the shell, efficient cooling (+120 to -150°C in 225 sec.) is facilitated by confining the vaporized cryogen to the small open volume surrounding the trap assembly.

5.2.1.8.2 The trap assembly and chromatographic valve are mounted on a baseplate fitted into the injection and auxiliary zones of the GC on an insulated pad directly above the column oven.

NOTE: Alternative trap assembly and connection to the GC may be used depending upon user's requirements.

5.2.1.8.3 The carrier gas line is connected to the injection end of the analytical column with a zero-dead-volume fitting that is usually held in the heated zone above the GC oven. An aluminum box is fitted over the sample handling elements to complete the package. Vaporized cryogen is vented through the top of the box.

5.2.2 **GC/MS System**

5.2.2.1 Gas chromatograph: The gas chromatographic (GC) system must be capable of temperature programming and have a flow controller that maintains a constant column flow rate throughout desorption and temperature program operations. The system must include or be interfaced to a preconcentrator (see above) and have all required accessories including analytical columns and gases. All GC carrier gas lines must be constructed from stainless steel or copper tubing. Non-polytetrafluoroethylene (PTFE) thread sealants or flow controllers with rubber components are not to be used. The column oven must be cooled to -50°C at the start of the gas chromatographic run; therefore, a sub-ambient oven temperature controller is required.

5.2.2.2 Chromatographic columns: 100% methyl silicone or 5% phenyl, 95% methyl silicone capillary columns of 0.25 to 0.53 mm I.D. x 50 m length, or equivalent, are required to provide separation of the target compounds.

5.2.2.3 Mass spectrometer: Capable of scanning from 35 to 300 amu every 1 second or less, utilizing 70 volts (nominal) electron energy in the electron impact ionization mode, and producing a mass spectrum which meets all the instrument performance acceptance criteria when 50 ng of p-bromofluorobenzene (BFB) is analyzed.

NOTE: BFB criteria must be met before any samples are analyzed. Any samples analyzed when BFB criteria have not been met will require reanalysis at no cost to the Agency. To ensure sufficient precision of mass spectral data, the MS scan rate should allow acquisition of at least five spectra while a sample compound elutes from the GC. The preconcentration GC/MS system must be in a room whose atmosphere is demonstrated to be free of all potential contaminants which will interfere with the analysis. The instrument must be vented to the outside of the facility or to a trapping system which prevents the release of contaminants into the instrument room.

5.2.2.4 GC/MS interface: Any gas chromatograph to mass spectrometer interface, that gives acceptable calibration points for each of the parameters of interest and achieves all acceptable performance criteria, may be used. Gas chromatograph to mass spectrometer interfaces constructed of all-glass or glass-lined materials are recommended. Glass should be deactivated and this can be accomplished by silanizing with dichlorodimethylsilane.

5.2.2.5 Data system: The computer system that is interfaced to the mass spectrometer must allow the continuous acquisition and storage, on machine readable media, of all mass spectra obtained throughout the duration of the chromatographic program. The computer must have software that allows searching any GC/MS data file for ions of a specified mass and plotting such ion abundances versus time or scan number. This type of plot is defined as a Selected Ion Current Profile (SICP). Software must also be available that allows integrating the abundance in any SICP between specified time or scan number limits. Also, for the non-target compounds, software must be available that allows for the comparison of sample spectra against reference library spectra. The 1990 (or most recent) release of the NIST Library shall be used as the reference library.

5.2.2.6 Magnetic tape storage device: Capable of recording data and must be suitable for long-term, off-line storage.

5.2.3 Calibration System and Manifold

NOTE: The following calibration system is based on EPA Compendium Method TO-14 which discusses gaseous calibration standards. Other calibration methods such as those used in purge and trap procedures may be used if, through such use, the analytical procedure is not compromised with respect to the performance specifications in of the analytical system.

5.2.3.1 Calibration manifold: Glass or high purity quartz manifold (1.25 cm I.D. x 66 cm) with sampling ports and internal baffles for flow disturbance to ensure proper mixing. The manifold should be heated to 50°C.

5.2.3.2 Humidifier: 500-mL impinger flask containing HPLC grade deionized water.

5.2.3.3 Electronic mass flow controllers: One 0 to 5 L/min unit and one or more 0 to 10 cm^3/min units for air, depending on number of cylinders in use for calibration.

5.2.3.4 Teflon filter(s): 47 mm Teflon filter for particulate control, best source.

5.2.3.5 Gastight syringes: For injecting internal standards mixtures.

5.3 **REAGENTS**

5.3.1 Neat standards or manufacturer-certified solutions/mixtures.

5.3.2 Helium and air: Ultrahigh purity grade in gas cylinders.

5.3.3 Liquid nitrogen.

5.3.4 Deionized water: HPLC grade, ultrahigh purity (for humidifier).

5.4 **STANDARDS**

5.4.1 The Contractor must provide all standards to be used with this contract. The Contractor must be able to verify that the standards are certified traceable to a NIST Standard Reference Material (SRM) or to a NIST/EPA approved Certified Reference Material (CRM). Manufacturer's certificates of analysis must be retained by the Contractor and presented upon request.

5.4.2 Neat standards must have a purity of 98 percent or greater. The weight may be used without correction to calculate the concentration of the stock solution.

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5.4.3 Commercially prepared stock standards may be used at any concentration if they are certified by the manufacturer or by an independent source, or traceable to EPA-supplied standards. Fresh stock standards must be prepared once every twelve months, or sooner, if standards have degraded or concentrated. Stock standards must be checked for signs of degradation or concentration just prior to preparing secondary dilution and working standards from them.

5.4.4 **Gas calibration stock standards**

Cylinder(s) containing approximately 10 ppmv of each of the target compounds are used as primary stock standards. The components may be purchased in one cylinder or in separate cylinders. Refer to manufacturer's specifications for guidance on purchasing and mixing VOCs in gas cylinders.

5.4.5 **Working Standards**

5.4.5.1 **Instrument Performance Check Standard**

Prepare a standard solution of BFB in humidified zero air at a concentration which will allow collection of 50 ng of BFB under the optimized preconcentration parameters.

5.4.5.2 **Calibration Standards**

Prepare five working calibration standards in humidified zero air at a concentration which will allow collection at the 2, 5, 10, 20, and 50 ppbv level for each component under the optimized preconcentration parameters.

5.4.5.3 **Internal Standard Spiking Mixture**

Prepare an internal standard spiking mixture containing bromochloromethane, chlorobenzene-d_5, and 1,4-difluorobenzene at 10 ppmv each in humidified zero air to be added to the sample or calibration standard. 500 μL of this solution spiked into 500 mL of sample will result in a concentration of 10 ppbv. The internal standard is introduced into the trap during the collection time for all calibration, blank, and sample (field and QC) analyses. The volume of internal standard spiking mixture spiked for each analysis must be the same from run to run.

5.4.6 **Standard Preparation by Dynamic Dilution Technique**

5.4.6.1 Standards may be prepared by dynamic dilution of the gaseous standards in the cylinder(s) with humidified zero air using mass flow controllers and a calibration manifold. The working standard may be delivered from the manifold to a clean, evacuated canister using a

pump and mass flow controller.

5.4.6.2 Alternatively, the analytical system may be calibrated by sampling directly from the manifold if the flow rates are optimized to provide the desired amount of calibration standards. However, the use of the canister as a reservoir prior to introduction into the preconcentration system resembles the similar procedure as in the sample analysis and is preferred. Flow rates of the dilution air and cylinder standards (all expressed in the same units) are measured using a bubble meter or calibrated electronic flow measuring device, and the concentrations of target compounds in the manifold are then calculated using the dilution ratio and the original concentration of each compound.

$$Manifold\ Conc. = \frac{Original\ Conc. \times Std.\ Gas\ Flowrate}{Air\ Flowrate + Std.\ Gas\ Flowrate} \quad \text{Eq. D/VC-5}$$

5.4.6.3 Example of 1 cm^3/min flow of 10 ppmv standard diluted with 1,000 cm^3/min of humid air provides a nominal 10 ppbv mixture, as calculated below:

$$Manifold\ Conc. = \frac{(10 \times 10^{-6})(1\ cm^3/min)}{(1000\ cm^3/min) + (1\ cm^3/min)} = 10\ ppb \quad \text{Eq. D/VC-6}$$

5.4.7 Standard Preparation by Static Dilution Bottle Technique

Standards may be prepared in canisters by spiking the canister with a mixture of components prepared in a static dilution bottle. This technique is used specifically for liquid standards. A Standard Operating Procedure for the preparation of static dilution bottles is available from the Atmospheric Research and Exposure Assessment Laboratory, Office of Research and Development, USEPA, Research Triangle Park, NC, 27711, Document AREAL/RTP-SOP-MRDD-036. A summarized version of the SOP is provided below.

5.4.7.1 Determine the approximate volume of a clean 2-liter round-bottom flask, modified with a threaded glass neck to accept a Mininert septum cap, by weighing the amount of water required to completely fill up the flask. Assuming a specific gravity for the water of 1, the weight of the water in grams is taken as the volume of the flask in milliliters.

5.4.7.2 Flush the flask with helium for by attaching a tubing onto the glass neck to deliver the helium. After a few minutes, remove the tubing and immediately close the glass neck with a Mininert septum cap.

5.4.7.3 Place the flask in a 60°C oven and allow to equilibrate at that temperature for about 15 minutes. Inject, with a gastight

syringe, predetermined aliquots of liquid standards into the flask making sure to keep the flask temperature constant at 60°C.

5.4.7.4 Before withdrawing aliquots from the flask, allow the contents to equilibrate in the oven for at least 30 minutes. Syringes must be preheated in the oven at the same temperature prior to withdrawal of aliquots to avoid condensation.

5.4.7.5 Aliquots may then be taken for introduction into the cryofocusing trap. An aliquot or aliquots totaling greater than 1 percent of the flask volume should be avoided.

5.4.7.6 Standards prepared by this method as stable for one week. The septum must be replaced with each freshly prepared standard.

5.4.7.7 Calculate the concentration of each component in the flask using the following equation:

$$Concentration,\ mg/L = \frac{(V_a)(d)}{V_f} \qquad \text{Eq. D/VC-7}$$

where: V_a = volume of liquid neat standard injected into the flask in μL;
d = density of the liquid neat standard in $mg/\mu L$; and
V_f = volume of the flask in liters.

5.4.7.8 To obtain concentrations in ppbv, the approximate volume at the vaporized phase can be determined using the equation given in section 5.4.8.7.

CAUTION: In the preparation of standards by this technique, the analyst should make sure that the volume of neat standard injected into the flask does not result in an overpressure due to the higher partial pressure produced by the standard compared to the vapor pressure in the flask. Precautions should also be taken to avoid a significant decrease in pressure inside the flask after withdrawal of aliquot(s).

5.4.8 Standard Preparation Procedure in High Pressure Cylinders

Standards may be prepared in high pressure cylinders as described in the procedure of Pollack and Holdren (1990)[1]. A modified summary of the procedure is provided below.

[1] A.J. Pollack, M.W. Holdren, "Multi-Adsorbent Preconcentration and Gas Chromatographic Analysis of Air Toxics with an Automated Collection/Analytical System," in the Proceedings of the 1990 EPA/A&WMA International Symposium on Measurement of Toxic and Related Air Pollutants, USEPA Report Number EPA/600/9-90/026, pp. 209-218.

5.4.8.1 Obtain the standard compounds as gases or neat liquids (greater than 98 percent purity).

5.4.8.2 Flush a 17.3 m^3 Teflon-lined aluminum cylinder with high-purity nitrogen gas and then evacuate.

5.4.8.3 Accurately measure predetermined amounts of each neat standard compound using a gastight syringe and inject into the cylinder.

5.4.8.4 Pressurize the cylinder to 1200 psig with humid zero air. The flow rate of the zero air should be kept at a constant in order to determine the total volume of diluent used by multiplying the flow rate by the delivery time.

5.4.8.5 Allow the contents of the cylinder to equilibrate prior to withdrawal of aliquots into the GC system.

5.4.8.6 Calculate the concentrations using the following equation:

$$Concentration,\ ppbv = \frac{Volume_{standard}}{Volume_{dilution\ gas}} \qquad \text{Eq. D/VC-8}$$

(Both values must be expressed in the same units.)

5.4.8.7 If the neat standard is a liquid, the approximate volume at the vaporized phase can be determined using the following equations:

$$V = \frac{nRT}{P} \qquad \text{Eq. D/VC-9}$$

and

$$n = \frac{(uL)(p)}{MW} \qquad \text{Eq. D/VC-10}$$

where:
- V = volume at gaseous state in liters;
- n = moles;
- R = gas constant in (0.08206 L-atm/mole °K);
- T = 273°K (standard temperature);
- P = 1 atm (standard pressure);
- μL = volume of liquid neat standard in microliters;
- p = specific gravity of the neat standard; and
- MW = molecular weight of the neat standard expressed in mg/mole.

NOTE: For the above compounds, the calculated cylinder concentrations are within ±20 percent of the 200 ppbv nominal targeted values. For lower concentrations, an aliquot of this

solution should be diluted according to one of the methods described under section 4.5.

5.4.9 **Standard Preparation by Water Methods**

Standards may be prepared by a water purge and trap method described in the procedure by Stephenson, Allen, and Slagle (1990)[2] and summarized below.

5.4.9.1 Pressurize a previously cleaned canister still under vacuum to 760 mm Hg absolute (1 atm) with zero grade air.

5.4.9.2 Remove the air gauge from the canister and connect the sparging vessel to the canister with the shortest length of 1/16 in. stainless steel tubing possible. (Extra effort should be made to minimize possible areas of dead volume to maximize transfer of analytes from the water to the canister.)

5.4.9.3 Spike 5 mL of water with the stock standard solution and the internal standard solution.

5.4.9.4 Transfer this water into the sparge vessel and purge the water with nitrogen for 10 mins at 100 cm^3/min while being heated at 40°C.

5.4.9.5 At the end of 10 mins, remove the sparge vessel from the canister, re-install the air gauge, and pressurize the canister with pure nitrogen to 1500 mm Hg absolute (approximately 15 psi).

5.4.9.6 Allow the canister to equilibrate overnight before use.

5.4.10 **Storage of Standards**

Working standards and internal standards prepared in canisters may be stored for thirty days in an atmosphere free of potential contaminants.

5.5 INSTRUMENT OPERATING CONDITIONS

5.5.1 **Preconcentrator**

The following are suggested cryogenic preconcentrator analytical conditions which may be optimized by the operator.

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2 J.H.M. Stephenson, F. Allen, T. Slagle, "Analysis of Volatile Organics in Air via Water Methods," in Proceedings of the 1990 EPA/A&WMA International Symposium on Measurement of Toxic and Related Air Pollutants, USEPA Report Number EPA/600/9-90/026, pp. 194-199.

5.5.1.1 Sample Collection Conditions

The cryogenic trap is at a setpoint from -150 to -170°C. A 500-cm^3 sample of whole air is passed through the trap during the sample collection period.

NOTE: The analyst should optimize the flow rate, duration of sampling, and absolute sample volume to be used. Other preconcentration systems may be used provided performance standards are realized.

5.5.1.2 Desorption Conditions

Desorb Temperature:	120°C
Desorb Flow Rate:	4 cm^3/min helium
Desorb Time:	<60 sec

5.5.1.3 Trap Reconditioning Conditions

Before initial use, condition the trap overnight at 120°C by flushing with 10 cm^3/min of inert gas. Vent the trap effluent to the room and not to the analytical column. Prior to daily use, condition the trap by heating at 120°C for 30 minutes while flushing with inert gas. The trap may be vented to the analytical column during daily conditioning.

Reconditioning Temperature:	120°C
Reconditioning Time:	30 min

5.5.2 GC/MS System

5.5.2.1 Optimize GC conditions for compound separation and sensitivity. Baseline separation of benzene and carbon tetrachloride is an indication of optimum chromatographic performance.

5.5.2.2 The following are the recommended gas chromatographic analytical conditions:

Carrier Gas:	Helium	
Flow Rate:	4 cm^3/min	
Temperature Program:	Initial Temperature:	-50°C
	Initial Hold Time:	2 min
	Ramp Rate:	8° C/min
	Final Temperature:	150°C
	Final Hold Time:	Until all target compounds elute.

5.5.2.3 The following are the required mass spectrometer conditions:

Electron Energy: 70 Volts (nominal)
Mass Range: 35-300 amu
Scan Time: To give at least 5 scans per peak, not to exceed 1 second per scan.

5.6 ANALYTICAL SEQUENCE

The GC/MS analytical sequence for each 12-hour time period shall be as follows:

- Instrument Performance Check (BFB)
- Initial or continuing calibration
- Laboratory Method Blank
- LCS
- ≤20 field samples
- Performance Evaluation (PE) Sample (if available)

5.7 INSTRUMENT PERFORMANCE CHECK

5.7.1 Summary

It is necessary to establish that a given GC/MS meets tuning and standard mass spectral abundance criteria prior to initiating any data collection. The GC/MS system is set up according to the manufacturer's specifications, and the mass calibration and resolution of the GC/MS system are then verified by the analysis of the instrument performance check standard, bromofluorobenzene (BFB).

5.7.2 Frequency

5.7.2.1 Prior to the analyses of any samples, blanks, or calibration standards, the Contractor must establish that the GC/MS system meets the mass spectral ion abundance criteria for the instrument performance check standard containing BFB. The instrument performance check solution must be analyzed initially and once per 12-hour time period of operation. Also, whenever the laboratory takes corrective action which may change or affect the mass spectral criteria (e.g., ion source cleaning or repair, column replacement, etc.), the instrument performance check must be verified irrespective of the 12-hour laboratory requirement.

5.7.2.2 The 12-hour time period for GC/MS instrument performance check and standards calibration (initial calibration and continuing calibration check criteria) begins at the injection of the BFB which the laboratory submits as documentation of a compliance tune. The time period ends after 12 hours have elapsed. In order to meet instrument performance check requirements, samples, blanks, and standards must be injected within 12 hours of the BFB injection.

5.7.3 Procedure

5.7.3.1 The analysis of the instrument performance check standard is performed by trapping 50 ng of BFB under the optimized preconcentration parameters. The BFB is introduced from a cylinder into the GC/MS via a sample loop valve injection system similar to that in the sample analysis section.

5.7.3.2 The mass spectrum of BFB must be acquired in the following manner. Three scans (the peak apex scan and the scans immediately preceding and following the apex) are acquired and averaged. Background subtraction is required, and must be accomplished using a single scan prior to the elution of BFB.

NOTE: All instrument conditions must be identical to those used in the sample analysis.

5.7.4 Technical Acceptance Criteria

5.7.4.1 Prior to the analysis of any samples, blanks, or calibration standards, the Laboratory must establish that the GC/MS system meets the mass spectral ion abundance criteria for the instrument performance check solution as specified in Table D/VC-2.

5.7.4.2 The instrument performance check standard must be injected once at the beginning of each 12-hour period during which samples, blanks, or standards are analyzed.

5.7.5 Corrective Action

5.7.5.1 If the BFB acceptance criteria are not met, the MS must be retuned. It may be necessary to clean the ion source, or quadrupoles, or take other necessary actions to achieve the acceptance criteria.

5.7.5.2 BFB acceptance criteria MUST be met before any standards, performance evaluation (PE) samples, or required blanks are analyzed. Any samples or required blanks analyzed when tuning criteria have not been met will require reanalysis at no additional cost to the Agency.

5.7.6 Documentation

Reporting requirements are listed in Exhibit B. Results of the BFB tuning are reported on Form IV-AAVC.

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5.8 INITIAL CALIBRATION

5.8.1 Summary

5.8.1.1 Prior to the analysis of samples and required blanks and after the instrument performance check standard criteria have been met, each GC/MS system must be calibrated at a minimum of five concentrations in an initial calibration sequence to determine instrument sensitivity and the linearity of GC/MS response for the target compounds.

5.8.1.2 All sample results, for sample analyses performed in the same 12-hour sequence as the initial calibration, are quantified against the initial calibration standard that is the same concentration as the continuing calibration standard (10 ppbv).

5.8.2 Frequency

5.8.2.1 Each GC/MS system must be calibrated upon award of the contract, whenever the Contractor takes corrective action which may change or affect the initial calibration criteria (e.g., ion source cleaning or repair, column replacement, etc.), or if the daily calibration acceptance criteria have not been met.

5.8.2.2 If time remains in the 12-hour time period after meeting the acceptance criteria for the initial calibration, samples may be analyzed.

5.8.2.3 If time does not remain in the 12-hour period after meeting the acceptance criteria for the initial calibration, a new analytical sequence shall commence with the analysis of the instrument performance standard.

5.8.3 Procedure

5.8.3.1 Verify that the GC/MS system meets the instrument performance criteria in section 5.7.

5.8.3.2 The GC must be operated using temperature and flow rate parameters equivalent to those in section 5.5. Calibrate the preconcentration-GC/MS system by drawing 500 cm^3 of standard into the system following one of the methods described under section 5.4. Add the equivalent of 10 ppbv of each internal standard into the trap.

5.8.4 Calculations

NOTE: In the following calculations, the area response is that of the primary quantitation ion unless otherwise stated.

5.8.4.1 Relative Response Factor: Calculate the relative response factors (RRF) for each target compound to the appropriate internal standard (see Table D/VC-3) using the following equation:

$$RRF = \frac{A_x C_{is}}{A_{is} C_x} \qquad \text{Eq. D/VC-11}$$

where: RRF = relative response factor;
A_x = area of the primary ion for the compound to be measured;
A_{is} = area of the primary ion for the internal standard;
C_{is} = concentration of internal standard spiking mixture, ppbv; and
C_x = concentration of the compound in the calibration standard, ppbv.

NOTE: The equation above is valid under the condition that the volume (500 μL) of internal standard spiking mixture added in all field and QC analyses is the same from run to run, and that the volume (500 cm^3) of field and QC sample introduced into the trap is the same for each analysis. C_{is} and C_x must be in the same units.

5.8.4.2 Mean Relative Response Factor: Calculate the mean RRF ($\overline{RRF}$) for each compound by averaging the values obtained at the five concentrations using the following equation:

$$\overline{RRF} = \sum_{i=1}^{n} \frac{x_i}{n} \qquad \text{Eq. D/VC-12}$$

where: $\overline{RRF}$ = mean relative response factor;
x_i = RRF of the compound; and
n = number of values.

5.8.4.3 Percent Relative Standard Deviation (%RSD): Using the RRFs from the initial calibration, calculate the %RSD for all target compounds using the following equations:

$$\%RSD = \frac{SD_{RRF}}{\overline{RRF}} \times 100 \qquad \text{Eq. D/VC-13}$$

and

$$SD_{RRF} = \sqrt{\sum_{i=1}^{N} \frac{(RRF_i - \overline{RRF})^2}{N - 1}} \qquad \text{Eq. D/VC-14}$$

where: SD_{RRF} = standard deviation of initial response factors (per compound);
RRF_i = relative response factor at a concentration level; and
$\overline{RRF}$ = mean of initial relative response factors (per compound).

5.8.4.4 Relative Retention Times (RRT): Calculate the RRTs for each target compound over the initial calibration range using the following equation:

$$RRT = \frac{RT_c}{RT_{IS}} \qquad \text{Eq. D/VC-15}$$

where: RT_c = retention time of the target compound; and
RT_{IS} = retention time of the internal standard.

5.8.4.5 Mean of the Relative Retention Times ($\overline{RRT}$): Calculate the mean of the relative retention times ($\overline{RRT}$) for each analyte target compound over the initial calibration range using the following equation:

$$\overline{RRT} = \sum_{i=1}^{n} \frac{RRT}{n} \qquad \text{Eq. D/VC-16}$$

where: $\overline{RRT}$ = mean relative retention time for the target compound for each initial calibration standard; and
RRT = relative retention time for the target compound at each calibration level.

5.8.4.6 Tabulate the area response (Y) of the primary ion (see Table D/VC-3) and the corresponding concentration for each compound and internal standard.

5.8.4.7 Mean Area Response ($\overline{Y}$) for Internal Standard: Calculate the mean area response ($\overline{Y}$) for each internal standard compound over the initial calibration range using the following equation:

$$\overline{Y} = \sum_{i=1}^{n} \frac{Y_i}{n} \qquad \text{Eq. D/VC-17}$$

where: $\overline{Y}$ = mean area response; and
Y = area response for the primary quantitation ion for the internal standard for each initial calibration standard.

5.8.4.8 Percent Area Response Change (%ARC): Calculate the %ARC at each calibration level for each of the internal standards using the following equation:

$$\%ARC = \frac{A_x - \bar{Y}}{\bar{Y}} \times 100 \qquad \text{Eq. D/VC-18}$$

where: %ARC = percent area response change;
A_x = area response of the internal standard at a concentration level; and
$\bar{Y}$ = mean area response of the internal standard over the entire calibration range.

5.8.4.9 Mean of the Retention Times ($\overline{RT}$) For Internal Standard: Calculate the mean of the retention times ($\overline{RT}$) for each internal standard over the initial calibration range using the following equation:

$$\overline{RT} = \sum_{i=1}^{n} \frac{RT_i}{n} \qquad \text{Eq. D/VC-19}$$

where: $\overline{RT}$ = mean retention time; and
RT = retention time for the internal standard for each initial calibration standard.

5.8.4.10 Internal Standard Retention Time Shift (RTS): Calculate the RTS between the RT of each internal standard at each concentration level and the $\overline{RT}$ for that internal standard over the entire calibration range using the following equation:

$$RTS = \overline{RT_i} - RT_x \qquad \text{Eq. D/VC-20}$$

where: $\overline{RT_i}$ = mean of the retention time for the internal standard in the initial calibration; and
RT_x = retention time of the internal standard at a concentration level.

5.8.5 Technical Acceptance Criteria

5.8.5.1 All initial calibration standards must be analyzed at the concentration levels and frequency described in this section on a GC/MS system meeting the BFB instrument performance check criteria.

5.8.5.2 The %RSD for all target compounds in the initial curve must be less than or equal to 30 percent. Up to two compounds may exceed the maximum %RSD criteria; the %RSD for those compounds, however, must not exceed 40 percent.

5.8.5.3 The RRT for each of the target compounds at each calibration level must be within ±0.06 RRT units of the mean relative retention time ($\overline{RRT}$) for the compound.

5.8.5.4 The %ARC at each calibration level must be within ±40

percent of the mean area response ($\bar{Y}$) over the initial calibration range for each internal standard.

5.8.5.5 The retention time shift for each of the internal standards at each calibration level must be within ±20.0 seconds compared to the mean retention time ($\overline{RT}$) over the initial calibration range for each internal standard.

5.8.6 Corrective Action

5.8.6.1 If the initial calibration technical acceptance criteria are not met, inspect the system for problems. It may be necessary to clean the ion source, change the column, or take other corrective actions to meet the initial calibration technical acceptance criteria.

5.8.6.2 Initial calibration acceptance criteria MUST be met before any field samples, performance evaluation (PE) samples, or required blanks are analyzed. Any samples or required blanks analyzed when initial calibration criteria have not been met will require reanalysis at no additional cost to the Agency.

5.8.7 Documentation

Reporting requirements are listed in Exhibit B. Results of the initial calibration are reported on Form V-AAVC; Internal standard area and RT shall be tabulated on Form VII-AAVC.

5.9 CONTINUING CALIBRATION

5.9.1 Summary

Prior to the analysis of samples and required blanks and after tuning criteria have been met, the initial calibration of each GC/MS system must be routinely checked by analyzing a continuing calibration standard to ensure that the instrument continues to meet the instrument sensitivity and linearity requirements of the method. The continuing calibration standard, which is the 10 ppbv level calibration standard, shall contain all the target compounds and internal standards.

5.9.2 Frequency

5.9.2.1 A check of the calibration curve must be performed once every 12 hours on a GC/MS system that has met the tuning criteria.

5.9.2.2 The continuing calibration sequence starts with the injection of the BFB. If the BFB analysis meets the ion abundance criteria for BFB, then a continuing calibration standard may be analyzed.

5.9.3 Procedure

Analyze the mid level standard (10 ppbv) in a GC/MS system that has met the tuning and mass calibration criteria following the same procedure in section 5.8.3 .

5.9.4 Calculations

NOTE: In the following calculations, the area response is that of the primary quantitation ion unless otherwise stated.

5.9.4.1 Relative Response Factor (RRF): Calculate a relative response factor (RRF) for each target compound using the equation in section 5.8.4.1.

5.9.4.2 Percent Difference (%D): Calculate the percent difference in the RRF of the daily RRF (12-hour) compared to the mean RRF in the most recent initial calibration. Calculate the %D for each target compound using the following equation:

$$\%D = \frac{RRF_c - \overline{RRF_i}}{\overline{RRF_i}} \times 100 \qquad \text{Eq. D/VC-21}$$

where: RRF_c = RRF of the compound in the continuing calibration standard; and

$\overline{RRF_i}$ = mean RRF of the compound in the most recent initial calibration.

5.9.5 Technical Acceptance Criteria

5.9.5.1 The continuing calibration standard must be analyzed at the concentration level and frequency described in this section on a GC/MS system meeting the BFB instrument performance check criteria.

5.9.5.2 The %D for each target compound in a daily calibration sequence must be within ±30 percent in order to to proceed with the analysis of samples and blanks.

5.9.6 Corrective Action

5.9.6.1 If the continuing calibration technical acceptance criteria are not met, inspect the system for problems. It may be necessary to clean the ion source, change the column, or take other corrective actions to meet the continuing calibration technical acceptance criteria.

5.9.6.2 Continuing calibration acceptance criteria MUST be met before any field samples, performance evaluation (PE) samples, or required blanks are analyzed. Any samples or required blanks analyzed when the continuing calibration criteria have not been met

will require reanalysis at no additional cost to the Agency.

5.9.7 **Documentation**

Reporting requirements are listed in Exhibit B. Results of the continuing calibration are reported on Form VI-AAVC; Internal standard area and RT shall be tabulated on Form VII-AAVC.

5.10 BLANK ANALYSIS

5.10.1 Summary

5.10.1.1 To monitor for possible laboratory contamination, laboratory method blanks are analyzed with each SDG at least once in a 12-hour analytical sequence. All steps in the analytical procedure are performed on the blank using all reagents, standards, equipment, apparatus, glassware, and solvents that would be used for a sample analysis.

5.10.1.2 A laboratory method blank is an unused, certified canister that has not left the laboratory. The blank canister is pressurized with zero air and carried through the same analytical procedure as a field sample. The injected aliquot of the blank must contain the same amount of internal standards that are added to each sample. All field samples must be analyzed with associated blanks.

5.10.2 Frequency

5.10.2.1 The laboratory method blank must be analyzed after the calibration standard(s) and before any samples are analyzed. A LMB shall be analyzed immediately before the LCS along with each batch of ≤20 samples and shall be carried through the entire analytical procedure.

5.10.2.2 Whenever an unusually concentrated sample is encountered, a LMB analysis shall be performed immediately after the sample analysis.

5.10.3 Procedure

5.10.3.1 Determine the average pressure of all the sample canisters in the SDG. Pressurize the blank canisters, which are evacuated to <0.05 mm Hg at the end of the canister certification procedure, to the average pressure of the sample canisters in the SDG (approximately 130 kPa) with humidified zero air.

5.10.3.2 Analyze the blanks following the same procedure outlined under section 5.12, "Sample Analysis".

5.10.4 Calculations

The blanks are analyzed similar to a field sample and the equations in section 5.12.4 apply.

5.10.5 Technical Acceptance Criteria

NOTE: If the most recent valid calibration is an initial calibration, internal standard area responses and RTs in the blank are evaluated against the corresponding internal standard area responses and RTs in the mid level standard (10 ppbv) of the initial calibration.

5.10.5.1 All blanks must be analyzed at the frequency described in section 5.10.2 on a GC/MS system meeting the BFB instrument performance check and initial calibration or continuing calibration technical acceptance criteria.

5.10.5.2 The area response for each IS in the blank must be within ±40 percent of area response of the IS in the most recent valid calibration.

5.10.5.3 The retention time for each of the internal standards must be within ±20.0 seconds between the blank and the most recent valid calibration.

5.10.5.4 The blank must not contain any target analyte at a concentration greater than its CRQL and must not contain additional compounds with elution characteristics and mass spectral features that would interfere with identification and measurement of a method analyte at its CRQL. The total level of analytes in the blank must not exceed 10 ppbv.

5.10.6 Corrective Action

5.10.6.1 If a Contractor's blanks do not meet the technical acceptance criteria, the Contractor must consider the analytical system to be out of control. It is the Contractor's responsibility to ensure that method interferences caused by contaminants in solvents, reagents, glassware, and other sample storage and processing hardware that lead to discrete artifacts and/or elevated baselines in gas chromatograms be eliminated. If contamination is a problem, the source of the contamination must be investigated and appropriate corrective measures MUST be taken and documented before further sample analysis proceeds.

5.10.6.2 All samples processed with a blank that is out of control (i.e., contaminated) shall be flagged with a "B".

5.10.7 Documentation

Reporting requirements are listed in Exhibit B. Laboratory method blank results are reported on Form II-AAVC, Laboratory Blank Summary Form. Internal standard area and RT shall be tabulated on Form VII-AAVC.

5.11 LABORATORY CONTROL SAMPLES (LCS)

5.11.1 Summary

The LCS is an internal laboratory quality control sample designed to assess (on an SDG-by-SDG basis) the capability of the Contractor to perform the analytical method listed in this Exhibit. Table D/VC-7 provides a list of LCS compounds and the corresponding percent recovery limits.

5.11.2 Frequency

The LCS must be analyzed and reported once per 12-hour analytical sequence, and concurrently with the samples in the SDG.

5.11.3 Procedure

5.11.3.1 Prepare a canister containing all the LCS compounds at a concentration of 10 ppbv for each compound.

5.11.3.2 Analyze an aliquot according to the same procedure as described in section 5.12.3.

5.11.4 Calculations

5.11.4.1 Calculate individual compound recoveries of the LCS using the following equation:

$$LCS\ \%Recovery = \frac{Concentration_{reported}}{Concentration_{spiked}} \times 100 \qquad \text{Eq. D/VC-22}$$

5.11.4.2 Field sample calculations in section 5.12 also apply to the LCS.

5.11.5 Technical Acceptance Criteria

NOTE: If the most recent valid calibration is an initial calibration, internal standard area responses and RTs in the LCS are evaluated against the corresponding internal standard area responses and RTs in the mid level standard (10 ppbv) of the initial calibration.

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5.11.5.1 The LCS must be analyzed on a GC/MS system meeting the BFB, initial or continuing calibration, and blank technical acceptance criteria at the frequency described in section 5.11.2.

5.11.5.2 The percent recovery for each of the compounds in the LCS must be within the recovery limits listed on Table D/VC-7.

5.11.5.3 The area response change between the LCS and the most recent valid calibration for each of the internal standards must be less than or equal to ±40 percent.

5.11.5.4 The retention time shift between the LCS and the most recent valid calibration for each of the internal standards must be within ±20.0 seconds.

5.11.6 **Corrective Action**

5.11.6.1 If the technical acceptance criteria for the internal standards are not met, check calculations and instrument performance. It may be necessary to recalibrate the instrument or take other corrective action procedures to meet the technical acceptance criteria.

5.11.6.2 The laboratory may not submit data from an SDG until all the LCS technical acceptance criteria are met. LCS contamination from laboratory sources or any LCS analyzed not meeting all the technical acceptance criteria will require reanalysis at no additional cost to the Agency.

5.11.6.3 LCS acceptance criteria MUST be met before any field samples, performance evaluation (PE) samples, or required blanks are analyzed. Any samples or required blanks analyzed when the LCS technical acceptance criteria have not been met will require reanalysis at no additional cost to the Agency.

5.11.7 **Documentation**

Reporting requirements are listed in Exhibit B. Laboratory Control Sample analysis data are reported on Form III-AAVC. Internal standard area and RT shall be tabulated on Form VII-AAVC.

5.12 **SAMPLE ANALYSIS**

5.12.1 **Summary**

An aliquot of the air sample collected in a canister is cryofocused and subsequently analyzed by GC/MS under conditions in section 5.5. Guidelines for qualitative and quantitative analysis are discussed in sections 5.13 and 5.14.

5.12.2 **Frequency**

5.12.2.1 If time remains in the 12-hour period in which an initial calibration is performed, samples may be analyzed without analysis of a continuing calibration standard.

5.12.2.2 If time does not remain in the 12-hour period since the injection of the instrument performance check standard in which an initial calibration is performed, both the instrument performance check standard and the continuing calibration standard must be analyzed before sample analysis may begin.

5.12.3 **Procedure - Instrumental Analysis**

5.12.3.1 All canister samples must be at ambient temperature before analysis.

5.12.3.2 Check and adjust the mass flow controllers to provide correct flow rates for the system.

5.12.3.3 Connect the sample canister to the inlet of the GC/MS analytical system, as shown in Figure D/VC-4. For pressurized samples with sufficient pressure to drive an electronic mass flow controller, place the controller on the canister, open the canister valve, and vent the canister flow past a tee inlet to the analytical system. The flow rate out of the canister is higher than the optimized sample flow rate so that excess sample is vented and exhausted from the pump, while the desired sample flow is established through the six-port chromatographic valve and the preconcentrator to the downstream flow controller. The absolute volume of sample being pulled through the trap must be consistent from run to run.

5.12.3.4 Cool the GC oven and cryogenic trap to their set points of -50°C and -150°C, respectively. As soon as the cryogenic trap reaches its lower set point of -150°C, the six-port chromatographic valve is cycled to the trap position to begin sample collection. Utilize the sample collection time which has been optimized by the analyst.

5.12.3.5 Use a gastight syringe or some alternate method of introduction of the internal standard during the sample collection period. Add sufficient internal standard equivalent to 10 ppbv in the sample. For example, a 0.5 cm^3 volume of a mixture of internal standard compounds, each at 10 ppmv concentration, added to a sample volume of 500 cm^3, will result in 10 ppbv of each internal standard in the sample.

5.12.3.6 After the sample and internal standards are preconcentrated on the cryogenic trap, the GC sampling valve is cycled to the inject position and the cryogenic trap is heated (-150°C to 120°C in 60 sec)

and swept with helium. The trapped analytes are thermally desorbed onto the head of the capillary column and are separated on the column using the GC oven temperature program. The canister valve is closed and the canister is disconnected from the mass flow controller and capped. The trap is maintained at 120°C until the beginning of the next analysis.

5.12.3.7 Upon sample injection onto the column, the GC/MS system is operated so that the MS scans the atomic mass range from 35 to 300 amu. At least five scans per eluting chromatographic peak should be acquired. Scanning allows identification of unknown compounds in the sample through searching of library spectra.

5.12.3.8 Each analytical run must be checked for saturation. The level at which an individual compound will saturate the detection system is a function of the overall system sensitivity and the mass spectral characteristics of that compound. When a sample is analyzed that has saturated ions from a compound, this analysis must be followed by a laboratory blank analysis. If the blank analysis is not free of interferences, the system must be decontaminated. Sample analysis may not resume until a blank can be analyzed that is free of interferences.

5.12.3.9 Secondary ion quantitation is allowed only when there are sample matrix interferences with the primary ion. If secondary ion quantitation is performed, document the reasons in the SDG Narrative.

5.12.4 Calculations

5.12.4.1 The equation below is used for calculating concentrations.

$$X_a = \frac{A_x C_{is} DF}{A_{is} RRF} \qquad \text{Eq. D/VC-23}$$

where: X_a = compound concentration, ppbv;
A_x = area of the characteristic ion for the compound to be measured;
A_{is} = area of the characteristic ion for the specific internal standard;
C_{is} = concentration of the internal standard spiking mixture, ppbv;
RRF = relative response factor from the analysis of the continuing calibration standard or the mid level standard of the initial calibration; and
DF = dilution factor calculated as described in 4.5. If no dilution is performed, DF = 1.

NOTE: The equation above is valid under the condition that the volume (500 µL) of internal standard spiking mixture added in all

field and QC analyses is the same from run to run, and that the volume (500 cm^3) of field and QC sample introduced into the trap is the same for each analysis.

5.12.4.2 Percent Area Response Change (%ARC): Calculate the change in area response for each internal standard by comparing with the most recent valid calibration using the following equation:

$$\%ARC = \frac{A_c - A}{A_c} \times 100 \qquad \text{Eq. D/VC-24}$$

where: %ARC = percent area response change;
A_c = area response of the IS in the most recent valid calibration; and
A = area response of the IS in the sample.

5.12.4.3 Internal Standard Retention Time Shift (RTS): Calculate the shift in retention time between the RT in the sample and in the most recent valid calibration standard for each of the internal standards using the following equation:

$$RTS = RT_c - RT \qquad \text{Eq. D/VC-25}$$

where: RT_c = retention time of the IS in the most recent valid calibration; and
RT = retention time of the IS in the sample.

5.12.5 Technical Acceptance Criteria

NOTE: If the most recent valid calibration is an initial calibration, internal standard area responses and RTs in the sample are evaluated against the corresponding internal standard area responses and RTs in the mid level standard (10 ppbv) of the initial calibration.

5.12.5.1 The field sample must be analyzed on a GC/MS system meeting the BFB tuning, initial calibration, and continuing calibration technical acceptance criteria at the frequency described in section 5.12.2.

5.12.5.2 The field sample must be analyzed with a laboratory method blank that met the blank technical acceptance criteria.

5.12.5.3 All of the target analyte peaks must be within the initial calibration range.

5.12.5.4 The retention time for each internal standard must be within ±20.0 seconds of the retention time of the internal standard in the most recent valid calibration.

5.12.5.5 The %ARC for each of the internal standards must be within ±40 percent of the most recent valid calibration.

5.12.6 **Corrective Action**

5.12.6.1 If the on-column concentration of any compound in any sample exceeds the initial calibration range, an aliquot of the original sample must be diluted as discussed in section 4.5 and reanalyzed. Guidance in performing dilutions, and exceptions to this requirement are given below.

5.12.6.1.1 Use the results of the original analysis to determine the approximate dilution factor required to get the largest analyte peak within the initial calibration range.

5.12.6.1.2 The dilution factor chosen should keep the response of the largest analyte peak for a target compound in the upper half of the initial calibration range of the instrument.

5.12.6.1.3 Do not submit data for more than two analyses, i.e., the original sample and one dilution, or, if the screening procedure was employed, the most concentrated dilution analyzed and one further dilution.

5.12.6.2 Internal standard responses and retention times must be evaluated during or immediately after data acquisition. If the retention time for any internal standard changes by more than 20 seconds from the latest daily (12-hour) calibration standard or mid level standard if samples are analyzed in an inital calibration analytical sequence, the GC/MS system must be inspected for malfunctions, and corrections made as required.

5.12.6.3 If the SICP area for any internal standard changes by more than ±40 percent between the sample and the most recent valid calibration, the GC/MS system must be inspected for malfunction and corrections made as appropriate. When corrections are made, reanalysis of samples analyzed while the system was malfunctioning is necessary.

5.12.6.4 If after reanalysis, the SICP areas or the RTs for all internal standards are inside the contract limits, then the problem with the first analysis is considered to have been within the control of the laboratory. Therefore, submit only data from the analysis with SICPs within the contract limits. This is considered the initial analysis and must be reported as such on all data deliverables.

5.12.6.5 If the reanalysis of the sample does not solve the problem, i.e., the SICP areas or internal standard RTs are outside the contract limits for both analyses, then submit the SICP data and

sample data from both analyses. Distinguish between the initial analysis and the reanalysis on all data deliverables, using the sample suffixes specified in Exhibit B. Document in the SDG Narrative all inspection and corrective actions taken.

5.12.6.6 When target compounds are below contract required quantitation limits (CRQL), but the spectra meet the identification criteria, report the concentration with a "J." For example, if the CRQL is 5 ppbv and a concentration of 2 ppbv is calculated, report as "2J."

5.12.7 Documentation

Reporting requirements are listed in Exhibit B. Sample analysis data are reported on Form I-AAVC; Internal standard area and RT shall be tabulated on Form VII-AAVC.

5.13 PERFORMANCE EVALUATION SAMPLES

5.13.1 Summary

The performance evaluation (PE) samples will assist the Agency in monitoring Contractor performance. The laboratory will not be informed as to which compounds are contained in the PE samples or the concentrations.

5.13.2 Frequency

The laboratory must analyze, and report the results of the PE sample once per sample delivery group, if available.

5.13.3 Procedure

5.13.3.1 The laboratory will receive humidified PE samples in SUMMA® canisters from the Agency. The samples will come with instructions concerning the analysis procedure required for the PE samples.

5.13.3.2 Each laboratory must analyze the PE sample using the procedure described in section 5.12 for those target compounds listed in Table D/VC-1.

5.13.4 Calculations

Calculations for PE samples are the same as those for field samples. Use the equations in section 5.12 for determining technical acceptance criteria compliance.

5.13.5 Technical Acceptance Criteria

NOTE: If the most recent valid calibration is an initial

calibration, internal standard area responses and RTs in the PE sample are evaluated against the corresponding internal standard area responses and RTs in the mid level standard (10 ppbv) of the initial calibration.

5.13.5.1 The PE sample must be analyzed on a GC/MS system meeting the BFB tuning, initial calibration, and continuing calibration technical acceptance criteria at the frequency described in section 5.13.2.

5.13.5.2 The PE sample must be analyzed with a method blank that met the blank technical acceptance criteria.

5.13.5.3 The retention time for each internal standard in the PE sample analsis must be within ±20.0 seconds of the retention time of the internal standard in the most recent valid calibration.

5.13.5.4 The %ARC for each of the internal standards in the PE sample analysis must be within ±40 percent of the most recent valid calibration.

5.13.5.5 The results of analysis must identify the target compounds provided in the performance evaluation sample and must meet precision and accuracy criteria in comparison with the known results, as outlined in section 6.

5.13.6 Corrective Action

5.13.6.1 If the PE sample technical acceptance criteria for the internal standards are not met, check calculations and instrument performance. It may be necessary to reanalyze the PE sample or take other corrective action procedures to meet the internal standard criteria.

5.13.6.2 If after reanalysis, the SICP areas or the RTs for all internal standards are inside the contract limits, then the problem with the first analysis is considered to have been within the control of the laboratory. Therefore, submit only data from the analysis with SICPs within the contract limits. This is considered the initial analysis and must be reported as such on all data deliverables.

5.13.6.3 If the reanalysis of the PE sample does not solve the problem, i.e., the SICP areas or internal standard RTs are outside the contract limits for both analyses, then submit the SICP data and sample data from both analyses. Distinguish between the initial analysis and the reanalysis on all data deliverables, using the sample suffixes specified in Exhibit B. Document in the SDG Narrative all inspection and corrective actions taken.

5.13.6.4 When target compounds are below contract required quantitation limits (CRQL), but the spectra meet the identification criteria, report the concentration with a "J." For example, if the CRQL is 5 ppbv and a concentration of 2 ppbv is calculated, report as "2J."

5.13.6.5 In addition to complying with the PE sample technical acceptance criteria, the Contractor will be responsible for correctly identifying the compounds included in the PE sample. The Agency will notify the Contractor of unacceptable performance.

5.13.6.6 If the PE sample is provided with the SDG, technical acceptance criteria for the PE sample MUST be met before sample data are reported. Also, the Contractor must demonstrate acceptable performance for compound identification and quantification. If the Contractor fails to meet the PE sample technical acceptance criteria, the Agency may take, but is not limited to, the following actions: reduction of the number of samples, suspension of sample shipment, a site visit, a full data audit, and/or require the laboratory to analyze a remedial PE sample.

5.13.7 **Documentation**

Reporting requirements are listed in Exhibit B. Sample analysis data are reported on Form I-AAVC; Internal standard area and RT shall be tabulated on Form VII-AAVC.

5.14 QUALITATIVE ANALYSIS

5.14.1 The compounds in Table D/VC-1 of this section shall be identified by an analyst competent in the interpretation of mass spectra (see Bidder Responsibility description) by comparison of the sample mass spectrum to the mass spectrum of a standard of the suspected compound. Two criteria must be satisfied to verify the target compound identifications: (1) elution of the sample component at the same GC retention time as the standard component, and (2) correspondence of the sample component and standard component mass spectra.

5.14.2 For establishing correspondence of the GC relative retention time (RRT), the sample component RRT must compare within ±0.06 RRT units of the RRT of the standard component. For reference, the standard must be run in the same 12-hour time period as the sample. If coelution of interfering components prohibits accurate assignment of the sample component RRT from the total ion chromatogram, the RRT should be assigned by using extracted ion current profiles for ions unique to the component of interest.

5.14.3 For comparison of standard and sample component mass spectra, mass spectra obtained on the Contractor's GC/MS are required. Once obtained, these standard spectra may be used for identification purposes

only if the Contractor's GC/MS meets the daily instrument performance requirements for BFB. These standard spectra may be obtained from the run used to obtain reference RRFs.

5.14.4 Requirements for Qualitative Verification

5.14.4.1 All ions present in the standard mass spectra at a relative intensity greater than 10 percent (most abundant ion in the spectrum equals 100 percent) must be present in the sample spectrum.

5.14.4.2 The relative intensities of the specified ions must agree within ±20 percent between the standard and sample spectra. (Example: For an ion with an abundance of 50 percent in the standard spectra, the corresponding sample abundance must be between 30 and 70 percent).

5.14.4.3 Ions greater than 10 percent in the sample spectrum but not present in the standard spectrum must be considered and accounted for by the analyst making the comparison. The verification process should favor false positives. All compounds meeting the identification criteria must be reported with their spectra. For all compounds below the CRQL report the actual value followed by a "J", e.g., "3J."

5.14.4.4 Ions present in the reference spectrum but not in the sample spectrum should be reviewed for possible subtraction from the sample spectrum because of background contamination or coeluting compounds. Data system library reduction programs can sometimes create these discrepancies.

NOTE: If a compound cannot be verified by all of the above criteria, but in the technical judgment of the mass spectral interpretation specialist, the identification is correct, then the Contractor shall report that identification and proceed with quantification.

5.14.5 Guidelines for Making Tentative Identification

5.14.5.1 A library search shall be executed for non-target sample components for the purpose of tentative identification. For this purpose, the 1990 (or more recent) release of the NIST Library, containing 50,000 spectra, shall be used. Computer generated library search routines must not use normalization routines that would misrepresent the library or unknown spectra when compared to each other.

5.14.5.2 Up to 10 VOCs of greatest apparent concentration not listed in Table D/VC-1 shall be tentatively identified via a forward search of the NIST Library. Only after visual comparison of sample spectra with the nearest library searches will the mass spectral interpretation specialist assign a tentative identification using the

following guidelines:

5.14.5.2.1 Characteristic ions in the reference spectrum (ions greater than 10% of the most abundant ion) should be present in the sample spectrum.

5.14.5.2.2 The relative intensities of the major ions should agree within ±20 percent. (Example: For an ion with an abundance of 50 percent of the standard spectra, the corresponding sample ion abundance must be between 30 and 70 percent.)

5.14.5.2.3 Ions present in the sample spectrum but not in the reference spectrum should be reviewed for possible background contamination or presence of coeluting compour s.

5.14.5.2.4 Ions present in the reference spectrum but not in the sample spectrum should be reviewed for possible subtraction from the sample spectrum because of background contamination or coeluting compounds. Data system library reduction programs can sometimes create these discrepancies.

NOTE: If in the technical judgment of the mass spectral interpretation specialist, no valid tentative identification can be made, the compound should be reported as unknown. The mass spectral specialist should give additional classification of the unknown compound if possible (i.e., unknown aromatic, unknown hydrocarbon, unknown acid type, unknown chlorinated compound). If probable molecular weights can be distinguished, include them.

5.15 QUANTITATIVE ANALYSIS

5.15.1 Target Compounds

5.15.1.1 Target compounds identified shall be quantified by the internal standard method using the SICP area of the characteristic ions of analytes listed in Table D/VC-3.

5.15.1.2 The relative response factor (RRF) from the daily calibration standard analysis or from the mid level standard, if samples are analyzed in the same 12-hour time period as the initial calibration, is used to calculate the concentration in the sample. The equation for determining concentration is provided in section 5.12.4.

5.15.2 Non-Target Compounds

5.15.2.1 An estimated concentration for non-target components that are tentatively identified shall be quantified by the internal standard method. For quantification, the nearest internal standard

free of interferences shall be used.

5.15.2.2 The formula for calculating concentrations is the same as in section 5.12.4. Total area counts (or peak heights) from the total ion chromatograms are to be used for both the compound to be measured and the internal standard. An RRF of 1 is to be assumed. The value from this quantitation shall be qualified as estimated (i.e., flagged "J"). This estimated concentration should be calculated for all tentatively identified compounds as well as those identified as unknowns.

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6 REQUIREMENTS FOR DEMONSTRATING METHOD ACCEPTABILITY FOR VOC ANALYSIS FROM CANISTERS

There are three performance criteria which must be met for a laboratory to demonstrate that its analysis method of choice can successfully perform VOC analysis on air samples. Criteria are established for: the method detection limit, replicate precision, and audit accuracy. These criteria are a detection limit of ≤5 ppbv, replicate precision within 25 percent, and audit accuracy within 30 percent for concentrations normally expected in ambient air. Specific criteria for each compound on the Target Compound List must be met by the participating laboratories. These criteria were established using monitoring data from the Toxics Air Monitoring System (TAMS) Network and the Urban Air Toxics Monitoring Program (UATMP) network. The primary reason to base the acceptability of analysis method on performance is to allow systems currently being used for the analysis of VOCs in water to be used for VOCs in air. Essentially these analytical systems would be used for analysis of an ambient air stream instead of the carrier air stream from a purge and trap system. Details for the determination of each of the criteria follow.

6.1 METHOD DETECTION LIMIT

The procedure chosen to define the method detection limit is that given in 40CFR136 Appendix B. The method detection limit is defined by each laboratory by making seven replicate measurements of a concentration of the compound of interest near (within a factor of five) the expected detection limit, computing the standard deviation for the seven replicate concentrations, and multiplying this value by 3.14 (the Student's t value for 99 percent confidence for 7 values). Employing this method, the detection limits given in Table D/VC-4 were obtained for some of the VOCs on the Target Compound List.

6.2 REPLICATE PRECISION

6.2.1 The measure of precision used for this program is the absolute value of the relative difference between replicate measurements of the same sample expressed as a percentage as follows:

$$\textit{percent difference} = \frac{|x_1 - x_2|}{\bar{x}} \times 100 \qquad \text{Eq. D/VC-26}$$

where: x_1 = first measurement value;
x_2 = second measurement value; and
$\bar{x}$ = average of the two values.

6.2.2 There are several factors which may affect the precision of the measurement. The nature of the compound of interest itself may have some effect on the precision, such as the observation that styrene generally shows slightly poorer precision than the bulk of nonpolar VOCs. The

primary influence on precision is the concentration level of the compound of interest in the sample, i.e., the precision degrades as the concentration approaches the detection limit. A "best case" measure of replicate precision was found to be within 6-7 percent for replicate calibration samples at the 10 ppbv level. A more conservative measure was obtained from replicate analysis of "real world" canister samples from the TAMS and UATMP networks. These data are given in Table D/VC-5. The information presented in Table D/VC-5 was used to determine the replicate precision value of 25 percent as a goal to be achieved for each of the target compounds.

6.3 AUDIT ACCURACY

6.3.1 A measure of analytical accuracy is the degree of agreement with audit standards. Audit accuracy is defined as the relative difference between the measurement result and the nominal concentration of the audit compound;

$$\textit{Audit Accuracy, \%} = \frac{\textit{Spiked Value - Observed Value}}{\textit{Spiked Value}} \times 100 \quad \text{Eq. D/VC-27}$$

6.3.2 Audit standards will be supplied to the participating laboratories, these audit standards analyzed, and the results used to obtain audit accuracy values. Audit accuracy values will be compared to similar values obtained from network data. Audit accuracy results for TAMS and UATMP analyses are summarized in Table D/VC-6. These values form the basis for a selection of 30 percent as the performance criterion for audit accuracy.

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TABLE D/VC-1. TARGET COMPOUND LIST (TCL) AND CONTRACT REQUIRED QUANTITATION LIMITS (CRQL) FOR VOLATILES COLLECTED IN CANISTERS

Compound	CAS RN	CRQL, ppbv
Acetone	67-64-1	5
Acetonitrile	75-05-8	5
Acrolein	107-02-8	5
Acrylonitrile	107-13-1	5
Benzene	71-43-2	2
Benzyl chloride	100-44-7	5
Bromodichloromethane	75-27-4	2
Bromomethane	74-83-9	5
1,3-Butadiene	106-99-0	5
2-Butanone	78-93-3	5
Carbon tetrachloride	56-23-5	2
Chlorobenzene	108-90-7	2
Chlorodifluoromethane	75-45-6	2
Chloroethane	75-00-3	2
Chloroform	67-66-3	2
Chloromethane	74-87-3	2
3-Chloro-1-propene	107-05-1	2
Dibromochloromethane	124-48-1	2
1,2-Dibromoethane	106-93-4	2
1,2-Dichlorobenzene	95-50-1	2
1,3-Dichlorobenzene	541-73-1	5
1,4-Dichlorobenzene	106-46-7	5
Dichlorodifluoromethane	75-71-8	2
1,1-Dichloroethane	75-34-3	2
1,2-Dichloroethane	107-06-2	2
1,1-Dichloroethene	75-35-4	5
cis-1,2-Dichloroethene	156-59-2	2
trans-1,2-Dichloroethene	156-60-5	2
1,2-Dichloropropane	78-87-5	2
cis-1,3-Dichloropropene	10061-01-5	2
trans-1,3-Dichloropropene	10061-02-6	2
1,2-Dichloro-1,1,2,2-tetrafluoroethane	76-14-2	2
Ethyl benzene	100-41-4	2
Heptane	142-82-5	2
Hexachlorobutadiene	87-68-3	5
Hexane	110-54-3	2

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TABLE D/VC-1. TARGET COMPOUND LIST (TCL) AND CONTRACT REQUIRED QUANTITATION LIMITS (CRQL) FOR VOLATILES COLLECTED IN CANISTERS
(continued)

Compound	CAS RN	CRQL ppbv
Methanol	167-56-1	5
Methylene chloride	75-09-2	5
Methyl methacrylate	80-62-6	2
4-Methyl-2-pentanone	108-10-1	5
alpha-Methyl styrene	98-83-9	5
Octane	111-65-9	2
n-Pentane	109-66-0	2
Propylene	115-07-1	5
Styrene	100-42-5	5
1,2,4-Trichlorobenzene	120-82-1	2
1,1,1-Trichloroethane	71-55-6	5
1,1,2-Trichloroethane	79-06-5	5
1,1,2,2-Tetrachloroethane	79-43-5	2
Tetrachloroethylene	127-18-4	5
Toluene	108-88-3	5
Trichloroethylene	79-01-6	2
Trichlorofluoromethane	75-69-4	2
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	2
1,2,4-Trimethylbenzene	95-63-6	2
1,3,5-Trimethylbenzene	108-67-8	2
Vinyl acetate	108-05-4	5
Vinyl chloride	75-01-4	2
Xylenes, m- and p-	1330-20-7	5
Xylene, o-	95-47-6	5

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TABLE D/VC-2. REQUIRED BFB KEY IONS AND ION ABUNDANCE CRITERIA

Mass	Ion Abundance Criteria
50	8.0 to 40.0 percent of m/e 95
75	30.0 to 66.0 percent of m/e 95
95	base peak, 100 percent relative abundance
96	5.0 to 9.0 percent of m/e 95 (See note)
173	less than 2.0 percent of m/e 174
174	50.0 to 120.0 percent of m/e 95
175	4.0 to 9.0 percent of m/e 174
176	93.0 to 101.0 percent of m/e 174
177	5.0 to 9.0 percent of m/e 176

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NOTE: All ion abundances must be normalized to m/z 95, the nominal base peak, even though the ion abundance of m/z 174 may be up to 120 percent that of m/z 95.

TABLE D/VC-3. QUANTITATION IONS FOR TARGET COMPOUNDS

Target Compound	Primary Ion*	Secondary Ions
Acetone+,°	43	58
Acetonitrile+,°	41	40
Acrolein	27	56, 25, 55, 28
Acrylonitrile+,°	53	26, 53, 52, 51
Benzene+,°	78	77, 50
Benzyl chloride°	91	126
Bromodichloromethane	83	85
Bromomethane+,°	94	96
1,3-Butadiene+	39	54, 27, 53, 28
2-Butanone+,°	72	57
Carbon tetrachloride+,°	117	119
Chlorobenzene+,°	112	77,114
Chlorodifluoromethane	51	31
Chloroethane°	64	29, 27
Chloroform+,°	83	85, 47
Chloromethane°	50	52
3-Chloro-1-propene°	41	39, 76
Dibromochloromethane	129	208, 206
1,2-Dibromoethane+,°	107	109, 27
1,2-Dichlorobenzene°	146	148, 111
1,3-Dichlorobenzene°	146	148, 111
1,4-Dichlorobenzene°	146	148, 111
Dichlorodifluoromethane+,°	85	87
1,1-Dichloroethane°	63	27, 65
1,2-Dichloroethane+,°	62	27, 64
1,1-Dichloroethene+,°	61	96, 63
cis-1,2-Dichloroethene°	61	96, 98
trans-1,2-Dichloroethene	61	96, 98
1,2-Dichloropropane+,°	63	41, 62
cis-1,3-Dichloropropene°	75	39, 77
trans-1,3-Dichloropropene°	75	39, 77
1,2-Dichloro-1,1,2,2-tetrafluoroethane+,°	85	135, 87
Ethyl benzene+,°	91	106

*The primary ion should be used unless interferences are present, in which case a secondary ion may be used.

+NIST certified gaseous standards are available for these compounds.

°Gaseous standards prepared gravimetrically using NIST traceable weights are available for these compounds.

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TABLE D/VC-3. QUANTITATION IONS FOR TARGET COMPOUNDS
(continued)

Target Compound	Primary Ion*	Secondary Ions
Heptane	43	41, 57, 71, 29
Hexachlorobutadiene°	225	227, 223
Hexane	57	43, 41, 29, 27
Methanol°	31	32, 29
Methylene chloride+,°	49	84, 86
Methyl methacrylate°	41	39, 69, 100
4-Methyl-2-pentanone	43	58, 100
alpha-Methyl styrene	118	117, 103, 78, 115
Octane	43	41, 29, 57, 85
n-Pentane	43	42, 41, 27, 29
Propylene	41	42, 39, 40, 27
Styrene°	104	78, 103
1,1,2,2-Tetrachloroethane°	83	85
Tetrachloroethene+,°	164	129, 131,166
Toluene+,°	91	92
1,2,4-Trichlorobenzene°	180	182, 184
1,1,1-Trichloroethane+,°	97	99, 61
1,1,2-Trichloroethane°	97	83, 61
Trichloroethene+,°	130	132, 95
Trichlorofluoromethane+,°	101	103
1,1,2-Trichloro-1,2,2-trifluoroethane+,°	151	101, 103
1,2,4-Trimethylbenzene°	105	120
1,3,5-Trimethylbenzene°	105	120
Vinyl acetate	43	86
Vinyl chloride+,°	62	27, 64
Xylenes, o-, m-, and p-°	91	106

*The primary ion should be used unless interferences are present, in which case a secondary ion may be used.

+NIST certified gaseous standards are available for these compounds.

°Gaseous standards prepared gravimetrically using NIST traceable weights are available for these compounds.

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TABLE D/VC-4. METHOD DETECTION LIMITS (MDL)*

TO-14 List	Lab #1, SCAN	Lab #2, SIM	MDL, ppbv
Benzene	0.34	0.29	0.4
Benzyl Chloride	--	--	--
Carbon tetrachloride	0.42	0.15	0.5
Chlorobenzene	0.34	0.02	0.4
Chloroform	0.25	0.07	0.3
m-Dichlorobenzene	0.36	0.07	0.4
1,2-Dibromoethane	--	0.08	0.3
p-Dichlorobenzene	0.70	0.12	0.7
o-Dichlorobenzene	0.44	--	0.5
1,1-Dichloroethane	0.27	0.05	0.3
1,2-Dichloroethane	0.24	--	0.3
1,1-Dichloroethene	--	0.22	1.1
cis-1,2-Dichloroethene	--	0.06	0.3
Dichloromethane	1.38	0.84	1.4
1,2-Dichloropropane	0.21	--	0.3
cis-1,3-Dichloropropene	0.36	--	0.4
trans-1,3-Dichloropropene	0.22	--	0.3
Ethylbenzene	0.27	0.05	0.3
Ethyl Chloride	0.19	--	0.2
4-Ethyltoluene	--	--	--
Freon 11	--	--	--
Freon 113	--	--	--
Freon 114	--	--	--
Freon 12	--	--	--
Hexachlorobutadiene	--	--	--
Methyl Bromide	0.53	--	0.6
Methyl Chloride	0.40	--	0.4
Styrene	1.64	0.06	1.7
1,1,2,2-Tetrachloroethane	0.28	0.09	0.3
Tetrachloroethylene	0.75	0.10	0.8
Toluene	0.99	0.20	1.0
1,2,4-Trichlorobenzene	--	--	--
1,1,1-Trichloroethane	0.62	0.21	0.7
1,1,2-Trichloroethane	0.50	--	0.5
Trichloroethene	0.45	0.07	0.5
1,2,4-Trimethylbenzene	--	--	--
1,3,5-Trimethylbenzene	--	--	--
Vinyl Chloride	0.33	0.48	0.4
m,p-Xylene	0.76	0.08	0.8
o-Xylene	0.57	0.28	0.6

*Method Detection Limits (MDLs) are defined as the product of the standard deviation of seven replicate analyses and the student's "t" test value for 99% confidence. For Lab #2, the MDLs represent an average over four studies. MDLs are for MS/SCAN for Lab #1 and for MS/SIM for Lab #2. For those compounds measured by SIM but not by SCAN, the SIM MDL has been multiplied by a factor of 5 and this value has been used as a substitute SCAN MDL. The resultant list of MDLs are given in the last column. Ten of the compounds have no listed MDLs.

TRIAL

TABLE D/VC-5. SUMMARY OF EPA DATA ON REPLICATE PRECISION (RP) FROM EPA NETWORK OPERATIONS*

Monitoring Compound Identification	Urban Air Toxics Monitoring Program (UATMP)			Toxics Air Monitoring Stations (TAMS)		
	%RP	#	ppbv	%RP	#	ppbv
Freon 12	--		--	13.9	47	0.9
Dichloromethane	16.3	07	4.3	19.4	47	0.6
1,2 Dichloroethane	36.2	31	1.6	--	--	--
1,1,1 Trichloroethane	14.1	44	1.0	10.6	47	2.0
Benzene	12.3	56	1.6	4.4	47	1.5
Trichloroethene	12.8	08	1.3	--	--	--
Toluene	14.7	76	3.1	3.4	47	3.1
Tetrachloroethene	36.2	12	0.8	--	--	--
Chlorobenzene	20.3	21	0.9	--	--	--
Ethylbenzene	14.6	32	0.7	5.4	47	0.5
m,p-Xylene	14.7	75	4.0	5.3	47	1.5
Styrene	22.8	59+	1.1	8.7	47	0.2+
o-Xylene	--		--	6.0	47	0.5
m-Dichlorobenzene	49.1	06	0.6	--	--	--
p-Dichlorobenzene	14.7	14	6.5	--	--	--

* # denotes the number of replicate or duplicate analysis used to generate the statistic. The replicate precision is defined as the mean ratio of absolute difference to the average value.

\+ Styrene and o-Xylene coelute from the GC column used in UATMP. For the TAMS entries, both values were below detection limits for 18 of 47 replicates and were not included in the calculation.

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TABLE D/VC-6. AUDIT ACCURACY (AA) VALUES* FOR SELECTED TO-14 COMPOUNDS

Selected Compounds From TO-14 List	FY-88 TAMS AA(%), N=30	FY-88 UATMP AA(%), N=3
Vinyl chloride	4.6	17.9
Methyl bromide	--	6.4
Freon 11	6.4	--
Dichloromethane	8.6	31.4
Chloroform	--	4.2
1,2-Dichloroethane	6.8	11.4
1,1,1-Trichloroethane	18.6	11.3
Benzene	10.3	10.1
Carbon tetrachloride	12.4	9.4
1,2-Dichloropropane	--	6.2
Trichloroethene	8.8	5.2
Toluene	8.3	12.5
Tetrachloroethylene	6.2	--
Chlorobenzene	10.5	11.7
Ethylbenzene	12.4	12.4
o-Xylene	16.2	21.2

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* Audit accuracy is defined as the average of multiple determinations of the absolute difference between the audit measurement result and its nominal value divided by the audit value. N denotes the number of audits averaged to obtain the audit accuracy value. Information is not available for other TO-14 compounds because they were not present in the audit materials.

TABLE D/VC-7. LABORATORY CONTROL SAMPLE (LCS) PERCENT RECOVERY LIMITS

LCS Compound	Percent recovery Limits
Benzene	60-140
Bromoform	60-140
Carbon tetrachloride	60-140
1,2-Dibromoethane	60-140
1,4-Dichlorobenzene	60-140
1,2-Dichloroethane	60-140
1,2-Dichloropropane	60-140
cis-1,3-Dichloropropene	60-140
Tetrachloroethylene	60-140
1,1,2-Trichloroethane	60-140
Trichloroethylene	60-140
Vinyl chloride	60-140

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TABLE D/VC-8. CORRESPONDING INTERNAL STANDARDS FOR SOME VOLATILE TARGET COMPOUNDS FOR GC/MS QUANTITATION

Bromochloromethane

Acetone
Bromomethane
2-Butanone
Chloroethane
Chloroform
Chloromethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethene
cis-1,2-Dichloroethene
trans-1,2-Dichloroethene
Methylene chloride
Vinyl chloride

1,4-Difluorobenzene

Benzene
Bromodichloromethane
Carbon tetrachloride
Dibromochloromethane
1,2-Dichloropropane
cis-1,3-Dichloropropene
trans-1,3-Dichloropropene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethylene

Chlorobenzene-d_5

Chlorobenzene
1,2-Dibromoethane
Ethylbenzene
4-Methyl-2-pentanone
Styrene
1,1,2,2-Tetrachloroethane
Tetrachloroethylene
Toluene
Xylenes, m- and p-
Xylene, o-

NOTE: For the following target compounds in the TCL, the internals standard used is the one closest in retention time to the target compound. In the future as more data become available, each target compound will be assigned a specific internal standard for quantitation.

Compound

Acetonitrile
Acrolein
Acrylonitrile
Benzyl chloride
1,3-Butadiene
Chlorodifluoromethane
3-Chloro-1-propene
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Dichlorodifluoromethane
1,2-Dichloro-1,1,2,2-tetrafluoroethane
Heptane
Hexachlorobutadiene
Hexane
Methanol
Methyl methacrylate
alpha-Methyl styrene
Octane
n-Pentane
Propylene
1,2,4-Trichlorobenzene
Trichlorofluoromethane
1,1,2-Trichloro-1,2,2-trifluoroethane
1,2,4-Trimethylbenzene
1,3,5-Trimethylbenzene
Vinyl acetate

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Figure D/VC-1

Canister Cleaning System

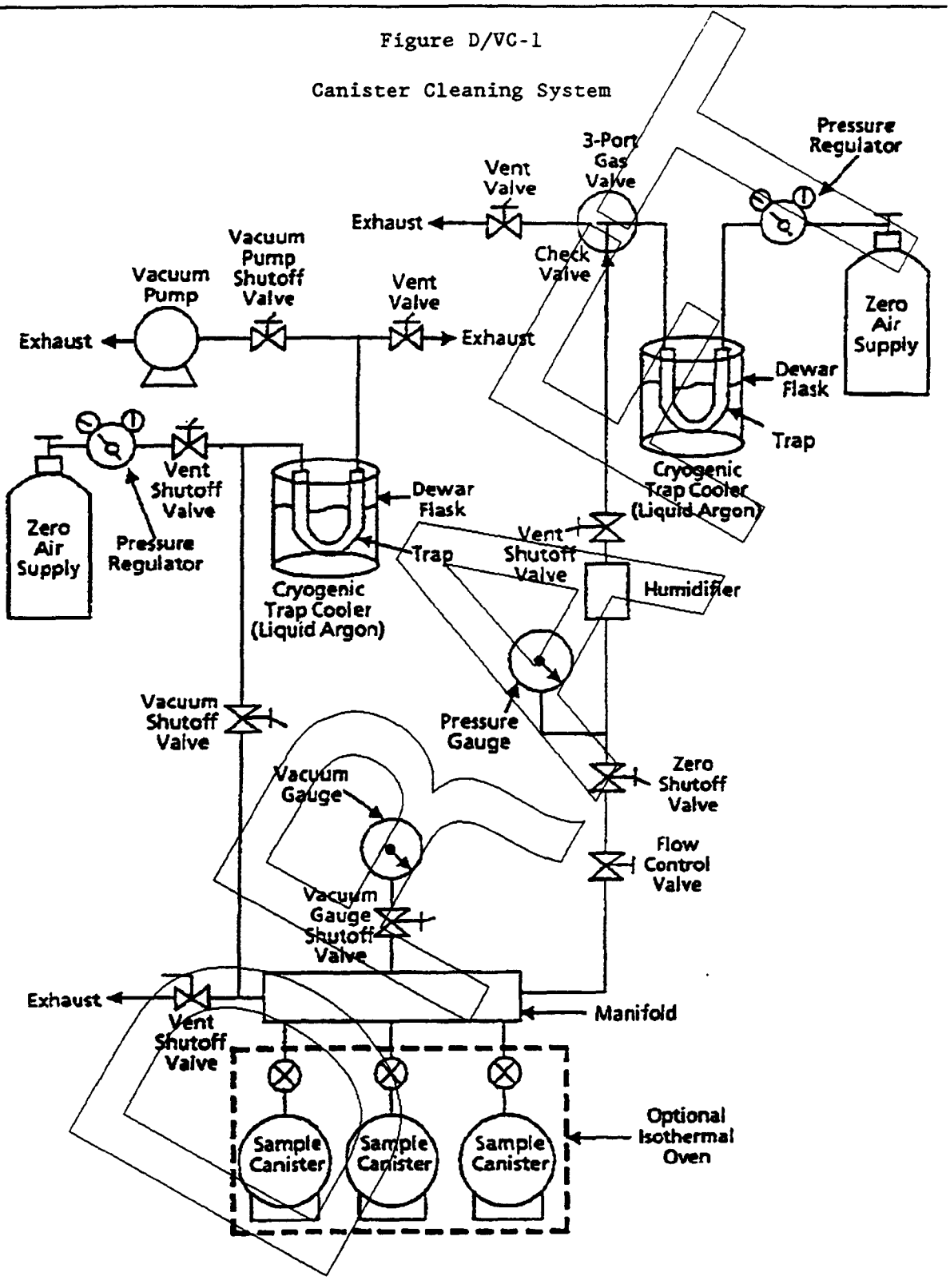


Figure D/VC-2

Alternate Canister Cleaning System

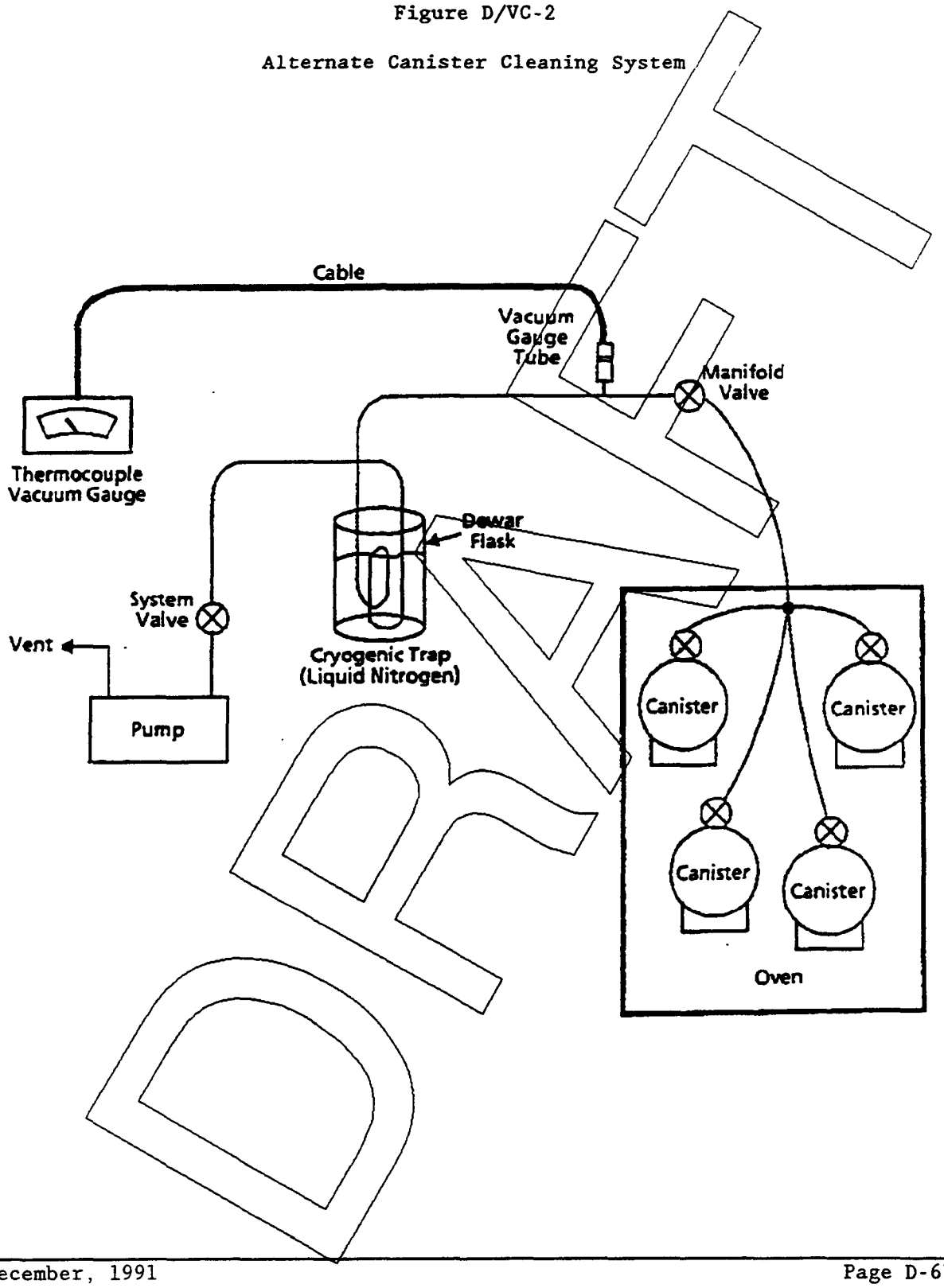
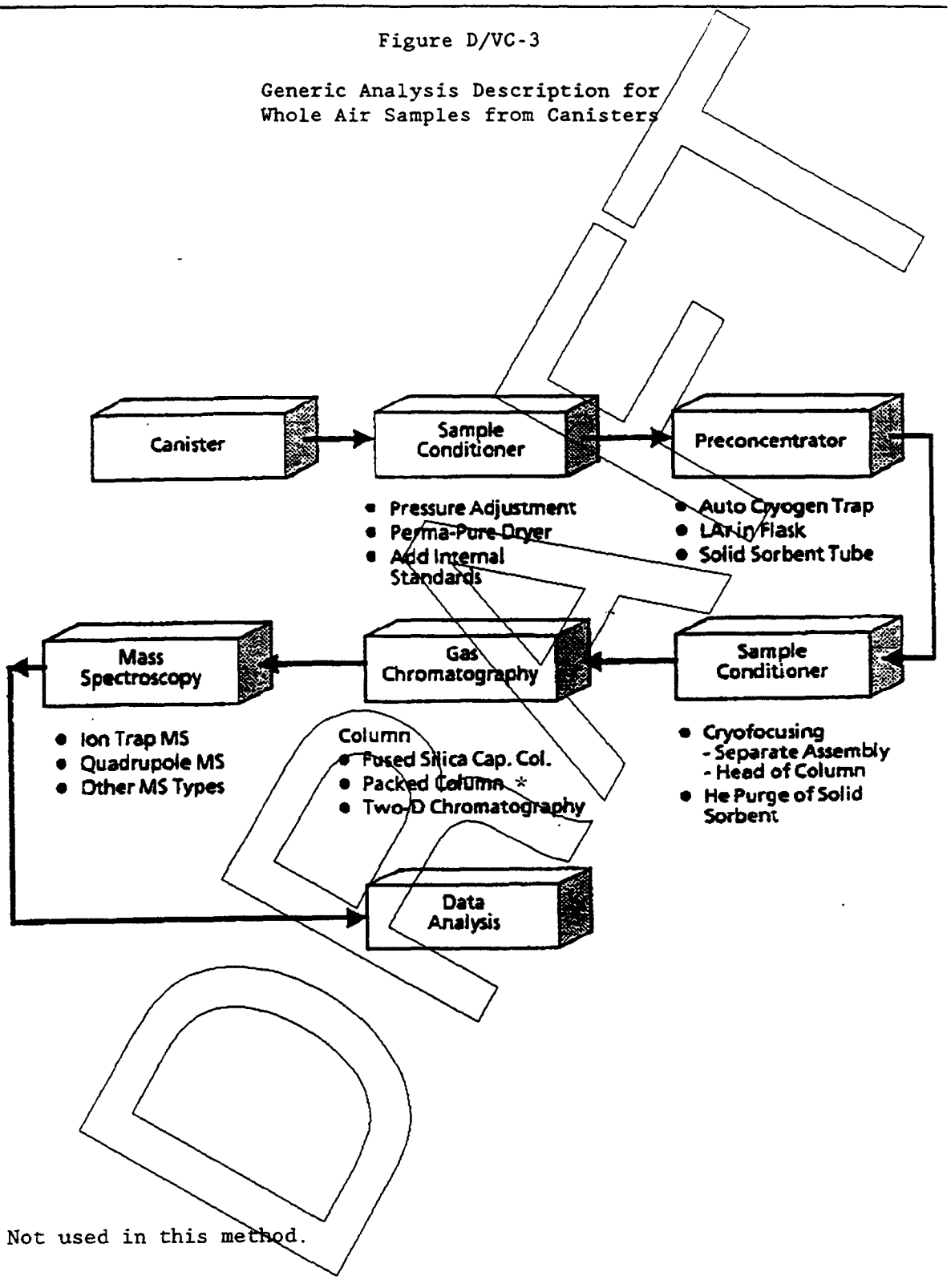


Figure D/VC-3

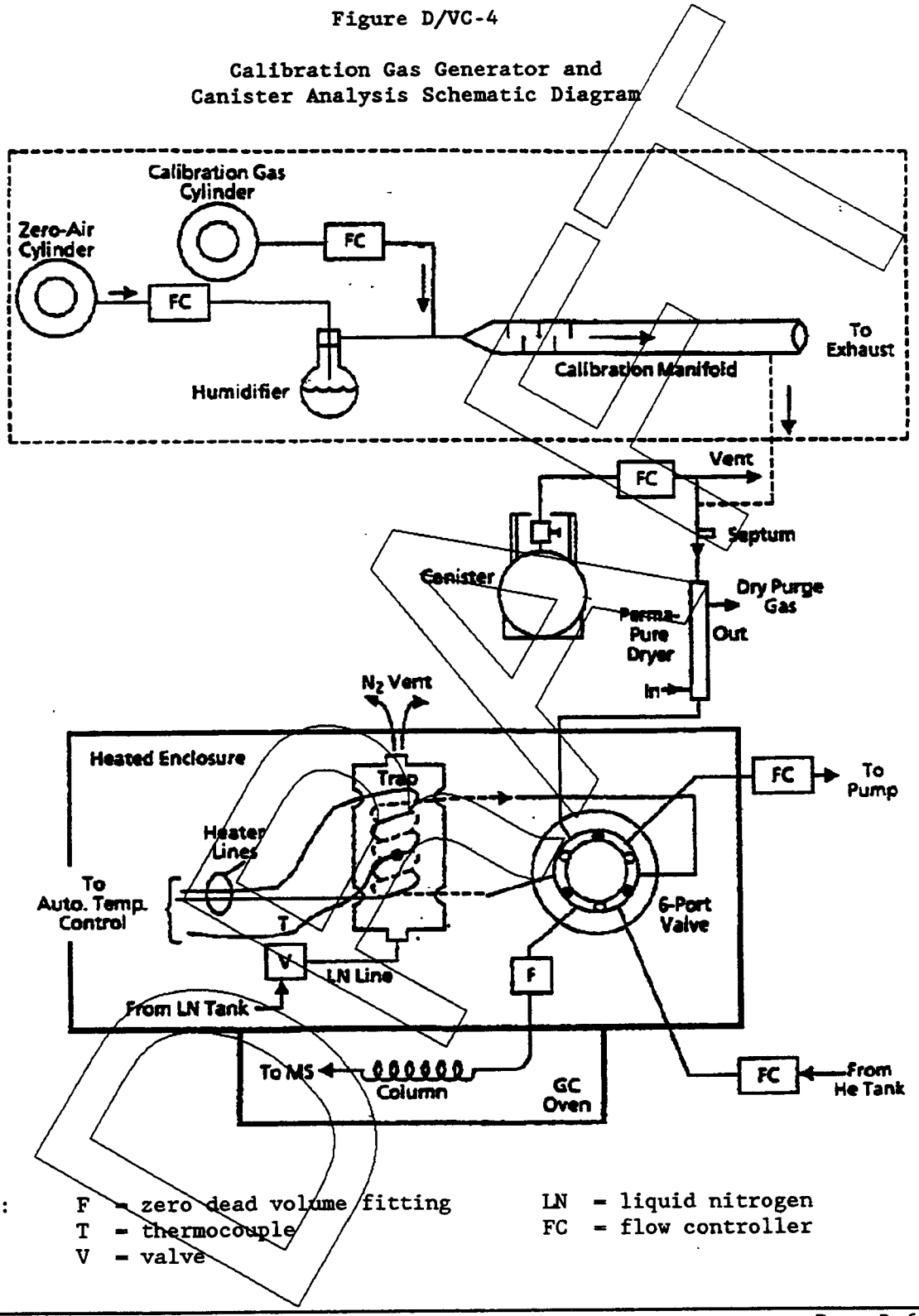
Generic Analysis Description for
Whole Air Samples from Canisters



* Not used in this method.

Figure D/VC-4

Calibration Gas Generator and
Canister Analysis Schematic Diagram



LEGEND:
F = zero dead volume fitting
T = thermocouple
V = valve
LN = liquid nitrogen
FC = flow controller

Figure D/VC-5

Canister Certification Flowchart

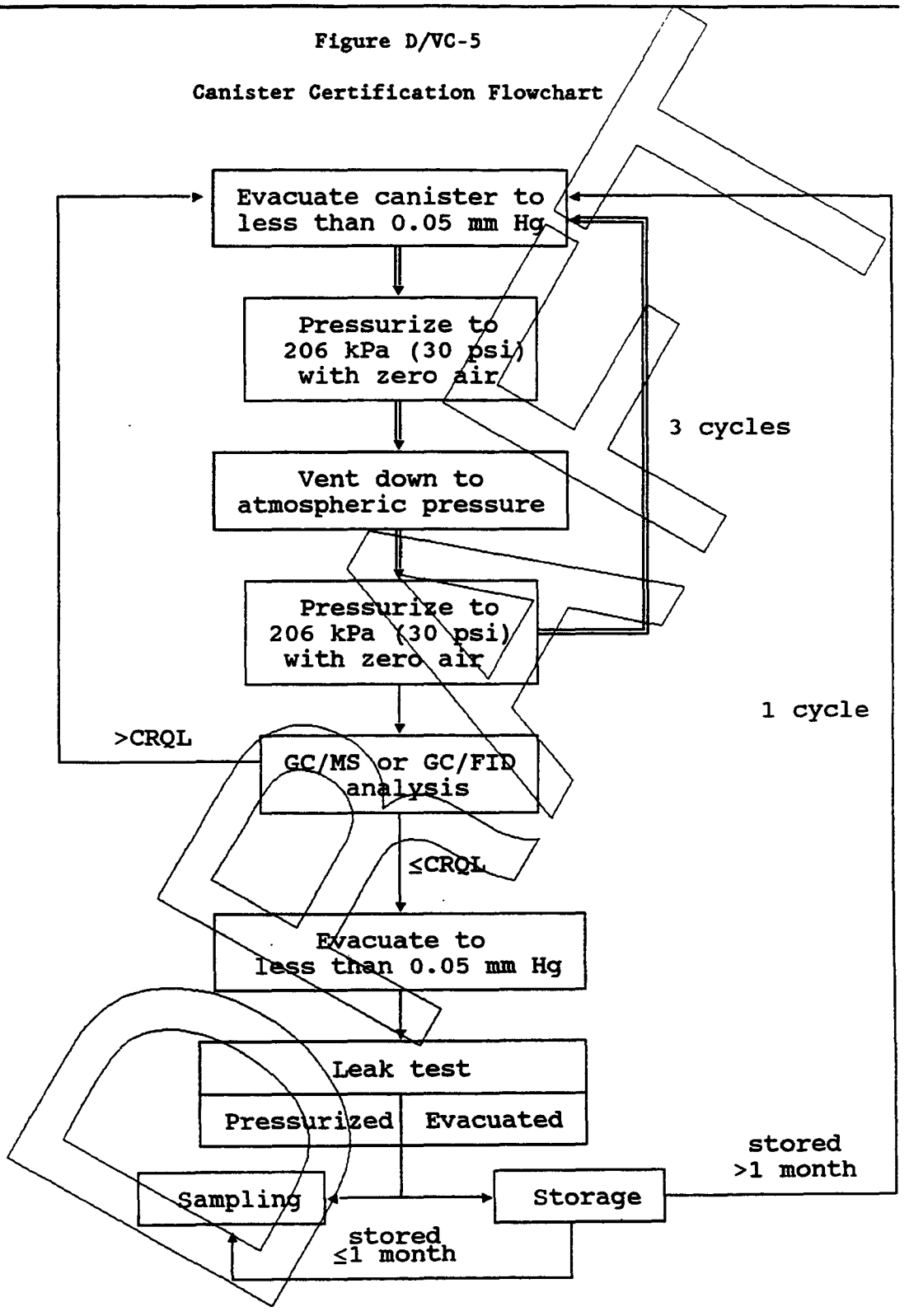
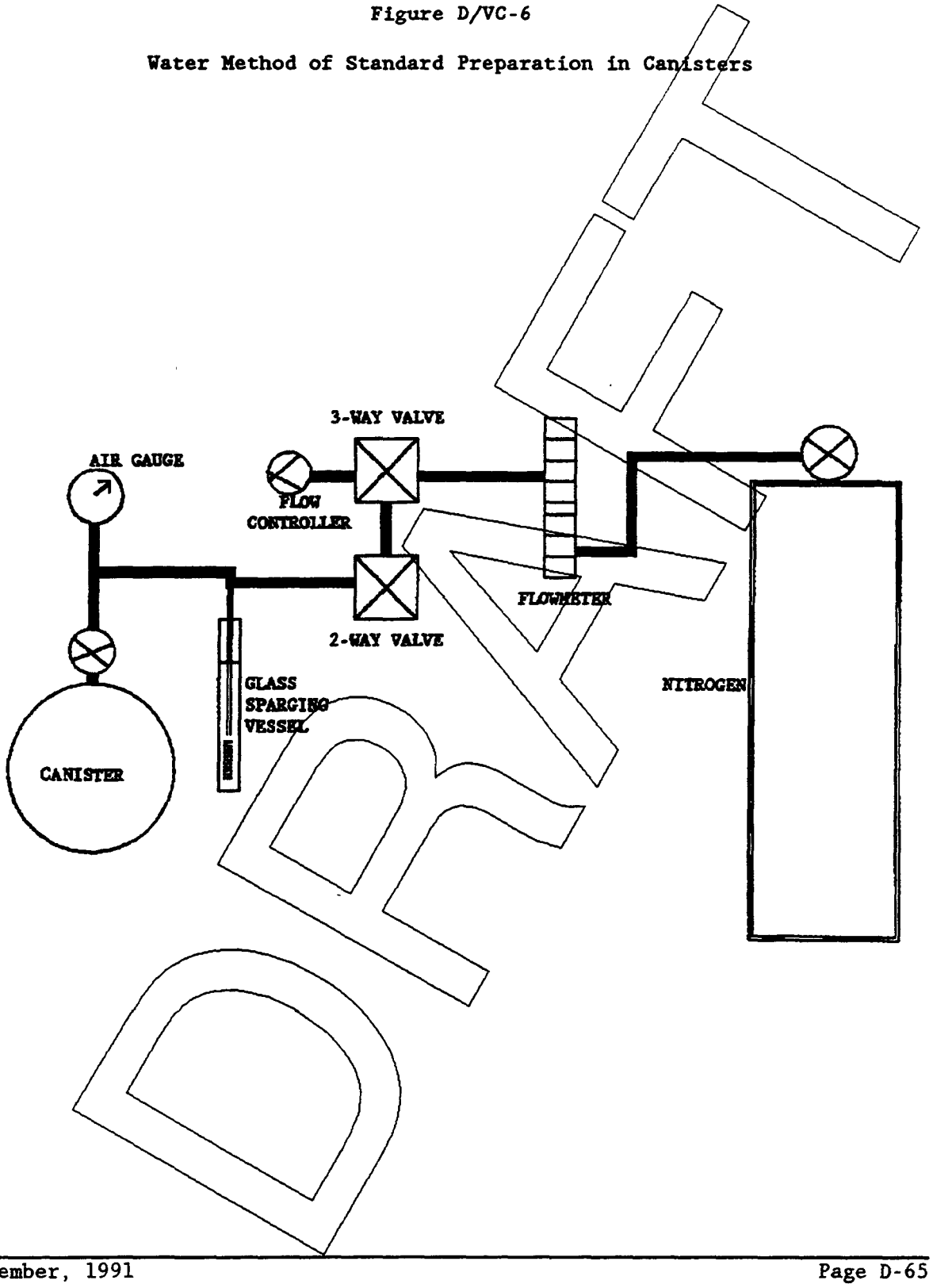


Figure D/VC-6

Water Method of Standard Preparation in Canisters



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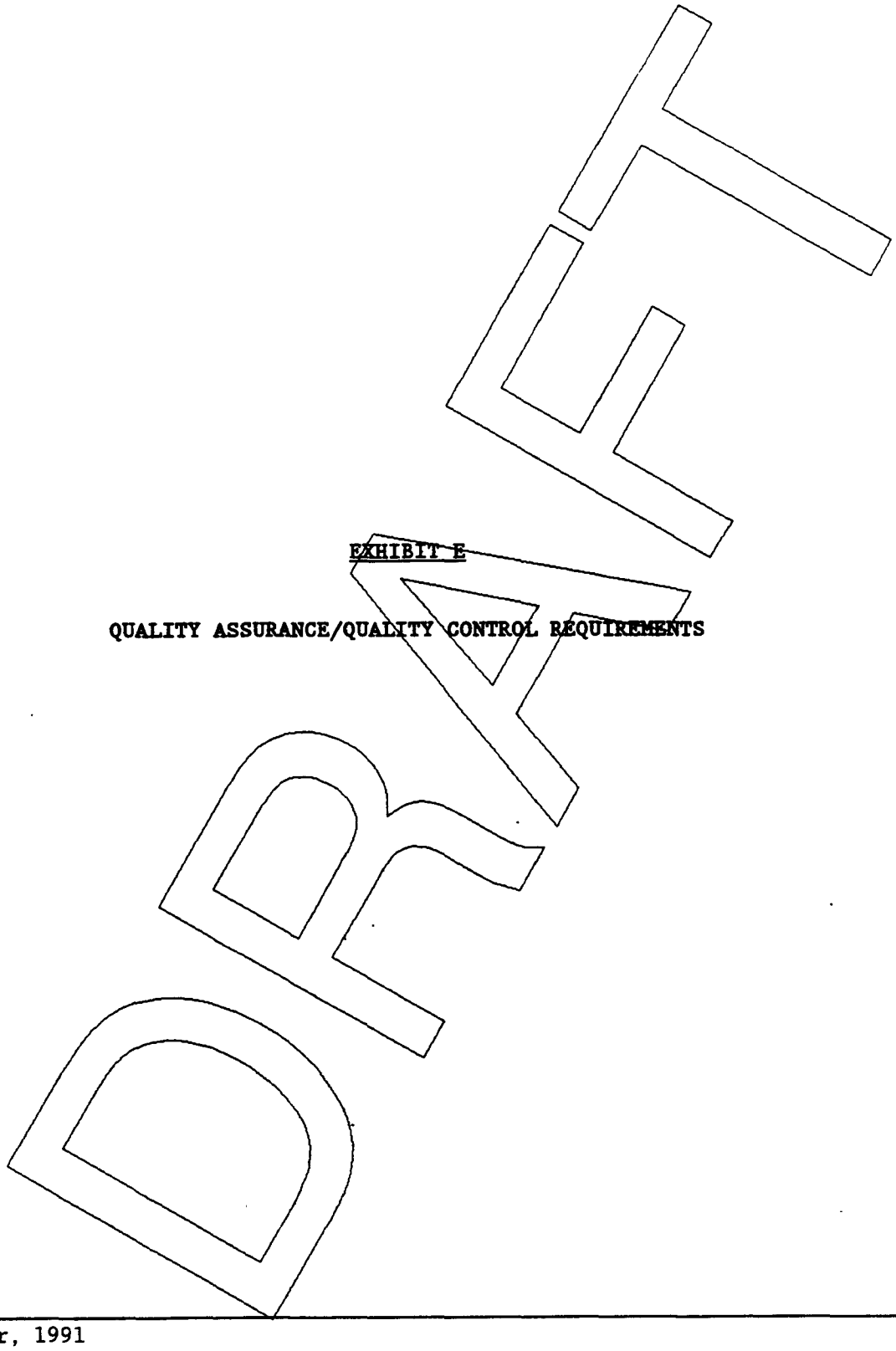

EXHIBIT E

QUALITY ASSURANCE/QUALITY CONTROL REQUIREMENTS

December, 1991

EXHIBIT E

QUALITY ASSURANCE/QUALITY CONTROL REQUIREMENTS

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SECTION 1

INTRODUCTION

1.1 Quality assurance (QA) and quality control (QC) are integral parts of EPA's Contract Laboratory Program (CLP). The CLP QA program consists of management review and oversight at the planning, implementation, and completion stages of environmental data generation activities, to ensure that data provided are of the quality required. The CLP QC program includes those activities required as part of data generation to ensure that the data are of known and documented quality.

1.2 During the planning of an environmental data collection program, QA activities focus on defining data quality objectives and criteria, and designing a QC system to measure and document the quality of data that will be generated. During the implementation of the data collection effort, QA activities ensure that the QC system is functioning effectively, and that the deficiencies uncovered by the QC system are identified and corrected. After environmental data are generated, QA activities focus on assessing the quality of data obtained to determine its suitability to support enforcement or remedial decisions.

1.3 The purpose of this Exhibit is to describe the overall QA/QC operations and the processes by which the CLP meets the QA/QC objectives defined above. This contract requires a variety of QA/QC activities. These contract requirements are the minimum QA/QC operations necessary to satisfy the analytical requirements associated with the determination of the different method analytes. These operations are designed to facilitate laboratory comparison by providing the EPA with comparable data from all Contractors. These requirements do not release the laboratory from maintaining its own QC checks on method and instrument performance.

1.4 Appropriate use of data generated under the great range of analytical conditions encountered in ambient air analyses requires reliance on the QC procedures and criteria incorporated into the methods. The methods in this contract have been validated on samples typical of those received by the laboratories participating in the CLP. However, the validation of these methods does not guarantee that they perform equally well for all samples collected under actual field conditions. Inaccuracies can result from causes such as sampling artifacts, equipment malfunctions, and human error. Therefore, the QC component of each method is indispensable.

1.5 The data acquired from QC procedures are used to estimate and evaluate analytical results and to determine the necessity for or the effect of corrective actions. The means used for evaluating the analytical results include quantitative and qualitative indicators of quality such as precision, accuracy, detection limit, and other quantitative and qualitative indicators. In addition, QC data give an overview of the activities required in an integrated program to generate environmental data of known and documented quality required to meet defined objectives.

1.6 Necessary components of a complete QA/QC program include internal QC criteria that demonstrate acceptable levels of performance, as determined by QA review. External review of data and procedures is accomplished by the monitoring activities of the National Program Office, Regional data users, Sample Management Office, NEIC, and EMSL/LV. Each external review accomplishes a different purpose. These reviews are described in specific sections of this Exhibit. Performance evaluation samples provide an external QA reference for the program. A laboratory on-site evaluation system is also part of the external QA monitoring. A feedback loop provides the results of the various review functions to the contract laboratories through direct communications with the Administrative Project Officers (APOs) and Technical Project Officers (TPOs).

1.7 This Exhibit is not a guide to constructing QA project plans, QC systems, or a QA organization. It is, however, an explanation of the QC and QA requirements of the CLP. It outlines some minimum standards for QA/QC programs. It also includes specific items that are required in a QA Plan and by the QA/QC documentation detailed in this contract. Delivery of this documentation provides the Agency with a complete data package which will stand alone, and limits the need for contact with the Contractor or with an analyst, at a later date, if some aspect of the analysis is questioned.

1.8 To ensure that the product delivered by the Contractor meets the requirements of the contract and to improve interlaboratory data comparison, the Agency requires the following from the Contractor.

1.8.1 Development and implementation of a QA program, and documentation of the key elements of that QA program through a written QA Plan, as described in Section 2 of this Exhibit.

1.8.2 Preparation of and adherence to written Standard Operating Procedures (SOPs) as described in Section 5 of this Exhibit.

1.8.3 Adherence to the analytical methods and associated QC requirements specified in the contract.

1.8.4 Verification of analytical standards and documentation of the purity of neat materials and the purity and accuracy of solutions obtained from private chemical houses.

1.8.5 Participation in the analysis of laboratory performance evaluation (PE) samples, including adherence to corrective action procedures.

1.8.6 Participation in on-site laboratory evaluations, including adherence to corrective action procedures.

1.8.7 Submission of all raw data and pertinent documentation for Regional review.

1.8.8 Submission, upon request, of GC/MS tapes and applicable documentation for tape audits.

1.8.9 Submission for Agency review of all original documentation generated during sample analyses.

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SECTION 2

QUALITY ASSURANCE PLANS

2.1 The Contractor shall establish a QA program with the objective of providing sound analytical chemical measurements. This program shall incorporate the QC procedures, any necessary corrective action, and all documentation required during data collection as well as the quality assessment measures performed by management to ensure acceptable data production.

2.2 As evidence of such a program, the Contractor shall prepare a written Quality Assurance Plan (QAP) which describes the procedures that are implemented to achieve the following:

2.2.1 Maintain data integrity, validity, and usability.

2.2.2 Ensure that analytical measurement systems are maintained in an acceptable state of stability and reproducibility .

2.2.3 Detect problems through data assessment and establish corrective action procedures which keep the analytical process reliable.

2.2.4 Document all aspects of the measurement process in order to provide data that are technically sound and legally defensible.

2.3 The QAP must present, in specific terms, the policies, organization, objectives, and specific QA and QC activities designed to achieve the data quality requirements in this contract. Where applicable, SOPs pertaining to each element shall be included or referenced as part of the QAP. The QAP must be available during On-Site Laboratory evaluation and upon written request by the Administrative Project Officer. Additional information relevant to the preparation of a QAP can be found in EPA and ASTM publications[2,4].

2.4 **ELEMENTS OF A QUALITY ASSURANCE PLAN**

2.4.1 The following key elements of the Contractor's quality assurance program shall be addressed in the QAP:

2.4.1.1 Contractor QA Policy and Objectives

2.4.1.2 Organization and Personnel

- QA Management;
- Organization;
- Assignment of QC and QA responsibilities; and

- Reporting relationships.

• Personnel;

- Staff resumes;
- Education and experience requirements pertinent to this Contract; and
- Training progress.

• Facilities and Equipment;

- Instrumentation and backup alternatives; and
- Maintenance activities and schedules.

• Document Control;

- Laboratory notebook policy;
- Sample and data tracking/custody procedures and documentation requirements;
- Logbook maintenance and archiving procedures;
- Case file organization, preparation, and review procedures; and
- Procedures for preparation, approval, review, revision, and distribution of SOPs.

• Analytical Methodology;

- Calibration procedures and frequency;
- Sample handling and storage procedures;
- Sample preparation procedures;
- Sample analysis procedures; and
- Standards preparation procedures.

• Data Generation;

- Data collection procedures;
- Data reduction procedures;

- Data review procedures;
- Data reporting and authorization procedures; and
- Data management procedures.

• Quality Control Program; and

- Solvent, reagent, and adsorbent check analysis;
- Reference material analysis;
- Internal QC checks; and
- Corrective action and determination of QC limit procedures.

• Quality Assurance Program Assessment.

- Data audits;
- Systems audits;
- Performance audits;
- Corrective action procedures;
- QA reporting procedures.

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SECTION 3

STANDARD OPERATING PROCEDURES

3.1 In order to obtain reliable results, adherence to prescribed analytical methodology is imperative. In any operation that is performed on a repetitive basis, reproducibility is best accomplished through the use of Standard Operating Procedures (SOPs). As defined by the EPA, an SOP is a written document that provides directions for the step-by-step execution of an operation, analysis, or action which is commonly accepted as the method for performing certain routine or repetitive tasks.

3.2 SOPs prepared by the Contractor must be functional, i.e., clear, comprehensive, up-to-date, and sufficiently detailed to permit duplication of results by qualified analysts. All SOPs, as presented to the Agency, must reflect activities as they are currently performed in the laboratory. In addition, all SOPs must:

3.2.1 Be consistent with current EPA regulations, guidelines, and the CLP contract's requirements;

3.2.2 Be consistent with instrument manufacturer's specific instruction manuals;

3.2.3 Be available to the EPA during an On-Site Laboratory Evaluation. A complete set of SOPs shall be bound together and available for inspection at such evaluations. During On-Site evaluations, laboratory personnel may be asked to demonstrate the application of the SOPs;

3.2.4 Provide for the development of documentation that is sufficiently complete to record the performance of all tasks required by the protocol;

3.2.5 Describe the mechanism for demonstrating the validity of data reported by the Contractor and explaining the cause of missing or inconsistent results;

3.2.6 Describe the corrective measures and feedback mechanism used when analytical results do not meet protocol requirements;

3.2.7 Be reviewed regularly and updated as necessary when contract, facility, or Contractor procedural modifications are made;

3.2.8 Be archived for future reference in usability or evidentiary situations;

3.2.9 Be available at specific work stations as appropriate; and

3.2.10 Be subject to a document control procedure which precludes the use of outdated or inappropriate SOPs.

3.3 SOP SPECIFICATIONS AND FORMAT

3.3.1 An SOP is defined as a written narrative step-by-step description of laboratory operating procedures including examples of laboratory documentation. The SOPs must accurately describe the actual procedures used in the laboratory, and copies of the written SOPs shall be available to ensure that analytical data produced under this contract are acceptable for use in EPA enforcement case preparation and litigation. The Contractor's SOPs shall provide mechanisms and documentation to meet each of the following specifications and shall be used by EPA sa the basis for laboratory evidence audits.

3.3.2 The format for SOPs may vary depending upon the kind of activity for which they are prepared. However, at a minimum, the following sections must be included.

3.3.2.1 Title page.

3.3.2.2 Scope and application.

3.3.2.3 Definitions.

3.3.2.4 Procedures.

3.3.2.5 QC acceptance criteria.

3.3.2.6 Corrective Action Procedures, including procedures for secondary review of information being generated.

3.3.2.7 Documentation Description and example forms.

3.3.2.8 Miscellaneous notes and precautions.

3.3.2.9 References.

3.4 REQUIRED SOPS

3.4.1 Evidentiary SOPs

The Contractor shall develop and use adequate written SOPs to ensure sample and data accountability. Evidentiary SOPs shall include specific procedures for the following processes as they are performed by the Contractor:

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3.4.1.1 **Sample receipt and logging**

3.4.1.1.1 The Contractor shall have written SOPs for receiving and logging in the samples. The procedures shall include, documentation of the following information:

- Presence or absence of EPA chain-of-custody forms;
- Presence or absence of airbills or airbill stickers;
- Presence or absence of EPA Traffic Reports or SAS packing lists;
- Presence or absence of custody seals on shipping and/or sample containers and their condition;
- Custody seal numbers, when present;
- Presence or absence of sample tags;
- Sample tag ID numbers;
- Condition of the shipping container;
- Condition of the sample container;
- Verification of agreement or nonagreement of information on receiving documents and sample containers;
- Resolution of problems or discrepancies with SMO; and
- The definition of any terms used to describe sample condition upon receipt.

3.4.1.1.2 The Contractor shall have a designated sample custodian responsible for receipt of samples and have written SOPs describing his/her duties and responsibilities.

3.4.1.2 **Sample identification**

3.4.1.2.1 The Contractor shall have written SOPs for maintaining identification of EPA samples throughout the laboratory.

3.4.1.2.2 If the Contractor assigns unique laboratory identifiers, written SOPs shall include a description of the method used to assign the unique laboratory identifier and cross-reference to the EPA sample number.

3.4.1.2.3 If the Contractor uses prefixes or suffixes in addition to sample identification numbers, the written SOPs shall include their definitions.

3.4.1.3 Sample security

The Contractor shall have written SOPs for maintenance of the security of samples after log-in and shall demonstrate security of the sample storage and laboratory areas. The SOPs shall specifically include descriptions of all storage areas for EPA samples in the laboratory, and steps taken to prevent sample contamination. The SOPs shall include a list of authorized personnel who have access to secure storage areas.

3.4.1.4 Internal chain-of-custody of samples and data.

The Contractor shall have written SOPs for the chain-of-custody consisting of sample identification, chain-of-custody procedures, sample receiving procedures, and sample tracking procedures. For more information concerning the chain-of-custody procedures see Section 4 of this Exhibit.

3.4.1.5 Internal tracking of samples and data.

The Contractor shall have written SOPs for tracking the work performed on any particular sample. The tracking SOP shall include the following:

- A description of the documentation used to record sample receipt, sample storage, sample transfers, sample preparations, and sample analyses;
- A description of the documentation used to record instrument calibration and other QA/QC activities; and
- Examples of the document formats and laboratory documentation used in the sample receipt, sample storage, sample transfer, and sample analyses.

3.4.1.6 **Laboratory document and information control**

3.4.2 **Analytical SOPs**

The Contractor shall develop and use adequeate written SOPs to ensure that all data generated for the CLP are of known, documented, and acceptable quality. Analytical SOPs shall include specific procedures for the following processes as they are performed by the Contractor:

3.4.2.1 The Contractor shall have written SOPs for preventing sample contamination, during sample preparation, cleaning of glassware, storage, and analysis.

3.4.2.2 The Contractor shall have SOPs to ensure traceability of standards used in sample analysis QA/QC.

3.4.3 **Quality Management SOPs**

3.4.3.1 The Contractor shall have written SOPs for technical and managerial review of laboratory operation and data package preparation, laboratory data review/laboratory self inspection system. The procedures shall include but not be limited to documenting the following information:

3.4.3.1.1 Data flow and chain-of-command for data review;

3.4.3.1.2 Procedures for measuring precision and accuracy.

3.4.3.1.3 Evaluation of parameters for identifying systematic errors.

3.4.3.1.4 Procedures to assure that hardcopy deliverables are complete and compliant with the requirements in Exhibit B.

3.4.3.1.5 Demonstration of internal QA inspection procedure (demonstrated by supervisory sign-off on personal notebooks, internal PE samples, etc.).

3.4.3.1.6 Frequency and type of internal audits (e.g., random, quarterly, spot checks, perceived trouble areas).

3.4.3.1.7 Demonstration of problem identification, corrective actions, and resumption of analytical processing. Sequence resulting from internal audit (i.e., QA feedback).

3.4.3.1.8 Documentation of audit reports, (internal and external), response, corrective action, etc.

3.4.3.2 The Contractor shall have written SOPs for organization and assembly of all documents relating to each EPA Case, including technical and managerial review. Documents shall be filed on a Case-specific basis. The procedures must ensure that all documents including logbook pages, sample tracking records, chromatographic charts, computer printouts, raw data summaries, correspondence, and any other written documents having reference to the Case are compiled in one location for submission to EPA. The system must include a document numbering and inventory procedure. For more information concerning document control and case file preparation, see Section 5 of this Exhibit.

3.4.3.3 The Contractor shall have written SOPs for sample analysis, management and handling, and reporting of data. The procedures shall include but not be limited to documenting the following information:

3.4.3.3.1 Procedures for controlling and estimating data entry errors.

3.4.3.3.2 Procedures for reviewing changes to data and deliverables and ensuring traceability of updates.

3.4.3.3.3 Life cycle management procedures for testing, modifying and implementing changes to existing computing systems including hardware, software, and documentation or installing new systems.

3.4.3.3.4 Database security, backup and archival procedures including recovery from system failures.

3.4.3.3.5 System maintenance procedures and response time.

3.4.3.3.6 Individual(s) responsible for system operation, maintenance, data integrity and security.

3.4.3.3.7 Specifications for staff training procedures.

3.4.3.4 The Contractor shall have written SOPs for laboratory safety.

3.5 HANDLING OF CONFIDENTIAL INFORMATION

3.5.1 A Contractor conducting work under this contract may receive EPA-designated confidential information from the Agency. Confidential information must be handled separately from other documentation developed under this contract. To accomplish this, the following procedures for the handling of confidential information have been established.

3.5.2 All confidential documents shall be under the supervision of a designated Document Control Officer (DCO).

3.5.3 Any samples or information received with a request of confidentiality shall be handled as "confidential." A separate locked file shall be maintained to store this information and shall be segregated from other nonconfidential information. Data generated from confidential samples shall be treated as confidential. Upon receipt of confidential information, the DCO logs these documents into a Confidential Inventory Log. The information is then made available to authorized personnel but only after it has been signed out to that person by the DCO. The documents shall be returned to the locked file at the conclusion of each working day. Confidential information may not be reproduced except upon approval by the EPA Contracting Officer. The DCO will enter all copies into the document control system. In addition, this information may not be disposed of except upon approval by the EPA Contracting Officer. The DCO shall remove and retain the cover page of any confidential information disposed of for one year and shall keep a record of the disposition in the Confidential Inventory Log.

3.6 SOPS DELIVERY REQUIREMENTS

Within forty-five (45) days of contract receipt, a complete set of SOPs relevant to this contract shall be sent to the TPO, SMO and EMSL/LV. Also, during the term of performance of the contract, copies of SOPs which have been amended or new SOPs which have been written shall be sent to the TPO, EMSL/LV (quality assurance SOPs) and NEIC (evidentiary SOPs).

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SECTION 4

CHAIN-OF-CUSTODY

A sample is physical evidence collected from a facility or from the environment. An essential part of hazardous waste investigation effort is that the evidence gathered be controlled. To accomplish this, the following sample identification, chain-of-custody, sample receiving, and sample tracking procedures have been established.

4.1 SAMPLE IDENTIFICATION

4.1.1 To ensure traceability of samples while in possession of the Contractor, the Contractor shall have a specified method for maintaining identification of samples throughout the laboratory.

4.1.2 Each sample and sample preparation container shall be labeled with the EPA number or a unique laboratory identifier. If a unique laboratory identifier is used, it shall be cross-referenced to the EPA number.

4.2 CHAIN-OF-CUSTODY PROCEDURES

Because of the nature of the data being collected, the custody of EPA samples must be traceable from the time the samples are collected until they are introduced as evidence in legal proceedings. The Contractor shall have procedures ensuring that EPA sample custody is maintained and documented. A sample is under custody if the following applies:

4.2.1 It is in your possession, or

4.2.2 It is in your view after being in your possession, or

4.2.3 It was in your possession and you locked it up, or

4.2.4 It is in a designated secure area (secure areas shall be accessible to authorized personnel only).

4.3 SAMPLE RECEIVING PROCEDURES

4.3.1 The Contractor shall designate a sample custodian responsible for receiving all samples.

4.3.2 The Contractor shall designate a representative to receive samples in the event that the sample custodian is not available.

4.3.3 The condition of the shipping containers and sample bottles shall be inspected upon receipt by the sample custodian or his/her representative.

4.3.4 The condition of the custody seals (intact/not intact) shall be inspected upon receipt by the sample custodian or his/her representative.

4.3.5 The sample custodian or his/her representative shall check for the presence or absence of the following documents accompanying the sample shipment.

4.3.5.1 Airbills or airbill stickers.

4.3.5.2 Custody seals.

4.3.5.3 EPA custody records.

4.3.5.4 EPA traffic reports or SAS packing lists.

4.3.5.5 Sample tags.

4.3.6 The sample custodian or his/her representative shall sign and date all forms (e.g., custody records, traffic reports or packing lists, and airbills) accompanying the samples at the time of sample receipt.

4.3.7 The Contractor shall contact SMO to resolve discrepancies and problems such as absent documents, conflicting information, broken custody seals, and unsatisfactory sample condition (e.g., leaking sample bottle).

4.3.8 The Contractor shall record the resolution of discrepancies and problems on Telephone Contact Logs.

4.3.9 The following information shall be recorded on appropriate Form AADC-1 by the sample custodian or his/her representative as samples are received and inspected.

4.3.9.1 Condition of the shipping container.

4.3.9.2 Presence or absence and condition of custody seals on shipping and/or sample containers.

4.3.9.3 Custody seal numbers, when present.

4.3.9.4 Condition of the sample bottles.

4.3.9.5 Presence or absence of airbills or airbill stickers.

4.3.9.6 Airbill or airbill sticker numbers.

4.3.9.7 Presence or absence of EPA custody records.

4.3.9.8 Presence or absence of EPA traffic reports or SAS packing lists.

4.3.9.9 Presence or absence of sample tags.

4.3.9.10 Sample tag identification numbers cross-referenced to the EPA sample numbers.

4.3.9.11 Verification of agreement or non-agreement of information recorded on shipping documents and sample containers.

4.3.9.12 Problems or discrepancies.

4.4 SAMPLE TRACKING PROCEDURES

The Contractor shall maintain records documenting all phases of sample handling from receipt to final analysis. The records shall include documentation of the movement of samples and prepared samples into and out of designated laboratory storage areas.

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SECTION 5

DOCUMENT CONTROL

The goal of the laboratory document control program is to assure that all documents for a specified Sample Delivery Group (SDG) will be accounted for when the project is completed. Accountable documents used by contract laboratories shall include but not be limited to logbooks, chain-of-custody records, sample work sheets, bench sheets, and other documents relating to the sample or sample analyses. The following document control procedures have been established to assure that all laboratory records are assembled and stored for delivery to the EPA or are available upon request from the EPA prior to the delivery schedule.

5.1 PREPRINTED LABORATORY FORMS AND LOGBOOKS

5.1.1 All documents produced by the Contractor which are directly related to the preparation and analysis of EPA samples shall become the property of the EPA and shall be placed in the complete sample delivery group file (CSF). All observations and results recorded by the laboratory but not on preprinted laboratory forms shall be entered into permanent laboratory logbooks. When all data from a SDG are compiled, all original laboratory forms and copies of all SDG-related logbook entries shall be included in the documentation package.

5.1.2 The Contractor shall identify the activity recorded on all laboratory documents which is directly related to the preparation and analysis of EPA samples.

5.1.3 Pre-printed laboratory forms shall contain the name of the laboratory and be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

5.1.4 Logbook entries shall be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

5.1.5 Logbook entries shall be in chronological order. Entries in logbooks, with the exception of instrument run logs and extraction logs, shall include only one SDG per page.

5.1.6 Pages in both bound and unbound logbooks shall be sequentially numbered.

5.1.7 Instrument run logs shall be maintained so as to enable a reconstruction of the run sequence of individual instruments. Because the laboratory must provide copies of the instrument run logs to the EPA,

the laboratory may exercise the option of using only laboratory or EPA sample identification numbers in the logs for sample ID rather than government agency or commercial client names to preserve the confidentiality of commercial clients.

5.1.8 Corrections to supporting documents and raw data shall be made by drawing a single line through the error and entering the correct information. Corrections and additions to supporting documents and raw data shall be dated and initialed. No information shall be obliterated or rendered unreadable. All notations shall be recorded in ink. Unused portions of documents shall be crossed out.

5.2 CONSISTENCY OF DOCUMENTATION

5.2.1 The Contractor shall assign a document control officer responsible for the organization and assembly of the CSF.

5.2.2 All copies of laboratory documents shall be complete and legible.

5.2.3 Original documents which include information relating to more than one SDG shall be filled in the CSF of the lowest SDG number. The copy(s) shall be placed in the other CSF(s) and the Contractor shall record the following information on the copy(ies) in red ink:

"COPY

ORIGINAL IS FILED IN CSF _____"

The Contractor shall sign and date this addition to the copy(ies).

5.2.4 Before releasing analytical results, the document control officer shall assemble and cross-check the information on sample tags, custody records, lab bench sheets, personal and instrument logs, and other relevant data to ensure that data pertaining to each particular sample or sample delivery group is consistent throughout the CSF.

5.3 DOCUMENT NUMBERING AND INVENTORY PROCEDURE

5.3.1 In order to provide document accountability of the completed analysis records, each item in a CSF shall be inventoried and assigned a serialized number as described in Exhibit B, Section 2.

CSF # - Region - Serialized number (For example: 75-2-0240).

5.3.2 All documents relevant to each sample delivery group, including logbook pages, bench sheets, mass spectra, chromatograms, screening records, re-preparation records, re-analysis records, records of failed or attempted analysis, custody records, library research results, etc., shall be inventoried.

5.3.3 The Document Control Officer (DCO) shall be responsible for ensuring that all documents generated are placed in the CSF for inventory and are delivered to the EPA. The DCO shall place the sample tags in plastic bags in the file. Figure E-1 is an example of a document inventory.

Figure E-1

Example

DOCUMENT INVENTORY

Document Control #*	Document Type	# Pages
232-2-0001	Case File Document Inventory Sheet	1
232-2-0002	Chain-of-Custody Records	2
232-2-0003	Shipping Manifests	2
232-2-0004	Sample Tags	50
232-2-0005	SMO Organics Traffic Reports	10
232-2-0006	Analysis Data Sheets	41
232-2-0007	Analysts' Organics Notebook Pages	14
232-2-0008	GC/MS and GC Instrument Logbook Pages	12
etc.	etc.	etc.

*This number is to be recorded on each set of documents.

5.4 STORAGE OF EPA FILES

The Contractor shall maintain EPA laboratory documents in a secure location.

5.5 SHIPPING DATA PACKAGES AND CSF

5.5.1 The Contractor shall document shipment of deliverables packages to the recipients. These shipments require custody seals on the containers placed such that they cannot be opened without damaging or breaking the seal. The Contractor shall document what was sent, to whom, the date, and the method (carrier) used.

5.5.2 The Contractor shall purge the CSF deliverable to the appropriate EPA Region 180 days after the report submission.

5.5.3 A copy of the transmittal letter for the CSF will be sent to the NEIC and the SMO.

5.5.4 The Document Control form is used to document the receipt and inspection of shipping containers and samples. The Contractor shall submit one (1) original FORM AADC-1 for each shipping container.

5.5.5 The Contractor shall sign and date the airbill (if present), examine the shipping containers, record the presence or absence of custody seals and their conditions.

5.5.6 The Contractor shall note any problems with the samples and follow the instructions explained in Exhibit B, Sample Log-In Sheet.

5.5.7 The Contractor shall submit a completed Document Control Form with each SDG package.

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SECTION 6

ANALYTICAL STANDARDS REQUIREMENTS

The U.S. Environmental Protection Agency will not supply analytical reference standards either for direct analytical measurements or for the purpose of traceability. All contract laboratories will be required to prepare from neat materials, from cylinders of compressed gases traceable to NIST Standard Reference Materials or NIST/EPA approved certified reference material, or purchase from private chemical supply houses those standards necessary to successfully and accurately perform the analyses required in this protocol.

6.1 PREPARATION OF CHEMICAL STANDARDS FROM THE NEAT HIGH PURITY BULK MATERIAL

6.1.1 A laboratory may prepare their chemical standards from neat materials. Commercial sources for neat chemical standards pertaining to analytes listed on the TCL are given in Appendix C of the "Quality Assurance Materials Bank: Analytical Reference Standards," Seventh Edition, January 1988. Laboratories should obtain the highest purity possible when purchasing neat chemical standards; standards purchased at less than 98% purity must be documented as to why a higher purity could not be obtained.

6.1.2 Neat chemical standards must be kept refrigerated when not being used in the preparation of standard solutions. Proper storage of neat chemicals is essential in order to safeguard them from decomposition.

6.1.3 The purity of a compound can sometimes be misrepresented by a chemical supply house. Since knowledge of purity is needed to calculate the concentration of solute in a solution standard, it is the contract laboratory's responsibility to have analytical documentation ascertaining that the purity of each compound is correctly stated. Purity confirmation, when performed, should use either differential scanning calorimetry, gas chromatography with flame ionization detection, high performance liquid chromatography, infrared spectrometry, or other appropriate techniques. Use of two or more independent methods is recommended. The correction factor for impurity when weighing neat materials in the preparation of solution standards is:

$$\text{Wt. of impure compound} = \frac{\text{Wt. of pure compound}}{\left(\frac{\text{percent purity}}{100}\right)} \quad \text{Eq. E-1}$$

where "weight of pure compound" is that required to prepare a specific volume of a solution standard of a specified concentration.

6.1.4 Mis-identification of compounds occasionally occurs and it is possible that a mislabeled compound may be received from a chemical supply house. It is the contract laboratory's responsibility to have analytical documentation confirming that all compounds used in the preparation of solution standards are correctly identified. Identification confirmation, when performed, should use GC/MS analysis on at least two different analytical columns, or other appropriate techniques.

6.1.5 Calculate the weight of material to be weighed out for a specified volume taking into account the purity of the compound and the desired concentration. A second person must verify the accuracy of the calculations. Check balances for accuracy with a set of standard weights. All weighing should be performed on an analytical balance to the nearest 0.1 mg and verified by a second person. The solvent used to dissolve the solute should be compatible with the protocol in which the standard is to be used; the solute should be soluble, stable, and nonreactive with the solvent. (For standards in canisters, the solvent is humid zero air.) In the case of a multicomponent solution, the components must not react with each other.

6.1.6 The primary standard is the solution of gas(es) in humid zero air prepared from neat standards. All subsequent dilutions must be traceable back to the primary standard.

6.1.7 Log notebooks are to be kept for all weighing and dilutions. All subsequent dilutions from the primary standard and the calculations for determining their concentrations are to be recorded and verified by a second person. All solution standards are to be refrigerated when not in use. All solution standards are to be clearly labeled as to the identity of the compound or compounds, concentration, date prepared, solvent, and initials of the preparer.

6.2 PREPARATION OF GASEOUS STANDARDS

6.2.1 As discussed in Exhibit D, the Contractor may prepare gaseous standards in a dynamic dilution system from compressed gases traceable to a National Institute of Standards (NIST) Standard Reference Material (SRM) or to a NIST/EPA approved Certified Reference Material (CRM). The components may be purchased in one cylinder or separate cylinders. Other methods of gaseous standards preparation are described in Exhibit D. For these alternate methods, equivalence must be established by the Contractor through an EPA audit procedure. In either method, the Contractor must be able to verify that the standards are certified. Manufacturer's certificates of analysis must be retained by the Contractor and presented upon request.

6.3 PURCHASE OF CHEMICAL STANDARDS IN SOLUTION

6.3.1 Solutions of analytical reference standards can be purchased by Contractors provided they meet the following criteria.

6.3.1.1 Contract laboratories must maintain the following documentation to verify the integrity of the standard solutions they purchase:

- Mass spectral identification confirmation of the neat material;
- Purity confirmation of the neat material; and
- Chromatographic and quantitative documentation that the solution standard was QC checked according to the following section.

6.3.1.2 The Contractor must purchase standards for which the quality is demonstrated statistically and analytically by a method of the supplier's choice. One way this can be demonstrated is to prepare and analyze three solutions; a high standard, a low standard, and a standard at the target concentration (see parts a and b below). The supplier must then demonstrate that the analytical results for the high standard and low standard are consistent with the difference in theoretical concentrations. This is done by the Student's t-test in part 6.3.1.3 which follows. If this is achieved, the supplier must then demonstrate that the concentration of the target standard lies midway between the concentrations of the low and high standards. This is done by the Student's t-test. Thus the standard is certified to be within 10 percent of the target concentration.

6.3.1.3 If the procedure above is used, the supplier must document that the following have been achieved.

- Two solutions of identical concentration must be prepared independently from neat materials. An aliquot of the first solution must be diluted to the intended concentration (the "target standard"). One aliquot is taken from the second solution and diluted to a concentration ten percent greater than the target standard. This is called the "high standard". One further aliquot is taken from the second solution and diluted to a concentration 10 percent less that the target standard. This is called the "low standard";
- Six replicate analyses of each standard (a total of 18 analyses) must be performed in the following sequence: low

standard, target, high standard, low standard, target standard, high standard; and

- The mean and variance of the six results for each solution must be calculated.

$$Mean = \frac{Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6}{6} \quad \text{Eq. E-2}$$

$$Variance = \frac{Y_{12} + Y_{22} + Y_{32} + Y_{42} + Y_{52} + Y_{62} - (6 \times Mean)_2}{5} \quad \text{Eq. E-3}$$

The values Y_1, Y_2, Y_3, ..., represent the results of the six analyses of each standard. The means of the low, target, and high standards are designated M_1, M_2, and M_3, respectively. The variances of the low, target, and high standards are designated V_1, V_2, and V_3, respectively. Additionally, a pooled variance, Vp, is calculated.

$$V_p = \frac{\frac{V_1}{0.81} + V_2 + V_3}{\frac{1.21}{3}} \quad \text{Eq. E-4}$$

If the square root of Vp is less than one percent of M_2, then M_2^2 /10,000 is to be used as the value of Vp in all subsequent calculations.

- The test statistic must be calculated:

$$TEST\ STATISTIC = \frac{\left| \frac{M_3}{1.1} - \frac{M_1}{0.9} \right|}{\left(\frac{V_p}{3} \right)^{0.5}} \quad \text{Eq. E-5}$$

If the test statistic exceeds 2.13 then the supplier has failed to demonstrate a twenty percent difference between the high and low standards. In such a case, the standards are not acceptable.

- The test statistic must be calculated:

$$TEST\ STATISTIC = \frac{\left|M_2 - \left(\frac{M_1}{1.8}\right) - \left(\frac{M_3}{2.2}\right)\right|}{\left(\frac{V_p}{4}\right)^{0.5}} \qquad \text{Eq. E-6}$$

If the test statistic exceeds 2.13, the supplier has failed to demonstrate that the target standard concentration is midway between the high and low standards. In such a case, the standards are not acceptable.

- The 95 percent confidence intervals for the mean result of each standard must be calculated:

$$INTERNAL\ FOR\ LOW\ STANDARD = M_1 \pm (2.13)\left(\frac{V_p}{6}\right)^{0.5} \qquad \text{Eq. E-7}$$

$$INTERNAL\ FOR\ TARGET\ STANDARD = M_2 \pm (2.13)\left(\frac{V_p}{6}\right)^{0.5} \qquad \text{Eq. E-8}$$

$$INTERNAL\ FOR\ HIGH\ STANDARD = M_3 \pm (2.13)\left(\frac{V_p}{6}\right)^{0.5} \qquad \text{Eq. E-9}$$

These intervals must not overlap. If overlap is observed, then the supplier has failed to demonstrate the ability to discriminate the 10 percent difference in concentrations. In such a case, the standards are not acceptable. In any event, the laboratory is responsible for the quality of the standards employed for analyses under this contract.

6.4 REQUESTING STANDARDS FROM THE EPA STANDARDS REPOSITORY

6.4.1 Solutions of analytical reference materials can be ordered from the U.S. EPA Chemical Standards Repository, depending on availability. The Contractor can place an order for standards only after demonstrating that these standards are not available from commercial vendors either in solution or as a neat material.

6.5 DOCUMENTATION OF THE VERIFICATION AND PREPARATION OF CHEMICAL STANDARDS

It is the responsibility of each laboratory to maintain the necessary documentation to show that the chemical standards they have used in the performance of CLP analysis conform to the requirements previously listed. Weighing logbooks, calculations, chromatograms, mass spectra, etc, whether produced by the laboratory or purchased from chemical supply houses, must be maintained by the laboratory and may be subject to review during on-site inspection visits. Documentation of

standards preparation may be required to be sent to EPA for verification of contract compliance. In those cases where the documentation is supportive of the analytical results of data packages sent to EPA, such documentation is to be kept on file by the laboratories for a period of one year.

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SECTION 7

METHOD SPECIFIC QA/QC REQUIREMENTS

7.1 This section outlines the minimum QC operations necessary to satisfy the analytical requirements associated with the determination of the volatile organic target compounds listed in Exhibit C, using the procedures in Exhibit D for samples of ambient air in canisters. This section is not intended as a comprehensive QC document, but rather as a guide to the specific QC operations that must be considered for volatile analyses using this method. At a minimum, the laboratory is expected to address these operations in preparing the QAP discussed in Section 2 and SOPs discussed in Section 3.

7.2 The specific QC operations that must be considered for volatile organics analysis include the following:

- Canister Cleaning and Certification;
- GC/MS Mass Calibration and Ion Abundance Patterns;
- GC/MS Initial and Continuing Calibration;
- Blank Analysis;
- Laboratory Control Sample Analysis;
- Sample Analysis;
- Internal Standard Responses and Retention Times; and
- Performance Evaluation (PE) Samples.

7.3 **Canister Cleaning and Certification**

7.3.1 Prior to the initial use of any canister in an analytical scheme, the laboratory shall certify the cleanliness of the canister. Before each use, the laboratory shall verify that the canister is leak-free and shall clean the canister and analyze a sample of humidified zero air to verify cleanliness.

7.3.2 Canisters must be certified clean before initial use as outlined in Exhibit D, Section 3. Results documenting initial certification are reported on Form VIII-AAVC, Canister Certification.

7.3.3 Before each use, the laboratory must clean each canister according to the procedures and meet the criteria described in Exhibit D, Section 3. Canisters cleaned and stored more than one month before use must be recleaned through one cycle of the standard three-cycle cleaning

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procedure; however, no subsequent analytical confirmation of cleanliness is required before use.

7.3.4 As a blank check of the canister(s) cleanup procedure, the final humid zero air fill of 100% of the canisters must be analyzed until the cleanup system and canisters are proven reliable as outlined in Exhibit D, Section 3.

7.3.5 Only canisters determined to be leak-free according to the procedures and criteria described in Exhibit D, Section 3 shall be used by the laboratory for sampling and analysis under this document.

7.4 GC/MS Mass Calibration and Ion Abundance Patterns

7.4.1 Before analysis of samples, blanks, or standards, the laboratory must demonstrate that a given GC/MS system meets the instrument performance check standard specified in Exhibit D, Section 5. The purpose of this instrument performance check is to ensure correct mass calibration, mass resolution, and mass transmission. This is accomplished through the analysis of bromofluorobenzene (BFB).

7.4.2 BFB analysis (once every 12 hours on each GC/MS system) is described in detail in Exhibit D, Section 5.7

7.4.3 The key ions produced during the analysis of BFB and their respective ion abundance criteria must be met.

7.4.4 The documentation includes reporting data on Form IV-AAVC, GC/MS Instrument Performance Check and Mass Calibration.

7.5 GC/MS Initial Calibration for Target Compounds

7.5.1 Prior to the analysis of samples and required blanks, and after instrument performance criteria have been met, the GC/MS system must be initially calibrated at a minimum of five concentrations to determine the linearity of response utilizing target compound standards.

7.5.2 The concentrations of the initial standards for volatile target compounds and system monitoring compounds are 2, 5, 10, 20, and 50 ppbv, as described in Exhibit D.

7.5.3 The standards are to be analyzed according to the procedures and at the frequency given in Exhibit D, Section 5.8.

7.5.4 The relative response factors (RRFs) are determined according to the procedures in Exhibit D, using the assignment of internal standards to target compounds given in Exhibit D, Table D/VC-8.

7.5.5 The calibration of the GC/MS is evaluated on the basis of the magnitude and stability of the relative response factors (RRF) of each target compound. The minimum RRF of each compound in the initial calibration and the percent relative standard deviation (%RSD) across all five points must meet the criteria given in Exhibit D, Section 5.8.

7.5.6 The documentation includes reporting data on Form V-AAVC, a GC/MS data system printout for the analysis of each VOC calibration standard, and the mass spectrum of each target compound.

7.6 **GC/MS Continuing Calibration for Target Compounds**

7.6.1 Once the GC/MS system has been calibrated, the calibration must be verified each 12-hour time period for each GC/MS system.

7.6.2 The standard is to be analyzed according to the procedures and at the frequency given in Exhibit D, Section 5.9, using Form VI-AAVC to report results.

7.6.3 The continuing calibration of the GC/MS system is evaluated on the basis of the magnitude of the relative response factors and the percent difference between the average RRF of each compound from the initial calibration and the RRF of that compound in the continuing calibration standard. The minimum RRF of each compound in the continuing calibration and the percent difference must meet the criteria given in Exhibit D, Section 5.9.

7.7 **Internal Standard Responses and Retention Times**

7.7.1 The response of each of the internal standards in all calibration standards, samples, and blanks is crucial to the provision of reliable analytical results, because the quantitative determination of volatile compounds by these procedures is based on the use of internal standards added immediately prior to analysis.

7.7.2 The specific compounds used as internal standards are given in Exhibit D. The concentration of each internal standard in the aliquot of sample analyzed by GC/MS must be 10 ppbv.

7.7.3 The retention time and the selected ion current profile (SICP) of each internal standard must be monitored for all analyses.

7.7.4 The area response of each internal standard from the SICP and the retention time of the internal standard are evaluated for stability, according to the procedures in Exhibit D. The area of the internal standard in a sample must not vary by more than a factor ±40 percent from the area of the same internal standard in the associated continuing calibration standard. Likewise, the retention time of an internal standard must be within ± 0.33 minutes (20 seconds) of its retention time

in the continuing calibration standard. Internal standard areas and retention times are reported on Form VII-AAVC.

7.8 Sample Analysis

7.8.1 The GC/MS must be set up per requirements of Exhibit D and meet BFB instrument performance and mass calibration criteria.

7.8.2 The internal standard must be added at a concentration outlined in Exhibit D, Section 5.12.

7.8.3 Guidelines for qualitative verification must be met as discussed in Exhibit D and outlined below:

7.8.3.1 All ions present in the standard mass spectra at a relative intensity greater than 10 percent (most abundant ion in the spectrum equals 100 percent) must be present in the sample spectrum.

7.8.3.2 The relative intensities of ions must agree within ± 20 percent between the standard and sample spectra as specified in Exhibit D. (Example: For an ion with an abundance of 50 percent in the standard spectra, the corresponding sample abundance must be between 30 and 70 percent).

7.8.3.3 Ions greater than ten percent in the sample spectrum but not present in the standard spectrum must be considered and accounted for by the analyst making the comparison. The verification process should favor false positive. All compounds meeting the identification criteria must be reported with their spectra. For all compounds below the CRQL report the actual value followed by a "J", e.g., "3J."

7.8.4 Guidelines for making tentative identification as presented in Exhibit D are outlined below:

7.8.4.1 Relative intensities of major ions in the reference spectrum (ions greater than ten percent of the most abundant ion) should be present in the sample spectrum.

7.8.4.2 The relative intensities of the major ions should agree within ± 20 percent. (Example: For an ion with an abundance of 50 percent of the standard spectra, the corresponding sample ion abundance must be between 30 and 70 percent.)

7.8.4.3 Molecular ions present in reference spectrum should be present in sample spectrum.

7.8.4.4 Ions present in the sample spectrum but not in the reference spectrum should be reviewed for possible background contamination of presence of coeluting compounds.

7.8.4.5 Ions present in the reference spectrum but not in the sample spectrum should be reviewed for possible subtraction from the sample spectrum because of background contamination or coeluting compounds. Data system library reduction programs can sometimes create these discrepancies.

7.8.5 Results are reported on Form I-AAVC. Other documentation includes Form VIII-AAVC, a GC/MS data system printout for the analysis of the volatile calibration standard, and the mass spectrum of each target compound.

7.9 Laboratory Method Blank Analysis

7.9.1 A laboratory method blank (LMB) is a certified canister spiked with humid zero air (air with no detectable levels of any analyte of interest), from which an aliquot is carried through the entire analytical procedure. The air aliquot volume must be equal to the sample aliquot associated with the blank. The purpose of a LMB is to determine the levels of contamination associated with the processing and analysis of samples.

7.9.2 An LMB must be analyzed once every 12 hours on each GC/MS system, as required in Exhibit D.

7.9.3 For the purposes of this protocol, an acceptable LMB analysis must result in no target compound at or above the CRQL as specified in Exhibit D, Table D/VC-1.

7.9.4 If a LMB exceeds the limits for contamination above, the Contractor must consider the analytical system out of control. The source of the contamination must be investigated and appropriate corrective actions taken and documented before further sample analysis proceeds. All samples processed with an LMB that is out of control must be reanalyzed at no additional cost to the agency. The laboratory manager or his designee must address problems and solutions in the SDG Narrative (Exhibit B).

7.9.5 An EPA sample number must be assigned to each LMB, as described in Exhibit B, Section 3.1. This EPA sample number is listed on Form III-AAVC Blank Summary, and the results of the blank analysis are reported on Form I-AAVC under this unique EPA sample number.

7.10 Performance Evaluation (PE) Samples

7.10.1 Performance evaluation (PE) samples are intended to assist the Agency in monitoring Contractor and method performance. The laboratory will not be informed as to which compounds are contained in the PE samples or the concentrations.

7.10.2 The laboratory shall analyze, and report the results (Form I-AAVC) of the PE sample once per sample delivery group, if available.

7.10.3 The laboratory will receive PE samples in SUMMA® canisters from the Agency. The samples will come with instructions concerning the extraction procedure required for the PE samples.

7.10.4 The laboratory must meet the following PE sample technical acceptance criteria:

7.10.4.1 The PE sample must be analyzed on a GC/MS system meeting the BFB tuning, initial calibration, and continuing calibration technical acceptance criteria at the frequency described in Exhibit D.

7.10.4.2 The PE sample must be preconcentrated according to Exhibit D.

7.10.4.3 The PE sample must be prepared and analyzed with a blank that meets the blank technical acceptance criteria.

7.10.4.4 The percent recovery for each of the target compounds in the PE Sample must be within replicate precision and accuracy, as outlined in Section 5 of this Exhibit.

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SECTION 8

REGIONAL DATA REVIEW

8.1 Contract laboratory data are generated to meet the specific needs of the Regions. In order to verify the usability of data for the intended purpose, each Region reviews data from the perspective of end-user, based upon functional aspects of data quality. General guidelines for data review have been developed jointly by the Region and the National Program Office. Each Region uses these guidelines as the basis for data evaluation. Individual Regions may augment the basic guideline review process with additional review based on Region-specific or site-specific concerns. Regional reviews, like the sites under investigation, vary based on the nature of the problems under investigation and the Regional response appropriate to the specific circumstances.

8.2 Regional data reviews relating usability of the data to a specific site are part of the collective assessment process. They complement the review done at the Sample Management Office, which is designed to identify contractual discrepancies, and the review done at EMSL/LV, which is designed to evaluate Contractor and method performance. These individual evaluations are integrated into a collective review that is necessary for program and laboratory administration and management and may be used to take appropriate action to correct deficiencies in the Contractor's performance.

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SECTION 9

LABORATORY EVALUATION SAMPLES

9.1 Although intralaboratory QC may demonstrate Contractor and method performance that can be tracked over time, an external performance evaluation program is an essential feature of a QA program. As a means of measuring Contractor and method performance, Contractors participate in interlaboratory comparison studies conducted by the EPA. Results from the analysis of these laboratory evaluation samples will be used by the EPA to verify the Contractor's continuing ability to produce acceptable analytical data. The results are also used to assess the precision and accuracy of the analytical methods for specific analytes.

9.2 Sample sets may be provided to participating Contractors as frequently as on an SDG-by-SDG basis as a recognizable QC sample of known composition; as a recognizable QC sample of unknown composition; or not recognizable as a QC material. The laboratory evaluation samples may be sent either by the Regional client or the National Program Office, and may be used for contract action.

9.3 Contractors are required to analyze the samples and return the data package and all raw data within the contract required turnaround time.

9.4 At a minimum, the results are evaluated for compound identification, quantification, and sample contamination. Confidence intervals for the quantification of target compounds are based on reported values using population statistics. EPA may adjust the scores on any given laboratory evaluation sample to compensate for unanticipated difficulties with a particular sample. Normally, a fraction of the compounds spiked into the sample are not specifically listed in the contract. Contractors are required to use the NIST/EPA/MSDC mass spectral library to tentatively identify a maximum number of non-target compounds in each fraction that are present above a minimal response. Tentative identification of these compounds based on contractually described spectral interpretation procedures is evaluated and integrated into the evaluation process.

9.5 A Contractor's results on the laboratory evaluation samples will determine the Contractor's performance as follows:

9.5.1 No response is required for a score of 90 percent or above.

9.5.2 For a score of 75 to 89, the Contractor shall describe the deficiency(ies) and the corrective action(s) taken in a letter to the APO, TPO, and EMSL/LV, within 14 days of receipt of notification from EPA.

9.5.3 For a score less than 75, the Contractor shall be notified by the APO or TPO concerning the remedy for its unacceptable performance. The Contractor may expect, but EPA is not limited to, the following actions: reduction of the number of samples sent under the contract, suspension of sample shipment to the Contractor, a site visit, a full data audit, analysis of remedial PE samples, and/or a contract sanction, such as a Cure Notice.

NOTE: A Contractor's prompt response demonstrating that corrective action has been taken to ensure the Contractor's capability to meet contract requirements will facilitate continuation of full sample delivery.

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SECTION 10

GC/MS TAPE AUDITS

10.1 Periodically, EPA requests from Contractors the GC/MS magnetic tapes corresponding to a specific Case in order to accomplish tape audits. Generally, tape submissions and audits are requested for the following reasons:

- Program overview;
- Indication of data quality problems from EMSL/LV, SMO, or Regional data reviews;
- Support for on-site audits; and
- Specific Regional requests.

10.2 Depending upon the reason for an audit, the tapes from a recent Case, a specific Case, or a laboratory evaluation sample may be requested. Tape audits provide a mechanism to assess adherence to contractual requirements and to ensure the consistency of data reported on the hardcopy/floppy diskettes with that generated on the GC/MS tapes. This function provides external monitoring of Program QC requirements and checks adherence of the Contractor to internal QA procedures. In addition, tape audits enable EPA to evaluate the utility, precision, and accuracy of the analytical methods.

10.3 The GC/MS tape shall include raw data and quantitation reports for samples, blanks, laboratory evaluation samples, initial calibrations, continuing calibration, and BFB associated with the Case requested. The specific requirements for submissions of GC/MS tapes are discussed in Exhibit B.

10.4 Upon request of the Administrative Project Officer or EMSL/LV, the required tapes and all necessary documentation shall be submitted to EPA within seven (7) days of notification.

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SECTION 11

ON-SITE LABORATORY EVALUATIONS

11.1 At a frequency dictated by a contract laboratory's performance, the Administrative Project Officer, Technical Project Officer or their authorized representative will conduct an on-site laboratory evaluation. On-site laboratory evaluations are carried out to monitor the Contractor's ability to meet selected terms and conditions specified in the contract. The evaluation process incorporates two separate categories: Quality Assurance Evaluation and an Evidentiary Audit.

11.2 QUALITY ASSURANCE ON-SITE EVALUATION

11.2.1 Quality assurance evaluators inspect the Contractor's facilities to verify the adequacy and maintenance of instrumentation, the continuity of personnel meeting experience or education requirements, and the acceptable performance of analytical and QC procedures. The Contractor should expect that items to be monitored will include but not be limited to the following items:

- Size and appearance of the facility;
- Quantity, age, availability, scheduled maintenance and performance of instrumentation;
- Availability, appropriateness, and utilization of SOPs;
- Staff qualifications, experience, and personnel training programs;
- Reagents, standards, and sample storage facilities;
- Standard preparation logbooks and raw data;
- Bench sheets and analytical logbook maintenance and review, and
- Review of the Contractor's sample analysis/data package inspection procedures.

11.2.2 Prior to an on-site evaluation, various documentation pertaining to performance of the specific Contractor is integrated in a profile package for discussion during the evaluation. Items that may be included are previous on-site reports, laboratory evaluation sample scores, Regional review of data, Regional QA materials, GC/MS tape audit reports, results of CCS, and data trend reports.

11.3 EVIDENTIARY AUDIT

11.3.1 Evidence auditors conduct an on-site laboratory evaluation to determine if laboratory policies and procedures are in place to satisfy evidence handling requirements as stated. The evidence audit is comprised of the following three activities.

11.3.1.1 Procedural Audit

The procedural audit consists of review and examination of actual standard operating procedures and accompanying documentation for the following laboratory operations:

- Sample receiving;
- Sample storage;
- Sample identification;
- Sample security;
- Sample tracking (from receipt to completion of analysis); and
- Analytical project file organization and assembly.

11.3.1.2 Written SOPs Audit

The written SOPs audit consists of review and examination of the written SOPs to determine if they are accurate and complete for the following laboratory operations: sample receiving, sample storage, sample identification, sample security, sample tracking (from receipt to completion of analysis), and analytical project file organization and assembly.

11.3.1.3 Analytical Project File Evidence Audit

The analytical project file evidence audit consists of review and examination of the analytical project file documentation. The auditors review the files to determine:

- Accuracy of the document inventory;
- Completeness of the file;
- Adequacy and accuracy of the document numbering system;
- Traceability of sample activity;

- Identification of activity recorded on the documents; and
- Error correction methods.

11.4 DISCUSSION OF THE ON-SITE TEAM'S FINDINGS

The QA and evidentiary auditors discuss their findings with the Administrative Project Officer/Technical Project Officer prior to debriefing the Contractor. During the debriefing, the auditors present their findings and recommendations for corrective actions necessary to the Contractor personnel.

11.5 CORRECTIVE ACTION REPORTS FOR FOLLOW-THROUGH TO QUALITY ASSURANCE AND EVIDENTIARY AUDIT REPORTS

11.5.1 Following an on-site evaluation, QA and evidentiary audit reports which discuss deficiencies found during the on-site evaluation will be forwarded to the Contractor. The Contractor must discuss the corrective actions taken to resolve the deficiencies discussed during the on-site visit and discussed in the on-site reports in a letter to the Administrative Project Officer, Technical Project Officer, EMSL/LV (response to the QA report) and NEIC (response to the evidentiary report) within 14 days of receipt of the finding or within the time agreed upon between the Administrative Project Officer/Technical Project Officer and the Contractor. If SOPs are required to be written or SOPs are required to be amended, the Contractor must provide the SOPs to the Technical Project Officer, EMSL/LV (QA/technical SOPs) and NEIC (evidentiary SOPs) within 30 days of receipt of the finding or within the time agreed upon between the Administrative Project Officer/Technical Project Officer and the Contractor.

11.5.2 If the Contractor fails to take appropriate corrective action to resolve the deficiencies discussed in the on-site reports, a Contractor may expect, but the Agency is not limited to, the following actions: reduction of the number of samples sent under the contract, suspension of sample shipment to the Contractor, a follow-up site visit, a full data audit, analysis of remedial PE samples and/or contract sanction, such as a Cure Notice.

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SECTION 12

QUALITY ASSURANCE AND DATA TREND ANALYSIS

12.1 Data submitted by laboratories are subject to review from several aspects: compliance with contract-required QC, usability, and full data package evaluation. Problems resulting from any of these reviews may determine the need for a GC/MS tape audit, an on-site laboratory evaluation and/or a remedial laboratory evaluation sample. In addition, QC prescribed in the methods provides information that is continually used by the Agency to assess sample data quality, Contractor data quality and Program data quality via data trend analysis. Trend analysis is accomplished by entering data into a computerized data base. Statistical reports that evaluate specific anomalies or disclose trends in many areas, including the following, are generated from this data base:

- Laboratory Control Sample;
- Blanks;
- GC/MS Instrument Performance Checks;
- Initial and Continuing Calibration Data; and
- Other QC and Method Parameters.

12.2 Program-wide statistical results are used to rank laboratories in order to observe the relative performance of each Contractor using a given protocol against its peers. The reports are also used to identify trends within laboratories. The results of many of these trends analyses are included in overall evaluation of a Contractor's performance, and are reviewed to determine if corrective action or an on-site laboratory evaluation is indicated in order to meet the QA/QC requirements of the contract.

12.3 Contractor performance over time is monitored using these trend analysis techniques to detect departures of Contractor output from required or desired levels of QC, and to provide an early warning of Contractor QA/QC problems which may not be apparent from the results of an individual case.

12.4 As a further benefit to the Program, the data base provides the information needed to establish performance-based criteria in updated analytical protocols, where advisory criteria have been previously used. The vast empirical data set produced by contract laboratories is carefully analyzed, with the results augmenting theoretical and research-based performance criteria. The result is a continuously monitored set of QC and performance criteria specifications of what is routinely achievable and expected of environmental chemistry laboratories in mass production analysis

of environmental samples. This, in turn, assists the Agency in meeting its objectives of obtaining data of known and documented quality.

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SECTION 13

DATA MANAGEMENT

13.1 Data management procedures are defined as procedures specifying the acquisition or entry, update, correction, deletion, storage and security of computer readable data and files. These procedures should be in written form and contain a clear definition for all databases and files used to generate or resubmit deliverables. Key areas of concern include: system organization (including personnel and security), documentation operations, traceability and quality control.

13.2 Data manually entered from hard-copy must be quality controlled and the error rates estimated. Systems should prevent entry of incorrect or out-of-range data and alert data entry personnel of errors. In addition, data entry error rates must be estimated and recorded on a monthly basis by reentering a statistical sample of the data entered and calculating discrepancy rates by data element.

13.3 The record of changes in the form of corrections and updates to data originally generated, submitted, and/or resubmitted must be documented to allow traceability of updates. Documentation must include the following for each change:

- Justification or rationale for the change;
- Initials of the person making the change or changes. Data changes must be implemented and reviewed by a person or group independent of the source generating the deliverable;
- Change documentation must be retained according to the schedule of the original deliverable;
- Resubmitted diskettes or other deliverables must be reinspected as a part of the laboratory's internal inspection process prior to resubmission. The entire deliverable, not just the changes, must be inspected;
- The Laboratory Manager must approve changes to originally submitted deliverables; and
- Documentation of data changes may be requested by laboratory auditors.

13.4 Lifecycle management procedures must be applied to computer software systems developed by the laboratory to be used to generate and edit contract deliverables. Such systems must be thoroughly tested and documented prior to utilization

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- A software test and acceptance plan including test requirements, test results and acceptance criteria must be developed, followed, and available in written form.

- System changes must not be made directly to production systems generating deliverables. Changes must be made first to a development system and tested prior to implementation.

- Each version of the production system will be given an identification number, date of installation, date of last operation and archived.

- System and operations documentation must be developed and maintained for each system. Documentation must include a user's manual and an operations and maintenance manual.

13.5 Individual(s) responsible for the following functions must be identified:

- System operation and maintenance including documentation and training;

- Database integrity, including data entry, data updating and quality control; and

- Data and system security, backup and archiving.

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SECTION 14

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EXHIBIT F

EVIDENTIARY REQUIREMENTS

December, 1991

EXHIBIT F

EVIDENTIARY REQUIREMENTS

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SECTION 1

SAMPLE CHAIN-OF-CUSTODY

A sample is physical evidence collected from a facility or from the environment. An essential part of hazardous waste investigation effort is that the evidence gathered be controlled. To accomplish this, the following sample identification, chain-of-custody, sample receiving, and sample tracking procedures have been established.

1.1 SAMPLE IDENTIFICATION

1.1.1 To assure traceability of samples while in possession of the Contractor, the Contractor shall have a specified method for maintaining identification of samples throughout the laboratory.

1.1.2 Each sample and sample preparation container shall be labeled with the EPA sample number or a unique laboratory identifier. If a unique laboratory identifier is used, it shall be cross-referenced to the EPA sample number.

1.2 CHAIN-OF-CUSTODY PROCEDURES

1.2.1 Because of the nature of the data being collected, the custody of EPA samples must be traceable from the time the samples are collected until they are introduced as evidence in legal proceedings. The Contractor shall have procedures ensuring that EPA sample custody is maintained and documented.

1.2.2 A sample is under custody if the following applies:

1.2.2.1 It is in your possession.

1.2.2.2 It is in your view after being in your possession.

1.2.2.3 It was in your possession and you locked it up.

1.2.2.4 It is in a designated secure area (secure areas shall be accessible to authorized personnel only).

1.3 SAMPLE RECEIVING PROCEDURES

1.3.1 The Contractor shall designate a sample custodian responsible for receiving all samples.

1.3.2 The Contractor shall designate a representative to receive samples in the event that the sample custodian is not available. The condition of the shipping containers and sample bottles shall be inspected upon receipt by the sample custodian or his/her representative.

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1.3.3 The condition of the custody seals (intact/not intact) shall be inspected upon receipt by the sample custodian or his/her representative.

1.3.4 The sample custodian or his/her representative shall check for the presence or absence of the following documents accompanying the sample shipment:

1.3.4.1 Airbills or airbill stickers.

1.3.4.2 Custody seals.

1.3.4.3 EPA custody records.

1.3.4.4 EPA traffic reports or SAS packing lists.

1.3.4.5 Sample tags.

1.3.5 The sample custodian or his/her representative shall sign and date all forms (e.g., custody records, traffic reports or packing lists, and airbills) accompanying the samples at the time of sample receipt.

1.3.6 The Contractor shall contact SMO to resolve discrepancies and problems such as absent documents, conflicting information, broken custody seals, and unsatisfactory sample condition (e.g., leaking sample bottle).

1.3.7 The Contractor shall record the resolution of discrepancies and problems on Telephone Contact Logs.

1.3.8 The following information shall be recorded on appropriate Form AADC-1 by the sample custodian or his/her representative as samples are received and inspected:

1.3.8.1 Condition of the shipping container.

1.3.8.2 Presence or absence and condition of custody seals on shipping and/or sample containers.

1.3.8.3 Custody seal numbers, when present.

1.3.8.4 Condition of the sample bottles.

1.3.8.5 Presence or absence of airbills or airbill stickers.

1.3.8.6 Airbill or airbill sticker numbers.

1.3.8.7 Presence or absence of EPA custody records.

1.3.8.8 Presence or absence of EPA traffic reports or SAS packing lists.

1.3.8.9 Presence or absence of sample tags.

1.3.8.10 Sample tag identification numbers cross-referenced to the EPA sample numbers.

1.3.8.11 Verification of agreement or non-agreement of information recorded on shipping documents and sample containers.

1.3.8.12 Problems or discrepancies.

1.4 SAMPLE TRACKING PROCEDURES

The Contractor shall maintain records documenting all phases of sample handling from receipt to final analysis. The records shall include documentation of the movement of samples and prepared samples into and out of designated laboratory storage areas.

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SECTION 2

DOCUMENT CONTROL PROCEDURES

The goal of the laboratory document control program is to assure that all documents for a specified SDG will be accounted for when the project is completed. Accountable documents used by contract laboratories shall include but not be limited to logbooks, chain-of-custody records, sample work sheets, bench sheets, and other documents relating to the sample or sample analyses. The following document control procedures have been established to assure that all laboratory records are assembled and stored for delivery to the EPA or are available upon request from the EPA prior to the delivery schedule.

2.1 PREPRINTED LABORATORY FORMS AND LOGBOOKS

2.1.1 All documents produced by the Contractor which are directly related to the preparation and analysis of EPA samples shall become the property of the EPA and shall be placed in the complete sample delivery group file (CSF). All observations and results recorded by the laboratory but not on preprinted laboratory forms shall be entered into permanent laboratory logbooks. When all data from a SDG are compiled, all original laboratory forms and copies of all SDG-related logbook entries shall be included in the documentation package.

2.1.2 The Contractor shall identify the activity recorded on all laboratory documents which is directly related to the preparation and analysis of EPA samples.

2.1.3 Pre-printed laboratory forms shall contain the name of the laboratory and be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

2.1.4 Logbook entries shall be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

2.1.5 Logbook entries shall be in chronological order. Entries in logbooks, with the exception of instrument run logs and extraction logs, shall include only one SDG per page.

2.1.6 Pages in both bound and unbound logbooks shall be sequentially numbered.

2.1.7 Instrument run logs shall be maintained so as to enable a reconstruction of the run sequence of individual instruments. Because the laboratory must provide copies of the instrument run logs to the EPA, the laboratory may exercise the option of using only laboratory or EPA

sample identification numbers in the logs for sample ID rather than government agency or commercial client names to preserve the confidentiality of commercial clients.

2.1.8 Corrections to supporting documents and raw data shall be made by drawing a single line through the error and entering the correct information. Corrections and additions to supporting documents and raw data shall be dated and initialed. No information shall be obliterated or rendered unreadable. All notations shall be recorded in ink. Unused portions of documents shall be crossed out.

2.2 CONSISTENCY OF DOCUMENTATION

2.2.1 The Contractor shall assign a document control officer responsible for the organization and assembly of the CSF.

2.2.2 All copies of laboratory documents shall be complete and legible.

2.2.3 Before releasing analytical results, the document control officer shall assemble and cross-check the information on sample tags, custody records, laboratory bench sheets, personal and instrument logs, and other relevant data to ensure that data pertaining to each particular sample or sample delivery group is consistent throughout the CSF.

2.3 DOCUMENT NUMBERING AND INVENTORY PROCEDURES

2.3.1 In order to provide document accountability of the completed analysis records, each item in a CSF shall be inventoried and assigned a serialized number as described in Exhibit B, Section 2.

CSF # - Region - Serialized number (For example: 75-2-0240).

2.3.2 All documents relevant to each SDG, including logbook pages, bench sheets, mass spectra, chromatograms, screening records, re-preparation records, re-analysis records, records of failed or attempted analysis, custody records, library research results, etc., shall be inventoried.

2.3.3 The Document Control Officer (DCO) shall be responsible for ensuring that all documents generated are placed in the CSF for inventory and are delivered to the EPA. The DCO shall place the sample tags in plastic bags in the file. Figure E-1 of Exhibit E is an example of a document inventory.

2.4 STORAGE OF EPA FILES

The Contractor shall maintain EPA laboratory documents in a secure location.

2.5 SHIPPING DATA PACKAGES AND CSF

2.5.1 The Contractor shall document shipment of deliverables packages to the recipients. These shipments require custody seals on the containers placed such that they cannot be opened without damaging or breaking the seal. The Contractor shall document what was sent, to whom, the date, and the method (carrier) used.

2.5.2 The Contractor shall purge the CSF deliverable to the appropriate EPA Region 180 days after the report submission.

2.5.3 A copy of the transmittal letter for the CSF will be sent to NEIC and SMO.

2.5.4 The Document Control form is used to document the receipt and inspection of shipping containers and samples. The Contractor shall submit one original FORM AADC-1 for each shipping container.

2.5.5 The Contractor shall sign and date the airbill (if present), examine the shipping containers, record the presence or absence of custody seals and their conditions.

2.5.6 The Contractor shall note any problems with the samples and follow the instructions explained in Exhibit B, Sample Log-In Sheet.

2.5.7 The Contractor shall submit a completed Document Control Form with each SDG package.

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SECTION 3

STANDARD OPERATING PROCEDURES

The Contractor must have written standard operating procedures (SOPs) for receipt of samples, maintenance of custody, sample identification, sample storage, tracking the analysis of samples, and assembly of completed data.

3.1 SPECIFICATIONS FOR WRITTEN STANDARD OPERATING PROCEDURES

3.1.1 An SOP is defined as a written narrative step-by-step description of laboratory operating procedures including examples of laboratory documentation. The SOPs must accurately describe the actual procedures used in the laboratory, and copies of the written SOPs shall be available to the appropriate laboratory personnel. These procedures are necessary to ensure that analytical data produced under this contract are acceptable for use in EPA enforcement case preparation and litigation.

3.1.2 The Contractor's SOPs shall provide mechanisms and documentation to meet each of the following specifications and shall be used by EPA as the basis for laboratory evidence audits. The Contractor must have written standard operating procedures (SOPs) for:

3.1.2.1 Sample receipt and logging.

3.1.2.2 Sample storage.

3.1.2.3 Preventing sample contamination.

3.1.2.4 Security for laboratory and samples.

3.1.2.5 Traceability of standards.

3.1.2.6 Maintaining instrument records and logbooks.

3.1.2.7 Sample analysis and data control systems.

3.1.2.8 Glassware cleaning.

3.1.2.9 Technical and managerial review of laboratory operation and data package preparation.

3.1.2.10 Internal review of contractually-required quality assurance and quality control data for each individual data package.

3.1.2.11 Sample analysis, data handling, and reporting.

3.1.2.12 Chain-of-Custody.

3.1.2.13 Document control, including Case file preparation.

3.1.3 The Contractor shall have a designated sample custodian responsible for receipt of samples and have written SOPs describing his/her duties and responsibilities.

3.1.4 The Contractor shall have written SOPs for receiving and logging in of the samples. The procedures shall include but not be limited to documenting the following information:

3.1.4.1 Presence or absence of EPA chain-of-custody forms.

3.1.4.2 Presence or absence of airbills or airbill stickers.

3.1.4.3 Presence or absence of EPA Traffic Reports or SAS packing lists.

3.1.4.4 Presence or absence of custody seals on shipping and/or sample containers and their condition.

3.1.4.5 Custody seal numbers, when present.

3.1.4.6 Presence or absence of sample tags.

3.1.4.7 Sample tag ID numbers.

3.1.4.8 Condition of the shipping container.

3.1.4.9 Condition of the sample container.

3.1.4.10 Verification of agreement or nonagreement of information on receiving documents and sample containers.

3.1.4.11 Resolution of problems or discrepancies with the SMO.

3.1.4.12 The definition of any terms used to describe sample condition upon receipt.

3.1.5 The Contractor shall have written SOPs for maintenance of the security of samples after log-in and shall demonstrate security of the sample storage and laboratory areas. The SOPs shall specifically include descriptions of all storage areas for EPA samples in the laboratory, and steps taken to prevent sample contamination. The SOPs shall include a list of authorized personnel who have access or keys to secure storage areas.

3.1.6 The Contractor shall have written SOPs for tracking the work performed on any particular sample. The tracking SOP shall include the

following:

3.1.6.1 A description of the documentation used to record sample receipt, sample storage, sample transfers, sample preparations, and sample analyses.

3.1.6.2 A description of the documentation used to record instrument calibration and other QA/QC activities.

3.1.6.3 Examples of the document formats and laboratory documentation used in the sample receipt, sample storage, sample transfer, and sample analyses.

3.1.7 The Contractor shall have written SOPs for maintaining identification of EPA samples throughout the laboratory.

3.1.8 If the Contractor assigns unique laboratory identifiers, written SOPs shall include a description of the method used to assign the unique laboratory identifier and cross-reference to the EPA sample number.

3.1.9 If the Contractor uses prefixes or suffixes in addition to sample identification numbers, the written SOPs shall include their definitions. The Contractor shall have written SOPs describing the method by which the laboratory maintains samples under custody.

3.1.10 The Contractor shall have written SOPs for organization and assembly of all documents relating to each EPA Case, including technical and managerial review. Documents shall be filed on a Case-specific basis. The procedures must ensure that all documents including logbook pages, sample tracking records, chromatographic charts, computer printouts, raw data summaries, correspondence, and any other written documents having reference to the Case are compiled in one location for submission to EPA. The system must include a document numbering and inventory procedure.

3.1.11 The Contractor shall have written SOPs for laboratory safety.

3.1.12 The Contractor shall have written SOPs for cleaning of glassware used in preparing and analyzing samples under this contract.

3.1.13 The Contractor shall have SOPs for traceability of standards used in sample analysis QA/QC.

3.2 HANDLING OF CONFIDENTIAL INFORMATION

3.2.1 A Contractor conducting work under this contract may receive EPA-designated confidential information from the Agency. Confidential information must be handled separately from other documentation developed

under this contract. To accomplish this, the following procedures for the handling of confidential information have been established.

3.2.2 All confidential documents shall be under the supervision of a designated Document Control Officer (DCO).

3.2.3 Any samples or information received with a request of confidentiality shall be handled as "confidential." A separate locked file shall be maintained to store this information and shall be segregated from other nonconfidential information. Data generated from confidential samples shall be treated as confidential. Upon receipt of confidential information, the DCO logs these documents into a Confidential Inventory Log. The information is then made available to authorized personnel but only after it has been signed out to that person by the DCO. The documents shall be returned to the locked file at the conclusion of each working day. Confidential information may not be reproduced except upon approval by the EPA Contracting Officer. The DCO will enter all copies into the document control system. In addition, this information may not be disposed of except upon approval by the EPA Contracting Officer. The DCO shall remove and retain the cover page of any confidential information disposed of for one year and shall keep a record of the disposition in the Confidential Inventory Log.

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EXHIBIT G

GLOSSARY OF TERMS

December, 1991

EXHIBIT G

GLOSSARY OF TERMS

Aliquot - A measured portion of a field sample taken for analysis.

Analysis Date/Time - The date and military time (24-hour clock) of the introduction of the sample, standard, or blank into the analysis system.

Analysis Group - An analysis group is a set of no more than twenty analytical samples (as defined below) for the purpose of method Quality Assurance/Quality Control (QA/QC), such that the QA/QC required by Exhibit E is, at a minimum, prepared and analyzed at a frequency of once per twenty analytical samples.

Analysis Replicate - A single analytical sample prossed through the analytical preparation method and analyzed in replicate.

Analyte - The compound an analysis seeks to determine; the compound of interest.

Analytical Sample - Any solution or media introduced into an instrument on which an analysis is performed excluding instrument calibration, initial calibration verification, initial calibration blank, continuing calibration verification and continuing calibration blank. Note the following are all defined as analytical samples: undiluted and diluted samples (EPA and non-EPA), duplicate samples, and laboratory control sample (LCS).

ASTM Type II Water - Distilled water with a conductivity of less than 1.0 μmho/cm at 25°C. For additional specifications refer to ASTM D1193-77, "Standard Specification for Reagent Water".

Background Correction - A technique to compensate for variable background contribution to the instrument signal in the determination of trace elements.

Batch - A group of samples prepared at the same time.

Calibration - The establishment of an analytical curve based on the absorbance, emission intensity, or other measured characteristic of known standards. Calibration procedures differ for the various methods included in this document.

Calibration Standards - A series of known standard solutions used by the analyst for calibration of the instrument (i.e., preparation of the analytical curve). The solutions are not subjected to the preparation method but contain the same matrix as the sample preparations to be analyzed.

Case - A finite, usually predetermined number of samples collected over a given time period from a particular site. Case numbers are assigned by the Sample Management Office. A Case consists of one or more Sample Delivery Groups.

Continuing Calibration - Analytical standard run at least every 12 hours to verify the calibration of the analytical system.

Contract Required Quantitation Limit (CRQL) - Minimum level of quantitation acceptable under the contract. Generally defined as 3.3 (or more) times the standard deviation of seven replicate analyses of the method blank.

Control Limits - A range within which specified measurement results must fall to be compliant. Control limits may be mandatory, requiring corrective action if exceeded, or advisory, requiring that noncompliant data be flagged.

Correlation Coefficient - A number (r) which indicates the degree of dependence between two variables (e.g., concentration - absorbance). The more dependent they are the closer the value to one. Determine on the basis of the least squares line.

Cryogen - A liquified gas used to obtain very low temperatures in the cryogenic trap of the analytical system. A typical cryogen is liquid nitrogen (bp - 195.8°C).

Data System - For the purpose of this document, computer system that allows the continuous acquisition and printout of time vs. intensity data throughout the chromatographic program.

Day - Unless otherwise specified, day shall mean calendar day.

Deuterated Chemicals - Those chemicals which contain deuterium (hydrogen isotope that is twice the mass of hydrogen); used as tracers for system quality assurance.

Duplicate - A second aliquot of a sample that is treated the same as the original sample in order to determine the precision of the method.

Dynamic Calibration - Calibration of an analytical system using calibration gas standard concentrations in a form identical or very similar to the samples to be analyzed and by introducing such standards into the inlet of the sampling or analytical system in a manner very similar to the normal sampling or analytical process.

Dynamic Dilution - Means of preparing calibration mixtures in which standard gas(es) from pressurized cylinders are continually blended with humidified zero air in a manifold so that a flowing stream of calibration mixture is available at the inlet of the analytical system.

EBCDIC - Extended Binary Coded Decimal Interchange Code.

External Standards - Target analytes analyzed at a known concentration prior to sample analysis, to determine response factors.

Field Sample - A portion of material received to be analyzed that is contained

in single or multiple containers and identified by a unique EPA Sample Number.

Holding Time - The elapsed time expressed in days from the date of receipt of the sample by the Contractor until the date of its analysis.

In-House - At the Contractor's facility.

Initial Calibration - Analysis of analytical standards for a series of different specified concentrations; used to define the linearity and dynamic range of the response of the analytical instrument to the target analytes.

Interferents - Substances which affect the analysis for the element of interest.

Internal Standards - Analytes added to every standard, blank, sample (for VOAs) at a known concentration, prior to analysis. Internal standards are used as the basis for quantitation of the target analysis.

Laboratory - Synonymous with Contractor as used herein.

Laboratory Control Sample - Aliquot spiked with known concentration of specific analytes and subjected to the entire analytical procedure in order to monitor method and contractor performance.

Laboratory Receipt Date - The date on which a sample is received at the Contractor's facility, as recorded on the shipper's delivery receipt and sample Traffic Report. Also referred to as VTSR (validated time of sample receipt).

Linear Range - The concentration range over which the analytical curve remains linear. The range of the instrument for a specific analyte, as determined using calibration standards. The upper limit of this linear range (determined at each analysis) is the highest concentration calibration standard that has a determined value within 10% of the known value.

Mass Spectral Interference - Defined as the inability to detect the internal standard quantification ion due to presence of high levels of mass spectral "noise" at the same mass.

Matrix - The predominant material of which the sample to be analyzed is composed.

Megabore® Column - One of two types of capillary columns, the other being the narrow bore, for the analysis of target compounds under this contract.

Method Detection Limit (MDL) - The chemical concentration that produces a signal, due to an analyte, which is equal to the student $t_{.99}$ times the standard deviation of a series of measurements on at least seven separate method blanks. In practice, a method detection limit will be substantially higher than an instrumental detection limit. The method detection limit for

metals is $t_{.99}$ times the standard deviation of seven method blank analyses. Of course, all spectral background techniques must be operative and the same integration times must be utilized as when actual samples are analyzed.

MS-SCAN - The gas chromatograph (GC) is coupled to a mass selective detector where the instrument is programmed to acquire all mass for target analytes and to disregard all others.

Narrative (SDG Narrative) - Portion of the data package which includes laboratory, contract, SDG and sample number identification, and descriptive documentation of any problems encountered in processing the samples, along with corrective action taken and problem resolution. Complete SDG Narrative specifications are included in Exhibit B.

Narrow-Bore Capillary Column - One of two capillary columns, the other being the wide-bore (Mega-bore®) capillary column, for the analysis of compounds under this contract.

Performance Evaluation (PE) Sample - A sample of known composition provided by EPA for Contractor analysis. Used by EPA to evaluate Contractor performance.

Protocol - A compilation of the procedures to be followed with respect to sample receipt and handling, analytical methods, data reporting and deliverables, and document control.

Qualitative Accuracy - The ability of an analytical system to correctly identify compounds.

Quantitative Accuracy - The ability of an analytical system to correctly measure the concentration of an identified compound.

Reconstructed Ion Chromatogram (RIC) - A mass spectral graphical representation of the separation achieved by a gas chromatograph; a plot of total ion current versus retention time.

Recovery - A determination of the accuracy of the analytical procedure made by comparing measured values for a fortified (spiked) sample against the known spike values. Recovery is determined by the following equation:

$$\%\text{Surrogate Recovery} = \frac{\text{measured value}}{\text{spiked value}} \times 100\%$$

Relative Response Factor (RRF) - A measure of the relative mass spectral response of an analyte compared to its internal standard. Relative Response Factors are determined by analysis of standards and are used in the calculation of concentrations of analytes in samples. RRF is determined by the following equation:

$$RRF = \frac{A_x C_{is}}{A_{is} C_x} \qquad \text{Eq. F-1}$$

where:
A = area of the characteristic ion measured
C = concentration
is = internal standard
x = analyte of interest

Resolution - Also termed separation, the separation between peaks on a chromatogram, calculated by dividing the height of the valley between the peaks by the peak height of the smaller peak being resolved, multiplied by 100.

Retention Time (RT) - The time to elute a specific chemical from a chromatographic column for a specific carrier gas flow rate, measured from the time the chemical is injected into the gas stream until its maximum concentration appears at the detector.

Retention Time Window - Retention time window is determined for each analyte of interest and is the time from injection to elution of a specific chemical from a chromatographic column. The window is determined by three injections of a single component standard over a 24-hour period as plus or minus three times the standard deviation of the absolute retention time for that analyte.

Run - A continuous analytical sequence consisting of prepared samples and all associated quality assurance measurements as required by the contract.

Sample - A portion of material to be analyzed that is contained in single or multiple containers and identified by a unique sample number.

Sample Delivery Group (SDG) - A unit within a sample Case that is used to identify a group of samples for delivery. An SDG is a group of 20 or fewer samples within a Case, received over a period of up to 14 calendar days. Data from all samples in an SDG are due concurrently. A Sample Delivery Group is defined by one of the following, whichever occurs first:

- Case; or
- Each 20 samples within a Case; or
- Each 14-day calendar period during which samples in a Case are received, beginning with receipt of the first sample in the Case or SDG.

Samples may be assigned to Sample Delivery Groups by sample collection method (i.e., all Tenax® tubes in one SDG, all canisters in another).

Sample Number (EPA Sample Number) - A unique identification number designated by EPA for each sample. The EPA Sample Number appears on the sample Traffic

Report which documents information on that sample.

Selected Ion Current Profile (SICP) - A plot of ion abundance vs. time or scan number for ions of a specified mass.

Standard Analysis - An analytical determination made with known quantities of target compounds; used to determine response factors.

Static Calibration - Calibration of an analytical system with known concentrations of calibration gas, obtained from a source such as gas cylinders or prepared from standard stock solutions.

Stock Solution - A standard solution which can be diluted to derive other standards.

Surrogates (Surrogate Standard) - Compounds added to every blank, sample, matrix spike, matrix spike duplicate, and standard; used to evaluate analytical efficiency by measuring recovery. Surrogates are brominated, fluorinated, or isotopically labelled compounds not expected to be detected in environmental media.

Tentatively Identified Compounds (TIC) - Compounds detected in samples that are not target compounds, internal standards or surrogate standards. Up to 10 peaks are subjected to mass spectral library searches for tentative identification.

Time - When required to record time on any deliverable item, time shall be expressed as Military Time, i.e., a 24-hour clock.

Traffic Report (TR) - An EPA sample identification form filled out by the sampler, which accompanies the sample during shipment to the laboratory and which is used for documenting sample condition and receipt by the laboratory.

Twelve-Hour Time Period - The twelve (12) hour time period for GC/MS system tuning, standards calibration (initial or continuing calibration) begins at the moment of injection of the BFB analysis that the laboratory submits as documentation of compliant tune. The time period ends after 12 hours has elapsed according to the system clock.

Validated Time of Sample Receipt (VTSR) - The date on which a sample is received at the Contractor's facility, as recorded on the shipper's delivery receipt and Sample Traffic Report.

Volatile Compounds - Target compounds with normal vapor pressures $\geq$ 0.1 mm Hg.

ATTACHMENT IV

USEPA CONTRACT LABORATORY PROGRAM

VOLATILE ORGANICS ANALYSIS OF AMBIENT AIR ON TENAX®

December, 1991

Revision VTAA01.0

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VOLATILE ORGANICS ANALYSIS OF
AMBIENT AIR ON TENAX®

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PREFACE

The purpose of this contract is to provide the U.S. Environmental Protection Agency (EPA) with chemical analytical services, quality control procedures, and an analysis structure which will generate data of known and documented quality. This document was developed with the guidance of the Air Toxics Workgroup to ensure that the needs of regional, state, and local air pollution programs are addressed.

The samples to be analyzed are of ambient air collected on Tenax® at or in the vicinity of known or suspected hazardous waste sites and may contain potentially hazardous organic and inorganic material at significant concentrations. The Contractor should be aware of the potential hazards associated with the handling and analyses of these samples. It is the Contractor's responsibility to take all necessary measures and precautions to ensure the health and safety of its employees. The Contractor is responsible for providing a safe working environment and making its employees aware of the potential hazards of working with and analyzing these samples.

Procedures specified herein shall be used in the preparation of Tenax® cartridges and analysis of air samples for the presence and quantitation of certain volatile organic compounds (VOCs). The Contractor shall employ safe handling procedures and generally accepted laboratory practices in the performance of contract requirements and shall follow the quality assurance and quality control (QA/QC) program specified herein.

The data obtained under this contract will be used by EPA to determine the existence and extent of risk posed by hazardous waste disposal sites to the public, to individuals involved in Superfund site cleanups, and to the environment. The data may be used in civil and/or criminal litigation which requires the strictest adherence to chain-of-custody protocol, document control, and quality assurance procedures.

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EXHIBIT A

SUMMARY OF REQUIREMENTS FOR VOLATILE ORGANICS ANALYSIS OF AMBIENT AIR ON TENAX®

December, 1991

EXHIBIT A

SUMMARY OF REQUIREMENTS FOR VOLATILE ORGANICS ANALYSIS OF AMBIENT AIR ON TENAX®

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SECTION 1

GENERAL REQUIREMENTS

1.1 The Contractor shall employ procedures specified in this contract in the preparation and analysis of the ambient air samples for the presence and quantitation of the organic compounds listed in Exhibit C.

1.2 The Contractor shall use proven techniques to identify and measure the organic compounds presented in the Target Compound List (TCL) as specified in Exhibit C. The Contractor shall perform sample preparation and analysis procedures as prescribed in Exhibit D, and meet specified sample preservation and holding time requirements.

1.3 For all samples analyzed under this contract, the Contractor shall adhere to the QA/QC protocols specified in Exhibit E and abide by the evidentiary protocols specified in Exhibit F.

1.4 Following sample analysis, the Contractor shall perform data reduction and shall report analytical activities, sample data, and quality control documentation as designated in Exhibit B. Exhibit B contains all reporting and deliverables requirements for this contract, including copies of the data reporting forms and form instructions guide.

1.5 To ensure proper understanding of the language in this contract, Exhibit G contains a glossary of terms. When a term is used in the text without explanation, the glossary meaning shall be applicable. Glossary definitions do not replace or take precedence over specific information included in the document text.

1.6 The samples to be analyzed by the Contractor are from known or suspected hazardous waste sites and may contain hazardous organic and/or inorganic materials at high concentration levels. The Contractor should be aware of the potential hazards associated with the handling and analysis of these samples. It is the Contractor's responsibility to take all necessary measures to ensure the health and safety of its employees. It is also the Contractor's responsibility to follow appropriate disposal procedures according to state and federal regulations.

1.7 In addition, the Contractor must be aware of the importance of maintaining the integrity of the data generated under this contract, as it may be used to make major decisions regarding public health and environmental welfare. In addition, data generated under this contract may be used in litigation against potentially responsible parties in the enforcement of Superfund legislation.

SECTION 2

SPECIFIC REQUIREMENTS

For each sample, the Contractor shall perform the following tasks:

2.1 TASK I: RECEIVE AMBIENT AIR SAMPLES ON TENAX® CARTRIDGES

2.1.1 The Contractor shall receive and handle samples under the chain-of-custody and document control procedures described in Exhibit F.

2.1.2 The Contractor shall provide the required analytical expertise and instrumentation for analyses of the TCL compounds equal to or lower than the quantitation limits specified in Exhibit C. In Exhibit D, EPA provides the Contractor with an appropriate set of analytical procedures that shall be used.

2.1.3 The Contractor shall analyze samples within the maximum holding times specified in Exhibit D, even if these times are less than the maximum data submission time allowed in this contract.

2.1.4 The Contractor is advised that the samples received under this contract are usually from known or suspected hazardous waste sites and may contain high levels of organic materials of a potentially hazardous nature and of unknown structure and concentration, and should be handled throughout the preparation and analysis with appropriate caution. The Contractor shall be responsible for all necessary measures and precautions to ensure the health and safety of laboratory employees.

2.2 TASK II: ANALYZE SAMPLES FOR THE IDENTIFICATION AND QUANTITATION OF SPECIFIC COMPOUNDS

2.2.1 For each sample received, the Contractor shall be required to perform the analyses described in Exhibit D. The documentation that accompanies the sample(s) to the Contractor facility shall indicate specific analytical requirements for that sample or set of samples.

2.2.2 Exhibit D specifies the analytical procedures that shall be used. Exhibit D contains instructions and references for the analysis of ambient air samples containing low-to-medium concentrations of volatile organics for GC/MS analysis. GC/MS may use automated computer programs to facilitate the identification of organic compounds.

2.2.3 For the purpose of this contract, a full sample analysis is defined as analysis for all of the TCL constituents identified in Exhibit C in accordance with the methods in Exhibit D and performance of related QA/QC as specified in Exhibit D and Exhibit E. Laboratory Control Samples (LCS) analyses shall be considered a separate full sample analysis. All other QA/QC requirements are considered an inherent part

of this contract and are included in the contract sample unit price.

2.2.4 The volatile compounds analyzed by GC/MS techniques and initially identified shall be verified by an analyst competent in the interpretation of mass spectra by comparison of the suspect mass spectra to the mass spectrum of a standard of the suspected compound. This procedure requires the use of multiple internal standards. Two criteria must be satisfied to verify the identifications:

2.2.4.1 Elution of the sample component at the same GC relative retention time as the standard component.

2.2.4.2 Correspondence of the sample component and standard component mass spectra.

2.2.5 For each sample analysis, the Contractor shall conduct mass spectral library searches of non-target compound sample components to determine tentative compound identifications as follows:

2.2.5.1 For each volatile organics analysis, the Contractor shall conduct a search to determine the possible identity of up to 10 organic compounds of greatest concentration which are not internal standards, surrogate compounds, and not listed in Exhibit C.

2.2.5.2 In performing searches, the most recent release of the National Institute of Standards and Technology (NIST)/EPA/MSDC mass spectral library must be used.

NOTE: Substances with responses of less than 10 percent of the nearest internal standard are not required to be searched in this fashion.

2.2.5.3 Only after visual comparison of sample spectra with the spectra from the library searches will the mass spectral interpretation specialist assign a tentative identification. If the compound does not meet the identification criteria, it shall be reported as unknown. The mass spectral specialist should give additional classification of the unknown compound, if possible (e.g., unknown aromatic, unknown hydrocarbon, unknown acid type, unknown chlorinated compound). If probable molecular weights can be distinguished, they also should be included.

2.3 TASK III: PERFORM REQUIRED QUALITY ASSURANCE AND QUALITY CONTROL PROCEDURES

2.3.1 All specific QA/QC procedures prescribed in Exhibits D and E shall be strictly adhered to by the Contractor. Records documenting the use of the protocol shall be maintained in accordance with the document control procedures prescribed in Exhibit F, and shall be reported in accordance

with Exhibit B requirements.

2.3.2 The Contractor shall establish and use on a continuing basis QA/QC procedures including the daily or (as required) more frequent use of standard reference solutions from EPA, NIST, or secondary standards traceable thereto, where available at appropriate concentrations (i.e., standard solutions designed to ensure that operating parameters of equipment and procedures, from sample receipt through identification and quantitation, produce reliable data). Exhibits D and E provide specific QA/QC requirements.

2.3.3 Additional QA/QC shall be required quarterly or more frequently, i.e., with each Case or Sample Delivery Group (SDG), in the form of Laboratory Control Samples (LCS) and Performance Evaluation (PE) samples for volatile organics submitted to EPA for Contractor analysis, and in the form of verification of instrument parameters, as described in Exhibit E.

2.3.3.1 EPA has provided to the Contractor formats for the reporting of data (Exhibit B). The Contractor shall be responsible for completing and returning analysis data sheets in the format specified in this contract and within the time specified in the Contract Performance/Delivery Schedule.

2.3.3.2 Use of formats other than those designated by EPA will be deemed as noncompliant. Such data are unacceptable. Resubmission in the specified format at no additional cost to the Government will be required.

2.3.3.3 Computer generated forms may be submitted in the hardcopy data package(s) provided that the forms are in exact EPA format. This means that the order of data elements is the same as on each EPA required form, including form numbers and titles, page numbers and header information, columns, and lines.

2.3.4 The Contractor shall provide analytical equipment and technical expertise for this contract as specified by the following:

2.3.4.1 Gas chromatograph/mass spectrometer (GC/MS) data system capable of meeting all the terms and conditions of the Contract with the following requirements:

2.3.4.1.1 The computer shall be interfaced by hardware to the mass spectrometer and be capable of acquiring continuous mass scans for the duration of the chromatographic program.

2.3.4.1.2 The computer shall be equipped with mass storage devices for saving all data from the GC/MS runs.

2.3.4.1.3 Computer software shall be available to allow searching GC/MS runs for specific ions and plotting the intensity of the ions with respect to time or scan number.

2.3.4.1.4 A computer data system must be interfaced to the MS that allows the continuous acquisition and storage, on machine-readable media, of all mass spectra obtained throughout the duration of the chromatographic program. The computer must have software that allows searching any GC/MS data file for ions of a specified mass and plotting such ion abundances versus time or scan number. This type of plot is defined as an Extracted Ion Current Profile (EICP) or Selected Ion Current Profile (SICP). Software must also be available that allows integrating the abundance in any EICP between specified time or scan number limits. Also, for the non-target compounds, software must be available that allows for the comparison of sample spectra against reference library spectra. The most recent release of the NIST/EPA/MSDC mass spectral library shall be used as the reference library. The data system must be capable of flagging all data files that have been edited manually by laboratory personnel.

2.3.4.1.5 The GC/MS shall be equipped with a GC to MS interface capable of extending a fused silica capillary column into the ion source. The column is to be 50 meters long by 0.25 to 0.53 mm I.D. 100% methyl silicone or 5% phenyl, 95% methyl silicone capillary column, or equivalent.

2.3.4.2 The Contractor shall use a magnetic tape storage device capable of recording data and suitable for long-term, off-line storage. The Contractor shall retain all raw GC/MS data acquired under this contract on magnetic tape in appropriate instrument manufacturer's format. The Contractor is required to retain the magnetic tapes with associated hardcopy tape logbook identifying tape contents (see Exhibit B) for 365 days after data submission. During that time, the Contractor shall submit tapes and logbook within seven days of request, as specified in the Contract Performance/Delivery Schedule.

2.3.4.3 The Contractor shall have a computerized MS library search system capable of providing a forward comparison, using the standard spectra contained in the mass spectral library. The 1985 (or most recent) release of the NIST library (containing 42,261 spectra) must be used.

2.3.4.4 The system shall provide a numerical ranking of the standard spectra most closely corresponding to the sample spectra examined, and the data system shall have software capable of removing background signals from spectra.

2.3.4.5 The Contractor shall have, in-house and operable, a device capable of analyzing volatile organics as described in Exhibit D.

2.3.4.6 The Contractor shall have, in-house, the appropriate standards for <u>all</u> target compounds listed in Exhibit C prior to accepting any samples from the Sample Management Office (SMO). Standards provided by EPA for use in the Preaward Performance Evaluation may not contain all the target compounds and thus shall <u>not</u> be used for routine analyses unless or until they have been supplemented with commercially-available standard materials.

2.3.5 The minimum functional requirements necessary to meet the terms and conditions of this contract are listed below. The Contractor shall designate and use qualified key personnel to perform these functions. The EPA reserves the right to review personnel qualifications and experience.

2.3.5.1 Project Manager

2.3.5.2 GC/MS Laboratory Supervisor

2.3.5.3 Quality Assurance Officer

2.3.5.4 Systems Manager

2.3.5.5 Programmer Analyst

2.3.5.6 GC/MS Operators

2.3.5.7 Mass Spectral Interpreter

2.3.5.8 Chemist (back-up)

NOTE: The Contractor shall designate a Sample Custodian and a Document Control Officer.

2.3.6 The Contractor shall respond within 10 days to requests from data recipients for additional information or explanations that result from the Government's inspection activities.

2.3.7 The Contractor is required to retain unused sample volumes and used sample containers for a period of 60 days after data submission unless otherwise instructed in Exhibit B or Exhibit D.

2.3.8 The Contractor shall adhere to the chain-of-custody and document control procedures described in Exhibit F. Documentation, as described therein, shall be required to show that all procedures are being strictly followed. This documentation shall be reported in the Complete Case File Purge (Exhibit B).

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2.3.9 Sample shipments to the Contractor's facility will be scheduled and coordinated by SMO, acting on behalf of the Administrative Project Officer (APO). The Contractor shall communicate with SMO personnel by telephone as necessary throughout the process of sample scheduling, shipment, analysis, and data reporting, to ensure that samples are properly processed.

2.3.10 If there are problems with the samples (e.g., mixed media, containers broken) or sample documentation/paperwork (e.g., Traffic Reports not with shipment, or sample and Traffic Report numbers do not correspond), the Contractor shall immediately contact SMO for resolution. The Contractor shall immediately notify SMO regarding any problems and laboratory conditions that affect the timeliness of analyses and data reporting. In particular, the Contractor shall notify SMO personnel in advance regarding sample data that will be delivered late and shall specify the estimated delivery date.

2.3.11 Sample analyses will be scheduled by groups of samples, each defined as a Case and identified by a unique EPA Case number assigned by SMO. A Case signifies a group of samples collected at one site or geographical area over a finite time period, and will include one or more field samples with associated blanks. Samples may be shipped to the Contractor in a single shipment or multiple shipments over a period of time, depending on the size of the Case. A Case consists of one or more SDG(s). An SDG is defined by the following:

2.3.11.1 Each Case of field samples received, or

2.3.11.2 Each 20 field samples within a Case, or

2.3.11.3 Each seven calendar day period during which field samples in a Case are received (said period beginning with the receipt of the first sample in the SDG).

2.3.12 Data for all samples in an SDG must be submitted together (in one package) in the order specified in Exhibit B. The SDG number is the EPA number of the first sample received in the SDG. When several samples are received together in the first SDG shipment, the SDG number is the lowest sample number (considering both alpha and numeric designations) in the first group of samples received under the SDG. The SDG number is reported on all data reporting forms. The SDG Receipt Date is the day that the last sample in the SDG is received.

2.3.13 The Contractor is responsible for identifying each SDG as samples are received, through proper sample documentation (see Exhibit B) and communication with SMO personnel.

2.3.14 Each sample received by the Contractor will be labeled with an EPA sample number, and accompanied by a Traffic Report (TR) form bearing

the sample number and descriptive information regarding the sample. The Contractor shall complete and sign the TR, recording the date of sample receipt and sample condition on receipt for each sample container.

2.3.15 The Contractor shall submit signed copies of TRs for all samples in an SDG to SMO within three calendar days following receipt of the last sample in the SDG. TRs shall be submitted in SDG sets (i.e., all TRs for a SDG shall be clipped together) with an SDG Cover Sheet containing information regarding the SDG, as specified in Exhibit B.

2.3.16 EPA Case numbers (including SDG numbers) and EPA sample numbers shall be used by the Contractor in identifying samples received under this contract both verbally and in reports/correspondence.

2.3.17 Samples will be routinely shipped directly to the Contractor through a delivery service. The Contractor shall be available to receive sample shipments at any time the delivery service is operating, including Saturdays and holidays. As necessary, the Contractor shall be responsible for any handling or processing required for the receipt of sample shipments, including pick-up of samples at the nearest servicing airport, bus station, or other carrier service within the Contractor's geographical area.

2.3.18 The Contractor shall accept all samples scheduled by SMO, provided that the total number of samples received in any calendar month does not exceed the monthly limitation expressed in the contract. Should the Contractor elect to accept additional samples, the Contractor shall remain bound by all contract requirements for analysis of those samples accepted.

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SECTION 3

DETAILED TECHNICAL & MANAGEMENT REQUIREMENTS

The Contractor shall have the following technical and management capabilities:

3.1 PERSONNEL

3.1.1 Project Manager

3.1.1.1 Responsible for all technical efforts of the laboratory to meet all terms and conditions of the contract.

3.1.1.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.1.3 Experience: Minimum of three years of laboratory experience, including at least one year in a supervisory position.

3.1.2 GC/MS Laboratory Supervisor

3.1.2.1 Responsible for all technical efforts of the GC/MS laboratory to meet all terms and conditions of the contract.

3.1.2.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.2.3 Experience: Minimum of three years of laboratory experience in operating a GC/MS, including at least one year in a supervisory position.

3.1.3 Quality Assurance Officer

3.1.3.1 Responsible for overseeing the quality assurance aspects of data generation and reporting directly to upper management.

3.1.3.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.3.3 Experience: Minimum of three years of laboratory experience, including at least one year of applied experience with QA principles and practices in an analytical laboratory.

3.1.4 Systems Manager

3.1.4.1 Responsible for the management and quality control of all computing systems (hardware, software, documentation, and procedures), generating, updating, and performing quality control on

automated deliverables.

3.1.4.2 Education: Minimum of Bachelor's degree with four or more intermediate courses in programming, information management, database management systems, or systems requirements analysis.

3.1.4.3 Experience: Minimum of three years experience in data or systems management or programming including one year experience with software used for data management and generation of deliverables.

3.1.5 Program Analyst

3.1.5.1 Responsible for the installation, operation, and maintenance of software and programs; generating, updating, and performing quality control procedures on analytical databases and automated deliverables.

3.1.5.2 Education: Minimum of Bachelor's degree with four or more intermediate courses in programming, information management, information systems, or systems requirements analysis.

3.1.5.3 Experience: Minimum of two years experience in systems or applications programming including one year of experience with software used for data management and generation of deliverables.

3.1.6 Gas Chromatography/Mass Spectrometer (GC/MS) Operator

3.1.6.1 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.6.2 Experience: Minimum of one year of experience in operating and maintaining GC/MS instruments in conjunction with the education requirement; or in lieu of education requirement, three additional years of experience in operating and maintaining GC/MS instrumentation.

3.1.7 Mass Spectral Interpreter

3.1.7.1 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline with specialized training in GC/MS.

3.1.7.2 Experience: Minimum of two years of applied experience with GC/MS analysis of environmental samples.

3.1.8 Technical Staff Redundancy

3.1.8.1 In order to ensure continuous operations to accomplish the required work as specified by the contract, the bidder shall have a minimum of one chemist available at all times as a back-up technical

person with the following qualifications.

3.1.8.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.8.3 Experience: Minimum of one year of experience in each of the following areas: GC/MS operation and maintenance.

3.2 FACILITIES

The adequacy of the facilities and equipment is as important as the technical staff for accomplishing the required work as specified by the EPA contract.

3.2.1 Sample Receipt Area

Adequate, contamination-free, well-ventilated work space with chemical resistant bench top shall be available for receipt and safe handling of EPA samples.

3.2.2 Storage Area

Sufficient refrigerator space to maintain unused EPA sample volume for up to 60 days after data submission shall be provided. Volatile samples must be stored in a refrigerator used only for storage of volatile samples from this contract. Samples must be stored in an atmosphere demonstrated to be free from all potential contaminants. Samples and standards must be stored separately.

3.2.3 Sample/Standard Preparation Area

Adequate, contamination-free, well-ventilated work space shall be provided with:

3.2.3.1 Benches with chemical resistant tops.

3.2.3.2 Exhaust hoods.

3.2.3.3 Glove box or isolated area in which to prepare standard materials.

3.2.3.4 Source of distilled or demineralized organic-free water.

3.2.3.5 Analytical balance(s) located away from draft and rapid change in temperature.

3.3 INSTRUMENTATION

At a minimum, the Contractor shall have the following instruments

operative at the time of the Preaward Site Evaluation and committed for the full duration of the contract.

3.3.1 100 Samples/Month Capacity Requirements

No. of Instrument(s)	Type of Instrument
1	GC/MS

NOTE: The Contractor shall have one (1) complete GC/MS system available (operational) at all times as a back-up system. These instruments must be included in the bidder's inventory of equipment. In addition, the Contractor shall have an in-house stock of instrument parts and circuit boards to ensure continuous operation to meet contract-specified holding and turnaround times.

3.3.2 200 Samples/Month Capacity Requirements

No. of Instrument(s)	Type of Instrument
2	GC/MS

NOTE: These instruments must be included in the bidder's inventory of equipment. In addition, the Contractor shall have an in-house stock of instrument parts and circuit boards to ensure continuous operation to meet contract-specified holding and turnaround times.

3.3.3 Instrument Specifications

Further information on instrument specifications and required ancillary equipment may be found in Exhibit D and other Exhibits in this contract.

3.4 DATA HANDLING AND PACKAGING

The Contractor shall be able to submit reports and data packages as specified in Exhibit B. To complete this task, the Contractor shall be required to:

3.4.1 Provide space, tables, and copy machines to meet the contract requirements.

3.4.2 Designate personnel responsible for report preparations and submission.

3.5 LABORATORY MANAGEMENT CAPABILITY

The Contractor shall have an organization with well-defined responsibilities for each individual in the management system to ensure

sufficient resources for EPA contract(s) and to maintain a successful operation. To establish this capability, the Contractor shall designate personnel to carry out the following responsibilities for the EPA contract. Functions include, but are not limited to, the following:

3.5.1 Technical Staff

Responsible for all technical efforts for the EPA contract such as sample analysis, sample validation, and troubleshooting of all instruments.

3.5.2 Project Manager

Responsible for overall aspects of EPA contract(s) (from sample receipt through data delivery) and shall be the primary contact for EPA Headquarters Administrative Project Officer (APO) and Regional Technical Project Officers (TPO).

3.5.3 Sample Custodian

Responsible for receiving the EPA samples (logging, handling, and storage).

3.5.4 Quality Assurance Officer

Responsible for overseeing the quality assurance aspects of the data and reporting directly to upper management.

3.5.5 Document Control Officer

Responsible for ensuring that all documents generated are placed in the Complete SDG File for inventory and are delivered to the appropriate EPA Region or other receiver as designated by EPA.

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EXHIBIT B

REPORTING

AND

DELIVERABLES REQUIREMENTS

December, 1991

EXHIBIT B

REPORTING AND DELIVERABLES REQUIREMENTS

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SECTION 1

CONTRACT REPORTS/DELIVERABLES DISTRIBUTION

The following table summarizes the contract reporting and deliverables requirements specified in the Contract Schedule and includes the distribution of each deliverable.

NOTE: Specific recipient names and addresses are subject to change during the term of the contract. The EPA APO or SMO will notify the Contractor in writing of such changes when they occur.

Item	No. of Copies	Schedule and Delivery	Distribution		
			(1)	(2)	(3)
Updated Standard Operating Procedures (SOPs)	2	45 days after contract award.		X	X
*Sample Traffic Reports	1	***3 days after receipt of last sample in Sample Delivery Group (SDG).	X		
**Sample Data Summary Package	1	14 days after receipt of last sample in SDG.	X		
**Sample Data Package including the Performance Evaluation (PE) Sample	3	35 days after receipt of last sample in SDG	X	X	X
Results of Intercomparison Study/Preaward Performance Evaluation (PPE) Sample	2	35 days after receipt of last sample in SDG	X	X	
Complete SDG File	1	35 days after data receipt of last sample in SDG.		X	
GC/MS Tapes	Lot	Retain for 365 days after data submission, or submit within 7 days after receipt of written request by APO.	As Directed		
****Quality Assurance Plan	1	Submit copy within 7 days by written request by APO.	As Directed		

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Distribution

(1) Sample Management Office
(2) Environmental Monitoring Systems Laboratory-Las Vegas
(3) USEPA Region

* Also required in each Sample Data Package.

** Concurrent delivery of these items to all recipients is required.

*** An SDG is a group of samples within a Case, received over a period of seven days or less and not exceeding 20 samples. Data for all samples in the SDG are due concurrently. (See Exhibit A, Task III, for further description).

**** See Exhibit E for description.

NOTE: As specified in the Contract Schedule in the IFB (Government Furnished Supplies and Materials), unless otherwise instructed by SMO, the Contractor shall dispose of unused sample volume and used sample bottles/containers no earlier than 60 days following submission of analytical data.

Address

(1) USEPA Contract Laboratory Program
Sample Management Office
P.O. Box 818
Alexandria, VA 22313

For overnight delivery service, use street address:

300 North Lee Street
Alexandria, VA 22313

(2) USEPA Environmental Monitoring Systems Laboratory
P.O. Box 93478
Las Vegas, NV 89193-3478
ATTN: Data Audit Staff

For overnight delivery service, use street address:

944 E. Harmon, Executive Center
Las Vegas, NV 89109
ATTN: Data Audit Staff

(3) USEPA REGIONS:

SMO, acting on behalf of the EPA APO, will provide the Contractor with the list of addresses for the 10 EPA Regions. SMO will provide the Contractor with updated Regional name/address lists as necessary throughout the period of the contract and identify other client recipients on a case-by-case basis.

NOTE: Specific recipient names and addresses are subject to change during the term of the contract. The APO will notify the Contractor in writing of such changes when they occur.

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SECTION 2

REPORT DESCRIPTIONS AND ORDER OF DATA DELIVERABLES

2.1 INTRODUCTION

2.1.1 The Contractor shall provide reports and other deliverables according to the schedule specified in Section F of the IFB, "SCHEDULE INFORMATION." The required content and form of each deliverable is described in this Exhibit.

2.1.2 All reports and documentation shall be:

2.1.2.1 Legible;

2.1.2.2 Clearly labeled and completed in accordance with instructions in this Exhibit;

2.1.2.3 Arranged in the order specified in this section;

2.1.2.4 Paginated; and

2.1.2.5 Single-sided.

2.1.3 If submitted documentation does not conform to the above criteria, the Contractor will be required to resubmit such documentation with deficiency(ies) corrected, at no additional cost to the Government.

2.1.4 Whenever the Contractor is required to submit or resubmit data as a result of an on-site laboratory evaluation or through an APO/TPO action, the data shall be clearly marked as "ADDITIONAL DATA" and shall be sent to all three contractual data recipients (SMO, EMSL-LV, and Region). A cover letter shall be included that describes which data are being delivered, to which EPA Case(s) the data pertain, and who requested the data.

2.1.5 Section 3 of this Exhibit contains instructions to the Contractor for properly completing all data reporting forms to provide the EPA with the required documentation and contains the required data forms in EPA-specified format.

2.1.6 Descriptions of the requirements for each deliverable item cited in the Contract Performance/Delivery Schedule (see Section F of the IFB "SCHEDULE INFORMATION") are specified in this Section. Items submitted concurrently must be arranged in the order listed. Additionally, the components of each item must be arranged in the order presented herein.

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2.2 UPDATED STANDARD OPERATING PROCEDURES

2.2.1 The Contractor shall submit updated copies of all required Standard Operating Procedures (SOPs) that were submitted with the Prebid Performance Evaluation (PPE) sample results. The updated SOPs must address any and all issues of laboratory performance and operation identified by the Contractor in the review of the PPE sample data and the evaluation of Bidder-Supplied Documentation.

2.2.2 The Contractor must supply SOPs for the following.

2.2.2.1 Evidentiary SOPs.

2.2.2.2 Sample receipt and logging.

2.2.2.3 Sample storage area.

2.2.2.4 Preventing sample contamination.

2.2.2.5 Security for laboratory and samples.

2.2.2.6 Traceability/equivalency of standards.

2.2.2.7 Maintaining instrument records and bound logbooks.

2.2.2.8 Glassware cleaning.

2.2.2.9 Technical and managerial review of laboratory operation and data package preparation.

2.2.2.10 Internal review of contractually-required QA/QC data for each individual data package.

2.2.2.11 Sample analysis, data handling, and data reporting.

2.2.2.12 Chain-of-custody and document control, including case file preparation.

2.2.2.13 Sample data validation/self-inspection system, including:

- Data flow and chain-of-command for data review;
- Procedures for measuring precision and accuracy;
- Evaluation parameters for identifying systematic errors;
- Procedures to ensure that hardcopy data are complete and compliant

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with the requirements in Exhibit B;

- Demonstration of internal QA inspection procedure (demonstrated by supervisory sign-off on personal notebooks, internal PE samples, etc.);
- Frequency and type of internal audits (e.g., random, quarterly, spot checks, perceived trouble areas);
- Demonstration of problem identification, corrective actions, and resumption of analytical processing resulting from internal audit (i.e., QA feedback); and
- Documentation of audit reports (internal and external), response, corrective action, etc.

2.2.2.14 Data Handling.

2.2.2.14.1 Data Management procedures are defined as written procedures that are clearly defined for all databases and files used to generate or re-submit deliverables specifying the acquisition or entry, update, correction, deletion, storage, and security of computer-readable data and files. Key areas of concern include: system organization including personnel and security, demonstration, operations, traceability, and quality control.

2.2.2.14.2 Data manually entered from hardcopy must be subjected to quality control procedures and error rates estimated.

2.2.2.14.3 The record of changes in the form of corrections and updates to data originally generated, submitted, and/or resubmitted must be documented to allow traceability of updates. Documentation must include the following information for each change:

- Justification or rationale for the change;
- Initials of the person making the changes or changes. Data changes must be identified when generating the deliverables;
- Changed documentation must be retained according to the schedule of the original deliverable;
- Resubmitted deliverables must be reinspected as a part of the laboratory's internal inspection process prior to submission. The entire deliverable and not just the changes must be reinspected;
- The laboratory manager must approve changes to originally

submitted deliverables; and

- Documentation of data changes may be requested by laboratory auditors.

2.2.2.14.4 Life cycle management procedures must be applied to computer systems used to generate and edit contract deliverables. Such systems must be thoroughly tested and documented prior to utilization.

2.2.2.14.5 A software test and acceptance plan including test requirements, test results, and acceptance criteria must be developed, followed, and available in written form.

2.2.2.14.6 System changes shall not be made directly to production systems generating deliverables. Changes must be made first to a development system and tested prior to implementation.

2.2.2.14.7 Each version of the production system will be given an identification number, date of installation, date of last operation, and archived.

2.2.2.14.8 System and operations documentation shall be developed and maintained for each system. Documentation must include a user's manual and an operations and maintenance manual.

2.2.2.14.9 Individual(s) responsible for the following functions shall be identified:

- System operation and maintenance including documentation and training; and

- Database integrity including data entry, data updating and QC.

2.2.2.14.10 Data and system security, backup, and archiving.

2.3 SAMPLE TRAFFIC REPORTS

2.3.1 The original sample TR page marked "Lab Copy for Return to SMO" shall be submitted to SMO with laboratory receipt information and signed in original Contractor signature, for each sample in the SDG.

2.3.2 TRs shall be submitted in SDG sets (i.e., TRs for all samples in an SDG shall be clipped together), with an SDG Cover Sheet attached.

2.3.3 The SDG Cover Sheet shall contain the following items:

2.3.3.1 Laboratory name.

2.3.3.2 Contract number.

2.3.3.3 Sample analysis price - full sample price from contract.

2.3.3.4 Case number.

2.3.3.5 List of EPA sample numbers of all samples in the SDG, identifying the first and last samples received, and their dates of receipt.

NOTE: When more than one sample is received in the first or last SDG shipment, the "first" sample received would be the lowest sample number (considering both alpha and numeric designations), and the "last" sample received would be the highest sample number (considering both alpha and numeric designations).

2.3.4 Each TR shall be clearly marked with the SDG Number and the EPA sample number of the first sample in the SDG. This information shall be entered below the laboratory receipt date on the TR. The TR for the last sample received in the SDG shall be clearly marked "SDG - FINAL SAMPLE."

2.3.5 If samples are received at the laboratory with multi-sample TRs, all the samples on one multi-sample TR may not necessarily be in the same SDG. In this instance, the laboratory shall make the appropriate number of photocopies of the TR, and submit one copy with each SDG cover sheet.

2.4 SAMPLE DATA SUMMARY PACKAGE

2.4.1 As specified in the Delivery Schedule, one Sample Data Summary Package shall be delivered to SMO concurrently with delivery of other required sample data. The Sample Data Summary Package shall be submitted separately (i.e., separated by rubber bands, clips or other means) directly preceding the Sample Data Package.

2.4.2 The Sample Data Summary Package shall contain data for samples in one SDG of the Case, as follows:

2.4.2.1 Cover Page.

2.4.2.2 By sample, tabulated target compound results (FORM I-AAVT) and tentatively identified compounds (FORM I-AAVT-TIC).

2.4.2.3 Laboratory Control Sample results (FORM III-AAVT).

2.4.2.4 Blank summary (FORM II-AAVT) and tabulated results (FORM I) including tentatively identified compounds (FORM I-AAVT-TIC).

2.4.2.5 Initial and Continuing Calibration Data (FORM V-AAVT and FORM VI-AAVT).

2.4.2.6 Internal standard area and retention time data (FORM VII-AAVT).

2.4.2.7 Surrogate Recovery (FORM IX-AAVT).

2.4.2.8 Analytical Sequence (FORM X-AAVT).

2.5 SAMPLE DATA PACKAGE

2.5.1 The sample data package shall be complete, consecutively paginated, and shall include data for analysis of all samples in an SDG such as field samples, blanks, and laboratory control samples.

2.5.2 The sample data package is divided into five units as follows:

2.5.2.1 Cover page.

2.5.2.1.1 This document shall be clearly labeled "Cover Page." The Cover Page shall contain: laboratory name; laboratory code; contract number; case number; SDG number; SAS number; EPA sample numbers in alphanumeric order, showing EPA sample number cross-referenced with laboratory ID numbers; and comments, describing in detail any problems encountered in processing the samples in the data package.

2.5.2.1.2 The Cover Page shall contain the following statement, verbatim:

"I certify that this data package is in compliance with the terms and conditions of the contract, both technically and for completeness, for other than the conditions detailed above. Release of the data contained in this hardcopy data package has been authorized by the Laboratory Manager or the Manager's designee, as verified by the following signature."

2.5.2.1.3 This statement shall be directly followed by the signature of the Laboratory Manager or his designee with a typed line below it containing the signer's name and title, and the date of signature.

2.5.2.1.4 In the event that the Laboratory Manager cannot validate all data reported for each sample, he/she must provide a detailed description of the problems associated with the sample(s) on the Cover Page.

2.5.2.2 Sample data (Results).

2.5.2.2.1 Sample data shall be arranged in packets with the Analysis Data Sheet (FORM I-AAVT, including FORM I AAVT-TIC), followed by the raw data for volatile samples. These sample packets should then be placed in increasing EPA sample number order, considering both letters and numbers.

NOTE: FORM I AAVT-TIC is the tabulated list of the highest probable match for up to 10 organic compounds that are not surrogates and internal standards and are not listed in Exhibit C (TCL). It includes the Chemical Abstracts Service (CAS) Registry Number, tentative identification, and estimated concentration.

2.5.2.2.1.1 Reconstructed total ion chromatograms (RIC) for each sample or sample extract.

2.5.2.2.1.2 RICs must be normalized to the largest nonsolvent component, and must contain the following header information:

- EPA sample number;
- Date and time of analysis;
- GC/MS instrument ID; and
- Laboratory file ID.

2.5.2.2.1.3 Internal standards are to be labeled with the names of compounds, either directly out from the peak, or on a print-out of retention times if retention times are printed over the peak.

2.5.2.2.1.4 Quantitation Report: The complete data system report must be included in all sample data packages, in addition to the reconstructed ion chromatogram for preliminary identification and/or quantitation using either the automated or manual data system procedures. The complete data system report shall include all of the information listed below:

- EPA sample number;
- Date and time of analysis;
- RT or scan number of identified target compounds;
- Ion used for quantitation with measured area;

- Copy of area table from data system;
- GC/MS instrument ID; and
- Laboratory file ID.

2.5.2.2.1.5 In all instances where the data system report has been edited, or where manual integration or quantitation has been performed, the GC/MS operator shall identify such edits or manual procedures by initialing and dating the changes made to the report.

2.5.2.2.1.6 Target Compound Mass Spectra: For each sample, by each compound identified, copies of the raw spectra and copies of background subtracted mass spectra of target compounds listed in Exhibit C that are identified in the sample and corresponding background subtracted target compound standard mass spectra shall be included in the data package. Spectra must be labeled with EPA sample number, laboratory file ID, date and time of analysis, and GC/MS instrument ID; compound names must be clearly marked on all spectra.

2.5.2.2.1.7 Tentatively Identified Compound Mass Spectra and Library Matches: For each sample, by each compound identified, copies of mass spectra of organic compounds not listed in Exhibit C, Tentatively Identified Compounds, with associated best-match spectra (three best matches), labeled as above shall be included in the data package.

2.5.2.2.2 Volatile Standard Data:

2.5.2.2.2.1 Initial Calibration: All initial calibration data must be included for all analyses associated with the SDG. When more than one initial calibration is performed, the reconstructed ion chromatograms and quantitation reports and each type of form must be put in chronological order, by instrument as follows:

- Initial Calibration Data Sheet (FORM V-AAVT);
- Internal Standard Area and Retention Time Summary (FORM VII-AAVT); and
- Volatile standard(s) reconstructed ion chromatograms and quantitation reports (or legible facsimiles) for the initial (five point) calibration are labeled according to 2.5.2.2.1.2 and 2.5.2.2.1.4. Spectra are not required.

2.5.2.2.2.2 Continuing Calibration: When more than one continuing

calibration is performed, the reconstructed ion chromatograms and quantitation reports and each type of form must be put in chronological order, by instrument if more than one instrument is used as follows:

- Continuing Calibration Data Sheet (FORM VI-AAVT);
- Internal Standard Area and Retention Time Summary (FORM VII-AAVT); and
- Volatile standard(s) reconstructed ion chromatograms and quantitation reports (or legible facsimiles) for the initial (five point) calibration are labeled according to 2.5.2.2.1.2 and 2.5.2.2.1.4. Spectra are not required.

2.5.2.3 Quality control summary.

2.5.2.3.1 The quality control summary shall contain the following forms:

NOTE: If more than one form is necessary, duplicate forms must be arranged in chronological order by date of analysis or instrument.

- Blank Summary (FORM Ii-AAVT);
- GC/MS Instrument Performance Check (FORM IV-AAVT); and
- Internal Standard Area and RT Summary (FORM VII-AAVT).

2.5.2.3.2 The quality control summary shall also contain the following:

NOTE: If more than one form is necessary, duplicate forms must be arranged in chronological order by date of analysis or instrument.

- GC/MS Tuning Data.
  - GC/MS Tuning - BFB data, for each 12-hour period, shall be arranged in chronological order by instrument for each GC/MS system utilized;
  - GC/MS Tuning and Mass Calibration - BFB (FORM IV-AAVT);
  - Bar graph spectrum, labeled as in 2.5.2.2.1.2 and 2.5.2.2.1.4; and
  - Mass listing, labeled as in 2.5.2.2.1.2. and 2.5.2.2.1.4.

- Blank data shall be arranged in chronological order by instrument. The blank data shall be arranged in packets with both of the Organic Analysis Data Sheets (FORM I-AAVT and FORM I-AAVT-TIC), followed by the raw data for volatile samples.

- Laboratory Control Sample Data.

  - Laboratory Control Sample Data Sheet (FORM III-AAVT); and

  - Reconstructed ion chromatograms and quantitation reports or legible facsimile (GC/MS), labeled according to 2.5.2.2.1.2 and 2.5.2.2.1.4. Spectra are not required.

2.5.2.4 Raw data.

2.5.2.4.1 For each reported value, the Contractor shall include all raw data from the instrument used to obtain the sample values (except for raw data for quarterly verifications of instrument parameters). Raw data shall contain all instrument readouts used for the sample results, including those readouts that may fall below the method quantitation limit. All GC/MS instruments must provide legible hard copy of the direct real-time instrument readout (i.e., stripcharts, printer tapes, etc.). A photocopy of the direct sequential instrument readout must be included.

2.5.2.4.2 All raw data shall include concentration units for GC/MS.

2.5.2.4.3 Organic raw data must be labeled with EPA sample number and appropriate codes as shown in Tables B-1 to identify unequivocally the following:

- Initial and continuing calibration standards;

- Blanks;

- Duplicates;

- Instrument used, any instrument adjustments, data corrections or other apparent anomalies on the measurement record, including all data voided or data not used to obtain reported values and a brief written explanation;

- Data and EPA sample number for GC/MS analyses clearly and sequentially identified on the raw data;

- All calculations for sample data, including percent recovery, coefficient of variation, slope and y-intercept of linear fit; and

- Time and date of each analysis. Instrument run logs can be submitted if they contain this information. If the instrument does not automatically provide time of analysis, these must be manually entered on all raw data for initial and continuing calibration verification and blanks, as well as interference check samples and linear range analysis standards.

2.5.2.5 Preparation logs.

These logs must include the following:

- Date;

- Standard weights and/or volumes;

- Sufficient information to identify unequivocally which QC samples (e.g., laboratory control sample, blank) correspond to each batch prepared; and

- Comments describing any significant sample changes or reactions which occur during preparation.

2.5.2.6 Sample TRs

A legible copy of the sample TRs and SDG Cover Sheet shall be submitted as described in section 2.3 of this Exhibit for all of the samples in the SDG. The TRs shall be arranged in increasing EPA sample number order, considering both alpha and numeric designations.

2.6 RESULTS OF INTERCOMPARISON/PERFORMANCE EVALUATION SAMPLE ANALYSES

The reporting of analytical results for Intercomparison Study/Preaward Performance Evaluation (PPE) sample analyses includes all requirements specified in section 2.4 for reporting of sample data. The PPE sample shall be carried through the exact same process as an analytical and field samples.

2.7 COMPLETE CASE FILE PURGE

2.7.1 The Complete SDG File package includes all laboratory records received or generated for a specific Case that have not been previously

submitted to EPA as a deliverable. These items shall be submitted to EPA as a deliverable. These items shall be submitted along with their Document Inventory Sheet FORM AADC-2 (see Exhibit E for description of document numbering and inventory procedure). These items include, but are not limited to, sample tags, custody records, sample tracking records, analysts' logbook pages, bench sheets, instrument readout records, computer printouts, raw data summaries, instrument logbook pages (including instrument conditions), correspondence, and the document inventory.

2.7.2 Shipment of the Complete SDG File package by first class mail, overnight courier, priority mail, or equivalent, is acceptable. Custody seals, which are provided by EPA, shall be placed on shipping containers and a document inventory and transmittal letter included. The Contractor is not required to maintain any documents for a sample Case after submission of the Complete SDG File package; however, the Contractor should maintain a copy of the document inventory and transmittal letter.

2.8 GC/MS TAPES

2.8.1 The Contractor must store all raw and processed GC/MS data on magnetic tape, in appropriate instrument manufacturer's format. This tape must include data for samples, blanks, laboratory control samples, initial calibrations, continuing calibrations, and BFB, as well as all laboratory generated spectral libraries and quantitation reports required to generate the data package. The Contractor shall maintain a written reference logbook of tape files to EPA sample number, calibration data, standards, blanks, and laboratory control samples. The logbook should include EPA sample numbers and standard and blank IDs, identified by Case and SDG.

2.8.2 The Contractor is required to retain the GC/MS tapes for 365 days after data submission. During that time, the Contractor shall submit tapes and associated logbook pages within seven days after receipt of a written request from the APO.

2.9 QUALITY ASSURANCE PLAN (QAP)

2.9.1 The Contractor shall prepare a written Quality Assurance Plan (QAP) which describes the procedures that are implemented to achieve the following: maintain data integrity, validity, and useability; ensure that analytical measurement systems are maintained in an acceptable state of stability and reproducibility; detect problems through data assessment and established corrective action procedures which keep the analytical process reliable; and document all aspects of the measurement process in order to provide data which are technically sound and legally defensible.

2.9.2 The QAP must present, in specific terms, the policies, organization, objectives, functional guidelines, and specific QA/QC activities designed

to achieve the data quality requirements in this contract. Where applicable, SOPs pertaining to each parameter shall be included or referenced as part of the QAP. The QAP must be available during on-site laboratory evaluation and upon written request by the APO.

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Table B-1

Codes for Labeling Organic Data

Sample	XXXXX
Duplicate Sample	XXXXXD
Laboratory Control Sample	VTLCS##
Laboratory Method Blank	VTMBLK##
Field Blank	VTFBLK##
Standards	VTSTD###

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SECTION 3

FORM INSTRUCTIONS GUIDE/DATA REPORTING FORMS

3.1 Form Instructions Guide

3.1.1 This section includes specific instructions for the completion of all required forms for volatile organics analysis utilizing Tenax® and other adsorbents. Each of the forms is specific to a given function. These instructions are arranged in the following order:

3.1.1.1 General Information and Header Information

3.1.1.2 Cover Page [COVER PAGE - AAVT]

3.1.1.3 Analysis Data Sheet [FORM I - AAVT]

3.1.1.4 Tentatively Identified Compounds [FORM I - AAVT-TIC]

3.1.1.5 Blank Summary [FORM II - AAVT]

3.1.1.6 Laboratory Control Sample Data Sheet [FORM III - AAVT]

3.1.1.7 GC/MS Instrument Performance Check and Mass Calibration [FORM IV - AAVT]

3.1.1.8 Initial Calibration Data Sheet [FORM V - AAVT]

3.1.1.9 Continuing Calibration Data Sheet [FORM VI - AAVT]

3.1.1.10 Internal Standard Area and Retention Times Summary [FORM VII - AAVT]

3.1.1.11 Tenax® Cartridge Certification [FORM VIII - AAVT]

3.1.1.12 Surrogate Recovery [FORM IX - AAVT]

3.1.1.13 Analytical Sequence [FORM X - AAVT]

3.1.1.14 Sample Receipt/Log-In Sheet [FORM AADC-1]

3.1.1.15 Complete SDG File (CSF) Document Inventory Sheet [FORM AADC-2]

3.1.2 General Information and Header Information

3.1.2.1 Values must be reported on the hardcopy forms according to the individual form instructions in this Section. For example, results for concentrations of volatile organic target compounds must

be reported to three significant figures if the value is greater than or equal to 10, and to two significant figures for values less than 10.

3.1.2.2 All characters which appear on the data reporting forms presented in the contract must be reproduced by the Contractor when submitting data, and the format of the forms submitted must be identical to that shown in the contract. No information may be added, deleted, or moved from its specified position without prior written approval of the EPA APO. The names of the various fields and compounds (i.e., "Lab Code," "Chloromethane") must appear as they do on the forms in the contract.

3.1.2.3 Alphabetic entries made onto the forms by the Contractor shall be in ALL UPPERCASE letters (i.e., "LOW", not "Low" or "low").

3.1.2.4 Six (6) pieces of information are common to the header sections of each data reporting form. They are Lab Name, Lab Code, Contract No., Case No., SDG No., and SAS No. These pieces of information must be entered on every form and must match on every form.

3.1.2.4.1 The "Lab Name" shall be the name chosen by the Contractor to identify the laboratory. It may not exceed 25 characters.

3.1.2.4.2 The "Lab Code" is an alphabetical abbreviation of up to 6 letters, assigned by the EPA, to identify the laboratory and aid in data processing. This code shall be assigned by the EPA at the time a contract is awarded, and shall not be modified by the Contractor, except at the direction of the EPA. If a change of name or ownership occurs at the laboratory, the Lab Code will remain the same until the contractor is directed by the EPA to use another Lab Code assigned by the EPA.

3.1.2.4.3 The "Contract No." is the number of the EPA contract under which the analyses were performed.

3.1.2.4.4 The "Case No." is the EPA-assigned case number associated with the sample, and reported on the Traffic Report.

3.1.2.4.5 The "SDG No." is the Sample Delivery Group (SDG) number. The SDG No. is the EPA Sample Number of the first sample received in the SDG. When several samples are received together in the first SDG shipment, the SDG number shall be the lowest sample number (considering both alpha and numeric designations) in the first group of samples received under the SDG.

3.1.2.4.6 The "SAS No." is the EPA-assigned number for analyses

performed under Special Analytical Services (SAS). If samples are to be analyzed under SAS only and reported on these forms, then enter SAS No. and leave Case No. blank. If samples are analyzed according to the "Routine Analytical Services" (RAS) protocols and have additional SAS requirements, list both Case No. and SAS No. on all forms. If the analyses have no SAS requirements, leave "SAS No." blank. Note that some samples in an SDG may have a SAS No. while others do not.

3.1.2.5 The "EPA Sample No." is the other information common to most of the forms. This number appears either in the upper right corner of the form, or as the left column of a table summarizing data from a number of samples. The "EPA Sample No." should be entered on the center part of the box.

3.1.2.5.1 All samples, spikes, blanks, and standards shall be identified with an EPA Sample Number. For field samples, the EPA Sample Number is the unique identifying number given in the Traffic Report that accompanied that sample.

3.1.2.5.2 In order to facilitate data assessment, the following sample suffixes must be used:

XXXXX = EPA sample number

XXXXXD = Duplicate sample

3.1.2.5.3 VOC standards prepared on Tenax® cartridges shall be identified as VTSTD###, where ### is the concentration in ng (on column) of the volatile standards (i.e., 005, 050, 100, 200, and 250).

3.1.2.5.4 As for the blank identifiers, these designations will have to be combined with other information to uniquely identify each blank. Field blanks shall be identified as VTFBLK## and laboratory method blanks shall be identified as VTMBLK##. The "EPA Sample No." must be unique for each blank analysis within an SDG. The laboratory must achieve this by replacing the two-character "##" terminator of the identifier with one or two characters or numbers, or a combination of both. For example, possible identifiers for volatiles-Tenax® blanks would be VTMBLK01, VTMBLK02, etc.

3.1.2.5.5 LCSs shall be identified as VTLCS##. The "EPA Sample No." must be unique for each LCS analysis within an SDG. The laboratory shall achieve this by replacing the two-character "##" terminator of the identifier with one or two characters or numbers, or a combination of both. For example, possible identifiers for volatiles-Tenax® cartridge LCSs would be VTLCS01, VTLCS02, etc.

3.1.2.6 Several other pieces of information are common to many of the Data Reporting Forms. These include Lab Sample ID, Lab File ID, Date Received, etc. Following is a brief description of each of these entries.

3.1.2.6.1 "Lab Sample ID" is an optional laboratory-generated internal identifier. Up to 12 alpha-numeric characters may be reported here. If the contractor does not have a Lab Sample ID, this field may be left blank.

3.1.2.6.2 "Lab File ID" is the laboratory-generated name of the GC/MS data system file containing information pertaining to a particular analysis. Up to 14 alpha-numeric characters may be used here.

3.1.2.6.3 "Date Received" is the date of sample receipt at the laboratory, as noted on the Traffic Report (i.e., the VTSR). It should be entered as MM/DD/YY.

3.1.2.6.4 "Date Analyzed" should be entered in a similar fashion. The date of sample receipt will be compared with the analysis dates to ensure that contract holding times were not exceeded.

3.1.2.6.5 "Instrument ID" is common to many of the forms, particularly those containing calibration data. The identifier used by the laboratory must include some indication of the manufacturer and/or model of the instrument, and contain additional characters that differentiate between all instrument of the same type in the laboratory.

3.1.2.6.6 "GC Column ID" or "Column ID" is common to various other forms. This field is used to identify the GC column.

3.1.2.7 For rounding off numbers to the appropriate level of precision, observe the following common rules. If the figure following those to be retained is less than 5, drop it (round down). If the figure is greater than 5, drop it and increase the last digit to be retained by 1 (round up). If the figure following the last digit to be retained equals 5, round up if the digit to be retained is odd, and round down if that digit is even.

3.1.2.8 All results must be transcribed to the forms in the raw data with the specified number of decimal places that are described in Exhibit B. The raw data result is to be rounded only when the number of figures in the raw data result exceeds the maximum number of figures specified for that result entry for that form. If there are not enough figures in the raw data result to enter in the specified space for that result, then zeros must be used for decimal places to the specified number of reporting decimals for that result for a specific form. The following examples are provided:

Raw Data Result	Specified Format	Correct Entry
5.9	6.3	5.900
5.99653	6.3	5.997
95.99653	6.3	95.997
995.99653	6.3	995.997
9995.996	6.3	9996.00
99995.9	6.3	99995.9
999995.9	6.3	invalid

NOTE: 6.3 stands for a maximum of six significant figures and up to three decimal places.

3.1.3 **Cover Page [COVER PAGE - AAVT]**

3.1.3.1 This form is used to list all billable samples analyzed within an SDG, and to provide certain analytical information and general comments. It is also the document which is signed by the Laboratory Manager to authorize and release all data and deliverables associated with the SDG.

3.1.3.2 Under the "EPA Sample No." column, enter up to 7 characters for the EPA sample number (including blanks and duplicates) for each required analysis within the SDG. Duplicates must contain a "D" suffix. These sample numbers must be listed on the form in ascending alphanumeric order using the Extended Binary Coded Decimal Interchange Code convention. Thus, if MAB123A is the lowest (considering both alpha and numeric characters) EPA Sample No. within the SDG, it would be entered in the first EPA Sample No. field. Samples listed below it would be in ascending sequence - MAB124A, MAB124B, MAB125A, MAC111A, MA1111A, MA1111AD, etc.

3.1.3.3 All EPA sample numbers must be listed in ascending alphanumeric order, continuing to the following Cover Page if applicable.

3.1.3.4 Under "Lab Sample ID", a Lab Sample ID (up to 10 characters) may be entered for each associated EPA Sample No. If a Lab Sample ID is entered, it must be entered identically (for each EPA Sample No.) on all associated data.

3.1.3.5 Under "Comments", enter any problems encountered, both technical and administrative, the corrective action taken, and resolution performed for all of the samples in the SDG.

3.1.3.6 Each Cover Page must be signed, in original, by the Laboratory Manager or the Manager's designee, and dated to authorize the release and verify the contents of all data and deliverables associated with an SDG.

3.1.4 Analysis Data Sheet [FORM I - AAVT]

3.1.4.1 This form is used for tabulating and reporting results for analysis of samples on Tenax® cartridges for the compounds in a Target Compound List for Volatiles as given in Exhibit C.

3.1.4.2 This form is used for reporting the detected concentrations of the target compounds in the field samples, blanks, laboratory control samples, and performance evaluation samples.

3.1.4.3 Complete the header information on each page of Form I-AAVT according to the instructions in section 3.1.2.

3.1.4.4 Enter the volume of air pumped into the cartridge during sample collection if indicated on the sample tag. If the sample tag provides the sampling flowrate and sampling time, the volume of air sampled may be calculated by multiplying the sampling flowrate by the sampling time.

3.1.4.5 For each positively identified target compound, the Contractor shall enter the detected concentration in ng/tube. If this value is greater than or equal to the quantitation limit, report the resulting true concentration uncorrected for blank contaminants. Report analytical results to two significant figure if the value is less than 10, and three significant figures if the value is greater than or equal to 10. If the air sample volume is known to the laboratory, convert the values in ng/tube to ng/m_3 and enter in the appropriate column.

3.1.4.6 Under the column labeled "Q" for qualifier, flag each result with the specific Data Reporting Qualifiers listed below. The Contractor is encouraged to use additional flags or footnotes. The definition of such flags must be explicit and must be included in the SDG Narrative.

3.1.4.7 For reporting results to the Agency, the following contract specific qualifiers are to be used. The seven qualifiers defined below are not subject to modification by the laboratory. Up to five qualifiers may be reported on Form I-AAVT for each compound. The seven EPA-defined qualifiers to be used are as follows:

U - Indicates compound was analyzed for but not detected. The sample quantitation limit must be corrected for dilution.

J - Indicates an estimated value. This flag is used either when estimating a concentration for tentatively identified compounds where a 1:1 response is assumed, or when the mass spectral data indicate the presence of a compound that meets the identification criteria but the result is less than the

sample quantitation limit but greater than zero. For example, if the sample quantitation limit is 20 ng, but a concentration of 10 ng is calculated, report it as "10J". The sample quantitation limit must be adjusted for dilution.

N - Indicates presumptive evidence of a compound. This flag is only used for tentatively identified compounds, where the identification is based on a mass spectral library search. It is applied to all TIC results.

B - This flag is used when the analyte is found in the associated blank as well as in the sample. It indicates possible/probable blank contamination and warns the data user to take appropriate action. This flag must be used for a TIC as well as for a positively identified target compound.

E - This flag identifies compounds whose concentrations exceed the calibration range of the GC/MS instrument for that specific analysis. If one or more compounds have a response greater than full scale, except as noted in Exhibit D, the sample should have the concentration flagged with an "E" on the Form I-AAVT for the original analysis.

X - Other specific flags may be required to properly define the results. If used, they must be fully described, and such description attached to the Sample Data Summary Package and the SDG Narrative. Begin by using "X". If more than one flag is required, use "Y" and "Z" as needed. If more than five qualifiers are required for a sample result, use the "X" flag to combine several flags, as needed. For instance, the "X" flag might combine the "B", and "D" flags for some sample. The laboratory-defined flags are limited to the letters "X", "Y", and "Z".

NOTE: The combination of flags "BU" or "UB" is expressly prohibited. Blank contaminants are flagged "B" only when they are detected in the sample.

3.1.5 **Tentatively Identified Compounds [FORM I - AAVT-TIC]**

3.1.5.1 Fill in all header information as above.

3.1.5.2 Report Tentatively Identified Compounds (TICs) including CAS number, compound name, retention time (RT), and the estimated concentration (criteria for reporting TICs are given in Exhibit D). Retention time must be reported in minutes and decimal minutes, not seconds or minutes:seconds.

3.1.5.3 If, in the opinion of the mass spectral interpretation

specialist, no valid tentative identification can be made, the compound shall be reported as unknown.

3.1.5.4 Include a Form I-AAVT-TIC for every sample and blank analyzed, even if no TICs are found. Total the number of TICs found, and enter this number in the "No. of TICs found." If none were found, enter "0" (zero). Form I-AAVT-TIC must be provided for every analysis, including required dilutions and reanalyses, even if no TICs are found.

3.1.6 **Blank Summary [FORM II - AAVT]**

3.1.6.1 This form summarizes the samples associated with each field and laboratory blank analysis. A copy of the appropriate Form II-AAVT is required for each blank reported on a Form I-AAVT.

3.1.6.2 Complete the header information on Form II-AAVT as described in section 3.1.2. The "EPA Sample No." entered in the box at the top of Form II-AAVT shall be the same number entered on the Form I-AAVT when reporting results for the blank itself.

3.1.6.3 On the numbered lines, enter the EPA sample numbers associated with the blank, along with the other information which identifies the EPA samples. The Cartridge ID for each sample must be provided under the "Cartridge" column, if available.

3.1.7 **Laboratory Control Sample Data Sheet [FORM III - AAVT]**

3.1.7.1 Form III-AAVT is used to report the recovery of the spiked analytes in the laboratory control samples (LCS).

3.1.7.2 Complete the header information according to the instructions in section 3.1.2.

3.1.7.3 Enter the date and time the LCS was analyzed.

3.1.7.4 In the table under "Spiked," enter the spiked concentration in ng/tube of each LCS compound. Under "Reported," enter the concentration obtained in ng/tube calculated from the analysis of the LCS. Calculate the percent recovery of each LCS compound to the nearest whole percent and enter in the column under "% Recovery". At the bottom of the table are the QC limits for LCS percent recoveries. Flag all values outside of the limits with an "*" in the column under the "Q" symbol.

3.1.7.5 Summarize the values outside the QC limits at the lower part of the form.

3.1.7.6 Enter any comments pertinent to the analysis of the LCS.

3.1.8 **GC/MS Instrument Performance Check and Mass Calibration [FORM IV - AAVT]**

3.1.8.1 This form is used to report the results of GC/MS instrument performance check (also known as "tuning") and to summarize the date and time of analysis of samples, standards, and blanks associated with each analysis of the instrument performance check solution.

3.1.8.2 Complete the header information as in section 3.1.2. Enter the "Lab File ID" for the injection containing the instrument performance check mixture of BFB. Enter the date and time (military time) of injection of the instrument performance check mixture.

3.1.8.3 For each ion listed on the form, enter the percent relative abundance in the right column. Report relative abundances to the number of significant figures given for each ion in the ion abundance criteria column.

3.1.8.4 Under "to m/e 95", all ion abundances are to be normalized to the nominal base peak listed on Form IV-AAVT. For some of the ions, determine the percentage of the ion abundance to the specified mass and report under "to specified mass". For example, if the relative ion abundance of mass 96 and mass 174 ions are 4 and 80 (under the "to m/e 95" column), respectively, then enter "5.0" (under the "to specified mass" column) as the ion abundance of mass 96 relative to mass 174.

3.1.8.5 All relative abundances must be reported as a number. If zero, enter "0", not a dash or other non-numeric character.

3.1.8.6 In the lower half of the form, list all samples and standards analyzed under that instrument performance check in <u>chronological order</u>, by time of analysis (in military time). Refer to section 3.1.2 for specific instructions for identifying standards and blanks. Enter "EPA Sample No.", "Lab Sample ID", "Lab File ID", "Date Analyzed", and "Time Analyzed" for all standards, samples, and blanks.

3.1.8.7 The GC/MS instrument performance check must be analyzed again twelve hours from the time of injection of the instrument performance check solution of BFB listed at the top of the form. In order to meet these requirements, samples, standards, or blanks must be injected within twelve hours of the injection of the instrument performance check solution.

3.1.9 **Initial Calibration Data Sheet [FORM V - AAVT]**

3.1.9.1 Each time the GC/MS system undergoes an initial calibration, the laboratory must complete and submit a Form V-AAVT.

3.1.9.2 Complete all header information as in section 3.1.2.

3.1.9.3 Enter the "Case No." and "SDG No." for the current data package, regardless of the original Case for which the initial calibration was performed. Enter "Instrument ID" and "GC Column ID".

3.1.9.4 Check the appropriate standard preparation method used to calibrate the GC/MS system - flash vaporization, static dilution bottle technique, or permeation calibration generator.

3.1.9.5 Enter the injection dates and times of each of the calibration standards analyzed under "Date injected" and "Time injected", respectively.

3.1.9.6 Enter the "EPA Sample No." and "Lab File ID" for each of the five calibration standards.

3.1.9.7 Complete the relative response factor (RRF) calculation for the five calibration points, and then calculate and report the average relative response factor ($\overline{RRF}$) and %RSD of the RRF values for each target and surrogate compound in the space provided.

3.1.10 **Continuing Calibration Data Sheet [FORM VI - AAVT]**

3.1.10.1 Each time the GC/MS system undergoes a continuing calibration to check for the validity of the initial calibration, the laboratory must complete and submit a Form VI-AAVT.

3.1.10.2 Complete all header information as in section 3.1.2. Enter the "Case No." and "SDG No." for the current data package, regardless of the original Case for which the initial calibration was performed. Enter "Instrument ID", "GC Column ID", and the date(s) of the most recent initial calibration. If the calendar date changes during the calibration procedure, the inclusive dates should be given on Form VI.

3.1.10.3 Enter the date and time of injection of the continuing calibration standard.

3.1.10.4 Complete the relative response factor (RRF) calculation for each target compound in the space provided.

3.1.10.5 Indicate with a check mark the method used for the continuing calibration. Note that direct injection calibration is allowed only for the continuing calibration check. If the continuing calibration standard is in a Tenax® cartridge, the same desorption method (flash vaporization, static dilution bottle technique, or permeation calibration generator) used for the initial calibration standards must be used for the continuing calibration standard.

3.1.10.6 Under the column "IC mean RRF", enter the mean relative response factor for each target compound as determined in the most recent valid initial calibration.

3.1.10.7 A RRF is calculated for this concentration and compared to the mean RRF value in the most recent valid initial calibration. Calculate the percent difference (%D) between the continuing calibration RRF and the mean RRF from the most recent valid initial calibration.

3.1.11 Internal Standard Area and Retention Time Summary [FORM VII - AAVT]

3.1.11.1 This form is used to summarize the peak areas and retention times of the internal standards added to all samples and blanks. The data are used to determine when changes in internal standard responses will adversely affect quantification of target compounds. This form must be completed each time an initial or continuing calibration is performed for each GC/MS system.

3.1.11.2 Complete the header information according to section 3.1.2.

3.1.11.3 Enter the Lab File ID of the 12-hour calibration standard, as well as the date and time of analysis of the calibration standard. If samples are analyzed immediately following an initial calibration, before another instrument performance check and a continuing calibration, a Form VII-AAVT shall be completed on the basis of the internal standard areas of the mid level (CAL 3) initial calibration standard. Use the date and time of analysis of this standard, and its Lab File ID and areas in place of those of a continuing calibration standard.

3.1.11.4 From the results of the analysis of the 12-hour calibration standard, enter the area measured for each internal standard and its retention time (in decimal minutes) under the appropriate column. For each internal standard, calculate the upper limit of the area as the area of the particular standard plus 40 percent of its area (i.e., 1.4 times the area in the 12 HOUR STD box), and the lower limit of the area as the area of the internal standard minus 40% of its area (i.e., 0.6 times the area in the 12 HOUR STD box). Report these values in the boxes labeled "UPPER LIMIT" and "LOWER LIMIT", respectively.

3.1.11.5 Calculate the upper limit of the retention time as the retention of the internal standard plus 0.33 minutes (20 seconds), and the lower limit of the retention time as the retention time in the standard minus 0.33 minutes (20 seconds).

3.1.11.6 For each sample and blank under a given 12-hour analytical sequence, enter the EPA Sample Number and the area measured for each internal standard and its retention time. If the internal standard

area is outside the upper or lower limits calculated above, flag that area with an asterisk (*) placed in the far right-hand space of the box for each internal standard area, directly under the "#" symbol. Similarly, flag the retention time of any internal standard that is outside the limits with an asterisk.

3.1.12 Tenax® Cartridge Certification [FORM VIII - AAVT]

3.1.12.1 This form is used to document the certification of Tenax® cartridges prior to use.

3.1.12.2 Complete the header information on each page of Form VII-AAVT according to the instructions in section 3.1.2.

3.1.12.3 Enter under "Tenax® Cartridge ID" (shaded cells) the identification number of up to five Tenax® cartridges used for certification.

3.1.12.4 Enter the results of the analysis of an unspiked certified clean cartridge. For target compounds that are not detected, enter the CRQL of the compound followed by a "U". If the detected level is less than the CRQL, enter the value followed by a "J".

3.1.12.5 At the bottom of each column, enter the total or subtotal level of VOCs found. Include on those that are positive hits; values flagged with a "U" are not included.

3.1.12.6 If the none of the values for a particular cartridge are more than the corresponding CRQL of any of the target compounds, and if the total level of VOCs is not greater than 10 ng/tube, then the cartridge is certified.

3.1.13 Surrogate Recovery [FORM IX - AAVT]

3.1.13.1 Form IX - AAVT is used to report the recoveries of the surrogate compounds added to each Tenax® adsorbent tube.

3.1.13.2 Complete the header information and enter EPA Sample Numbers as described in section 3.2.1. For each surrogate, report the percent recovery to the nearest whole percentage point, and to the number of significant figures given by the QC limits at the bottom of the form.

3.1.13.3 Flag each surrogate recovery outside the QC limits with an asterisk (*). The asterisk must be placed in the last space in each appropriate column, under the "#" symbol. In the far righthand column, total the number of surrogate recoveries outside the QC limits for each sample (Total Out). If no surrogates were outside the limits, enter "0".

3.1.14 Analytical Sequence [FORM X - AAVT]

3.1.14.1 A Form X-AAVT is required for each analytical sequence for each GC/MS system used to perform VOA on Tenax® cartridge samples in an SDG.

3.1.14.2 Complete the header information on each page of Form VII-AAVT according to the instructions in section 3.1.2.

3.1.14.3 On the numbered lines, enter the EPA sample numbers along with the other information which identifies the samples, blanks, and standards. The first item in the table must be the BFB since the 12-hour time period starts at the injection of the instrument performance check standard. Arrange the items in chronological order for each GC/MS system.

3.1.15 Sample Receipt/Log-In Sheet [FORM AADC-1]

3.1.15.1 This form is used to document the receipt and inspection of sample containers and samples. One original of Form AADC-1 is required for each sample shipping container. If the samples in a single sample shipping container must be assigned to more than one Sample Delivery Group, the original Form AADC-1 shall be placed with the deliverables for the Sample Delivery Group of the lowest Arabic number and a copy of Form AADC-1 must be placed with the deliverables for the other Sample Delivery Group(s). The copies should be identified as "copy(ies)," and the location of the original should be noted on the copies.

3.1.15.2 Sign and date the airbill (if present). Examine the shipping container and record the presence/absence of custody seals and their condition (i.e., intact, broken) in item 1 on Form AADC-1. Record the custody seal numbers in item 2.

3.1.15.3 Open the container, remove the enclosed sample documentation, and record the presence/absence of chain-of-custody record(s), SMO forms (i.e., Traffic Reports, Packing Lists), and airbills or airbill stickers in items 3-5 on Form AADC-1. Specify if there is an airbill present or an airbill sticker in item 5 on Form AADC-1. Record the airbill or sticker number, if present.

3.1.15.4 Remove the samples from the shipping container(s), examine the samples and the sample tags (if present), and record the condition of the sample (i.e., intact, dent, leaking) and presence of absence of sample tags in items 6 and 7 on Form AADC-1.

3.1.15.5 Review the sample shipping documents and complete the header information described in section 3.1.2. Compare the information recorded on all the documents and samples and circle the appropriate

answer in item 8 on Form AADC-1.

3.1.15.6 If there are no problems observed during receipt, sign and date (include time) Form AADC-1, the chain-of-custody record, and Traffic Report, and write the sample numbers on Form AADC-1. Record the appropriate sample tags and assigned laboratory numbers, if applicable. The log-in date should be recorded at the top of Form AADC-1 and the date and time of sample receipt at the laboratory should be recorded in items 9 and 10. Record the fraction designation (if appropriate) and the specific area designation (e.g., refrigerator number) in the Sample Transfer block located in the bottom left corner of Form AADC-1. Sign and date the Sample Transfer block. Cross out unused columns and spaces.

3.1.15.7 If there are problems observed during receipt or an answer marked with an asterisk (i.e., "absent*") was circled, contact SMO and document the contact as well as resolution of the problem on a CLP Communication Log. Following resolution, sign and date the forms as specified in the preceding paragraph and note, where appropriate, the resolution of the problem.

3.1.16 Complete SDG File (CSF) Document Inventory Sheet [FORM AADC-2]

3.1.16.1 This form is used to record the inventory of the SDG File Purge documents and count of documents in the original Sample Data Package which is sent to the Region.

3.1.16.2 Organize all EPA-CSF documents as described in Exhibit B, Section 1. Assemble the documents in the order specified on Form AADC-2, and stamp each page with a consecutive number. (Do not number the AADC-2 form). Inventory the CSF by reviewing the document numbers and recording page numbers ranges in the columns provided in the Form AADC-2. If there are no documents for a specific document type, enter an "NA" in the empty space.

3.1.16.3 Certain laboratory specific documents related to the CSF may not fit into a clearly defined category. The laboratory should review AADC-2 to determine if it is most appropriate to place them under No. 17, 18, 19, or 20. Category 20 should be used if there is no appropriate previous category. These types of documents should be described or listed in the blanks under each appropriate category.

3.2 Data Reporting Forms

3.2.1 Cover Page [COVER PAGE - AAVT]

3.2.2 Analysis Data Sheet [FORM I - AAVT]

3.2.3 Tentatively Identified Compounds [FORM I - AAVT-TIC]

3.2.4 Blank Summary [FORM II - AAVT]

3.2.5 Laboratory Control Sample Data Sheet [FORM III - AAVT]

3.2.6 GC/MS Instrument Performance Check and Mass Calibration [FORM IV - AAVT]

3.2.7 Initial Calibration Data Sheet [FORM V - AAVT]

3.2.8 Continuing Calibration Data Sheet [FORM VI - AAVT]

3.2.9 Internal Standard Area and Retention Times Summary [FORM VII - AAVT]

3.2.10 Tenax® Cartridge Certification [FORM VIII - AAVT]

3.2.11 Surrogate Recovery [FORM IX - AAVT]

3.2.12 Analytical Sequence [FORM X - AAVT]

3.2.13 Sample Receipt/Log-In Sheet [FORM AADC-1]

3.2.14 Complete SDG File (CSF) Document Inventory Sheet [FORM AADC-2]

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U. S. ENVIRONMENTAL PROTECTION AGENCY
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Volatile Organics in Ambient Air – Tenax

COVER PAGE

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____

	EPA Sample No.	Lab Sample ID
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
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20		

Comments:

I certify that this data package is in compliance with the terms and conditions of the contract, both technically and for completeness, for other than the conditions detailed above. Release of the data contained in this hardcopy data package and in the computer-readable data (if submitted) on floppy diskette has been authorized by the Laboratory Manager's designee, as verified by the following signature:

Signature: Name:
Date: Title:

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Tenax

SAMPLE RECEIPT/LOG–IN SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____

ITEM	REMARKS	EPA Sample No.	Sample Tag No.	Assigned Lab No.	Spl Vol (m^3)	REMARKS: Conditions of Sample Shipment,etc.
1. Custody Seal(s)	Present/Absent/Intact/Broken*					
2. Custody Seal No(s).						
3. Chain–of–Custody records	Present/Absent*					
4. Traffic Reports or Packing List	Present/Absent*					
5. Airbill	Sticker/Present/Absent*					
Airbill No(s).						
6. Sample Tags	Present/Absent*					
Sample Tag No(s):	Listed/Not Listed on COC					
7. Sample Condition	Intact/Broken/Leaking*					
8. Do informations on custody records, traffic reports, and sample tags agree?	Yes/No*					
9. Date Received at Lab:						
10. Time Received at Lab:						
Sample Transfer						
Area #:						
By:						
On:						

* If circled, contact SMO and attach record of resolution.

Received by:
Signature:_____ Log–in Date:_____
Print Name:_____

Reviewed by:
Signature:_____ Date:_____
Logbook No.:_____ Logbook Page No.:_____

FORM AADC–1

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Tenax

COMPLETE SDG FILE (CSF) DOCUMENT INVENTORY SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No:_____ SDG No.:_____

DOCUMENT	Page Nos. From	Page Nos. To	Please Check Lab	Please Check Reg
1. Cover Page (Cover Page – AAVT)				
2. Sample Receipt/Log–In Sheet (FORM AADC–1)				
3. CSF Document Inventory Sheet (FORM AADC–2)				
4. Analysis Data Sheet (FORM I – AAVT)				
5. Tentatively Identified Compounds (FORM I – AAVT–TIC)				
6. Blank Summary Form (FORM II – AAVT)				
7. Laboratory Control Sample Data Sheet (FORM III – AAVT)				
8. GC/MS Tuning with BFB (FORM IV – AAVT)				
9. Initial Calibration Data Sheet (FORM V – AAVT)				
10. Continuing Calibration Data Sheet (FORM VI – AAVT)				
13. Internal Standard Area and RT Summary (FORM VII – AAVT)				
14. Tenax Cartridge Certification Data Sheet (FORM VIII – AAVT)				
15. Surrogate Recovery Form (FORM IX – AAVT)				
16. Analytical Sequence (FORM X – AAVT)				
17. EPA Shipping/Receiving Documents				
Airbill (No. of shipments:___)				
Chain–of–Custody Records				
Sample Tags				
Sample Log–In Sheet (Lab & AADC–1)				
17. Misc. Shipping/Receiving Records (list individual records)				
Telephone Logs				
18. Internal Lab Sample Transfer Records				
19. Internal Original Sample Preparation and Analysis Records				
20. Other Records (describe or list)				

Comments:

Completed by (CLP Lab):
Signature:_____ Date:_____
Printed Name/Title:_____
Audited by (EPA):
Signature:_____ Date:_____
Printed Name/Title:_____

FORM AADC–2

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Tenax

ANALYSIS DATA SHEET

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Lab Sample ID:_____ Date Received:_____ Instrument ID:_____
Lab File ID:_____ Date Analyzed:_____ Column ID:_____
Sampled Air Volume, m^3 (corrected to STP):_____

CAS RN	COMPOUND NAME	Concentration		Q
		ng/tube	ng/m^3	
100–52–7	Benzaldehyde			
71–43–2	Benzene			
100–47–0	Benzonitrile			
108–86–1	Bromobenzene			
74–97–5	Bromochloromethane			
109–70–6	1–Bromo–3–chloropropane			
74–96–4	Bromoethane			
75–62–7	Bromotrichloromethane			
104–51–8	n–Butylbenzene			
56–23–5	Carbon tetrachloride			
108–90–7	Chlorobenzene			
78–86–4	2–Chlorobutane			
106–89–8	1–Chloro–2,3–epoxypropane			
110–75–8	2–Chloroethoxyethene			
67–66–3	Chloroform			
540–54–5	1–Chloropropane			
75–29–6	2–Chloropropane			
107–05–1	3–Chloro–1–propene			
108–41–8	m–Chlorotoluene			
95–49–8	o–Chlorotoluene			
106–43–4	p–Chlorotoluene			
106–93–4	1,2–Dibromoethane			
74–95–3	Dibromomethane			
78–75–1	1,2–Dibromopropane			
95–50–1	1,2–Dichlorobenzene			
541–73–1	1,3–Dichlorobenzene			
106–46–7	1,4–Dichlorobenzene			
1190–22–3	1,3–Dichlorobutane			
110–56–5	1,4–Dichlorobutane			

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Tenax

ANALYSIS DATA SHEET

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Lab Sample ID:_____ Date Received:_____ Instrument ID:_____
Lab File ID:_____ Date Analyzed:_____ Column ID:_____
Sampled Air Volume, m^3 (corrected to STP):_____

CAS RN	COMPOUND NAME	Concentration		Q
		ng/tube	ng/m^3	
7581-97-7	2,3-Dichlorobutane			
764-41-0	cis-1,4-Dichloro-2-butene			
760-23-6	3,4-Dichloro-1-butene			
75-34-3	1,1-Dichloroethane			
107-06-2	1,2-Dichloroethane			
75-35-4	1,1-Dichloroethene			
78-87-5	1,2-Dichloropropane			
142-28-9	1,3-Dichloropropane			
123-91-1	1,4-Dioxane			
1073-67-2	1-Ethenyl-4-chlorobenzene			
100-41-4	Ethylbenzene			
98-82-8	(1-Methylethyl) benzene			
99-87-6	1-Methyl-4-(1-methylethyl) benzene			
76-01-7	Pentachloroethane			
98-86-2	1-Phenylethanone			
100-42-5	Styrene			
630-20-6	1,1,1,2-Tetrachloroethane			
79-43-5	1,1,2,2-Tetrachloroethane			
127-18-4	Tetrachloroethylene			
109-99-9	Tetrahydrofuran			
108-88-3	Toluene			
75-25-2	Tribromomethane			
71-55-6	1,1,1-Trichloroethane			
79-06-5	1,1,2-Trichloroethane			
79-01-6	Trichloroethylene			
96-18-4	1,2,3-Trichloropropane			
108-67-8	1,3,5-Trimethylbenzene			
1330-20-7	Xylenes, m- and p-			
95-47-6	Xylene, o-			

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CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Tenax

TENTATIVELY IDENTIFIED COMPOUNDS

EPA Sample No. _____

Lab Name: _____ Contract No.: _____
Lab Code: _____ Case No.: _____
Lab Sample ID: _____ Lab File ID: _____
SAS No.: _____ Date Received: _____
SDG No: _____ Date Analyzed: _____
GC Column ID: _____ Instrument ID: _____
No. of TICs Found: _____ Sampled Air Volume, m^3 (at STP): _____

	CAS RN	COMPOUND NAME	Estimated Concentration ng/tube	Estimated Concentration ng/m^3	RT (mins.)	Q
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

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Volatile Organics in Ambient Air – Tenax

BLANK SUMMARY

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Lab Sample ID:_____ Date Analyzed:_____ Instrument ID:_____
Lab File ID:_____ Time Analyzed:_____ Column ID:_____

THIS BLANK APPLIES TO THE FOLLOWING SAMPLES:

	EPA Sample No.	Laboratory ID			Analysis	
		Sample	File	Cartridge	Date	Time
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						

Comments:

U. S. ENVIRONMENTAL PROTECTION AGENCY
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LABORATORY CONTROL SAMPLE DATA SHEET

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Lab Sample ID:_____ Date Analyzed:_____ Instrument ID:_____
Lab File ID:_____ Time Analyzed:_____ Column ID:_____

CAS RN	COMPOUND NAME	Concentration (ng/tube)		% Recovery	Q
		Spiked	Reported		
71–43–2	Benzene				
56–23–5	Carbon tetrachloride				
106–93–4	1,2–Dibromoethane				
106–46–7	1,4–Dichlorobenzene				
107–06–2	1,2–Dichloroethane				
78–87–5	1,2–Dichloropropane				
127–18–4	Tetrachloroethylene				
79–06–5	1,1,2–Trichloroethane				
79–01–6	Trichloroethylene				

%Recovery QC Limits: 60–140%

LCS Recovery: _____ outside limits out of _____ total.

Comments:

U. S. ENVIRONMENTAL PROTECTION AGENCY
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Volatile Organics in Ambient Air – Tenax

GC/MS INSTRUMENT PERFORMANCE CHECK AND MASS CALIBRATION

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Lab Sample ID:_____ Date Injected:_____ Instrument ID:_____
Lab File ID:_____ Time Injected:_____ GC Column ID:_____
Mass BFB Injected (ng):_____

m/e	ION ABUNDANCE CRITERIA	% Relative Abundance	
		to m/e 95	to specified mass
50	8.0 – 40.0% of m/e 95		
75	30.0 – 66.0 of m/e 95		
95	Base peak, 100% relative abundance		
96	5.0 – 9.0% of m/e 174		
173	Less than 2.0% of m/e 174		
174	50.0 – 120.0% of m/e 95		
175	4.0 – 9.0% of m/e 174		
176	93.0 – 101.0% of m/e 174		
177	5.0 – 9.0% of m/e 176		

THIS TUNE APPLIES TO THE FOLLOWING:

	EPA Sample No.	Lab Sample ID	Lab File ID	Date Analyzed	Time Analyzed
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

U. S. ENVIRONMENTAL PROTECTION AGENCY
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INITIAL CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Instrument ID:_____ GC Column ID:_____
Standard Preparation Method:____flash vaporization ____static dilution ____permeation calibration

STANDARD	CAL 1	CAL 2	CAL 3	CAL 4	CAL 5		
EPA Sample No.							
Lab File ID							
Date injected							
Time injected							
	Relative Response Factor (RRF)					mean	
COMPOUND NAME	CAL 1	CAL 2	CAL 3	CAL 4	CAL 5	RRF	%RSD
Benzene–d_6							
Chlorobenzene–d_5							
1,2–Dichlorobenzene–d_4							
Benzaldehyde							
Benzene							
Benzonitrile							
Bromobenzene							
Bromochloromethane							
1–Bromo–3–chloropropane							
Bromoethane							
Bromotrichloromethane							
n–Butylbenzene							
Carbon tetrachloride							
Chlorobenzene							
2–Chlorobutane							
1–Chloro–2,3–epoxypropane							
2–Chloroethoxyethene							
Chloroform							
1–Chloropropane							
2–Chloropropane							
3–Chloro–1–propene							
m–Chlorotoluene							
o–Chlorotoluene							
p–Chlorotoluene							
1,2–Dibromoethane							
Dibromomethane							
1,2–Dibromopropane							
1,2–Dichlorobenzene							
1,3–Dichlorobenzene							
1,4–Dichlorobenzene							
1,3–Dichlorobutane							

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Tenax

INITIAL CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Instrument ID:_____ GC Column ID:_____
Standard Preparation Method:____flash vaporization ____static dilution ____permeation calibration

STANDARD	CAL 1	CAL 2	CAL 3	CAL 4	CAL 5		
EPA Sample No.							
Lab File ID							
Date injected							
Time injected							
	Relative Response Factor (RRF)					mean	
COMPOUND NAME	CAL 1	CAL 2	CAL 3	CAL 4	CAL 5	RRF	%RSD
1,4–Dichlorobutane							
2,3–Dichlorobutane							
cis–1,4–Dichloro–2–butene							
3,4–Dichloro–1–butene							
1,1–Dichloroethane							
1,2–Dichloroethane							
1,1–Dichloroethene							
1,2–Dichloropropane							
1,3–Dichloropropane							
1,4–Dioxane							
1–Ethenyl–4–chlorobenzene							
Ethylbenzene							
(1–Methylethyl) benzene							
1–Methyl–4–(1–methylethyl)benzene							
Pentachloroethane							
1–Phenylethanone							
Styrene							
1,1,1,2–Tetrachloroethane							
1,1,2,2–Tetrachloroethane							
Tetrachloroethylene							
Tetrahydrofuran							
Toluene							
Tribromomethane							
1,1,1–Trichloroethane							
1,1,2–Trichloroethane							
Trichloroethylene							
1,2,3–Trichloropropane							
1,3,5–Trimethylbenzene							
Xylenes, m– and p–							
Xylene, o–							

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Tenax

CONTINUING CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
EPA Sample No.:_____ Lab File ID:_____
Instrument ID:_____ GC Column ID:_____
Date Injected:_____ Time Injected:_____
Calibration Method:____direct injection ____via cartridge Date of Init. Cal.:_____

COMPOUND NAME	IC mean RRF	RRF	%D
Benzene–d_6			
Chlorobenzene–d_5			
1,2–Dichlorobenzene–d_4			
Benzaldehyde			
Benzene			
Benzonitrile			
Bromobenzene			
Bromochloromethane			
1–Bromo–3–chloropropane			
Bromoethane			
Bromotrichloromethane			
n–Butylbenzene			
Carbon tetrachloride			
Chlorobenzene			
2–Chlorobutane			
1–Chloro–2,3–epoxypropane			
2–Chloroethoxyethene			
Chloroform			
1–Chloropropane			
2–Chloropropane			
3–Chloro–1–propene			
m–Chlorotoluene			
o–Chlorotoluene			
p–Chlorotoluene			
1,2–Dibromoethane			
Dibromomethane			
1,2–Dibromopropane			
1,2–Dichlorobenzene			
1,3–Dichlorobenzene			
1,4–Dichlorobenzene			
1,3–Dichlorobutane			

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
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CONTINUING CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
EPA Sample No.:_____ Lab File ID:_____
Instrument ID:_____ GC Column ID:_____
Date Injected:_____ Time Injected:_____
Calibration Method:_____direct injection _____via cartridge Date of Init. Cal.:_____

COMPOUND NAME	IC mean RRF	RRF	%D
1,4–Dichlorobutane			
2,3–Dichlorobutane			
cis–1,4–Dichloro–2–butene			
3,4–Dichloro–1–butene			
1,1–Dichloroethane			
1,2–Dichloroethane			
1,1–Dichloroethene			
1,2–Dichloropropane			
1,3–Dichloropropane			
1,4–Dioxane			
1–Ethenyl–4–chlorobenzene			
Ethylbenzene			
(1–Methylethyl) benzene			
1–Methyl–4–(1–methylethyl) benzene			
Pentachloroethane			
1–Phenylethanone			
Styrene			
1,1,1,2–Tetrachloroethane			
1,1,2,2–Tetrachloroethane			
Tetrachloroethylene			
Tetrahydrofuran			
Toluene			
Tribromomethane			
1,1,1–Trichloroethane			
1,1,2–Trichloroethane			
Trichloroethylene			
1,2,3–Trichloropropane			
1,3,5–Trimethylbenzene			
Xylenes, m– and p–			
Xylene, o–			

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Tenax

INTERNAL STANDARD AREA AND RT SUMMARY

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____

	Perfluorotoluene		1,2-Dichlorobenzene-d_4		1,4-Difluorobenzene	
	Area #	RT #	Area #	RT #	Area #	RT #
12-HOUR STANDARD						
Upper Limit						
Lower Limit						
EPA Sample No.						
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						

AREA: Upper Limit: +40% of internal standard area. RT: Upper Limit: +0.33 minutes of internal standard RT.
Lower Limit: −40% of internal standard area. Lower Limit: −0.33 minutes of internal standard RT.

All values outside of the QC limits must be followed by an "*" under the "#" column.

FORM VII – AAVT

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Tenax

TENAX CARTRIDGE CERTIFICATION

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No:_____
SAS No.:_____ SDG No.:_____

	COMPOUND NAME	Tenax Cartridge ID				
1	Benzaldehyde					
2	Benzene					
3	Benzonitrile					
4	Bromobenzene					
5	Bromochloromethane					
6	1–Bromo–3–chloropropane					
7	Bromoethane					
8	Bromotrichloromethane					
9	n–Butylbenzene					
10	Carbon tetrachloride					
11	Chlorobenzene					
12	2–Chlorobutane					
13	1–Chloro–2,3–epoxypropane					
14	2–Chloroethoxyethene					
15	Chloroform					
16	1–Chloropropane					
17	2–Chloropropane					
18	3–Chloro–1–propene					
19	m–Chlorotoluene					
20	o–Chlorotoluene					
21	p–Chlorotoluene					
22	1,2–Dibromoethane					
23	Dibromomethane					
24	1,2–Dibromopropane					
25	1,2–Dichlorobenzene					
26	1,3–Dichlorobenzene					
27	1,4–Dichlorobenzene					
28	1,3–Dichlorobutane					
29	1,4–Dichlorobutane					
	Subtotal VOCs (ng/tube)					

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U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Tenax

TENAX CARTRIDGE CERTIFICATION

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No:_____
SAS No.:_____ SDG No.:_____

	COMPOUND NAME	Tenax Cartridge ID				
30	2,3–Dichlorobutane					
31	cis–1,4–Dichloro–2–butene					
32	3,4–Dichloro–1–butene					
33	1,1–Dichloroethane					
34	1,2–Dichloroethane					
35	1,1–Dichloroethene					
36	1,2–Dichloropropane					
37	1,3–Dichloropropane					
38	1,4–Dioxane					
39	1–Ethenyl–4–chlorobenzene					
40	Ethylbenzene					
41	(1–Methylethyl) benzene					
42	1–Methyl–4–(1–methylethyl)benzene					
43	Pentachloroethane					
44	1–Phenylethanone					
45	Styrene					
46	1,1,1,2–Tetrachloroethane					
47	1,1,2,2–Tetrachloroethane					
48	Tetrachloroethylene					
49	Tetrahydrofuran					
50	Toluene					
51	Tribromomethane					
52	1,1,1–Trichloroethane					
53	1,1,2–Trichloroethane					
54	Trichloroethylene					
55	1,2,3–Trichloropropane					
56	1,3,5–Trimethylbenzene					
57	Xylenes, m– and p–					
58	Xylene, o–					
Total VOCs (ng/tube)						

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Tenax

SURROGATE RECOVERY

Lab Name: _____ Contract No.: _____
Lab Code: _____ Case No.: _____
SAS No.: _____ SDG No.: _____

	EPA Sample No.	Surrogate Percent Recovery						Total Out
		benzene–d_6	#	chlorobenzene–d_5	#	dichlorobenzene–d_4	#	
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								

Surrogate %Recovery Limits: 80–120%
Values outside of QC limits are flagged with a "*" under the "#" column

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U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Volatile Organics in Ambient Air – Tenax

ANALYTICAL SEQUENCE

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Instrument ID:_____ GC Column ID:_____

	EPA Sample No.	Lab Sample ID	Analysis Time	Analysis Date
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				

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FORM X – AAVT

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EXHIBIT C

TARGET COMPOUND LISTS

TABLE 1

VOLATILES IN AMBIENT AIR
TARGET COMPOUND LIST (TCL) AND
CONTRACT REQUIRED QUANTITATION LIMITS (CRQL)

Target Compound	CAS RN	ng, on column
Benzaldehyde	100-52-7	20
Benzene	71-43-2	9
Benzonitrile	100-47-0	5
Bromobenzene	108-86-1	45
Bromochloromethane	74-97-5	7
1-Bromo-3-chloropropane	109-70-6	5
Bromoethane	74-96-4	26
Bromotrichloromethane	75-62-7	6
n-Butylbenzene	104-51-8	3
Carbon tetrachloride	56-23-5	7
Chlorobenzene	108-90-7	6
2-Chlorobutane	78-86-4	12
1-Chloro-2,3-epoxypropane	106-89-8	26
2-Chloroethoxyethene	110-75-8	27
Chloroform	67-66-3	9
1-Chloropropane	540-54-5	6
2-Chloropropane	75-29-6	11
3-Chloro-1-propene	107-05-1	6
m-Chlorotoluene	108-41-8	2
o-Chlorotoluene	95-49-8	2
p-Chlorotoluene	106-43-4	2
1,2-Dibromoethane	106-93-4	11
Dibromomethane	74-95-3	15
1,2-Dibromopropane	78-75-1	48
1,2-Dichlorobenzene	95-50-1	4
1,3-Dichlorobenzene	541-73-1	5
1,4-Dichlorobenzene	106-46-7	41
1,3-Dichlorobutane	1190-22-3	2
1,4-Dichlorobutane	110-56-5	27
2,3-Dichlorobutane	7581-97-7	17
1,4-Dichloro-2-butene	764-41-0	7
3,4-Dichloro-1-butene	760-23-6	22

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TABLE 1

VOLATILES IN AMBIENT AIR
TARGET COMPOUND LIST (TCL) AND
CONTRACT REQUIRED QUANTITATION LIMITS (CRQL)

Target Compound	CAS RN	ng, on column
1,1-Dichloroethane	75-34-3	19
1,2-Dichloroethane	107-06-2	13
1,1-Dichloroethene	75-35-4	23
1,2-Dichloropropane	78-87-5	13
1,3-Dichloropropane	142-28-9	32
1,4-Dioxane	123-91-1	13
1-Ethenyl-4-chlorobenzene	1073-67-2	7
Ethylbenzene	100-41-4	6
1-(methylethyl)benzene	98-82-8	4
1-Methyl-4-(1-methylethyl)benzene	99-87-6	13
Pentachloroethane	76-01-7	6
1-Phenylethanone	98-86-2	10
Styrene	100-42-5	6
1,1,1,2-Tetrachloroethane	630-20-6	3
1,1,2,2-Tetrachloroethane	79-43-5	22
Tetrachloroethylene	127-18-4	9
Tetrahydrofuran	109-99-9	4
Toluene	108-88-3	7
Tribromomethane	75-25-2	28
1,1,1-Trichloroethane	71-55-6	6
1,1,2-Trichloroethane	79-06-5	7
Trichloroethylene	79-01-6	3
1,2,3-Trichloropropane	96-18-4	16
1,3,5-Trimethylbenzene	108-67-8	9
Xylenes, m- and p-	1330-20-7	2
Xylene, o-	95-47-6	2

NOTE: The values in Table 1 are Contract Required Quantitation Limits (CRQL), not absolute detection limits. The quantitation limits in these tables are set near the concentrations in the sample equivalent to the concentration of the lowest calibration standard analyzed for each analyte.

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TABLE 2

VOLATILE ORGANIC COMPOUNDS FOR
TENTATIVE IDENTIFICATION AND DEVELOPMENT OF CRQL DATA*

Target Compound	CAS RN
Carbon disulfide	75-15-0
Pyridine	110-86-1
1,2-Dibromo-3-chloropropane	96-12-8
2-Chloro-1 3-butadiene	126-99-8
trans-1,4-Dichlorobutene	110-57-6
Propanal	123-38-6
2-Hexanone	591-78-6
Cyclohexanone	108-94-1
1-Bromobutane	109-65-9
2-Methylnaphthalene	91-57-6
1,3,4-Trimethylbenzene	95-63-6
2,2-Dichloropropane	594-20-7
1,1-Dichloropropene	563-58-6
n-Propylbenzene	103-65-1
tert-Butylbenzene	98-06-6
sec-Butylbenzene	135-98-8
1,2,3-Trichlorobenzene	87-61-6

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* This table lists additional compounds for which the adsorbent method has not been validated, but which were ranked as air toxics of concern or identified as compounds of Regional interest during the development of this document. Data developed during method validation and subsequent analysis under SAS and RAS may lead to validation of the VOC methods in this document for some or all of these compounds.

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EXHIBIT D

ANALYTICAL METHOD FOR THE DETERMINATION OF VOLATILE ORGANIC COMPOUNDS (VOCs) IN AIR COLLECTED ON TENAX® AND ANALYZED BY GAS CHROMATOGRAPHY/MASS SPECTROMETRY (GC/MS)

December, 1991

EXHIBIT D

ANALYTICAL METHOD FOR THE DETERMINATION OF VOLATILE ORGANIC COMPOUNDS (VOCs) IN AIR COLLECTED ON TENAX® AND ANALYZED BY GAS CHROMATOGRAPHY/MASS SPECTROMETRY (GC/MS)

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EXHIBIT D

ANALYTICAL METHOD FOR THE DETERMINATION OF VOLATILE ORGANIC COMPOUNDS (VOCs) IN AIR COLLECTED ON TENAX® AND ANALYZED BY GAS CHROMATOGRAPHY/MASS SPECTROMETRY (GC/MS)

1 INTRODUCTION

1.1 Scope and Application

1.1.1 This document describes a method for determining the presence and concentration of specific volatile organic compounds (VOCs) in ambient air included in the Target Compound List (Exhibit C) and in Table D/VT-1. The method is based on the collection of VOCs on Tenax® solid adsorbent, which is made of poly(2,6-diphenylphenylene oxide), and subsequently thermally desorbing and analyzing the VOCs by gas chromatography/mass spectrometry (GC/MS).

1.1.2 While this method outlines the use of Tenax® as the adsorbent, alternative adsorbents (e.g., multibed) will be allowed. The Laboratory must demonstrate audit accuracy and replicate precision limits of the alternative adsorbent as well as adsorbent characteristic data for selected analytes in order for it to be equivalent. In addition, the analysis of Performance Evaluation (PE) samples must meet required audit accuracy and replicate precision limits as outlined in Section 5. These accuracy and precision limits were based upon data acquired over the last five (5) years from USEPA's Toxic Air Monitoring System (TAMS). The TAMs utilized Tenax® adsorbent tubes as part of the distributive air volume methodology where four tubes are arranged in close proximity, each pulling a different air volume through the resin bed to help address breakthrough, artifact formation, and biases in the sampling methodology.

1.1.3 This method is designed to allow some flexibility in order to accommodate procedures currently in use. However, such flexibility also places considerable responsibility on the user to document that such procedures give acceptable results, i.e., documentation of method performance within each laboratory situation is required. Each contractor must generate standard operating procedures (SOPs) describing specific stepwise instructions for the Tenax® preparation and handling as well as the analytical procedures. SOPs should be readily available to and understood by all involved personnel.

1.1.4 This method is based upon procedures developed by the U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC and outlined in "Standard Operating Procedure for the GC/MS Determination of Volatile Organic Compounds Collected on Tenax®." Compounds which can be determined by this method are nonpolar organics having boiling points in the range of

approximately 80 to 200°C. However, not all compounds falling into this category can be determined. Exhibit C and Table D/VT-1 of this exhibit list the target compounds to be analyzed by this method. Other compounds (e.g., semi-polar) may yield satisfactory results but validation by the individual user is required.

1.2 Summary of Method

1.2.1 In the field, ambient air is drawn through an adsorbent cartridge containing approximately 1 to 2 grams of Tenax® adsorbent. While highly volatile organic compounds and most inorganic atmospheric constituents pass through the cartridge, certain volatile organic compounds are retained on the adsorbent bed. The cartridge is then tagged and transported back to the laboratory for analysis.

1.2.2 Prior to desorption and subsequent analysis by GC/MS, internal standards are added to the cartridges. During the preconcentration step, the VOCs trapped on the Tenax® are thermally desorbed by heating the sample cartridge under a flow of helium. The desorbed vapors are collected in a cryogenic trap which is cooled by liquid nitrogen temperature. The cryogenic trap containing the organics is then heated to transfer the sample to the capillary GC column, the front of which is cooled to liquid nitrogen temperatures (-150°C). This step is essential to focus the organic compounds and allow their application to the front of the capillary column in a discrete band.

1.2.3 The scan of the mass spectrometer is initiated and the analytical procedure is begun. Under a flow of helium, the GC column is programmed to a temperature to allow the elution of all of the organic compounds while the mass spectrometer is scanning. Data are recorded by the computer for subsequent processing.

1.2.4 Components are identified in a computerized library search routine, on the basis of the GC retention time and mass spectral characteristics. Quantitation is performed by the method of relative response factors, where the proportionate system responses for analyte and standard are determined prior to the analysis of the sample and this relative system response is used to determine the quantity of compound present on the sample cartridge.

1.2.5 Quantitative calculations are performed using the method of relative response factors. Data are reported as "ng/tube" since the entire contents of each cartridge is desorbed and analyzed in one GC/MS run. If the air sample volume in m^3 pumped through each sample cartridge is known to the laboratory, the concentration may also be reported in "ng/m^3."

1.3 Interferences and Limitations

1.3.1 In the use of Tenax® adsorbent, artifacts can arise from chemical reactions due to oxidants in the sample, degradation of the Tenax®, or thermal alterations of certain VOCs. This can usually be resolved by running blank and laboratory control samples prior to analysis and using multiple sampling volumes.

1.3.2 Excessive concentrations of water vapor on high humidity days may cause some changes in retention properties of Tenax®. In general, this can be minimized by multiple sampling volumes, smaller sampling volumes, and the use of desiccants in the culture tubes used for storage.

1.3.3 Contamination of the Tenax® adsorbent with the compound(s) of interest is a commonly encountered problem in the method. The user must be extremely careful in the preparation, storage, and handling of the cartridges throughout the entire sampling and analysis process to minimize this problem. Otherwise, false positive detection of chloroform, toluene, benzene, and other common volatile organics may occur. Precautions should be taken for sampling caustic atmospheres which contain levels of NO_x and molecular halogens greater than 2-5 ppm and 25 ppb, respectively.

1.3.4 Breakthrough volumes of the compounds of interest must be known or determined prior to use. Breakthrough volumes for some compounds (e.g., vinyl chloride, chloroform, etc.) may be so small that quantitative collection is impractical. Other characteristics of Tenax® which may adversely affect its preparation and use in this method are: (1) poor desorption of highly polar compounds; (2) possible retention of oxygen, leading to sample oxidation; and (3) high benzene background due to manufacturing.

1.3.5 Tenax® breakthrough volume also influences the linear range of the method, detection limits, and reproducibility. The linear range depends upon two factors. First, it is a function of the breakthrough volume of each specific compound and second, it is related to the limits of MS detection for each analyte. Thus, the range and limit of detection are a direct function of each compound which is present in the sampled air. The nominal linear range for quantitation using a capillary GC/MS/data system is generally two to three orders of magnitude (5-500 ng, 5-5,000 ng). Absolute limit of detection may vary from 0.1 ng to approximately 50 ng. Curvature of the calibration plot may begin at levels as low as 1000 ng and must be determined for each compound.

1.3.6 The reproducibility of this method is generally ±30 percent RSD, but depends on the chemical and physical nature of each analyte. The inherent analytical errors are a function of several factors: (1) the ability to accurately determine the breakthrough volume and its relation to field sampling conditions for each of the organic compounds identified;

(2) the accurate measurement of sample volume; (3) the percent recovery of the organic from the sampling cartridge after a period of storage; (4) the reproducibility of thermal desorption for a compound from the cartridge and its introduction into the analytical system; (5) the accuracy of determining the response factor ratios between the identified compound and the quantitat n standard used for calibrating the analytical system; and (6) the reproducibility of transmitting the sample through the high resolution GC column.

1.4 **Definitions**

NOTE: Definitions used in this test method and any user-prepared SOPs should be consistent with ASTM Test Methods D1356, B260, and E355. All abbreviations and symbols are defined within this document at the initial point of use.

1.4.1 Cryogen: A liquified gas used to obtain very low temperatures (-150°C) in the cryogenic trap of the analytical system. A typical cryogen is liquid nitrogen.

1.4.2 Dynamic calibration: Calibration of an analytical system with calibration gas concentrations that are generated in a dynamic, flowing system, by metering known volumetric flow rates of concentrated gas standards and zero gas into a common inlet line to the system.

1.4.3 MS-SCAN: The GC is coupled to a mass selective detector where the instrument is programmed to acquire all mass data for the target compounds and to disregard all others.

1.4.4 Deuterated compounds: Those chemicals which contain deuterium (hydrogen isotope that is twice the mass of hydrogen) used as tracers for system quality assurance.

1.4.5 Static calibration: Calibration of an analytical system with known concentrations of calibrations gas, obtained from a source such as gas cylinders or prepared from standard stock solutions.

1.4.6 Retention time (RT): The time to elute a specific chemical from a chromatographic column for a specific carrier gas flow rate, measured from the time the chemical is injected into the gas stream until its maximum concentration appears at the detector.

1.4.7 Relative retention time (RRT): Ratio of RTs of two different chemicals for the same GC column and carrier gas flow rate, where the denominator represents the retention time for a reference chemical.

2 SAMPLE STORAGE AND HOLDING TIMES

2.1 Receipt of Exposed Cartridges

2.1.1 Receive all exposed Tenax® cartridge tubes in a sealed can with the appropriate Chain-of-Custody sheet. Match the Chain-of-Custody sheet with the corresponding sample to ensure that no mixup has occurred.

2.1.2 Check each Chain-of-Custody Sheet carefully for the following items: (1) a signature of a person relinquishing custody; (2) the amounts of surrogate loaded on the cartridge; (3) the sampling temperature and volume collected; and (4) the Tenax® batch number. Do not analyze any sample for which Chain-of-Custody sheet or any of the above information is missing.

2.2 Procedures for Sample Storage

2.2.1 Put all cans of samples in the cartridge freezer when received, and log each sample in the appropriate notebook as received. Place each Chain-of-Custody sheet in the project notebook (with all other information regarding that particular sample) after signing and dating it, and store any used cartridges in sealed cans so they can be recycled, cleaned, and used again.

2.2.2 The samples must be stored in an atmosphere demonstrated to be free of all potential contaminants. The sample cartridges should not be stored at elevated temperatures. High temperatures may result in leaking and thermal alteration of target compounds.

2.2.3 Samples and standards must be stored separately.

2.3 Contract Required Holding Times

Analysis of air samples must be completed within 14 days of the validated time of sample receipt (VTSR).

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3 CARTRIDGE PREPARATION AND CERTIFICATION

3.1 Cartridge Preparation

3.1.1 Summary

The following routine shall be followed (as illustrated in Figure D/.T-5) in the preparation of Tenax® cartridges for air sampling:

3.1.1.1 Cleaning and preparation of Tenax® adsorbent;

3.1.1.2 Preparation of the empty tube and selection of the cartridge design to be used;

3.1.1.3 Packing of the Tenax® adsorbent into the tubes; and

3.1.1.4 Pre-conditioning of the Tenax® cartridges.

3.1.2 Apparatus and Materials

NOTE: All glassware must be soaked for at least one hour in Amway SA-8 laundry compound, or equivalent, followed by several rinses with Deionized water, and baking for a minimum of four hours at 500-550°C.

3.1.2.1 Extraction thimbles: Cellulose (60 mm x 180 mm).

3.1.2.2 Soxhlet extraction apparatus: Extraction flask and condenser Fisher Scientific, 711 Forbes Avenue, Pittsburgh, PA, 15219, or equivalent.

3.1.2.3 Aluminum shipping cylinder: 17.8 cm x 1.6 cm O.D., TEKMAR Co., P.O. Box 371856, Cincinnati, OH 45222.

3.1.2.4 Vacuum oven equipped with a dry ice trap and connected to water apparatus vacuum supply - Fisher Scientific, 711 Forbes Avenue, Pittsburgh, PA, 15219, or equivalent.

3.1.2.5 Beaker: 100-mL.

3.1.2.6 Variable transformer.

3.1.2.7 Heating mantle for 1000-mL flask.

3.1.2.8 Mettler balance: Type H15 for weighing Tenax®, Fisher Scientific, 711 Forbes Avenue, Pittsburgh, PA, 15219, or equivalent.

3.1.2.9 Desiccator with gas connectors and desiccant (Drierite).

3.1.2.10 Jar, wide-mouth, amber.

3.1.2.11 Crystallizing dish, Kimax®.

3.1.2.12 Aluminum foil.

3.1.2.13 Pyrex disks: For drying Tenax®.

3.1.2.14 Sieves: 40 and 60 mesh.

3.1.2.15 Glass funnel.

3.1.2.16 Cotton gloves.

3.1.2.17 Pre-washed glass wool, unsilanized.

3.1.2.18 Glass wool, silanized.

3.1.2.19 Teflon cap liners: 24 mm.

3.1.2.20 Stainless steel tweezers.

3.1.2.21 Screw caps: 24 mm.

3.1.2.22 Silicone septa: Teflon®-backed.

3.1.2.23 One-gallon clean metal paint cans: To hold clean Tenax® cartridges.

3.1.2.24 Stainless steel tubes: 10 cm x 1.6 cm O.D., TEKMAR Co., P.O. Box 371856, Cincinnati, OH 45222.

3.1.2.25 Glass jar: Capped with Teflon®-lined screw cap. For storage of purified Tenax®.

3.1.3 Reagents

3.1.3.1 Tenax®, 60/80 mesh (2,6-diphenylphenylene oxide polymer), GC or TA - Alltech Associates, Inc., Deerfield, IL 60015.

3.1.3.2 Granular activated charcoal: For preventing contamination of Tenax® cartridges during storage.

3.1.3.3 Acetone: Pesticide quality or equivalent.

3.1.3.4 Methanol: Distilled in glass.

3.1.3.5 n-Pentane: Distilled in glass.

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3.1.4 **Tenax® Cleaning**

NOTE: The following adsorbent purification procedure is based on U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory (AREAL), Research Triangle Park, NC, Standard Operating Procedure (SOP) manual entitled "SOP for Preparation of Clean Tenax® Cartridges". Deviations from this procedure should be carefully evaluated before implementation into the user prepared SOP. Shorter cleaning procedures of the Tenax® have been documented. It is the laboratory's responsibility to provide documentation to the variation from this cleaning procedure to the Agency prior to implementation into the laboratory SOP.

3.1.4.1 All Tenax®, whether new or recycled, must be purified through solvent extraction and thermal treatment before it is used for sample collection of organic compounds. All glassware used in Tenax® purification as well as cartridge materials should be thoroughly cleaned by water rinsing followed by an acetone rinse and dried in an oven at 250°C.

3.1.4.2 To the batch of Tenax®, assign a unique number and record on the Tenax® Cleanup Worksheet, as illustrated in Figure D/VT-6. If possible, new Tenax® should be taken from a single batch that has been certified clean by the manufacturer.

3.1.4.3 If the Tenax® is new, also record batch number on the Worksheet. If the Tenax® is used, record previous Tenax® blank value and matrix in which Tenax® was used (i.e., fixed-site monitoring, breath or personal air).

3.1.4.4 In a hood, set up a sufficient number of Soxhlet extraction units, each with a 1000-mL round flask and a water-cooled condenser. Load approximately 50 g of Tenax® into each thimble and cover the Tenax® with approximately 2 cm of unsilanized glass wool.

3.1.4.5 Place the thimble in the Soxhlet, add 600 mL of methanol to the 1000-mL flask, and carefully pour an additional 300 mL of methanol onto the Tenax®.

NOTE: The 300 mL of extra methanol is added directly onto the Tenax® to ensure sufficient solvent for the extraction process after the initial adsorption of solvent.

3.1.4.6 Turn on the condenser water and the temperature-controlled heating mantle and record on the Tenax® Worksheet the date and time the extraction was started. After the first extraction cycle, adjust the temperature with the variable transformer to obtain five cycles per hour. Continue the extraction for 16-24 hours, checking the

extraction units twice daily and entering the information on the Worksheet.

NOTE: To avoid solvent losses, ensure that sufficient water is flowing to cool the condensers.

3.1.4.7 After 16 to 24 hours, cool the system and discard the methanol. With a pair of tweezers carefully pull out the thimble and let it drain in a 100-mL beaker for 10 minutes. Rinse the thimble with 50 mL of clean n-pentane. Repeat the rinse twice and then return the thimble to the Soxhlet. Discard the n-pentane.

NOTE: To avoid contamination, do not handle the thimble with your hands.

3.1.4.8 Transfer 700 mL of clean pentane to the flask. Reposition the Soxhlet and heat to reflux. Record in the Worksheet the date and time that the pentane extraction began. After the first cycle, adjust the temperature to obtain five cycles per hour.

3.1.4.9 Obtain and fill out a Tenax® cleanup worksheet, recording date and time of each operation. Complete the information on the Worksheet for this Tenax® batch, and continue the extraction for 16-24 hours. After extraction, cool the system to room temperature, remove the thimble from the Soxhlet with a pair of tweezers, and discard the pentane.

3.1.4.10 Place the beakers containing the thimbles in the desiccator at room temperature under a slow nitrogen flow (e.g., 25 mL/min) through a cryogenic trap to remove residual organics. After at least 24 hours, transfer the contents of the two thimbles to a large crystallizing dish. Cover the dish loosely with aluminum foil, set the dish in the vacuum oven, and recharge the cryogenic trap with dry ice/isopropanol and dry the Tenax® overnight at 100°C and slight vacuum.

3.1.4.11 After 24 hours, turn off the heater and allow the oven to reach room temperature (about 3 hours) before opening the oven. To open the vacuum oven, first close off the valve leading to the pump. Connect the nitrogen line to the other valve connector on the vacuum oven and slowly turn on the nitrogen flow with one hand while opening the valve with the other hand. Ensure that the nitrogen is vented out the oven through an activated charcoal tube.

3.1.4.12 Remove the Tenax® from the vacuum oven, open the valve leading to the pump and then immediately turn the vacuum pump off.

3.1.4.13 Store the Tenax® tubes, protected from the light, in a clean

wide mouth jar with Teflon®-lined cap.

3.1.4.14 Dry the rest of the Tenax® batch following the above procedures from step 3.1.4.10.

3.1.4.15 Combine the contents of the jars containing Tenax® from the same batch.

3.1.4.16 As an option, sieve the combined material and collect the fraction in the 40/60 mesh range. Return this fraction to the jar. Label the jar "sieved Tenax®" and indicate the date. Record this operation on the Worksheet.

3.1.5 Tube Preparation

NOTE: A 10-cm tube (stainless steel or glass) packed with Tenax® is referred to as a Tenax® cartridge. This section describes preparation of the empty cartridge prior to packing with the adsorbent.

3.1.5.1 The first step in preparing the cartridge is to select the type of design to be used. The most common design is shown in Figure D/VT-1a where the contact of the sample with metal surfaces is minimized. However, a disadvantage of this design is the need to rigorously avoid contamination of the outside portion of the cartridge since the entire surface is subjected to the purge gas stream during the desorption process. Clean cotton gloves must be worn at all times when handling such cartridges and exposure of the open cartridge to ambient air must be minimized.

3.1.5.2 A second common type of design is shown in Figure D/VT-1b. This design eliminates the need to avoid direct contact with the exterior surface, since only the interior of the cartridge is purged.

3.1.5.3 For adsorbent packing, a multibed option has been developed by Supelco, as illustrated in Figure D/VT-1c. The tube contains three adsorbent beds to capture the more volatile organics which Tenax® cannot retain.

3.1.5.4 Regardless of the cartridge design chosen, the thermal desorption module and sampling system must be selected to be compatible with that particular cartridge design.

3.1.5.5 Place the Teflon® liners in a beaker and sonicate them in methanol for 10 minutes, and rinse the liners with fresh methanol.

3.1.5.6 Repeat the above with n-pentane instead of methanol.

3.1.5.7 Dry the Teflon® liners in the vacuum oven for five hours at

100°C and slight vacuum. Store the liners in a wide-mouth jar, protected from light.

NOTE: To avoid contamination of the Teflon®, always use a pair of tweezers to handle the liners.

3.1.5.8 Clean the silicone septa by the above procedures from step 3.1.5.5.

3.1.5.9 Soak the 24-mm screw caps in methanol for 30 minutes, then remove the paper-lined foil from the caps with a spatula. Rinse the caps in clean methanol and dry them in the vacuum oven overnight at 100°C.

3.1.5.10 Wrap the Kimax® culture tube with aluminum foil and secure it with clear tape and place a 4-cm glass wool plug at the bottom of the culture tube.

3.1.5.11 Place a silicone septum in the screw cap. Cover the septum with a cleaned Teflon-liner, and loosely close the culture tube with the screw cap.

3.1.6 Tube Packing

NOTE: To avoid contamination of the Tenax® and the tube, always use a pair of tweezers and a pair of gloves.

3.1.6.1 Carefully inspect the tubes before packing. Discard glass tubes with rough ends or cracks.

3.1.6.2 Set the tubes in a rack and insert a 4-cm glass wool plug into one end of the tube and press the glass wool plug lightly into place with a dowel.

3.1.6.3 Using a glass funnel, transfer a known amount (approximately 2 g) of Tenax® to the tube.

3.1.6.4 Insert another 4-cm glass wool plug into the other end of the tube (see Figure D/VT-1) and lightly compress it with a dowel.

3.1.6.5 Store the Tenax® cartridges in the prepared culture tubes until pre-conditioning.

3.1.7 Tenax® Cartridge Pre-conditioning

3.1.7.1 Place the Tenax® cartridge into the conditioning unit and turn on the helium tank. This allows oxygen to be purged from the cartridge before heating.

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3.1.7.2 Turn on the desorption unit to 250°C, place liquid nitrogen in the cryogenic trap, and open the helium line to the desorption chambers.

NOTE: Ensure that a cryogenic trap has been placed in the helium line to remove residual organics.

3.1.7.3 Adjust the helium flow under each chamber to approximately 15 mL/min., then condition the Tenax® cartridges for five hours at 250°C. Make sure that helium flow is maintained to each cartridge throughout desorption.

3.1.7.4 Refill the cryogenic trap with liquid nitrogen every hour, or when the level of liquid nitrogen is less than one-third full.

NOTE: If liquid nitrogen in the trap is depleted, all the impurities trapped in the line will be transported to the Tenax®.

3.1.7.5 Record all pertinent information on the Tenax® Cleanup Worksheet for specific Tenax® batch.

3.1.7.6 Allow cartridges to cool to room temperature under the helium flow. Remove each cartridge with a pair of tweezers and immediately place the hot cartridge in a shipping container.

3.1.7.7 Seal the tube and label the screw cap with the Tenax® batch number and the culture tube with the pre-conditioning date, and place in a tightly sealed friction-top container. (For cartridges of the type shown in Figure D/VT-1a, the culture tube, not the cartridge, is labeled).

3.1.7.8 The Tenax® cartridges are now ready for certification.

3.2 Tenax® Cartridge Certification

3.2.1 Summary

The Tenax® cartridges are analyzed by GC/MS or GC/FID to ensure the integrity of the cleaning and desorbing procedures. While analysis can be accomplished by GC/MS, laboratories may choose to use GC/FID due to logistical and cost considerations.

3.2.2 Frequency

Initially, all Tenax® cartridges must be checked after cleaning/preparation to establish the percentage that pass the cleanliness criteria. A total of forty individual cartridges should be analyzed in ten batches to check for individual cartridge contamination and for batch contamination by the cleaning apparatus.

If and when only two or less individual cartridges are contaminated and no batch contamination is evident, the laboratory may reduce the number of cartridges tested for cleanliness after cleaning, but must continue to check 10 percent of the cartridges or one cartridge from each Tenax® cartridge batch, whichever is greater.

3.2.3 Procedure

3.2.3.1 Calibrate the GC/FID or the GC/MS system that has met all the tuning criteria, using a single injection of the mid level (CAL 3) standard containing all the target and surrogate compounds, prepared according to one of the calibration standard preparation procedures described in Section 4.

3.2.3.2 Analyze the clean, preconditioned cartridges following the desorption and preconcentration method outlined in section 5.6.

3.2.3.3 Cartridges should be used for sampling within two weeks after preparation and analyzed within two weeks after sampling. If possible, the cartridges should be stored at -10°C in a clean freezer (i.e., no solvent extracts or other sources of volatile organics are contained in the freezer).

3.2.3.4 The certified cartridges are considered clean for a period of two weeks after certification. If a certified cartridge is stored for a period of two weeks or more after being successfully cleaned, it must be reconditioned according to section 3.1.7 above; however, no subsequent analytical confirmation of cleanliness is required before using.

3.2.4 Calculations

For the GC screening analysis, target compound concentrations are determined using the external standard quantitation method. Use the following equation to determine target compound concentration levels:

$$Concentration,\ ng/tube = \frac{(A_x)\,(C_s)}{(A_s)} \qquad \text{EQ. D/VT-1}$$

where: A_x = peak response of analyte in the sample tube;
A_s = peak response of analyte in the calibration standard; and
C_s = amount of analyte in the injected calibration standard, ng.

3.2.5 Technical Acceptance Criteria

3.2.5.1 Each batch of Tenax® cartridges prepared must be checked for contamination by analyzing 10 percent of the cartridges or at least

one cartridge in each batch, whichever is greater, immediately after preparation. The analyzed cartridge(s) must not contain any of the target VOCs at levels greater than the CRQL, and the total level of VOCs per cartridge must not exceed 10 ng.

3.2.5.2 While acceptance criteria can vary depending on the components of interest and anticipated concentration level, at a minimum, the clean cartridge should be demonstrated to contain less than the CRQL of each component. For most compounds, the blank level should be less than 10 ng total VOCs per cartridge in order to be acceptable. More rigid criteria may be adopted, if necessary, within a specific laboratory.

3.2.6 Corrective Action

3.2.6.1 Any cartridge with a target analyte concentration greater than the its CRQL or a total concentration greater than 10 ng (target and non-target) shall be recleaned and reanalyzed subject to the same criteria for cleanliness, or be set aside.

3.2.6.2 If a cartridge does not meet these acceptance criteria, the entire batch should be rejected.

3.2.7 Documentation

Results of the certification of the Tenax® cartridges shall be reported on Form VIII-AAVT.

3.3 Supplying Cartridges for Collection of Samples

3.3.1 As a quality assurance indicator, all Tenax® cartridges shall be spiked with three surrogate standards (100 ng each of benzene-d_6, chlorobenzene-d_5, and 1,4-dichlorobenzene-d_4) as indicators of performance during sampling and analysis.

3.3.2 The surrogate compounds can be added to the adsorbent cartridge by either flash vaporization, static dilution, or by the permeation gas generation (see Section 4). The same spiking technique must be employed for all samples, blanks, and standards in an analytical sequence.

3.3.3 Prepare the Chain-of-Custody and Field Data Sheet for all samples to be collected. Remove and label the requested number of Tenax® cartridges from the Tenax® storage area. Store all of the labeled Tenax® cartridges in the Tenax® storage area until needed.

NOTE: If more than one Tenax® batch number has been assigned per matrix, use Tenax® from same batch for all the field and duplicate samples.

4 CALIBRATION STANDARDS PREPARATION PROCEDURES

4.1 Flash Vaporization

4.1.1 Summary

4.1.1.1 A dilute solution of one or more organic compounds in methanol is injected into a heated zone in a helium stream. The methanol and the solute compounds are rapidly vaporized and then swept onto a sorbent cartridge. Methanol has little affinity for Tenax® sorbent and is rapidly eluted from the cartridge while the target VOCs are retained in the cartridge.

4.1.1.2 The solute compounds remain in the sorbent bed when the cartridge is removed from the flow system, and may subsequently be desorbed from the cartridge and delivered to an analytical instrument for analysis.

4.1.1.3 Since the quantity of each compound in the cartridge can be determined from its concentration in the solution and the volume of solution injected, this method may be used to spike quantitative standards on sorbent cartridges.

4.1.2 Interferences

4.1.2.1 Contamination of the methanol solvent with compounds to be calibrated or with compounds producing similar instrumental responses will result in false high or false positive responses.

4.1.2.2 Chemical reactions between compounds can deplete them from the mixture and might also result in unexpected reaction products. Absorption of a compound into the matrix of sorbent particles will probably result in part of it being retained in the cartridge during desorption, with consequent decreased response.

4.1.2.3 Use of a syringe for consecutive injections from the same bottle without cleaning after each injection may result in erratic responses due to buildup of sample residues in the syringe. Rinse individual syringes with methanol and acetone and dry in a vacuum syringe cleaner for approximately 30 seconds. (A heat gun is used to heat the barrel of the syringe during vacuum drying.)

NOTE: Syringes must be rigorously cleaned after each injection to remove traces of sample. Even if more than one injection is needed from any given source, a freshly cleaned syringe must be used for each injection. Failure to do so may result in erratic responses.

4.1.3 **Apparatus and Materials**

4.1.3.1 Flash vaporization unit (see Figure D/VT-3).

4.1.3.2 Liquid microsyringes: 5-, 10-, 50-, and 100-µL for injecting liquid standards into flash vaporization system.

4.1.3.3 Volumetric flasks: 25-, 50-, 100-, 250-mL.

4.1.3.4 Helium cylinder and pressure regulator and needle valves for controlling flow rate.

4.1.3.5 Flow meter (i.e., soap bubble, rotameter).

4.1.3.6 Thermal conductivity detector.

4.1.3.7 Vacuum syringe cleaner.

4.1.4 **Procedure**

4.1.4.1 Assemble the flash vaporization unit, as illustrated in Figure D/VT-3.

4.1.4.2 Adjust the helium flow to 30 mL/min and the heating mantle to 310 ± 10°C.

4.1.4.3 Allow the helium to flow for approximately 30 minutes to equilibrate the system.

4.1.4.4 The volume of helium required to elute methanol from a sorbent cartridge is determined by using a thermal conductivity detector. Several different flow rates are tried to find one which results in as sharp a methanol peak as possible without sweeping volatile solutes out of the cartridge before it can be removed from the system.

4.1.4.5 Set the helium flow to 30 mL/min and the heater to 310° ± 10°C. Place a clean Tenax® cartridge in line, and pass helium through the cartridge for a period of 5 minutes.

4.1.4.6 Using a heated syringe, retrieve from the individual standard flask an aliquot using the solvent flushing technique.

4.1.4.7 With the aliquot of the standard in the syringe, inject smoothly, at the standard injection point, the syringe contents over a period of about 5 seconds. Allow the helium containing the injection standard to pass through the cartridge for 50 minutes or until 1500 mL of helium has passed. Remove the cartridge from the system, cap, and store at 5°C.

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4.1.5 Calculations

4.1.5.1 The approximate volume of solution to be injected is calculated by working backward from the size of the spike to be placed in the sorbent cartridge. An example of this calculation follows.

- If a 500 ng spike is needed, it could be done by injecting 10 µL of methanol containing 50 ng/µL of solute. Therefore, 10 µL x 50 ng/µL solution = 500 ng.
- A solution containing 50 ng/µL of solute is prepared by dissolving 5 mg of neat compound in a 100-mL volumetric flask and diluting to mark with methanol.
- If the density of the neat compound is 0.9726 g/mL (0.9726 mg/µL), then the measured neat compound would be 5 mg/(0.9726 mg/µL) = 5.14 µL.
- Therefore, 5.14 µL of solute measured with a syringe would produce 50 ng/µL solution when diluted to 100 mL with methanol
- It is not practical to measure fractions of microliters, so usual practice would be to dissolve 5 µL of sample in 100 mL of methanol to produce a concentration of: (0.9726 mg/µL x 5 µL)/100 mL = 0.0486 mg/mL = 48.63 ng/µL.
- A 10 µL aliquot of this solution would contain 486.3 ng.

4.1.5.2 As a further example, a typical mixture can be prepared as follows:

Standard	Density g/mL	Volume µL	Weight mg	Deliverable Volume µL	Spiked on Cartridges ng
ethylbenzene	0.867	11.0	9.54	3	286
p-xylene	0.861	12.0	10.33	3	310
acetophenone	1.028	10.0	10.28	3	308
2-nonanone	0.821	12.0	9.85	3	296

Each compound is measured into a 100-mL volumetric flask using a microsyringe. The flasks are filled to the mark with spectrographic grade methanol and the contents mixed thoroughly. Three microliters (3 µL) each of these solutions, when injected into the flash vaporization unit, will deposit approximately 100 ng of each compound on a sorbent cartridge as shown in the table above. The solution must be used within 12 hours.

4.2 Static Dilution Bottle Technique

4.2.1 Summary

4.2.1.1 A quantity of liquid organic compound is injected into a 2-L round bottom helium-filled flask through a septum cap. After injections are completed, the flask is agitated and heated to achieve complete vaporization.

4.2.1.2 Aliquots of the resulting vapor are then delivered to sorbent cartridges or analytical instruments. The weight of each compound delivered is calculated from: (1) the density of the liquid; (2) the volume of liquid injected into the known volume of the bottle; and (3) the volume of the vapor aliquot removed.

NOTE: The quantity of any compound injected into the dilution flask must be substantially less than that which would result in a partial pressure equal to its vapor pressure at ambient temperature. Vaporization of liquid aliquots injected into the bottle must not result in a large positive pressure, and removal of vapor aliquots from the flask must not result in a substantial vacuum. If these precautions are not taken erratic responses may occur.

4.2.1.3 The static dilution bottle technique for preparing standards has been validated for the following 22 compounds:

Acetophenone	1-Ethenyl-4-chlorobenzene
Benzonitrile	3-Chloro-1-propene
1,1,1,2-Tetrachloroethane	1,4-Dichlorobutane
1,4-Dioxane	1,2,3-Trichloropropane
1-Chloro-2,3-epoxypropane	1,1-Dichloroethane
1,3-Dichlorobutane	2-Chlorobutane
1,4-Dichlorobenzene	2-Chloroethoxyethene
cis-1,4-Dichloro-2-butene	1-Methylethylbenzene
3,4-Dichloro-1-butene	1,3,5-Trimethylbenzene
Perfluorotoluene	Butylbenzene
Fluoroiodobenzene	1-Methyl-4-(1-Methylethyl)benzene

4.2.1.4 Amounts used have ranged between 0.3 and 4 μL of liquid samples. Repeatability of daily injections of a mixture of the 22 compounds into the GC/MS is about ±10 percent RSD. Precision depends on the substance introduced, the skill of the individual producing the flask standard, and the skill of the operator of the instrument used to analyze the flask contents. Accuracy has not been established.

4.2.2 Interferences

4.2.2.1 Adsorption of vapor molecules on the walls of the bottle or

on the septum will result in loss of material, with a consequent decrease in response. This is especially likely when new, freshly annealed bottles are used. Contamination of apparatus may result in adsorption loss or provide unexpected sources of compounds in a mixture.

4.2.2.2 Chemical reactions between compounds can deplete them from the mixture and might also result in unexpected reaction products. Use of a syringe for consecutive injections from the same bottle without cleaning after each injection may result in erratic responses due to buildup of sample residues in the syringe. Rinse individual syringes with methanol and acetone and dry in a vacuum syringe cleaner for approximately 30 seconds. (A heat gun is used to heat the barrel of the syringe during vacuum drying.)

NOTE: Syringes must be rigorously cleaned after each injection to remove traces of sample. Even if more than one injection is needed from any given source a freshly cleaned syringe must be used for each injection. Failure to do so may result in erratic responses.

4.2.3 **Apparatus and Materials**

4.2.3.1 Round-bottom flask (2-L) containing 30 3-mm diameter glass beads and a 1-in. Teflon®-coated magnetic stirring bar - the flask is modified to accept a screw-on Mininert septum cap, TEKMAR Co., P.O. Box 371856, Cincinnati, OH 45222.

4.2.3.2 Gas-tight glass microsyringes: 10-, 25-, 50-, 100-, 500-, 1000-, and 2500-μL.

4.2.3.3 Laboratory oven: large enough to contain at least two dilution bottles and capable of maintaining 60 ± 5°C.

4.2.3.4 Drying oven capable of 300°C.

4.2.3.5 Helium cylinder and pressure regulator connected to a length of flexible tubing.

4.2.3.6 Vacuum syringe cleaner.

4.2.3.7 Magnetic stirrer.

4.2.3.8 Heat gun.

4.2.3.9 50-mL vial fitted with a septum cap.

4.2.4 **Procedure**

4.2.4.1 Wash the 2-L flask with detergent and water, rinse several

times with deionized water, and dry in an oven at 300°C for 4 hours.

4.2.4.2 Place 30 3-mm glass beads inside the flask and weigh on an analytical balance to an accuracy of 0.01 g.

4.2.4.3 Fill the flask with deionized water to the level of the septum cap.

4.2.4.4 Weigh the flask containing the glass beads and water on an analytical balance to an accuracy of 0.01 g.

4.2.4.5 The weight of the water required to fill the bottle is the difference between the two weights, as calculated below:

$$V_f = Wt_f - Wt_i \qquad \text{EQ. D/VT-2}$$

where: V_f = volume of flask, mL;
Wt_f = final weight of flask with beads and water, g; and
Wt_i = initial weight of flask with beads, g.

4.2.4.6 Two methods have been used to load the dilution flask with organic components for standards - direct injection of each compound separately into the flask and a single direct injection of a previously prepared mixture of compounds. These methods have been shown to produce indistinguishable results.

- The first method involves injecting each compound (one at a time) into the flask. The flask is inverted after each injection with the syringe in place through the septum, in order for the beads to remove any liquid remaining on the syringe needle. The second method involves preparing a master solution by injecting 1 mL of each component into a culture vial fitted with a septum cap. After all the compounds have been added, the vial is agitated to produce a homogeneous liquid mixture. The vial is then recapped with a new septum. Aliquots of this master solution are removed and injected into the dilution flask as needed in the same manner as indicated above; and

- The second method involves retrieving a clean, dry 2-L flask containing 70 3-mm glass beads and flushing the flask with helium for a period of five minutes. At the end of the flushing process, immediately cap with a Mininert septum cap. Place the 2-L flask on a magnetic stirring apparatus and set at the maximum speed. Using the syringes, inject the calculated volume of each compound (one at a time) or from the mixture solution into the flask while the glass beads are agitated by the stirring bar at the maximum setting of the magnetic stirrer. Invert the flask after each injection with the syringe in place through the septum,

in order for the beads to remove any liquid remaining on the syringe needle. After all substances have been introduced, place the flask in the oven at 60°C for 30 minutes to equilibrate. Store the flask in the oven at 60°C until needed. Bottles are stable for one week after preparation.

NOTE: The technique of injecting a solution of targeted compounds rather than individual injection of specific compounds is preferred if many substances are involved, because it is more rapid, and the master solution can be used over a long period if it is refrigerated at 0°C. Before use, the refrigerated solution is allowed to sit at room temperature for about an hour. It is recommended that a total less than 90 μL of liquid be injected and a total less than 20,000 μL of gas be removed.

4.2.4.7 Remove the flask from the oven and place on the magnetic stirrer for approximately 15 seconds.

4.2.4.8 Place the syringe to be used in the extraction procedure in the oven at 60°C to prevent condensation in the syringe during delivery. Using the heated syringe, insert its needle through the septum and pump three times slowly.

4.2.4.9 After the third pump, fill the syringe to approximately 25 percent greater volume than needed. After a 5-second pause, withdraw the needle from the Mininert septum valve. Flush the excess sample from the syringe, then draw a small quantity of air into the syringe to retard diffusion of sample through the syringe tip. The aliquot sample must be used immediately.

4.2.4.10 If the aliquot is to be injected into a clean sorbent cartridge, the tip of the needle is inserted to the center of the sorbent bed. Then the plunger is depressed over a 10 second period while the needle tip is being withdrawn about half the distance to the end of the bed.

4.2.4.11 If the aliquot is injected directly into the analytical instrument, injection is made in the normal manner unless column-head freeze-trapping (cryofocusing) is being employed, in which case the plunger is depressed over about a 10 second period.

4.2.4.12 If an aliquot is too large to be injected in one step, two or more injections may be made. This causes no complication for injection into a sorbent cartridge, but cryofocusing must be employed when multiple injections are made directly into a gas chromatograph.

4.2.5 Calculations

4.2.5.1 Volumes to be introduced into the 2-L flask are calculated by

working backwards from the quantity of material to be delivered. For example, if a 500 ng delivery is needed, it could conveniently be accomplished by using a 50-µL syringe containing 10 ng/µL of compound. Therefore:

$$50\ \mu L \times 10\ ng/\mu L = 500\ ng$$

4.2.5.2 If the typical volume of the flask is 2.065 L, then to get that concentration (10 ng/µL) in the flask, one would have to add 20.65 mg of liquid compound to the flask. The calculation would therefore involve: 10 ng/µL x 2.065 L = quantity of liquid needed to develop a flask concentration of 10 ng/µL.

$$10\ ng/\mu L \times 2.065\ L = 20.65\ mg$$

4.2.5.3 If the density of the solution was 0.9726 g/mL (or 0.9726 mg/µL), then the volume of solution needed to add to the flask to maintain a concentration of 10 ng/µL or a deliverable of 500 ng would be 21.23 µL, as calculated below:

$$20.65\ mg/(0.9726\ mg/\mu L) = 21.23\ \mu L$$

4.2.5.4 It is not practical to deliver and measure fractions of a microliter; therefore, in practice, 21 µL would be used. The deliverable would be calculated:

$$(21\ \mu L \times 0.9726\ mg/\mu L)/2065\ mL = 0.00989\ mg/mL = 0.00989\ \mu g/\mu L$$

4.2.5.5 This is equivalent to 9.89 ng/µL, so a 50-µL injection of the vapor compound from the static dilution flask would contain 494.5 ng of compound delivered as calculated below:

$$9.89\ ng/\mu L \times 50\ \mu L = 494.5\ ng$$

4.3 Permeation Calibration Generator

4.3.1 Summary

4.3.1.1 A permeation calibration generator is designed to allow the permeation of gas through Teflon® or other plastic material at a constant rate in a water bath at constant temperature to generate test atmospheres.

4.3.1.2 The permeation tube is made by sealing a liquid chemical in a tube made of some permeable material. It is essential that the chemical be in the liquid state for the permeation tube to operate properly. In many cases the chemical is a gas at atmospheric pressure, but is maintained in the liquid state under its own saturation vapor pressure in the permeation tube. The tube is sealed

at both ends with a non-permeable plug.

4.3.1.3 Permeation of the vapor within the tube occurs through the exposed sidewalls because of the concentration gradient that exists between the inner and outer tube walls. By passing different flows of diluent gas over the tube, gases of varying concentration can be generated. If the tube is held at a constant temperature, the permeation rate will remain constant. By measuring the weight loss at this constant temperature over a given period of time, the permeation rate may be determined. The output rate of the tube will remain essentially constant until nearly all of the liquid in the tube has permeated through the walls. In general, permeation tubes can be used to generate known concentrations of target compounds between 0.7 to 200 ppbv.

4.3.2 Apparatus and Materials

4.3.2.1 Permeation system (see Figure D/VT-4).

4.3.2.2 Nylon gloves.

4.3.2.3 Long glass hook (for retrieving permeation tubes).

4.3.2.4 Permeation tubes.

4.3.2.5 Lint-free tissues (e.g., Kimwipes®).

4.3.2.6 Stopwatch.

4.3.3 Procedure

4.3.3.1 Before a permeation device can be used in the laboratory or in the field, its permeation rate must be determined. The permeation rate, R, is determined gravimetrically. The tube is weighed, then placed in a temperature bath (±1°C) for a period of time. The tube is removed and reweighed. This process is repeated over several days to calculate a permeation rate at that specific temperature. The difference between initial and recorded weight (ng), divided by time (min) determines the permeation rate at that specific temperature.

$$R = \frac{W}{T} \qquad \text{EQ. D/VT-3}$$

where: R = Permeation rate, ng/min;
W = Weight change, ng; and
T = Time, minutes.

4.3.3.2 The permeation rate can be calculated either manually, as

shown in the above equation, or recorded automatically. At different temperatures, different permeation rates can be calculated.

4.3.3.3 Permeation tubes should be kept at the temperature specified by the manufacturer and at a constant temperature (±0.05°C) during calibration procedures. Changes in temperature as small as 0.1°C can significantly affect the permeation rate. Tubes should initially be allowed to equilibrate for 24 hours. After small changes in temperature (1 to 5°C), the tube should be allowed to equilibrate for at least half an hour.

4.3.3.4 A permeation tube system has been developed for application of loading known standards onto Tenax® cartridges for use in determining the relative response factor and the column performance evaluation of the GC/MS-DS system in conjunction with the flash vaporization system.

4.3.3.5 In addition, the permeation tube system may be used for generating internal standards to be loaded by syringe onto the Tenax® tube to determine relative retention times, relative response factors, and stability of the GC/MS system and for generating surrogate standards used in the evaluation of breakthrough volumes associated with Tenax®.

4.3.3.6 A permeation system consists of three main parts (see Figure D/VT-4): (1) a temperature-controlled chamber containing permeation tubes; (2) a mixing chamber; and (3) permeation tube storage chamber. A stream of nitrogen flows through the system. The amounts of compounds transported downstream remain constant once the system has become equilibrated with the compounds to be loaded. The amount of compounds can be determined by measuring the time and the gas flow through the cartridge.

4.3.3.7 The permeation system may be used to load any volatile compound that will permeate at a constant rate under controlled conditions, and to inject a calibration standard onto a sorbent via syringe.

NOTE: Because the compounds in the permeation tubes may be toxic or contain suspected carcinogen, the Permeation Generator Assembly should be housed in a properly ventilated hood.

4.3.3.8 The following routine should be followed when Tenax® cartridges are loaded with standards via a permeation system: (1) determine the number of cartridges to be loaded, 2) select the permeation tubes; (3) determine the loading conditions to be used; (4) equilibrate the system (5) load the cartridges; (6) calculate the amounts of compounds loaded (7) ensure the integrity of the loading

procedure; and (8) pack and store the cartridges.

- Obtain a copy of the field sampling schedule from the Monitoring Coordinator or Program Manager;
- Determine the number of standards to satisfy the sampling objectives;
- Check the permeation notebooks (located in the laboratory) to see which permeation tubes are available for the needed standards; and
- Select only the permeation tubes whose permeation rates are stable.

NOTE: A permeation rate is considered stable when the mean permeation rate has a coefficient of variation (CV) of less than 10 percent. The mean permeation rate is calculated using the last five individual permeation rates. Do not use permeation tubes with permeation rates below 100 ng/min or above 1×10^5 ng/min.

- In a bound notebook assigned for the specific project, prepare a table including the numbers of the tubes to be used, the names of the compounds, and the corresponding mean permeation rates.

4.3.4 Calculations

4.3.4.1 For any compound, calculate the amounts needed to be loaded onto a Tenax® cartridge using the following formula:

$$G = \frac{(P)(t)(F_1)}{(F_1 + F_2)} \qquad \text{EQ. D/VT-4}$$

where: G = Amount loaded of compound onto Tenax® tube;
P = Permeation rate of specific compound, ng/min;
t = Loading time of compound onto Tenax® tube, minutes;
F_1 = Flow rate through the Tenax® cartridge, mL/min; and
F_2 = Exhaust flow rate, mL/min.

NOTE: The four variables G, t, F_1, and F_2 determine the loading conditions. Any three may be fixed and the fourth one calculated from the equation.

4.3.4.2 The following restrictions must be followed to minimize error: (1) do not load for less than two minutes; (2) do not load with a cartridge flow below 50 mL/min or above 150 mL/min; and (3) do not operate the system with a total flow below 250 mL/min.

4.3.4.3 If the GC/MS system needs to operate in the range of 200-500

ng per analyte, then the analyst must generate standards concurrent with that range. Fixing three of the four variables of the above equation will enable calculation of the needed loading onto the Tenax® tube.

4.3.4.4 As an example, the following calculations are provided to assist the user in determining operating parameters of the permeation tube system in generating standards on QA/QC checks.

OBJECTIVE: To load chlorobenzene and chloroform onto a cartridge in the range of 200-500 per analyte.

GIVEN: G = 200 ng per analyte
F_1 = 80 mL/min
t = 4 min
P = 270 ng/min for chlorobenzene
= 520 ng/min for chloroform

Chlorobenzene

$G = (P)(t)[F_1/(F_1+F_2)]$
200 ng = [(270 ng/min)(4 min)] x [(80 mL/min)/(80 mL/min+F_2)]
F_2 = {[(270 ng/min)(4 min)(80 mL/min)]/200 ng) - 80 mL/min
F_2 = 352 mL/min

Now, since all tubes are in the permeation device together, the flow (F_2) for chloroform will be 352 mL/min. Therefore, the loading on the Tenax® tube for chloroform must be calculated to verify that it falls within the 200-500 ng per tube loading.

Chloroform

$G = (P)(t)[F_1/(F_1+F_2)]$
G = (520 ng/min)(4 min)[(80 mL/min)/(80 mL/min + 352 mL/min)]
G = 385 ng

All values obtained are within the acceptable range.
NOTE: Permeation tubes may contain toxic or carcinogenic materials. The following procedures should be carried out in a properly ventilated glove box or hood. Wear nylon gloves when handling permeation tubes.

4.3.4.5 Locate the chambers in which the selected permeation tubes are stored. With a long glass hook, remove the selected permeation tubes from the storage chamber and transfer immediately to the loading chamber of the permeation system.

NOTE: When a cartridge is not being loaded, a dummy cartridge is placed in the loading position.

4.3.4.6 Direct nitrogen flow to the side where the Tenax® cartridge will be loaded and allow the system to equilibrate for 30 minutes before loading cartridges with the generated test atmospheres.

4.3.4.7 Divert the nitrogen flow to the side that will not be used for loading cartridges and insert the Tenax® cartridge into the chamber.

4.3.4.8 Start the stopwatch and immediately direct the test atmospheres gas flow through the cartridge.

4.3.4.9 Calculate the time needed to load the amounts desired as follows:

$$t = (G/P) \times [(F_1 + F_2)/F_1]$$

NOTE: Base the calculation only on the compound whose permeation tube has the highest or lowest permeation rate.

4.3.4.10 At the calculated time, rotate the two stopcocks to direct gas flow away from the cartridge being loaded.

4.3.4.11 Handling the cartridge with a Kimwipe®, remove the cartridge and return it to its culture tube. Seal the tube, then label with the following information: (1) project number; (2) standard mixture followed by a number indicating the order of loading; and (3) the date.

4.3.4.12 For every compound, calculate the amount loaded onto a cartridge using the general formula:

$$G = (P)(t)[F_1/(F_1 + F_2)]$$

4.3.4.13 Deliver the loaded permeation tubes to the GC/MS for use in the quality assurance program.

5 GC/MS ANALYSIS OF VOLATILES FROM TENAX® CARTRIDGES

5.1 Summary

5.1.1 This section includes a description of the GC/MS system and associated procedures for GC/MS tuning, characterizing the performance of the GC/MS calibration procedures, and analysis of the exposed Tenax® cartridges and QC samples.

5.1.2 The analytical system is comprised of a GC equipped with a mass spectrometer set in the full scan mode. The GC/MS is set up for automatic, repetitive analysis and programmed to acquire data for the target compounds. The Contract Required Quantitation Limits (CRQL) range from 1 to 50 ng in the full scan mode with an analytical precision of about 5 percent RSD. Concentration of compounds based upon a previously installed calibration table is reported by an automated data reduction program.

5.1.3 The relative response factor (RRF) from the continuing calibration standard analysis is used to calculate the concentration in the sample. Secondary ion quantitation is allowed ONLY when there are sample interferences with the primary ion. If secondary ion quantitation is performed, document the reasons in the SDG Narrative. The area of a secondary ion cannot be substituted for the area of a primary ion unless a relative response factor is calculated using the secondary ion.

5.1.4 Quantitation is based on integration of the SICP of a quantitation mass or primary ion for the compound. This mass has been previously selected for each compound based on its spectral uniqueness, intensity, and lack of potential interferences from known coeluting compounds. Currently used masses are listed in Table D/VT-5 for both primary and secondary ions.

5.2 Apparatus and Materials

NOTE: Considerable variation from one laboratory to another is expected in terms of instrument configuration. Therefore, each laboratory must be responsible for verifying that their particular system yields satisfactory results. Section 6 discusses specific performance requirements which must be met.

5.2.1 Sampling/Preconcentration System

5.2.1.1 Sample Desorption/Injection Unit: Designed for thermally heating a Tenax® sample cartridge (glass or stainless steel) for sample transfer into a suitable GC/MS system for analysis. The configuration of the thermal desorption unit should permit the enclosure and rapid heating of the Tenax® cartridge from room

temperature to approximately 250°C while purging with an inert gas (helium) into a cryogenically cooled (liquid nitrogen) trap. The cryogenically cooled sample must then be rapidly heated to a preselected temperature (200-250°C) and a helium gas supply allowed to sweep the sample from the trap onto the gas chromatographic column. A schematic diagram of a typical thermal desorption/GC/MS configuration is shown in Figure D/VT-2.

5.2.1.2 A block diagram of the typical system required for analysis of Tenax® cartridges is shown in Figure D/VT-2. The thermal desorption module must be designed to accommodate the specific cartridge configuration used in the sampling protocol. Steel or nickel metal surfaces should be employed. The volume of tubing and fittings leading from the cartridge to the GC column must be minimized and all areas must be well-swept by helium carrier gas.

5.2.1.3 Sample cartridge: Sampling cartridges consist of 13.5 x 100 mm borosilicate glass with polished-flat end surfaces. One end is etched with an I (inlet) and the other with an E (exit). Stainless steel cartridges (12.7 mm OD x 100 mm long) may also be used. (see Figure D/VT-1). Cartridges must fit into the thermal desorption unit.

5.2.1.4 Glass fiber filters, 25 mm (optional).

5.2.1.5 Forceps.

5.2.1.6 Lint-free tissues: (e.g., Kimwipes®).

5.2.1.7 Filter holder: Stainless steel or aluminum (to accommodate 1 inch diameter filter).

5.2.1.8 Cotton gloves: For handling Tenax® cartridges.

5.2.2 GC/MS System

5.2.2.1 The GC/MS system should be capable of subambient temperature programming, exhibit unit mass resolution up to 400 amu, and be capable of scanning a 35-300 amu region every second. Equipped with data system for instrument control as well as data acquisition, data processing using spectral enhancement algorithms, and historical library screening and storage.

5.2.2.2 The GC column required for this method is fused silica, 0.30 mm ID x 50 m, SE-30 or OV-1 coating. The GC column inlet should be capable of being cooled to 10°C and subsequently increased rapidly to approximately 30°C. This can be most readily accomplished using a GC equipped with an automated subambient cooling capability (liquid nitrogen), although other approaches such as manually cooling the

inlet of the column with a cotton swab containing liquid nitrogen may be acceptable.

5.2.2.3 The specific GC column and temperature program employed will be dependent on the specific compounds of interest. Appropriate conditions are described in Table D/VT-2. In general a nonpolar stationary phase (e.g., SE-30, OV-1) temperature-programmed from 30 to 245°C at 4°/min will be suitable.

5.2.3 Data System

5.2.3.1 GC/MS analysis is based on a combination of retention times and relative abundances of target ions. These qualifiers are stored on the hard disk of the GC/MS computer and are applied for identification of each chromatographic peak. The computer must have software that allows searching any GC/MS data file for ions of a specified mass and plotting such ion abundances versus time or scan number. This type of plot is defined as Selected Ion Current Profile (SICP). Software must also be available that allows integrating the abundance in any SICP between specified time or scan number limits. Also, for the non-target compounds, software must be available that allows for the comparison of sample spectra against reference library spectra. The 1990 (or more recent) release of the National Institute of Standards and Technology (NIST) Mass Spectral Library shall be used as the reference library. The data system must be capable of flagging all data files that have been edited manually by laboratory personnel. The retention time qualifier must be determined to be within ±6 seconds of the library retention time of the compound. The acceptance level for relative abundance must be determined to be within ± 20 percent of the expected abundance. Any peak that fails any of the qualifying tests is flagged. All the data are manually examined by the analyst to determine the reason for the flag and whether the compound should be reported as detected. While this adds some subjective judgment to the analysis, computer generated identification problems can be clarified by an experienced operator. Manual inspection of the quantitative results is also performed to verify concentrations outside the expected range.

5.3 Reagents

5.3.1 Nitrogen gas: certified 99.995 percent.

5.3.2 Helium: certified 99.995 percent, with regulator.

5.3.3 Neat standards: chemical compounds to be used as standards.

5.3.4 Spectrograde methanol: distilled in glass.

5.3.5 Spectrograde acetone: distilled in glass.

NOTE: Individual chemicals to be used for standards, as well as isotopic standards, must have a manufacturer's determined purity of ≥98 percent or better. Purity should be checked by NMR or direct probe MS. Each chemical received by the laboratory is checked by injection of an aliquot into a GC, using a 50-m SE-30 WCOT glass capillary bonded (cross-linked) column and FID. The resulting chromatogram is examined for extraneous peaks. If such peaks are observed and amount to more than 2 percent of the standard peak, the standard is unacceptable.

5.4 Standards

5.4.1 The procedures for the preparation of calibration standards are described in more detail in Section 4. This section presents three procedures for generating known concentrations of targeted VOCs for direct injection into the GC/MS for calibration, or for deposition on Tenax® for calibration of the entire GC/MS analytical system. (Note that direct injection is allowed only for a continuing calibration standard.) They are: (1) use of flash vaporization technique for loading targeted VOC standards upon Tenax® tubes; (2) preparation of known concentrations utilizing static dilution bottles; and (3) use of permeation tube system for generating known concentrations of VOC standards on Tenax®.

5.4.2 The Contractor must provide all standards to be used with this contract. The Contractor must be able to verify that the standards are certified. Manufacturer's certificates of analysis must be retained by the Contractor and presented upon request.

5.4.3 Neat standards must have a purity of 98 percent or greater. The weight may be used without correction to calculate the concentration of the stock solution.

5.4.4 Alternate methods of generating standards may be used if equivalency is established through an EPA audit procedure. Standards on Tenax® may be stored for no more than two weeks.

5.4.5 **Calibration Stock Standards**

Primary stock standards containing the target compounds at 10 mg/mL are used as primary stock standards.

5.4.6 **Working Standards**

5.4.6.1 **Instrument Performance Check Standard**

Prepare a standard solution of BFB in methanol at a concentration which will allow injection of 50 ng of BFB under the

optimized instrument parameters. Prepare fresh BFB solution every six months, or sooner, if the solution has degraded or evaporated.

5.4.6.2 Calibration Standards

Prepare five calibration standards at the concentration levels for each component as outlined in Table D/VT-4.

5.4.6.3 Internal Standard Spiking Mixture

Prepare an internal standard spiking mixture containing perfluorotoluene (PFT), 1,2-dichlorobenzene-d_4, and 1,4-difluorobenzene at a concentration that will allow deposition of 100 ng of each internal standard on the Tenax® cartridges. The amount of internal standard spiking mixture used for each analysis must be the same from run to run. Internal standards are spiked into the samples, blanks, and standard cartridges just prior to thermal desorption and subsequent GC/MS analysis.

5.4.6.4 Surrogate Compounds Spiking Mixture

Prepare the surrogate compounds spiking mixture containing benzene-d_6, chlorobenzene-d_5, and 1,4-dichlorobenzene-d_4 at a concentration that will allow deposition of 100 ng of each surrogate compound on the Tenax® cartridges. The amount of surrogate spiked into each cartridge must be the same for all analysis. The surrogate compounds are spiked onto the sample cartridges prior to field deployment.

5.4.6.5 Laboratory Control Sample (LCS) Spiking Mixture

Prepare the LCS spiking mixture containing all of the compounds listed below to allow deposition of 100 ng of each compound onto a Tenax® cartridge:

benzene	1,2-dichloropropane
carbon tetrachloride	tetrachloroethylene
1,2-dibromoethane	1,1,2-trichloroethane
1,2-dichlorobenzene	trichloroethylene
1,2-dichloroethane	

5.4.7 Storage of Standards in Cartridges

5.4.7.1 Secure the cartridge inside the Kimax® tube with a glass wool plug to avoid breakage during transport. For deuterated standards, label the top of the screw cap with the symbol, "D*".

NOTE: The star (*) indicates that deuterated standards have been loaded onto the cartridge. This symbol will also be added to the participant's code.

5.4.7.2 Store the cartridges in a sealed paint can in the freezer until they are ready to be sent to the field.

5.5 Instrument Operating Conditions

The typical instrument conditions for the analysis of VOCs on Tenax® sampling cartridge are outlined below using a NuTech Model 320, Tekmar Model 5000, or equivalent thermal desorption unit. The thermal desorption chamber and the six port Valco valve are maintained at 250°C during analysis. The detector is a quadrupole spectrometer capable of electron impact ionization. The nickel capillary trap on the inlet manifold should be cooled with liquid nitrogen.

5.5.1 Thermal Desorption Unit

Purge gas (prior to desorption)	-	Helium @ 1.2 mL/min
Desorption cycle		8 minutes
Initial desorption temperature	-	25°C
Final desorption temperature	-	150°C
Thermal desorption unit purge	-	10 mL/min

5.5.2 Gas Chromatography

Injection/Detector temperature	-	200°C
Initial column temperature	-	30°C
Initial hold time	-	0.1 minutes
Program (ramp rate)	-	4°C/min to 240°C
Final hold temperature	-	240°C
Final hold time	-	0.1 minutes
Maximum oven temperature	-	245°C
Carrier gas	-	Helium; velocity 20 cm^3/sec at 250°C
GC/MS interface	-	Direct coupling or glass jet
Sample injection to MS	-	Direct Probe
Column	-	Hewlett-Packard OV-1 glass capillary crosslinked methyl silicone (50 m x 0.3 mm, 0.17 μm film thickness) Scientific Glass Engineering SE-30 glass capillary crosslinked methyl silicone (50 m x 0.5 mm, 0.80 μm film thickness),or equivalent.

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5.5.3 Mass Spectrometer

Mass range	-	35 to 300 amu
Scan time	-	1 sec/10 min over entire range
EI condition	-	70 eV
Mass scan and detector mode	-	Follow manufacturer instruction for select MSD and scan mode
Routine tuning	-	p-bromofluorobenzene (BFB)
Preamp sensitivity	-	10^7
Emission current	-	0.45
Electron multiplier voltage	-	1000 to 1500
Mass filter	-	10 amu/sec
Filter	-	x 100
Total Ion Current sensitivity	-	1
Resolution	-	Normal
Display	-	TIC
Response	-	Fast

5.6 Instrumental Analysis

5.6.1 Initial Start-Up

5.6.1.1 Prior to instrument calibration or sample analysis, helium purge flows (through the desorption unit) and carrier gas flow to the GC/MS are set at approximately 10 mL/min and 1-2 mL/min, respectively. If applicable, the injector sweep flow is set at 2-4 mL/min.

5.6.1.2 After the column and other system components are assembled, condition the column as specified by the manufacturer.

5.6.1.3 The MS and data system are set according to the manufacturer's instructions. The mass range should be from 35 to 300 amu, the scan time should be at least five scans per peak and not to exceed one second per scan. Table D/VT-2 outlines general operating conditions for the GC/MS system.

5.6.1.4 Once the entire GC/MS system has been set up, the user should prepare a detailed standard operating procedure describing the operation of the specific instrument being used.

5.6.1.5 Turn on the power to the mass-flow controllers and set line pressures for the following gases:

- Helium: 60 psig
- Compressed Air: 40 psig
- Nitrogen: 30 psig

5.6.1.6 Flow rates for the thermal desorption and GC system should be established according to instrument requirements.

5.6.1.7 Turn on the master power switch to the chromatograph, set manifold temperature to 105 ± 5°C, and set source ionization temperature to 260°C.

5.6.1.8 Turn on the power to the thermal desorption unit and set the temperatures for the valve, trap, and transfer line on the vernier dials on the control box of the thermal desorption unit according to manufacturer's specification. Typical values are:

- Valves 275°C
- Trap 250°C
- Line 210°C

5.6.2 Thermal Desorption of Tenax® Adsorbent Tubes

5.6.2.1 Initially, the thermal desorption unit is cold and the Tenax® cartridges are placed inside while flowing helium through them. This allows oxygen to be purged from the trap, reducing oxidative degradation of Tenax®. Then, during the thermal desorption cycle, helium gas continues to flow through the cartridge to purge the organic vapors on the Tenax® into the liquid nitrogen capillary trap.

5.6.2.2 After the desorption has been completed, the six-port valve is rotated and the temperature on the capillary loop is rapidly raised (greater than 100°C/min); the carrier gas then introduces the vapors onto the high resolution GC column. The bonded-phase fused silica capillary column is temperature-programmed from 40°C (5 min hold) to 240°C at 4°C/min and held at the upper limit until all target compounds elute.

5.6.2.3 The column is programmed to a temperature that will allow the elution of all of the organic compounds while the mass spectrometer is scanning. Data are recorded by the computer for subsequent processing. Quantitation is performed by the method of relative response factors, where the proportionate system responses for analyte and standard are determined prior to the analysis of the sample and this relative system response is used to determine the quantity of compound present on the sample cartridge.

5.6.2.4 The following outlines typical steps associated with sample handling immediately prior to thermal desorption using the NuTech device. They are presented as a guideline to follow when using this or similar equipment.

5.6.2.4.1 Remove the sealed paint can containing the desired Tenax® cartridge from the freezer.

NOTE: Use the freezer in the laboratory designated for cartridge storage ONLY for this purpose. Inadvertent storage of containers of solvent in this freezer will result in contamination of all cartridges stored in the freezer and will compromise the analysis, since organic solvents are frequently target compounds for quantitative analysis. Verify that the laboratory personnel are not involved in any process which exposes open containers of organic solvents, as organic solvent vapor will contaminate a Tenax® cartridge exposed to this atmosphere in only a few seconds, thus compromising the quantitative and/or qualitative assay.

5.6.2.4.2 Open the sealed lid of the paint can, using a flat-bladed screwdriver, beverage can opener, or other convenient tool for this purpose.

NOTE: The cartridge will be in a stainless steel tube with a Teflon-lined screw cap.

5.6.2.4.3 Remove a single Tenax® tube from the paint can. Seal the paint can and replace in the freezer, and release the Teflon cap of the desorption chamber.

5.6.2.4.4 Remove the cartridge from the shipping tube using forceps.

NOTE: DO NOT TOUCH THE CARTRIDGE WITH YOUR HANDS! Organic compounds present on the fingertips can be sufficient to compromise the analysis. If the cartridge is inadvertently touched, make careful note of the circumstances in both the instrument log and the project notebook.

5.6.2.4.5 Insert the cartridge immediately into the desorption chamber. Close the Teflon cap of the desorption chamber, and initiate the timing of the eight-minute desorption cycle. During this time period, helium is flowing through the desorption chamber.

5.6.2.5 At the end of the eight-minute desorption cycle, turn the desorption unit valve to the INJECT mode. The following steps are automatic on some commercially available instruments.

5.6.2.5.1 Start the GC temperature program;

5.6.2.5.2 Initiate heating of the nickel trap;

5.6.2.5.3 Turn on data acquisition system; and

5.6.2.5.4 Turn off the trap after it has heated to 250°C.

5.6.2.6 Turn the thermal desorption unit valve back to desorb and remove the Tenax® cartridge. At the end of the run, the GC will recycle and cool to 30°C, and the data acquisition will stop automatically after all compounds have eluted.

5.6.2.7 Repeat this procedure for each Tenax® cartridge.

5.6.2.8 Data from GC/MS runs are normally processed by the data system in an automated program which locates the compounds of interest in the data set, quantifies those compounds for which calibration data are available, and prints a report. A typical report will present the quantification parameters and result for those compounds identified and quantifiable. The report will typically list those compounds which were searched for in the sample, indicate which ones were not found, print the identifying characteristics and quantification results for those which were found, and present comments for the operator's benefit, such as the criteria which caused a peak to be rejected or the center scan for any search which failed. The information in the report can also be saved in a DS file for archival storage and DS transfer purposes.

5.6.2.9 The DS library should contain a file containing one entry for each compound of interest. For each entry, the library contains the compound name, its mass spectrum from the Mass Spectral Data Base, its absolute retention time, and its retention time relative to the internal standards, as determined from calibration standards. Response lists are compound specific DS files containing the quantitative calibration data for each of the target compounds.

5.6.2.10 The automated procedure attempts to locate chromatographic peaks corresponding to target compounds by a reverse library search using the following recommended criteria for scan window:

5.6.2.10.1 For internal standards:	±100 seconds from library scan number.
5.6.2.10.2 For single compounds:	±20 seconds from the calculated scan.
5.6.2.10.3 For isomer groups:	-20 and +20 seconds from the calculated seconds for the earliest and latest eluting members of the group, respectively.

5.6.2.10.4	Peak identification:	As determined by the laboratory.
5.6.2.10.5	Peak selection:	The scan list is partitioned in order of increasing distance from the center of the scan window, except for isomer groups.

5.6.2.11 The automated procedure begins by attempting to locate the two retention time markers (perfluorotoluene and 1,2-dichlorobenzene-d_4). If the early eluting standard, PFT, is not located, a warning message is printed and the procedure is terminated. If only the late eluting internal standard is not found, the procedure uses the scan number calculated from the library retention time for this standard as a default value.

NOTE: Alternatively, the operator may specify scan numbers for the internal standards and then initiate the remainder of the automated procedure. The procedure cycles through the compounds in the library list attempting to locate each compound in turn.

5.6.2.12 If one or more peaks are identified in the search for a target compound, the resulting scan list is partitioned to order the scans in increasing distance from the center of the search window. The mass spectra in the partitioned list are sequentially compared to the library entry for the target compound in order to the mass weighted purity, fit and rfit.

5.6.2.13 If the mass spectrum at the peak maximum passes either of the above tests, the procedure attempts to quantify the peak. If the target is a single compound, only the first peak to pass the qualitative criteria is processed further. If the target is an isomer group, all peaks detected by the search are processed through the qualitative filters and all that pass these filters are quantified. If no peaks are found by the search or pass through the qualitative filters, a "not detected" entry is placed in the report.

NOTE: The failure of a peak to satisfy these criteria does not necessarily prove the absence of the compound in the sample. Interfering compounds or low levels of the compound of interest may cause the test values to fall outside of the acceptance range. It is also possible to obtain acceptable values for fit/purity and rfit/purity, but have a questionable identification. If the absence of a particular compound is of crucial importance and the DS procedure fails to locate the compound, manual inspection of the data by a person skilled in the interpretation of GC/MS data is necessary for confirmation.

5.7 **Analytical Sequence**

The GC/MS analytical sequence for each 12-hour time period shall be as follows:

5.7.1 Instrument Performance Check (BFB);

5.7.2 Initial or continuing calibration;

5.7.3 Laboratory Method Blank;

5.7.4 LCS;

5.7.5 Field Blank;

5.7.6 ≤20 field samples; and

5.7.7 Performance Evaluation (PE) Sample (if available).

5.8 **Instrument Performance Check**

5.8.1 **Summary**

Instrument performance check and mass standardization of the MS system is performed according to manufacturer's instructions and relevant information from the user-prepared SOP. The mass calibration and resolution of the GC/MS system are verified by the analysis of the instrument performance check standard.

5.8.2 **Frequency**

5.8.2.1 Prior to the analyses of any samples, blanks, or calibration standards, the Contractor must establish that a given GC/MS meets the standard mass spectral abundance criteria. This is accomplished through the analysis of p-bromofluorobenzene (BFB). The instrument conditions required for the acquisition of the BFB mass spectrum are given in Exhibit E.

5.8.2.2 Each GC/MS used for analysis must be checked for performance daily or once per each twelve hour period of operation, whichever is most frequent, to meet the technical acceptance criteria for BFB as outlined in Table D/VT-3. Also, whenever corrective action which could change or affect the instrument performance check for BFB (e.g., ion source cleaning or repair, column replacement, etc.), the instrument performance check must be verified immediately irrespective of the 12-hour or daily performance check requirement.

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5.8.3 **Procedure**

5.8.3.1 Prepare a 25 ng/μL solution of BFB in methanol. Prepare fresh BFB solution every six months or sooner if the solution has degraded or evaporated.

NOTE: The 25 ng/μL concentration is used with a 2 μL injection volume. The laboratory may prepare a 50 ng/μL solution of BFB if a 1 μL injection volume is used.

5.8.3.2 Inject 50 ng BFB into the GC/MS.

5.8.3.3 Set time and parameters for the acquisition of the data and initiate data acquisition by following instructions in the operator's manual.

5.8.3.4 The instrument parameters (e.g., lens voltages, resolution) should be adjusted to give the relative ion abundances shown in Table D/VT-3 as well as acceptable resolution and peak shape. If these approximate relative abundances cannot be achieved, the ion source or quadrapoles may require cleaning according to manufacturer's instructions. The Contractor must obtain the required relative ion abundances for BFB before proceeding with sample analysis.

5.8.4 **Technical Acceptance Criteria**

5.8.4.1 Prior to the analysis of any samples, blanks, or calibration standards, the Laboratory must establish that the GC/MS system meets the mass spectral ion abundance criteria for the instrument performance check solution.

5.8.4.2 The instrument performance check standard must be injected once at the beginning of each 12-hour period during which samples or standards are to be analyzed.

5.8.5 **Corrective Action**

5.8.5.1 If the BFB acceptance criteria are not met, the MS must be retuned. It may be necessary to clean the ion source, or quadrupoles, or take other actions to achieve the acceptance criteria.

5.8.5.2 BFB acceptance criteria MUST be met before any standards, performance evaluation (PE) samples, or required blanks are analyzed.

5.8.6 **Documentation**

Reporting requirements are listed in Exhibit B. Results of the GC/MS tuning are reported on Form IV-AAVT.

5.9 Initial Calibration

5.9.1 Summary

5.9.1.1 Prior to the analysis of samples and required blanks and after the instrument performance check standard criteria have been met, each GC/MS system must be calibrated at a minimum of five concentrations in an initial calibration sequence to determine instrument sensitivity and the linearity of GC/MS response for the target and surrogate compounds.

5.9.1.2 All sample results, for sample analyses performed in the same 12-hour sequence as the initial calibration, are quantified against the initial calibration standard that is the same concentration as the continuing calibration standard.

5.9.2 Frequency

5.9.2.1 Each GC/MS system must be calibrated upon award of the contract, whenever the Contractor takes corrective action which may change or affect the initial calibration criteria (e.g., ion source cleaning or repair, column replacement, etc.), or if the continuing calibration standard acceptance criteria have not been met.

5.9.2.2 If time remains in the 12-hour time period after meeting the acceptance criteria for the initial calibration, samples may be analyzed. If time does not remain in the 12-hour period after meeting the acceptance criteria for the initial calibration, a new analytical sequence shall commence with the analysis of the instrument performance standard.

5.9.3 Procedure

5.9.3.1 Verify that the GC/MS system meets the instrument performance criteria in section 5.8.

5.9.3.2 The GC must be operated using temperature and flow rate parameters equivalent to those in section 5.5.

5.9.3.3 Prepare five calibration standards containing all the target compounds spiked on clean Tenax® tubes as outlined in Section 4 and at concentrations outlined in Table D/VT-4. To each of these tubes, add known concentrations of internal standards and surrogate standards at 100 ng/cartridge.

5.9.3.4 Analyze each tube according to section 5.6.

5.9.4 Calculations

NOTE: In the following calculations, the area response is that of the primary quantitation ion unless otherwise stated.

5.9.4.1 Relative Response Factor: Calculate the relative response factors (RRF) for each target and surrogate compound to the appropriate internal standard using the following equation:

$$RRF = \frac{A_x C_{is}}{A_{is} C_x} \qquad \text{EQ. D/VT-5}$$

where: RRF = relative response factor;
A_x = area of the primary ion for the compound to be measured;
A_{is} = area of the primary ion for the internal standard;
C_{is} = amount of internal standard, ng; and
C_x = amount of the compound in the calibration standard, ng.

5.9.4.2 Mean Relative Response Factor: Calculate the mean RRF ($\overline{RRF}$) for each compound by averaging the values obtained at the five concentrations using the following equation:

$$\overline{RRF} = \sum_{i=1}^{n} \frac{x_i}{n} \qquad \text{EQ. D/VT-6}$$

where: $\overline{RRF}$ = mean relative response factor;
x_i = RRF of the compound; and
n = number of values.

5.9.4.2.1 Percent Relative Standard Deviation (%RSD): Using the RRFs from the initial calibration, calculate the %RSD for all target and surrogate compounds using the following equations:

$$\%RSD = \frac{SD_{RRF}}{\overline{RRF}} \times 100 \qquad \text{EQ. D/VT-7}$$

and

$$SD_{RRF} = \sqrt{\sum_{i=1}^{N} \frac{(RRF_i - \overline{RRF})^2}{N - 1}} \qquad \text{EQ. D/VT-8}$$

where: SD_{RRF} = standard deviation of initial response factors (per compound);
RRF_i = relative response factor at a concentration level; and
$\overline{RRF}$ = mean of initial RRFs (per compound).

5.9.4.3 Relative Retention Times (RRT): Calculate the RRTs for each target and surrogate compound over the initial calibration range using the following equation:

$$RRT = \frac{RT_c}{RT_{IS}} \qquad \text{EQ. D/VT-9}$$

where: RT_c = retention time of the target or surrogate compound; and
RT_{IS} = retention time of the internal standard.

25.9.4.4 Mean of the Relative Retention Times ($\overline{RRT}$): Calculate the mean of the relative retention times ($\overline{RRT}$) for each analyte target and surrogate compound over the initial calibration range using the following equation:

$$\overline{RRT} = \sum_{i=1}^{n} \frac{RRT}{n} \qquad \text{EQ. D/VT-10}$$

where: $\overline{RRT}$ = mean relative retention time for the target or surrogate compound for each initial calibration standard; and
RRT = relative retention time for the target or surrogate compound at each calibration level.

5.9.4.5 Tabulate the area response (Y) of the primary ion (see Table D/VT-5) and the corresponding concentration for each compound and internal standard.

5.9.4.6 Mean Area Response ($\overline{Y}$) for Internal Standard: Calculate the mean area response ($\overline{Y}$) for each internal standard compound over the initial calibration range using the following equation:

$$\overline{Y} = \sum_{i=1}^{n} \frac{Y_i}{n} \qquad \text{EQ. D/VT-11}$$

where: $\overline{Y}$ = mean area response; and
Y_i = area response for the primary quantitation ion for the internal standard for each initial calibration standard.

5.9.4.7 Percent Area Response Change (%ARC): Calculate the %ARC at each calibration level for each of the internal standards using the following equation:

$$\%ARC = \frac{A_x - \overline{Y}}{\overline{Y}} \times 100 \qquad \text{EQ. D/VT-12}$$

where: %ARC = percent area response change;
A_x = area response of the internal standard at a concentration level; and
$\overline{Y}$ = mean area response of the internal standard over the entire calibration range.

5.9.4.8 Mean of the Retention Times ($\overline{RT}$) For Internal Standard: Calculate the mean retention time ($\overline{RT}$) for each internal standard over the initial calibration range using the following equation:

$$\overline{RT} = \sum_{i=1}^{n} \frac{RT_i}{n} \qquad \text{EQ. D/VT-13}$$

where: $\overline{RT}$ = mean retention time; and
RT = retention time for the internal standard for each initial calibration standard.

5.9.4.9 Internal Standard Retention Time Shift (RTS): Calculate the RTS between the RT of each internal standard at each concentration level and the $\overline{RT}$ for that internal standard over the entire calibration range using the following equation:

$$RTS = \overline{RT_i} - RT_x \qquad \text{EQ. D/VT-14}$$

where: $\overline{RT_i}$ = mean of the retention time for the internal standard in the initial calibration; and
RT_x = retention time of the internal standard at a concentration level.

5.9.4.10 Tabulate peak height or area responses against concentration for each compound and internal standard. Table D/VT-5 contains primary quantitation ions to be used for each target and surrogate compound and internal standard.

5.9.4.11 Internal standard responses and retention times in all standards must be evaluated during or immediately after data acquisition.

5.9.5 **Technical Acceptance Criteria**

5.9.5.1 All initial calibration standards must be analyzed at the concentration levels and frequency described in this section on a GC/MS system meeting the BFB instrument performance check criteria.

5.9.5.2 The %RSD for all target and surrogate compounds in the initial curve must be less than or equal to 30.0 percent. Up to two compounds may exceed the maximum %RSD criteria; the %RSD for those compounds, however, must not exceed 40.0 percent.

5.9.5.3 The RRT for each of the target and surrogate compounds at each calibration level must be within ±0.06 RRT units of the mean relative retention time ($\overline{RRT}$) for the compound.

5.9.5.4 The %ARC at each calibration level must be within ±40 percent of the mean area response ($\overline{Y}$) over the initial calibration range for each internal standard.

5.9.5.5 The retention time shift for each of the internal standards at each calibration level must be within ±20.0 seconds compared to the mean retention time ($\overline{RT}$) over the initial calibration range for each internal standard.

5.9.6 **Corrective Action**

5.9.6.1 If the retention time for any internal standard changes by more than 20 seconds from mean retention time from the entire calibration range, the chromatographic system must be inspected for malfunctions, and corrections made as required.

5.9.6.2 If the %RSD of the RRFs in the initial curve is not within ±30.0 percent, initial calibration standards are rerun until the %RSD is within the QC limits.

5.9.6.3 If the SICP area for any internal standard is not within 40 percent of the mean initial calibration area ($\overline{Y}$), the mass spectrometric system must be inspected for malfunction and corrections made as appropriate. Document in the SDG Narrative all inspection and corrective actions taken.

5.9.6.4 If the initial calibration technical acceptance criteria are not met, inspect the system for problems. It may be necessary to clean the ion source, change the column, or take other corrective actions to meet the initial calibration technical acceptance criteria.

5.9.6.5 Initial calibration acceptance criteria MUST be met before any field samples, performance evaluation (PE) samples, or required blanks are analyzed. Any samples or required blanks analyzed when initial calibration criteria have not been met will require analysis of additional sample or blank cartridges (if available) at no additional cost to the Agency.

5.9.7 Documentation

Reporting requirements are listed in Exhibit B. Results of the initial calibration are reported on Form V-AAVT; Internal standard area and RT shall be tabulated on Form VII-AAVT.

5.10 Continuing Calibration

5.10.1 Summary

5.10.1.1 Prior to the analysis of samples and required blanks and after tuning criteria have been met, the initial calibration of each GC/MS system must be routinely checked by analyzing a continuing calibration standard to ensure that the instrument continues to meet the instrument sensitivity and linearity requirements of the method.

5.10.1.2 The continuing calibration standard, which is the mid level (CAL 3) standard, shall contain all the target compounds, surrogate compounds, and internal standards.

5.10.1.3 All sample results are quantified against the RRFs obtained from the continuing calibration standard.

5.10.2 Frequency

5.10.2.1 A check of the calibration curve must be performed once every 12 hours on a GC/MS system that has met the tuning criteria.

5.10.2.2 The continuing calibration sequence starts with the injection of the BFB. If the BFB analysis meets the ion abundance criteria for BFB, then a continuing calibration standard may be analyzed.

5.10.3 Procedure

Analyze the mid level standard (CAL 3) in a GC/MS system that has met the tuning and mass calibration criteria following the same procedure under Instrumental Analysis, section 5.6.

5.10.4 Calculations

NOTE: In the following calculations, the area response is that of the primary quantitation ion unless otherwise stated.

5.10.4.1 Relative Response Factor (RRF): Calculate a relative response factor (RRF) for each target compound and surrogate using the equation in section 5.9.4.1.

5.10.4.2 Percent Difference (%D): Calculate the percent difference in the RRF of the daily RRF (12-hour) compared to the mean RRF in the most recent initial calibration. Calculate the %D for each target and surrogate compound using the following equation:

$$\%D = \frac{RRF_c - \overline{RRF_i}}{\overline{RRF_i}} \times 100 \qquad \text{EQ. D/VT-15}$$

where: %D = percent difference;
RRF_c = RRF of the compound in the continuing calibration standard; and
$\overline{RRF_i}$ = mean RRF of the compound in the most recent initial calibration.

5.10.5 **Technical Acceptance Criteria**

5.10.5.1 The continuing calibration standard must be analyzed at the concentration level and frequency described in this section on a GC/MS system meeting the BFB instrument performance check criteria.

5.10.5.2 The %D for each target and surrogate compound RRF in a continuing calibration sequence must be within ±30.0 percent of the initial calibration mean RRF in order to proceed with the analysis of samples and blanks. Up to two compounds may exceed the maximum %D criteria; the %D for those compounds, however, must not exceed 40.0 percent.

5.10.5.3 **Corrective Action**

5.10.5.4 If the retention time for any internal standard changes by more than 20 seconds from the latest continuing (12-hour) calibration standard, the chromatographic system must be inspected for malfunctions, and corrections made as required.

5.10.5.5 If the continuing calibration technical acceptance criteria are not met, inspect the system for problems. It may be necessary to clean the ion source, change the column, or take other corrective actions to meet the continuing calibration technical acceptance criteria.

5.10.5.6 Continuing calibration acceptance criteria MUST be met before any field samples, performance evaluation (PE) samples, or required blanks are analyzed. Any samples or required blanks analyzed when the continuing calibration criteria have not been met will require analysis of additional sample or blank cartridges (if available) at no additional cost to the Agency.

5.10.6 **Documentation**

Reporting requirements are listed in Exhibit B. Results of the continuing calibration are reported on Form VI-AAVT; Internal standard area and RT shall be tabulated on Form VII-AAVT.

5.11 **Blank Analysis**

5.11.1 **Summary**

5.11.1.1 To monitor for possible laboratory contamination, laboratory method blanks are analyzed with each SDG at least once in a 12-hour analytical sequence. All steps in the analytical procedure are performed on the blank using all reagents, standards, equipment, apparatus, glassware, and solvents that would be used for a sample analysis.

5.11.1.2 A field blank is designed to detect potential sample contamination during the handling and shipping process of a field sample. The Tenax® cartridge used as a field blank must be associated with the actual sampling process; therefore, the blank cartridge is opened with the other cartridges, resealed, and carried through the same handling process as those used to sample ambient air.

5.11.1.3 A laboratory method blank (LMB) is an unused, certified Tenax® that has not left the laboratory. The blank cartridge is spiked with the same amount of surrogate compounds and internal standard and carried through the same analytical procedure as a field sample.

5.11.1.4 The same amount of internal standards that are added to each sample is added to each blank. All field samples must be analyzed with associated blanks.

5.11.2 **Frequency**

5.11.2.1 A field blank is analyzed once per sample delivery group. A field blank shall be analyzed along with each batch of ≤20 samples and shall be carried through the entire analytical procedure.

5.11.2.2 The LMB must be analyzed after the calibration standard(s) before any samples are analyzed.

5.11.2.3 Whenever an unusually concentrated sample is encountered, an LMB analysis shall be performed immediately after the sample analysis.

5.11.3 **Procedure**

5.11.3.1 Spike the blank cartridges with the same amount of internal

standards and surrogate compounds and using the same spiking technique as the field samples.

5.11.3.2 Analyze the blanks following the same procedure outlined under section 5.13, "Sample Analysis".

5.11.4 Calculations

The blanks are analyzed similar to a field sample and the equations in section 5.13.4 apply.

5.11.5 Technical Acceptance Criteria

NOTE: If the most recent valid calibration is an initial calibration, internal standard area responses and RTs in the blank are evaluated against the corresponding internal standard area responses and RTs in the mid level (CAL 3) standard of the initial calibration.

5.11.5.1 All blanks must be analyzed at the frequency described in section 5.11.2 on a GC/MS system meeting the BFB instrument performance check and initial calibration or continuing calibration technical acceptance criteria.

5.11.5.2 The percent recovery of each of the surrogate compounds in the blanks must be between 80 and 120 percent.

5.11.5.3 The area response for each IS in the blank must be within ±40 percent of area response of the IS in the most recent valid calibration.

5.11.5.4 The retention time for each of the internal standards must be within ±20.0 seconds between the blank and the most recent valid calibration.

5.11.5.5 The blank must not contain any target analyte at a concentration greater than its CRQL and must not contain additional compounds with elution characteristics and mass spectral features that would interfere with identification and measurement of a method analyte at its CRQL. The total level of analytes in the blank other than the surrogates and internal standards must not exceed 10 ng.

5.11.6 Corrective Action

5.11.6.1 If a Contractor's blanks do not meet the technical acceptance criteria, the Contractor must consider the analytical system to be out of control. It is the Contractor's responsibility to ensure that method interferences caused by contaminants in solvents, reagents, glassware, and other sample storage and processing hardware

that lead to discrete artifacts and/or elevated baselines in gas chromatograms be eliminated. If contamination is a problem, the source of the contamination must be investigated and appropriate corrective measures MUST be taken and documented before further sample analysis proceeds.

5.11.6.2 All samples processed with a blank that is out of control (i.e., contaminated) shall be flagged with a "B".

5.11.7 **Documentation**

Reporting requirements are listed in Exhibit B. Blank results are reported on Form I-AAVT. and the associated samples are summarized on Form II-AAVT. Internal standard area and RT shall be tabulated on Form VII-AAVT.

5.12 Laboratory Control Samples (LCS)

5.12.1 Summary

The LCS is an internal laboratory quality control sample designed to assess the capability of the Contractor to perform the analytical method listed in this Exhibit. Section 5.4.6.5 lists the LCS compounds.

5.12.2 Frequency

The LCS must be analyzed and reported once per 12-hour analytical sequence, and concurrently with the samples in the SDG.

5.12.3 Procedure

5.12.3.1 Prepare a Tenax® cartridge containing all the LCS compounds at a concentration of 100 ng for each compound according to section 5.4.6.5, and the surrogates and internal standards at a concentration of 100 ng each using the same spiking technique as the samples and blanks.

5.12.3.2 Analyze the LCS following the same procedure described in section 5.13, Sample Analysis.

5.12.4 Calculations

5.12.4.1 Calculate individual compound recoveries of the LCS using the following equation:

$$LCS\ \%Recovery = \frac{Concentration_{reported}}{Concentration_{spiked}} \times 100 \qquad \text{EQ. D/VT-16}$$

5.12.4.2 Field sample calculations in section 5.13 also apply to the LCS in monitoring the area and retention time of each of the internal standards.

5.12.5 Technical Acceptance Criteria

NOTE: If the most recent valid calibration is an initial calibration, internal standard area responses and RTs in the LCS are evaluated against the corresponding internal standard area responses and RTs in the mid level (CAL 3) standard of the initial calibration.

5.12.5.1 The LCS must be analyzed on a GC/MS system meeting the BFB, initial or continuing calibration, and blank technical acceptance criteria at the frequency described in section 5.12.2.

5.12.5.2 The percent recovery of each of the surrogate compounds in the LCS must be between 80 and 120 percent.

5.12.5.3 The percent recovery for each of the LCS compounds must be within the percent recovery limits of 60 to 140 percent.

5.12.5.4 The area response change between the LCS and the most recent valid calibration for each of the internal standards must be within ±40 percent.

5.12.5.5 The retention time shift between the LCS and the most recent valid calibration for each of the internal standards must be within ±20.0 seconds.

5.12.6 Corrective Action

5.12.6.1 If the technical acceptance criteria for the internal standards are not met, check calculations and instrument performance. It may be necessary to recalibrate the instrument or take other corrective action procedures to meet the technical acceptance criteria.

5.12.6.2 The laboratory may not submit data from an SDG until all the LCS technical acceptance criteria are met. LCS contamination from laboratory sources or any LCS analyzed not meeting all the technical acceptance criteria will require analysis of additional LCS cartridges at no additional cost to the Agency.

5.12.6.3 LCS acceptance criteria MUST be met before any field

samples, performance evaluation (PE) samples, or required blanks are analyzed. Any samples or required blanks analyzed when the LCS technical acceptance criteria have not been met will require analysis of additional LCS cartridges at no additional cost to the Agency.

5.12.7 Documentation

Reporting requirements are listed in Exhibit B. Laboratory Control Sample analysis data are reported on Form III-AAVT. Internal standard area and RT shall be tabulated on Form VII-AAVT.

5.13 Sample Analysis

5.13.1 Summary

Prior to the analysis of samples, the appropriate GC/MS operating conditions are established, instrument performance check standard is analyzed, and the GC/MS system is calibrated. The contents of the sample cartridge is desorbed, preconcentrated, and subsequently analyzed by GC/MS under conditions in section 5.5. Guidelines for qualitative and quantitative analysis are discussed in sections 5.14 and 5.15.

5.13.2 Frequency

5.13.2.1 If time remains in the 12-hour period in which an initial calibration is performed, samples may be analyzed without analysis of a continuing calibration standard.

5.13.2.2 If time does not remain in the 12-hour period since the injection of the instrument performance check standard in which an initial calibration is performed, both the instrument performance check standard and the continuing calibration standard must be analyzed before sample analysis may begin.

5.13.3 Procedure

5.13.3.1 Analyze samples under the instrument conditions provided in section 5.5 and according to the GC/MS instrumental analysis procedure outlined in section 5.6.

5.13.3.2 Upon introduction of the cryofocused sample onto the column, the GC/MS system is operated so that the MS scans the atomic mass range from 35 to 300 amu. At least five scans per eluting chromatographic peak should be acquired. Scanning allows identification of unknown compounds in the sample through searching of library spectra.

5.13.3.3 Each analytical run must be checked for saturation. The level at which an individual compound will saturate the detection system is a function of the overall system sensitivity and the mass spectral characteristics of that compound. When a sample is analyzed that has saturated ions from a compound, this analysis must be followed by a blank analysis. If the blank analysis is not free of interferences, the system must be decontaminated. Sample analysis may not resume until a blank analyzed is found to be free of interferences.

5.13.3.4 Secondary ion quantitation is allowed only when there are sample matrix interferences with the primary ion. If secondary ion quantitation is performed, document the reasons in the SDG Narrative.

5.13.4 Calculations

5.13.4.1 The equation below is used for calculating concentrations.

$$X_a = \frac{A_x C_{is}}{A_{is} RRF} \qquad \text{EQ. D/VT-17}$$

where: X_a = compound concentration, ng/tube;
A_x = area of the characteristic ion for the compound to be measured;
A_{is} = area of the characteristic ion for the specific internal standard;
C_{is} = amount of the internal standard spiked into the cartridge, ng; and
RRF = relative response factor from the analysis of the continuing calibration standard or the mid level (CAL 3) standard of the initial calibration.

5.13.4.2 Surrogates percent recovery (%R): Calculate the surrogate percent recovery using the following equation:

$$\%R = \frac{Q_d}{Q_a} \times 100 \qquad \text{EQ. D/VT-18}$$

where: Q_d = quantity determined by analysis, ng; and
Q_a = quantity added to sample/blank, ng.

5.13.4.3 Percent Area Response Change (%ARC): Calculate the change in area response for each internal standard by comparing with the most recent valid calibration using the following equation:

$$\%ARC = \frac{A_c - A}{A_c} \times 100 \qquad \text{EQ. D/VT-19}$$

where: %ARC = percent area response change;
A_c = area response of the IS in the most recent valid calibration; and
A = area response of the IS in the sample.

5.13.4.4 Internal Standard Retention Time Shift (RTS): Calculate the shift in retention time between the RT in the sample and in the most recent valid calibration standard for each of the internal standards using the following equation:

$$RTS = RT_c - RT \qquad \text{EQ. D/VT-20}$$

where: RT_c = retention time of the IS in the most recent valid calibration; and
RT = retention time of the IS in the sample.

5.13.5 Technical Acceptance Criteria

NOTE: If the most recent valid calibration is an initial calibration, internal standard area responses and RTs in the sample are evaluated against the corresponding internal standard area responses and RTs in the mid level (CAL 3) standard of the initial calibration.

5.13.5.1 The field sample must be analyzed on a GC/MS system meeting the BFB tuning, initial calibration, and continuing calibration technical acceptance criteria at the frequency described in section 5.13.2.

5.13.5.2 The retention time for each internal standard must be within ±20.0 seconds of the retention time of the internal standard in the most recent valid calibration.

5.13.5.3 The %ARC for each of the internal standards must be within ±40 percent of the most recent valid calibration.

5.13.5.4 The sample must be desorbed and analyzed within the contract holding times.

5.13.5.5 The sample must have a laboratory method blank meeting the blank technical acceptance criteria of less than 10 ng of total VOCs per blank analysis.

5.13.5.6 The percent recovery of each of the surrogate compounds in the sample must be between 80 and 120 percent.

5.13.5.7 All target compound concentrations must not exceed the upper limit of the initial calibration range and no compound ion (excluding the compound peaks in the solvent front) may saturate the detector.

5.13.6 Corrective Action

5.13.6.1 If the on-column concentration of any compound in any sample exceeds the initial calibration range, flag results for the compounds that are out of range.

5.13.6.2 Internal standard responses and retention times must be evaluated during or immediately after data acquisition. If the retention time for any internal standard changes by more than 20 seconds (0.33 minutes) from the latest continuing (12-hour) calibration standard or mid level (CAL 3) standard if samples are analyzed in an initial calibration analytical sequence, the GC/MS system must be inspected for malfunctions, and corrections made as required.

5.13.6.3 If the SICP area for any internal standard changes by more than ±40 percent between the sample and the most recent valid calibration, the GC/MS system must be inspected for malfunction and corrections made as appropriate.

5.13.6.4 When target compounds are below contract required quantitation limits (CRQL), but the spectra meet the identification criteria, report the concentration with a "J." For example, if the CRQL is 5 ng and a concentration of 2 ng is calculated, report as "2J."

5.13.6.5 If the sample technical acceptance criteria for the surrogates and internal markers are not met, check calculations, surrogate and internal standard solutions, and instrument performance. It may be necessary to recalibrate the instrument or take other corrective action procedures to meet the surrogate and internal standard technical acceptance criteria.

5.13.6.6 If the Contractor needs to analyze more than one (1) sample to have all the target compounds within the initial calibration range and to have all compound ions not saturating the detector (excluding the peaks in the solvent front), contact Sample Management Office (SMO). SMO will contact the Region for instructions.

5.13.6.7 Samples that do not meet technical acceptance criteria must be flagged.

5.13.7 Documentation

Reporting requirements are listed in Exhibit B. Sample analysis

data are reported on Form I-AAVT; Internal standard area and RT shall be tabulated on Form VII-AAVT.

5.14 Performance Evaluation Samples

5.14.1 Summary

5.14.1.1 The performance evaluation (PE) samples will assist the Agency in monitoring Contractor performance. The laboratory will not be informed as to which compounds are contained in the PE samples or the concentrations.

5.14.1.2 The laboratory will receive PE samples on Tenax® adsorbent tubes from the Agency. The samples will come with instructions concerning the desorption procedure required for the PE samples. Add internal standards and surrogate compounds to the PE sample, following procedures in Section 4.

5.14.1.3 In addition to complying with the PE sample technical acceptance criteria, the laboratory will be responsible for correctly identifying the quantifying the compounds included in the PE sample. The agency will notify the laboratory of unacceptable performance.

5.14.2 Frequency

The Laboratory must desorb, analyze, and report the results of the PE sample once per SDG, if available.

5.14.3 Procedure

Desorb and analyze the PE sample using the procedure described in section 5.13, Sample Analysis.

5.14.4 Calculations

Calculations for PE samples are the same as those for field samples. Use the equations in section 5.13 for determining technical acceptance criteria compliance.

5.14.5 Technical Acceptance Criteria

NOTE: If the most recent valid calibration is an initial calibration, internal standard area responses and RTs in the PE sample are evaluated against the corresponding internal standard area responses and RTs in the mid level (CAL 3) standard of the initial calibration.

5.14.5.1 The PE sample must be analyzed on a GC/MS system meeting the BFB tuning, initial calibration, and continuing calibration technical acceptance criteria at the frequency described in section 5.14.2

5.14.5.2 The PE sample must be analyzed with a method blank that met the blank technical acceptance criteria.

5.14.5.3 The percent recovery of each of the surrogate compounds in the sample must be between 80 and 120 percent.

5.14.5.4 The retention time for each internal standard in the PE sample analysis must be within ±20.0 seconds of the retention time of the internal standard in the most recent valid calibration.

5.14.5.5 The %ARC for each of the internal standards in the PE sample analysis must be within ±40 percent of the most recent valid calibration.

5.14.5.6 The results of analysis must identify the target compounds provided in the performance evaluation sample and must meet precision and accuracy criteria in comparison with the known results, as outlined in Section 6.

5.14.6 Corrective Action

5.14.6.1 If the PE sample technical acceptance criteria for the internal standard and surrogates are not met, check calculations, standard solutions and instrument performance. It may be necessary to recalibrate the instrument or take other corrective action procedures to meet the technical acceptance criteria.

5.14.6.2 If duplicate cartridges of the PE samples are provided, the PE sample must be reanalyzed if technical acceptance criteria are not met. If after reanalysis, the SICP areas or the RTs for all internal standards are inside the contract limits, then the problem with the first analysis is considered to have been within the control of the laboratory. Therefore, submit only data from the analysis with SICPs within the contract limits. This is considered the initial analysis and must be reported as such on all data deliverables.

5.14.6.3 If the reanalysis of the PE sample does not solve the problem, i.e., the SICP areas or internal standard RTs are outside the contract limits for both analyses, then submit the SICP data and sample data from both analyses. Distinguish between the initial analysis and the reanalysis on all data deliverables, using the sample suffixes specified in Exhibit B. Document in the SDG Narrative all inspection and corrective actions taken.

5.14.6.4 If no other PE sample cartridges are provided for reanalysis, report the results after flagging the data as required. Put comments in the SDG narrative, if necessary.

5.14.6.5 In addition to complying with the PE sample technical acceptance criteria, the Contractor will be responsible for correctly identifying the compounds included in the PE sample. The Agency will notify the Contractor of unacceptable performance.

5.14.6.6 If the PE sample is provided with the SDG, PE sample technical acceptance criteria MUST be met before sample data are reported. Also, the Contractor must demonstrate acceptable performance for compound identification and quantification. If the Contractor fails to meet the PE sample technical acceptance criteria, the Agency may take, but is not limited to the following actions: reduction of the number of samples, suspension of sample shipment, a site visit, a full data audit, and/or require the laboratory to analyze a remedial PE sample, and/or a contract sanction, such as a Cure Notice.

5.14.7 Documentation

Reporting requirements are listed in Exhibit B. Sample analysis data are reported on Form I-AAVT; Internal standard area and RT shall be tabulated on Form VII-AAVT.

5.15 Qualitative Analysis

5.15.1 Target Compounds

5.15.1.1 The compounds listed in the Target Compound List (TCL) in Exhibit C and in Table D/VT-1 of this chapter shall be identified by an analyst competent in the interpretation of mass spectra (see Bidder Responsibility description) by comparison of the sample mass spectrum to the mass spectrum of a standard of the suspected compound.

5.15.1.2 Two criteria must be satisfied to verify the identifications:

- Elution of the sample component at the same GC retention time as the standard component; and
- Correspondence of the sample component and standard component mass spectra (primary and secondary ion identification).

5.15.1.3 For establishing correspondence of the GC relative retention time (RRT), the sample component RRT must compare within ±0.06 RRT units of the RRT of the standard component. For reference, the standard must be run in the same 12-hour time period as the sample. If coelution of interfering components prohibits accurate assignment of the sample component RRT from the total ion chromatogram, the RRT should be assigned by using SICPs for ions unique to the component of

interest.

5.15.1.4 For comparison of standard and sample component mass spectra, mass spectra obtained on the Contractor's GC/MS are required. Once obtained, these standard spectra may be used for identification purposes only if the Contractor's GC/MS meets the daily instrument performance requirements for BFB. These standard spectra may be obtained from the run used to obtain reference RRTs.

5.15.1.5 The requirements for qualitative verification by comparison of mass spectra are as follows:

- All ions present in the standard mass spectra at a relative intensity greater than 10 percent (most abundant ion in the spectrum equals 100 percent) must be present in the sample spectrum;
- The relative intensities of such ions must agree within ±20 percent between the standard and sample spectra. (Example: For an ion with an abundance of 50 percent in the standard spectra, the corresponding sample abundance must be between 30 and 70 percent);
- For each internal standard, determine that the area measured in the sample extract has not changed by greater than 40 percent from the area measured during the most recent continuing calibration check or by greater than 50 percent from the mean area measured during initial calibration. If either criterion is not met, remedial action must be taken to improve sensitivity; and
- Ions greater than 25 percent in the sample spectrum but not present in the standard spectrum must be considered and accounted for by the analyst making the comparison. All compounds meeting the identification criteria must be reported with their spectra. For all compounds below the CRQL report the actual value followed by a "J", e.g., "3J."

5.15.1.6 If a compound cannot be verified by all of the above criteria, but in the technical judgement of the mass spectral interpretation specialist the identification is correct, then the Contractor shall report that identification and proceed with quantification.

5.15.2 Non-Target Compounds

5.15.2.1 A library search shall be executed for non-target sample components for the purpose of tentative identification. For this

purpose, the 1990 (or more recent) release of the NIST Library, containing 50,000 spectra, shall be used. Computer generated library search routines must not use normalization routines that would misrepresent the library or unknown spectra when compared to each other. Up to 10 organic compounds of greatest apparent concentration not listed in Exhibit C shall be tentatively identified via a forward search of the NIST Library. Only after visual comparison of sample spectra with the nearest library searches will the mass spectral interpretation specialist assign a tentative identification.

5.15.2.2 **Guidelines For Making Tentative Identification:**

- Relative intensities of major ions in the reference spectrum (ions greater than 10 percent of the most abundant ion) should be present in the sample spectrum;

- The relative intensities of the major ions should agree within ±20 percent. (Example: For an ion with an abundance of 50 percent of the standard spectra, the corresponding sample ion abundance must be between 30 and 70 percent);

- Molecular ions present in reference spectrum should be present in sample spectrum;

- Ions present in the sample spectrum but not in the reference spectrum should be reviewed for possible background contamination or presence of coeluting compounds; and

- Ions present in the reference spectrum but not in the sample spectrum should be reviewed for possible subtraction from the sample spectrum because of background contamination or coeluting compounds. Data system library reduction programs can sometimes create these discrepancies.

5.15.2.3 If in the technical judgment of the mass spectral interpretation specialist, no valid tentative identification can be made, the compound should be reported as unknown. The mass spectral specialist should give additional classification of the unknown compound if possible (i.e., unknown aromatic, unknown hydrocarbon, unknown chlorinated compound). If probable molecular weights can be distinguished, include them.

5.16 Quantitative Analysis

The quantitative analysis is performed by a combination of manual and computerized procedures: the computer identifies both primary and secondary characteristic ions in a full scan mode. At this point the operator intervenes to determine if the compound of interest has been

located correctly. If the compound identification is correct, the computer then performs the quantitative calculation using the method of relative response factors. Data are reported as ng or ng/tube (since the entire contents of the tube is introduced into the GC/MS system, and can be subsequently converted to ng/m³ if the volume of air sampled is known to the laboratory.

5.16.1 Target Compound Quantitation

5.16.1.1 Sample quantitation is performed by the data processing system for all desired ions of all target compounds. Target compounds are quantified according to the following equation:

$$X,\ ng/m^3 = \frac{A_x ng_{IS}}{A_s V_o RRF} \qquad \text{EQ. D/VT-21}$$

where: X = target compound air concentration, ng/m³,
A_x = area of ion of analyte,
ng_{IS} = mass of internal standard applied to tube, ng,
A_s = area of standard,
RRF = relative response factor (RRF), and
V_o = volume of air sampled (m³), STP.

If the volume of air sampled is not known to the laboratory, the above equation becomes:

$$X,\ ng = \frac{A_x ng_{IS}}{A_s RRF} \qquad \text{EQ. D/VT-22}$$

5.16.1.2 The computer must be able to print out peak number, m/e, scan number, time, relative retention time, area and amount.

5.16.1.3 Standard responses and retention times in all standards must be evaluated during or immediately after data acquisition. If the retention time for any standard changes by more than 30 seconds from the latest continuing (12 hour) calibration, the chromatographic system must be inspected for malfunctions, and corrections made as required. The SICP of the internal standards must be monitored and evaluated for each sample and blank. If the SICP area for any internal standard changes by more than 40 percent, the mass spectrometric system must be inspected for malfunction and corrections made as appropriate. When corrections are made, reanalysis of duplicate samples analyzed while the system was malfunctioning is necessary.

5.16.2 Non-Target Compound Quantitation

5.16.2.1 An estimated concentration for non-target components

tentatively identified shall be quantified by the standard method. The nearest internal standard free of interferences shall be used.

5.16.2.2 The formula for calculating concentrations is the same as in section 5.16.1.1. Total area counts (or peak heights) from the total ion chromatograms are to be used for both the compound to be measured and the standard. A relative response factor (RRF) of one (1) is to be assumed. The value from this quantitation shall be qualified as estimated (i.e., flagged "J"). This estimated concentration should be calculated for all tentatively identified compounds as well as those identified as unknowns.

5.16.2.3 An estimated concentration should be calculated for all tentatively identified compounds as well as those identified as unknowns. This estimated concentration must be calculated for all tentatively identified compounds as well as those identified as unknowns.

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6 PERFORMANCE REQUIREMENTS FOR DEMONSTRATING METHOD ACCEPTABILITY FOR THE ANALYSIS OF AMBIENT AIR

6.1 Summary

6.1.1 Although this method describes the GC/MS analysis of target compounds collected on Tenax®, collection on other adsorbents is acceptable if the performance criteria described in this section are met. Specifically, the analyst must demonstrate that collection on an alternate solid adsorbent and subsequent GC/MS analysis produce results meeting these general criteria:

- Minimum contract required quantitation limits (CRQL) listed in Table D/VT-1;
- Replicate precision within 30 percent RSD; and
- Audit accuracy of 30 percent* for target compound concentrations normally expected in ambient air.

* Exceptions are carbon tetrachloride and 1,1,1-trichloroethane, for which higher audit accuracies are reported in the USEPA TAMs study.

6.1.2 These criteria were established using historical data from the application of TO-10 methodology to samples from the Toxics Air Monitoring System (TAMs) and the Urban Air Toxics Monitoring Program (UATMP). The primary reason to base the acceptability of analysis method on performance is to allow systems currently being used for the analysis of VOCs in water to be used for VOCs in air. Solutions rather than compressed gas standards may be used for calibration. However, audit standards must be humidified gas standards, to most closely resemble the air matrix. Details for the determination of each of the criteria follow.

6.2 Minimum Contract Required Quantitation Limits (CRQL)

The minimum CRQL is defined by each laboratory by making seven replicate measurements of a concentration of the compound of interest near the expected detection limit, the standard deviation computed for the seven replicate concentrations, and this value multiplied by 3.14 (the Student's t value for 99 percent confidence for 7 values).

6.3 Replicate Precision

The measure of precision used for this program is the unsigned relative difference between replicate measurements of the same sample. There are several factors which may affect the quoted precision of the measurement. The nature of the compound of interest itself may have some effect on the precision such as the observation that styrene generally

shows slightly poorer precision than the bulk of nonpolar VOCs. The primary influence on precision is the concentration level of the compound of interest in the sample, i.e., the percent relative standard deviation for a set of replicate values degrades as the concentration approaches the detection limit. A conservative measure of precision was obtained from replicate analysis of Tenax® samples from the TAMs network. This is the source for the 30 percent figure of merit for overall replicate precision given above.

6.4 Audit Accuracy

Audit Bias is defined as the relative difference between the measurement result and the nominal concentration of the audit spiked compound, i.e., [(True - Found x 100]/True. Audit standards will be supplied to the participating laboratories, these audit standards analyzed, and the results judged against criteria based on historical data.

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Table D/VT-1

Target Compound List for Volatiles Collected on Tenax® Tubes and Contract Required Quantitation Limits (CRQL)

Compound	CAS RN	CRQL, on column (ng)
Benzaldehyde	100-52-7	20
Benzene	71-43-2	9
Benzonitrile	100-47-0	5
Bromobenzene	108-86-1	45
Bromochloromethane	74-97-5	7
1-Bromo-3-chloropropane	109-70-6	5
Bromoethane	74-96-4	26
Bromotrichloromethane	75-62-7	6
n-Butylbenzene	104-51-8	3
Carbon Tetrachloride	56-23-5	7
Chlorobenzene	108-90-7	6
2-Chlorobutane	78-86-4	12
1-Chloro-2,3-epoxypropane	106-89-8	26
2-Chloroethoxyethene	110-75-8	27
Chloroform	67-66-3	9
1-Chloropropane	540-54-5	6
2-Chloropropane	75-29-6	11
3-Chloro-1-propene	107-05-1	6
m-Chlorotoluene	108-41-8	2
o-Chlorotoluene	95-49-8	2
p-Chlorotoluene	106-43-4	2
1,2-Dibromoethane	106-93-4	11
Dibromomethane	74-95-3	15
1,2-Dibromopropane	78-75-14	8
1,2-Dichlorobenzene	95-50-1	4
1,3-Dichlorobenzene	541-73-1	4
1,4-Dichlorobenzene	106-46-7	41
1,3-Dichlorobutane	1190-22-3	2
1,4-Dichlorobutane	110-56-5	27
2,3-Dichlorobutane	7581-97-7	17
cis-1,4-Dichloro-2-butene	764-41-0	7
3,4-Dichloro-1-butene	760-23-6	22
1,1-Dichloroethane	75-34-3	19
1,2-Dichloroethane	107-06-2	13
1,1-Dichloroethene	75-35-4	23
1,2-Dichloropropane	78-87-5	13
1,3-Dichloropropane	142-28-9	32
1,4-Dioxane	123-91-1	13
1-Ethenyl-4-chlorobenzene	1073-67-2	7

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Table D/VT-1
(continued)

Target Compound List for Volatiles Collected on Tenax® Tubes
and Contract Required Quantitation Limits (CRQL)

Compound	CAS RN	CRQL, on column (ng)
Ethylbenzene	100-41-4	6
(1-Methylethyl)benzene	98-82-8	4
1-Methyl-4-(1-methylethyl)benzene	99-87-6	13
Pentachloroethane	76-01-7	6
1-Phenylethanone	98-86-2	10
Styrene	100-42-5	6
1,1,1,2-Tetrachloroethane	630-20-6	3
1,1,2,2-Tetrachloroethane	79-43-5	22
Tetrachloroethylene	127-18-4	9
Tetrahydrofuran	109-99-9	4
Toluene	108-88-3	7
Tribromomethane	75-25-2	28
1,1,1-Trichloroethane	71-55-6	6
1,1,2-Trichloroethane	79-06-5	7
Trichloroethylene	79-01-6	3
1,2,3-Trichloropropane	96-18-4	16
1,3,5-Trimethylbenzene	108-67-8	9
m- and p-Xylenes	1330-20-7	2
o-Xylene	95-47-6	2

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Table D/VT-2

Typical Operating Conditions for a GC/MS System

Thermal Desorption Unit - NuTech Model 320, Tekman Model 5000, or equivalent

Purge gas (prior to desorption)	Helium @ 1.2 mL/min
Desorption cycle	8 minutes
Initial desorption temperature	25°C
Final desorption temperature	150°C
Thermal desorption unit purge	10 mL/min

Gas Chromatography

Injection/Detector temperature	200°C
Initial column temperature	30°C
Initial hold time	0.1 minutes
Program (ramp rate)	4°C/min to 240°C
Final hold temperature	240°C
Final hold time	0.1 minutes
Maximum oven temperature	245°C
Carrier gas	Helium; velocity 20 cm^3/sec at 250°C
GC/MS interface	Direct coupling or glass jet
Sample injection to MS	Direct Probe
Column	Hewlett-Packard OV-1 glass capillary crosslinked methyl silicone (50 m x 0.3 mm, 0.17 μm film thickness) Scientific Glass Engineering SE-30 glass capillary crosslinked methyl silicone (50 m x 0.5 mm, 0.80 μm film thickness),or equivalent.

Mass Spectrometer - Quadrupole Spectrometer, Electron Impact (EI)

Mass range	35 to 300 amu
Scan time	1 sec-10 min over entire range
EI condition	70 eV
Mass scan and detector mode	Follow manufacturer instruction for select mass selective detector (MS) and scan mode
Routine tuning	p-bromofluorobenzene (BFB)
Preamp sensitivity	10^{-7}
Emission current	-0.45
Electron multiplier voltage	1000 to 1500
Mass filter	10 amu/sec
Filter	x 100
Total Ion Current sensitivity	1
Resolution	Normal
Display	TIC
Response	Fast

Table D/VT-3

Required BFB Key Ions and Ion Abundance Criteria

M/e	Ion Abundance Criteria
50	8.0 to 40.0 percent of m/e 95
75	30.0 to 66.0 percent of m/e 95
95	base peak, 100 percent relative abundance
96	5.0 t0 9.0 percent of m/e 95
173	less than 2.0 percent of m/e 174
174	50.0 to 120.0 percent of m/e 95
175	4.0 to 9.0 percent of m/e 174
176	93.0 to 101.0 percent of m/e 174
177	5.0 to 9.0 percent of m/e 176

NOTE: All ion abundances must be normalized to m/z 95, the nominal base peak, even though the ion abundance of m/z 174 may be up to 120 percent that of m/z 95.

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Table D/VT-4

Composition and Concentration (ng, on column injection) of Calibration Standards

Compound	Cal 1	Cal 2	Cal 3	Cal 4	Cal 5
benzaldehyde	5	50	100	150	200
benzene	5	50	100	150	200
benzonitrile	5	50	100	150	200
bromobenzene	20	75	150	200	250
bromochloromethane	5	50	100	150	200
1-bromo-3-chloropropane	5	50	100	150	200
bromoethane	20	50	150	200	250
bromotrichloromethane	5	50	100	150	200
butylbenzene	5	50	100	150	200
carbon tetrachloride	5	50	100	150	200
chlorobenzene	5	50	100	150	200
2-chlorobutane	5	50	100	150	250
1-chloro-2,3-epoxypropane	20	75	150	200	250
2-chloroethoxyethene	20	75	150	200	250
chloroform	5	50	100	150	200
1-chloropropane	5	50	100	150	200
2-chloropropane	5	50	100	150	200
3-chloro-1-propene	5	50	100	150	200
m-chlorotoluene	5	50	100	150	200
o-chlorotoluene	5	50	100	150	200
p-chlorotoluene	5	50	100	150	200
1,2-dibromoethane	5	50	100	150	200
dibromomethane	5	50	100	150	200
1,2-dibromopropane	20	75	150	200	250
1,2-dichlorobenzene	20	75	150	200	250
1,3-dichlorobenzene	20	75	150	200	250
1,4-dichlorobenzene	20	75	150	200	250
1,3-dichlorobutane	5	50	100	150	200
1,4-dichlorobutane	20	75	150	200	250
2,3-dichlorobutane	20	75	150	200	250
3,4-dichloro-1-butene	20	75	150	200	250
cis-1,4-dichloro-2-butane	5	50	100	150	200
1,1-dichloroethane	5	50	100	150	200
1,2-dichloroethane	5	50	100	150	200

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Table D/VT-4
(continued)

Composition and Concentration (ng, on column injection) of Calibration Standards

Compound	Cal 1	Cal 2	Cal 3	Cal 4	Cal 5
1,1-dichloroethene	20	75	150	200	250
1,2-dichloropropane	5	50	100	150	200
1,3-dichloropropane	20	75	150	200	250
1,2-dimethylbenzene	5	50	100	150	200
1,4-dioxane	5	50	100	150	200
1-ethenyl-4-chlorobenzene	5	50	100	150	200
ethylbenzene	5	50	100	150	200
(1-methylethyl) benzene	5	50	100	150	200
1-methyl-4-(1-methylethyl)benzene	5	50	100	150	200
pentachloroethane	5	50	100	150	200
1-phenylethanone	5	50	100	150	200
styrene	5	50	100	150	200
1,1,1,2-tetrachloroethane	5	50	100	150	200
1,1,2,2-tetrachloroethane	20	75	150	200	250
tetrachloroethene	5	50	100	150	200
tetrachloromethane	5	50	100	150	200
tetrahydrofuran	5	50	100	150	200
tribromomethane	20	75	150	200	250
1,1,1-trichloroethane	5	50	100	150	200
1,1,2-trichloroethane	5	50	100	150	200
trichloroethene	5	50	100	150	200
1,2,3-trichloropropane	5	50	100	150	200
1,3,5-trimethylbenzene	5	50	100	150	200
toluene	5	50	100	150	200
xylene, m- and p-	5	50	100	150	200
xylene, o-	5	50	100	150	200

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Table D/VT-5

Target Compound List for Volatiles Collected on Tenax® Cartridges with Characteristic Ions (Primary and Secondary)

Compound	Primary Ion	Secondary Ions
Benzene	78	77,50
Bromobenzene	156	158,77,51
Bromochloromethane	130	128,51
1-Bromo-3-chloropropane	158	156,77,76
Bromoethane	108	110,29,27
Bromotrichloromethane	163	161,82,47
n-Butylbenzene	91	134,92
Carbon Tetrachloride	117	119
Chlorobenzene	112	77,114
2-Chlorobutane	57	56,41
1-Chloro-2,3-epoxypropane	57	92
2-Chloroethoxyethene	63	43,44,106
Chloroform	83	85,47
1-Chloropropane	42	29,26
2-Chloropropane	43	27,63,78
3-Chloro-1-propene	41	39,76
m-Chlorotoluene	126	91,63
o-Chlorotoluene	126	91,39,63
p-Chlorotoluene	126	125,91,28
1,2-Dibromoethane	107	109,27
Dibromomethane	174	93,94,81
1,2-Dibromopropane	121	123,41
1,2-Dichlorobenzene	146	148,111
1,3-Dichlorobenzene	146	148,111
1,4-Dichlorobenzene	146	148,111
1,3-Dichlorobutane	55	27,90
2,3-Dichlorobutane	90	55,65
1,4-Dichlorobutane	55	27,41
cis-1,4-Dichloro-2-butene	75	53,89
3,4-Dichloro-1-butene	75	89,77
1,1-Dichloroethane	63	27,65
1,2-Dichloroethane	62	27,64
1,1-Dichloroethene	61	96,63
1,2-Dichloropropane	63	41,62

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Table D/VT-5
(continued)

Target Compound List for Volatiles Collected on Tenax® Cartridges with Characteristic Ions (Primary and Secondary)

Compound	Primary Ion	Secondary Ions
1,3-Dichloropropane	76	41,27
1,4-Dioxane	88	58,29,31
Ethylbenzene	91	106
1-Ethenyl-4-chlorobenzene	138	103,140
(1-Methylethyl) benzene	105	120
1-Methyl-4-(1-methylethyl)benzene	119	134,91
Pentachloroethane	167	119,95
1-Phenylethanone	105	77,51,120
Styrene	104	78,103
1,1,1,2-Tetrachloroethane	131	117,119,96
1,1,2,2-Tetrachloroethane	83	85
Tetrahydrofuran	72	43,41,73
Tetrachloroethylene	164	129,131,166
Tribromomethane	171	175,93,81
1,1,1-Trichloroethane	97	99,61
1,1,2-Trichloroethane	97	83,61
Trichloroethylene	130	132,95
1,2,3-Trichloropropane	75	39,49,110
1,3,5-Trimethylbenzene	105	120
Toluene	91	92
Xylenes, o-, m-, and p-	91	106

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Table D/VT-6

Typical Compounds Used in Response Factor (RF) Determination with Specific Mass Loading onto Spiked Cartridge

Compound	ng Loaded
Benzene	304
Chloroform	114
1,1,1-Trichloroethane	174
Carbon Tetrachloride	201
1,2-Dichloroethane	329
Trichloroethylene	403
1,1,2,2-Tetrachloroethane	409
Chlorobenzene	140
Tetrachloroethylene	323
Ethylbenzene	346
o-, m-, and p-Xylenes	344
Styrene	362
o-Dichlorobenzene	260
p-Dichlorobenzene	260

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Figure D/VT-1

Common Designs of Adsorbent Cartriges

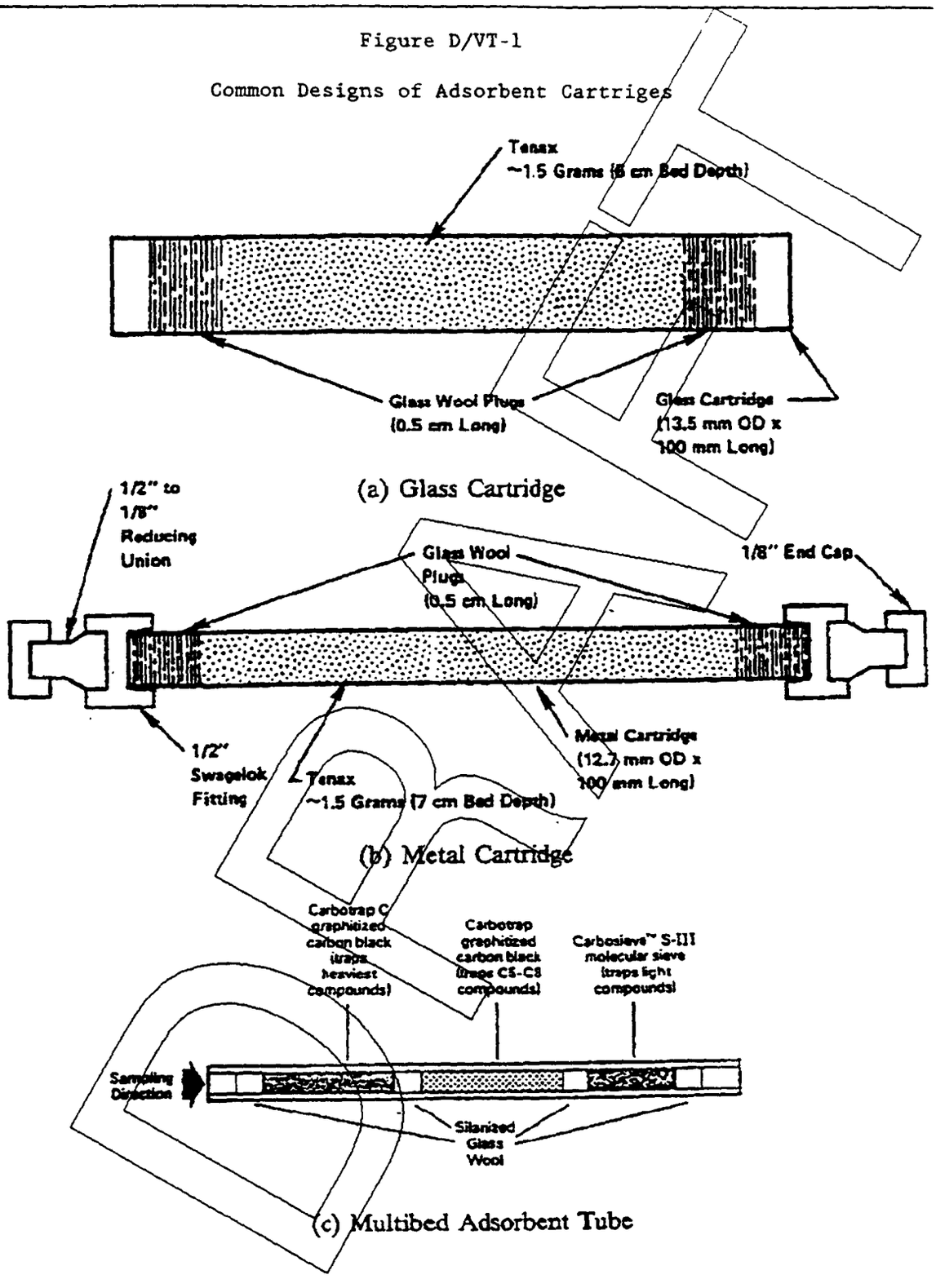

Figure D/VT-2

Typical Desorption GC/MS Configuration

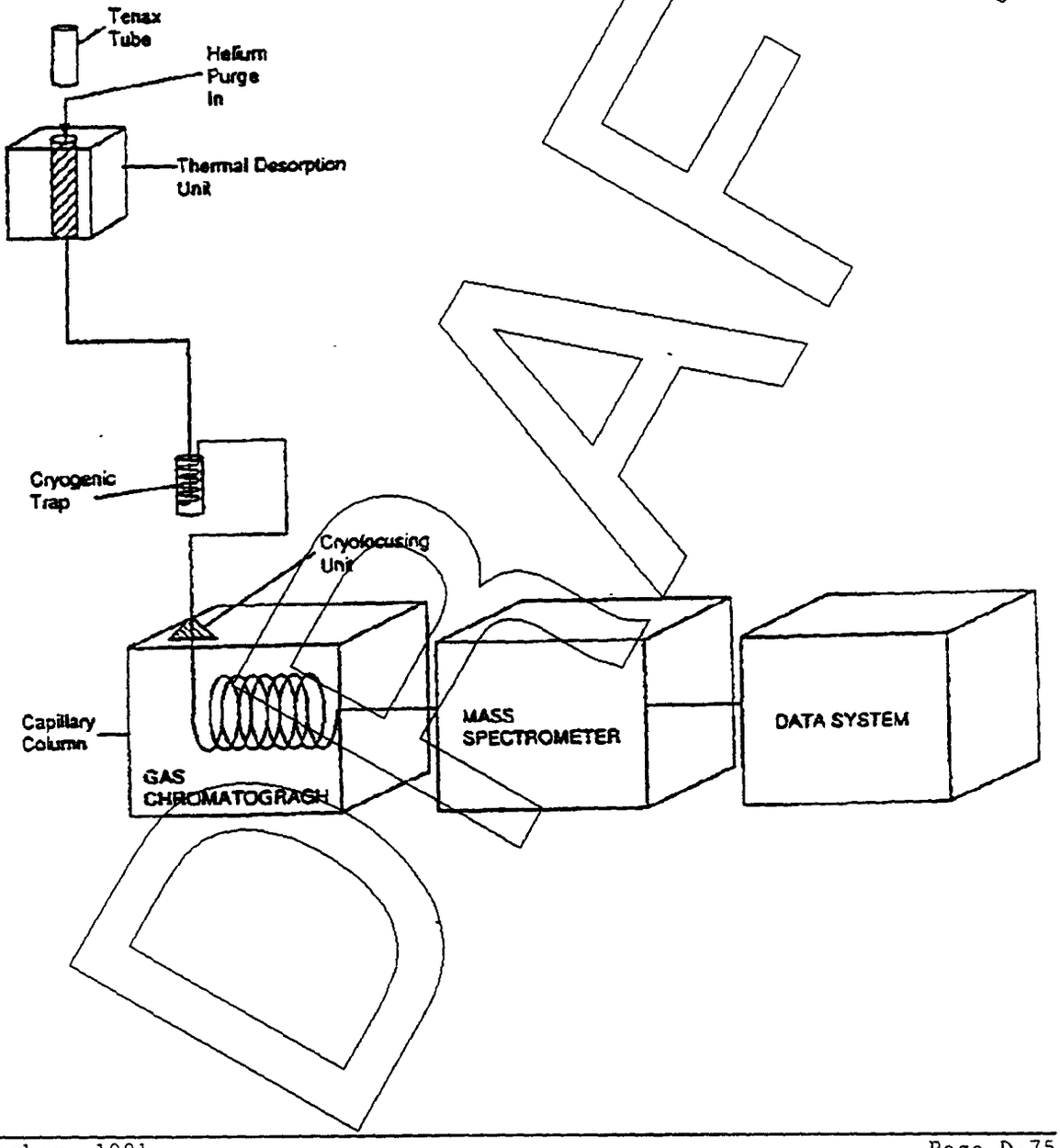

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Figure D/VT-3

Flash Evaporation Unit

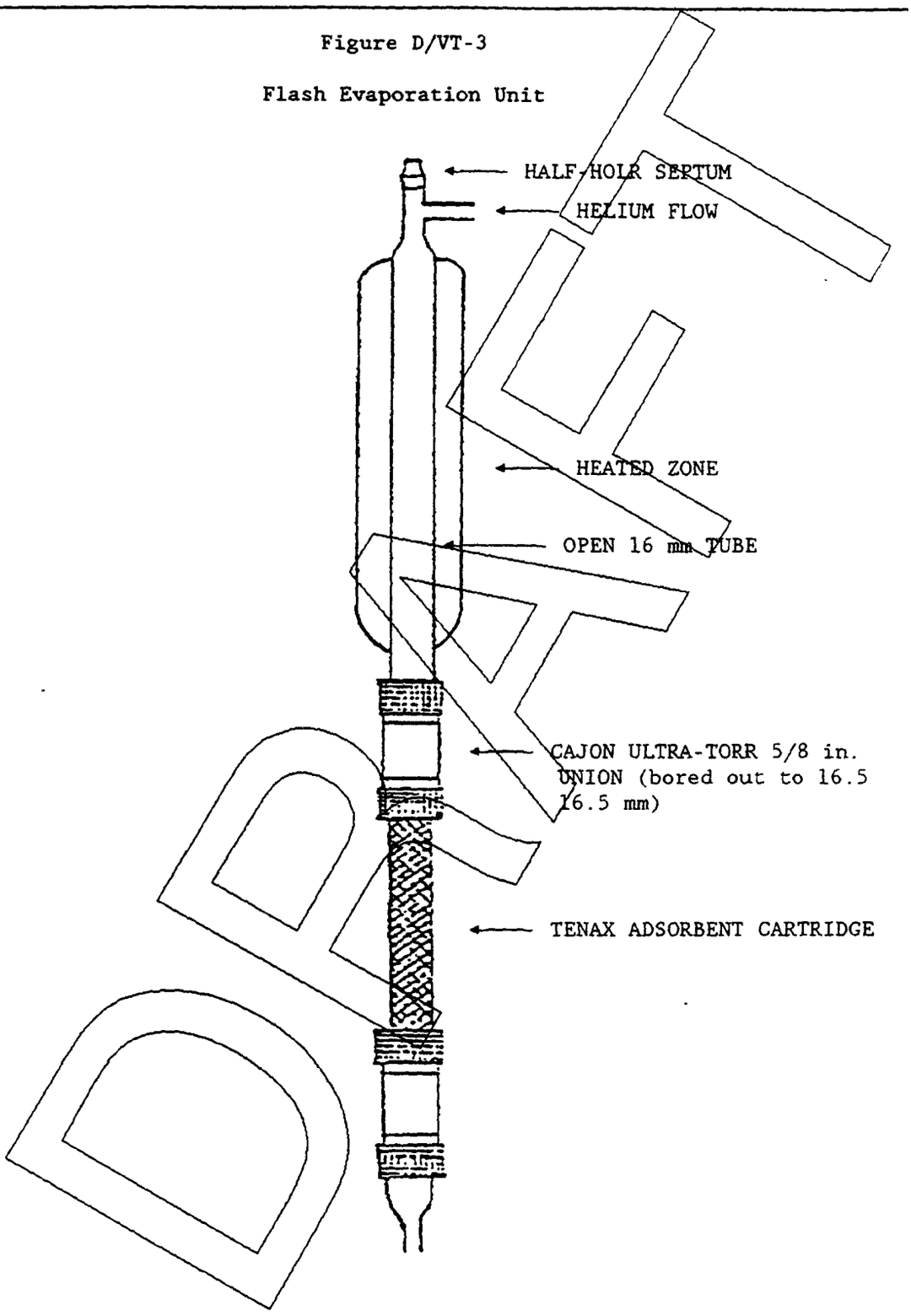

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Figure D/VT-4

Permeation Tube System for
Generating Standard Gas Atmospheres

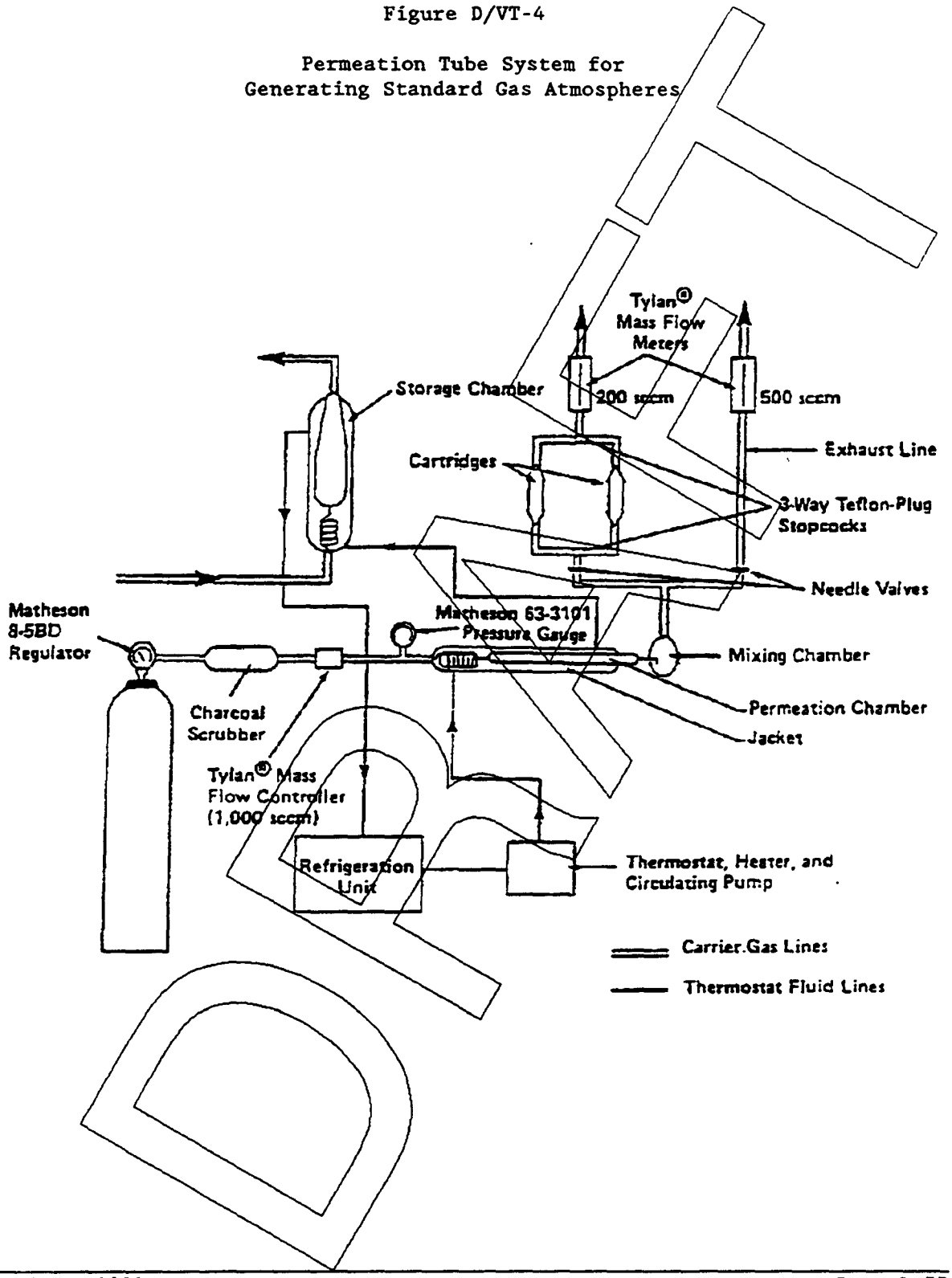

Figure D/VT-5

Tenax Cleanup Schematic Diagram

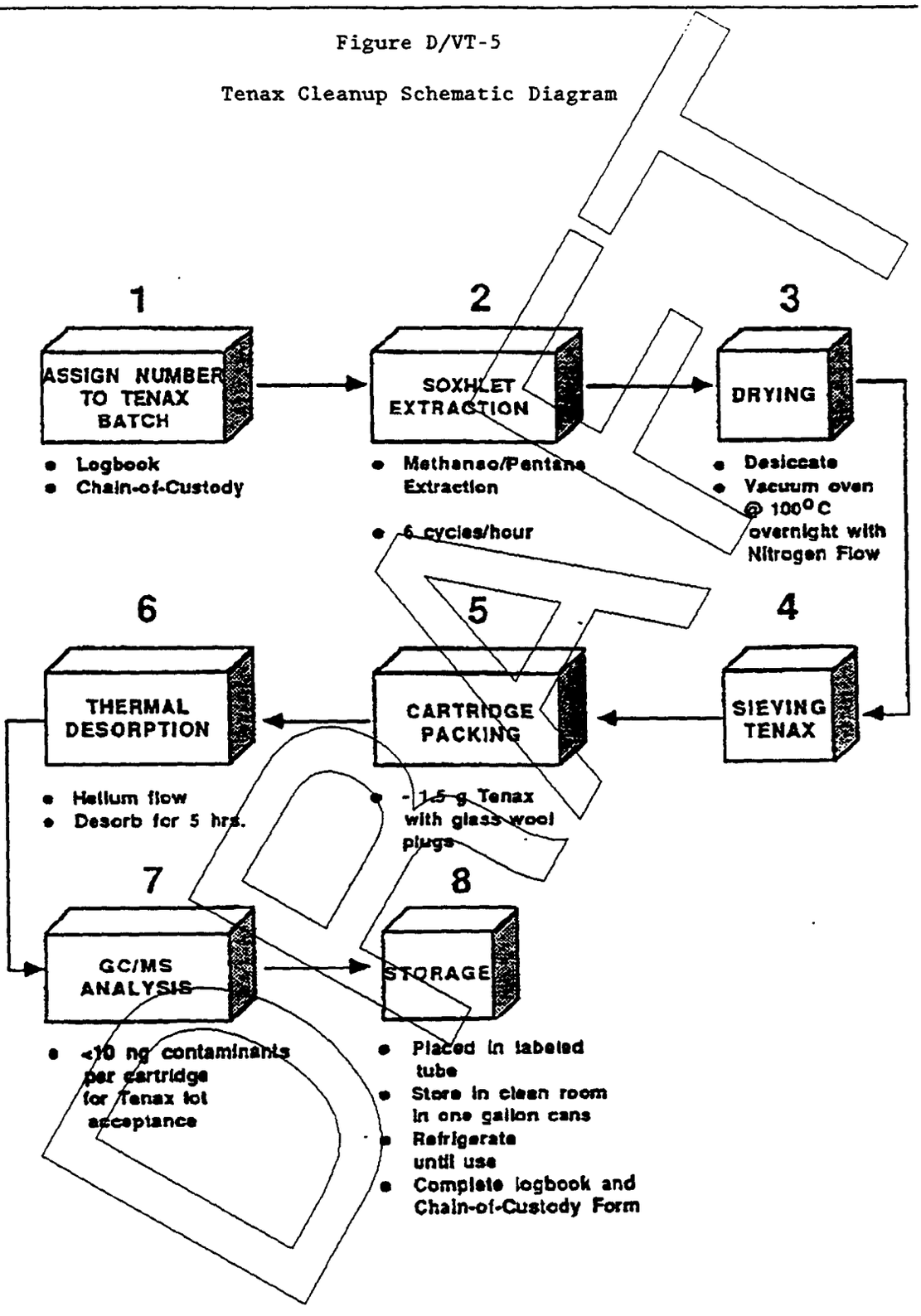

Figure D/VC-6

Tenax Cleanup Worksheet

Tenax Batch No.:_____ Projected Use:_____

Virgin_____ Recycled_____ (check one) Recycled Source_____

No. of cartridges:_____

EXTRACTION

No. of Soxhlet units (circle one) 1 2 3 4 5

Methanol extraction:
Date:
Hours:
Siphon rate:

Pentane extraction:
Date:
Hours:
Siphon rate:

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Nitrogen chamber:
Date:
Hours:
Approximate Flowrate:

Vacuum oven:
Date:
Hours:
Pump trap:
Cooldown (hours):
N_2 vent through Act. C:

SIEVING/PACKING

Sieve (40/60) Date:

Packing Date:

CLEANUP

Teflon septum Date:

Teflon liner Date:

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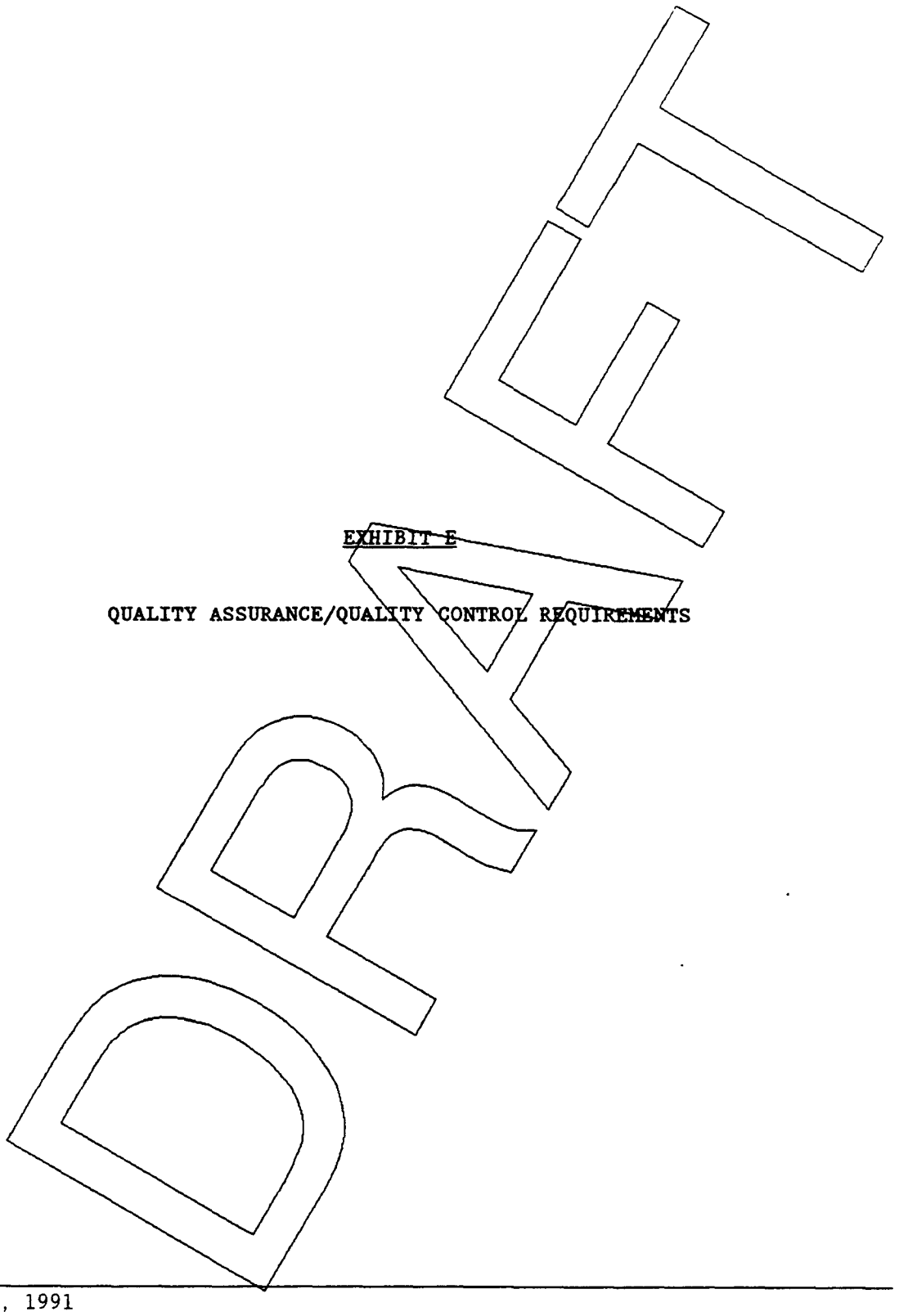

EXHIBIT E

QUALITY ASSURANCE/QUALITY CONTROL REQUIREMENTS

December, 1991

EXHIBIT E

QUALITY ASSURANCE/QUALITY CONTROL REQUIREMENTS

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SECTION 1

INTRODUCTION

1.1 Quality assurance (QA) and quality control (QC) are integral parts of EPA's Contract Laboratory Program (CLP). The CLP QA program consists of management review and oversight at the planning, implementation, and completion stages of environmental data generation activities, to ensure that data provided are of the quality required. The CLP QC program includes those activities required as part of data generation to ensure that the data are of known and documented quality.

1.2 During the planning of an environmental data collection program, QA activities focus on defining data quality objectives and criteria, and designing a QC system to measure and document the quality of data that will be generated. During the implementation of the data collection effort, QA activities ensure that the QC system is functioning effectively, and that the deficiencies uncovered by the QC system are identified and corrected. After environmental data are generated, QA activities focus on assessing the quality of data obtained to determine its suitability to support enforcement or remedial decisions.

1.3 The purpose of this Exhibit is to describe the overall QA/QC operations and the processes by which the CLP meets the QA/QC objectives defined above. This contract requires a variety of QA/QC activities. These contract requirements are the minimum QA/QC operations necessary to satisfy the analytical requirements associated with the determination of the different method analytes. These operations are designed to facilitate laboratory comparison by providing the EPA with comparable data from all Contractors. These requirements do not release the laboratory from maintaining its own QC checks on method and instrument performance.

1.4 Appropriate use of data generated under the great range of analytical conditions encountered in ambient air analyses requires reliance on the QC procedures and criteria incorporated into the methods. The methods in this contract have been validated on samples typical of those received by the laboratories participating in the CLP. However, the validation of these methods does not guarantee that they perform equally well for all samples collected under actual field conditions. Inaccuracies can result from causes such as sampling artifacts, equipment malfunctions, and human error. Therefore, the QC component of each method is indispensable.

1.5 The data acquired from QC procedures are used to estimate and evaluate analytical results and to determine the necessity for or the effect of corrective actions. The means used for evaluating the analytical results include quantitative and qualitative indicators of quality such as precision, accuracy, detection limit, and other quantitative and qualitative indicators. In addition, QC data give an overview of the activities required in an integrated program to generate environmental data of known and documented quality required to meet defined objectives.

1.6 Necessary components of a complete QA/QC program include internal QC criteria that demonstrate acceptable levels of performance, as determined by QA review. External review of data and procedures is accomplished by the monitoring activities of the National Program Office, Regional data users, Sample Management Office, NEIC, and EMSL/LV. Each external review accomplishes a different purpose. These reviews are described in specific sections of this Exhibit. Performance evaluation samples provide an external QA reference for the program. A laboratory on-site evaluation system is also part of the external QA monitoring. A feedback loop provides the results of the various review functions to the contract laboratories through direct communications with the Administrative Project Officers (APOs) and Technical Project Officers (TPOs).

1.7 This Exhibit is not a guide to constructing QA project plans, QC systems, or a QA organization. It is, however, an explanation of the QC and QA requirements of the CLP. It outlines some minimum standards for QA/QC programs. It also includes specific items that are required in a QA Plan and by the QA/QC documentation detailed in this contract. Delivery of this documentation provides the Agency with a complete data package which will stand alone, and limits the need for contact with the Contractor or with an analyst, at a later date, if some aspect of the analysis is questioned.

1.8 To ensure that the product delivered by the Contractor meets the requirements of the contract and to improve interlaboratory data comparison, the Agency requires the following from the Contractor.

1.8.1 Development and implementation of a QA program, and documentation of the key elements of that QA program through a written QA Plan, as described in Section 2 of this Exhibit.

1.8.2 Preparation of and adherence to written Standard Operating Procedures (SOPs) as described in Section 5 of this Exhibit.

1.8.3 Adherence to the analytical methods and associated QC requirements specified in the contract.

1.8.4 Verification of analytical standards and documentation of the purity of neat materials and the purity and accuracy of solutions obtained from private chemical houses.

1.8.5 Participation in the analysis of laboratory performance evaluation (PE) samples, including adherence to corrective action procedures.

1.8.6 Participation in on-site laboratory evaluations, including adherence to corrective action procedures.

1.8.7 Submission of all raw data and pertinent documentation for Regional review.

1.8.8 Submission, upon request, of GC/MS tapes and applicable documentation for tape audits.

1.8.9 Submission for Agency review of all original documentation generated during sample analyses.

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SECTION 2

QUALITY ASSURANCE PLANS

2.1 The Contractor shall establish a QA program with the objective of providing sound analytical chemical measurements. This program shall incorporate the QC procedures, any necessary corrective action, and all documentation required during data collection as well as the quality assessment measures performed by management to ensure acceptable data production.

2.2 As evidence of such a program, the Contractor shall prepare a written Quality Assurance Plan (QAP) which describes the procedures that are implemented to achieve the following:

2.2.1 Maintain data integrity, validity, and usability.

2.2.2 Ensure that analytical measurement systems are maintained in an acceptable state of stability and reproducibility .

2.2.3 Detect problems through data assessment and establish corrective action procedures which keep the analytical process reliable.

2.2.4 Document all aspects of the measurement process in order to provide data that are technically sound and legally defensible.

2.3 The QAP must present, in specific terms, the policies, organization, objectives, and specific QA and QC activities designed to achieve the data quality requirements in this contract. Where applicable, SOPs pertaining to each element shall be included or referenced as part of the QAP. The QAP must be available during On-Site Laboratory evaluation and upon written request by the Administrative Project Officer. Additional information relevant to the preparation of a QAP can be found in EPA and ASTM publications[2,4].

2.4 **ELEMENTS OF A QUALITY ASSURANCE PLAN**

2.4.1 The following key elements of the Contractor's quality assurance program shall be addressed in the QAP:

2.4.1.1 **Contractor QA Policy and Objectives**

2.4.1.2 **Organization and Personnel**

- QA Management;
- Organization;
- Assignment of QC and QA responsibilities; and

- Reporting relationships.

• Personnel;

- Staff resumes;
- Education and experience requirements pertinent to this Contract; and
- Training progress.

• Facilities and Equipment;

- Instrumentation and backup alternatives, and
- Maintenance activities and schedules.

• Document Control;

- Laboratory notebook policy;
- Sample and data tracking/custody procedures and documentation requirements;
- Logbook maintenance and archiving procedures;
- Case file organization, preparation, and review procedures; and
- Procedures for preparation, approval, review, revision, and distribution of SOPs.

• Analytical Methodology;

- Calibration procedures and frequency;
- Sample handling and storage procedures;
- Sample preparation procedures;
- Sample analysis procedures; and
- Standards preparation procedures.

• Data Generation;

- Data collection procedures;
- Data reduction procedures;

- Data review procedures;
- Data reporting and authorization procedures; and
- Data management procedures.

• Quality Control Program; and

- Solvent, reagent, and adsorbent check analysis;
- Reference material analysis;
- Internal QC checks; and
- Corrective action and determination of QC limit procedures.

• Quality Assurance Program Assessment.

- Data audits;
- Systems audits;
- Performance audits;
- Corrective action procedures; and
- QA reporting procedures.

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SECTION 3

STANDARD OPERATING PROCEDURES

3.1 In order to obtain reliable results, adherence to prescribed analytical methodology is imperative. In any operation that is performed on a repetitive basis, reproducibility is best accomplished through the use of Standard Operating Procedures (SOPs). As defined by the EPA, an SOP is a written document that provides directions for the step-by-step execution of an operation, analysis, or action which is commonly accepted as the method for performing certain routine or repetitive tasks.

3.2 SOPs prepared by the Contractor must be functional, i.e., clear, comprehensive, up-to-date, and sufficiently detailed to permit duplication of results by qualified analysts. All SOPs, as presented to the Agency, must reflect activities as they are currently performed in the laboratory. In addition, all SOPs must:

3.2.1 Be consistent with current EPA regulations, guidelines, and the CLP contract's requirements;

3.2.2 Be consistent with instrument manufacturer's specific instruction manuals;

3.2.3 Be available to the EPA during an On-Site Laboratory Evaluation. A complete set of SOPs shall be bound together and available for inspection at such evaluations. During On-Site evaluations, laboratory personnel may be asked to demonstrate the application of the SOPs;

3.2.4 Provide for the development of documentation that is sufficiently complete to record the performance of all tasks required by the protocol;

3.2.5 Describe the mechanism for demonstrating the validity of data reported by the Contractor and explaining the cause of missing or inconsistent results;

3.2.6 Describe the corrective measures and feedback mechanism used when analytical results do not meet protocol requirements;

3.2.7 Be reviewed regularly and updated as necessary when contract, facility, or Contractor procedural modifications are made;

3.2.8 Be archived for future reference in usability or evidentiary situations;

3.2.9 Be available at specific work stations as appropriate; and

3.2.10 Be subject to a document control procedure which precludes the use of outdated or inappropriate SOPs.

3.3 SOP SPECIFICATIONS AND FORMAT

3.3.1 An SOP is defined as a written narrative step-by-step description of laboratory operating procedures including examples of laboratory documentation. The SOPs must accurately describe the actual procedures used in the laboratory, and copies of the written SOPs shall be available to ensure that analytical data produced under this contract are acceptable for use in EPA enforcement case preparation and litigation. The Contractor's SOPs shall provide mechanisms and documentation to meet each of the following specifications and shall be used by EPA sa the basis for laboratory evidence audits.

3.3.2 The format for SOPs may vary depending upon the kind of activity for which they are prepared. However, at a minimum, the following sections must be included.

3.3.2.1 Title page.

3.3.2.2 Scope and application.

3.3.2.3 Definitions.

3.3.2.4 Procedures.

3.3.2.5 QC acceptance criteria.

3.3.2.6 Corrective Action Procedures, including procedures for secondary review of information being generated.

3.3.2.7 Documentation Description and example forms.

3.3.2.8 Miscellaneous notes and precautions.

3.3.2.9 References.

3.4 REQUIRED SOPS

3.4.1 Evidentiary SOPs

The Contractor shall develop and use adequate written SOPs to ensure sample and data accountability. Evidentiary SOPs shall include specific procedures for the following processes as they are performed by the Contractor:

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3.4.1.1 Sample receipt and logging

3.4.1.1.1 The Contractor shall have written SOPs for receiving and logging in the samples. The procedures shall include, documentation of the following information:

- Presence or absence of EPA chain-of-custody forms;
- Presence or absence of airbills or airbill stickers;
- Presence or absence of EPA Traffic Reports or SAS packing lists;
- Presence or absence of custody seals on shipping and/or sample containers and their condition;
- Custody seal numbers, when present;
- Presence or absence of sample tags;
- Sample tag ID numbers;
- Condition of the shipping container;
- Condition of the sample container;
- Verification of agreement or nonagreement of information on receiving documents and sample containers;
- Resolution of problems or discrepancies with SMO; and
- The definition of any terms used to describe sample condition upon receipt.

3.4.1.1.2 The Contractor shall have a designated sample custodian responsible for receipt of samples and have written SOPs describing his/her duties and responsibilities.

3.4.1.2 Sample identification

3.4.1.2.1 The Contractor shall have written SOPs for maintaining identification of EPA samples throughout the laboratory.

3.4.1.2.2 If the Contractor assigns unique laboratory identifiers, written SOPs shall include a description of the method used to assign the unique laboratory identifier and cross-reference to the EPA sample number.

3.4.1.2.3 If the Contractor uses prefixes or suffixes in addition to sample identification numbers, the written SOPs shall include their definitions.

3.4.1.3 Sample security

The Contractor shall have written SOPs for maintenance of the security of samples after log-in and shall demonstrate security of the sample storage and laboratory areas. The SOPs shall specifically include descriptions of all storage areas for EPA samples in the laboratory, and steps taken to prevent sample contamination. The SOPs shall include a list of authorized personnel who have access to secure storage areas.

3.4.1.4 Internal chain-of-custody of samples and data.

The Contractor shall have written SOPs for the chain-of-custody consisting of sample identification, chain-of-custody procedures, sample receiving procedures, and sample tracking procedures. For more information concerning the chain-of-custody procedures see Section 4 of this Exhibit.

3.4.1.5 Internal tracking of samples and data.

The Contractor shall have written SOPs for tracking the work performed on any particular sample. The tracking SOP shall include the following:

- A description of the documentation used to record sample receipt, sample storage, sample transfers, sample preparations, and sample analyses;
- A description of the documentation used to record instrument calibration and other QA/QC activities; and
- Examples of the document formats and laboratory documentation used in the sample receipt, sample storage, sample transfer, and sample analyses.

3.4.1.6 Laboratory document and information control

3.4.2 Analytical SOPs

The Contractor shall develop and use adequate written SOPs to ensure that all data generated for the CLP are of known, documented, and acceptable quality. Analytical SOPs shall include specific procedures for the following processes as they are performed by the Contractor:

3.4.2.1 The Contractor shall have written SOPs for preventing sample contamination, during sample preparation, cleaning of glassware, storage, and analysis.

3.4.2.2 The Contractor shall have SOPs to ensure traceability of standards used in sample analysis QA/QC.

3.4.3 **Quality Management SOPs**

3.4.3.1 The Contractor shall have written SOPs for technical and managerial review of laboratory operation and data package preparation, laboratory data review/laboratory self inspection system. The procedures shall include but not be limited to documenting the following information:

3.4.3.1.1 Data flow and chain-of-command for data review;

3.4.3.1.2 Procedures for measuring precision and accuracy.

3.4.3.1.3 Evaluation of parameters for identifying systematic errors.

3.4.3.1.4 Procedures to assure that hardcopy deliverables are complete and compliant with the requirements in Exhibit B.

3.4.3.1.5 Demonstration of internal QA inspection procedure (demonstrated by supervisory sign-off on personal notebooks, internal PE samples, etc.).

3.4.3.1.6 Frequency and type of internal audits (e.g., random, quarterly, spot checks, perceived trouble areas).

3.4.3.1.7 Demonstration of problem identification, corrective actions, and resumption of analytical processing. Sequence resulting from internal audit (i.e., QA feedback).

3.4.3.1.8 Documentation of audit reports, (internal and external), response, corrective action, etc.

3.4.3.2 The Contractor shall have written SOPs for organization and assembly of all documents relating to each EPA Case, including technical and managerial review. Documents shall be filed on a Case-specific basis. The procedures must ensure that all documents including logbook pages, sample tracking records, chromatographic charts, computer printouts, raw data summaries, correspondence, and any other written documents having reference to the Case are compiled in one location for submission to EPA. The system must include a document numbering and inventory procedure. For more information

concerning document control and case file preparation, see Section 5 of this Exhibit.

3.4.3.3 The Contractor shall have written SOPs for sample analysis, management and handling, and reporting of data. The procedures shall include but not be limited to documenting the following information:

3.4.3.3.1 Procedures for controlling and estimating data entry errors.

3.4.3.3.2 Procedures for reviewing changes to data and deliverables and ensuring traceability of updates.

3.4.3.3.3 Life cycle management procedures for testing, modifying and implementing changes to existing computing systems including hardware, software, and documentation or installing new systems.

3.4.3.3.4 Database security, backup and archival procedures including recovery from system failures.

3.4.3.3.5 System maintenance procedures and response time.

3.4.3.3.6 Individual(s) responsible for system operation, maintenance, data integrity and security.

3.4.3.3.7 Specifications for staff training procedures.

3.4.3.4 The Contractor shall have written SOPs for laboratory safety.

3.5 HANDLING OF CONFIDENTIAL INFORMATION

3.5.1 A Contractor conducting work under this contract may receive EPA-designated confidential information from the Agency. Confidential information must be handled separately from other documentation developed under this contract. To accomplish this, the following procedures for the handling of confidential information have been established.

3.5.2 All confidential documents shall be under the supervision of a designated Document Control Officer (DCO).

3.5.3 Any samples or information received with a request of confidentiality shall be handled as "confidential." A separate locked file shall be maintained to store this information and shall be segregated from other nonconfidential information. Data generated from confidential samples shall be treated as confidential. Upon receipt of confidential information, the DCO logs these documents into a Confidential Inventory Log. The information is then made available to authorized personnel but only after it has been signed out to that person by the DCO. The documents shall be returned to the locked file at the conclusion of each

working day. Confidential information may not be reproduced except upon approval by the EPA Contracting Officer. The DCO will enter all copies into the document control system. In addition, this information may not be disposed of except upon approval by the EPA Contracting Officer. The DCO shall remove and retain the cover page of any confidential information disposed of for one year and shall keep a record of the disposition in the Confidential Inventory Log.

3.6 SOPS DELIVERY REQUIREMENTS

Within forty-five (45) days of contract receipt, a complete set of SOPs relevant to this contract shall be sent to the TPO, SMO and EMSL/LV. Also, during the term of performance of the contract, copies of SOPs which have been amended or new SOPs which have been written shall be sent to the TPO, EMSL/LV (quality assurance SOPs) and NEIC (evidentiary SOPs).

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SECTION 4

CHAIN-OF-CUSTODY

A sample is physical evidence collected from a facility or from the environment. An essential part of hazardous waste investigation effort is that the evidence gathered be controlled. To accomplish this, the following sample identification, chain-of-custody, sample receiving, and sample tracking procedures have been established.

4.1 SAMPLE IDENTIFICATION

4.1.1 To ensure traceability of samples while in possession of the Contractor, the Contractor shall have a specified method for maintaining identification of samples throughout the laboratory.

4.1.2 Each sample and sample preparation container shall be labeled with the EPA number or a unique laboratory identifier. If a unique laboratory identifier is used, it shall be cross-referenced to the EPA number.

4.2 CHAIN-OF-CUSTODY PROCEDURES

Because of the nature of the data being collected, the custody of EPA samples must be traceable from the time the samples are collected until they are introduced as evidence in legal proceedings. The Contractor shall have procedures ensuring that EPA sample custody is maintained and documented. A sample is under custody if the following applies:

4.2.1 It is in your possession, or

4.2.2 It is in your view after being in your possession, or

4.2.3 It was in your possession and you locked it up, or

4.2.4 It is in a designated secure area (secure areas shall be accessible to authorized personnel only).

4.3 SAMPLE RECEIVING PROCEDURES

4.3.1 The Contractor shall designate a sample custodian responsible for receiving all samples.

4.3.2 The Contractor shall designate a representative to receive samples in the event that the sample custodian is not available.

4.3.3 The condition of the shipping containers and sample bottles shall be inspected upon receipt by the sample custodian or his/her representative.

4.3.4 The condition of the custody seals (intact/not intact) shall be inspected upon receipt by the sample custodian or his/her representative.

4.3.5 The sample custodian or his/her representative shall check for the presence or absence of the following documents accompanying the sample shipment.

4.3.5.1 Airbills or airbill stickers.

4.3.5.2 Custody seals.

4.3.5.3 EPA custody records.

4.3.5.4 EPA traffic reports or SAS packing lists.

4.3.5.5 Sample tags.

4.3.6 The sample custodian or his/her representative shall sign and date all forms (e.g., custody records, traffic reports or packing lists, and airbills) accompanying the samples at the time of sample receipt.

4.3.7 The Contractor shall contact SMO to resolve discrepancies and problems such as absent documents, conflicting information, broken custody seals, and unsatisfactory sample condition (e.g., leaking sample bottle).

4.3.8 The Contractor shall record the resolution of discrepancies and problems on Telephone Contact Logs.

4.3.9 The following information shall be recorded on appropriate Form AADC-1 by the sample custodian or his/her representative as samples are received and inspected.

4.3.9.1 Condition of the shipping container.

4.3.9.2 Presence or absence and condition of custody seals on shipping and/or sample containers.

4.3.9.3 Custody seal numbers, when present.

4.3.9.4 Condition of the sample bottles.

4.3.9.5 Presence or absence of airbills or airbill stickers.

4.3.9.6 Airbill or airbill sticker numbers.

4.3.9.7 Presence or absence of EPA custody records.

4.3.9.8 Presence or absence of EPA traffic reports or SAS packing lists.

4.3.9.9 Presence or absence of sample tags.

4.3.9.10 Sample tag identification numbers cross-referenced to the EPA sample numbers.

4.3.9.11 Verification of agreement or non-agreement of information recorded on shipping documents and sample containers.

4.3.9.12 Problems or discrepancies.

4.4 SAMPLE TRACKING PROCEDURES

The Contractor shall maintain records documenting all phases of sample handling from receipt to final analysis. The records shall include documentation of the movement of samples and prepared samples into and out of designated laboratory storage areas.

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SECTION 5

DOCUMENT CONTROL

The goal of the laboratory document control program is to assure that all documents for a specified Sample Delivery Group (SDG) will be accounted for when the project is completed. Accountable documents used by contract laboratories shall include but not be limited to logbooks, chain-of-custody records, sample work sheets, bench sheets, and other documents relating to the sample or sample analyses. The following document control procedures have been established to assure that all laboratory records are assembled and stored for delivery to the EPA or are available upon request from the EPA prior to the delivery schedule.

5.1 PREPRINTED LABORATORY FORMS AND LOGBOOKS

5.1.1 All documents produced by the Contractor which are directly related to the preparation and analysis of EPA samples shall become the property of the EPA and shall be placed in the complete sample delivery group file (CSF). All observations and results recorded by the laboratory but not on preprinted laboratory forms shall be entered into permanent laboratory logbooks. When all data from a SDG are compiled, all original laboratory forms and copies of all SDG-related logbook entries shall be included in the documentation package.

5.1.2 The Contractor shall identify the activity recorded on all laboratory documents which is directly related to the preparation and analysis of EPA samples.

5.1.3 Pre-printed laboratory forms shall contain the name of the laboratory and be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

5.1.4 Logbook entries shall be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

5.1.5 Logbook entries shall be in chronological order. Entries in logbooks, with the exception of instrument run logs and extraction logs, shall include only one SDG per page.

5.1.6 Pages in both bound and unbound logbooks shall be sequentially numbered.

5.1.7 Instrument run logs shall be maintained so as to enable a reconstruction of the run sequence of individual instruments. Because the laboratory must provide copies of the instrument run logs to the EPA, the

laboratory may exercise the option of using only laboratory or EPA sample identification numbers in the logs for sample ID rather than government agency or commercial client names to preserve the confidentiality of commercial clients.

5.1.8 Corrections to supporting documents and raw data shall be made by drawing a single line through the error and entering the correct information. Corrections and additions to supporting documents and raw data shall be dated and initialed. No information shall be obliterated or rendered unreadable. All notations shall be recorded in ink. Unused portions of documents shall be crossed out.

5.2 CONSISTENCY OF DOCUMENTATION

5.2.1 The Contractor shall assign a document control officer responsible for the organization and assembly of the CSF.

5.2.2 All copies of laboratory documents shall be complete and legible.

5.2.3 Original documents which include information relating to more than one SDG shall be filled in the CSF of the lowest SDG number. The copy(s) shall be placed in the other CSF(s) and the Contractor shall record the following information on the copy(ies) in red ink:

"COPY

ORIGINAL IS FILED IN CSF _____"

The Contractor shall sign and date this addition to the copy(ies).

5.2.4 Before releasing analytical results, the document control officer shall assemble and cross-check the information on sample tags, custody records, lab bench sheets, personal and instrument logs, and other relevant data to ensure that data pertaining to each particular sample or sample delivery group is consistent throughout the CSF.

5.3 DOCUMENT NUMBERING AND INVENTORY PROCEDURE

5.3.1 In order to provide document accountability of the completed analysis records, each item in a CSF shall be inventoried and assigned a serialized number as described in Exhibit B, Section 2.

CSF # - Region - Serialized number (For example: 75-2-0240).

5.3.2 All documents relevant to each sample delivery group, including logbook pages, bench sheets, mass spectra, chromatograms, screening records, re-preparation records, re-analysis records, records of failed or attempted analysis, custody records, library research results, etc., shall be inventoried.

5.3.3 The Document Control Officer (DCO) shall be responsible for ensuring that all documents generated are placed in the CSF for inventory and are delivered to the EPA. The DCO shall place the sample tags in plastic bags in the file. Figure E-1 is an example of a document inventory.

Figure E-1

Example

DOCUMENT INVENTORY

Document Control #*	Document Type	# Pages
232-2-0001	Case File Document Inventory Sheet	1
232-2-0002	Chain-of-Custody Records	2
232-2-0003	Shipping Manifests	2
232-2-0004	Sample Tags	30
232-2-0005	SMO Organics Traffic Reports	10
232-2-0006	Analysis Data Sheets	41
232-2-0007	Analysts' Organics Notebook Pages	14
232-2-0008	GC/MS and GC Instrument Logbook Pages	12
etc.	etc.	etc.

*This number is to be recorded on each set of documents.

5.4 STORAGE OF EPA FILES

The Contractor shall maintain EPA laboratory documents in a secure location.

5.5 SHIPPING DATA PACKAGES AND CSF

5.5.1 The Contractor shall document shipment of deliverables packages to the recipients. These shipments require custody seals on the containers placed such that they cannot be opened without damaging or breaking the seal. The Contractor shall document what was sent, to whom, the date, and the method (carrier) used.

5.5.2 The Contractor shall purge the CSF deliverable to the appropriate EPA Region 180 days after the report submission.

5.5.3 A copy of the transmittal letter for the CSF will be sent to the NEIC and the SMO.

5.5.4 The Document Control form is used to document the receipt and inspection of shipping containers and samples. The Contractor shall submit one (1) original FORM AADC-1 for each shipping container.

5.5.5 The Contractor shall sign and date the airbill (if present), examine the shipping containers, record the presence or absence of custody seals and their conditions.

5.5.6 The Contractor shall note any problems with the samples and follow the instructions explained in Exhibit B, Sample Log-In Sheet.

5.5.7 The Contractor shall submit a completed Document Control Form with each SDG package.

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SECTION 6

ANALYTICAL STANDARDS REQUIREMENTS

The U.S. Environmental Protection Agency will not supply analytical reference standards either for direct analytical measurements or for the purpose of traceability. All contract laboratories will be required to prepare from neat materials, from cylinders of compressed gases traceable to NIST Standard Reference Materials or NIST/EPA approved certified reference material, or purchase from private chemical supply houses those standards necessary to successfully and accurately perform the analyses required in this protocol.

6.1 PREPARATION OF CHEMICAL STANDARDS FROM THE NEAT HIGH PURITY BULK MATERIAL

6.1.1 A laboratory may prepare their chemical standards from neat materials. Commercial sources for neat chemical standards pertaining to analytes listed on the TCL are given in Appendix C of the "Quality Assurance Materials Bank: Analytical Reference Standards," Seventh Edition, January 1988. Laboratories should obtain the highest purity possible when purchasing neat chemical standards; standards purchased at less than 98% purity must be documented as to why a higher purity could not be obtained.

6.1.2 Neat chemical standards must be kept refrigerated when not being used in the preparation of standard solutions. Proper storage of neat chemicals is essential in order to safeguard them from decomposition.

6.1.3 The purity of a compound can sometimes be misrepresented by a chemical supply house. Since knowledge of purity is needed to calculate the concentration of solute in a solution standard, it is the contract laboratory's responsibility to have analytical documentation ascertaining that the purity of each compound is correctly stated. Purity confirmation, when performed, should use either differential scanning calorimetry, gas chromatography with flame ionization detection, high performance liquid chromatography, infrared spectrometry, or other appropriate techniques. Use of two or more independent methods is recommended. The correction factor for impurity when weighing neat materials in the preparation of solution standards is:

$$\text{Wt. of impure compound} = \frac{\text{Wt. of pure compound}}{\left(\frac{\text{percent purity}}{100}\right)} \qquad \text{Eq. E-1}$$

where "weight of pure compound" is that required to prepare a specific volume of a solution standard of a specified concentration.

6.1.4 Mis-identification of compounds occasionally occurs and it is possible that a mislabeled compound may be received from a chemical supply house. It is the contract laboratory's responsibility to have analytical documentation confirming that all compounds used in the preparation of solution standards are correctly identified. Identification confirmation, when performed, should use GC/MS analysis on at least two different analytical columns, or other appropriate techniques.

6.1.5 Calculate the weight of material to be weighed out for a specified volume taking into account the purity of the compound and the desired concentration. A second person must verify the accuracy of the calculations. Check balances for accuracy with a set of standard weights. All weighing should be performed on an analytical balance to the nearest 0.1 mg and verified by a second person. The solvent used to dissolve the solute should be compatible with the protocol in which the standard is to be used; the solute should be soluble, stable, and nonreactive with the solvent. In the case of a multicomponent solution, the components must not react with each other.

6.1.6 Log notebooks are to be kept for all weighing and dilutions. All subsequent dilutions from the primary standard and the calculations for determining their concentrations are to be recorded and verified by a second person. All solution standards are to be refrigerated when not in use. All solution standards are to be clearly labeled as to the identity of the compound or compounds, concentration, date prepared, solvent, and initials of the preparer.

6.2 PURCHASE OF CHEMICAL STANDARDS IN SOLUTION

6.2.1 Solutions of analytical reference standards can be purchased by Contractors provided they meet the following criteria.

6.2.1.1 Contract laboratories must maintain the following documentation to verify the integrity of the standard solutions they purchase:

- Mass spectral identification confirmation of the neat material;
- Purity confirmation of the neat material; and
- Chromatographic and quantitative documentation that the solution standard was QC checked according to the following section.

6.2.1.2 The Contractor must purchase standards for which the quality is demonstrated statistically and analytically by a method of the supplier's choice. One way this can be demonstrated is to prepare and analyze three solutions: a high standard, a low standard, and a standard at the target concentration (see sections 6.2.1.3 and 6.2.1.4 below). The supplier must then demonstrate that the analytical

results for the high standard and low standard are consistent with the difference in theoretical concentrations. This is done by the Student's t-test in part 6.3.1.3 which follows. If this is achieved, the supplier must then demonstrate that the concentration of the target standard lies midway between the concentrations of the low and high standards. This is done by the Student's t-test. The standard is certified to be within 10 percent of the target concentration.

6.2.1.3 If the procedure above is used, the supplier must document that the following have been achieved.

- Two solutions of identical concentration must be prepared independently from neat materials. An aliquot of the first solution must be diluted to the intended concentration (the "target standard"). One aliquot is taken from the second solution and diluted to a concentration ten percent greater than the target standard. This is called the "high standard". One further aliquot is taken from the second solution and diluted to a concentration 10 percent less that the target standard. This is called the "low standard";

- Six replicate analyses of each standard (a total of 18 analyses) must be performed in the following sequence: low standard, target, high standard, low standard, target standard, high standard; and

- The mean and variance of the six results for each solution must be calculated.

$$Mean = \frac{Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6}{6} \qquad \text{Eq. E-2}$$

$$Variance = \frac{Y_{12} + Y_{22} + Y_{32} + Y_{42} + Y_{52} + Y_{62} - (6 \times Mean)_2}{5} \qquad \text{Eq. E-3}$$

The values Y_1, Y_2, Y_3, ..., represent the results of the six analyses of each standard. The means of the low, target, and high standards are designated M_1, M_2, and M_3, respectively. The variances of the low, target, and high standards are designated V_1, V_2, and V_3, respectively. Additionally, a pooled variance, Vp, is calculated.

$$V_p = \frac{\frac{V_1}{0.81} + V_2 + V_3}{\frac{1.21}{3}} \qquad \text{Eq. E-4}$$

If the square root of Vp is less than one percent of M_2, then M_2^2 /10,000 is to be used as the value of Vp in all subsequent calculations.

- The test statistic must be calculated:

$$TEST\ STATISTIC = \frac{\left| \frac{M_3}{1.1} - \frac{M_1}{0.9} \right|}{\left(\frac{V_p}{3}\right)^{0.5}} \qquad \text{Eq. E-5}$$

If the test statistic exceeds 2.13 then the supplier has failed to demonstrate a twenty percent difference between the high and low standards. In such a case, the standards are not acceptable.

- The test statistic must be calculated:

$$TEST\ STATISTIC = \frac{\left| M_2 - \left(\frac{M_1}{1.8}\right) - \left(\frac{M_3}{2.2}\right) \right|}{\left(\frac{V_p}{4}\right)^{0.5}} \qquad \text{Eq. E-6}$$

If the test statistic exceeds 2.13, the supplier has failed to demonstrate that the target standard concentration is midway between the high and low standards. In such a case, the standards are not acceptable.

- The 95 percent confidence intervals for the mean result of each standard must be calculated:

$$INTERNAL\ FOR\ LOW\ STANDARD = M_1 \pm (2.13)\left(\frac{V_p}{6}\right)^{0.5} \qquad \text{Eq. E-7}$$

$$INTERNAL\ FOR\ TARGET\ STANDARD = M_2 \pm (2.13)\left(\frac{V_p}{6}\right)^{0.5} \qquad \text{Eq. E-8}$$

$$INTERNAL\ FOR\ HIGH\ STANDARD = M_3 \pm (2.13)\left(\frac{V_p}{6}\right)^{0.5} \qquad \text{Eq. E-9}$$

These intervals must not overlap. If overlap is observed, then the supplier has failed to demonstrate the ability to discriminate the 10 percent difference in concentrations. In such a case, the standards are not acceptable. In any event, the laboratory is responsible for the quality of the standards employed for analyses under this contract.

6.3 REQUESTING STANDARDS FROM THE EPA STANDARDS REPOSITORY

Solutions of analytical reference materials can be ordered from the U.S. EPA Chemical Standards Repository, depending on availability. The Contractor can place an order for standards only after demonstrating that

these standards are not available from commercial vendors either in solution or as a neat material.

6.4 DOCUMENTATION OF THE VERIFICATION AND PREPARATION OF CHEMICAL STANDARDS

It is the responsibility of each laboratory to maintain the necessary documentation to show that the chemical standards they have used in the performance of CLP analysis conform to the requirements previously listed. Weighing logbooks, calculations, chromatograms, mass spectra, etc, whether produced by the laboratory or purchased from chemical supply houses, must be maintained by the laboratory and may be subject to review during on-site inspection visits. Documentation of standards preparation may be required to be sent to EPA for verification of contract compliance. In those cases where the documentation is supportive of the analytical results of data packages sent to EPA, such documentation is to be kept on file by the laboratories for a period of one year.

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SECTION 7

METHOD SPECIFIC QA/QC REQUIREMENTS

7.1 This section outlines the minimum quality control (QC) operations necessary to satisfy the analytical requirements associated with the determination of the volatile organic compounds listed in Exhibit C, using the procedures in Exhibit D for samples of ambient air captured on Tenax®. This section is not intended as a comprehensive quality control document, but rather is a guide to the specific QC operations that must be addressed during analysis of volatiles using this method. The laboratory is expected to address these operations in preparing the quality assurance plan and Standard Operating Procedures discussed in Sections 2 and 3 of this Exhibit.

7.2 The specific QC operations that must be considered for volatile organics analysis include the following:

- Testing and Spiking of Tenax® cartridges;
- GC/MS Instrument Performance Check and Ion Abundance Patterns;
- GC/MS Initial and Continuing Calibration;
- Internal Standard Area and Retention Time;
- Blank Analysis;
- Surrogate Compound Recoveries; and
- Performance Evaluation (PE) Samples;

7.2.1 Testing and Spiking of Tenax® Cartridges

7.2.1.1 As part of the procedure for preparing Tenax® cartridges for sampling and subsequent analysis, the laboratory is required to analyze by GC/MS or FID one cartridge from each batch of prepared Tenax® cartridges, and confirm that total VOCs are less than 10 ng. If the total VOCs exceed 10 ng, the entire batch of Tenax® cartridges shall be rejected.

7.2.1.2 For acceptable batches, the laboratory is also required to spike each cartridge with 100 ng each of PFT, 1,2-dichlorobenzene-d_4, as internal standards, and benzene-d_6, chlorobenzene-d_5, and 1,4-dichlorobenzene-d_4, as the surrogate compounds.

7.2.2 GC/MS Performance Checking the Mass Spectrometer and Ion Abundance Patterns

7.2.2.1 Prior to initiating any data collection activities involving samples, blanks, or standards, it is necessary to establish that a given

GC/MS system meets the instrument performance criteria specified in Exhibit D. The purpose of this instrument performance check is to ensure correct mass calibration, mass resolution, and mass transmission. This is accomplished through the analysis of bromofluorobenzene (BFB).

7.2.2.2 The required frequency of BFB analysis (once every 12 hours on each GC/MS system) is described in detail in Exhibit D.

7.2.2.3 The key ions produced during the analysis of BFB and their respective ion abundance criteria are given in Exhibit D, Section 2, Table 3.

7.2.2.4 The documentation includes Form IV-AAVT and a mass listing and bar graph spectrum for BFB analysis.

7.2.3 **Initial Calibration of GC/MS for Target and Surrogate Compounds**

Prior to the analysis of samples and required blanks and after instrument performance criteria have been met, the GC/MS system must be initially calibrated utilizing target compound (see Table 4) and surrogate compounds.

7.2.4 **Internal Standard Calibration Procedures**

7.2.4.1 The GC/MS may be calibrated by analyzing standards spiked onto Tenax® tubes, and calculating concentrations by the relative response factor (RRF) method.

7.2.4.2 Calibration standards containing the target compounds of interest are prepared as outlined in Exhibit D.

7.2.4.3 The Tenax® tubes are then spiked with known concentrations of internal markers and surrogate standards as described in Exhibit D.

7.2.4.4 The tubes are then analyzed as described in Exhibit D.

7.2.4.5 Relative response factors (RRFs) are calculated as described in Exhibit D.

7.2.4.6 The documentation includes Form VII-AAVT, a GC/MS data system printout for the analysis of each volatile calibration standard, and the mass spectrum of each target and surrogate compound.

7.2.5 **GC/MS Continuing Calibration for Target and Surrogate Compounds**

7.2.5.1 Once the GC/MS system has been calibrated, the calibration must be verified each twelve (12) hour time period for each GC/MS system.

7.2.5.2 The standard is to be analyzed according to the procedures and at the frequency given in Exhibit D.

7.2.5.3 The continuing calibration of the GC/MS system is evaluated on the basis of the magnitude of the response factors and the percent difference between the average RRF of each compound from the initial calibration and the RRF of that compound in the continuing calibration standard. The minimum response factors of each compound in the continuing calibration and the percent difference must meet the criteria given in Exhibit D. Allowance is made for any two volatile compounds that fail to meet these criteria. The minimum or RRF of those two compounds must be greater than or equal to 0.010, and the percent difference must be less than or equal to 30.0 percent for the continuing calibration to be acceptable.

7.2.5.4 The documentation included Form VI-AAVT, a GC/MS data system printout for the analysis of the volatile calibration standard, and the mass spectrum of each target surrogate compound.

7.2.6 Internal Markers and Surrogate Standards and Retention Times

7.2.6.1 The response of each of the internal standards in all calibration standards, samples, and blanks is crucial to the provision of reliable analytical results, because the quantitative determination of volatile compounds by these procedures is based on the use of internal standards added immediately prior to analysis.

7.2.6.2 The specific compounds used as internal markers and surrogate standards are given in Exhibit D. Each internal marker and surrogate standard is spiked on the Tenax® cartridge at a level of approximately 300 ng.

7.2.6.3 The retention time and the selected ion current profile (SICP) of each internal marker and surrogate standard must be monitored for all analyses.

7.2.6.4 The area response of each internal marker and surrogate standard from the SICP and the retention time of the internal marker and surrogate standard are evaluated for stability, according to the procedures in Exhibit D. The area of the internal marker and surrogate standard in a sample must not vary by more than 40 percent from the area of the same internal marker and surrogate standard in the associated continuing calibration standard. Likewise, the retention time of an internal marker and surrogate standard must be within 30 seconds of its retention time in the continuing calibration standard, as described in Exhibit D.

7.2.6.5 Requirements for analysis of samples when internal marker and surrogate standards do not meet specifications are given in Exhibit D.

7.2.6.6 The documentation includes Form III-AAVT and the GC/MS data system printout for the analysis of each sample, blank, matrix spike, and standard.

7.2.7 Method Blank Analysis

7.2.7.1 A method blank is a certified clean Tenax® tube thermally desorbed with a volume of helium carried through the entire analytical procedure. The volume of helium must be approximately equal to the volume associated with the blank. The purpose of a method blank is to determine the levels of contamination associated with the processing and analysis of samples.

7.2.7.2 A method blank shall be analyzed once every 12 hours on each GC/MS system, as described in detail in Exhibit D.

7.2.7.3 For the purposes of this protocol, an acceptable method blank must contain less than or equal to the Contract Required Quantitation Limit (see Exhibit C) of any single target compound, or less than 10 ng/cartridge for total VOCs, whichever is less.

7.2.7.4 If a method blank exceeds the limits for contamination above, the Contractor must consider the analytical system out of control. The source of the contamination shall be investigated and appropriate corrective actions taken and documented before further sample analysis proceeds. The requirements for reanalysis of associated samples are given in Exhibit D.

7.2.7.5 The documentation includes Form IV-AAVT for the blank analysis and a GC/MS data system printout for the analysis of the method blank.

7.2.8 Surrogate Compound Recoveries

7.2.8.1 The recoveries of the three surrogate compounds are calculated from the analysis of each sample, blank, and matrix spike. The purpose of the surrogate compounds is to evaluate the performance of the Tenax® sampling and desorption system. Poor purging efficiency, leaks, and cold spots in transfer lines are only a few of the potential causes of poor recovery of these compounds.

7.2.8.2 The surrogate compounds are added to each Tenax® tube prepared for sampling at the concentration described in Exhibit D.

7.2.8.3 The recoveries of the surrogate compounds are calculated according to the procedures in Exhibit D. The recoveries must be within the quality control limits given in Exhibit D. If the recovery of any one surrogate compound is outside these limits, the Contractor must follow the steps outlined in Exhibit D.

7.2.8.4 The documentation includes Form IX-AAVT, and a GC/MS data system printout for the analysis of each sample, blank, and matrix spike.

7.2.9 Performance Evaluation (PE) Samples

7.2.9.1 Performance and method evaluation samples are intended to assist the Agency in monitoring Contractor performance. The laboratory will not be informed as to which compounds are contained in the PE samples or the concentrations.

7.2.9.2 The Laboratory shall extract, analyze, and report the results of the PE sample once per sample delivery group, if available.

7.2.9.3 The laboratory will receive PE samples on Tenax® cartridges from the Agency. The samples will come with instructions concerning the desorption procedure required for the PE samples. The Laboratory must add internal markers and surrogate compounds to the PE sample, following procedures in Exhibit D.

7.2.9.4 Each laboratory must extract and concentrate the PE sample using the procedure described in Exhibit D for those target compounds listed in Exhibit C, Table 1.

7.2.9.5 The laboratory must meet the following PE sample technical acceptance criteria as detailed in Exhibit D.

7.2.9.5.1 The PE sample must be analyzed on a GC/MS system meeting the BFB tuning, initial calibration, and continuing calibration technical acceptance criteria.

7.2.9.5.2 The PE sample must be prepared and analyzed with a method blank that meets the blank technical acceptance criteria.

7.2.9.5.3 The percent recovery for each of the surrogates must be within acceptable windows as outlined in Exhibit D.

7.2.9.5.4 The area response change between the PE sample and the most recent calibration standard analysis for each of the surrogate standards must be within 40 percent.

7.2.9.5.5 The percent recovery for each of the target compounds must be within replicate precision and audit accuracy, as outlined in Section 5, Exhibit D.

SECTION 8

REGIONAL DATA REVIEW

8.1 Contract laboratory data are generated to meet the specific needs of the Regions. In order to verify the usability of data for the intended purpose, each Region reviews data from the perspective of end-user, based upon functional aspects of data quality. General guidelines for data review have been developed jointly by the Region and the National Program Office. Each Region uses these guidelines as the basis for data evaluation. Individual Regions may augment the basic guideline review process with additional review based on Region-specific or site-specific concerns. Regional reviews, like the sites under investigation, vary based on the nature of the problems under investigation and the Regional response appropriate to the specific circumstances.

8.2 Regional data reviews relating usability of the data to a specific site are part of the collective assessment process. They complement the review done at the Sample Management Office, which is designed to identify contractual discrepancies, and the review done at EMSL/LV, which is designed to evaluate Contractor and method performance. These individual evaluations are integrated into a collective review that is necessary for program and laboratory administration and management and may be used to take appropriate action to correct deficiencies in the Contractor's performance.

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SECTION 9

LABORATORY EVALUATION SAMPLES

9.1 Although intralaboratory QC may demonstrate Contractor and method performance that can be tracked over time, an external performance evaluation program is an essential feature of a QA program. As a means of measuring Contractor and method performance, Contractors participate in interlaboratory comparison studies conducted by the EPA. Results from the analysis of these laboratory evaluation samples will be used by the EPA to verify the Contractor's continuing ability to produce acceptable analytical data. The results are also used to assess the precision and accuracy of the analytical methods for specific analytes.

9.2 Sample sets may be provided to participating Contractors as frequently as on an SDG-by-SDG basis as a recognizable QC sample of known composition; as a recognizable QC sample of unknown composition; or not recognizable as a QC material. The laboratory evaluation samples may be sent either by the Regional client or the National Program Office, and may be used for contract action.

9.3 Contractors are required to analyze the samples and return the data package and all raw data within the contract required turnaround time.

9.4 At a minimum, the results are evaluated for compound identification, quantification, and sample contamination. Confidence intervals for the quantification of target compounds are based on reported values using population statistics. EPA may adjust the scores on any given laboratory evaluation sample to compensate for unanticipated difficulties with a particular sample. Normally, a fraction of the compounds spiked into the sample are not specifically listed in the contract. Contractors are required to use the NIST/EPA/MSDC mass spectral library to tentatively identify a maximum number of non-target compounds in each fraction that are present above a minimal response. Tentative identification of these compounds based on contractually described spectral interpretation procedures is evaluated and integrated into the evaluation process.

9.5 A Contractor's results on the laboratory evaluation samples will determine the Contractor's performance as follows:

9.5.1 No response is required for a score of 90 percent or above.

9.5.2 For a score of 75 to 89, the Contractor shall describe the deficiency(ies) and the corrective action(s) taken in a letter to the APO, TPO, and EMSL/LV, within 14 days of receipt of notification from EPA.

9.5.3 For a score less than 75, the Contractor shall be notified by the APO or TPO concerning the remedy for its unacceptable performance. The

Contractor may expect, but EPA is not limited to, the following actions: reduction of the number of samples sent under the contract, suspension of sample shipment to the Contractor, a site visit, a full data audit, analysis of remedial PE samples, and/or a contract sanction, such as a Cure Notice.

NOTE: A Contractor's prompt response demonstrating that corrective action has been taken to ensure the Contractor's capability to meet contract requirements will facilitate continuation of full sample delivery.

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SECTION 10

GC/MS TAPE AUDITS

10.1 Periodically, EPA requests from Contractors the GC/MS magnetic tapes corresponding to a specific Case in order to accomplish tape audits. Generally, tape submissions and audits are requested for the following reasons:

- Program overview;
- Indication of data quality problems from EMSL/LV, SMO, or Regional data reviews;
- Support for on-site audits; and
- Specific Regional requests.

10.2 Depending upon the reason for an audit, the tapes from a recent Case, a specific Case, or a laboratory evaluation sample may be requested. Tape audits provide a mechanism to assess adherence to contractual requirements and to ensure the consistency of data reported on the hardcopy with that generated on the GC/MS tapes. This function provides external monitoring of Program QC requirements and checks adherence of the Contractor to internal QA procedures. In addition, tape audits enable EPA to evaluate the utility, precision, and accuracy of the analytical methods.

10.3 The GC/MS tape shall include raw data and quantitation reports for samples, blanks, laboratory evaluation samples, initial calibrations, continuing calibration, and BFB associated with the Case requested. The specific requirements for submissions of GC/MS tapes are discussed in Exhibit B.

10.4 Upon request of the Administrative Project Officer or EMSL/LV, the required tapes and all necessary documentation shall be submitted to EPA within seven (7) days of notification.

SECTION 11

ON-SITE LABORATORY EVALUATIONS

11.1 At a frequency dictated by a contract laboratory's performance, the Administrative Project Officer, Technical Project Officer or their authorized representative will conduct an on-site laboratory evaluation. On-site laboratory evaluations are carried out to monitor the Contractor's ability to meet selected terms and conditions specified in the contract. The evaluation process incorporates two separate categories: Quality Assurance Evaluation and an Evidentiary Audit.

11.2 QUALITY ASSURANCE ON-SITE EVALUATION

11.2.1 Quality assurance evaluators inspect the Contractor's facilities to verify the adequacy and maintenance of instrumentation, the continuity of personnel meeting experience or education requirements, and the acceptable performance of analytical and QC procedures. The Contractor should expect that items to be monitored will include but not be limited to the following items:

- Size and appearance of the facility;
- Quantity, age, availability, scheduled maintenance and performance of instrumentation;
- Availability, appropriateness, and utilization of SOPs;
- Staff qualifications, experience, and personnel training programs;
- Reagents, standards, and sample storage facilities;
- Standard preparation logbooks and raw data;
- Bench sheets and analytical logbook maintenance and review, and
- Review of the Contractor's sample analysis/data package inspection procedures.

11.2.2 Prior to an on-site evaluation, various documentation pertaining to performance of the specific Contractor is integrated in a profile package for discussion during the evaluation. Items that may be included are previous on-site reports, laboratory evaluation sample scores, Regional review of data, Regional QA materials, GC/MS tape audit reports, and data trend reports.

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11.3 EVIDENTIARY AUDIT

11.3.1 Evidence auditors conduct an on-site laboratory evaluation to determine if laboratory policies and procedures are in place to satisfy evidence handling requirements as stated. The evidence audit is comprised of the following three activities.

11.3.1.1 Procedural Audit

The procedural audit consists of review and examination of actual standard operating procedures and accompanying documentation for the following laboratory operations:

- Sample receiving;
- Sample storage;
- Sample identification;
- Sample security;
- Sample tracking (from receipt to completion of analysis); and
- Analytical project file organization and assembly.

11.3.1.2 Written SOPs Audit

The written SOPs audit consists of review and examination of the written SOPs to determine if they are accurate and complete for the following laboratory operations: sample receiving, sample storage, sample identification, sample security, sample tracking (from receipt to completion of analysis), and analytical project file organization and assembly.

11.3.1.3 Analytical Project File Evidence Audit

The analytical project file evidence audit consists of review and examination of the analytical project file documentation. The auditors review the files to determine:

- Accuracy of the document inventory;
- Completeness of the file;
- Adequacy and accuracy of the document numbering system;
- Traceability of sample activity;
- Identification of activity recorded on the documents; and

- Error correction methods.

11.4 DISCUSSION OF THE ON-SITE TEAM'S FINDINGS

The QA and evidentiary auditors discuss their findings with the Administrative Project Officer (APO)/Technical Project Officer (TPO) prior to debriefing the Contractor. During the debriefing, the auditors present their findings and recommendations for corrective actions necessary to the Contractor personnel.

11.5 CORRECTIVE ACTION REPORTS FOR FOLLOW-THROUGH TO QUALITY ASSURANCE AND EVIDENTIARY AUDIT REPORTS

11.5.1 Following an on-site evaluation, QA and evidentiary audit reports which discuss deficiencies found during the on-site evaluation will be forwarded to the Contractor. The Contractor must discuss the corrective actions taken to resolve the deficiencies discussed during the on-site visit and discussed in the on-site reports in a letter to the APO/TPO, EMSL/LV (response to the QA report) and NEIC (response to the evidentiary report) within 14 days of receipt of the finding or within the time agreed upon between APO/TPO and the Contractor. If SOPs are required to be written or SOPs are required to be amended, the Contractor must provide the SOPs to the TPO, EMSL/LV (QA/technical SOPs) and NEIC (evidentiary SOPs) within 30 days of receipt of the finding or within the time agreed upon between the APO/TPO and the Contractor.

11.5.2 If the Contractor fails to take appropriate corrective action to resolve the deficiencies discussed in the on-site reports, a Contractor may expect, but the Agency is not limited to, the following actions:

- reduction of the number of samples sent under the contract;
- suspension of sample shipment to the Contractor;
- a follow-up site visit, a full data audit; and
- analysis of remedial PE samples and/or contract sanction, such as a Cure Notice.

SECTION 12

QUALITY ASSURANCE AND DATA TREND ANALYSIS

12.1 Data submitted by laboratories are subject to review from several aspects: compliance with contract-required QC, usability, and full data package evaluation. Problems resulting from any of these reviews may determine the need for a GC/MS tape audit, an on-site laboratory evaluation and/or a remedial laboratory evaluation sample. In addition, QC prescribed in the methods provides information that is continually used by the Agency to assess sample data quality, Contractor data quality and Program data quality via data trend analysis. Trend analysis is accomplished by entering data into a computerized data base. Statistical reports that evaluate specific anomalies or disclose trends in many areas, including the following, are generated from this data base:

- Laboratory Control Sample;
- Blanks;
- GC/MS Instrument Performance Checks;
- Initial and Continuing Calibration Data; and
- Other QC and Method Parameters.

12.2 Program-wide statistical results are used to rank laboratories in order to observe the relative performance of each Contractor using a given protocol against its peers. The reports are also used to identify trends within laboratories. The results of many of these trends analyses are included in overall evaluation of a Contractor's performance, and are reviewed to determine if corrective action or an on-site laboratory evaluation is indicated in order to meet the QA/QC requirements of the contract.

12.3 Contractor performance over time is monitored using these trend analysis techniques to detect departures of Contractor output from required or desired levels of QC, and to provide an early warning of Contractor QA/QC problems which may not be apparent from the results of an individual case.

12.4 As a further benefit to the Program, the data base provides the information needed to establish performance-based criteria in updated analytical protocols, where advisory criteria have been previously used. The vast empirical data set produced by contract laboratories is carefully analyzed, with the results augmenting theoretical and research-based performance criteria. The result is a continuously monitored set of QC and performance criteria specifications of what is routinely achievable and expected of environmental chemistry laboratories in mass production analysis

of environmental samples. This, in turn, assists the Agency in meeting its objectives of obtaining data of known and documented quality.

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SECTION 13

DATA MANAGEMENT

13.1 Data management procedures are defined as procedures specifying the acquisition or entry, update, correction, deletion, storage and security of computer readable data and files. These procedures should be in written form and contain a clear definition for all databases and files used to generate or resubmit deliverables. Key areas of concern include: system organization (including personnel and security), documentation operations, traceability and quality control.

13.2 Data manually entered from hard-copy must be quality controlled and the error rates estimated. Systems should prevent entry of incorrect or out-of-range data and alert data entry personnel of errors. In addition, data entry error rates must be estimated and recorded on a monthly basis by reentering a statistical sample of the data entered and calculating discrepancy rates by data element.

13.3 The record of changes in the form of corrections and updates to data originally generated, submitted, and/or resubmitted must be documented to allow traceability of updates. Documentation must include the following for each change:

- Justification or rationale for the change;
- Initials of the person making the change or changes. Data changes must be implemented and reviewed by a person or group independent of the source generating the deliverable;
- Change documentation must be retained according to the schedule of the original deliverable;
- Resubmitted diskettes or other deliverables must be reinspected as a part of the laboratory's internal inspection process prior to resubmission. The entire deliverable, not just the changes, must be inspected;
- The Laboratory Manager must approve changes to originally submitted deliverables; and
- Documentation of data changes may be requested by laboratory auditors.

13.4 Lifecycle management procedures must be applied to computer software systems developed by the laboratory to be used to generate and edit contract deliverables. Such systems must be thoroughly tested and documented prior to utilization

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- A software test and acceptance plan including test requirements, test results and acceptance criteria must be developed, followed, and available in written form.

- System changes must not be made directly to production systems generating deliverables. Changes must be made first to a development system and tested prior to implementation.

- Each version of the production system will be given an identification number, date of installation, date of last operation and archived.

- System and operations documentation must be developed and maintained for each system. Documentation must include a user's manual and an operations and maintenance manual.

13.5 Individual(s) responsible for the following functions must be identified:

- System operation and maintenance including documentation and training;

- Database integrity, including data entry, data updating and quality control; and

- Data and system security, backup and archiving.

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SECTION 14

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EXHIBIT F

EVIDENTIARY REQUIREMENTS

December, 1991

EXHIBIT F

EVIDENTIARY REQUIREMENTS

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SECTION 1

SAMPLE CHAIN-OF-CUSTODY

A sample is physical evidence collected from a facility or from environment. An essential part of hazardous waste investigation effort is that the evidence gathered be controlled. To accomplish this, the following sample identification, chain-of-custody, sample receiving, and sample tracking procedures have been established.

1.1 SAMPLE IDENTIFICATION

1.1.1 To assure traceability of samples while in possession of the Contractor, the Contractor shall have a specified method for maintaining identification of samples throughout the laboratory.

1.1.2 Each sample and sample preparation container shall be labeled with the EPA sample number or a unique laboratory identifier. If a unique laboratory identifier is used, it shall be cross-referenced to the EPA sample number.

1.2 CHAIN-OF-CUSTODY PROCEDURES

1.2.1 Because of the nature of the data being collected, the custody of EPA samples must be traceable from the time the samples are collected until they are introduced as evidence in legal proceedings. The Contractor shall have procedures ensuring that EPA sample custody is maintained and documented.

1.2.2 A sample is under custody if the following applies:

1.2.2.1 It is in your possession.

1.2.2.2 It is in your view after being in your possession.

1.2.2.3 It was in your possession and you locked it up.

1.2.2.4 It is in a designated secure area (secure areas shall be accessible to authorized personnel only).

1.3 SAMPLE RECEIVING PROCEDURES

1.3.1 The Contractor shall designate a sample custodian responsible for receiving all samples.

1.3.2 The Contractor shall designate a representative to receive samples in the event that the sample custodian is not available. The condition of the shipping containers and sample bottles shall be

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inspected upon receipt by the sample custodian or his/her representative.

1.3.3 The condition of the custody seals (intact/not intact) shall be inspected upon receipt by the sample custodian or his/her representative.

1.3.4 The sample custodian or his/her representative shall check for the presence or absence of the following documents accompanying the sample shipment:

1.3.4.1 Airbills or airbill stickers.

1.3.4.2 Custody seals.

1.3.4.3 EPA custody records.

1.3.4.4 EPA traffic reports or SAS packing lists.

1.3.4.5 Sample tags

1.3.5 The sample custodian or his/her representative shall sign and date all forms (e.g., custody records, traffic reports or packing lists, and airbills) accompanying the samples at the time of sample receipt.

1.3.6 The Contractor shall contact SMO to resolve discrepancies and problems such as absent documents, conflicting information, broken custody seals, and unsatisfactory sample condition (e.g., leaking sample bottle).

1.3.7 The Contractor shall record the resolution of discrepancies and problems on Telephone Contact Logs.

1.3.8 The following information shall be recorded on Form AADC-1 by the sample custodian or his/her representative as samples are received and inspected:

1.3.8.1 Condition of the shipping container.

1.3.8.2 Presence or absence and condition of custody seals on shipping and/or sample containers.

1.3.8.3 Custody seal numbers, when present.

1.3.8.4 Condition of the sample bottles.

1.3.8.5 Presence or absence of airbills or airbill stickers.

1.3.8.6 Airbill or airbill sticker numbers.

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1.3.8.7 Presence or absence of EPA custody records.

1.3.8.8 Presence or absence of EPA traffic reports or SAS packing lists.

1.3.8.9 Presence or absence of sample tags.

1.3.8.10 Sample tag identification numbers cross-referenced to the EPA sample numbers.

1.3.8.11 Verification of agreement or non-agreement of information recorded on shipping documents and sample containers.

1.3.8.12 Problems or discrepancies.

1.4 SAMPLE TRACKING PROCEDURES

The Contractor shall maintain records documenting all phases of sample handling from receipt to final analysis. The records shall include documentation of the movement of samples and prepared samples into and out of designated laboratory storage areas.

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SECTION 2

DOCUMENT CONTROL PROCEDURES

The goal of the laboratory document control program is to assure that all documents for a specified SDG will be accounted for when the project is completed. Accountable documents used by contract laboratories shall include but not be limited to logbooks, chain-of-custody records, sample work sheets, bench sheets, and other documents relating to the sample or sample analyses. The following document control procedures have been established to assure that all laboratory records are assembled and stored for delivery to the EPA or are available upon request from the EPA prior to the delivery schedule.

2.1 PREPRINTED LABORATORY FORMS AND LOGBOOKS

2.1.1 All documents produced by the Contractor which are directly related to the preparation and analysis of EPA samples shall become the property of the EPA and shall be placed in the complete sample delivery group file (CSF). All observations and results recorded by the laboratory but not on preprinted laboratory forms shall be entered into permanent laboratory logbooks. When all data from a SDG are compiled, all original laboratory forms and copies of all SDG-related logbook entries shall be included in the documentation package.

2.1.2 The Contractor shall identify the activity recorded on all laboratory documents which is directly related to the preparation and analysis of EPA samples.

2.1.3 Pre-printed laboratory forms shall contain the name of the laboratory and be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

2.1.4 Logbook entries shall be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

2.1.5 Logbook entries shall be in chronological order. Entries in logbooks, with the exception of instrument run logs and extraction logs, shall include only one SDG per page.

2.1.6 Pages in both bound and unbound logbooks shall be sequentially numbered.

2.1.7 Instrument run logs shall be maintained so as to enable a reconstruction of the run sequence of individual instruments. Because the laboratory must provide copies of the instrument run logs to the EPA, the laboratory may exercise the option of using only laboratory or EPA

sample identification numbers in the logs for sample ID rather than government agency or commercial client names to preserve the confidentiality of commercial clients.

2.1.8 Corrections to supporting documents and raw data shall be made by drawing a single line through the error and entering the correct information. Corrections and additions to supporting documents and raw data shall be dated and initialed. No information shall be obliterated or rendered unreadable. All notations shall be recorded in ink. Unused portions of documents shall be crossed out.

2.2 CONSISTENCY OF DOCUMENTATION

2.2.1 The Contractor shall assign a document control officer responsible for the organization and assembly of the CSF.

2.2.2 All copies of laboratory documents shall be complete and legible.

2.2.3 Before releasing analytical results, the document control officer shall assemble and cross-check the information on sample tags, custody records, laboratory bench sheets, personal and instrument logs, and other relevant data to ensure that data pertaining to each particular sample or sample delivery group is consistent throughout the CSF.

2.3 DOCUMENT NUMBERING AND INVENTORY PROCEDURES

2.3.1 In order to provide document accountability of the completed analysis records, each item in a CSF shall be inventoried and assigned a serialized number as described in Exhibit B, Section 2.

CSF # - Region - Serialized number (For example: 75-2-0240).

2.3.2 All documents relevant to each SDG, including logbook pages, bench sheets, mass spectra, chromatograms, screening records, re-preparation records, re-analysis records, records of failed or attempted analysis, custody records, library research results, etc., shall be inventoried.

2.3.3 The Document Control Officer (DCO) shall be responsible for ensuring that all documents generated are placed in the CSF for inventory and are delivered to the EPA. The DCO shall place the sample tags in plastic bags in the file. Figure E-1 of Exhibit E is an example of a document inventory.

2.4 STORAGE OF EPA FILES

The Contractor shall maintain EPA laboratory documents in a secure location.

2.5 SHIPPING DATA PACKAGES AND CSF

2.5.1 The Contractor shall document shipment of deliverables packages to the recipients. These shipments require custody seals on the containers placed such that they cannot be opened without damaging or breaking the seal. The Contractor shall document what was sent, to whom, the date, and the method (carrier) used.

2.5.2 The Contractor shall purge the CSF deliverable to the appropriate EPA Region 180 days after the report submission.

2.5.3 A copy of the transmittal letter for the CSF will be sent to NEIC and SMO.

2.5.4 The Document Control form is used to document the receipt and inspection of shipping containers and samples. The Contractor shall submit one original FORM AADC-1 for each shipping container.

2.5.5 The Contractor shall sign and date the airbill (if present), examine the shipping containers, record the presence or absence of custody seals and their conditions.

2.5.6 The Contractor shall note any problems with the samples and follow the instructions explained in Exhibit B, Sample Log-In Sheet.

2.5.7 The Contractor shall submit a completed Document Control Form with each SDG package.

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SECTION 3

STANDARD OPERATING PROCEDURES

The Contractor must have written standard operating procedures (SOPs) for receipt of samples, maintenance of custody, sample identification, sample storage, tracking the analysis of samples, and assembly of completed data.

3.1 SPECIFICATIONS FOR WRITTEN STANDARD OPERATING PROCEDURES

3.1.1 An SOP is defined as a written narrative step-by-step description of laboratory operating procedures including examples of laboratory documentation. The SOPs must accurately describe the actual procedures used in the laboratory, and copies of the written SOPs shall be available to the appropriate laboratory personnel. These procedures are necessary to ensure that analytical data produced under this contract are acceptable for use in EPA enforcement case preparation and litigation.

3.1.2 The Contractor's SOPs shall provide mechanisms and documentation to meet each of the following specifications and shall be used by EPA as the basis for laboratory evidence audits. The Contractor must have written standard operating procedures (SOPs) for:

3.1.2.1 Sample receipt and logging.

3.1.2.2 Sample storage.

3.1.2.3 Preventing sample contamination.

3.1.2.4 Security for laboratory and samples.

3.1.2.5 Traceability of standards.

3.1.2.6 Maintaining instrument records and logbooks.

3.1.2.7 Sample analysis and data control systems.

3.1.2.8 Glassware cleaning.

3.1.2.9 Technical and managerial review of laboratory operation and data package preparation.

3.1.2.10 Internal review of contractually-required quality assurance and quality control data for each individual data package.

3.1.2.11 Sample analysis, data handling, and reporting.

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3.1.2.12 Chain-of-Custody.

3.1.2.13 Document control, including Case file preparation.

3.1.3 The Contractor shall have a designated sample custodian responsible for receipt of samples and have written SOPs describing his/her duties and responsibilities.

3.1.4 The Contractor shall have written SOPs for receiving and logging in of the samples. The procedures shall include but not be limited to documenting the following information:

3.1.4.1 Presence or absence of EPA chain-of-custody forms.

3.1.4.2 Presence or absence of airbills or airbill stickers.

3.1.4.3 Presence or absence of EPA Traffic Reports or SAS packing lists.

3.1.4.4 Presence or absence of custody seals on shipping and/or sample containers and their condition.

3.1.4.5 Custody seal numbers, when present.

3.1.4.6 Presence or absence of sample tags.

3.1.4.7 Sample tag ID numbers.

3.1.4.8 Condition of the shipping container.

3.1.4.9 Condition of the sample container.

3.1.4.10 Verification of agreement or nonagreement of information on receiving documents and sample containers.

3.1.4.11 Resolution of problems or discrepancies with SMO.

3.1.4.12 The definition of any terms used to describe sample condition upon receipt.

3.1.5 The Contractor shall have written SOPs for maintenance of the security of samples after log-in and shall demonstrate security of the sample storage and laboratory areas. The SOPs shall specifically include descriptions of all storage areas for EPA samples in the laboratory, and steps taken to prevent sample contamination. The SOPs shall include a list of authorized personnel who have access or keys to secure storage areas.

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3.1.6 The Contractor shall have written SOPs for tracking the work performed on any particular sample. The tracking SOP shall include the following:

3.1.6.1 A description of the documentation used to record sample receipt, sample storage, sample transfers, sample preparations, and sample analyses.

3.1.6.2 A description of the documentation used to record instrument calibration and other QA/QC activities.

3.1.6.3 Examples of the document formats and laboratory documentation used in the sample receipt, sample storage, sample transfer, and sample analyses.

3.1.7 The Contractor shall have written SOPs for maintaining identification of EPA samples throughout the laboratory.

3.1.8 If the Contractor assigns unique laboratory identifiers, written SOPs shall include a description of the method used to assign the unique laboratory identifier and cross-reference to the EPA sample number.

3.1.9 If the Contractor uses prefixes or suffixes in addition to sample identification numbers, the written SOPs shall include their definitions. The Contractor shall have written SOPs describing the method by which the laboratory maintains samples under custody.

3.1.10 The Contractor shall have written SOPs for organization and assembly of all documents relating to each EPA Case, including technical and managerial review. Documents shall be filed on a Case-specific basis. The procedures must ensure that all documents including logbook pages, sample tracking records, chromatographic charts, computer printouts, raw data summaries, correspondence, and any other written documents having reference to the Case are compiled in one location for submission to EPA. The system must include a document numbering and inventory procedure.

3.1.11 The Contractor shall have written SOPs for laboratory safety.

3.1.12 The Contractor shall have written SOPs for cleaning of glassware used in preparing and analyzing samples under this contract.

3.1.13 The Contractor shall have SOPs for traceability of standards used in sample analysis QA/QC.

3.2 HANDLING OF CONFIDENTIAL INFORMATION

3.2.1 A Contractor conducting work under this contract may receive

EPA-designated confidential information from the Agency. Confidential information must be handled separately from other documentation developed under this contract. To accomplish this, the following procedures for the handling of confidential information have been established.

3.2.2 All confidential documents shall be under the supervision of a designated Document Control Officer (DCO).

3.2.3 Any samples or information received with a request of confidentiality shall be handled as "confidential." A separate locked file shall be maintained to store this information and shall be segregated from other nonconfidential information. Data generated from confidential samples shall be treated as confidential. Upon receipt of confidential information, the DCO logs these documents into a Confidential Inventory Log. The information is then made available to authorized personnel but only after it has been signed out to that person by the DCO. The documents shall be returned to the locked file at the conclusion of each working day. Confidential information may not be reproduced except upon approval by the EPA Contracting Officer. The DCO will enter all copies into the document control system. In addition, this information may not be disposed of except upon approval by the EPA Contracting Officer. The DCO shall remove and retain the cover page of any confidential information disposed of for one year and shall keep a record of the disposition in the Confidential Inventory Log.

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EXHIBIT G

GLOSSARY OF TERMS

December, 1991

EXHIBIT G

GLOSSARY OF TERMS

Aliquot - A measured portion of a field sample taken for analysis.

Analysis Date/Time - The date and military time (24-hour clock) of the introduction of the sample, standard, or blank into the analysis system.

Analysis Group - An analysis group is a set of no more than twenty analytical samples (as defined below) for the purpose of method Quality Assurance/Quality Control (QA/QC), such that the QA/QC required by Exhibits D and E are, at a minimum, prepared and analyzed at a frequency of once per twenty analytical samples.

Analytical Sample - Any solution or media introduced into an instrument on which an analysis is performed excluding instrument calibration, initial calibration verification, initial calibration blank, continuing calibration verification and continuing calibration blank. Note the following are all defined as analytical samples: field samples, duplicate samples, laboratory control sample (LCS), and performance evaluation (PE) samples.

ASTM Type II Water - Distilled water with a conductivity of less than 1.0 μmho/cm at 25°C. For additional specifications refer to ASTM D1193-77, "Standard Specification for Reagent Water".

Autozero - Zeroing the instrument at the proper wavelength. It is equivalent to running a standard blank with the absorbance set at zero.

Background Correction - A technique to compensate for variable background contribution to the instrument signal in the determination of trace elements.

Batch - A group of samples prepared at the same time.

Breakthrough volume (V_B) - Sample volume at which point a particular component will be initially detected in the eluate from the Tenax® sample cartridge.

Calibration - The establishment of an analytical curve based on the absorbance, emission intensity, or other measured characteristic of known standards. Calibration procedures differ for the various methods included in this document. Refer to the method of interest for a definition specific to that method.

Calibration Standards - A series of known standard solutions used by the analyst for calibration of the instrument (i.e., preparation of the analytical curve). The solutions are not subjected to the preparation method but contain the same matrix as the sample preparations to be analyzed.

Case - A finite, usually predetermined number of samples collected over a given time period from a particular site. Case numbers are assigned by the Sample Management Office. A Case consists of one or more Sample Delivery Groups.

Coefficient of Variation (CV) - The standard deviation as a percent of the arithmetic mean.

Continuing Calibration Standard - A standard solution prepared by the analyst to be used to verify the stability of the instrument calibration with time and the instrument performance during the analysis of samples. The continuing calibration standard should have a concentration in the middle of the calibrated range. Analytical standard run every 20 analytical samples or every 12 hours, whichever is more frequent, to verify the calibration of the analytical system.

Contract Required Quantitation Limit (CRQL) - Minimum level of quantitation acceptable under the contract Statement of Work. Generally defined as 3.3 (or more) times the standard deviation of seven replicate analyses of the method blank.

Control Limits - A range within which specified measurement results must fall to be compliant. Control limits may be mandatory, requiring corrective action if exceeded, or advisory, requiring that noncompliant data be flagged.

Correlation Coefficient - A number (r) which indicates the degree of dependence between two variables (e.g., concentration - absorbance). The more dependent they are the closer the value to one. Determine on the basis of the least squares line.

Cryogen - A liquified gas used to obtain very low temperatures in the cryogenic trap of the analytical system. A typical cryogen is liquid nitrogen (bp - 195.8 °C).

Data System - For the purpose of this contract, computer system that allows the continuous acquisition and printout of time vs intensity data throughout the chromatographic program.

Day - Unless otherwise specified, day shall mean calendar day.

DDI - Deionized Distilled water.

Deuterated Chemicals - Those chemicals which contain deuterium (hydrogen isotope that is twice the mass of hydrogen); used as tracers for system quality assurance.

Field Blank - Any sample submitted from the field identified as a blank.

Field Sample - A portion of material received to be analyzed that is contained in single or multiple containers and identified by a unique EPA Sample Number.

Holding Time - The elapsed time expressed in days from the date of receipt of the sample by the Contractor until the date of its analysis.

In-House - At the Contractor's facility.

Initial Calibration - Analysis of analytical standards for a series of different specified concentrations; used to define the linearity and dynamic range of the response of the analytical instrument to the target compounds.

Interferents - Substances which affect the analysis for the compound of interest.

Internal Standards -Compounds added to every standard, blank, sample at a known concentration, prior to analysis. Internal standards are used as the basis for quantitation of the target analysis.

Laboratory - Synonymous with Contractor as used herein.

Laboratory Control Sample (LCS)- Aliquot spiked with known concentration of specific compounds and subjected to the entire analytical procedure in order to monitor method and contractor performance.

Laboratory Method Blank (LMB)- A clean unused cartridge analyzed along with and performing the same analytical procedure as the field samples. The LMB cartridge never leaves the laboratory.

Laboratory Receipt Date - The date on which a sample is received at the Contractor's facility, as recorded on the shipper's delivery receipt and sample Traffic Report. Also referred to as VTSR (validated time of sample receipt).

Linear Range - The concentration range over which the analytical curve remains linear. The range of the instrument for a specific compound, as determined using calibration standards. The upper limit of this linear range (determined at each analysis) is the highest concentration calibration standard that has a determined value within 10% of the known value.

Mass Spectral Interference - Defined as the inability to detect the internal standard quantification ion due to presence of high levels of mass spectral "noise" at the same mass.

Matrix - The predominant material of which the sample to be analyzed is composed.

Megabore® Column - One of two types of capillary columns, the other being the narrow bore, for the analysis of target compounds under this contract.

Method Detection Limit (MDL) - The chemical concentration that produces a signal, due to an analyte, which is equal to the student $t_{.99}$ times the standard deviation of a series of measurements on at least seven separate method blanks. In practice, a method detection limit will be substantially higher than an instrumental detection limit. The method detection limit for metals is $t_{.99}$ times the standard deviation of seven method blank analyses. Of course, all spectral background techniques must be operative and the same integration times must be utilized as when actual samples are analyzed.

MS-SCAN - The gas chromatograph (GC) is coupled to a mass selective detector where the instrument is programmed to acquire all mass for target compounds and to disregard all others.

Narrative (SDG Narrative) - Portion of the data package which includes laboratory, contract, SDG and sample number identification, and descriptive documentation of any problems encountered in processing the samples, along with corrective action taken and problem resolution. Complete SDG Narrative specifications are included in Exhibit B.

Narrow-Bore Capillary Column - One of two capillary columns, the other being the wide-bore (Megabore®) capillary column, for the analysis of compounds under this contract.

Performance Evaluation (PE) Sample - A sample of known composition provided by EPA for Contractor analysis. Used by EPA to evaluate Contractor performance.

Protocol - A compilation of the procedures to be followed with respect to sample receipt and handling, analytical methods, data reporting and deliverables, and document control.

Qualitative Accuracy - The ability of an analytical system to correctly identify compounds.

Quantitative Accuracy - The ability of an analytical system to correctly measure the concentration of an identified compound.

Reconstructed Ion Chromatogram (RIC) - A mass spectral graphical representation of the separation achieved by a gas chromatograph; a plot of total ion current versus retention time.

Recovery - A determination of the accuracy of the analytical procedure made by comparing measured values for a fortified (spiked) sample against the known spike values. Recovery is determined by the following equation:

$$\%\text{Recovery} = \frac{\text{measured value}}{\text{spiked value}} \times 100\%$$

Relative Response Factor (RRF) - A measure of the relative mass spectral response of an analyte compared to its internal standard. Relative Response Factors are determined by analysis of standards and are used in the calculation of concentrations of analytes in samples. RRF is determined by the following equation:

$$RRF = \frac{A_x}{A_{is}} \times \frac{C_{is}}{C_x}$$

where: A = area of the characteristic ion measured;
C = concentration;
is = internal standard; and
x = compound of interest.

Resolution - Also termed separation, the separation between peaks on a chromatogram, calculated by dividing the height of the valley between the peaks by the peak height of the smaller peak being resolved, multiplied by 100.

Retention Time (RT) - The time to elute a specific chemical from a chromatographic column for a specific carrier gas flow rate, measured from the time the chemical is injected into the gas stream until its maximum concentration appears at the detector.

Retention Time Window - Retention time window is determined for each compound of interest and is the time from injection to elution of a specific chemical from a chromatographic column. The window is determined by three injections of a single component standard over a 24-hour period as plus or minus three times the standard deviation of the absolute retention time for that compound.

Rounding Rules - If the figure following those to be retained is less than 5, the figure is dropped, and the retained figures are kept unchanged. As an example, 11.443 is rounded off to 11.44.

If the figure following those to be retained is greater than 5, the figure is dropped, and the last retained figure is raised by 1. As an example, 11.446 is rounded off to 11.45.

If the figure following those to be retained is 5, and if there are no

figures other than zeros beyond the five, the figure 5 is dropped, and the last-place figure retained is increased by one if it is an odd number or it is kept unchanged if an even number. As an example, 11.435 is rounded off to 11.44, while 11.425 is rounded off to 11.42.

If a series of multiple operations is to be performed (add, subtract, divide, multiply), all figures are carried through the calculations. Then the final answer is rounded to the proper number of significant figures.

See forms instructions (Exhibit B) for exceptions.

Run - A continuous analytical sequence consisting of prepared samples and all associated quality assurance measurements as required by this contract.

Sample - A portion of material to be analyzed that is contained in single or multiple containers and identified by a unique sample number.

Sample Delivery Group (SDG) - A unit within a sample Case that is used to identify a group of samples for delivery. An SDG is a group of 20 or fewer samples within a Case, received over a period of up to 14 calendar days. Data from all samples in an SDG are due concurrently. An SDG is defined by one of the following, whichever occurs first:

- Case; or
- Each 20 samples within a Case; or
- Each 14-day calendar period during which samples in a Case are received, beginning with receipt of the first sample in the Case or SDG.

Sample Number (EPA Sample Number) - A unique identification number designated by EPA for each sample. The EPA Sample Number appears on the sample Traffic Report which documents information on that sample.

Selected Ion Current Profile (SICP) - A plot of ion abundance vs time or scan number for ions of a specified mass.

Standard Analysis - An analytical determination made with known quantities of target compounds; used to determine response factors.

Static Calibration - Calibration of an analytical system with known concentrations of calibration gas, obtained from a source such as gas cylinders or prepared from standard stock solutions.

Stock Solution - A standard solution which can be diluted to derive other standards.

Surrogates (Surrogate Standard) - Compounds added to every blank, sample, matrix spike, matrix spike duplicate, and standard; used to evaluate analytical efficiency by measuring recovery. Surrogates are brominated, fluorinated, or isotopically labelled compounds not expected to be detected in environmental media.

Target compound - The compound an analysis seeks to determine; the compound of interest.

Tentatively Identified Compounds (TIC) - Compounds detected in samples that are not target compounds, internal standards or surrogate standards. Up to 10 peaks are subjected to mass spectral library searches for tentative identification.

Time - When required to record time on any deliverable item, time shall be expressed as Military Time, i.e., a 24-hour clock.

Traffic Report (TR) - An EPA sample identification form filled out by the sampler, which accompanies the sample during shipment to the laboratory and which is used for documenting sample condition and receipt by the laboratory.

Twelve-Hour Time Period - The twelve (12) hour time period for GC/MS system tuning, standards calibration (initial or continuing calibration) begins at the moment of injection of the BFB analysis that the laboratory submits as documentation of compliant tune. The time period ends after 12 hours has elapsed according to the system clock.

Validated Time of Sample Receipt (VTSR) - The date on which a sample is received at the Contractor's facility, as recorded on the shipper's delivery receipt and Sample Traffic Report.

Volatile Compounds - Target compounds with normal vapor pressures $\geq$ 0.1 mm Hg by the analytical method in this document.

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ATTACHMENT V

USEPA CONTRACT LABORATORY PROGRAM

SEMIVOLATILE ORGANICS ANALYSIS OF AMBIENT AIR

January, 1992

Revision SVAA01.0

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SEMIVOLATILE ORGANICS ANALYSIS
OF AMBIENT AIR

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PREFACE

The purpose of this contract is to provide the U.S. Environmental Protection Agency (EPA) with chemical analytical services, quality control procedures, and an analysis structure which will generate data of known and documented quality. This document was developed with the guidance of the Air Toxics Workgroup to ensure that the needs of regional, state, and local air pollution programs are addressed.

The samples to be analyzed are of ambient air collected on PUF/XAD-2 at or in the vicinity of known or suspected hazardous waste sites and may contain potentially hazardous organic and inorganic materials at significant concentrations. The Contractor should be aware of the potential hazards associated with the handling and analyses of these samples. It is the Contractor's responsibility to take all necessary measures and precautions to ensure the health and safety of its employees. The Contractor is responsible for providing a safe working environment and making its employees aware of the potential hazards of working with and analyzing these samples.

Procedures specified herein shall be used in the preparation of PUF/XAD-2 cartridges and analysis of air samples for the presence and quantitation of certain semivolatile organic compounds (SVOCs). The Contractor shall employ safe handling procedures and generally accepted laboratory practices in the performance of contract requirements and shall follow the quality assurance and quality control (QA/QC) program specified herein.

The data obtained under this contract will be used by EPA to determine the existence and extent of risk posed by hazardous waste disposal sites to the public, to individuals involved in Superfund site cleanups, and to the environment. The data may be used in civil and/or criminal litigation which requires the strictest adherence to chain-of-custody protocol, document control, and quality assurance procedures.

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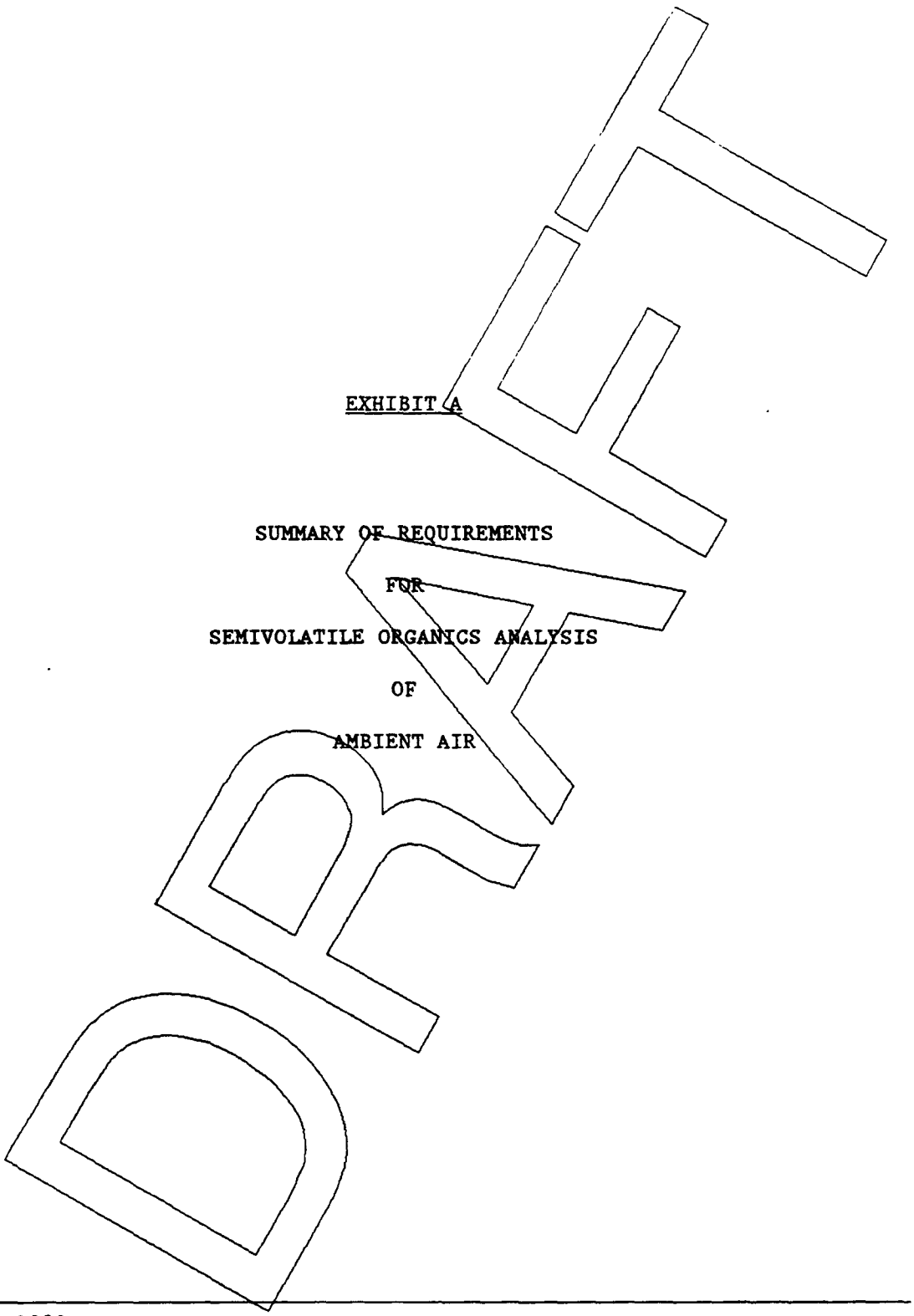

EXHIBIT A

SUMMARY OF REQUIREMENTS FOR SEMIVOLATILE ORGANICS ANALYSIS OF AMBIENT AIR

January, 1992

EXHIBIT A

SUMMARY OF REQUIREMENTS FOR
SEMIVOLATILE ORGANICS ANALYSIS OF AMBIENT AIR

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SECTION 1

GENERAL REQUIREMENTS

1.1 The Contractor shall employ procedures specified in this contract in the preparation and analysis of the ambient air samples for the presence and quantitation of the organic compounds listed in Exhibit C.

1.2 The Contractor shall use proven techniques to identify and measure the organic compounds presented in the Target Compound List (TCL) as specified in Exhibit C. The Contractor shall perform sample preparation and analysis procedures as prescribed in Exhibit D, and meet specified sample and extract preservation and holding time requirements.

1.3 For all samples analyzed under this contract, the Contractor shall adhere to the QA/QC protocols specified in Exhibit E and abide by the evidentiary protocols specified in Exhibit F.

1.4 Following sample analysis, the Contractor shall perform data reduction and shall report analytical activities, sample data, and quality control documentation as designated in Exhibit B. Exhibit B contains all reporting and deliverables requirements for this contract, including copies of the data reporting forms and form instructions guide.

1.5 To ensure proper understanding of the language in this contract, Exhibit G contains a glossary of terms. When a term is used in the text without explanation, the glossary meaning shall be applicable. Glossary definitions do not replace or take precedence over specific information included in the document text.

1.6 The samples to be analyzed by the Contractor are from known or suspected hazardous waste sites and may contain hazardous organic and/or inorganic materials at high concentration levels. The Contractor should be aware of the potential hazards associated with the handling and analysis of these samples. It is the Contractor's responsibility to take all necessary measures to ensure the health and safety of its employees. It is also the Contractor's responsibility to follow appropriate disposal procedures according to state and federal regulations.

1.7 In addition, the Contractor must be aware of the importance of maintaining the integrity of the data generated under this contract, as it may be used to make major decisions regarding public health and environmental welfare. In addition, data generated under this contract may be used in litigation against potentially responsible parties in the enforcement of Superfund legislation.

SECTION 2

SPECIFIC REQUIREMENTS

For each sample, the Contractor shall perform the following tasks:

2.1 TASK I: RECEIVE AMBIENT AIR SAMPLES ON PUF/XAD-2 CARTRIDGES

2.1.1 The Contractor shall receive and handle samples under the chain-of-custody and document control procedures described in Exhibit F.

2.1.2 The Contractor shall provide the required analytical expertise and instrumentation for analyses of the TCL compounds equal to or lower than the quantitation limits specified in Exhibit C. In Exhibit D, EPA provides the Contractor with an appropriate set of analytical procedures that shall be used.

2.1.3 The Contractor shall extract samples and analyze the extracts within the maximum holding times specified in Exhibit D, even if these times are less than the maximum data submission time allowed in this contract.

2.1.4 The Contractor is advised that the samples received under this contract are usually from known or suspected hazardous waste sites and may contain high levels of organic and/or inorganic materials of a potentially hazardous nature and of unknown structure and concentration, and should be handled throughout the preparation and analysis with appropriate caution. The Contractor shall be responsible for all necessary measures and precautions to ensure the health and safety of laboratory employees.

2.2 TASK II: ANALYZE SAMPLES FOR THE IDENTIFICATION AND QUANTITATION OF SPECIFIC COMPOUNDS

2.2.1 For each sample received, the Contractor shall be required to perform the sample extraction and analysis procedures described in Exhibit D. The documentation that accompanies the sample(s) to the Contractor facility shall indicate specific analytical requirements for that sample or set of samples.

2.2.2 Exhibit D specifies the analytical procedures that shall be used. Exhibit D contains instructions and references for the analysis of ambient air samples containing low-to-medium concentrations of semivolatile organics for GC/MS analysis. GC/MS may use automated computer programs to facilitate the identification of organic compounds.

2.2.3 For the purpose of this contract, a full sample analysis is defined as analysis for all of the TCL constituents identified in Exhibit C in accordance with the methods in Exhibit D and performance of related

QA/QC as specified in Exhibit D and Exhibit E. Laboratory Control Samples (LCS) analyses shall be considered a separate full sample analysis. All other QA/QC requirements are considered an inherent part of this contract and are included in the contract sample unit price.

2.2.4 The semivolatile compounds analyzed by GC/MS techniques and initially identified shall be verified by an analyst competent in the interpretation of mass spectra by comparison of the suspect mass spectra to the mass spectra of a standard of the suspected compound. This procedure requires the use of multiple internal standards. Two criteria must be satisfied to verify the identifications:

2.2.4.1 Elution of the sample component at the same GC relative retention time as the standard component.

2.2.4.2 Correspondence of the sample component and standard component mass spectra.

2.2.5 For each sample analysis, the Contractor shall conduct mass spectral library searches of non-target compound sample components to determine tentative compound identifications as follows:

2.2.5.1 For each semivolatile organics analysis, the Contractor shall conduct a search to determine the possible identity of up to 10 organic compounds of greatest concentration which are not internal standards, surrogate compounds, and not listed in Exhibit C.

2.2.5.2 In performing searches, the most recent release of the National Institute of Standards and Technology (NIST)/EPA/MSDC mass spectral library must be used.

NOTE: Substances with responses of less than 10 percent of the nearest internal standard are not required to be searched in this fashion.

2.2.5.3 Only after visual comparison of sample spectra with the spectra from the library searches will the mass spectral interpretation specialist assign a tentative identification. If the compound does not meet the identification criteria, it shall be reported as unknown. The mass spectral specialist should give additional classification of the unknown compound, if possible (e.g., unknown aromatic, unknown hydrocarbon, unknown acid type, unknown chlorinated compound). If probable molecular weights can be distinguished, they also should be included.

2.3 TASK III: PERFORM REQUIRED QUALITY ASSURANCE AND QUALITY CONTROL PROCEDURES

2.3.1 All specific QA/QC procedures prescribed in Exhibits D and E shall

be strictly adhered to by the Contractor. Records documenting the use of the protocol shall be maintained in accordance with the document control procedures prescribed in Exhibit F, and shall be reported in accordance with Exhibit B requirements.

2.3.2 The Contractor shall establish, and use on a continuing basis, QA/QC procedures including the daily or (as required) more frequent use of standard reference solutions from EPA, NIST, or secondary standards traceable thereto, where available at appropriate concentrations (i.e., standard solutions designed to ensure that operating parameters of equipment and procedures, from sample receipt through identification and quantitation, produce reliable data). Exhibits D and E provide specific QA/QC requirements.

2.3.3 Additional QA/QC shall be required quarterly or more frequently, i.e., with each Case or Sample Delivery Group (SDG), in the form of Laboratory Control Samples (LCS) and Performance Evaluation (PE) samples for semivolatile organics submitted to EPA for Contractor analysis, and in the form of verification of instrument parameters, as described in Exhibit E.

2.3.3.1 EPA has provided to the Contractor formats for the reporting of data (Exhibit B). The Contractor shall be responsible for completing and returning analysis data sheets in the format specified in this contract and within the time specified in the Contract Performance/Delivery Schedule.

2.3.3.2 Use of formats other than those designated by EPA will be deemed as noncompliant. Such data are unacceptable. Resubmission in the specified format at no additional cost to the Government will be required.

2.3.3.3 Computer generated forms may be submitted in the hardcopy data package(s) provided that the forms are in exact EPA format. This means that the order of data elements is the same as on each EPA required form, including form numbers and titles, page numbers and header information, columns, and lines.

2.3.4 The Contractor shall provide analytical equipment and technical expertise for this contract as specified by the following:

2.3.4.1 Gas chromatograph/mass spectrometer (GC/MS) data system capable of meeting all the terms and conditions of the Contract with the following requirements:

2.3.4.1.1 The computer shall be interfaced by hardware to the mass spectrometer and be capable of acquiring continuous mass scans for the duration of the chromatographic program.

2.3.4.1.2 The computer shall be equipped with mass storage devices for saving all data from the GC/MS runs.

2.3.4.1.3 Computer software shall be available to allow searching GC/MS runs for specific ions and plotting the intensity of the ions with respect to time or scan number.

2.3.4.1.4 A computer data system must be interfaced to the MS that allows the continuous acquisition and storage, on machine-readable media, of all mass spectra obtained throughout the duration of the chromatographic program. The computer must have software that allows searching any GC/MS data file for ions of a specified mass and plotting such ion abundances versus time or scan number. This type of plot is defined as an Extracted Ion Current Profile (EICP) or Selected Ion Current Profile (SICP). Software must also be available that allows integrating the abundance in any EICP between specified time or scan number limits. Also, for the non-target compounds, software must be available that allows for the comparison of sample spectra against reference library spectra. The most recent release of the NIST/EPA/MSDC mass spectral library shall be used as the reference library. The data system must be capable of flagging all data files that have been edited manually by laboratory personnel.

2.3.4.1.5 The GC/MS shall be equipped with a GC to MS interface capable of extending a fused silica capillary column into the ion source. The column is to be 50 meters long by 0.25 to 0.53 mm I.D. 100% methyl silicone or 5% phenyl, 95% methyl silicone capillary column, or equivalent.

2.3.4.2 The Contractor shall use a magnetic tape storage device capable of recording data and suitable for long-term, off-line storage. The Contractor shall retain all raw GC/MS data acquired under this contract on magnetic tape in appropriate instrument manufacturer's format. The Contractor is required to retain the magnetic tapes with associated hardcopy tape logbook identifying tape contents (see Exhibit B) for 365 days after data submission. During that time, the Contractor shall submit tapes and logbook within seven days of request, as specified in the Contract Performance/Delivery Schedule.

2.3.4.3 The Contractor shall have a computerized MS library search system capable of providing a forward comparison, using the standard spectra contained in the mass spectral library. The 1985 (or most recent) release of the NIST library (containing 42,261 spectra) must be used.

2.3.4.4 The system shall provide a numerical ranking of the standard spectra most closely corresponding to the sample spectra examined,

and the data system shall have software capable of removing background signals from spectra.

2.3.4.5 The Contractor shall have, in-house and operable, a device capable of analyzing semivolatile organics as described in Exhibit D.

2.3.4.6 The Contractor shall have, in-house, the appropriate standards for all target compounds listed in Exhibit C prior to accepting any samples from the Sample Management Office (SMO). Standards provided by EPA for use in the Preaward Performance Evaluation may not contain all the target compounds and thus shall not be used for routine analyses unless or until they have been supplemented with commercially available standard materials.

2.3.5 The minimum functional requirements necessary to meet the terms and conditions of this contract are listed below. The Contractor shall designate and use qualified key personnel to perform these functions. The EPA reserves the right to review personnel qualifications and experience.

2.3.5.1 Project Manager

2.3.5.2 GC/MS Laboratory Supervisor

2.3.5.3 Quality Assurance Officer

2.3.5.4 Systems Manager

2.3.5.5 Program Analyst

2.3.5.6 GC/MS Operators

2.3.5.7 Mass Spectral Interpreter

2.3.5.8 Sample Preparation/Extraction Supervisor;

2.3.5.9 Sample Preparation/Extraction Specialist;

2.3.5.10 Chemist (back-up)

NOTE: The Contractor shall designate a Sample Custodian and a Document Control Officer.

2.3.6 The Contractor shall respond within 10 days to requests from data recipients for additional information or explanations that result from the Government's inspection activities.

2.3.7 The Contractor is required to retain unused samples and sample extracts, and used sample containers for a period of 60 days after data

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submission unless otherwise instructed in Exhibit B or Exhibit D.

2.3.8 The Contractor shall adhere to the chain-of-custody and document control procedures described in Exhibit F. Documentation, as described therein, shall be required to show that all procedures are being strictly followed. This documentation shall be reported in the Complete Case File Purge (Exhibit B).

2.3.9 Sample shipments to the Contractor's facility will be scheduled and coordinated by SMO, acting on behalf of the Administrative Project Officer (APO). The Contractor shall communicate with SMO personnel by telephone as necessary throughout the process of sample scheduling, shipment, analysis, and data reporting, to ensure that samples are properly processed.

2.3.10 If there are problems with the samples (e.g., mixed media, containers broken) or sample documentation/paperwork (e.g., Traffic Reports not with shipment, or sample and Traffic Report numbers do not correspond), the Contractor shall immediately contact SMO for resolution. The Contractor shall immediately notify SMO regarding any problems and laboratory conditions that affect the timeliness of analyses and data reporting. In particular, the Contractor shall notify SMO personnel in advance regarding sample data that will be delivered late and shall specify the estimated delivery date.

2.3.11 Sample analyses will be scheduled by groups of samples, each defined as a Case and identified by a unique EPA Case number assigned by SMO. A Case signifies a group of samples collected at one site or geographical area over a finite time period, and will include one or more field samples with associated blanks. Samples may be shipped to the Contractor in a single shipment or multiple shipments over a period of time, depending on the size of the Case. A Case consists of one or more SDG(s). An SDG is defined by the following:

2.3.11.1 Each Case of field samples received, or

2.3.11.2 Each 20 field samples within a Case, or

2.3.11.3 Each seven calendar day period during which field samples in a Case are received (said period beginning with the receipt of the first sample in the SDG).

2.3.12 Data for all samples in an SDG must be submitted together (in one package) in the order specified in Exhibit B. The SDG number is the EPA number of the first sample received in the SDG. When several samples are received together in the first SDG shipment, the SDG number is the lowest sample number (considering both alpha and numeric designations) in the first group of samples received under the SDG. The SDG number is reported on all data reporting forms. The SDG Receipt Date is the day

that the last sample in the SDG is received.

2.3.13 The Contractor is responsible for identifying each SDG as samples are received, through proper sample documentation (see Exhibit B) and communication with SMO personnel.

2.3.14 Each sample received by the Contractor will be labeled with an EPA sample number, and accompanied by a Traffic Report (TR) form bearing the sample number and descriptive information regarding the sample. The Contractor shall complete and sign the TR, recording the date of sample receipt and sample condition on receipt for each sample container.

2.3.15 The Contractor shall submit signed copies of TRs for all samples in an SDG to SMO within three calendar days following receipt of the last sample in the SDG. TRs shall be submitted in SDG sets (i.e., all TRs for an SDG shall be clipped together) with an SDG Cover Sheet containing information regarding the SDG, as specified in Exhibit B.

2.3.16 EPA Case numbers (including SDG numbers) and EPA sample numbers shall be used by the Contractor in identifying samples received under this contract both verbally and in reports/correspondence.

2.3.17 Samples will be routinely shipped directly to the Contractor through a delivery service. The Contractor shall be available to receive sample shipments at any time the delivery service is operating, including Saturdays and holidays. As necessary, the Contractor shall be responsible for any handling or processing required for the receipt of sample shipments, including pick-up of samples at the nearest servicing airport, bus station, or other carrier service within the Contractor's geographical area.

2.3.18 The Contractor shall accept all samples scheduled by SMO, provided that the total number of samples received in any calendar month does not exceed the monthly limitation expressed in the contract. Should the Contractor elect to accept additional samples, the Contractor shall remain bound by all contract requirements for analysis of those samples accepted.

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SECTION 3

DETAILED TECHNICAL & MANAGEMENT REQUIREMENTS

The Contractor shall have the following technical and management capabilities:

3.1 PERSONNEL

3.1.1 Project Manager

3.1.1.1 Responsible for all technical efforts of the laboratory to meet all terms and conditions of the contract.

3.1.1.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.1.3 Experience: Minimum of three years of laboratory experience, including at least one year in a supervisory position.

3.1.2 GC/MS Laboratory Supervisor

3.1.2.1 Responsible for all technical efforts of the GC/MS laboratory to meet all terms and conditions of the contract.

3.1.2.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.2.3 Experience: Minimum of three years of laboratory experience in operating a GC/MS, including at least one year in a supervisory position.

3.1.3 Quality Assurance Officer

3.1.3.1 Responsible for overseeing the quality assurance aspects of data generation and reporting directly to upper management.

3.1.3.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.3.3 Experience: Minimum of three years of laboratory experience, including at least one year of applied experience with QA principles and practices in an analytical laboratory.

3.1.4 Systems Manager

3.1.4.1 Responsible for the management and quality control of all computing systems (hardware, software, documentation, and procedures), generating, updating, and performing quality control on

automated deliverables.

3.1.4.2 Education: Minimum of Bachelor's degree with four or more intermediate courses in programming, information management, database management systems, or systems requirements analysis.

3.1.4.3 Experience: Minimum of three years experience in data or systems management or programming including one year experience with software used for data management and generation of deliverables.

3.1.5 **Program Analyst**

3.1.5.1 Responsible for the installation, operation, and maintenance of software and programs; generating, updating, and performing quality control procedures on analytical databases and automated deliverables.

3.1.5.2 Education: Minimum of Bachelor's degree with four or more intermediate courses in programming, information management, information systems, or systems requirements analysis.

3.1.5.3 Experience: Minimum of two years experience in systems or applications programming including one year of experience with software used for data management and generation of deliverables.

3.1.6 **Gas Chromatography/Mass Spectrometer (GC/MS) Operator**

3.1.6.1 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.6.2 Experience: Minimum of one year of experience in operating and maintaining GC/MS instruments in conjunction with the education requirement; or in lieu of education requirement, three additional years of experience in operating and maintaining GC/MS instrumentation.

3.1.7 **Mass Spectral Interpreter**

3.1.7.1 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline with specialized training in GC/MS.

3.1.7.2 Experience: Minimum of two years of applied experience with GC/MS analysis of environmental samples.

3.1.8 **Sample Preparation/Extraction Supervisor**

3.1.8.1 The bidder shall have a minimum of one extraction specialist responsible for all technical efforts of sample preparations and extractions to meet all terms and conditions of the EPA contract.

3.1.8.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.8.3 Experience: Minimum of three years of laboratory experience, including at least one year of supervisory experience.

3.1.9 **Sample Extraction/Preparation Specialist**

3.1.9.1 Education: Minimum of Bachelor's degree in chemistry, or equivalent.

3.1.9.2 Experience: Minimum of one year of applied experience in an analytical laboratory.

3.1.10 **Technical Staff Redundancy**

3.1.10.1 In order to ensure continuous operations to accomplish the required work as specified by the contract, the bidder shall have a minimum of one chemist available at all times as a back-up technical person with the following qualifications.

3.1.10.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.10.3 Experience: Minimum of one year of experience in each of the following areas: GC/MS operation and maintenance.

3.2 **FACILITIES**

The adequacy of the facilities and equipment is as important as the technical staff for accomplishing the required work as specified by the EPA contract.

3.2.1 **Sample Receipt Area**

Adequate, contamination-free, well-ventilated work space with chemical resistant bench top shall be available for receipt and safe handling of EPA samples.

3.2.2 **Storage Area**

Sufficient refrigerator space to maintain unused EPA sample volume for up to 60 days after data submission shall be provided. Semivolatile samples must be stored in a refrigerator used only for storage of semivolatile samples from this contract. Samples must be stored in an atmosphere demonstrated to be free from all potential contaminants. Samples, sample extracts, and standards must be stored separately.

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3.2.3 **Sample/Standard Preparation Area**

Adequate, contamination-free, well-ventilated work space shall be provided with:

3.2.3.1 Benches with chemical resistant tops.

3.2.3.2 Exhaust hoods.

3.2.3.3 Glove box or isolated area in which to prepare standard materials.

3.2.3.4 Source of distilled or demineralized organic-free water.

3.2.3.5 Analytical balance(s) located away from draft and rapid change in temperature.

3.3 **INSTRUMENTATION**

At a minimum, the Contractor shall have the following instruments operative at the time of the Preaward Site Evaluation and committed for the full duration of the contract.

3.3.1 **100 Samples/Month Capacity Requirements**

No. of Instrument(s)	Type of Instrument
1	GC/MS

NOTE: The Contractor shall have one (1) complete GC/MS system available (operational) at all times as a back-up system. These instruments must be included in the bidder's inventory of equipment. In addition, the Contractor shall have an in-house stock of instrument parts and circuit boards to ensure continuous operation to meet contract-specified holding and turnaround times.

3.3.2 **200 Samples/Month Capacity Requirements**

No. of Instrument(s)	Type of Instrument
2	GC/MS

NOTE: These instruments must be included in the bidder's inventory of equipment. In addition, the Contractor shall have an in-house stock of instrument parts and circuit boards to ensure continuous operation to meet contract-specified holding and turnaround times.

3.3.3 **Instrument Specifications**

Further information on instrument specifications and required ancillary equipment may be found in Exhibit D and other Exhibits in this contract.

3.4 **DATA HANDLING AND PACKAGING**

The Contractor shall be able to submit reports and data packages as specified in Exhibit B. To complete this task, the Contractor shall be required to:

3.4.1 Provide space, tables, and copy machines to meet the contract requirements.

3.4.2 Designate personnel responsible for report preparations and submission.

3.5 **LABORATORY MANAGEMENT CAPABILITY**

The Contractor shall have an organization with well-defined responsibilities for each individual in the management system to ensure sufficient resources for EPA contract(s) and to maintain a successful operation. To establish this capability, the Contractor shall designate personnel to carry out the following responsibilities for the EPA contract. Functions include, but are not limited to, the following:

3.5.1 **Technical Staff**

Responsible for all technical efforts for the EPA contract such as sample analysis, sample validation, and troubleshooting of all instruments.

3.5.2 **Project Manager**

Responsible for overall aspects of EPA contract(s) (from sample receipt through data delivery) and shall be the primary contact for EPA Headquarters Administrative Project Officer (APO) and Regional Technical Project Officers (TPO).

3.5.3 **Sample Custodian**

Responsible for receiving the EPA samples (logging, handling, and storage).

3.5.4 **Quality Assurance Officer**

Responsible for overseeing the quality assurance aspects of the data and reporting directly to upper management.

3.5.5 Document Control Officer

Responsible for ensuring that all documents generated are placed in the Complete SDG File for inventory and are delivered to the appropriate EPA Region or other receiver as designated by EPA.

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EXHIBIT B

REPORTING

AND

DELIVERABLES REQUIREMENTS

January, 1992

EXHIBIT B

REPORTING AND DELIVERABLES REQUIREMENTS

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SECTION 1

CONTRACT REPORTS/DELIVERABLES DISTRIBUTION

1.1 The following table summarizes the contract reporting and deliverables requirements specified in the Contract Schedule and includes the distribution of each deliverable.

NOTE: Specific recipient names and addresses are subject to change during the term of the contract. The EPA APO or SMO will notify the Contractor in writing of such changes when they occur.

Item	No. of Copies	Schedule and Delivery	Distribution		
			(1)	(2)	(3)
Updated Standard Operating Procedures (SOPs)	2	45 days after contract award.		X	X
*Sample Traffic Reports	1	***3 days after receipt of last sample in Sample Delivery Group (SDG).	X		
**Sample Data Summary Package	1	14 days after receipt of last sample in SDG.	X		
**Sample Data Package including the Performance Evaluation (PE) Sample	3	35 days after receipt of last sample in SDG	X	X	X
Results of Intercomparison Study/Preaward Performance Evaluation (PPE) Sample	2	35 days after receipt of last sample in SDG	X	X	
Complete SDG File	1	35 days after data receipt of last sample in SDG.		X	
GC/MS Tapes	Lot	Retain for 365 days after data submission, or submit within 7 days after receipt of written request by APO.	As Directed		
****Quality Assurance Plan	1	Submit copy within 7 days by written request by APO.	As Directed		

Distribution

(1) Sample Management Office
(2) Environmental Monitoring Systems Laboratory-Las Vegas
(3) USEPA Region

* Also required in each Sample Data Package.

** Concurrent delivery of these items to all recipients is required.

*** An SDG is a group of samples within a Case, received over a period of seven days or less and not exceeding 20 samples. Data for all samples in the SDG are due concurrently. (See Exhibit A, Task III, for further description).

**** See Exhibit E for description.

NOTE: As specified in the Contract Schedule in the IFB (Government Furnished Supplies and Materials), unless otherwise instructed by SMO, the Contractor shall dispose of unused sample volume and used sample bottles/containers no earlier than 60 days following submission of analytical data.

Address

(1) USEPA Contract Laboratory Program
Sample Management Office
P.O. Box 818
Alexandria, VA 22313

For overnight delivery service, use street address:

300 North Lee Street
Alexandria, VA 22313

(2) USEPA Environmental Monitoring Systems Laboratory
P.O. Box 93478
Las Vegas, NV 89193-3478
ATTN: Data Audit Staff

For overnight delivery service, use street address:

944 E. Harmon, Executive Center
Las Vegas, NV 89109
ATTN: Data Audit Staff

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(3) USEPA REGIONS:

SMO, acting on behalf of the EPA APO, will provide the Contractor with the list of addresses for the 10 EPA Regions. SMO will provide the Contractor with updated Regional name/address lists as necessary throughout the period of the contract and identify other client recipients on a case-by-case basis.

NOTE: Specific recipient names and addresses are subject to change during the term of the contract. The APO will notify the Contractor in writing of such changes when they occur.

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SECTION 2

REPORT DESCRIPTIONS AND ORDER OF DATA DELIVERABLES

2.1 The Contractor shall provide reports and other deliverables according to the schedule specified in Section F of the IFB, "SCHEDULE INFORMATION." The required content and form of each deliverable is described in this Exhibit.

2.1.1 All reports and documentation shall be:

2.1.1.1 Legible;

2.1.1.2 Clearly labeled and completed in accordance with instructions in this Exhibit;

2.1.1.3 Arranged in the order specified in this section;

2.1.1.4 Paginated; and

2.1.1.5 Single-sided.

2.1.2 If submitted documentation does not conform to the above criteria, the Contractor will be required to resubmit such documentation with deficiency(ies) corrected, at no additional cost to the Government.

2.1.3 Whenever the Contractor is required to submit or resubmit data as a result of an on-site laboratory evaluation or through an APO/TPO action, the data shall be clearly marked as "ADDITIONAL DATA" and shall be sent to all three contractual data recipients (SMO, EMSL-LV, and Region). A cover letter shall be included that describes which data are being delivered, to which EPA Case(s) the data pertain, and who requested the data.

2.1.4 Section 3 of this Exhibit contains instructions to the Contractor for properly completing all data reporting forms to provide the EPA with the required documentation and contains the required data forms in EPA-specified format.

2.1.5 Descriptions of the requirements for each deliverable item cited in the Contract Performance/Delivery Schedule (see Section F of the IFB "SCHEDULE INFORMATION") are specified in this Section. Items submitted concurrently must be arranged in the order listed. Additionally, the components of each item must be arranged in the order presented herein.

2.2 UPDATED STANDARD OPERATING PROCEDURES

2.2.1 The Contractor shall submit updated copies of all required Standard Operating Procedures (SOPs) that were submitted with the Prebid Performance

Evaluation (PPE) sample results. The updated SOPs must address any and all issues of laboratory performance and operation identified through the review of the PPE sample data and the evaluation of Bidder-Supplied Documentation.

2.2.2 The Contractor must supply SOPs for the following.

2.2.2.1 Evidentiary SOPs.

2.2.2.2 Sample receipt and logging.

2.2.2.3 Sample and extract storage area.

2.2.2.4 Preventing sample contamination.

2.2.2.5 Security for laboratory and samples.

2.2.2.6 Traceability/equivalency of standards.

2.2.2.7 Maintaining instrument records and bound logbooks.

2.2.2.8 Glassware cleaning.

2.2.2.9 Technical and managerial review of laboratory operation and data package preparation.

2.2.2.10 Internal review of contractually-required QA/QC data for each individual data package.

2.2.2.11 Sample extraction and analysis, data handling, and data reporting.

2.2.2.12 Chain-of-custody and document control, including case file preparation.

2.2.2.13 Sample data validation/self-inspection system, including:

- Data flow and chain-of-command for data review;
- Procedures for measuring precision and accuracy;
- Evaluation parameters for identifying systematic errors;
- Procedures to ensure that hardcopy data are complete and compliant with the requirements in Exhibit B;
- Demonstration of internal QA inspection procedure (demonstrated

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by supervisory sign-off on personal notebooks, internal PE samples, etc.);

- Frequency and type of internal audits (e.g., random, quarterly, spot checks, perceived trouble areas);
- Demonstration of problem identification, corrective actions, and resumption of analytical processing resulting from internal audit (i.e., QA feedback); and
- Documentation of audit reports (internal and external), response, corrective action, etc.

2.2.2.14 Data Handling.

2.2.2.14.1 Data Management procedures are defined as written procedures that are clearly defined for all databases and files used to generate or re-submit deliverables specifying the acquisition or entry, update, correction, deletion, storage, and security of computer-readable data and files. Key areas of concern include: system organization including personnel and security, demonstration, operations, traceability, and quality control.

2.2.2.14.2 Data manually entered from hardcopy must be subjected to quality control procedures and error rates estimated.

2.2.2.14.3 The record of changes in the form of corrections and updates to data originally generated, submitted, and/or resubmitted must be documented to allow traceability of updates. Documentation must include the following information for each change:

- Justification or rationale for the change;
- Initials of the person making the changes or changes. Data changes must be identified when generating the deliverables;
- Changed documentation must be retained according to the schedule of the original deliverable;
- Resubmitted deliverables must be reinspected as a part of the laboratory's internal inspection process prior to submission. The entire deliverable and not just the changes must be reinspected;
- The laboratory manager must approve changes to originally submitted deliverables; and

- Documentation of data changes may be requested by laboratory auditors.

2.2.2.14.4 Life cycle management procedures must be applied to computer systems used to generate and edit contract deliverables. Such systems must be thoroughly tested and documented prior to utilization.

2.2.2.14.5 A software test and acceptance plan including test requirements, test results, and acceptance criteria must be developed, followed, and available in written form.

2.2.2.14.6 System changes shall not be made directly to production systems generating deliverables. Changes must be made first to a development system and tested prior to implementation.

2.2.2.14.7 Each version of the production system will be given an identification number, date of installation, date of last operation, and archived.

2.2.2.14.8 System and operations documentation shall be developed and maintained for each system. Documentation must include a user's manual and an operations and maintenance manual.

2.2.2.14.9 Individual(s) responsible for the following functions shall be identified:

- System operation and maintenance including documentation and training; and
- Database integrity including data entry, data updating and QC.

2.2.2.14.10 Data and system security, backup, and archiving.

2.3 SAMPLE TRAFFIC REPORTS

2.3.1 The original sample TR page marked "Lab Copy for Return to SMO" shall be submitted to SMO with laboratory receipt information and signed in original Contractor signature, for each sample in the SDG.

2.3.2 TRs shall be submitted in SDG sets (i.e., TRs for all samples in an SDG shall be clipped together), with an SDG Cover Sheet attached.

2.3.3 The SDG Cover Sheet shall contain the following items:

2.3.3.1 Laboratory name.

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2.3.3.2 Contract number.

2.3.3.3 Sample analysis price - full sample price from contract.

2.3.3.4 Case number.

2.3.3.5 List of EPA sample numbers of all samples in the SDG, identifying the first and last samples received, and their dates of receipt.

NOTE: When more than one sample is received in the first or last SDG shipment, the "first" sample received would be the lowest sample number (considering both alpha and numeric designations), and the "last" sample received would be the highest sample number (considering both alpha and numeric designations).

2.3.4 Each TR shall be clearly marked with the SDG Number and the EPA sample number of the first sample in the SDG. This information shall be entered below the laboratory receipt date on the TR. The TR for the last sample received in the SDG shall be clearly marked "SDG - FINAL SAMPLE."

2.3.5 If samples are received at the laboratory with multi-sample TRs, all the samples on one multi-sample TR may not necessarily be in the same SDG. In this instance, the laboratory shall make the appropriate number of photocopies of the TR, and submit one copy with each SDG cover sheet.

2.4 SAMPLE DATA SUMMARY PACKAGE

2.4.1 As specified in the Delivery Schedule, one Sample Data Summary Package shall be delivered to SMO concurrently with delivery of other required sample data. The Sample Data Summary Package shall be submitted separately (i.e., separated by rubber bands, clips or other means) directly preceding the Sample Data Package.

2.4.2 The Sample Data Summary Package shall contain data for samples in one SDG of the Case, as follows:

2.4.2.1 Cover Page (COVER PAGE - AASV).

2.4.2.2 By sample, tabulated target compound results (FORM I-AASV) and tentatively identified compounds (FORM I-AASV-TIC).

2.4.2.3 Laboratory Control Sample results (FORM III-AASV).

2.4.2.4 Blank summary (FORM II-AASV) and tabulated results (FORM I-AASV) including tentatively identified compounds (FORM I-AASV-TIC).

2.4.2.5 Initial and Continuing Calibration Data (FORM V-AASV and FORM VI-AASV).

2.4.2.6 Internal Standard Area and Retention Time Summary (FORM VII-AASV).

2.4.2.7 Filter/Adsorbent Cartridge Certification Data Sheet (FORM VIII-AASV)

2.4.2.8 Surrogate Recovery (FORM IX-AASV).

2.4.2.9 Analytical Sequence (FORM X-AASV).

2.5 SAMPLE DATA PACKAGE

2.5.1 The sample data package shall be complete, consecutively paginated, and shall include data for analysis of all samples in an SDG such as field samples, blanks, and laboratory control samples.

2.5.2 The sample data package is divided into five units as follows:

2.5.2.1 Cover page.

2.5.2.1.1 This document shall be clearly labeled "Cover Page." The Cover Page shall contain: laboratory name; laboratory code; contract number; case number; SDG number; SAS number; EPA sample numbers in alphanumeric order, showing EPA sample number cross-referenced with laboratory ID numbers; and comments, describing in detail any problems encountered in processing the samples in the data package.

2.5.2.1.2 The Cover Page shall contain the following statement, verbatim:

"I certify that this data package is in compliance with the terms and conditions of the contract, both technically and for completeness, for other than the conditions detailed above. Release of the data contained in this hardcopy data package has been authorized by the Laboratory Manager or the Manager's designee, as verified by the following signature."

2.5.2.1.3 This statement shall be directly followed by the signature of the Laboratory Manager or his designee with a typed line below it containing the signer's name and title, and the date of signature.

2.5.2.1.4 In the event that the Laboratory Manager cannot validate

all data reported for each sample, he/she must provide a detailed description of the problems associated with the sample(s) on the Cover Page.

2.5.2.2 Sample data (Results).

2.5.2.2.1 Sample data shall be arranged in packets with the Analysis Data Sheet (FORM I-AASV, including FORM I-AASV-TIC), followed by the raw data for semivolatile samples. These sample packets should then be placed in increasing EPA sample number order, considering both letters and numbers.

NOTE: FORM I AASV-TIC is the tabulated list of the highest probable match for up to 10 organic compounds that are not surrogates and internal standards and are not listed in Exhibit C (TCL). It includes the Chemical Abstracts Service (CAS) Registry Number, tentative identification, and estimated concentration.

2.5.2.2.1.1 Reconstructed total ion chromatograms (RIC) for each sample or sample extract.

2.5.2.2.1.2 RICs must be normalized to the largest nonsolvent component, and must contain the following header information:

- EPA sample number;
- Date and time of analysis;
- GC/MS instrument ID; and
- Laboratory file ID.

2.5.2.2.1.3 Internal standards are to be labeled with the names of compounds, either directly out from the peak, or on a printout of retention times if retention times are printed over the peak.

2.5.2.2.1.4 Quantitation Report: The complete data system report must be included in all sample data packages, in addition to the reconstructed ion chromatogram for preliminary identification and/or quantitation using either the automated or manual data system procedures. The complete data system report shall include all of the information listed below:

- EPA sample number;
- Date and time of analysis;

- RT or scan number of identified target compounds;
- Ion used for quantitation with measured area;
- Copy of area table from data system;
- GC/MS instrument ID; and
- Laboratory file ID.

2.5.2.2.1.5 In all instances where the data system report has been edited, or where manual integration or quantitation has been performed, the GC/MS operator shall identify such edits or manual procedures by initialing and dating the changes made to the report.

2.5.2.2.1.6 Target Compound Mass Spectra: For each sample, by each compound identified, copies of the raw spectra and copies of background subtracted mass spectra of target compounds listed in Exhibit C that are identified in the sample and corresponding background subtracted target compound standard mass spectra shall be included in the data package. Spectra must be labeled with EPA sample number, laboratory file ID, date and time of analysis, and GC/MS instrument ID; compound names must be clearly marked on all spectra.

2.5.2.2.1.7 Tentatively Identified Compound Mass Spectra and Library Matches: For each sample, by each compound identified, copies of mass spectra of organic compounds not listed in Exhibit C, Tentatively Identified Compounds, with associated best-match spectra (three best matches), labeled as above shall be included in the data package.

2.5.2.2.2 Semivolatile Standard Data:

2.5.2.2.2.1 Initial Calibration: All initial calibration data must be included for all analyses associated with the SDG. When more than one initial calibration is performed, the reconstructed ion chromatograms and quantitation reports and each type of form must be put in chronological order, by instrument as follows:

- Initial Calibration Data Sheet (FORM V-AASV);
- Internal Standard Area and Retention Time Summary (FORM VII-AASV); and
- Semivolatile standard(s) reconstructed ion chromatograms

and quantitation reports (or legible facsimiles) for the initial (five point) calibration are labeled according to 2.5.2.2.1.2 and 2.5.2.2.1.4. Spectra are not required.

2.5.2.2.2.2 Continuing Calibration: When more than one continuing calibration is performed, the reconstructed ion chromatograms and quantitation reports and each type of form must be put in chronological order, by instrument if more than one instrument is used as follows:

- Continuing Calibration Data Sheet (FORM VI-AASV);
- Internal Standard Area and Retention Time Summary (FORM VII-AASV); and
- Semivolatile standard(s) reconstructed ion chromatograms and quantitation reports (or legible facsimiles) for the initial (five point) calibration are labeled according to 2.5.2.2.1.2 and 2.5.2.2.1.4. Spectra are not required.

2.5.2.3 Quality control summary.

2.5.2.3.1 The quality control summary shall contain the following forms:

NOTE: If more than one form is necessary, duplicate forms must be arranged in chronological order by date of analysis or instrument.

- Blank Summary (FORM II-AASV);
- GC/MS Instrument Performance Check (FORM IV-AASV); and
- Internal Standard Area and RT Summary (FORM VII-AASV).

2.5.2.3.2 The quality control summary shall also contain the following:

NOTE: If more than one form is necessary, duplicate forms must be arranged in chronological order by date of analysis or instrument.

- GC/MS Tuning Data
  - GC/MS Tuning - BFB data, for each 12-hour period, shall be arranged in chronological order by instrument for each GC/MS system utilized;
  - GC/MS Tuning and Mass Calibration - BFB (FORM IV-AASV);

- Bar graph spectrum, labeled as in 2.5.2.2.1.2 and 2.5.2.2.1.4; and

- Mass listing, labeled as in 2.5.2.2.1.2. and 2.5.2.2.1.4.

• Blank data shall be arranged in chronological order by instrument. The blank data shall be arranged in packets with both of the Semivolatile Organics Analysis Data Sheets (FORM I-AASV and FORM I-AASV-TIC), followed by the raw data for semivolatile samples.

• Laboratory Control Sample Data

- Laboratory Control Sample Data Sheet (FORM III-AASV); and

- Reconstructed ion chromatograms and quantitation reports or legible facsimile (GC/MS), labeled according to 2.5.2.2.1.2 and 2.5.2.2.1.4. Spectra are <u>not</u> required.

2.5.2.4 Raw data.

2.5.2.4.1 For each reported value, the Contractor shall include all raw data from the instrument used to obtain the sample values (except for raw data for quarterly verifications of instrument parameters). Raw data shall contain all instrument readouts used for the sample results, including those readouts that may fall below the method quantitation limit. All GC/MS instruments must provide legible hard copy of the direct real-time instrument readout (i.e., stripcharts, printer tapes, etc.). A photocopy of the direct sequential instrument readout must be included.

2.5.2.4.2 All raw data shall include concentration units for GC/MS.

2.5.2.4.3 Organic raw data must be labeled with EPA sample number and appropriate codes as shown in Table B-1 to identify unequivocally the following:

• Initial and continuing calibration standards;

• Blanks;

• Duplicates;

• Instrument used, any instrument adjustments, data corrections or other apparent anomalies on the measurement record, including all data voided or data not used to obtain reported values and a brief written explanation;

- Data and EPA sample number for GC/MS analyses clearly and sequentially identified on the raw data;
- All calculations for sample data, including percent recovery, coefficient of variation, slope and y-intercept of linear fit; and
- Time and date of each analysis. Instrument run logs can be submitted if they contain this information. If the instrument does not automatically provide time of analysis, these must be manually entered on all raw data for initial and continuing calibration verification and blanks, as well as interference check samples and linear range analysis standards.

2.5.2.5 Preparation logs.

These logs must include the following:

- Date;
- Standard weights and/or volumes;
- Sufficient information to identify unequivocally which QC samples (e.g., laboratory control sample, blank) correspond to each batch prepared; and
- Comments describing any significant sample changes or reactions which occur during preparation.

2.5.2.6 Sample TRs.

A legible copy of the sample TRs and SDG Cover Sheet shall be submitted as described in section 2.3 of this Exhibit for all of the samples in the SDG. The TRs shall be arranged in increasing EPA sample number order, considering both alpha and numeric designations.

2.6 RESULTS OF INTERCOMPARISON/PERFORMANCE EVALUATION SAMPLE ANALYSES

The reporting of analytical results for Intercomparison Study/Preaward Performance Evaluation (PPE) sample analyses includes all requirements specified in section 2.4 for reporting of sample data. The PPE sample shall be carried through the exact same process as an analytical and field samples.

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2.7 COMPLETE CASE FILE PURGE

2.7.1 The Complete SDG File package includes all laboratory records received or generated for a specific Case that have not been previously submitted to EPA as a deliverable. These items shall be submitted to EPA as a deliverable. These items shall be submitted along with their Document Inventory Sheet FORM AADC-2 (see Exhibit E for description of document numbering and inventory procedure). These items include, but are not limited to, sample tags, custody records, sample tracking records, analysts' logbook pages, bench sheets, instrument readout records, computer printouts, raw data summaries, instrument logbook pages (including instrument conditions), correspondence, and the document inventory.

2.7.2 Shipment of the Complete SDG File package by first class mail, overnight courier, priority mail, or equivalent, is acceptable. Custody seals, which are provided by EPA, shall be placed on shipping containers and a document inventory and transmittal letter included. The Contractor is not required to maintain any documents for a sample Case after submission of the Complete SDG File package; however, the Contractor should maintain a copy of the document inventory and transmittal letter.

2.8 GC/MS TAPES

2.8.1 The Contractor must store all raw and processed GC/MS data on magnetic tape, in appropriate instrument manufacturer's format. This tape must include data for samples, blanks, laboratory control samples, initial calibrations, continuing calibrations, and BFB, as well as all laboratory generated spectral libraries and quantitation reports required to generate the data package. The Contractor shall maintain a written reference logbook of tape files to EPA sample number, calibration data, standards, blanks, and laboratory control samples. The logbook should include EPA sample numbers and standard and blank IDs, identified by Case and SDG.

2.8.2 The Contractor is required to retain the GC/MS tapes for 365 days after data submission. During that time, the Contractor shall submit tapes and associated logbook pages within seven days after receipt of a written request from the APO.

2.9 QUALITY ASSURANCE PLAN (QAP)

2.9.1 The Contractor shall prepare a written Quality Assurance Plan (QAP) which describes the procedures that are implemented to achieve the following: maintain data integrity, validity, and useability; ensure that analytical measurement systems are maintained in an acceptable state of stability and reproducibility; detect problems through data assessment and established corrective action procedures which keep the analytical process reliable; and document all aspects of the measurement process in order to

provide data which are technically sound and legally defensible.

2.9.2 The QAP must present, in specific terms, the policies, organization, objectives, functional guidelines, and specific QA/QC activities designed to achieve the data quality requirements in this contract. Where applicable, SOPs pertaining to each parameter shall be included or referenced as part of the QAP. The QAP must be available during on-site laboratory evaluation and upon written request by the APO.

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Table B-1

Codes for Labeling Organic Data

Sample	XXXXX
Duplicate Sample	XXXXXD
Reanalyzed Sample	XXXXXRE
Laboratory Control Sample	SVLCS##
Laboratory Method Blank	SVMBLK##
Field Blank	SVFBLK##
Standards	SVSTD###

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SECTION 3

FORM INSTRUCTIONS GUIDE/DATA REPORTING FORMS

3.1 Form Instructions Guide

3.1.1 This section includes specific instructions for the completion of all required forms for semivolatile organics analysis utilizing PUF/XAD-2. Each of the forms is specific to a given function. These instructions are arranged in the following order:

3.1.1.1 General Information and Header Information

3.1.1.2 Cover Page [COVER PAGE - AASV]

3.1.1.3 Analysis Data Sheet [FORM I - AASV]

3.1.1.4 Tentatively Identified Compounds [FORM I - AASV-TIC]

3.1.1.5 Blank Summary [FORM II - AASV]

3.1.1.6 Laboratory Control Sample Data Sheet [FORM III - AASV]

3.1.1.7 GC/MS Instrument Performance Check and Mass Calibration [FORM IV - AASV]

3.1.1.8 Initial Calibration Data Sheet [FORM V - AASV]

3.1.1.9 Continuing Calibration Data Sheet [FORM VI - AASV]

3.1.1.10 Internal Standard Area and Retention Times Summary [FORM VII - AASV]

3.1.1.11 Filter/Adsorbent Cartridge Certification [FORM VIII - AASV]

3.1.1.12 Surrogate Recovery [FORM IX - AASV]

3.1.1.13 Analytical Sequence [FORM X - AASV]

3.1.1.14 Sample Receipt/Log-In Sheet [FORM AADC-1]

3.1.1.15 Complete SDG File (CSF) Document Inventory Sheet [FORM AADC-2]

3.1.2 General Information and Header Information

3.1.2.1 Values must be reported on the hardcopy forms according to the individual form instructions in this Section. For example,

results for concentrations of semivolatile organic target compounds must be reported to three significant figures if the value is greater than or equal to 10, and to two significant figures for values less than 10.

3.1.2.2 All characters which appear on the data reporting forms presented in the contract must be reproduced by the Contractor when submitting data, and the format of the forms submitted must be identical to that shown in the contract. No information may be added, deleted, or moved from its specified position without prior written approval of the EPA APO. The names of the various fields and compounds (i.e., "Lab Code," "Pentachlorophenol") must appear as they do on the forms in the contract.

3.1.2.3 Alphabetic entries made onto the forms by the Contractor shall be in ALL UPPERCASE letters (i.e., "LOW", not "Low" or "low").

3.1.2.4 Six (6) pieces of information are common to the header sections of each data reporting form. They are Lab Name, Lab Code, Contract No., Case No., SDG No., and SAS No. These pieces of information must be entered on every form and must match on every form.

3.1.2.4.1 The "Lab Name" shall be the name chosen by the Contractor to identify the laboratory. It may not exceed 25 characters.

3.1.2.4.2 The "Lab Code" is an alphabetical abbreviation of up to 6 letters, assigned by the EPA, to identify the laboratory and aid in data processing. This code shall be assigned by the EPA at the time a contract is awarded, and shall not be modified by the Contractor, except at the direction of the EPA. If a change of name or ownership occurs at the laboratory, the Lab Code will remain the same until the contractor is directed by the EPA to use another Lab Code assigned by the EPA.

3.1.2.4.3 The "Contract No." is the number of the EPA contract under which the analyses were performed. In the case of multiple laboratories operating under a corporate-wide contract, the contract number entered shall be that of the corporate contract, regardless of the facility performing the analyses (see Lab Code).

3.1.2.4.4 The "Case No." is the EPA-assigned case number associated with the sample, and reported on the Traffic Report.

3.1.2.4.5 The "SDG No." is the Sample Delivery Group (SDG) number. The SDG No. is the EPA Sample Number of the first sample received in the SDG. When several samples are received together in the first SDG shipment, the SDG number shall be the lowest

sample number (considering both alpha and numeric designations) in the first group of samples received under the SDG.

3.1.2.4.6 The "SAS No." is the EPA-assigned number for analyses performed under Special Analytical Services (SAS). If samples are to be analyzed under SAS only and reported on these forms, then enter SAS No. and leave Case No. blank. If samples are analyzed according to the "Routine Analytical Services" (IFB) protocols and have additional SAS requirements, list both Case No. and SAS No. on all forms. If the analyses have no SAS requirements, leave "SAS No." blank. Note that some samples in an SDG may have a SAS No. while others do not.

3.1.2.5 The "EPA Sample No." is the other information common to most of the forms. This number appears either in the upper right corner of the form, or as the left column of a table summarizing data from a number of samples. When the "EPA Sample No." is entered into the triple-spaced box in the upper right corner, it should be entered on the middle line of the three lines that comprise the box.

3.1.2.5.1 All samples, blanks, and standards shall be identified with an EPA Sample Number. For field samples, the EPA Sample Number is the unique identifying number given in the Traffic Report that accompanied that sample.

3.1.2.5.2 In order to facilitate data assessment, the following sample suffixes must be used:

XXXXX	=	EPA sample number
XXXXXD	=	Duplicate sample
XXXXXRE	=	Reanalyzed sample

3.1.2.5.3 Semivolatile standards prepared on PUF/XAD-2 cartridges shall be identified as SVSTD###, where ### is the concentration in ng (on column) of the semivolatile standards (e.g., 010, 025, 050, 100, and 200).

3.1.2.5.4 As for the blank identifiers, these designations will have to be combined with other information to uniquely identify each standard. Field blanks shall be identified as SVFBLK## and laboratory method blanks shall be identified as SVMBLK##. The "EPA Sample No." must be unique for each blank analysis within an SDG. The laboratory must achieve this by replacing the two-character "##" terminator of the identifier with one or two characters or numbers, or a combination of both. For example, possible identifiers for semivolatiles-PUF/XAD-2 blanks would be SVMBLK01, SVMBLK02, etc.

3.1.2.5.5 LCSs shall be identified as SVLCS##. The "EPA Sample No." must be unique for each LCS analysis within an SDG. The laboratory must achieve this by replacing the two-character "##" terminator of the identifier with one or two characters or numbers, or a combination of both. For example, possible identifiers for semivolatiles-PUF/XAD-2 cartridge LCSs would be SVLCS01, SVLCS02, etc.

3.1.2.6 Several other pieces of information are common to many of the Data Reporting Forms. These include Lab Sample ID, Lab File ID, Date Received, etc. Following is a brief description of each of these entries.

3.1.2.6.1 "Lab Sample ID" is an optional laboratory-generated internal identifier. Up to 12 alpha-numeric characters may be reported here. If the contractor does not have a Lab Sample ID, this field may be left blank.

3.1.2.6.2 "Lab File ID" is the laboratory-generated name of the GC/MS data system file containing information pertaining to a particular analysis. Up to 14 alpha-numeric characters may be used here.

3.1.2.6.3 "Date Received" is the date of sample receipt at the laboratory, as noted on the Traffic Report (i.e., the VTSR). It should be entered as MM/DD/YY.

3.1.2.6.4 "Date Extracted" is the date the sample was extracted by the laboratory. It should be entered as MM/DD/YY.

3.1.2.6.5 "Date Analyzed" should be entered in a similar fashion. The date of sample receipt will be compared with the analysis dates to ensure that contract holding times were not exceeded.

3.1.2.6.6 "Instrument ID" is common to many of the forms, particularly those containing calibration data. The identifier used by the laboratory must include some indication of the manufacturer and/or model of the instrument, and contain additional characters that differentiate between all instrument of the same type in the laboratory.

3.1.2.6.7 "GC Column ID" or "Column ID" is common to various other forms. This field is used to identify the GC column.

3.1.2.7 For rounding off numbers to the appropriate level of precision, observe the following common rules. If the figure following those to be retained is less than 5, drop it (round down). If the figure is greater than 5, drop it and increase the last digit

to be retained by 1 (round up). If the figure following the last digit to be retained equals 5, round up if the digit to be retained is odd, and round down if that digit is even.

3.1.2.8 All results must be transcribed to the forms in the raw data with the specified number of decimal places that are described in Exhibit B. The raw data result is to be rounded only when the number of figures in the raw data result exceeds the maximum number of figures specified for that result entry for that form. If there are not enough figures in the raw data result to enter in the specified space for that result, then zeros must be used for decimal places to the specified number of reporting decimals for that result for a specific form. The following examples are provided:

Raw Data Result	Specified Format	Correct Entry
5.9	6.3	5.900
5.99653	6.3	5.997
95.99653	6.3	95.997
995.99653	6.3	995.997
9995.996	6.3	9996.00
99995.9	6.3	99995.9
999995.9	6.3	invalid

NOTE: 6.3 stands for a maximum of six significant figures and up to three decimal places.

3.1.3 Cover Page [COVER PAGE - AASV]

3.1.3.1 This form is used to list all billable samples analyzed within an SDG, and to provide certain analytical information and general comments. It is also the document which is signed by the Laboratory Manager to authorize and release all data and deliverables associated with the SDG.

3.1.3.2 Under the "EPA Sample No." column, enter up to 7 characters for the EPA sample number (including blanks and duplicates) for each required analysis within the SDG. Duplicates must contain a "D" suffix. These sample numbers must be listed on the form in ascending alphanumeric order using the Extended Binary Coded Decimal Interchange Code convention. Thus, if MAB123A is the lowest (considering both alpha and numeric characters) EPA Sample No. within the SDG, it would be entered in the first EPA Sample No. field. Samples listed below it would be in ascending sequence - MAB124A, MAB124B, MAB125A, MAC111A, MA1111A, MA1111AD, etc.

3.1.3.3 All EPA sample numbers must be listed in ascending alphanumeric order, continuing to the following Cover Page if applicable.

3.1.3.4 Under "Lab Sample ID", a Lab Sample ID (up to 10 characters) may be entered for each associated EPA Sample No. If a Lab Sample ID is entered, it must be entered identically (for each EPA Sample No.) on all associated data.

3.1.3.5 Under "Comments", enter any problems encountered, both technical and administrative, the corrective action taken, and resolution performed for all of the samples in the SDG.

3.1.3.6 Each Cover Page must be signed, in original, by the Laboratory Manager or the Manager's designee, and dated to authorize the release and verify the contents of all data and deliverables associated with an SDG.

3.1.4 **Analysis Data Sheet [FORM I - AASV]**

3.1.4.1 This form is used for tabulating and reporting results for analysis of samples on PUF/XAD-2 cartridges for the compounds in a Target Compound List for Semivolatiles as given in Exhibit C.

3.1.4.2 This form is used for reporting the detected concentrations of the target compounds in the field samples, blanks, laboratory control samples, and performance evaluation samples.

3.1.4.3 Complete the header information on each page of Form I-AASV according to the instructions in section 3.1.2.

3.1.4.4 For "Lab Sample ID", enter the lab sample ID for the sample, as listed on the Cover Page. Enter the "Lab File ID", if applicable.

3.1.4.5 For "Cleanup Procedure", enter the cleanup procedure used (Lobar or 610). If no cleanup procedure was used, enter "NONE".

3.1.4.6 For "Date Received," enter the date (formatted month/day/year) the sample was received at the laboratory, as recorded on the Traffic Report (TR) [i.e., the Validated Time of Sample Receipt (VTSR)].

3.1.4.7 For "Date Extracted," enter the date (formatted month/day/year) the sample cartridge was extracted.

3.1.4.8 For "Date Analyzed," enter the date (formatted month/day/year) the sample extract was analyzed.

3.1.4.9 Enter "Instrument ID", "GC Column ID", and "Injection Volume (μL)".

3.1.4.10 Enter the dilution factor. If no dilution was performed, enter "1".

3.1.4.11 Enter the "Air Sample Volume" corrected to standard temperature and pressure (STP) in cubic meter (m^3). If the volume of ambient air sampled is not known, enter "NA".

3.1.4.12 Under the column labeled "Concentration", if the analytical result is greater than or equal to the Contract Required Quantitation Limit (CRQL), report the result. If the result is lower than the CRQL, report the value followed with a "J" under the "Q" column (see section 3.1.15). For example, if the CRQL of an analyte is 5 ng and the detected level is 3 ng, then enter "3" under the "ng" column and "J" under "Q". In this analysis, the CRQL is expressed in "ng" on-column injected and "ng/m^3". Both columns must be filled if the volume of ambient air sampled is known to the laboratory. If the volume of ambient air sampled is not known to the laboratory, then only the levels in ng injected is reported.

3.1.4.13 Analytical results must be reported to two significant figures if the result value is less than 10. Values greater than or equal to 10 shall be reported to three significant figures.

3.1.4.14 The requirement for reporting results to two or three significant figures applies to FORM I-AASV only. Follow the specific instructions for reporting all other results on required forms as described in this Exhibit.

3.1.4.15 For reporting results to the Agency, the following contract specific qualifiers are to be used. The seven qualifiers defined below are not subject to modification by the laboratory. Up to five qualifiers may be reported on Form I-AASV for each compound. The seven EPA-defined qualifiers to be used are as follows:

U - Indicates compound was analyzed for but not detected. The sample quantitation limit must be corrected for dilution.

J - Indicates an estimated value. This flag is used either when estimating a concentration for tentatively identified compounds where a 1:1 response is assumed, or when the mass spectral data indicate the presence of a compound that meets the identification criteria but the result is less than the sample quantitation limit but greater than zero. For example, if the sample quantitation limit is 20 ng, but a concentration of 10 ng is calculated, report it as "10J". The sample quantitation limit must be adjusted for dilution.

N - Indicates presumptive evidence of a compound. This flag is only used for tentatively identified compounds, where the identification is based on a mass spectral library search. It is applied to all TIC results.

B - This flag is used when the analyte is found in the associated blank as well as in the sample. It indicates possible/probable blank contamination and warns the data user to take appropriate action. This flag must be used for a TIC as well as for a positively identified target compound.

E - This flag identifies compounds whose concentrations exceed the initial calibration range of the instrument for that specific analysis. If one or more compounds have a response that exceed the initial calibration range, the sample or extract must be diluted and reanalyzed according to the specifications in Exhibit D. All such compounds should have the concentration flagged with an "E" on the Form I for the original analysis. The dilution of the sample may cause some compounds identified in the first analysis to be below the calibration range in the second analysis. The results of both analyses shall be reported on separate FORM Is. The FORM I for the diluted sample shall have the "DL" suffix appended to the EPA Sample Number.

X - Other specific flags may be required to properly define the results. If used, they must be fully described, and such description attached to the Sample Data Summary Package and the SDG Narrative. Begin by using "X". If more than one flag is required, use "Y" and "Z" as needed. If more than five qualifiers are required for a sample result, use the "X" flag to combine several flags, as needed. For instance, the "X" flag might combine the "B", and "D" flags for some sample. The laboratory-defined flags are limited to the letters "X", "Y", and "Z".

NOTE: The combination of flags "BU" or "UB" is expressly prohibited. Blank contaminants are flagged "B" only when they are detected in the sample.

3.1.5 Tentatively Identified Compounds [FORM I - AASV-TIC]

3.1.5.1 FORM I-AASV-TIC is used for reporting the identification and estimated concentration for up to 10 of the non-surrogate, non-internal standard, and non-target compounds.

3.1.5.2 Include a FORM I-AASV-TIC for every sample, performance evaluation sample, and blank analyzed. FORM I-AASV-TIC must be provided for every analysis that requires a FORM I-AASV for target compounds, including required dilutions and reanalyses, even if no TICs are found.

3.1.5.3 Complete the header information according to the header instructions in section 3.1.2.

3.1.5.4 Total the number of TICs found, and enter this number in the "No. of TICs Found". If no TICs were found, enter "0" (zero).

3.1.5.5 Report tentatively identified compounds (TICs) including "CAS RN", "Compound Name", "RT" (retention time), and the estimated concentration (criteria for reporting TICs are given in Exhibit D). Retention time must be reported in minutes and decimal minutes, not seconds or minutes and seconds.

3.1.5.6 If in the opinion of the mass spectral interpretation specialist, no valid tentative identification can be made, the compound shall be reported as unknown.

3.1.5.7 Under the column labeled "Q", enter result qualifiers as identified in section 3.1.4. If additional qualifiers are used, their explicit definitions must be included on the Cover Page in the Comments section.

3.1.6 **Blank Summary [FORM II - AASV]**

3.1.6.1 This form summarizes the samples associated with each field and laboratory method blank analysis. A copy of the appropriate Form II-AASV is required for each blank reported on a Form I-AASV.

3.1.6.2 Complete the header information on Form II-AASV as described in section 3.1.2. The "EPA Sample No." entered in the box at the top of Form II-AASV shall be the same number entered on the Form I-AASV when reporting results for the blank itself.

3.1.6.3 On the numbered lines, enter the EPA sample numbers associated with the blank, along with the other information which identifies the EPA samples. The Cartridge ID for each sample must be provided under the "Cartridge" column, if available.

3.1.7 **Laboratory Control Sample Data Sheet [FORM III - AASV]**

3.1.7.1 Form III-AASV is used to report the recovery of the spiked analytes in the laboratory control samples (LCS).

3.1.7.2 Complete the header information according to the instructions in section 3.1.2.

3.1.7.3 Enter the date and time the LCS was analyzed.

3.1.7.4 In the table under "Spiked," enter the spiked concentration in ng (per injection) of each LCS compound. Under "Reported," enter the concentration obtained in ng (per injection) calculated from the analysis of the LCS. Calculate the percent recovery of each LCS compound to the nearest whole percent and enter in the column under

"% Recovery". At the bottom of the table are the QC limits for LCS percent recoveries. Flag all values outside of the limits with an "*" in the column under the "Q" symbol.

3.1.7.5 Summarize the values outside the QC limits at the lower part of the form.

3.1.8 GC/MS Instrument Performance Check and Mass Calibration [FORM IV - AASV]

3.1.8.1 This form is used to report the results of GC/MS instrument performance check (also known as "tuning") and to summarize the date and time of analysis of samples, standards, and blanks associated with each analysis of the instrument performance check solution.

3.1.8.2 Complete the header information as in section 3.1.2. Enter the "Lab File ID" for the injection containing the instrument performance check mixture. Enter the date and time (military time) of injection of the instrument performance check mixture.

3.1.8.3 For each ion listed on the form, enter the percent relative abundance in the right column. Report relative abundances to the number of significant figures given for each ion in the ion abundance criteria column.

3.1.8.4 Under "to m/e 198", all ion abundances are to be normalized to the nominal base peak listed on Form IV-AASV. For some of the ions, determine the percentage of the ion abundance to the specified mass and report under "to specified mass". For example, if the relative ion abundance of mass 443 and mass 442 ions under the "to m/e 198" column are 10 and 50 , respectively, then enter "20" (under the "to specified mass" column) as the ion abundance of mass 443 relative to mass 442.

3.1.8.5 All relative abundances must be reported as a number. If zero, enter "0", not a dash or other non-numeric character.

3.1.8.6 In the lower half of the form, list all samples and standards analyzed under that instrument performance check in <u>chronological order</u>, by time of analysis (in military time). Refer to section 3.1.2 for specific instructions for identifying standards and blanks. Enter "EPA Sample No.", "Lab Sample ID", "Lab File ID", "Date Analyzed", and "Time Analyzed" for all standards, samples, and blanks.

3.1.8.7 The GC/MS instrument performance check must be analyzed again 12 hours from the time of injection of the instrument performance check solution listed at the top of the form. In order to meet these requirements, samples, standards, or blanks must be injected within 12 hours of the injection of the instrument performance check solution.

3.1.9 **Initial Calibration Data Sheet [FORM V - AASV]**

3.1.9.1 Each time the GC/MS system undergoes a five-point calibration to initialize subsequent quantitation of semivolatiles in sample and blank analysis, the laboratory must complete and submit a Form V-AASV.

3.1.9.2 Complete all header information as in section 3.1.2.

3.1.9.3 Enter the "Case No." and "SDG No." for the current data package, regardless of the original Case for which the initial calibration was performed. Enter "Instrument ID", "GC Column ID", and "Injection Volume" in microliters.

3.1.9.4 Enter the "EPA Sample No." and "Lab File ID" for each of the five calibration standards.

3.1.9.5 Enter the injection dates and times of each of the calibration standards analyzed under "Date injected" and "Time injected", respectively.

3.1.9.6 Complete the relative response factor (RRF) calculation for the five calibration points, and then calculate and report the average relative response factor ($\overline{RRF}$) and %RSD of the RRF values for each target and surrogate compound in the space provided.

3.1.9.7 At the bottom of the last Form V-AASV, enter the EPA Sample number, Lab Sample ID, and date and time of analysis of the samples and blanks associated with the initial calibration.

3.1.10 **Continuing Calibration Data Sheet [FORM VI - AASV]**

3.1.10.1 Each time the GC/MS system undergoes a continuing calibration to check for the validity of the initial calibration, the laboratory must complete and submit a Form VI-AASV.

3.1.10.2 Complete all header information as in section 3.1.2. Enter the "Case No." and "SDG No." for the current data package, regardless of the original Case for which the initial calibration was performed. Enter "Instrument ID", "GC Column ID", and the date(s) of the most recent initial calibration. If the calendar date changes during the calibration procedure, the inclusive dates should be given on Form VI-AASV.

3.1.10.3 Enter the date and time of injection of the continuing calibration standard.

3.1.10.4 Under the column "IC mean RRF", enter the mean relative response factor for each target compound as determined in the most recent valid initial calibration.

3.1.10.5 Complete the relative response factor (RRF) calculation for each target compound in the space provided.

3.1.10.6 Calculate the percent difference (%D) between the continuing calibration RRF and the mean RRF from the most recent valid initial calibration for each target and surrogate compound and enter the values obtained under the "%D" column.

3.1.10.7 At the last Form VI-AASV, enter the EPA Sample number, Lab Sample ID, and date and time of analysis of the samples and blanks associated with the continuing calibration.

3.1.11 **Internal Standard Area and Retention Time Summary [FORM VII - AASV]**

3.1.11.1 This form is used to summarize the peak areas and retention times of the internal standards added to all samples and blanks. The data are used to determine when changes in internal standard responses will adversely affect quantification of target compounds. This form must be completed each time an initial or continuing calibration is performed for each GC/MS system.

3.1.11.2 Complete the header information according to section 3.1.2.

3.1.11.3 Enter the Lab File ID of the 12-hour calibration standard, as well as the date and time of analysis of the calibration standard. If samples are analyzed immediately following an initial calibration, before another instrument performance check and a continuing calibration, a Form VII-AASV shall be completed on the basis of the internal standard areas of the mid level (CAL 3) initial calibration sequence standard. Use the date and time of analysis of this standard, and its Lab File ID and areas in place of those of a continuing calibration standard.

3.1.11.4 From the results of the analysis of the 12-hour calibration standard, enter the area measured for each internal standard and its retention time (in decimal minutes) under the appropriate column. For each internal standard, calculate the upper limit of the area as the area of the particular standard plus 40 percent of its area (i.e., 1.4 times the area in the 12 HOUR STD box), and the lower limit of the area as the area of the internal standard minus 40% of its area (i.e., 0.6 times the area in the 12 HOUR STD box). Report these values in the boxes labeled "UPPER LIMIT" and "LOWER LIMIT", respectively.

3.1.11.5 Calculate the upper limit of the retention time as the retention of the internal standard plus 0.33 minutes (20 seconds), and the lower limit of the retention time as the retention time in the standard minus 0.33 minutes (20 seconds).

3.1.11.6 For each sample and blank under a given 12-hour analytical sequence, enter the EPA Sample Number and the area measured for each internal standard and its retention time. If the internal standard area is outside the upper or lower limits calculated above, flag that area with an asterisk (*) placed in the far right-hand space of the box for each internal standard area, directly under the "#" symbol. Similarly, flag the retention time of any internal standard that is outside the limits with an asterisk.

3.1.12 Filter/Adsorbent Cartridge Certification [FORM VIII - AASV]

3.1.12.1 This form is used to document the certification of PUF/XAD-2 cartridges prior to use.

3.1.12.2 Complete the header information on each page of Form VIII-AASV according to the instructions in section 3.1.2.

3.1.12.3 Enter "Filter Batch No.", "PUF Batch No.", and "XAD-2 Batch No.", where applicable.

3.1.12.4 Enter the results of the analysis of an unspiked certified clean cartridge. For target compounds that are not detected, enter the CRQL of the compound followed by a "U". If the detected level is less than the CRQL, enter the value followed by a "J".

3.1.12.5 If none of the values for a particular cartridge are more than the corresponding CRQL of any of the target compounds, and if the total level of semivolatiles is not greater than 10 μg/cartridge, then the cartridge is certified.

3.1.13 Surrogate Recovery [FORM IX - AASV]

3.1.13.1 Form IX - AASV is used to report the recoveries of the surrogate compounds added to each PUF/XAD-2 adsorbent cartridge.

3.1.13.2 Complete the header information and enter EPA Sample Numbers as described in section 3.2.1. For each surrogate, report the percent recovery to the nearest whole percentage point, and to the number of significant figures given by the QC limits at the bottom of the form.

3.1.13.3 Flag each surrogate recovery outside the QC limits with an asterisk (*). The asterisk must be placed in the last space in each appropriate column, under the "#" symbol. In the far right-hand column, total the number of surrogate recoveries outside the QC limits for each sample (Total Out). If no surrogates were outside the limits, enter "0".

3.1.14 Analytical Sequence [FORM X - AASV]

3.1.14.1 A Form X-AASV is required for each analytical sequence for each GC/MS system used to perform semivolatile analysis on PUF/XAD-2 cartridge samples in an SDG.

3.1.14.2 Complete the header information on each page of Form X-AASV according to the instructions in section 3.1.2.

3.1.14.3 On the numbered lines, enter the EPA sample numbers along with the other information which identifies the samples, blanks, and standards. The first item in the table must be the DFTPP since the 12-hour time period starts at the injection of the instrument performance check standard. Arrange the items in chronological order for each GC/MS system.

3.1.15 Sample Receipt/Log-In Sheet [FORM AADC-1]

3.1.15.1 This form is used to document the receipt and inspection of sample containers and samples. One original of Form AADC-1 is required for each sample shipping container. If the samples in a single sample shipping container must be assigned to more than one Sample Delivery Group, the original Form AADC-1 shall be placed with the deliverables for the Sample Delivery Group of the lowest Arabic number and a copy of Form AADC-1 must be placed with the deliverables for the other Sample Delivery Group(s). The copies should be identified as "copy(ies)," and the location of the original should be noted on the copies.

3.1.15.2 Sign and date the airbill (if present). Examine the shipping container and record the presence/absence of custody seals and their condition (i.e., intact, broken) in item 1 on Form AADC-1. Record the custody seal numbers in item 2.

3.1.15.3 Open the container, remove the enclosed sample documentation, and record the presence/absence of chain-of-custody record(s), SMO forms (i.e., Traffic Reports, Packing Lists), and airbills or airbill stickers in items 3-5 on Form AADC-1. Specify if there is an airbill present or an airbill sticker in item 5 on Form AADC-1. Record the airbill or sticker number, if present.

3.1.15.4 Remove the samples from the shipping container(s), examine the samples and the sample tags (if present), and record the condition of the sample (i.e., intact, dent, leaking) and presence of absence of sample tags in items 6 and 7 on Form AADC-1.

3.1.15.5 Review the sample shipping documents and complete the header information described in section 3.1.2. Compare the information recorded on all the documents and samples and circle the appropriate

answer in item 8 on Form AADC-1.

3.1.15.6 If there are no problems observed during receipt, sign and date (include time) Form AADC-1, the chain-of-custody record, and Traffic Report, and write the sample numbers on Form AADC-1. Record the appropriate sample tags and assigned laboratory numbers, if applicable. The log-in date should be recorded at the top of Form AADC-1 and the date and time of sample receipt at the laboratory should be recorded in items 9 and 10. Record the specific area designation (e.g., refrigerator number) in the Sample Transfer block located in the bottom left corner of Form AADC-1. Sign and date the Sample Transfer block. Cross out unused columns and spaces.

3.1.15.7 If there are problems observed during receipt or if an answer marked with an asterisk (i.e., "absent*") was circled, contact SMO and document the contact as well as resolution of the problem on a CLP Communication Log. Following resolution, sign and date the forms as specified in the preceding paragraph and note, where appropriate, the resolution of the problem.

3.1.16 Complete SDG File (CSF) Document Inventory Sheet [FORM AADC-2]

3.1.16.1 This form is used to record the inventory of the SDG File Purge documents and count of documents in the original Sample Data Package which is sent to the Region.

3.1.16.2 Organize all EPA-CSF documents as described in Exhibit B, Section 1. Assemble the documents in the order specified on Form AADC-2, and stamp each page with a consecutive number. (Do not number the AADC-2 form). Inventory the CSF by reviewing the document numbers and recording page numbers ranges in the columns provided in the Form AADC-2. If there are no documents for a specific document type, enter an "NA" in the empty space.

3.1.16.3 Certain laboratory specific documents related to the CSF may not fit into a clearly defined category. The laboratory should review AADC-2 to determine if it is most appropriate to place them under No. 16, 17, 18, or 19. Category 19 should be used if there is no appropriate previous category. These types of documents should be described or listed in the blanks under each appropriate category.

3.2 Data Reporting Forms

3.2.1 Cover Page [COVER PAGE - AASV]

3.2.2 Analysis Data Sheet [FORM I - AASV]

3.2.3 Tentatively Identified Compounds [FORM I - AASV-TIC]

3.2.4 Blank Summary [FORM II - AASV]

3.2.5 Laboratory Control Sample Data Sheet [FORM III - AASV]

3.2.6 GC/MS Instrument Performance Check and Mass Calibration [FORM IV - AASV]

3.2.7 Initial Calibration Data Sheet [FORM V - AASV]

3.2.8 Continuing Calibration Data Sheet [FORM VI - AASV]

3.2.9 Internal Standard Area and Retention Times Summary [FORM VII - AASV]

3.2.10 Filter/Adsorbent Cartridge Certification [FORM VIII - AASV]

3.2.11 Surrogate Recovery [FORM IX - AASV]

3.2.12 Analytical Sequence [FORM X - AASV]

3.2.13 Sample Receipt/Log-In Sheet [FORM AADC-1]

3.2.14 Complete SDG File (CSF) Document Inventory Sheet [FORM AADC-2]

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ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

COVER PAGE

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SDG No.:_____ SAS No.:_____

	EPA Sample No.	Lab Sample ID
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

Comments: _____

I certify that this data package is in compliance with the terms and conditions of the contract, both technically and for completeness, for other than the conditions detailed above. Release of the data contained in this hardcopy data package and in the computer-readable data on floppy diskette has been authorized by the Laboratory Manager's Designee, as verified by the following signature:

Signature: _____ Name: _____
Date: _____ Title: _____

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

SAMPLE RECEIPT/LOG-IN SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SDG No.:_____ SAS No.:_____

ITEM	REMARKS	EPA Sample No.	Sample Tag No.	Assigned Lab No.	Sample Volume	REMARKS: Conditions of Sample Shipment,etc.
1. Custody Seal(s)	Present/Absent/Intact/Broken*					
2. Custody Seal No(s).						
3. Chain-of-Custody records	Present/Absent*					
4. Traffic Reports or	Present/Absent*					
Packing List						
5. Airbill	Sticker/Present/Absent*					
Airbill No(s).						
6. Sample Tags	Present/Absent*					
Sample Tag No(s):	Listed/Not Listed on COC					
7. Sample Condition	Intact/Broken/Leaking*					
8. Do informations on custody						
records, traffic reports, and						
sample tags agree?	Yes/No*					
9. Date Received at Lab:						
10. Time Received at Lab:						
Sample Transfer						
Area #:						
By:						
On:						

* Contact SMO and attach record of resolution.

Received by:
Signature:_____ Log-in Date:_____
Print Name:_____

Reviewed by:
Signature:_____ Date:_____
Logbook No.:_____ Logbook Page No.:_____

FORM AADC-1

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

COMPLETE SDG FILE (CSF) DOCUMENT INVENTORY SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SDG No.:_____ SAS No.:_____

DOCUMENT	Page Nos. From	Page Nos. To	Please Check Lab	Please Check Reg
1. Cover Sheet (Cover Page – AASV)				
2. Sample Receipt/Log–In Form (FORM AADC–1)				
3. CSF Document Inventory Sheet (FORM AADC–2)				
4. Analysis Data Sheet (FORM I – AASV)				
5. Tentatively Identified Compounds (FORM I – AASV–TIC)				
6. Blank Summary (FORM II – AASV)				
7. Laboratory Control Sample Data Sheet (FORM III – AASV)				
8. GC/MS Tuning with DFTPP (FORM IV –AASV)				
9. Initial Calibration Data Sheet (FORM V – AASV)				
10. Continuing Calibration Data Sheet (FORM VI – AASV)				
11. Internal Standard Area and RT Summary (FORM VII – AASV)				
12. Filter/Cartridge Certification Data Sheet (FORM VIII – AASV)				
13. Analytical Sequence (FORM IX –AASV)				
14. Percent Surrogate Recovery (FORM X – AASV)				
15. EPA Shipping/Receiving Documents				
Airbill (No. of shipments: ___)				
Chain–of–Custody Records				
Sample Tags				
Sample Log–In Sheet (Lab & AADC–1)				
16. Misc. Shipping/Receiving Records (list individual records)				
Telephone Logs				
17. Internal Lab Sample Transfer Records				
18. Internal Original Sample Preparation and Analysis Records				
19. Other Records (describe or list)				

Comments:_____

Completed by (CLP Lab):
Signature:_____ Printed Name/Title:_____ Date:_____
Audited by (EPA):
Signature:_____ Printed Name/Title:_____ Date:_____

FORM AADC–2

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

ANALYSIS DATA SHEET

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
Lab Sample ID:_____ Lab File ID:_____
SDG No.:_____ SAS No.:_____
Date Received:_____ Date Extracted:_____ Date Analyzed:_____
Instrument ID:_____ GC Column ID:_____
Cleanup Procedure:_____ Dilution Factor:_____
Air Sample Volume (STP):_____ m^3 Injection Volume (uL):_____

CAS RN	COMPOUND NAME	Concentration ng	Concentration ng/m^3	Q
83-32-9	Acenaphthene			
208-96-8	Acenaphthylene			
98-86-2	Acetophenone			
116-06-3	Aldicarb			
309-00-2	Aldrin			
62-53-3	Aniline			
120-12-7	Anthracene			
22781-23-3	Bendiocarb			
92-87-5	Benzidine			
56-55-3	Benz[a]anthracene			
50-32-8	Benzo[a]pyrene			
205-99-2	Benzo[b]fluoranthene			
192-97-2	Benzo[e]pyrene			
191-24-2	Benzo[g,h,i]perylene			
207-08-9	Benzo[k]fluoranthene			
100-51-6	Benzyl alcohol			
319-84-6	alpha-BHC			
58-89-9	gamma-BHC (Lindane)			
92-67-1	p-Biphenylamine			
84-74-2	Bis(n-butyl)phthalate			

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

ANALYSIS DATA SHEET

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
Lab Sample ID:_____ Lab File ID:_____
SDG No.:_____ SAS No.:_____
Date Received:_____ Date Extracted:_____ Date Analyzed:_____
Instrument ID:_____ GC Column ID:_____
Cleanup Procedure:_____ Dilution Factor:_____
Air Sample Volume (STP):_____ m^3 Injection Volume (uL):_____

CAS RN	COMPOUND NAME	Concentration		Q
		ng	ng/m^3	
85-68-7	Butylbenzylphthalate			
133-06-2	Captan			
5103-71-9	alpha-Chlordane			
5103-74-2	gamma-Chlordane			
59-50-7	4-Chloro-3-methylphenol			
106-47-8	4-Chloroaniline			
111-91-1	Bis(2-chloroethoxy)methane			
111-44-4	Bis(2-chloroethyl)ether			
1897-45-6	Chlorothalonil			
2921-88-2	Chlorpyrifos			
218-01-9	Chrysene			
1861-32-1	Dacthal (DCPA)			
72-54-8	4,4'-DDD			
72-55-9	4,4'-DDE			
50-29-3	4,4'-DDT			
333-41-5	Diazinon			
53-70-3	Dibenz[a,h]anthracene			
62-73-7	Dichlorvos (DDVP)			
115-32-2	Dicofol			
60-57-1	Dieldrin			

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

ANALYSIS DATA SHEET

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
Lab Sample ID:_____ Lab File ID:_____
SDG No.:_____ SAS No.:_____
Date Received:_____ Date Extracted:_____ Date Analyzed:_____
Instrument ID:_____ GC Column ID:_____
Cleanup Procedure:_____ Dilution Factor:_____
Air Sample Volume (STP):_____ m^3 Injection Volume (uL):_____

CAS RN	COMPOUND NAME	Concentration		Q
		ng	ng/m^3	
84-66-2	Diethylphthalate			
105-67-9	2,4-Dimethylphenol			
131-11-3	Dimethylphthalate			
534-52-1	4,6-Dinitro-2-methylphenol			
51-28-5	2,4-Dinitrophenol			
121-14-2	2,4-Dinitrotoluene			
959-98-8	Endosulfan I			
33213-65-9	Endosulfan II			
72-20-8	Endrin			
7421-93-4	Endrin aldehyde			
533-41-5	Endrin ketone			
117-81-7	Bis(2-ethylhexyl)phthalate			
206-44-0	Fluoranthene			
86-73-7	Fluorene			
133-07-3	Folpet			
76-44-8	Heptachlor			
1024-57-3	Heptachlor epoxide			
118-74-1	Hexachlorobenzene			
77-47-4	Hexachlorocyclopentadiene			
67-72-1	Hexachloroethane			

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

ANALYSIS DATA SHEET

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
Lab Sample ID:_____ Lab File ID:_____
SDG No.:_____ SAS No.:_____
Date Received:_____ Date Extracted:_____ Date Analyzed:_____
Instrument ID:_____ GC Column ID:_____
Cleanup Procedure:_____ Dilution Factor:_____
Air Sample Volume (STP):_____ m^3 Injection Volume (uL):_____

CAS RN	COMPOUND NAME	Concentration		Q
		ng	ng/m^3	
193-39-5	Indeno(1,2,3-c,d)pyrene			
78-59-1	Isophorone			
72-43-5	Methoxychlor			
91-57-6	2-Methylnaphthalene			
95-48-7	2-Methylphenol			
106-44-5	4-Methylphenol			
2385-85-5	Mirex			
91-20-3	Naphthalene			
91-59-8	2-Naphthylamine			
88-74-4	2-Nitroaniline			
100-01-6	3-Nitroaniline			
98-95-3	Nitrobenzene			
92-93-3	4-Nitrodiphenyl			
88-75-5	2-Nitrophenol			
100-02-7	4-Nitrophenol			
117-84-0	Bis(n-octyl)phthalate			
27304-13-8	Oxychlordane			
56-38-2	Parathion			
608-93-5	Pentachlorobenzene			
87-86-5	Pentachlorophenol			

ENVIRONMENTAL PROTECTION AGENCY
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Semivolatile Organics in Air

ANALYSIS DATA SHEET

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
Lab Sample ID:_____ Lab File ID:_____
SDG No.:_____ SAS No.:_____
Date Received:_____ Date Extracted:_____ Date Analyzed:_____
Instrument ID:_____ GC Column ID:_____
Cleanup Procedure:_____ Dilution Factor:_____
Air Sample Volume (STP):_____ m^3 Injection Volume (uL):_____

CAS RN	COMPOUND NAME	Concentration		Q
		ng	ng/m^3	
52645-53-1	cis/trans-Permethrin			
85-01-8	Phenanthrene			
108-95-2	Phenol			
90-43-7	o-Phenylphenol			
114-26-1	Propoxur			
129-00-0	Pyrene			
10453-86-8	Resmethrin			
299-84-3	Ronnel			
95-95-4	2,4,5-Trichlorophenol			
88-06-2	2,4,6-Trichlorophenol			
27323-18-8	Monochlorobiphenyls			
25512-42-9	Dichlorobiphenyls			
25323-68-6	Trichlorobiphenyls			
26914-33-0	Tetrachlorobiphenyls			
25429-29-2	Pentachlorobiphenyls			
26601-64-9	Hexachlorobiphenyls			
28655-71-2	Heptachlorobiphenyls			
31472-83-0	Octachlorobiphenyls			
53742-07-7	Nonachlorobiphenyls			
2051-24-3	Decachlorobiphenyls			

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

ANALYSIS DATA SHEET
TENTATIVELY IDENTIFIED COMPOUNDS

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
Lab Sample ID:_____ Lab File ID:_____
SDG No.:_____ SAS No.:_____
Date Received:_____ Date Extracted:_____ Date Analyzed:_____
Instrument ID:_____ GC Column ID:_____
Injection Volume (uL):_____ Dilution Factor:_____
Air Sample Volume (STP):_____ m^3 Cleanup Procedure:_____

	CAS RN	COMPOUND NAME	Concentration ng	Concentration ng/m^3	RT	Q
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

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CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Ambient Air

BLANK SUMMARY

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Lab Sample ID:_____ Date Analyzed:_____ Instrument ID:_____
Lab File ID:_____ Time Analyzed:_____ Column ID:_____

THIS BLANK APPLIES TO THE FOLLOWING SAMPLES:

	EPA Sample No.	Laboratory ID			Analysis	
		Sample	File	Cartridge	Date	Time
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						

Comments:_____

U. S. ENVIRONMENTAL PROTECTION AGENCY
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Semivolatile Organics in Air

LABORATORY CONTROL SAMPLE DATA SHEET

EPA Sample No.

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Lab Sample ID:_____ Date Analyzed:_____ Instrument ID:_____
Lab File ID:_____ Time Analyzed:_____ Column ID:_____

COMPOUND NAME	Concentration (ng) Spiked	Reported	% Recovery	Q
Bis-(2-chloroethyl)ether				
Benzyl alcohol				
Methylphenol				
Hexachloroethane				
Nitrobenzene				
2,4-Dimethylphenol				
Bis(2-chloroethoxy)methane				
2-Methylnaphthalene				
Hexachlorocyclopentadiene				
3-Nitroaniline				
4-Nitrophenol				
Diethylphthalate				
Fluorene				
Bendiocarb				
Pentachlorophenol				
Diazinon				
Fluoranthene				
Folpet				
Endrin				
Butylbenzylphthalate				
Endrin ketone				
Dicofol				
2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl				
Indeno(1,2,3-cd)pyrene				
Dibenz(a,h)anthracene				

%Recovery QC Limits:

LCS Recovery: _____ outside limits out of _____ total.

FORM III - AASV

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

GC/MS INSTRUMENT PERFORMANCE CHECK AND MASS CALIBRATION

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
Lab Sample ID:_____ Lab File ID:_____
Date Injected:_____ Time Injected:_____
Instrument ID:_____ GC Column ID:_____
Injection Volume (uL):_____ Mass DFTPP Injected (ng):_____

m/e	ION ABUNDANCE CRITERIA	% Relative Abundance	
		to m/e 198	to specified mass
51	30–80% of mass 198		
68	Less than 2.0% of mass 69		
69	Present		
70	Less than 2.0% of mass 69		
127	25–75% of mass 198		
197	Less than 1.0% of mass 198		
198	Base peak, 100% relative abundance		
199	5–9% of mass 198		
275	10–30% of mass 198		
365	Greater than 0.75% of mass 198		
441	Present, but less than mass 443		
442	40–110% of mass 198		
443	15–24% of mass 442		

THIS TUNE APPLIES TO THE FOLLOWING:

	EPA Sample No.	Lab Sample ID	Lab File ID	Date Analyzed	Time Analyzed
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

ENVIRONMENTAL PROTECTION AGENCY
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Semivolatile Organics in Air

INITIAL CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
GC Column ID:_____ Instrument ID:_____
Injection Volume (uL):_____

STANDARD	CAL 1	CAL 2	CAL 3	CAL 4	CAL 5
EPA Sample No.					
LAB FILE ID					
MASS INJECTED (ng)					
DATE INJECTED					
TIME INJECTED					

	Relative Response Factor (RRF)					mean	
COMPOUND NAME	CAL 1	CAL 2	CAL 3	CAL 4	CAL 5	RRF	%RSD
Acenaphthene							
Acenaphthylene							
Acetophenone							
Aldicarb							
Aldrin							
Aniline							
Anthracene							
Bendiocarb							
Benzidine							
Benz[a]anthracene							
Benzo[a]pyrene							
Benzo[b]fluoranthene							
Benzo[e]pyrene							
Benzo[g,h,i]perylene							
Benzo[k]fluoranthene							
Benzyl alcohol							
alpha-BHC							
gamma-BHC (Lindane)							
p-Biphenylamine							
Bis(n-butyl)phthalate							
Butylbenzylphthalate							
Captan							
alpha-Chlordane							
gamma-Chlordane							
4-Chloro-3-methylphenol							
4-Chloroaniline							
Bis(2-chloroethoxy)methane							
Bis(2-chloroethyl)ether							
Chlorothalonil							

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

INITIAL CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
GC Column ID:_____ Instrument ID:_____
Injection Volume (uL):_____

COMPOUND NAME	Relative Response Factor (RRF)					mean RRF	%RSD
	CAL 1	CAL 2	CAL 3	CAL 4	CAL 5		
Chlorpyrifos							
Chrysene							
Dacthal (DCPA)							
4,4'-DDD							
4,4'-DDE							
4,4'-DDT							
Diazinon							
Dibenz[a,h]anthracene							
Dichlorvos (DDVP)							
Dicofol							
Dieldrin							
Diethylphthalate							
2,4-Dimethylphenol							
Dimethylphthalate							
4,6-Dinitro-2-methylphenol							
2,4-Dinitrophenol							
2,4-Dinitrotoluene							
Endosulfan I							
Endosulfan II							
Endrin							
Endrin aldehyde							
Endrin ketone							
Bis(2-ethylhexyl)phthalate							
Fluoranthene							
Fluorene							
Folpet							
Heptachlor							
Heptachlor epoxide							
Hexachlorobenzene							
Hexachlorocyclopentadiene							
Hexachloroethane							
Indeno(1,2,3-c,d)pyrene							
Isophorone							
Methoxychlor							

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

INITIAL CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
GC Column ID:_____ Instrument ID:_____
Injection Volume (uL):_____

COMPOUND NAME	Relative Response Factor (RRF) CAL 1	CAL 2	CAL 3	CAL 4	CAL 5	mean RRF	%RSD
Hexachlorocyclopentadiene							
Hexachloroethane							
Indeno(1,2,3-c,d)pyrene							
Isophorone							
Methoxychlor							
2-Methylnaphthalene							
2-Methylphenol							
4-Methylphenol							
Mirex							
Naphthalene							
2-Naphthylamine							
2-Nitroaniline							
3-Nitroaniline							
Nitrobenzene							
4-Nitrodiphenyl							
2-Nitrophenol							
4-Nitrophenol							
Bis(n-octyl)phthalate							
Oxychlordane							
Parathion							
Pentachlorobenzene							
Pentachlorophenol							
cis/trans-Permethrin							
Phenanthrene							
Phenol							
o-Phenylphenol							
Propoxur							
Pyrene							
Resmethrin							
Ronnel							
2,4,5-Trichlorophenol							
2,4,6-Trichlorophenol							

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

INITIAL CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____
GC Column ID:_____ Instrument ID:_____
Injection Volume (uL):_____

	Relative Response Factor (RRF)					mean	
COMPOUND NAME	CAL 1	CAL 2	CAL 3	CAL 4	CAL 5	RRF	%RSD
PCBs							
Monochlorobiphenyls							
Dichlorobiphenyls							
Trichlorobiphenyls							
Tetrachlorobiphenyls							
Pentachlorobiphenyls							
Hexachlorobiphenyls							
Heptachlorobiphenyls							
Octachlorobiphenyls							
Nonachlorobiphenyls							
Decachlorobiphenyls							
SURROGATES							
Nitrobenzene–d_5							
2–Fluorobiphenyl							
p–Terphenyl–d_{14}							
Phenol–d_5							
2–Fluorophenol							
2,4,6–Tribromophenol							
Anthracene–d_{10}							
Benzo(a)pyrene–d_{12}							

THIS INITIAL CALIBRATION APPLIES TO THE FOLLOWING:

EPA Sample No.	Lab Sample ID	Date Analyzed	Time Analyzed

ENVIRONMENTAL PROTECTION AGENCY
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CONTINUING CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SDG No.:_____ SAS No.:_____
EPA Sample No.:_____ Lab File ID:_____
GC Column ID:_____ Instrument ID:_____
Date injected:_____ Time injected:_____
Injection volume (uL):_____ Date of I.C.:_____

COMPOUND NAME	IC mean RRF	CAL 3 RRF	% D
Acenaphthene			
Acenaphthylene			
Acetophenone			
Aldicarb			
Aldrin			
Aniline			
Anthracene			
Bendiocarb			
Benzidine			
Benz[a]anthracene			
Benzo[a]pyrene			
Benzo[b]fluoranthene			
Benzo[e]pyrene			
Benzo[g,h,i]perylene			
Benzo[k]fluoranthene			
Benzyl alcohol			
alpha-BHC			
gamma-BHC (Lindane)			
p-Biphenylamine			
Bis(n-butyl)phthalate			
Butylbenzylphthalate			
Captan			
alpha-Chlordane			
gamma-Chlordane			
4-Chloro-3-methylphenol			
4-Chloroaniline			
Bis(2-chloroethoxy)methane			
Bis(2-chloroethyl)ether			

ENVIRONMENTAL PROTECTION AGENCY
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Semivolatile Organics in Air

CONTINUING CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SDG No.:_____ SAS No.:_____
EPA Sample No.:_____ Lab File ID:_____
GC Column ID:_____ Instrument ID:_____
Date injected:_____ Time injected:_____
Injection volume (uL):_____ Date of I.C.:_____

COMPOUND NAME	IC mean RRF	CAL 3 RRF	% D
Chlorothalonil			
Chlorpyrifos			
Chrysene			
Dacthal (DCPA)			
4,4'-DDD			
4,4'-DDE			
4,4'-DDT			
Diazinon			
Dibenz[a,h]anthracene			
Dichlorvos (DDVP)			
Dicofol			
Dieldrin			
Diethylphthalate			
2,4-Dimethylphenol			
Dimethylphthalate			
4,6-Dinitro-2-methylphenol			
2,4-Dinitrophenol			
2,4-Dinitrotoluene			
Endosulfan I			
Endosulfan II			
Endrin			
Endrin aldehyde			
Endrin ketone			
Bis(2-ethylhexyl)phthalate			
Fluoranthene			
Fluorene			
Folpet			
Heptachlor			

ENVIRONMENTAL PROTECTION AGENCY
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CONTINUING CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SDG No.:_____ SAS No.:_____
EPA Sample No.:_____ Lab File ID:_____
GC Column ID:_____ Instrument ID:_____
Date injected:_____ Time injected:_____
Injection volume (uL):_____ Date of I.C.:_____

COMPOUND NAME	IC mean RRF	CAL 3 RRF	% D
Heptachlor epoxide			
Hexachlorobenzene			
Hexachlorocyclopentadiene			
Hexachloroethane			
Indeno(1,2,3-c,d)pyrene			
Isophorone			
Methoxychlor			
Hexachlorocyclopentadiene			
Hexachloroethane			
Indeno(1,2,3-c,d)pyrene			
Isophorone			
Methoxychlor			
2-Methylnaphthalene			
2-Methylphenol			
4-Methylphenol			
Mirex			
Naphthalene			
2-Naphthylamine			
2-Nitroaniline			
3-Nitroaniline			
Nitrobenzene			
4-Nitrodiphenyl			
2-Nitrophenol			
4-Nitrophenol			
Bis(n-octyl)phthalate			
Oxychlordane			
Parathion			
Pentachlorobenzene			

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ENVIRONMENTAL PROTECTION AGENCY
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Semivolatile Organics in Air

CONTINUING CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SDG No.:_____ SAS No.:_____
EPA Sample No.:_____ Lab File ID:_____
GC Column ID:_____ Instrument ID:_____
Date injected:_____ Time injected:_____
Injection volume (uL):_____ Date of I.C._____

COMPOUND NAME	IC mean RRF	CAL 3 RRF	% D
Pentachlorophenol			
cis/trans-Permethrin			
Phenanthrene			
o-Phenylphenol			
Phenol			
Propoxur			
Pyrene			
Resmethrin			
Ronnel			
2,4,5-Trichlorophenol			
2,4,6-Trichlorophenol			
Monochlorobiphenyls			
Dichlorobiphenyls			
Trichlorobiphenyls			
Tetrachlorobiphenyls			
Pentachlorobiphenyls			
Hexachlorobiphenyls			
Heptachlorobiphenyls			
Octachlorobiphenyls			
Nonachlorobiphenyls			
Decachlorobiphenyls			
Nitrobenzene-d_5			
2-Fluorobiphenyl			
p-Terphenyl-d_{14}			
Phenol-d_5			
2-Fluorophenol			
2,4,6-Tribromophenol			
Anthracene-d_{10}			
Benzo(a)pyrene-d_{12}			

ENVIRONMENTAL PROTECTION AGENCY
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Semivolatile Organics in Air

CONTINUING CALIBRATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SDG No.:_____ SAS No.:_____
EPA Sample No.:_____ Lab File ID:_____
GC Column ID:_____ Instrument ID:_____
Date injected:_____ Time injected:_____
Injection volume (uL):_____ Date of I.C.:_____

THIS CONTINUING CALIBRATION APPLIES TO THE FOLLOWING:

EPA Sample No.	Lab Sample ID	Date Analyzed	Time Analyzed

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INTERNAL STANDARD AREA AND RT SUMMARY

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____

	Dichlorobenzene–d_4				Naphthalene–d_8				Acenaphthene–d_{10}			
	Area	#	RT	#	Area	#	RT	#	Area	#	RT	#
12–HOUR STANDARD												
Upper Limit												
Lower Limit												
EPA Sample No.												
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												

AREA: Upper Limit: +40% of internal standard area.
Lower Limit: −40% of internal standard area.

RT: Upper Limit: +0.33 minutes of internal standard RT.
Lower Limit: −0.33 minutes of internal standard RT.

All values outside of the QC limits must be followed by an "*" under the "#" column.

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INTERNAL STANDARD AREA AND RT SUMMARY

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____

		Phenanthrene-d_{10}			Chrysene-d_{12}			Perylene-d_{12}		
		Area	#	RT	#	Area	#	RT	#	Area	#	RT	#
12-HOUR STANDARD													
Upper Limit													
Lower Limit													
EPA Sample No.													
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													

AREA: Upper Limit: +40% of internal standard area. RT: Upper Limit: +0.33 minutes of internal standard RT.
Lower Limit: −40% of internal standard area. Lower Limit: −0.33 minutes of internal standard RT.

All values outside of the QC limits must be followed by an "*" under the "#" column.

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

FILTER/ADSORBENT CARTRIDGE CERTIFICATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
Lab Sample ID:_____ Lab File ID:_____
SDG No.:_____ SAS No.:_____
Date Extracted:_____ Date Analyzed:_____
Instrument ID:_____ GC Column ID:_____
Filter Batch No.:_____ PUF Batch No.:_____
Injection Volume:_____(uL) XAD-2 Batch No.:_____

CAS RN	COMPOUND NAME	Concentration ug/assembly
83-32-9	Acenaphthene	
208-96-8	Acenaphthylene	
98-86-2	Acetophenone	
116-06-3	Aldicarb	
309-00-2	Aldrin	
62-53-3	Aniline	
120-12-7	Anthracene	
22781-23-3	Bendiocarb	
92-87-5	Benzidine	
56-55-3	Benz[a]anthracene	
50-32-8	Benzo[a]pyrene	
205-99-2	Benzo[b]fluoranthene	
192-97-2	Benzo[e]pyrene	
191-24-2	Benzo[g,h,i]perylene	
207-08-9	Benzo[k]fluoranthene	
100-51-6	Benzyl alcohol	
319-84-6	alpha-BHC	
58-89-9	gamma-BHC (Lindane)	
92-67-1	p-Biphenylamine	
84-74-2	Bis(n-butyl)phthalate	
85-68-7	Butylbenzylphthalate	
133-06-2	Captan	
5103-71-9	alpha-Chlordane	
5103-74-2	gamma-Chlordane	
59-50-7	4-Chloro-3-methylphenol	
106-47-8	4-Chloroaniline	

ENVIRONMENTAL PROTECTION AGENCY
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Semivolatile Organics in Air

FILTER/ADSORBENT CARTRIDGE CERTIFICATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
Lab Sample ID:_____ Lab File ID:_____
SDG No.:_____ SAS No.:_____
Date Extracted:_____ Date Analyzed:_____
Instrument ID:_____ GC Column ID:_____
Filter Batch No.:_____ PUF Batch No.:_____
Injection Volume:_____(uL) XAD-2 Batch No.:_____

CAS RN	COMPOUND NAME	Concentration ug/assembly
111-91-1	Bis(2-chloroethoxy)methane	
111-44-4	Bis(2-chloroethyl)ether	
1897-45-6	Chlorothalonil	
2921-88-2	Chlorpyrifos	
218-01-9	Chrysene	
1861-32-1	Dacthal (DCPA)	
72-54-8	4,4'-DDD	
72-55-9	4,4'-DDE	
50-29-3	4,4'-DDT	
333-41-5	Diazinon	
53-70-3	Dibenz[a,h]anthracene	
62-73-7	Dichlorvos (DDVP)	
115-32-2	Dicofol	
60-57-1	Dieldrin	
84-66-2	Diethylphthalate	
105-67-9	2,4-Dimethylphenol	
131-11-3	Dimethylphthalate	
534-52-1	4,6-Dinitro-2-methylphenol	
51-28-5	2,4-Dinitrophenol	
121-14-2	2,4-Dinitrotoluene	
959-98-8	Endosulfan I	
33213-65-9	Endosulfan II	
72-20-8	Endrin	
7421-93-4	Endrin aldehyde	
533-41-5	Endrin ketone	
117-81-7	Bis(2-ethylhexyl)phthalate	

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

FILTER/ADSORBENT CARTRIDGE CERTIFICATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
Lab Sample ID:_____ Lab File ID:_____
SDG No.:_____ SAS No.:_____
Date Extracted:_____ Date Analyzed:_____
Instrument ID:_____ GC Column ID:_____
Filter Batch No.:_____ PUF Batch No.:_____
Injection Volume:_____(uL) XAD-2 Batch No.:_____

CAS RN	COMPOUND NAME	Concentration ug/assembly
206-44-0	Fluoranthene	
86-73-7	Fluorene	
133-07-3	Folpet	
76-44-8	Heptachlor	
1024-57-3	Heptachlor epoxide	
118-74-1	Hexachlorobenzene	
77-47-4	Hexachlorocyclopentadiene	
67-72-1	Hexachloroethane	
193-39-5	Indeno(1,2,3-c,d)pyrene	
78-59-1	Isophorone	
72-43-5	Methoxychlor	
91-57-6	2-Methylnaphthalene	
95-48-7	2-Methylphenol	
106-44-5	4-Methylphenol	
2385-85-5	Mirex	
91-20-3	Naphthalene	
91-59-8	2-Naphthylamine	
88-74-4	2-Nitroaniline	
100-01-6	3-Nitroaniline	
98-95-3	Nitrobenzene	
92-93-3	4-Nitrodiphenyl	
88-75-5	2-Nitrophenol	
100-02-7	4-Nitrophenol	
117-84-0	Bis(n-octyl)phthalate	
27304-13-8	Oxychlordane	
56-38-2	Parathion	

ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Air

FILTER/ADSORBENT CARTRIDGE CERTIFICATION DATA SHEET

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
Lab Sample ID:_____ Lab File ID:_____
SDG No.:_____ SAS No.:_____
Date Extracted:_____ Date Analyzed:_____
Instrument ID:_____ GC Column ID:_____
Filter Batch No.:_____ PUF Batch No.:_____
Injection Volume:_____(uL) XAD-2 Batch No.:_____

CAS RN	COMPOUND NAME	Concentration ug/assembly
608-93-5	Pentachlorobenzene	
87-86-5	Pentachlorophenol	
52645-53-1	cis/trans-Permethrin	
85-01-8	Phenanthrene	
108-95-2	Phenol	
90-43-7	o-Phenylphenol	
114-26-1	Propoxur	
129-00-0	Pyrene	
10453-86-8	Resmethrin	
299-84-3	Ronnel	
95-95-4	2,4,5-Trichlorophenol	
88-06-2	2,4,6-Trichlorophenol	
	PCBs	
27323-18-8	Monochlorobiphenyls	
25512-42-9	Dichlorobiphenyls	
25323-68-6	Trichlorobiphenyls	
26914-33-0	Tetrachlorobiphenyls	
25429-29-2	Pentachlorobiphenyls	
26601-64-9	Hexachlorobiphenyls	
28655-71-2	Heptachlorobiphenyls	
31472-83-0	Octachlorobiphenyls	
53742-07-7	Nonachlorobiphenyls	
2051-24-3	Decachlorobiphenyls	

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Ambient Air

SURROGATE RECOVERY

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____

		Surrogate Percent Recovery					Total
	EPA Sample No.	Nitrobenzene-d_6	#	2-Fluorobiphenyl	#	p-Terphenyl-d_{14}	#	Out
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								

%Recovery QC Limits: 25-150%
Values outside of QC limits are flagged with a "*" under the "#" column

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U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Ambient Air

SURROGATE RECOVERY

Lab Name:_____ Contract No.:_____
Lab Code:_____ Case No.:_____
SAS No.:_____ SDG No.:_____

	EPA Sample No.	Surrogate Percent Recovery					Total out
		Anthracene-d_{10} #	Benzo(a)pyrene-d_{12} #	Tribromophenol #	2-Fluorophenol #	Phenol-d_5 #	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							

%Recovery QC Limits: 25-150%, except for 2-Fluorophenol, 10-150%.
Values outside of QC limits are flagged with a "*" under the "#" column

FORM IX - AASV-2

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Semivolatile Organics in Ambient Air

ANALYTICAL SEQUENCE

Lab Name: _____ Contract No.: _____
Lab Code: _____ Case No.: _____
SAS No.: _____ SDG No.: _____
Instrument ID: _____ GC Column ID: _____

THE FOLLOWING IS THE ANALYTICAL SEQUENCE ARRANGED IN CHRONOLOGICAL ORDER:

	EPA Sample No.	Lab Sample ID	Analysis Time	Analysis Date
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				

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FORM X – AASV

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EXHIBIT C

TARGET COMPOUND LISTS

EXHIBIT C

SEMIVOLATILES IN AMBIENT AIR
TARGET COMPOUND LIST (TCL) AND
CONTRACT REQUIRED QUANTITATION LIMITS (CRQL)

I. PAHs, PESTICIDES, AND OTHER SEMIVOLATILES

Target Compound	CAS RN	CRQL	
		On-column Injection, ng	ng/m^3
Acenaphthene	83-32-9	10	37
Acenaphthylene	208-96-8	10	37
Acetophenone	98-86-2	10	37
Aldicarb	116-06-3	40	146
Aldrin	309-00-2	40	146
Aniline	62-53-3	20	73
Anthracene	120-12-7	10	37
Bendiocarb	22781-23-3	50	183
Benzidine	92-87-5	20	73
Benzo(a)anthracene	56-55-3	10	37
Benzo(a)Pyrene	50-32-8	10	37
Benzo(b)fluoranthene	205-99-2	10	37
Benzo(e)pyrene	192-97-2	10	37
Benzo(g,h,i)perylene	191-24-2	10	37
Benzo(k)fluoranthene	207-08-9	10	37
Benzyl alcohol	100-51-6	10	37
alpha-BHC	319-84-6	40	146
gamma-BHC (Lindane)	58-89-9	40	146
p-Biphenylamine	92-67-1	50	183
Bis(n-butyl)phthalate	84-74-2	10	37
Butylbenzylphthalate	85-68-7	10	37
Captan	133-06-2	50	183
alpha-Chlordane	5103-71-9	40	146
gamma-Chlordane	5103-74-2	40	146
4-Chloro-3-methylphenol	59-50-7	50	183
4-Chloroaniline	106-47-8	20	73
Bis(2-chloroethoxy)methane	111-91-1	10	183
Bis(2-chloroethyl)ether	111-44-4	10	37
Chlorothalonil	1897-45-6	50	183
Chlorpyrifos	2921-88-2	50	183
Chrysene	218-01-9	10	37
Dacthal (DCPA)	1861-32-1	50	183
4,4'-DDD	72-54-8	40	146
4,4'-DDE	72-55-9	40	146
4,4'-DDT	50-29-3	40	146

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TABLE 3

SEMIVOLATILES IN AMBIENT AIR
TARGET COMPOUND LIST (TCL) AND
CONTRACT REQUIRED QUANTITATION LIMITS (CRQL)
(continued)

I. PAHs, PESTICIDES, AND OTHER SEMIVOLATILES (continued)

Target Compound	CAS RN	CRQL On-column Injection, ng	CRQL ng/m³
Diazinon	333-41-5	50	183
Dibenzo(a,h)anthracene	53-70-3	10	37
Dichlorvos (DDVP)	62-73-7	50	183
Dicofol	115-32-2	50	183
Dieldrin	60-57-1	40	146
Diethyl Phthalate	84-66-2	20	73
2,4-Dimethyl phenol	105-67-9	20	73
Dimethylphthalate	131-11-3	10	37
4,6-Dinitro-2-methylphenol	534-52-1	50	183
2,4-Dinitrophenol	51-28-5	20	73
2,4-Dinitrotoluene	121-14-2	10	37
Endosulfan I	959-98-8	10	37
Endosulfan II	33213-65-9	10	37
Endrin	72-20-8	10	37
Endrin Aldehyde	7421-93-4	10	37
Endrin ketone	533-41-5	50	183
Bis(2-ethylhexyl)phthalate	117-81-7	10	37
Fluoranthene	206-44-0	10	37
Fluorene	86-73-7	10	37
Folpet	133-07-3	50	183
Heptachlor	76-44-8	40	146
Heptachlor Epoxide	1024-57-3	40	146
Hexachlorobenzene	118-74-1	10	37
Hexachlorocyclopentadiene	77-47-4	10	37
Hexachloroethane	67-72-1	10	37
Indeno(1,2,3-c,d)pyrene	193-39-5	10	37
Isophorone	78-59-1	10	37
Methoxychlor	72-43-5	40	146
2-Methylnaphthalene	91-57-6	10	37
2-Methylphenol	95-48-7	50	183
4-Methylphenol	106-44-5	50	183
Mirex	2385-85-5	40	146
Naphthalene	91-20-3	10	37
2-Naphthylamine	91-59-8	50	183

SEMIVOLATILES IN AMBIENT AIR
TARGET COMPOUND LIST (TCL) AND
CONTRACT REQUIRED QUANTITATION LIMITS (CRQL)
(continued)

I. **PAHs, PESTICIDES, AND OTHER SEMIVOLATILES** (continued)

Target Compound	CAS RN	CRQL On-column Injection, ng	CRQL ng/m^3
2-Nitroaniline	88-74-4	20	73
3-Nitroaniline	100-01-6	20	73
Nitrobenzene	98-95-3	10	37
4-Nitrodiphenyl	92-93-3	50	183
2-Nitrophenol	88-75-5	20	73
4-Nitrophenol	100-02-7	50	183
Bis(n-octyl)phthalate	117-84-0	10	37
Oxychlordane	27304-13-8	50	183
Parathion	56-38-2	40	146
Pentachlorobenzene	608-93-5	50	183
Pentachlorophenol	87-86-5	50	183
cis/trans-Permethrin	52645-53-1	50	183
Phenanthrene	85-01-8	10	37
Phenol	108-95-2	50	183
o-Phenylphenol	90-43-7	50	183
Propoxur	114-26-1	50	183
Pyrene	129-00-0	10	37
Resmethrin	10453-86-8	50	183
Ronnel	299-84-3	50	183
2,4,6-Trichlorophenol	88-06-2	50	183
2,4,5-Trichlorophenol	95-95-4	50	183

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SEMIVOLATILES IN AMBIENT AIR
TARGET COMPOUND LIST (TCL) AND
CONTRACT REQUIRED QUANTITATION LIMITS (CRQL)
(continued)

II. PCBs (Congeners)

Target Compound	CAS RN	CRQL	
		On-column Injection, ng	ng/m^3
Monochlorobiphenyls	27323-18-8	40	146
Dichlorobiphenyls	25512-42-9	40	146
Trichlorobiphenyls	25323-68-6	40	146
Tetrachlorobiphenyls	26914-33-0	40	146
Pentachlorobiphenyls	25429-29-2	40	146
Hexachlorobiphenyls	26601-64-9	40	146
Heptachlorobiphenyls	28655-71-2	80	293
Octachlorobiphenyls	31472-83-0	80	293
Nonachlorobiphenyls	53742-07-7	100	366
Decachlorobiphenyl	2051-24-3	100	366

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ANALYTICAL METHOD FOR THE DETERMINATION OF SEMIVOLATILE ORGANICS COLLECTED ON PUF/XAD-2 AND ANALYZED BY GAS CHROMATOGRAPHY AND MASS SPECTROMETRY (GC/MS)

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January, 1992

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ANALYTICAL METHOD FOR THE DETERMINATION OF SEMIVOLATILE ORGANICS COLLECTED ON PUF/XAD-2 AND ANALYZED BY GAS CHROMATOGRAPHY AND MASS SPECTROMETRY (GC/MS)

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EXHIBIT D

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1 INTRODUCTION

1.1 SCOPE AND APPLICATION

1.1.1 Polynuclear aromatic hydrocarbons (PAHs), pesticides, polychlorinated biphenyls (PCBs), and other semivolatile compounds (SVOCs) have received increased attention in recent years in air pollution studies because some of these compounds are highly carcinogenic or mutagenic. In particular, benzo[a]pyrene (B[a]P), 4,4'-DDD, 4,4'-DDT, and PCBs have all been identified as being highly carcinogenic.

1.1.2 The analytical method that follows is designed to analyze samples containing the compounds listed on the Target Compound List in Exhibit C.

1.1.3 The analysis technique is based on modifications of EPA Test Methods 610 and 625, Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater; Methods 8000, 8270, and 8310, Test Methods for Evaluation of Solid Waste (SW-846); the USEPA Contract Laboratory Program Statement of Work for Low Concentration Water for Organics Analysis; and EPA Method 680, Determination of Pesticides and PCBs in Water and Soil/Sediment by Gas Chromatography/Mass Spectrometry (GC/MS).

1.1.4 Three surrogate compounds (pre-sampling) are added to each PUF/XAD-2 cartridge brought to the field. Five additional surrogate compounds (post-sampling) are spiked on the cartridges received from the field just prior to extraction. For the laboratory method blank (LMB), laboratory control sample (LCS), and performance evaluation (PE) samples, all of the eight surrogate compounds are spiked onto the cartridges just prior to extraction, since these cartridges are not sent to the field. Internal standards are added to each blank and sample extract before GC/MS analysis. Each concentration measurement is based on an integrated ion abundance of one characteristic ion. Analytes are identified as individual compounds, and a concentration is calculated by relating the MS response of each compound to the MS response of the corresponding internal standard. Table D/SV-3 provides the internal standard assignments for each target and surrogate compound.

1.1.5 An interfaced data system (DS) to control data acquisition and to store, retrieve, and manipulate mass spectral data is essential.

1.1.6 Applicability of the Method to PCBs

1.1.6.1 This method is applicable to samples containing PCBs as single congeners. PCBs are identified and measured as isomer groups (i.e., by level of chlorination) by GC/MS using a special software.

1.1.6.2 The existence of 209 possible PCB congeners makes the listing of the Chemical Abstracts Service Registry Number (CAS RN) for each potential method analyte impractical.

1.1.6.3 A concentration is measured for each PCB isomer group, and total PCB concentration for each sample extract is obtained by summing isomer group concentrations. Nine selected PCB congeners are used as calibration standards and one internal standard, chrysene-d_{12}, is used to calibrate MS response to PCBs. Because PCBs are identified and measured as isomer groups, the non-specific CAS RN for each level of chlorination is used to describe method analytes.

1.1.7 Detection Limits

Detection limits vary among method analytes and with sample matrix, sample preparation procedures, condition of the GC/MS system, type of data acquisition, and individual samples. Based on numerous analyses of calibration solutions using one instrument over a period of approximately six months, the following comments are provided to assist the analyst:

1.1.7.1 Pesticide analytes other than endosulfans I and II can be identified and accurately measured when the injected aliquot contains 2 ng of each analyte. The endosulfans require about 4 ng each.

1.1.7.2 Detection limits for individual PCB congeners increase with increasing number of chlorine atoms, with the detection limit for decachlorobiphenyl being about 5 to 10 times higher than that of a monochlorobiphenyl. A monochlorobiphenyl can be identified and accurately measured when the injected extract aliquot contains 1 ng and full scan data acquisition is used.

1.1.7.3 The detection limit for total PCBs will depend on the number of individual PCB congeners present.

1.1.8 Safety

1.1.8.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. From this viewpoint, exposure to these chemicals must be reduced to the lowest possible level by whatever means available. The laboratory is responsible for

maintaining a current awareness file of Occupational Safety and Health Administration (OSHA) regulations regarding the safe handling of the chemicals specified in this method. A reference file of material safety data sheets (MSDSs) should also be made available to all personnel involved in the chemical analysis. Additional references to laboratory safety are available and have been identified for the analyst.

1.1.8.2 Care must be exercised when working with these substances. This method does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this method to consult and establish appropriate safety and health practices, and determine the applicability of regulatory limitations prior to use. The user should be thoroughly familiar with the chemical and physical properties of targeted substances.

1.1.8.3 Treat all analytes as carcinogens. Neat compounds should be weighed in a glove box. Spent samples and unused standards are toxic wastes and should be disposed according to regulations. Regularly check counter tops and equipment with "black light" for fluorescence as an indicator of semivolatile contamination.

1.1.8.4 Precautions must be taken with diethyl ether because of its extreme fire hazard and the possibility that peroxides may form producing an explosive mixture should the solution be allowed to evaporate to dryness. It is the laboratory's duty to instruct all its personnel on the proper use and handling of this solvent. Standard safety practices for handling ethers must be implemented.

1.2 SUMMARY OF METHOD

1.2.1 Prior to field use, the filter and adsorbent cartridge (PUF/XAD-2/PUF) are cleaned in solvents and vacuum-dried. The cartridge is then spiked with a minimum of three surrogate compounds. The filter and spiked adsorbent cartridge are stored in screw-capped jars wrapped in aluminum foil prior to installation on the sampler.

1.2.2 In the field, approximately 273 m^3 of ambient air is drawn through the filter and adsorbent cartridge where the analytes of interest are retained. At the end of the specified sampling period, the amount of air sampled is recorded, and the filter and cartridge are placed in an appropriately labeled container and shipped along with blank filter and adsorbent cartridges to the analytical laboratory for analysis.

1.2.3 Each pair of the filters and PUF/XAD-2 adsorbent cartridge are extracted together by Soxhlet extraction with diethyl ether/hexane solvent (10 percent v/v). The extract is concentrated using a Kuderna-Danish (K-D) evaporator and further concentrated to 1.0 mL by micro-Snyder column or by nitrogen blowdown technique. Prior to analysis by GC/MS, internal

standards are added to the concentrate. (If applicable, the concentrated extract is screened for levels of semivolatiles utilizing a GC with a flame ionization detector (FID) or an electron capture detector (ECD).)

1.2.4 For final identification and quantification, 1 µL of the extract is injected onto a GC with a capillary column and temperature-programmed to separate the compounds, which are then detected with a mass spectrometer (MS) in the full scan data acquisition mode.

NOTE: This method is based upon full scan data acquisition. All concentrations are based upon the use of 1-µL injections. If different volumes are used, the concentrations must be appropriately adjusted.

1.2.5 Target compounds are identified in the samples by analyzing standards under the same analytical conditions used as the samples and comparing resultant mass spectra and GC retention times. A relative response factor is established for each target compound during the initial and continuing calibrations by comparing the MS response for the primary ion produced by the compound to the MS response for the primary ion produced by an internal standard. Each identified target compound in a sample is quantified by comparing the responses for the target compound and the internal standard, while taking into account the relative response factor from the most recent calibration, the initial and final sample volume, and any sample dilutions.

1.2.6 Non-target compounds are identified by comparing the resultant mass spectra from the non-target compounds to mass spectra contained in the National Institute of Standards and Technology (NIST) Mass Spectral Library. Non-target compounds are quantified by comparing the MS response for the non-target compound peaks to the MS response produced by the nearest internal standard. A response factor of 1 is assumed.

1.3 INTERFERENCES AND LIMITATIONS

1.3.1 Contaminants in solvents, reagents, glassware and other sample processing hardware may cause method interferences such as discrete artifacts and/or elevated baselines in the total ion current profiles (TICPs). Laboratory method blanks are analyzed with each analytical sequence to demonstrate that these materials are free of interferences under the analytical conditions used for samples. Matrix interferences may be caused by contaminants that are coextracted from the sample. The extent of matrix interferences will vary considerably from source to source.

1.3.2 To minimize interferences, glassware should be meticulously cleaned. As soon as possible after use, rinse glassware with the last solvent used. Then wash with detergent in hot water and rinse with tap water followed by distilled water. Drain dry and heat in a muffle furnace at 450°C for a few hours (volumetric glassware should not be heated in a

muffle furnace). After cooling, store glassware inverted or covered with aluminum foil. Before using, rinse each piece with an appropriate solvent.

NOTE: Some thermally stable materials such as PCBs may not be eliminated by this treatment. Solvent rinses with acetone and pesticide-quality hexane may be substituted for the muffle furnace.

1.3.3 For both pesticides and PCBs, interference can be caused by the presence of much greater quantities of other sample components that overload the capillary column; additional sample extract preparation procedures must then be used to eliminate interferences. Capillary column GC retention times and the compound-specific characteristics of mass spectra eliminate many interferences that formerly were of concern with pesticide/PCB determinations by electron capture detection. The approach and identification criteria used in this method for PCBs eliminate interference by most chlorinated compounds other than PCBs. With the isomer group approach, coeluting PCBs that contain the same number of chlorines are identified and measured together. Therefore, coeluting PCBs are a problem only if they contain a different number of chlorine atoms.

1.4 DEFINITIONS

NOTE: Definitions used in this document and in any user-prepared standard operating procedures (SOPs) should be consistent with ASTM Methods D1356, D1605-60, E260, and E255. All abbreviations and symbols are defined within this document at the point of use. A detailed glossary of terms can be found in Exhibit G.

1.4.1 CAL: Calibration standards are defined in Table D/SV-1 in which 5 levels of calibration are defined; CAL 1, CAL 2, CAL 3, CAL 4, and CAL 5. CAL 1 is the lowest concentration and CAL 5 is the highest concentration. CAL 3, which is the mid level standard, is designated as the solution to be used for continuing calibrations.

1.4.2 Continuing calibration standard: A solution of method analytes used to evaluate the mass spectrometer response over a period of time. A check of the initial calibration is performed once each 12-hour period. The continuing calibration standard is CAL 3 of the initial calibration curve.

1.4.3 GC response (A_x): The peak area or height of analyte, x.

1.4.4 Internal standard (IS): A compound added to a sample extract in known amounts and used to calibrate concentration measurements of other compounds that are sample components. The internal standard must be a compound that is not a sample component.

1.4.5 Laboratory method blank (LMB): The concentrate from the extraction

of a clean, certified filter/adsorbent cartridge solution that is treated as a sample. The filter/adsorbent cartridge is carried through the same analytical procedure as a field sample. The surrogates are spiked onto the cartridge bed prior to extraction. The purpose of the LMB is to monitor for possible laboratory contamination.

1.4.6 Mass spectral interference: Defined as the inability to detect the analyte quantification ion due to presence of high levels of mass spectral "noise" at the same mass.

1.4.7 Method detection limit (MDL): A statistically determined value indicating the minimum concentration of an analyte that can be identified and measured in a sample matrix with 99 percent confidence that the analyte concentration is greater than zero. This value varies with the precision of the replicate measurements used for the calculation. (See 40CFR 136 APP.B)

1.4.8 PAH: Polynuclear aromatic hydrocarbon.

1.4.9 PCB: Polychlorinated biphenyl.

1.4.10 Performance evaluation (PE) sample: A sample containing known concentrations of method analytes that has been analyzed to statistically determine the accuracy and precision that can be expected when a method is performed by a competent analyst. Analyte identification and concentrations are unknown to the analyst. PE samples are supplied by the Agency.

1.4.11 PUF: Polyurethane foam used as an adsorbent and as a support for XAD-2.

1.4.12 Retention time window: Retention time is determined for each analyte of interest as the time from injection to elution of a specific chemical from a chromatographic column. The window is determined by five injections of a initial calibration standard over a 24-hour period as plus or minus three times the standard deviation of the absolute retention time for that analyte. For this document, the window is ±0.06 RRT units of the continuing or mid level calibration standard RRT for each target and surrogate compound.

1.4.13 Selected Ion Current Profile (SICP): A plot of ion abundances of the ions of an analyte produced by the mass spectrometer. SICP is used interchangeably with EICP, extracted ion current profile.

1.4.14 Stock standard solution: A solution used to prepare calibration standards. Normally, this solution will be at a concentration which is easily diluted to a level which can be injected into the GC.

1.4.15 Surrogate compound: A compound not expected to be found in the

sample that is added to each sample prior to field deployment and before extraction, and is measured with the same procedures used to measure sample components. The purpose of a surrogate compound is to monitor method performance with each sample.

1.4.16 VTSR: Validated Time of Sample Receipt is the time the sample is logged-in on the Chain-of-Custody Log-In Sheet by the laboratory.

1.4.17 Working standard solution: A solution which is prepared as a calibration standard. Normally, this solution will be injected into the GC without additional dilution.

1.4.18 XAD-2: A resin used as an adsorbent for semivolatile compounds.

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2 SAMPLE STORAGE AND HOLDING TIMES

2.1 SAMPLE IDENTIFICATION

2.1.1 In the field, the samples are packed in dry ice to ensure that the glass sample container containing the filter and adsorbent cartridge are properly chilled, and shipped to the designated laboratory.

2.1.2 The samples are logged in the laboratory logbook or appropriate data tracking system according to sample location, filter and adsorbent cartridge number identification, and total air volume sampled, corrected to standard temperature and pressure (STP). The time the samples are logged-in on the Chain of Custody Log-In Sheet at the laboratory is the validated time of sample receipt (VTSR).

2.1.3 If the time between sample receipt and extraction is greater than 24 hours, then the samples must be kept refrigerated. Minimize exposure of samples to fluorescent light. All samples must be extracted within five (5) days of VTSR.

2.2 SAMPLE/SAMPLE EXTRACT STORAGE

2.2.1 The samples must be contained in air-tight glass containers, protected from light, and refrigerated at 4°C (±2°C) from the time of receipt until extraction. Unused samples must be disposed of or regenerated in a manner that complies with all applicable regulations.

2.2.2 Sample extracts must be protected from light and stored at 4°C (±2°C) until 30 days after delivery of a complete data package to the Agency.

2.2.3 Samples and sample extracts must be stored in an atmosphere demonstrated to be free of all potential contaminants.

2.2.4 Samples, sample extracts, and standards must be stored separately.

2.3 CONTRACT REQUIRED HOLDING TIMES

2.3.1 The extraction shall be started within 5 days of the VTSR.

2.3.2 Extracts must be analyzed within 25 days following the start of the extraction.

3 CARTRIDGE PREPARATION AND CERTIFICATION

3.1 SUMMARY OF METHOD

This section discusses pertinent information regarding the preparation and cleaning of the filter, adsorbents, and filter/adsorbent cartridge assembly. The separate batches of filters and adsorbents are extracted with the appropriate solvent. At least one PUF/XAD-2/PUF cartridge assembly and one filter from each batch, or 10 percent of the batch, whichever is greater, must be extracted and certified before the batch is considered for field use. Prior to field sampling, the cartridges are spiked with surrogate compounds.

3.2 APPARATUS AND MATERIALS

3.2.1 Acid-washed Pallflex filter: 4 inch Pallflex filter, General Metal Works, Inc., Cat. No. GMW QMA-4, 145 South Miami Ave., Village of Cleves, OH, 45002, 800-543-7412, or Supelco Inc., Cat. No. 1-62, Supelco Park, Bellefonte, PA, 16823-0048, or equivalent.

3.2.2 Polyurethane foam (PUF): Two separates plugs, 6.5 cm by 2.5 cm and 6.5 cm by 5 cm. These can be manufactured from a 3 inch thick sheet stock, polyether type (density 0.022 g/cm^3) used in furniture upholstering, General Metal Works, Inc., Cat. No. PS-1-16, 145 South Miami Ave., Village of Cleves, OH, 45002, 800-543-7412, or Supelco Inc., Cat. No. 1-63, Supelco Park, Bellefonte, PA, 16823-0048, or equivalent. The two separate plugs are also commercially available from General Metal Works.

3.2.3 XAD-2 resin: Supelco Inc., Cat. No. 2-02-79, Supelco Park, Bellefonte, PA, 16823-0048, or equivalent.

3.2.4 Aluminum foil: baked in an oven overnight at 500°C after rinsing with hexane.

3.2.5 Soxhlet extractors: Capable of extracting GMW Model PS-1 filter and adsorbent cartridges (2.3" x 5" length), 1000-mL flask, and condenser.

3.2.6 Minivials: 2-mL, borosilicate glass, with conical reservoir and screw caps lined with Teflon®-faced silicone septa, and a vial holder.

3.2.7 Glass vials: 40-mL.

3.2.8 Erlenmeyer flasks: 50-mL.

3.2.9 Spatulas and spoons: Teflon®-coated stainless steel.

3.2.10 Kuderna-Danish (K/D) apparatus: 500-mL evaporation flask (Kontes K-570001-500, or equivalent), 10-mL graduated concentrator tubes (Kontes K-570050-1025, or equivalent) with ground-glass stoppers, and 3-ball

macro-Snyder Column (Kontes K-5700010500, K-50300-0121, and K-569001-219, or equivalent).

3.2.11 Adsorption columns for column chromatography: 1 cm x 10 cm with stands.

3.2.12 White cotton gloves: For handling cartridges and filters.

3.2.13 Glove box: For working with extremely toxic standards and reagents, with explosion-proof hood for venting fumes from solvents, reagents, etc.

3.2.14 Vacuum oven: Vacuum drying oven system capable of maintaining a vacuum at 240 torr (flushed with nitrogen) overnight.

3.2.15 Concentrator tubes and a nitrogen evaporation apparatus: with variable flow rate.

3.2.16 Laboratory refrigerator.

3.2.17 Boiling chips: Solvent-extracted 10/40 mesh silicon carbide, or equivalent.

3.2.18 Water bath: Heated, with concentric ring cover, capable of ±5°C temperature control.

3.2.19 Vortex evaporator (optional).

3.2.20 Teflon® sleeves for the ground-glass joints on the Soxhlet extraction apparatus.

3.3 REAGENTS

3.3.1 Hexane: chromatographic grade, glass distilled.

3.3.2 Diethyl ether: chromatographic grade, glass distilled.

3.3.3 Methylene chloride: Chromatographic grade, glass-distilled.

3.3.4 Sodium sulfate: Anhydrous (ACS), granular (purified by washing with methylene chloride followed by heating at 400°C for 4 hours in a shallow tray).

3.3.5 Nitrogen: High purity grade.

3.4 PROCEDURES FOR PREPARATION OF FILTER, ADSORBENT, AND CARTRIDGE

3.4.1 Glass Fiber Filter Preparation

3.4.1.1 The quartz fiber filters are baked at 600°C for five hours

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before use. To ensure acceptable filters, they are extracted with methylene chloride in a Soxhlet apparatus, similar to the cleaning of the XAD-2 resin. The extract may be analyzed for the purpose of determining cleanliness prior to certification.

3.4.1.2 The extracted filters are set aside in a clean container prior to combined extraction (certification) with the PUF/XAD-2/PUF glass cartridge assembly.

3.4.2 **XAD-2 Adsorbent Preparation**

3.4.2.1 For initial cleanup of the XAD-2 resin, a batch of XAD-2 (approximately 50-60 grams) is placed in a Soxhlet apparatus and extracted with methylene chloride for 16 hours at approximately 4 cycles per hour.

3.4.2.2 At the end of the initial Soxhlet extraction, the spent methylene chloride is discarded and replaced with fresh reagent. The XAD-2 resin is once again extracted for 16 hours at approximately 4 cycles per hour.

3.4.2.3 The XAD-2 resin is removed from the Soxhlet apparatus, placed in a vacuum oven connected to an ultra-pure nitrogen gas stream and dried at room temperature for approximately 2-4 hours (until no solvent odor is detected).

NOTE: Alternatively, a 600 g batch of XAD-2 resin is extracted with methylene chloride for 16 hours. After extraction, the resin is transferred to a clean drying column. Then the resin is dried with high-purity nitrogen using Teflon® tubing from the nitrogen cylinder with a charcoal tube in the line. In an alternative method of drying, the XAD-2 resin is placed in a Pyrex® column (10 cm x 60 cm), allowing sufficient space for fluidizing. The column is wrapped with heat tape, maintained at 40°C, during the drying process. High purity air, scrubbed through a charcoal trap, is forced through the resin bed, fluidizing the bed while generating a minimum load at the exit of the column.

3.4.2.4 The extract from the Soxhlet extraction procedure from each batch may be analyzed for the purpose of determining initial cleanliness prior to certification.

3.4.3 **PUF Adsorbent Preparation**

3.4.3.1 The PUF adsorbent is a polyether-type polyurethane foam (density 0.0225 g/cm^3).

3.4.3.2 The adsorbent assembly is composed of two inserts, as illustrated in Figure D/SV-2. The bottom PUF is 6.5-cm by 2.5-cm, while the top plug is 6.5-cm by 5.0-cm. The PUF inserts are cut from

sheet stock and should fit with slight compression in the glass cartridge, supported by the wire screen. The two PUF plugs (i.e., 1-inch and 2-inch deep) are also commercially available as pre-cut separate pieces.

3.4.3.3 For initial cleanup, the PUF plugs are placed in a Soxhlet apparatus and extracted with acetone for 16 hours at approximately 4 cycles per hour. When cartridges are reused, diethyl ether/hexane (5 to 10 percent v/v) can be used as the cleanup solvent.

NOTE: A modified PUF cleanup procedure can be used to remove unknown interference components of the PUF blank. This method consists of compressed rinsing 50 times with toluene, acetone, and diethyl ether/hexane (5 to 10 percent v/v) and followed by Soxhlet extraction.

3.4.3.4 The extracted PUF is placed in a vacuum oven connected to a water aspirator and a source of clean dry nitrogen or air. Nitrogen or air is purged through the oven to dry the PUF at room temperature for approximately 2 to 4 hours. At the end of the drying period, there should be no solvent odor detected.

3.4.3.5 The extract from the Soxhlet extraction procedure from each batch may be analyzed for the purpose of determining initial cleanliness prior to certification.

3.4.4 **PUF/XAD-2 Adsorbent Cartridge Preparation**

3.4.4.1 A nickel or stainless steel screen (mesh size 200/200) is fitted to the bottom of a hexane-rinsed glass sampling cartridge to retain the PUF/XAD-2 adsorbents, as illustrated in Figures D/SV-1 and D/SV-2. A Soxhlet-extracted, vacuum dried PUF (2.5-cm thick by 6.5-cm diameter) is placed on top of the screen in the glass sampling cartridge using polyester gloves.

3.4.4.2 Approximately 10 g of 35/60 mesh Soxhlet-extracted, vacuum dried XAD-2 resin is placed into the sampling cartridge (using clean white cotton gloves) on top of the PUF. A second Soxhlet-extracted, vacuum-dried PUF adsorbent (6.5-cm x 5.0-cm) is placed on top of the XAD-2 resin bed. Finally, the top nickel or stainless steel screen is fitted to the sampling cartridge.

3.4.4.3 The glass module containing the PUF/XAD-2 adsorbent is wrapped with hexane-rinsed aluminum foil, placed in a labeled container, and tightly sealed with Teflon® tape or liner.

NOTE: The aluminum foil should be baked in an oven overnight at 500°C after rinsing with hexane to ensure that no residuals remain.

3.5 PROCEDURE FOR CERTIFICATION OF PUF/XAD-2 CARTRIDGE ASSEMBLIES

3.5.1 Assemble the Soxhlet apparatus. Charge the Soxhlet apparatus with 500 mL of the extraction solvent (10 percent v/v diethyl ether/hexane) and reflux for 2 hours. Let the apparatus cool, disassemble it, and discard the used extraction solvent. Transfer the filter and PUF/XAD-2 glass cartridge to the Soxhlet apparatus (the use of an extraction thimble is optional).

NOTE: The filter and adsorbent assembly are tested together in order to reach detection limits and to minimize cost.

3.5.2 Add 500 mL of diethyl ether/hexane (10 percent v/v) to the Soxhlet apparatus. Reflux the sample for 18 hours at a rate of at least 3 cycles per hour. Allow to cool, then disassemble the apparatus.

3.5.3 Assemble a K-D concentrator by attaching a 10-mL concentrator tube to a 500-mL evaporative flask. Other concentration devices or techniques may be used in place of the K-D, if equivalency is demonstrated for all the target analyte compounds listed in Exhibit C.

3.5.4 Transfer the extract by pouring the extract through a drying column containing about 10 cm of anhydrous granular sodium sulfate, and collect the extract in the K-D concentrator. Rinse the Erlenmeyer flask and column with 20 to 30 mL of 10% diethylether/hexane to complete the quantitative transfer.

3.5.5 Add one or two clean boiling chips and attach a three-ball Snyder column to the evaporative flask. Pre-wet the Snyder column by adding about 1 mL of the extraction solvent to the top of the column. Place the K-D apparatus on a hot water bath (50°C) so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in one hour. At the proper rate of distillation, the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches approximately 5 mL, remove the K-D apparatus from the water bath and allow it to drain and cool for at least 5 minutes. Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 5 mL of hexane. A 5-mL syringe is recommended for this operation.

3.5.6 Two different types of concentration techniques are permitted to obtain a final volume of 1.0 mL: micro-Snyder column and nitrogen blowdown techniques outlined in sections 4.4.2.4 and 4.4.2.5, respectively.

3.5.7 Analyze the extract by GC/MS according to the conditions in section 6.6. Only a single point standard is used for certification. The

analytes in the standard should have concentrations at or slightly above the analyte CRQLs per injection (similar to CAL 1).

3.5.8 The level of each target analyte for the extract each pair of filter and adsorbent assembly analyzed must be less than or equal to the analyte's CRQL, and the total level of target compounds must not exceed 10 μg.

3.5.9 Document results on Form VIII-AASV, Filter/Adsorbent Cartridge Certification Form. Reporting requirements are listed in Exhibit B.

3.6 DEPLOYMENT OF CARTRIDGES FOR FIELD SAMPLING

3.6.1 Prior to field deployment, a minimum of three surrogate compounds (i.e., chemically inert compounds not expected to occur in an environmental sample) are added to the center bed of the top PUF cartridge, using a microsyringe. The surrogate compounds must be added to each cartridge assembly.

3.6.2 The recoveries of the surrogate compounds are used to monitor for unusual matrix effects and gross sampling processing errors. Surrogate recovery is evaluated for acceptance by determining whether the measured concentration falls within the acceptance limits.

3.6.3 The following surrogate standards have been successfully used in determining matrix effects, breakthrough, and analytical problems by GC/MS. Refer to section 6.5.4 for preparation of surrogate spiking mixture.

	Surrogate Compound	Spiked Amount (μg/cartridge)
	Anthracene-d_{10}	100
	Benzo(a)pyrene-d_{12}	100
	2,4,6-Tribromophenol	100
	2-Fluorophenol	100
	Phenol-d_5	100
*	Nitrobenzene-d_5	100
*	2-Fluorobiphenyl	100
*	p-Terphenyl-d_{14}	100

* These three surrogate compounds must be added to each adsorbent cartridge sent out to the field as pre-sampling surrogates. The other five surrogate compounds must be added to the cartridges just prior to extraction. These concentrations are based upon a 1-μL injection of the resulting extract.

4 SAMPLE PREPARATION FOR GC/MS ANALYSIS

4.1 SUMMARY OF METHOD

The filters and adsorbent cartridges are spiked with post-sampling surrogate compounds and extracted with a Soxhlet apparatus with the appropriate solvent. The extract is concentrated by Kuderna-Danish (K-D) evaporator, followed by optional GC/ECD or GC/FID screening, and finally GC/MS analysis, as illustrated in Figure D/SV-3.

4.2 APPARATUS AND MATERIALS

4.2.1 Soxhlet extractors: Capable of extracting GMW Model PS-1 filter and adsorbent cartridges (2.3 in. x 5 in. length), 1000-mL flask, and condenser.

4.2.2 Pyrex glass tube furnace system: For activating silica gel at 180°C under purified nitrogen gas purge for an hour, with the capability of raising temperature gradually, best source.

4.2.3 Glass vials: 40-mL.

4.2.4 Erlenmeyer flask: 50-mL.

4.2.5 Spatulas and spoons: Teflon-coated stainless steel.

4.2.6 Kuderna-Danish (K-D) apparatus: 500-mL evaporation flask (Kontes K-570001-500, or equivalent), 10-mL graduated concentrator tubes (Kontes K-570050-1025, or equivalent) with ground-glass stoppers, and 3-ball macro Snyder Column (Kontes K-5700010500, K-50300-0121, and K-569001-219, or equivalent).

4.2.7 Adsorption columns for column chromatography: 1 cm x 10 cm with stands.

4.2.8 White cotton gloves: For handling cartridges and filters.

4.2.9 Minivials: 2-mL, borosilicate glass, with conical reservoir and screw caps lined with Teflon-faced silicone disks, and a vial holder.

4.2.10 Glove box: For working with extremely toxic standards and reagents with explosion-proof hood for venting fumes from solvents, reagents, etc.

4.2.11 Vacuum oven: Vacuum drying oven system capable of maintaining a vacuum at 240 torr (flushed with nitrogen) overnight.

4.2.12 Concentrator tubes and a nitrogen evaporation apparatus: With a variable flow rate.

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4.2.13 Laboratory refrigerator.

4.2.14 Boiling chips: Solvent-extracted 10/40 mesh silicon carbide, or equivalent.

4.2.15 Water bath: Heated, with concentric ring cover, capable of ±5°C temperature control.

4.2.16 Vortex evaporator (optional).

4.2.17 Teflon® sleeves for the ground-glass joints on the Soxhlet extraction apparatus.

NOTE: Reuse of glassware should be minimized to avoid the risk of cross-contamination. All glassware that is used, especially glassware that is reused, must be scrupulously cleaned as soon as possible after use. Rinse glassware with the last solvent used in it and then with high-purity acetone and hexane. Wash with hot water containing detergent. Rinse with copious amounts of tap water and several portions of distilled water. Drain dry and heat in a muffle furnace at 400°C for 4 hours. Volumetric glassware must not be heated in a muffle furnace; rather, it should be rinsed with high-purity acetone and hexane. After the glassware is dry and cool, rinse it with hexane, and store it inverted or capped with solvent-rinsed aluminum foil in a clean environment.

4.3 REAGENTS

4.3.1 Methylene chloride: Chromatographic grade, glass-distilled.

4.3.2 Sodium sulfate: Anhydrous (ACS), granular (purified by washing with methylene chloride followed by heating at 400°C for 4 hours in a shallow tray).

4.3.3 Diethyl ether: Chromatographic grade, glass-distilled.

4.3.4 Hexane: Chromatographic grade, glass-distilled.

4.3.5 Nitrogen: High purity grade.

4.4 PROCEDURE

4.4.1 Soxhlet Extraction

4.4.1.1 Assemble the Soxhlet apparatus. Charge the Soxhlet apparatus with 500 mL of the extraction solvent and reflux for 2 hours. Let the apparatus cool, disassemble it, transfer the PUF/XAD-2 adsorbent and filter to the Soxhlet apparatus (the use of an extraction thimble is optional), and discard the spent solvent.

NOTE: The filter and adsorbent are analyzed together in order to reach Contract Required Quantitation Limits (CRQLs), to avoid questionable interpretation of the data, and to minimize cost.

4.4.1.2 Prior to extraction, the following five additional surrogate compounds are spiked onto each cartridge received from the field.

Surrogate Compound	Spiked Amount (µg/cartridge)
Anthracene-d_{10}	100
Benzo(a)pyrene-d_{12}	100
2,4,6-Tribromophenol	100
2-Fluorophenol	100
Phenol-d_5	100

For blank and sample cartridges not sent out to the field, these surrogate compounds are spiked along with the three pre-sampling surrogates (nitrobenzene-d_5, 2-fluorobiphenyl, and p-terphenyl-d_{14}) just prior to extraction. The surrogate spiking technique is illustrated in Figure D/SV-5 at the end of this exhibit.

NOTE: The recovery of the surrogate standards are used to monitor for unusual matrix effects, gross sample processing errors, problems with the analytical method, etc. Surrogate recovery is evaluated for acceptance by determining whether the measured concentration falls within the acceptance limits.

4.4.1.3 Add 500 mL of diethyl ether/hexane (10 percent v/v) to the Soxhlet apparatus. Reflux the sample for 18 hours at a rate of at least 3 cycles per hour. Allow to cool then disassemble the apparatus.

4.4.2 Extract Concentration

4.4.2.1 Assemble a K-D concentrator by attaching a 10-mL concentrator tube to a 500-mL evaporative flask. Other concentration devices or techniques may be used in place of the K-D, if equivalency is demonstrated for all the target analyte compounds listed in Exhibit C.

4.4.2.2 Transfer the extract from section 4.4.1.3 by pouring the extract through a drying column containing about 10 cm of anhydrous granular sodium sulfate, and collect the extract into the K-D concentrator. Rinse the flask and column with 20 to 30 mL of 10% diethyl ether/hexane to complete the quantitative transfer.

4.4.2.3 Add one or two clean boiling chips and attach a three-ball Snyder column to the evaporative flask. Pre-wet the Snyder column by adding about 1 mL of the extraction solvent to the top of the column. Place the K-D apparatus on a hot water bath (50°C) so that the

concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed with hot vapor. Adjust the vertical position of the apparatus and the water temperature as required to complete the concentration in one hour. At the proper rate of distillation, the balls of the column will actively chatter but the chambers will not flood with condensed solvent. When the apparent volume of liquid reaches 5 mL, remove the K-D apparatus from the water bath and allow it to drain and cool for at least 5 minutes. Remove the Snyder column and rinse the flask and its lower joint into the concentrator tube with 5 mL of hexane. A 5-mL syringe is recommended for this operation. The extract is now ready for further concentration to 1.0 mL by either the micro-Snyder column or nitrogen blowdown techniques.

4.4.3 Micro-Snyder Column Technique

4.4.3.1 Add another one or two clean boiling chips to the concentrator tube and attach a two-ball micro-Snyder column.

4.4.3.2 Pre-wet the Snyder column by adding about 1 mL of hexane to the top of the column.

4.4.3.3 Place the K-D apparatus on a hot water bath (50°) so that the concentrator tube is partially immersed in hot water.

4.4.3.4 Adjust the vertical position of the apparatus and the water temperature required to complete the concentration in 15 to 20 minutes. At the proper rate of distillation the balls of the column will actively chatter but the chambers will not flood with condensed solvent.

4.4.3.5 When the apparent volume of liquid reaches about 0.5 mL, remove the K-D apparatus from the water bath and allow it to drain for a least 10 minutes while cooling.

4.4.3.6 Remove the Snyder column and rinse its flask and its lower joint into the concentrator tube with 0.2 mL of hexane.

4.4.3.7 Adjust the final volume to 1.0 mL with hexane.

4.4.3.8 Transfer the extract to a Teflon-sealed screw-cap amber vial. Label the vial and store at 4°C (±2°C). The extract is now ready for optional GC/FID or GC/ECD screening, followed by GC/MS analysis.

4.4.4 Nitrogen Blowdown Technique (from ASTM Method D3086)

CAUTION: Gas lines from the gas source to the blowdown apparatus must be stainless steel, copper, or Teflon tubing.

4.4.4.1 Place the concentrator tube with an open micro-Snyder attachment in a warm water bath (30° to 35°C) and evaporate the solvent volume to just below 1 mL by blowing a gentle stream of clean, dry nitrogen (filtered through a column of activated carbon) above the extract.

4.4.4.2 The internal wall of the concentrator tube must be rinsed down several times with hexane during the operation.

4.4.4.3 During evaporation, the tube solvent level must be kept below the water level of the bath. The extract must never be allowed to become dry.

4.4.4.4 Bring the final volume brought to 1.0 mL with hexane. Transfer the extract to a Teflon-sealed screw-cap amber vial, label the vial and store at 4°C (±2°C). The extract is now ready for optional GC/FID or GC/ECD screening, followed by GC/MS analysis.

4.5 DILUTIONS

4.5.1 When a sample extract is analyzed that has an analyte target compound concentration greater than the upper limit of the initial calibration range or saturated ions from a compound (excluding the compound peaks in the solvent front), the extract must be diluted and reanalyzed. Secondary ion quantitation is only allowed when there are sample interferences with the primary quantitation ion. If secondary ion quantitation is used, calculate a relative response factor using the area response from the most intense secondary ion which is free of sample interferences, and document the reasons for the use of the secondary ion in the SDG Narrative.

4.5.2 Calculate the sample dilution necessary to keep the semivolatile target compounds that required dilution within the upper half of the initial calibration range and so that no compound has saturated ions (excluding the compound peaks in the solvent front). Dilute the sample in hexane in a volumetric flask. Analyze the diluted sample per section 6.13.3.

4.5.3 The dilution factor chosen should keep the response of the largest peak for a target compound in the upper half of the initial calibration range of the instrument.

4.5.4 If the on-column concentration of any target compound in any sample exceeds the initial calibration range, that sample must be diluted, the internal standard concentration readjusted, and the sample extract reanalyzed.

4.5.5 Use the results of the original analysis to determine the approximate dilution factor required to get the largest analyte peak

within the initial calibration range.

4.5.6 Do not submit data for more than two analyses, i.e., the original sample extract and one dilution, or, if the semivolatile screening procedure was employed, from the most concentrated dilution analyzed and one further dilution.

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5 GC/FID OR GC/ECD OPTIONAL SCREENING METHODOLOGY

5.1 SUMMARY OF METHOD

As an option, the sample extract may be screened prior to GC/MS analysis to approximate the range of concentration of target compounds for dilution prior to quantitation with the GC/MS. Screening is accomplished utilizing a gas chromatograph coupled to specific detectors. For pesticides and other chlorinated compounds, electron capture detector (ECD) is used, and for the other semivolatiles, a flame ionization detector (FID) is employed.

5.2 APPARATUS

5.2.1 Gas chromatograph: The gas chromatograph (GC) system must adequately regulate temperature in order to give a reproducible temperature program and have a flow controller that maintains a constant column flow rate throughout temperature program operations. The system must be suitable for splitless injection and have all required accessories including syringes, analytical columns, and gases.

5.2.2 GC column: 30 m x 0.25 mm I.D. fused silica column, 1.0 μm filter thickness (DB-5, J&W Scientific, Folsom, CA, or equivalent).

5.2.3 Electron capture detector: The makeup gas must be P-5, P-10 (argon/methane) or nitrogen according to the instrument specification. The GC/ECD system must be in a room in which the atmosphere has been demonstrated to be free of all contaminants which may interfere with the analysis. The instrument must be vented to the outside of the facility or to a trapping system which prevents the release of contaminants into the instrument room.

5.2.4 Flame ionization detector.

5.2.5 Data system: A data system must be interfaced to the GC/FID or GC/ECD. The data system must allow the continuous acquisition of data throughout the duration of the chromatographic program and must permit, at the minimum, the output of time vs intensity (peak height or peak area) data. Also, the data system must be able to rescale chromatographic data in order to report chromatograms meeting the requirements listed within this method.

5.3 REAGENTS

The carrier gas for routine applications is helium. Laboratories may choose to use hydrogen as a carrier gas, but must clearly identify its use in the SDG Narrative and on all divider pages preceding raw chromatographic data in submissions to the Agency. Laboratories that choose to use hydrogen are advised to exercise caution in its use. Use of

a hydrogen leak detector is highly recommended when hydrogen is used as the carrier gas. All GC carrier gas lines must be constructed from stainless steel or copper tubing. Non-polytetrafluoroethylene (PTFE) thread sealants or flow controllers with rubber components are not to be used.

5.4 STANDARD PREPARATION

5.4.1 The CAL 3 working standard solutions in hexane prepared according to section 6.5.11 may be used for screening purposes.

5.4.2 If the level of chlorinated solvent (from the stock solutions) in the standards prepared for GC/MS analysis interferes with the GC screening methods, stock standard solutions made purely in non-chlorinated solvents such as hexane may be prepared, then accurately diluted in an appropriate solvent to contain CAL 3 levels outlined in Table D/SV-1.

5.5 INSTRUMENT OPERATING CONDITIONS

Suggested GC operating conditions are as follows:

GC Column:	DB-5 fused silica, 1.0 μm 5% phenyl methyl siloxane bonded, 30 m x 0.25 mm I.D.
Carrier Gas:	Helium, 28-30 cm/sec
Flow Rate:	1 cm/minute.
Column Program:	Initial Temperature: 40°C
Initial Time:	1 min
Ramp Rate:	15°C/min to 200°C, increase to 3°C/min
Final Temperature:	300°C.

5.6 PROCEDURE

5.6.1 Before analysis can be performed, make sure that the system is within optimum operating conditions. This is an optimal screening procedure, and it is up to the laboratory to ensure that the GC is properly calibrated, and that stable retention times are obtained.

5.6.2 Inject the calibration standard which may be the mid level (CAL 3) standard in the GC/MS analysis initial calibration range.

5.6.3 Inject the appropriate extract from Section 4 including the blanks. The laboratory must note that if an ECD detector is used, the internal standards which are in methylene chloride should not be in the extract when performing GC/ECD screening.

5.6.4 If no peaks are observed from the extract, it may be analyzed by GC/MS without dilution.

5.6.5 If peaks are detected, calculate the approximate concentrations and

the necessary dilutions, if any, to reduce the major peaks to between half and full scale deflection when performing GC/MS analysis.

5.6.6 Make any necessary dilutions and proceed with GC/MS analysis (Section 6).

5.6.7 It is recommended that extracts be diluted so that all peaks are on scale. Overlapping peaks are not always evident when peaks are off scale. Computer reproduction of chromatograms, manipulated to ensure all peaks are on scale over a 100-fold range, are acceptable if linearity is demonstrated. Peak height measurements are recommended over peak area integration when overlapping peaks cause errors in area integration.

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6 GC/MS ANALYSIS

6.1 SUMMARY OF METHOD

This method outlines a GC/MS procedure for the analysis of semivolatiles following sample preparation (Section 4) or optional screening (Section 5).

6.2 INTERFERENCES

6.2.1 Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that result in discrete artifacts and/or elevated baselines in the detector profiles. All of these materials must be routinely demonstrated to be free from interferences under the conditions of the analysis by running a laboratory method blanks (LMB).

6.2.2 Glassware must be scrupulously cleaned. Clean all glassware as soon as possible after use by rinsing with the last solvent used in it. This should be followed by detergent washing with hot water and rinsing with tap water and reagent water. It should then be drained dry, solvent rinsed with acetone and spectrographic grade hexane. After drying and rinsing, glassware should be sealed and stored in a clean environment to prevent any accumulation of dust or other contaminants. Glassware should be stored inverted or capped with aluminum foil.

NOTE: The glassware, except for volumetrics, may be further cleaned by placing in a muffle furnace at 450°C for 8 hours to remove trace organics.

6.2.3 The use of high purity water, reagents, and solvents helps to minimize interference problems. Purification of solvents by distillation in all-glass systems may be required.

6.2.4 Matrix interferences may be caused by contaminants that are coextracted from the sample.

6.2.5 The extent of interferences that may be encountered has not been fully assessed. Although GC conditions described allow for unique resolution of compounds covered by this method, other compounds may interfere. The analytical system must be routinely demonstrated to be free of internal contaminants such as contaminated solvents, glassware, or other reagents which may lead to method interferences. A laboratory reagent blank may be run for each batch of reagents used to determine if reagents are contaminant-free.

6.2.6 There are concerns that during sample transport and analysis, heat, ozone, NO_2, and ultraviolet (UV) light may cause sample degradation. These problems should be addressed as part of the user-prepared SOP manual. Where possible, incandescent or UV-shielded fluorescent lighting in the laboratory should be used during analysis.

6.3 APPARATUS AND MATERIALS

6.3.1 Gas chromatograph: An analytical system complete with a temperature-programmable gas chromatograph suitable for splitless injection equipped with a flow controller that maintains a constant column flow rate throughout temperature program operations, and all required accessories, including syringes, analytical columns, and gases. All GC carrier gas lines must be constructed from stainless steel or copper tubing. Non-polytetrafluoroethylene (PTFE) thread sealants or flow controllers with rubber components should not be used.

6.3.2 Mass spectrometer: Capable of scanning from 35 to 510 amu every 1 second or less, utilizing 70 volts (nominal) electron energy in the electron impact (EI) ionization mode and producing a mass spectrum which meets all the instrument performance criteria when 50 ng of decafluorotriphenylphosphine (DFTPP) is injected through the GC inlet. To ensure sufficient precision of mass spectral data, the MS scan rate must allow acquisition of at least five scans while a sample compound elutes from the GC. The GC/MS system must be in a room with atmosphere demonstrated to be free of all potential contaminants which will interfere with the analysis. The instrument must be vented outside the facility or to a trapping system which prevents the release of contaminants into the instrument room.

NOTE: DFTPP criteria must be met before any sample extracts are analyzed. Any samples analyzed when DFTPP criteria have not been met will require reanalysis at no cost to the Agency.

6.3.3 GC/MS interface: Any gas chromatograph to mass spectrometer interface that gives acceptable calibration points for each of the parameters of interest, and achieves all acceptable performance criteria (Exhibit E), may be used. Gas chromatograph to mass spectrometer interfaces constructed of all-glass or glass-lined materials are recommended. Glass can be deactivated by silanizing with dichlorodimethylsilane.

6.3.4 Data system: A computer system must be interfaced to the mass spectrometer that allows the continuous acquisition and storage on machine-readable media of all mass spectra obtained throughout the duration of the chromatographic program. The computer must have software that allows searching the GC/MS data file for ions of a specific mass and plotting such ion abundances versus time or scan number. This type of plot is defined as Selected Ion Current Profile (SICP). Software must be available that allows integrating the abundance in any SICP between specified time or scan number limits. Also, for the non-target compounds, software must be available that allows comparing sample spectra against reference spectra. The most recent release of the NIST/EPA/MSDC mass spectral library shall be used as the reference library. The data system must be capable of flagging all data files that have been edited manually by laboratory personnel.

6.3.5 Magnetic tape storage device: The magnetic tape storage device must be capable of recording data and suitable for long-term, off-line storage.

6.3.6 Chromatographic Column: A 30 m x 0.25 mm I.D. (or 0.32 mm I.D.) bonded-phase silicone-coated fused silica capillary column (J&W Scientific DB-5, Alltech Associates SE-54, or equivalent) must be used. A film thickness of 1.0 μm is recommended because of its larger capacity. A film thickness of 0.25 μm may also be used. A megabore column (0.53 mm I.D.) may also be used as long as all QC criteria are met.

6.4 REAGENTS

6.4.1 Hydrogen and helium: Gas cylinders of ultra high purity, (99.9999 percent).

6.4.2 Combustion air: Ultra high purity.

6.4.3 Zero air: May be obtained from a cylinder or zero-grade compressed air scrubbed with Drierite or silica gel and 5A molecular sieve or activated charcoal, or by catalytic cleanup of ambient air. All zero air must pass through a liquid argon cold trap for final cleanup.

6.5 STANDARDS

6.5.1 The Contractor must provide all standards to be used with this contract. These standards may be used only after they have been certified according to the procedure in Exhibit E or by the manufacturer. The Contractor must be able to verify that the standards are certified. Manufacturer's certificates of analysis must be retained by the Contractor and presented upon request. Each calibration standard solution shall contain all the appropriate surrogates and internal standards. Neat standards with compound purity of at least 97 percent must be used.

6.5.2 Commercially prepared stock standards may be used at any concentration if they are certified by the manufacturer or by an independent source, or traceable to EPA-supplied standards. Fresh stock standards must be prepared once every twelve months, or sooner, if standards have degraded or concentrated. Stock standards should be checked for signs of degradation or concentration just prior to preparing secondary dilution and working standards from them. Table D/SV-1 outlines the concentrations of the working calibration standards.

CAUTION: Each time a vial containing small volumes of solution is warmed to room temperature and opened, a small volume of solvent in the vial headspace evaporates, significantly affecting concentration.

6.5.3 Instrument performance check solution

Prepare a solution of decafluorotriphenylphosphine (DFTPP), such

that a 2-μL injection will contain 50 ng of DFTPP. The DFTPP should also be included in the calibration standards at this level.

6.5.4 Surrogate Compounds Spiking Solution

Prepare separate solutions to contain approximately 1000 μg/mL of each surrogate compound. From these solutions, prepare the spiking solution to obtain the following amounts when 1 mL is spiked into the cartridges. Fill a 1-mL syringe with the surrogate spiking solution and randomly inject a 200-μL portion into each of the five locations in the cartridge as illustrated in Figure D/SV-5.

	Surrogate Compound	Amount Spiked on Cartridge, μg
	Anthracene-d_{10}	100
	Benzo(a)pyrene-d_{12}	100
	2,4,6-Tribromophenol	100
	2-Fluorophenol	100
	Phenol-d_5	100
*	Nitrobenzene-d_5	100
*	2-Fluorobiphenyl	100
*	p-Terphenyl-d_{14}	100

* These surrogate compounds are spiked into the cartridges that are sent out to the field prior to field deployment (pre-sampling surrogates).

6.5.5 Internal Standards

Internal standard solutions of 1,4-dichlorobenzene-d_4, naphthalene-d_8, acenaphthene-d_{10}, phenanthrene-d_{10}, chrysene-d_{12}, and perylene-d_{12} can be prepared by dissolving 100 mg of each compound in 100 mL of methylene chloride. It may be necessary to use 5 to 10 percent benzene or toluene in this solution and a few minutes of ultrasonic mixing in order to dissolve all the constituents. The resulting solution will contain each standard at a concentration of 1000 ng/μL. A 40-μL portion of this solution should be added to each 1 mL of sample extract. This will result in 40 ng of each internal standard in the 1-μL volume of extract injected into the GC/MS. See Table D/SV-3 for the internal standards used for each target and surrogate compound.

6.5.6 Laboratory Control Sample Spiking Solution

Table D/SV-11 lists the compounds used for the laboratory control sample (LCS). Prepare two spiking mixtures containing the acid-neutral LCS compounds and the base-neutral LCS compounds at a concentration level of 1000 μg/mL. Spike a clean cartridge with the mixtures to contain 50 μg of each LCS compound.

NOTE: Each mixture (acid-neutral and base-neutral) may be spiked

separately onto the cartridge or may be mixed into one solution just prior to injection into the cartridge.

6.5.7 **PAHs Stock Standard Solutions**

6.5.7.1 Place 0.1 gram of native PAHs on a tared aluminum weighing disk and weigh on a balance.

6.5.7.2 Quantitatively transfer each to a 10-mL volumetric flask. Rinse the weighing disk with several small portions of methylene chloride. Ensure all material has been transferred. Dilute to mark with methylene chloride. The concentration of the stock standard solution of PAHs in the flask is 10 $\mu g/\mu L$.

6.5.7.3 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4°C (±2°C) and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing working standards.

6.5.7.4 Secondary standards may be prepared by diluting the stock standard solutions. Working standards are then prepared from the secondary standard solutions.

6.5.8 **Pesticides Stock Standard Solutions**

6.5.8.1 Prepare from pure standard materials. Weigh approximately 25.0 mg (with accuracy of 0.1 mg) of each pure pesticide analyte, except Endosulfan I and Endosulfan II. For these two pesticides, prepare a stock solution twice as concentrated as that prepared for other pesticide analytes. Dissolve each compound in hexane and dilute to volume in a 10-mL (5-mL for the two Endosulfans) volumetric flask. (Concentration of each component = 3.5 mg/mL, except the Endosulfans, which should be 5 mg/mL.) Smaller or larger volumes of stock solution may be used if desired.

6.5.8.2 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4°C (±2°C) and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing working standards.

6.5.8.3 Secondary standards may be prepared by diluting the stock standard solutions. Working standards are then prepared from the secondary standard solutions.

6.5.9 **PCBs Stock Standard Solutions**

6.5.9.1 Prepare a stock solution of each of the nine PCB concentration calibration congeners at a concentration of 1 $\mu g/\mu L$ in

hexane. Place each solution in a clean glass vial with a Teflon-lined screw cap. Fill to the top so no headspace is evident. Store at 4°C if solutions are not to be used right away. Solutions are stable indefinitely if solvent evaporation is prevented.

6.5.9.2 The 9 individual PCB congeners listed in Table D/SV-4 are used as the calibration compounds for PCB determinations. One isomer at each level of chlorination is used as the concentration calibration standard for all other isomers at that level of chlorination, except decachlorobiphenyl (Cl_{10}) which is used for both Cl_9 and Cl_{10} isomer groups. The basis for selection of these calibration congeners has been reported and referenced in Section 7 (Citation 9) and Table D/SV-4.

6.5.9.3 Take aliquots of the stock solutions of the nine PCB concentration calibration congeners and mix together in the proportions that will provide a primary dilution standard solution of the composition ratios illustrated in Table D/SV-1. Place each solution in a clean glass vial with a Teflon-lined screw cap and store at 4°C. Mark the meniscus on the vial wall to monitor solution volume during storage; solutions are stable indefinitely if solvent evaporation is prevented.

6.5.9.4 Five calibration solutions are required containing the internal standards, surrogates, and target compounds as specified in Table D/SV-1. Because MS response to PCBs decreases with increasing level of chlorination, PCB congener concentrations in calibration solutions increase with level of chlorination. Components of the highest concentration solution (CAL 5) are present at a concentration that allow injections of 1 μL aliquots without MS saturation or GC column overloading.

6.5.10 **Stock Standard Solutions of Other Semivolatiles**

6.5.10.1 Place 0.1 gram of each native semivolatile target analyte on a tared aluminum weighing disk and weigh on a balance.

6.5.10.2 Quantitatively transfer to a 10-mL volumetric flask. Rinse the weighing disk with several small portions of methylene chloride. Ensure that all material have been transferred. Dilute to mark with methylene chloride. The concentration of the stock standard solution of semivolatiles in the flask is 10 μg/μL.

6.5.10.3 Transfer the stock standard solutions into Teflon-sealed screw-cap bottles. Store at 4°C (±2°C) and protect from light. Stock standard solutions should be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards.

6.5.10.4 Secondary standards may be prepared by diluting the stock

standard solutions. Working standards are then prepared from the secondary standard solutions.

6.5.11 **Working Calibration Standards**

Prepare calibration standards in hexane at a minimum of five concentration levels as outlined in Table D/SV-1. Each calibration standard shall contain the appropriate target compounds, internal standards, and surrogate compounds as outlined in Tables D/SV-1. Great care must be taken to maintain the integrity of all standard solutions. Store all standard solutions at 4°C (±2°C) in screw-cap amber bottles with Teflon liners. Fresh standards should be prepared every twelve months at a minimum. The continuing calibration standard (see Table D/SV-1, CAL 3) should be prepared weekly and stored at 4°C (±2°C).

6.5.12 **Storage of Standard Solutions**

6.5.12.1 Store the stock and secondary standard solutions at 4°C (±2°C) in Teflon-lined screw-cap amber bottles. Store the working standard solutions at 4°C (±2°C) in Teflon-lined screw-cap amber bottles.

6.5.12.2 Protect all standards from light. Samples, sample extracts, and standards must be stored separately.

6.5.12.3 Stock standard solutions must be replaced every twelve months, or sooner, if comparison with quality control check samples indicates a problem.

6.6 **INSTRUMENT OPERATING CONDITIONS**

6.6.1 Gas chromatograph: The following are the recommended gas chromatographic analytical conditions, as outlined also in Table D/SV-2, to optimize conditions for compound separation and sensitivity.

Carrier Gas:	Helium
Linear Velocity:	28-29 cm^3/sec
Injector Temperature:	250-300°C
Injector:	Grob-type, splitless.
Temperature Program:	Initial Temperature: 50°C
Initial Hold Time:	4.0 ± 0.1 min.
Ramp Rate:	8°C/min
Final Temperature:	280°C
Analytical Time:	approximately 50 minutes
Injection Volume*:	1-µL

NOTE: A volume of 1-µL has been found to work with the concentrations shown in this document. If a different volume is used, the laboratory

must make appropriate adjustments to the calibration concentrations. Smaller volumes may be used only with automated systems.

6.6.2 Mass spectrometer: The following are the required mass spectrometer conditions for full range data acquisition.

Transfer Line Temperature:	250-300°C
Source Temperature:	According to Manufacturer's Specifications
Electron Energy:	70 volts (nominal)
Ionization Mode:	EI
Mass Range:	35 to 500 amu, full range data acquisition
Scan Time:	At least 5 scans per peak, not to exceed 1 second per scan.

6.7 ANALYTICAL SEQUENCE

The GC/MS analytical sequence for each 12-hour time period shall be as follows:

6.7.1 Instrument Performance Check (DFTPP)

6.7.2 Initial or continuing calibration

6.7.3 Laboratory method blank (LMB)

6.7.4 Laboratory Control Sample (LCS)

6.7.5 Field Blank

6.7.6 ≤20 field sample extracts

6.7.7 Performance Evaluation (PE) Sample (if available)

6.8 INSTRUMENT PERFORMANCE CHECK

6.8.1 Summary

It is necessary to establish that a given GC/MS meet tuning and standard mass spectral abundance criteria prior to initiating any on-going data collection, as illustrated in Figure D/SV-4. This is accomplished through the analysis of decafluorotriphenylphosphine (DFTPP).

6.8.2 Frequency

6.8.2.1 The instrument performance check solution of DFTPP must be analyzed initially and once per 12-hour time period of operation. Also, whenever the laboratory takes corrective action which may change

or affect the mass spectral criteria (e.g., ion source cleaning or repair, column replacement, etc.), the instrument performance check must be verified irrespective of the 12-hour laboratory requirement.

6.8.2.2 The 12-hour time period for GC/MS analysis begins at the injection of the DFTPP which the laboratory submits as documentation of a compliance tune. The time period ends after 12 hours have elapsed. In order to meet instrument performance check requirements, samples, blanks, and standards must be injected within 12 hours of the DFTPP injection.

6.8.3 **Procedure**

6.8.3.1 Inject 50 ng of DFTPP into the GC/MS system. All instrument conditions must be identical to those listed in section 6.6 except that a different temperature program may be used.

6.8.3.2 The DFTPP may be analyzed separately or as part of the calibration standard.

6.8.4 **Technical Acceptance Criteria**

6.8.4.1 Prior to the analysis of any samples, blanks, or calibration standards, the laboratory must establish that the GC/MS system meets the mass spectral ion abundance criteria for the instrument performance check solution containing DFTPP.

6.8.4.2 The GC/MS system must be checked for instrument performance at the frequency described in section 6.8.2. The GC/MS system must be tuned to meet the manufacturer's specifications, using a suitable calibrant. The mass calibration and resolution of the GC/MS system are verified by the analysis of the instrument performance check solution.

6.8.4.3 The abundance criteria listed in Table D/SV-5 must be met for a 50 ng injection of DFTPP. The mass spectrum of DFTPP must be acquired by averaging three scans (the peak apex scan and the scans immediately preceding and following the apex). Background subtraction is required, and must be accomplished using a single scan prior to the elution of DFTPP.

NOTE: All ion abundance **MUST** be normalized to m/z 198, the nominal base peak, even though the ion abundances of m/z 442 may be up to 110 percent that of m/z 198.

6.8.4.4 The criteria above are based on adherence to the acquisition specifications identified in Table D/SV-5 and were developed for the specific target compound list associated with this document. The criteria are based on performance characteristics of instruments

currently utilized in routine support of Program activities. These specifications, in conjunction with relative response factor criteria for target analytes are designed to control and monitor instrument performance associated with the requirements of this document. As they are performance-based criteria for these specific analytical requirements, they may not be optimal for additional target compounds.

6.8.5 Corrective Action

6.8.5.1 If the DFTPP acceptance criteria are not met, the MS must be retuned. It may be necessary to clean the ion source, or quadrupoles, or take other actions to achieve the acceptance criteria.

6.8.5.2 The DFTPP acceptance criteria MUST be met before any standards, field samples, or required blanks are analyzed. Any standards, field samples, or required blanks analyzed when tuning criteria have not been met will require reanalysis at no additional cost to the Agency.

6.8.6 Documentation

Reporting requirements are listed in Exhibit B. Instrument Performance Check data results are reported on Form IV-AASV, GC/MS Instrument Performance Check and Mass Calibration Form.

6.9 INITIAL CALIBRATION

6.9.1 Summary

6.9.1.1 Prior to the analysis of samples and required blanks, and after tuning criteria (instrument performance check) have been met, each GC/MS system must be initially calibrated at a minimum of five concentrations to determine instrument sensitivity and the linearity of GC/MS response for the analyte compounds and the surrogates.

6.9.1.2 All sample results are quantified using the RRFs from CAL 3 in the initial calibration or the RRFs from the most recent valid continuing calibration standard within the same 12-hour period.

6.9.2 Frequency

Each GC/MS system must be initially calibrated upon award of the contract, whenever the laboratory takes corrective action which may change or affect the initial calibration criteria (e.g., ion source cleaning or repair, column replacement, etc.), or if the continuing calibration acceptance criteria (see section 6.10.5) have not been met.

6.9.3 **Procedure**

6.9.3.1 Set up the GC/MS system under the conditions outlined in section 6.6.

6.9.3.2 All working standard solutions must be allowed to warm to ambient temperature (approximately 1 hour) before analysis.

6.9.3.3 Tune the GC/MS system to meet the technical acceptance criteria in section 6.8.4 for DFTPP.

6.9.3.4 Prepare five calibration standards containing the target compounds, internal standards, and surrogate compounds at the concentrations outlined in Table D/SV-1 and according to the procedure in section 6.5.

6.9.3.5 Calibrate the GC/MS by injecting 1.0 µL of each standard. If a compound saturates when the CAL 5 standard is injected, and the GC/MS system is calibrated to achieve a detection sensitivity of no less than the CRQL for each compound, the laboratory must document it in the SDG Narrative, and attach a quantitation report and chromatogram (see Exhibit B). In this instance, the laboratory must calculate the results based on a four-point initial calibration for the specific compound that saturates. Secondary ion quantitation is only allowed when there are sample interferences with the primary quantitation ion. If secondary ion quantitation is used, calculate a relative response factor using the area response from the most intense secondary ion which is free of interferences, and document the reasons for the use of the secondary ion in the SDG Narrative.

6.9.3.6 Record a spectrum of each target compound. Background subtraction and spectrum averaging may be needed. Judge the acceptability of recorded spectra by comparing them to spectra in libraries. If an acceptable spectrum of a calibration standard component is not acquired, take necessary actions to correct GC/MS performance. If performance cannot be corrected, report sample extract data for the particular compound(s), but document the affected compound(s) and the nature of the problem.

6.9.3.7 For PCBs, compare the quantitation ion to the confirmation ion. A proper calibration using the CAL 3 standard should document the ratio in the ranges found in Table D/SV-7.

6.9.4 **Calculations**

NOTE: In the following calculations, the area response is that of the primary quantitation ion unless otherwise stated.

6.9.4.1 Relative Response Factors (RRF): Table D/SV-8 outlines

characteristic ions for the surrogate compounds and internal standards. Table D/SV-9 outlines primary and secondary quantitation ions for the target compounds. Calculate RRFs for each analyte target compound and surrogate to the appropriate internal standard using the following equation:

$$RRF = \frac{A_x C_{is}}{A_{is} C_x} \qquad \text{Eq. D/SV-1}$$

where: A_x = area of the primary quantitation ion for the compound to be measured;
A_{is} = area of the primary quantitation ion for the internal standard;
C_{is} = concentration or amount of the internal standard; and
C_x = concentration or amount of the compound to be measured.

NOTE: C_{is} and C_x must be in the same units.

6.9.4.2 Percent Relative Standard Deviation (%RSD): Using the RRFs from the initial calibration, calculate the %RSD for all target compounds and surrogates using the following equations:

$$\%RSD = \frac{SD_{RRF}}{\bar{x}} \times 100 \qquad \text{Eq. D/SV-2}$$

and

$$SD_{RRF} = \sqrt{\sum_{i=1}^{N} \frac{(x_i - \bar{x})^2}{N - 1}} \qquad \text{Eq. D/SV-3}$$

where: SD_{RRF} = standard deviation of initial response factors (per compound);
$\bar{x}$ = mean of initial relative response factors (per compound); and
x_i = RRF for each calibration level.

6.9.4.3 Relative Retention Times (RRT): Calculate the RRTs for each target compound and surrogate over the initial calibration range using the following equation:

$$RRT = \frac{RT_c}{RT_{is}} \qquad \text{Eq. D/SV-4}$$

where: RT_c = retention time of the target compound; and
RT_{is} = retention time of the internal standard.

6.9.4.4 Mean of the Relative Retention Times ($\overline{RRT}$): Calculate the mean of the relative retention times ($\overline{RRT}$) for each analyte target compound and surrogate over the initial calibration range using the following equation:

$$\overline{RRT} = \sum_{i=1}^{n} \frac{RRT_i}{n} \qquad \text{Eq. D/SV-5}$$

where: $\overline{RRT}$ = mean relative retention time for the target compound or surrogate for each initial calibration standard; and
RRT_i = relative retention time for the target compound or surrogate for each initial calibration standard.

6.9.4.5 Mean Area Response ($\overline{Y}$) for Internal Standard: Calculate the area response (Y) mean for primary quantitation ion each internal standard compound over the initial calibration range using the following equation:

$$\overline{Y} = \sum_{i=1}^{n} \frac{Y_i}{n} \qquad \text{Eq. D/SV-6}$$

where: $\overline{Y}$ = mean area response; and
Y_i = area response for the primary quantitation ion for the internal standard for each calibration level.

6.9.4.6 Percent Area Response Change (%ARC): Calculate the %ARC at each calibration level for each of the internal standards using the following equation.

$$\%ARC = \frac{A_x - \overline{Y}}{\overline{Y}} \times 100 \qquad \text{Eq. D/SV-7}$$

where: %ARC = percent area response change;
A_x = area response of the internal standard at a concentration level; and
$\overline{Y}$ = mean area response of the internal standard in the entire calibration range.

6.9.4.7 Mean of the Retention Times ($\overline{RT}$) For Internal Standard: Calculate the mean of the retention times ($\overline{RT}$) for each internal standard over the initial calibration range using the following equation:

$$\overline{RT} = \sum_{i=1}^{n} \frac{RT_i}{n} \qquad \text{Eq. D/SV-8}$$

where: $\overline{RT}$ = mean retention time; and
RT = retention time for the internal standard for each initial calibration standard.

6.9.4.8 Internal Standard Retention Time Shift (RTS): Calculate the RTS between the RT of each internal standard at each concentration level and the $\overline{RT}$ for that internal standard over the entire calibration range using the following equation:

$$RTS = \overline{RT_i} - RT_x \qquad \text{Eq. D/SV-9}$$

where: $\overline{RT_i}$ = mean of the retention time for the internal standard in the initial calibration; and
RT_x = retention time of the internal standard at a concentration level.

6.9.5 Technical Acceptance Criteria

6.9.5.1 All initial calibration standards must be analyzed at the concentration levels and frequency described in this section on a GC/MS system meeting the DFTPP instrument performance check criteria.

6.9.5.2 The performance criteria for initial calibration of the CAL 3 must show:

- Baseline separation of beta-BHC and gamma-BHC;
- Baseline separation of endrin ketone and chrysene-d_{12};
- Signal/noise ratio of ≥5 for m/z 499 of PCB congener Cl_{10}-PCB to illustrate MS sensitivity;
- Lack of degradation of endrin: examine an extracted ion current profile (EICP) for m/z 67 in the retention time window between 4,4'-DDE and endosulfan sulfate; confirm that the abundance of m/z 67 at the retention time of endrin aldehyde is greater than 10 percent of the abundance of m/z 67 produced by endrin; and

6.9.5.3 The RRFs at each calibration concentration for each target compound and surrogate that has a required minimum response factor value must be greater than or equal to the compound's minimum acceptable relative response factor see Table D/SV-6.

6.9.5.4 The %RSD over the initial calibration range for each target compound and surrogate that has a required maximum %RSD must be less than or equal to the required maximum value. For all the other target compounds, the value for %RSD must be less than or equal to 25 percent. When the value for %RSD exceeds 25 percent, analyze additional aliquots of appropriate CALs to obtain an acceptable %RSD of RRFs over the entire concentration range, or take action to improve GC/MS performance.

6.9.5.5 The RRT for each of the target compounds and surrogates at

each calibration level must be within ±0.06 relative retention time units of the mean relative retention time for the compound.

6.9.5.6 The internal standard %ARC at each calibration level must be within ±40 percent of the mean area response ($\bar{Y}$) over the initial calibration range for each internal standard.

6.9.5.7 The retention time shift for each of the internal standards at each calibration level must be within ±20.0 seconds compared to the mean retention time ($\overline{RT}$) over the initial calibration range for each internal standard.

6.9.5.8 The compounds listed in Exhibit C must meet the minimum RRF and maximum %RSD criteria for the initial calibration, with allowance made for up to four target and surrogate compounds. However, the RRFs for those four compounds must be greater than 0.010, and the %RSD of those four compounds must be less than or equal to 40.0 percent for the initial calibration to be acceptable.

6.9.6 Corrective Action

6.9.6.1 If the technical acceptance criteria for initial calibration are not met, inspect the system for problems. It may be necessary to clean the ion source, change the column, or take other corrective actions to achieve the acceptance criteria.

6.9.6.2 All initial calibration technical acceptance criteria MUST be met before any samples or required blanks are analyzed in a 12-hour time period for an initial calibration analytical sequence. Any samples or required blanks analyzed when initial calibration criteria have not been met will require reanalysis at no additional cost to the Agency.

6.9.7 Documentation

Reporting requirements are listed in Exhibit B. Initial calibration data results are reported on Form V-AASV, Initial Calibration Data Sheet. Internal standard area and retention times shall be tabulated on Form VII-AASV.

6.10 CONTINUING CALIBRATION

6.10.1 Summary

Prior to the analysis of samples and required blanks and after tuning criteria have been met, the initial calibration of each GC/MS system must be routinely checked by analyzing a continuing calibration standard (CAL 3) to ensure that the instrument continues to meet the instrument sensitivity and linearity requirements of the method, as illustrated in Figure D/SV-4. The continuing calibration standard

(CAL 3) shall contain the appropriate target compounds, surrogates, and internal standards.

6.10.2 **Frequency**

The GC/MS system shall be calibrated with a continuing calibration standard (CAL 3) at the beginning of every 12-hour time period after the injection of DFTPP, to check for the validity of the initial calibration.

6.10.3 **Procedure**

6.10.3.1 Set up the GC/MS system under the conditions outlined in section 6.6 and as specified by the manufacturer, and tune the GC/MS system to meet the technical acceptance criteria in section 6.8.4 for DFTPP.

6.10.3.2 All working standard solutions must be allowed to warm to ambient temperature (approximately 1 hour) before analysis.

6.10.3.3 Start the analysis of the continuing calibration by injecting 1.0 μL of the CAL 3 standard solution which contains the appropriate target analytes, surrogate compounds, and internal standards using the procedure listed the initial calibration section.

6.10.4 **Calculations**

6.10.4.1 Relative Response Factor (RRF): Calculate a relative response factor (RRF) for each target compound and surrogate using the equation in section 6.9.4.1.

6.10.4.2 Percent Difference (%D): Calculate the percent difference between the mean relative response factor ($\overline{RRF}$) from the most recent initial calibration and the continuing calibration RRF for each analyte target compound and surrogate using the following equation:

$$\%D_{RRF} = \frac{RRF_c - \overline{RRF_i}}{\overline{RRF_i}} \times 100 \qquad \text{Eq. D/SV-10}$$

where: $\%D_{RRF}$ = percent difference between relative response factors;
$\overline{RRF_i}$ = average relative response factor from the most recent initial calibration; and
RRF_c = relative response factor from the continuing calibration standard.

6.10.5 **Technical Acceptance Criteria**

6.10.5.1 The continuing calibration standard must be analyzed for the compounds listed in Exhibit C at the frequency described in section

6.10.2 on a GC/MS system meeting the DFTPP instrument performance check and the initial calibration technical acceptance criteria.

6.10.5.2 The RRF for each target analyte and surrogate that has a required minimum relative response factor value must be greater than or equal to the compound's minimum acceptable relative response factor.

6.10.5.3 For an acceptable continuing calibration, the %D between the measured RRF for each target/surrogate compound of the CAL 3 standard and the mean value calculated during initial calibration must be within ±25.0 percent. If the criteria for %D are not met for any target or surrogate compound, remedial action must be taken and recalibration may be necessary.

6.10.6 Corrective Action

6.10.6.1 If the continuing calibration technical acceptance criteria are not met, recalibrate the GC/MS instrument according to section 6.9. It may be necessary to clean the ion source, change the column or take other corrective actions to achieve the acceptance criteria.

6.10.6.2 Continuing calibration technical acceptance criteria **MUST** be met before any samples or required blanks are analyzed in a 12-hour continuing calibration analytical sequence. Any samples or required blanks analyzed when continuing calibration criteria have not been met will require reanalysis at no additional cost to the Agency.

6.10.6.3 Remedial actions, which include but are not limited to the following, must be taken if criteria are not met:

- Check and adjust GC and/or MS operating conditions;
- Clean or replace injector liner;
- Flush column with solvent according to manufacturers instructions;
- Break off a short portion (approximately 0.33 m) of the column;
- Replace GC column (performance of all initial calibration procedures are then required);
- Adjust MS for greater or lesser resolution;
- Calibrate MS mass scale;
- Prepare and analyze new continuing calibration; and
- Prepare a new initial calibration curve.

6.10.7 Documentation

Reporting requirements are listed in Exhibit B. Continuing calibration data results are reported on Form VI-AASV, Continuing Calibration Data Form. Internal standard area and retention time shall be tabulated on Form VII-AASV.

6.11 BLANK ANALYSIS

6.11.1 Summary

6.11.1.1 To monitor for possible laboratory and field contamination, laboratory method blank (LMB) and field blanks are extracted with each SDG and analyzed at least once in a 12-hour analytical sequence. All steps in the analytical procedure are performed on the LMB using all reagents, standards, surrogate compounds, equipment, apparatus, glassware, and solvents that would be used for a sample analysis.

6.11.1.2 An LMB is an unused, certified filter/cartridge assembly which is carried through the same extraction procedure as a field sample. The LMB extract must contain the same amount of surrogate compounds and internal standards that is added to each sample. All field samples must be extracted and analyzed with an associated LMB.

6.11.1.3 A field blank is designed to detect potential sample contamination during the handling and shipping process of a field sample. The cartridge used as a field blank must be associated with the actual sampling process; therefore, the blank cartridge is opened with the other cartridges, resealed, and carried through the same handling process as those used to sample ambient air.

6.11.1.4 The same amount of internal standards that are added to each sample is added to each blank. All field samples must be analyzed with associated blanks.

6.11.2 Frequency

6.11.2.1 An LMB along shall be prepared along with each batch of ≤20 samples and shall be carried through the entire extraction, concentration, and analysis procedures. The laboratory method blank must be analyzed after the calibration standard(s) before any samples are analyzed. Whenever an unusually concentrated sample is encountered, an LMB analysis shall be performed immediately after the sample analysis.

6.11.2.2 A field blank is analyzed once per sample delivery group. A field blank shall be analyzed along with each batch of ≤20 samples and shall be carried through the entire analytical procedure.

6.11.2.3 The laboratory may also analyze a laboratory reagent blank which is the same as an LMB except that no cartridge is extracted, and no surrogate compounds or internal standards are added; this demonstrates that reagents do not contain impurities that produce an ion current above the level of background noise for any target compound quantitation ions.

6.11.3 Procedure

6.11.3.1 Spike the blank cartridges with the same amount of surrogate compounds using the same spiking technique as the field samples (see Figure D/SV-5). For the field blank, the three pre-sampling surrogates are spiked onto the cartridge prior to field deployment, along with the cartridges to be used for sampling ambient air. For the LMB, all eight surrogate compounds are spiked into the cartridges just prior to extraction.

6.11.3.2 Extract the blanks following the procedures in Section 4.

6.11.3.3 Add the internal standards to the blank extracts at the same concentration as the field sample extracts.

6.11.3.4 Analyze the blank extracts following the same analysis procedures as the field sample extracts.

6.11.4 Calculations

The equations in section 6.13.4 apply to the blanks.

6.11.5 Technical Acceptance Criteria

6.11.5.1 All blanks must be analyzed at the frequency described in section 6.11.2 on a GC/MS system meeting the DFTPP instrument performance check and initial calibration or continuing calibration technical acceptance criteria.

6.11.5.2 The percent recovery for each of the surrogates in the blank must be within the acceptance windows listed in section 6.13.5.3.

6.11.5.3 The percent area response change (%ARC) for each of the internal standards for the blank must be within ±40 percent compared to the internal standards in the most recent CAL 3 analysis.

6.11.5.4 The retention time for each of the internal standards must be within ±20.0 seconds between the blank and the most recent CAL 3 analysis.

6.11.5.5 The blank must not contain any target analyte at a concentration greater than its CRQL and must not contain additional

compounds with elution characteristics and mass spectral features that would interfere with identification and measurement of a method analyte at its CRQL. The total level of analytes in the blank filter/cartridge must not exceed 10 µg. If the LMB that was extracted along with a batch of samples is contaminated, the reported values for the entire batch of samples must be flagged with a "B."

6.11.6 Corrective Action

6.11.6.1 If a Contractor's blanks do not meet the technical acceptance criteria, the Contractor must consider the analytical system to be out of control. It is the Contractor's responsibility to ensure that method interferences caused by contaminants in solvents, reagents, glassware, and other sample storage and processing hardware that lead to discrete artifacts and/or elevated baselines in gas chromatograms be eliminated. If contamination is a problem, the source of the contamination must be investigated and appropriate corrective measures MUST be taken and documented before further sample analysis proceeds.

6.11.6.2 All samples processed with a method blank that is out of control (i.e., contaminated) must be flagged with a "B".

6.11.7 Documentation

Reporting requirements are listed in Exhibit B. Blank results are reported on Form I-AASV and associated samples are entered in Form II-AASV, except the surrogate recoveries, which are reported on Form IX-AASV. Internal standard area and retention time shall be tabulated on Form VII-AASV.

6.12 LABORATORY CONTROL SAMPLES (LCS)

6.12.1 Summary

The LCS is an internal laboratory quality control sample designed to assess (on an SDG-by-SDG basis) the capability of the Contractor to perform the analytical method listed in this Exhibit.. Table D/SV-11 lists the LCS compounds and the corresponding QC recovery limits.

6.12.2 Frequency

The LCS must be analyzed and reported once per 12-hour analytical sequence, and concurrently with the samples in the SDG.

6.12.3 Procedure

6.12.3.1 Prepare a PUF/XAD-2 cartridge spiked with the LCS spiking mixture(s), prepared according to section 6.5.6, to contain each LCS

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compound at a concentration of 50 μg.

6.12.3.2 Spike the LCS cartridge with the surrogate compounds at the same concentration as the field samples.

6.12.3.3 Extract the LCS extract following the procedures in Section 4.

6.12.3.4 Add the internal standards to the LCS extract at the same concentration as the field sample extracts.

6.12.3.5 Analyze the LCS extract following the same analysis procedures as the field sample extracts.

6.12.4 **Calculations**

6.12.4.1 Calculate individual compound recoveries of the LCS using the following equation:

$$LCS\ \%Recovery = \frac{Concentration_{reported}}{Concentration_{spiked}} \times 100 \qquad \text{Eq. D/SV-11}$$

6.12.4.2 Field sample calculations in section 6.13 also apply to the LCS for the internal standards.

6.12.5 **Technical Acceptance Criteria**

6.12.5.1 The LCS must be analyzed on a GC/MS system meeting the tuning, initial or continuing calibration, and blank technical acceptance criteria at the frequency described in section 6.12.2.

6.12.5.2 The percent recovery for each of the surrogates in the LCS must be within the acceptance windows listed in section 6.13.5.3.

6.12.5.3 The percent recovery for each of the LCS compounds must be within the QC recovery limits listed in Table D/SV-11.

6.12.5.4 The area response change between the LCS and the most recent valid CAL 3 analysis for each of the internal standards must be less than or equal to ±40 percent.

6.12.5.5 The retention time shift between the LCS and the most recent valid CAL 3 analysis for each of the internal standards must be within ±20.0 seconds.

6.12.6 Corrective Action

6.12.6.1 If the technical acceptance criteria for the internal standards are not met, check calculations and instrument performance.

It may be necessary to recalibrate the instrument or take other corrective action procedures to meet the technical acceptance criteria.

6.12.6.2 The laboratory may not submit data from an SDG until all the LCS technical acceptance criteria are met. LCS contamination from laboratory sources or any LCS analyzed not meeting all the technical acceptance criteria will require analysis of additional LCS cartridges at no additional cost to the Agency.

6.12.6.3 LCS acceptance criteria MUST be met before any field samples, performance evaluation (PE) samples, or required blanks are analyzed. Any samples or required blanks analyzed when the LCS technical acceptance criteria have not been met will require analysis of additional LCS cartridges at no additional cost to the Agency.

6.12.7 Documentation

Reporting requirements are listed in Exhibit B. Laboratory Control Sample analysis data are reported on Form III-AASV. Internal standard area and RT shall be tabulated on Form VII-AASV, and surrogate recoveries are reported on Form IX-AASV.

6.13 SAMPLE ANALYSIS

6.13.1 Summary

The sample extract from Section 4 is analyzed by GC/MS and quantitated by the internal standard method.

6.13.2 Frequency

6.13.2.1 Before samples can be analyzed, the instrument must meet the GC/MS tuning and initial calibration or continuing calibration technical acceptance criteria.

6.13.2.2 If there is time remaining in the 12-hour time period with a valid initial calibration or continuing calibration, samples may be analyzed in the GC/MS system that meets the instrument performance check criteria.

6.13.3 Procedure

6.13.3.1 Set up the GC/MS system under the conditions outlined in section 6.6.

6.13.3.2 All sample extracts must be allowed to warm to ambient temperature (approximately 1 hour) before analysis. All sample extracts must be analyzed under the same instrumental conditions as

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the calibration standards.

6.13.3.3 Add the internal standard spiking solution to the 1.0 mL extract to contain 40 ng/μL. For sample dilutions, add an appropriate amount of the internal standard spiking solution to maintain the concentration of the internal standards at 40 ng/μL in the diluted extract.

6.13.3.4 Inject 1.0 μL of sample extract into the GC/MS, and start data acquisition.

6.13.3.5 When all semivolatile target compounds have eluted from the GC, terminate the MS data acquisition and store data files on the data system storage device. Use appropriate data output software to display full range mass spectra and SICPs.

6.13.4 Calculations

6.13.4.1 Calculate target compound concentrations using the following equation:

$$Concentration\ (ug/cartridge) = \frac{A_x I_s V_t D_f}{A_{is} V_i RRF} \qquad \text{Eq. D/SV-12}$$

where: A_x = area response for the compound to be measured. The primary quantitation ions for the target compounds, internal standards, and surrogates are listed in Table D/SV-8 and D/SV-9;

A_{is} = area response for the internal standard. The target compounds are listed with their associated internal standard in Table D/SV-3;

I_s = amount of internal standard, in micrograms (μg), spiked into the total sample extract;

RRF = the RRF from the most recent continuing calibration or CAL 3;

V_i = volume of extract injected in microliters (μL);

V_t = volume of final extract in microliters (μL); and

D_f = dilution factor for the extract. If there was no dilution, D_f equals 1. If the sample was diluted, the D_f is greater than 1.

NOTE: Total PCB concentration in each sample extract is obtained by summing isomer group concentrations.

6.13.4.2 If the volume of air sampled is known to the laboratory, the above equation becomes:

$$Concentration\ (ng/m^3) = \frac{A_x I_s V_t D_f}{A_{is} V_o V_i RRF} \times \frac{1000\ ng}{ug} \qquad \text{Eq. D/SV-13}$$

where: V_o = volume of air sampled (m^3), STP.

6.13.4.3 The equation in section 6.13.6.1 is also used for calculating the concentrations of the non-target compounds. Total area counts (or peak heights) from the total ion chromatograms are to be used for both the non-target compound to be measured (A_x) and the internal standard (A_{is}). Associate the nearest internal standard free of interferences with the non-target compound to be measured. A relative response factor (RRF) of one (1) is to be assumed. The value from this quantitation shall be qualified as estimated ("J") (estimated, due to lack of a compound-specific response factor) and "N" (presumptive evidence of presence), indicating the quantitative and qualitative uncertainties associated with this non-target component. An estimated concentration should be calculated for all tentatively identified compounds as well as those identified as unknowns. This estimated concentration must be calculated for all tentatively identified compounds as well as those identified as unknowns.

6.13.4.4 Surrogate Percent Recovery (%R): Calculate the surrogate percent recovery using the following equation:

$$\%R = \frac{Q_d}{Q_a} \times 100 \qquad \text{Eq. D/SV-14}$$

where: Q_d = Quantity determined by analysis; and
Q_a = Quantity added to sample/blank.

6.13.4.5 Percent Area Response Change (%ARC): Calculate the percent area response change (%ARC) for the sample/blank analysis compared to the most recent CAL 3 analysis for each of the internal standard compounds using the following equation:

$$\%ARC = \frac{A_s - A_x}{A_x} \times 100 \qquad \text{Eq. D/SV-15}$$

where: %ARC = percent area response change;
A_s = area response of the internal standard in the sample/blank analysis; and
A_x = area response of the internal standard in the most recent CAL 3 analysis.

The %ARC for the internal standard must not exceed ±40 percent.

6.13.4.6 Internal Standard Retention Time Shift (RTS): Calculate the retention time shift (RTS) between the sample/blank analysis and the most recent CAL 3 analysis for each of the internal standards using the following equation:

$$RTS = RT_s - RT_x \qquad \text{Eq. D/SV-16}$$

where: RT_s = retention time of the IS in the sample: and
RT_x = retention time of the IS in the most recent CAL 3 analysis.

6.13.5 **Technical Acceptance Criteria**

6.13.5.1 All target compound concentrations must not exceed the upper limit of the initial calibration range and no compound ion (excluding the compound peaks in the solvent front) may saturate the detector.

6.13.5.2 Internal standard responses and retention times in all samples must be evaluated during or immediately after data acquisition. If the retention time for any internal standard changes by more than 20 seconds from the latest continuing calibration standard or CAL 3 if samples are analyzed in the same 12-hour sequence as the initial calibration, the chromatographic system must be inspected for malfunctions, and corrections made as required. The SICP of the internal standards must be monitored and evaluated for each field and QC sample. The criteria are described in detail in the instructions for FORM VII-AASV, Internal Standard Area Summary. If the SICP area for any internal standard changes by more than a factor of ±40 percent, the mass spectrometric system must be inspected for malfunction and corrections made as appropriate. If the analysis of a subsequent sample or standard indicates that the system is functioning properly, then corrections may not be required.

6.13.5.3 The percent surrogate recoveries must be within the limits specified as follows:

Surrogate	Recovery Limits
Anthracene-d_{10}	25-150%
Benzo(a)pyrene-d_{12}	25-150%
Nitrobenzene-d_5	25-150%
2-Fluorobiphenyl	25-150%
p-Terphenyl-d_{14}	25-150%
2,4,6-Tribromophenol	25-150%
2-Fluorophenol	10-150%
Phenol-d_5	25-150%

6.13.5.4 When target compounds are below CRQLs but the spectrum meets the identification criteria, report the concentration with a "J." For example, if the CRQL is 3 ng and concentration of 1 ng is calculated, report as "1J."

6.13.6 Corrective Action

6.13.6.1 If the sample technical acceptance criteria for the surrogates and internal standards are not met, check calculations, surrogate and internal standard solutions, and instrument performance. It may be necessary to recalibrate the instrument or take other corrective action procedures to meet the surrogate and internal standard technical acceptance criteria.

6.13.6.2 If the Contractor needs to analyze more than one (1) sample dilution to have all the target compounds within the initial calibration range and to have all compound ions not saturating the detector (excluding the peaks in the solvent front), contact SMO. SMO will contact the Region for instructions.

6.13.6.3 Sample analysis technical acceptance criteria MUST be met before data are reported. Samples contaminated from laboratory sources, or associated with a contaminated method blank or any samples analyzed not meeting the technical acceptance criteria will require reanalysis at no additional cost to the Agency.

6.13.6.4 Sample reruns performed as a result of suspected matrix interferences beyond the scope of the method will be reviewed on a case-by-case basis for payment purposes by the Project Officer.

6.13.6.5 The samples or standards with SICP areas outside the limits must be reanalyzed. If corrections are made, then the laboratory must demonstrate that the mass spectrometric system is functioning properly. This must be accomplished by the analysis of a standard or sample that meets the SICP criteria. After corrections are made, the reanalysis of samples analyzed while the system was malfunctioning is required.

6.13.6.6 If after reanalysis, the SICP areas for all internal standards are inside the contract limits (±40 percent), then the problem with the first analysis is considered to have been within the control of the laboratory. Therefore, submit only data from the analysis with SICPs within the contract limits. This is considered the initial analysis and must be reported as such on all data deliverables.

6.13.6.7 If the reanalysis of the sample does not solve the problem, i.e., the SICP areas are outside the contract limits for both analyses, then submit the SICP data and sample data from both analyses. Distinguish between the initial analysis and the reanalysis on all data deliverables, using the sample suffixes specified in Exhibit B. Document in the SDG Narrative all inspection and corrective actions taken.

6.13.7 **Documentation**

Reporting requirements are listed in Exhibit B. Sample analysis results are reported on Form I-AASV, Analysis Data Sheet. Surrogate recoveries are reported on Form IX-AASV, and tentatively identified compounds (TICs) are reported on Form I-AASV-TIC. Internal standard area and RT shall be tabulated on Form VII-AASV.

6.14 **PERFORMANCE EVALUATION (PE) SAMPLES**

6.14.1 **Summary**

6.14.1.1 Performance evaluation (PE) samples will assist the Agency in monitoring laboratory performance. The Laboratory will not be informed as to which compounds are contained in the PE samples or the concentrations.

6.14.1.2 The PE sample containing known concentrations of analytes is analyzed by the laboratory to demonstrate that it can obtain acceptable identifications and measurements with procedures used to analyze environmental samples containing the same or similar analytes. Analyte and their concentrations are unknown by the analyst.

6.14.2 **Frequency**

The Laboratory shall extract, analyze, and report the results of the PE sample once per SDG, if available.

6.14.3 **Procedure**

6.14.3.1 The laboratory will receive PE samples on PUF/XAD-2 cartridges from the Agency. The samples may come with special instructions concerning the extraction procedure required for the PE samples.

6.14.3.2 Extract and concentrate the PE sample using the procedure described in Section 4. Add the surrogate and internal standards solution to the PE sample solution. Analyze the PE sample as described in section 6.13.

6.14.4 **Calculations**

See section 6.13 for equations necessary for calculations.

6.14.5 **Technical Acceptance Criteria**

6.14.5.1 The PE sample must be analyzed on a GC/MS system meeting the DFTPP tuning, initial calibration, and continuing calibration technical acceptance criteria at the required frequency.

6.14.5.2 The PE sample must be extracted and concentrated according to Section 4.

6.14.5.3 The PE sample must be prepared and analyzed with a method blank that met the blank technical acceptance criteria.

6.14.5.4 The percent recovery for each of the surrogates must be within the acceptance windows listed in section 6.13.5.3.

6.14.5.5 The area response change between the PE sample and the most recent continuing calibration check standard analysis for each of the internal standards must be within ±40 percent.

6.14.5.6 The retention time shift between the PE sample and the most recent CAL 3 analysis for each of the internal standards must be within ±20.0 seconds.

6.14.5.7 In addition to complying with the PE sample technical acceptance criteria, the laboratory will be responsible for correctly identifying and quantifying the compounds included in the PE sample. The Agency will notify the laboratory of unacceptable performance.

6.14.6 Corrective Action

6.14.6.1 If the PE sample technical acceptance criteria for the internal standard and surrogates are not met, check calculations, standard solutions and instrument performance. It may be necessary to recalibrate the instrument or take other corrective action procedures to meet the technical acceptance criteria.

6.14.6.2 Specifically, the Laboratory must meet the following criteria associated with the PE sample:

- Minimum detection limits listed in Exhibit C;
- Replicate precision within ±30 percent RSD; and
- Audit accuracy of less than or equal to 30 percent for identified analytes in PE sample.

6.14.6.3 The PE sample technical acceptance criteria **MUST** be met before sample data are reported if the PE sample is provided with the SDG. Also, the Contractor must demonstrate acceptable performance for compound identification and quantification. If the Contractor fails to meet the PE sample technical acceptance criteria or achieves a score of less than 75 percent, the Agency may take, but is not limited to the following actions: reduction of the number of samples, suspension of sample shipment, a site visit, a full data audit, and/or require the laboratory to analyze a remedial PE sample, and/or a

contract sanction, such as a Cure Notice.

6.14.7 Documentation

Reporting requirements are listed in Exhibit B. Performance evaluation (PE) sample results are reported on Form I-AASV. Surrogate recoveries are reported on Form IX-AASV.

6.15 QUALITATIVE ANALYSIS

6.15.1 Target Compounds

6.15.1.1 The compounds listed in the Target Compound List (TCL), Exhibit C, shall be identified by an analyst competent in the interpretation of mass spectra by comparison of the sample mass spectrum to the mass spectrum of a standard of the suspected compound. Two criteria must be satisfied to verify the identifications:

- Elution of the sample compound at the same GC relative retention time as the standard compound, and
- Correspondence of the sample compound and standard compound mass spectra.

6.15.1.2 PCBs are identified and measured with a special software (available from Hewlett-Packard and Finnigan), using information found in Table D/SV-7 and the criteria presented in Table D/SV-4. The intensity ratio of the two major ions in the molecular cluster for each homolog is the major identification criteria used. A ±20 percent range in this ratio around the theoretical or expected value is considered acceptable. The labeled surrogates are examined for correct retention time and the absence of interference as shown by the ratio of selected ion abundances from the molecular ion cluster.

6.15.1.3 The identification and quantification extends from the calibration utilizing the relative response factors (RRFs) for each PCB homolog group with respect to the chrysene-d_{12} internal standard. The primary ion is used to calculate a response factor with respect to the primary ion of the internal standard. This response factor is used to quantify each member of a specific homolog group. Thus, reported PCB congener concentrations are corrected for the different instrumental sensitivities of each Cl_x (homolog) group. This method of quantitation does not, however, take into account the range of sensitivities that may occur within a single homolog series, e.g., among the 42 tetrachloro PCB isomers. Therefore, use the mean RRF calculated during initial calibration or the RRF calculated in the continuing calibration.

NOTE: For PCB analyses with automated data interpretation, a linear fit algorithm will produce erroneous concentration data.

6.15.1.4 Examine results obtained on the special PCB qualitative report (for individual components identified as PCBs) and the quantitation report (for pesticide analytes) and PCB isomer groups. Individual spectra should be examined and compared to appropriate spectra acquired during calibration. Report calculated values to two significant figures.

6.15.1.5 For establishing correspondence of the GC relative retention time, the same compound RRT must be within ±0.06 RRT units of the RRT of the standard compound. For reference, the standard must be run on the same shift as the sample. If coelution of interfering compounds prohibits accurate assignment of the sample compound RRT from the extracted ion current profile for the primary ion, the RRT must be assigned by using the total ion chromatogram.

6.15.1.6 For comparison of standard and sample compound mass spectra, mass spectra obtained on the Contractor's GC/MS are required. These standard spectra may be used for identification purposes, only if the Contractor's GC/MS meets the DFTPP daily tuning technical acceptance criteria. These standard spectra may be obtained from the analysis used to obtain reference relative retention times.

6.15.1.7 The guidelines for qualitative verification by comparison of mass spectra are as follows:

- All ions present in the standard mass spectra at a relative intensity greater than 10 percent must be present in the sample spectrum.
- The relative intensities of the major ions must agree within ±20 percent between the standard and sample spectra. (Example: for an ion with an abundance of 50 percent in the standard spectra, the corresponding sample ion abundance must be between 30 and 70 percent.)
- Ions greater than 25 percent in the sample spectrum but not present in the standard spectrum must be considered and accounted for by the analyst making the comparison. The verification process should FAVOR FALSE POSITIVE. All compounds meeting the identification criteria must be reported with their spectra.
- If a compound cannot be verified by all of the above criteria, but in the technical judgement of the mass spectral interpretation specialist, the identification is correct, then the Contractor shall report that identification and proceed with quantification.

6.15.2 **Non-target Compounds**

6.15.2.1 All non-target compounds with a response greater than 10 percent of the nearest internal standard shall be tentatively identified via a forward search of the NIST Mass Spectral Library. Only after visual comparison of sample spectra with the nearest library searches will the mass spectral interpretation specialist assign a tentative identification. Computer generated library search must not use normalization routines if those routines would misrepresent the library or unknown spectra when compared to each other.

6.15.2.2 The following are guidelines for tentative identification:

- Relative intensities of major ions in the reference spectrum (ions greater than 25 percent of the most abundant ion) should be present in the sample spectrum.
- The relative intensities of the major ions should agree within ±20 percent. (Example: For an ion with an abundance of 50 percent in the standard spectra, the corresponding sample ion abundance should be between 30 and 70 percent.)
- Molecular ions present in the reference spectrum should be present in the sample spectrum.
- Ions present in the sample spectrum but not in the reference spectrum should be reviewed for possible background contamination or presence of coeluting compounds.
- Ions present in the reference spectrum but not in the sample spectrum should be reviewed for possible subtraction from the sample spectrum because of background contamination or coeluting compounds. Data system library reduction programs can sometimes create these discrepancies.
- If, in the technical judgement of the mass interpretation spectral specialist, no valid tentative identification can be made, the compound should be reported as unknown. The mass spectral specialist should give additional classification of the unknown compound, if possible (e.g., unknown phthalate, unknown hydrocarbon, unknown acid type, unknown chlorinated compound). If a probable molecular weight can be distinguished, include it.

6.16 QUANTITATIVE ANALYSIS

6.16.1 Target Compound Quantitation

6.16.1.1 Target components identified shall be quantified by the internal standard method. The internal standard used for the target compounds are outlined in Table D/SV-3 or shall be the one nearest the retention time to that of a given analyte. The SICP area of characteristic ions of analytes listed in Table D/SV-9 are used for quantitation.

6.16.1.2 The relative response factor (RRF) from the daily continuing calibration standard analysis (or RRF of CAL 3 if the sample is analyzed in the same 12-hour sequence as the initial calibration) is used to calculate the concentration in the sample. Secondary ion quantitation is allowed ONLY when there are sample interferences with the primary ion. If secondary ion quantitation is performed, document the reasons in the SDG Narrative. The area of a secondary ion cannot be substituted for the area of a primary ion unless a relative response factor is calculated using the secondary ion.

6.16.1.3 A retention time window is calculated for each single component analyte and surrogate. Windows are established as ±0.01 RRT units of the retention time for the analyte in CAL 3 of the initial calibration or the continuing calibration.

6.16.1.4 Sample quantitation is performed by the data processing system for all desired ions of all target compounds. Target compounds are quantified according to the equation in section 6.13.4.1.

6.16.1.5 The computer must be able to print out peak number, m/e, scan #, time, relative retention time, area and amount.

6.16.1.6 Standard responses and retention times in all standards must be evaluated during or immediately after data acquisition. If the retention time for any standard changes by more than 30 seconds from the latest daily (12 hour) calibration, the chromatographic system must be inspected for malfunctions, and corrections made as required. The SICP of the internal standards must be monitored and evaluated for each sample and blank. If the SICP area for any internal standard changes by more than 40 percent, the mass spectrometric system must be inspected for malfunction and corrections made as appropriate. When corrections are made, reanalysis of duplicate samples analyzed while the system was malfunctioning is necessary.

6.16.2 Non-Target Compound Quantitation

6.16.2.1 An estimated concentration for non-target components tentatively identified shall be quantified by the standard method.

The nearest internal standard free of interferences shall be used.

6.16.2.2 The formula for calculating concentrations is the same as in section 6.13.4.1. Total area counts (or peak heights) from the total ion chromatograms are to be used for both the compound to be measured and the standard. A relative response factor (RRF) of one (1) is to be assumed. The value from this quantitation shall be qualified as estimated (i.e., flagged "J"). This estimated concentration should be calculated for all tentatively identified compounds as well as those identified as unknowns.

6.16.2.3 An estimated concentration should be calculated for all tentatively identified compounds as well as those identified as unknowns. This estimated concentration must be reported for ten highest tentatively identified compounds as well as those identified as unknowns.

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TABLE D/SV-1a

CONCENTRATION OF CALIBRATION SOLUTIONS

Target Compound	Solution†	Concentration, ng/on column				
		CAL 1	CAL 2	CAL 3††	CAL 4	CAL 5
Acenaphthene	B	10	25	50	100	200
Acenaphthylene	B	10	25	50	100	200
Acetophenone	B	10	25	50	100	200
Aldicarb	A	10	25	50	100	200
Aldrin	B	10	25	50	100	200
Aniline	B	10	25	50	100	200
Anthracene	B	10	25	50	100	200
Bendiocarb	A	10	25	50	100	200
Benzidine	B	10	25	50	100	200
Benz(a)anthracene	B	10	25	50	100	200
Benzo(a)Pyrene	B	10	25	50	100	200
Benzo(b)fluoranthene	B	10	25	50	100	200
Benzo(e)pyrene	B	10	25	50	100	200
Benzo(g,h,i)perylene	B	10	25	50	100	200
Benzo(k)fluoranthene	B	10	25	50	100	200
Benzyl alcohol	A	10	25	50	100	200
alpha-BHC	B	10	25	50	100	200
gamma-BHC (Lindane)	B	10	25	50	100	200
p-Biphenylamine	B	10	25	50	100	200
Bis(n-butyl)phthalate	B	10	25	50	100	200
Butylbenzylphthalate	B	10	25	50	100	200
Captan	A	10	25	50	100	200
alpha-Chlordane	A	10	25	50	100	200
gamma-Chlordane	A	10	25	50	100	200
4-Chloro-3-methylphenol	A	10	25	50	100	200
4-Chloroaniline	B	10	25	50	100	200
Bis(2-chloroethoxy)methane	A	10	25	50	100	200
Bis(2-chloroethyl)ether	B	10	25	50	100	200
Chlorothalonil	B	10	25	50	100	200
Chlorpyrifos	A	10	25	50	100	200
Chrysene	B	10	25	50	100	200
Dacthal (DCPA)	A	10	25	50	100	200
4,4'-DDD	B	10	25	50	100	200
4,4'-DDE	B	10	25	50	100	200
4,4'-DDT	B	10	25	50	100	200

† Recommended solutions A and B may be used as separate calibration mixtures or mixed just prior to injection.

†† CAL 3 is used for continuing calibration.

TABLE D/SV-1a (continued)

CONCENTRATION OF CALIBRATION SOLUTIONS

Target Compound	Solution†	Concentration, ng/on column CAL 1	CAL 2	CAL 3††	CAL 4	CAL 5
Diazinon	A	10	25	50	100	200
Dibenz(a,h)anthracene	B	10	25	50	100	200
Dichlorvos (DDVP)	A	10	25	50	100	200
Dicofol	A	10	25	50	100	200
Dieldrin	B	10	25	50	100	200
Diethyl Phthalate	B	10	25	50	100	200
2,4-Dimethyl phenol	A	10	25	50	100	200
Dimethylphthalate	B	10	25	50	100	200
4,6-Dinitro-2-methylphenol	A	10	25	50	100	200
2,4-Dinitrophenol	A	10	25	50	100	200
2,4-Dinitrotoluene	A	10	25	50	100	200
Endosulfan I	B	10	25	50	100	200
Endosulfan II	B	10	25	50	100	200
Endrin	B	10	25	50	100	200
Endrin Aldehyde	B	10	25	50	100	200
Endrin ketone	B	10	25	50	100	200
Bis(2-ethylhexyl)phthalate	B	10	25	50	100	200
Fluoranthene	B	10	25	50	100	200
Fluorene	B	10	25	50	100	200
Folpet	A	10	25	50	100	200
Heptachlor	B	10	25	50	100	200
Heptachlor Epoxide	B	10	25	50	100	200
Hexachlorobenzene	A	10	25	50	100	200
Hexachlorocyclopentadiene	A	10	25	50	100	200
Hexachloroethane	A	10	25	50	100	200
Indeno(1,2,3-c,d)pyrene	B	10	25	50	100	200
Isophorone	A	10	25	50	100	200
Methoxychlor	B	10	25	50	100	200
2-Methylnaphthalene	A	10	25	50	100	200
2-Methyl phenol	A	10	25	50	100	200
4-Methyl phenol	A	10	25	50	100	200
Mirex	B	10	25	50	100	200
Naphthalene	B	10	25	50	100	200
2-Naphthylamine	B	10	25	50	100	200
2-Nitroaniline	B	10	25	50	100	200

† Recommended solutions A and B may be used as separate calibration mixtures or mixed just prior to injection.

†† CAL 3 is used for continuing calibration.

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TABLE D/SV-1a (continued)

CONCENTRATION OF CALIBRATION SOLUTIONS

Target Compound	Solution†	Concentration, ng/on column CAL 1	CAL 2	CAL 3††	CAL 4	CAL 5
3-Nitroaniline	B	10	25	50	100	200
Nitrobenzene	A	10	25	50	100	200
4-Nitrodiphenyl	A	10	25	50	100	200
2-Nitrophenol	A	10	25	50	100	200
4-Nitrophenol	A	10	25	50	100	200
Bis(n-octyl)phthalate	B	10	25	50	100	200
Oxychlordane	A	10	25	50	100	200
Parathion	A	10	25	50	100	200
Pentachlorobenzene	B	10	25	50	100	200
Pentachlorophenol	A	10	25	50	100	200
cis/trans-Permethrin	A	10	25	50	100	200
Phenanthrene	B	10	25	50	100	200
Phenol	A	10	25	50	100	200
o-Phenylphenol	A	10	25	50	100	200
Propoxur	A	10	25	50	100	200
Pyrene	B	10	25	50	100	200
Resmethrin	A	10	25	50	100	200
Ronnel	A	10	25	50	100	200
2,4,5-Trichlorophenol	A	10	25	50	100	200
2,4,6-Trichlorophenol	A	10	25	50	100	200
PCB Calibration Congeners†††						
Cl_1	A	10	25	50	100	200
Cl_2	A	10	25	50	100	200
Cl_3	A	10	25	50	100	200
Cl_4	A	10	25	50	100	200
Cl_5	A	10	25	50	100	200
Cl_6	A	10	25	50	100	200
Cl_7	A	10	25	50	100	200
Cl_8	A	10	25	50	100	200
Cl_9	A	10	25	50	100	200
Cl_{10}	A	10	25	50	100	200

† Recommended solutions A and B may be used as separate calibration mixtures or mixed just prior to injection.

†† CAL 3 is used for continuing calibration.

††† These congeners are used to quantitate PCBs using the special software.

TABLE D/SV-1b

APPROXIMATE CONCENTRATION OF INTERNAL STANDARDS AND SURROGATE COMPOUNDS IN CALIBRATION SOLUTIONS

Compound Name		Concentration, ng/on column CAL 1	CAL 2	CAL 3	CAL 4	CAL 5
Internal Standards						
1,4-Dichlorobenzene-d_4		40	40	40	40	40
Naphthalene-d_8		40	40	40	40	40
Acenaphthene-d_{10}		40	40	40	40	40
Phenanthrene-d_{10}		40	40	40	40	40
Chrysene-d_{12}		40	40	40	40	40
Perylene-d_{12}		40	40	40	40	40
Surrogate Compounds						
Anthracene-d_{10}		10	25	50	100	200
Benzo(a)pyrene-d_{12}		10	25	50	100	200
2,4,6-Tribromophenol		10	25	50	100	200
2-Fluorophenol		10	25	50	100	200
Phenol-d_5		10	25	50	100	200
Nitrobenzene-d_5	Pre-sampling	10	25	50	100	200
2-Fluorobiphenyl	Pre-sampling	10	25	50	100	200
p-Terphenyl-d_{14}	Pre-sampling	10	25	50	100	200

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TABLE D/SV-2

GC/MS OPERATING CONDITIONS

Activity	Conditions
Gas Chromatography	
Column	J&W Scientific, DB-5 crosslinked 5% phenylmethyl silicone (30 m x 0.32 mm, 1.0 μm film thickness) or equivalent
Carrier Gas	Helium, velocity between 28-29 cm^3/sec at 250°C
Injection Volume	1 μL, Grob-type, splitless
Injector Temperature:	250-300°C
Temperature Program	
Initial Column Temp.	50°C
Initial Hold Time	4 ± 0.1 min.
Program	8°C/min
Final Temperature	280°C
Final Hold Time	15 min. or until all compounds of interest have eluted
Mass Spectrometer	
Transfer Line Temperature:	250-300°C
Source Temperature:	According to Manufacturer's Specifications.
Electron Energy:	70 volts (nominal)
Ionization Mode:	EI
Mass Range:	35 to 500 amu, full range data acquisition (SCAN) mode
Scan Time:	At least 5 scans per peak, not to exceed 1 second per scan.

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TABLE D/SV-3
INTERNAL STANDARDS FOR SEMIVOLATILE GC/MS ANALYSIS

Naphthalene-d_8

Acetophenone
p-Biphenylamine
Bis(2-chloroethoxy)methane
4-Chloro-3-methylphenol
4-Chloroaniline
2,4-Dimethyl phenol
Dichlorvos (DDVP)
Isophorone
2-Methylnaphthalene
Naphthalene
Nitrobenzene
Nitrobenzene-d_5
2-Nitrophenol
Nitrophenols (mixed)

Acenaphthene-d_{10}

Acenaphthene
Acenaphthylene
Diethyl Phthalate
Dimethylphthalate
2,4-Dinitrophenol
2,4-Dinitrotoluene
2-Fluorobiphenyl
Fluorene
Hexachlorocyclopentadiene
2-Naphthylamine
2-Nitroaniline
3-Nitroaniline
o-Phenylphenol
Propoxur
2,4,5-Trichlorophenol
2,4,6-Tribromophenol
2,4,6-Trichlorophenol

1,4-Dichlorobenzene-d_4

Aldicarb
Aniline
Benzyl alcohol
Bis(2-chloroethyl)ether
2-Fluorophenol
Hexachloroethane
2-Methyl phenol
4-Methyl phenol
Phenol-d_5

Phenanthrene-d_{10}

Aldrin
alpha-BHC
gamma-BHC (Lindane)
Anthracene
Anthracene-d_{10}
Bendiocarb
Bis(n-butyl)phthalate
Butylbenzylphthalate
Captan
Chlorothalonil
Chlorpyrifos
Dacthal (DCPA)
Diazinon
4,6-Dinitro-2-methylphenol
Endosulfan I
Fluoranthene
Folpet
Heptachlor
Heptachlor Epoxide
Hexachlorobenzene
Oxychlordane
4-Nitrodiphenyl
Parathion
Pentachlorobenzene
Pentachlorophenol
Phenanthrene
Polybrominated biphenyls
Ronnel

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TABLE D/SV-3 (continued)

INTERNAL STANDARDS FOR SEMIVOLATILE GC/MS ANALYSIS

Chrysene-d_{12}

Benzidine
Benzo(a)anthracene
Bis(2-ethylhexyl)phthalate
alpha-Chlordane
gamma-Chlordane
Chrysene
4,4'-DDD
4,4'-DDE
4,4'-DDT
$^{13}C_{12}$-4,4'-DDT
Dicofol
Dieldrin
Endosulfan II
Endrin
Endrin Aldehyde
Methoxychlor
cis/trans-Permethrin
Pyrene
Resmethrin
p-Terphenyl-d_{14}
Monochlorobiphenyls
Dichlorobiphenyls
Trichlorobiphenyls
Tetrachlorobiphenyls
Pentachlorobiphenyls
Heptachlorobiphenyls
Hexachlorobiphenyls
Octachlorobiphenyls
Nonachlorobiphenyls
Decachlorobiphenyl

Perylene-d_{12}

Benzo(a)pyrene
Benzo(a)pyrene-d_{12}
Benzo(b)fluoranthene
Benzo(e)pyrene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Bis(n-octyl)phthalate
Dibenzo(a,h)anthracene
Endrin ketone
Indeno(1,2,3-c,d)pyrene
Mirex

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TABLE D/SV-4

PCB CONGENERS USED AS CALIBRATION STANDARDS

PCB Isomer Group	Congener Number[a]	Chlorine Substitution
Concentration Calibration Standard		
Monochlorobiphenyl	1	2
Dichlorobiphenyl	5	2,3
Trichlorobiphenyl	29	2,4,5
Tetrachlorobiphenyl	50	2,2',4,6
Pentachlorobiphenyl	87	2,2',3,4,5'
Hexachlorobiphenyl	154	2,2'4,4',5,6'
Heptachlorobipehnyl	188	2,2'3,4',5,6,6'
Octachlorobiphenyl	200	2,2'3,3',4,5',6,6'
Nonachlorobiphenyl[b]	-	---
Decachlorobiphenyl	209	2,2'3,3',4,4',5,5',6,6'

[a] Numbered according to the system of Ballschmiter and Zell. (see section 3.7, Citation 2).
[b] Decachlorobiphenyl is used as the calibration congener for both nona-and decachlorobiphenyl isomer groups.

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TABLE D/SV-5

DFTPP KEY IONS & ION ABUNDANCE CRITERIA

Mass	Ion Abundance Criteria
51	30-80% of mass 198
68	Less than 2% of mass 69
69	Present
70	Less than 2% of mass 69
127	25-75% of mass 198
197	Less than 1% of mass 198
198	Base peak, 100% relative abundance
199	5-9% of mass 198
275	10-30% of mass 198
365	Greater than 0.75% of mass 198
441	Present but less than mass 443
442	40-110% of mass 198
443	15-24% of mass 442

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TABLE D/SV-6
RELATIVE RESPONSE FACTOR CRITERIA FOR INITIAL AND CONTINUING CALIBRATION OF SEMIVOLATILE TARGET COMPOUNDS

Semivolatile Compounds	Minimum RRF	Maximum %RSD	Maximum %Diff
2-Methylnaphthalene	0.400	25.0	25.0
2-Methylphenol	0.700	25.0	25.0
2-Nitrophenol	0.100	25.0	25.0
2,4-Dimethylphenol	0.200	25.0	25.0
2,4-Dinitrotoluene	0.200	25.0	25.0
2,4,5-Trichlorophenol	0.200	25.0	25.0
2,4,6-Trichlorophenol	0.200	25.0	25.0
4-Chloro-3-methylphenol	0.200	25.0	25.0
4-Methylphenol	0.600	25.0	25.0
Acenaphthylene	1.300	25.0	25.0
Acenaphthene	0.800	25.0	25.0
Anthracene	0.700	25.0	25.0
Benz(a)anthracene	0.800	25.0	25.0
Benzo(a)pyrene	0.700	25.0	25.0
Benzo(b)fluoranthene	0.700	25.0	25.0
Benzo(g,h,i)perylene	0.500	25.0	25.0
Benzo(k)fluoranthene	0.700	25.0	25.0
bis(-2-Chloroethoxy)methane	0.300	25.0	25.0
bis(-2-Chloroethyl)ether	0.700	25.0	25.0
Chrysene	0.700	25.0	25.0
Dibenzo(a,h)anthracene	0.400	25.0	25.0
Fluoranthene	0.600	25.0	25.0
Fluorene	0.900	25.0	25.0
Hexachlorobenzene	0.100	25.0	25.0
Hexachloroethane	0.300	25.0	25.0
Indeno(1,2,3-cd)pyrene	0.500	25.0	25.0
Isophorone	0.400	25.0	25.0
Naphthalene	0.700	25.0	25.0
Nitrobenzene	0.200	25.0	25.0
Pentachlorophenol	0.050	25.0	25.0
Phenanthrene	0.700	25.0	25.0
Phenol-d_5	0.800	25.0	25.0
Pyrene	0.600	25.0	25.0
Terphenyl-d_{14}	0.500	25.0	25.0

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TABLE D/SV-6
RELATIVE RESPONSE FACTOR CRITERIA FOR INITIAL AND CONTINUING CALIBRATION OF SEMIVOLATILE TARGET COMPOUNDS
(continued)

Semivolatile Compounds	Minimum RRF	Maximum %RSD	Maximum %Diff
Naphthalene	0.700	25.0	25.0
Acenaphthylene	1.300	25.0	25.0
Acenaphthene	0.800	25.0	25.0
Fluorene	0.900	25.0	25.0
Phenanthrene	0.700	25.0	25.0
Anthracene	0.700	25.0	25.0
Fluoranthene	0.600	25.0	25.0
Pyrene	0.600	25.0	25.0
Benz(a)anthracene	0.800	25.0	25.0
Chrysene	0.700	25.0	25.0
Benzo(b)fluoranthene	0.700	25.0	25.0
Benzo(k)fluoranthene	0.700	25.0	25.0
Benzo(a)pyrene	0.700	25.0	25.0
Indeno(1,2,3-cd)pyrene	0.500	25.0	25.0
Dibenz(a,h)anthracene	0.400	25.0	25.0
Benzo(g,h,i)perylene	0.500	25.0	25.0

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TABLE D/SV-7
QUANTITATION, CONFIRMATION, AND INTERFERENCE CHECK IONS FOR PCBs, INTERNAL STANDARDS, AND SURROGATE COMPOUNDS

Analyte/ Internal Std	Quant. Ion	Confirm. Ion	Expected Ratio[a]	Accepted Ratio[a]
PCB Isomer Group				
Cl_1	188	190	3.0	2.5-3.5
Cl_2	222	224	1.5	1.3-1.7
Cl_3	256	258	1.0	0.8-1.2
Cl_4	292	290	1.3	1.1-1.5
Cl_5	326	324	1.6	1.4-1.8
Cl_6	360	362	1.2	1.0-1.4
Cl_7	394	396	1.0	0.8-1.2
Cl_8	430	428	1.1	0.9-1.3
Cl_9	464	466	1.3	1.1-1.5
Cl_{10}	498	500	1.1	0.9-1.3
Internal Standard (IS)				
Chrysene-d_{12}	240	241	5.1	4.3-5.9

[a] Ratio of quantitation ion to confirmation ion

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TABLE D/SV-8

CHARACTERISTIC IONS FOR SURROGATES AND INTERNAL STANDARDS

Classification	Primary Ion	Secondary
Surrogates		
Phenol-d_5	99	42, 71
2-Fluorophenol	112	64
2.4,6-Tribromophenol	330	332, 54
Nitrobenzene-d_5	82	128, 54
2-Fluorobiphenyl	172	171
p-Terphenyl-d_{14}	244	122, 212
Anthracene-d_{10}	188	
Benzo(a)pyrene-d_{12}	264	
Internal Standards		
1,4-Dichlorobenzene-d_4	152	115
Naphthalene-d_8	136	68
Acenaphthene-d_{10}	164	162, 160
Phenanthrene-d_{10}	188	94, 80
Chrysene-d_{12}	240	120, 236
Perylene-d_{12}	264	260, 265

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TABLE D/SV-9

QUANTITATION IONS FOR TARGET COMPOUNDS

TARGET COMPOUND	PRIMARY	SECONDARY
Acenaphthene	153	152, 154
Acenaphthylene	152	151, 153
Acetophenone	100	77, 120
Aldicarb	144	86, 89, 58
Aldrin	66	263, 220
Aniline	93	66, 65
Anthracene	178	179, 176
Bendiocarb	151	126, 166, 223, 58, 51
Benzidine	184	-
Benz(a)anthracene	228	229, 226
Benzo(a)Pyrene	252	253, 125
Benzo(b)fluoranthene	252	253, 125
Benzo(e)pyrene	252	253, 125
Benzo(g,h,i)perylene	276	138, 277
Benzo(k)fluoranthene	252	253, 125
Benzyl alcohol	108	107, 79
alpha-BHC	183	181, 109
gamma-BHC (Lindane)	183	181, 109
p-Biphenylamine	169	168, 170
Bis(n-butyl)phthalate	149	150,104
Butylbenzylphthalate	149	91, 206
Captan	79	119, 117, 77, 149
alpha-Chlordane	373	375, 377
gamma-Chlordane	373	375, 377
4-Chloro-3-methylphenol	107	144, 142
4-Chloroaniline	127	129
Bis(2-chloroethoxy)methane	93	95, 123
Bis(2-chloroethyl)ether	93	63, 95
Chlorothalonil	266	264, 268, 109, 124, 133
Chlorpyrifos	197	97, 199, 125, 258
Chrysene	228	226, 229
Dacthal (DCPA)	299	45, 44, 142, 221
4,4'-DDD	235	237, 165
4,4'-DDE	246	248, 176
4,4'-DDT	235	237, 165
Diazinon	137	179, 199, 93, 97
Dibenz(a,h)anthracene	278	139, 279
Dichlorvos (DDVP)	109	79, 185, 187, 202
Dicofol	139	111, 141, 250, 75, 140
Dieldrin	263	82, 81
Diethyl Phthalate	149	177, 150
2,4-Dimethyl phenol	107	121, 122

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TABLE D/SV-9 (continued)

QUANTITATION IONS FOR TARGET COMPOUNDS

TARGET COMPOUND	PRIMARY	SECONDARY
Dimethylphthalate	163	194, 164
4,6-Dinitro-2-methylphenol	198	182, 77
2,4-Dinitrophenol	184	63, 154
2,4-Dinitrotoluene	165	63, 182
Endosulfan I	195	339, 341
Endosulfan II	337	339, 341
Endrin	263	82, 81
Endrin Aldehyde	67	345, 250
Endrin Ketone	317	67, 319
Bis(2-ethylhexyl)phthalate	149	167, 279
Fluoranthene	202	101, 100
Fluorene	166	165, 167
Folpet	260	262, 130, 117, 104, 76
Heptachlor	100	272, 274
Heptachlor Epoxide	353	355, 351
Hexachlorobenzene	284	142, 249
Hexachlorocyclopentadiene	237	235, 272
Hexachloroethane	117	201, 199
Indeno(1,2,3-cd)pyrene	276	138, 227
Isophorone	82	95, 138
Methoxychlor	227	228
2-Methylnaphthalene	142	144
2-Methylphenol	108	107
4-Methylphenol	108	107
Mirex	272	274, 270
Naphthalene	128	129, 127
2-Naphthylamine	143	115
2-Nitroaniline	65	92, 138
3-Nitroaniline	138	108, 92
Nitrobenzene	77	123, 65
4-Nitrodiphenyl	199	152
2-Nitrophenol	139	65, 109
4-Nitrophenol	109	139,65
Bis(n-octyl)phthalate	149	-
Oxychlordane	115	57, 87, 117, 149, 121
Parathion	291	109, 97, 155, 137, 139
Pentachlorobenzene	250	252, 248
Pentachlorophenol	266	264, 268
cis/trans-Permethrin	183	
Phenanthrene	178	179, 176
o-Phenylphenol	170	169, 168, 141, 115
Propoxur	110	111, 41, 43, 81

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TABLE D/SV-9 (continued)

QUANTITATION IONS FOR TARGET COMPOUNDS

TARGET COMPOUND	PRIMARY	SECONDARY
Pyrene	202	101, 100
Resmethrin	123	128, 143, 141, 171, 81
Ronnel	125	119, 93, 79, 57, 62
2,4,5-Trichlorophenol	196	198, 200
2,4,6-Trichlorophenol	196	198, 200
PCB Calibration Congeners		
Cl_1	188	189, 190
Cl_2	222	224, 223, 225
Cl_3	256	258, 260, 257
Cl_4	292	290, 294, 296, 291
Cl_5	326	328, 324, 330
Cl_6	360	362, 358, 364, 361
Cl_7	394	396, 398, 392, 400
Cl_8	430	428, 432, 426, 434, 431
Cl_9	(464)	(462, 466, 468, 460)
Cl_{10}	498	500, 496, 502, 494, 504

[a] Congener Number

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TABLE D/SV-10

KNOWN RELATIVE ABUNDANCES OF IONS IN PCB MOLECULAR ION CLUSTERS

m/z	Relative Intensity
Monochlorobiphenyls	
188	100
189	13.5
190	33.4
192	4.41
Dichlorobiphenyls	
222	100
223	13.5
224	66.0
225	8.82
226	11.2
227	1.44
Trichlorobiphenyls	
256	100
257	13.5
258	98.6
259	13.2
260	32.7
261	4.31
262	3.73
263	0.47
Tetrachlorobiphenyls	
290	76.2
291	10.3
292	100
293	13.4
294	49.4
295	6.57
296	11.0
297	1.43
298	0.95
Pentachlorobiphenyls	
324	61.0
325	8.26
326	100
327	13.5
328	65.7
329	8.78
330	21.7
331	2.86
332	3.62
333	0.47
334	0.2
Hexachlorobiphenyls	
358	50.9
359	6.89
360	100
361	13.5
362	82.0
363	11.0
364	36.0
365	4.77
366	8.92
367	1.17
368	1.20
369	0.15
Heptachlorobiphenyls	
392	43.7
393	5.91
394	100
395	13.5
396	98.3
397	13.2
398	53.8
399	7.16
400	17.7
401	2.34
402	3.52
403	0.46
404	0.40
Octachlorobiphenyls	
426	33.4
427	4.51
428	87.3
429	11.8
430	100
431	13.4
432	65.6
433	8.76
434	26.9
435	3.57
436	7.10
437	0.93
438	1.18
439	0.15
440	0.11
Nonachlorobiphenyls	
460	26.0
461	3.51
462	76.4
463	76.4
464	100
465	13.4
466	76.4
467	10.2
468	37.6
469	5.00
470	12.4
471	1.63
472	2.72
473	0.35
474	0.39
Decachlorobiphenyl	
494	20.8
495	2.81
496	68.0
497	9.17
498	100
499	13.4
500	87.3
501	11.7
502	50.0
503	6.67
504	19.7
505	2.61
506	5.40
507	0.71
508	1.02
509	0.13

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TABLE D/SV-11

LABORATORY CONTROL SAMPLE COMPUNDS

Target Compound	%Recovery QC Limit
Bendiocarb	
Benzo(b)fluoranthene	
Benzo(k)fluoranthene	
Benzyl alcohol	
Butylbenzylphthalate	
Bis(2-chloroethoxy)methane	
Bis(2-chloroethyl)ether	
Decachlorobiphenyl	
Diazinon	
Dibenz(a,h)anthracene	
Dicofol	
Diethyl Phthalate	
2,4-Dimethyl phenol	
Endrin	
Endrin ketone	
Fluoranthene	
Fluorene	
Folpet	
Hexachlorocyclopentadiene	
Hexachloroethane	
Indeno(1,2,3-c,d)pyrene	
2-Methylnaphthalene	
2-Methyl phenol	
3-Nitroaniline	
Nitrobenzene	
4-Nitrophenol	
Nonachlorobiphenyl	
Pentachlorophenol	

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NOTE: Percent Recovery Limits are not established at this time. The appropriate values shall be determined from multi-laboratory studies conducted under SAS analyses.

Figure D/SV-1. Sampling Head Configuration for Semivolatiles

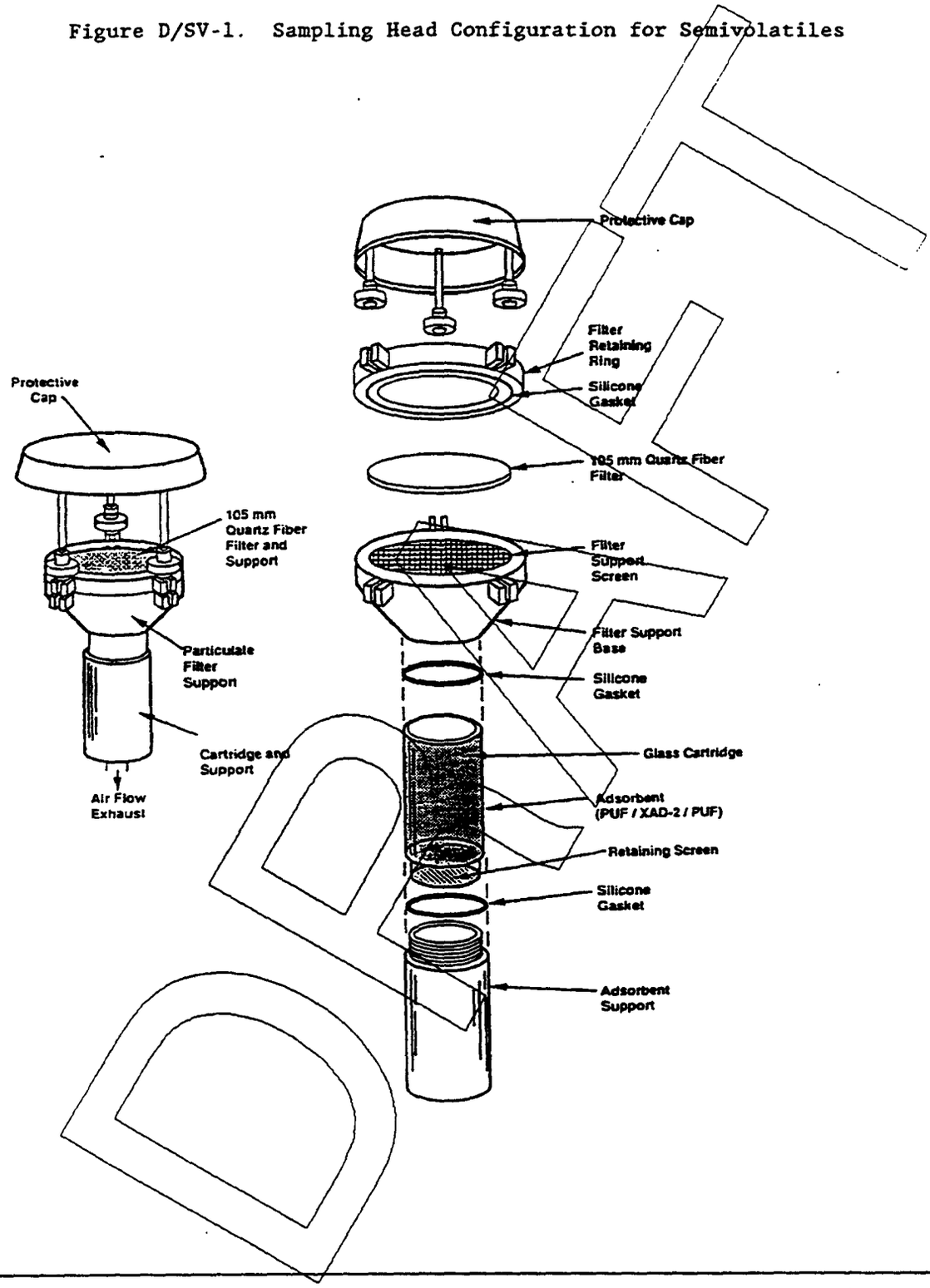

Figure D/SV-2. Configuration of the PUF/XAD-2/PUF Assembly

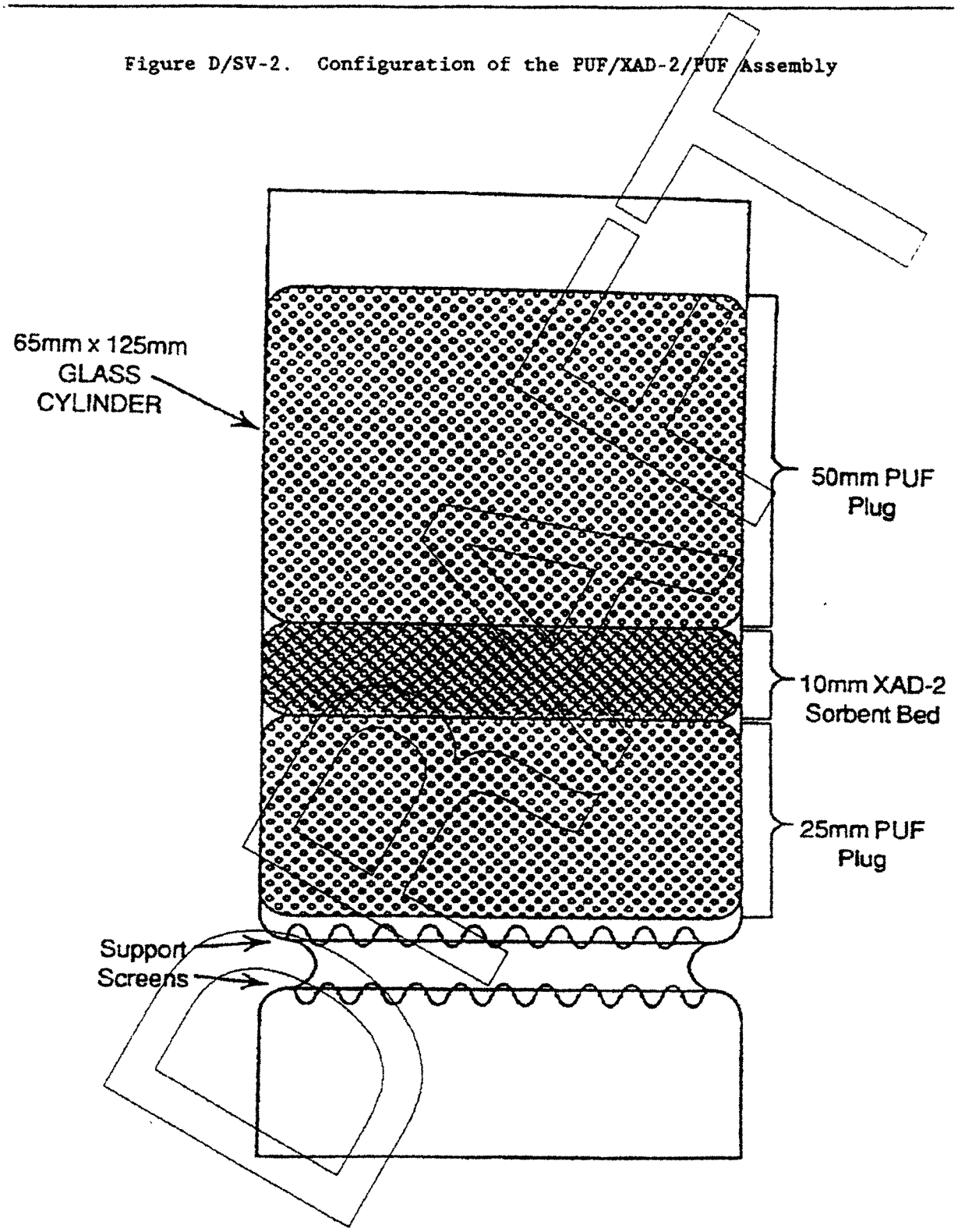

Figure D/SV-3. Analytical Scheme for the Analysis of Semivolatiles

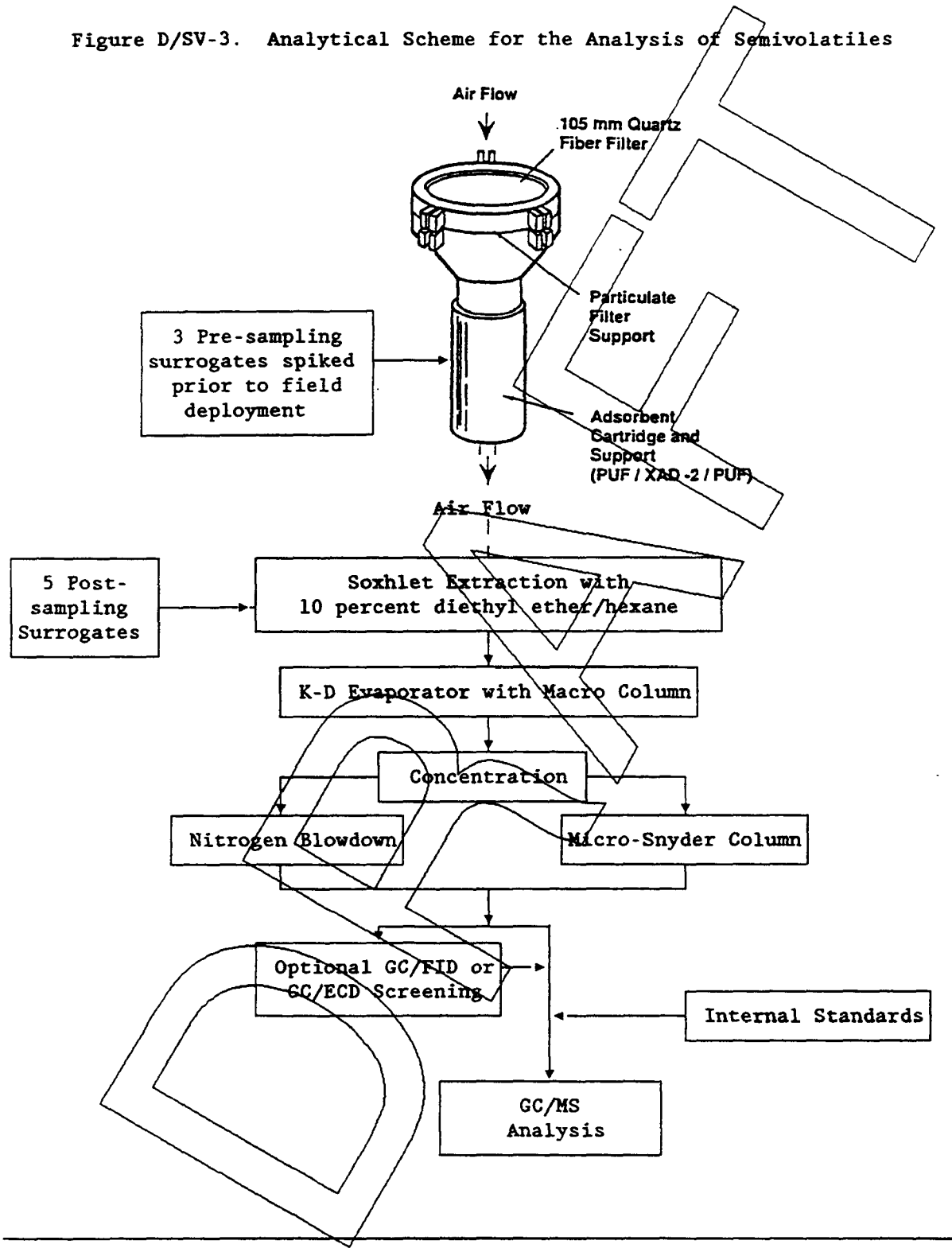

Figure D/SV-4. GC/MS Calibration and Analysis Schematic Diagram

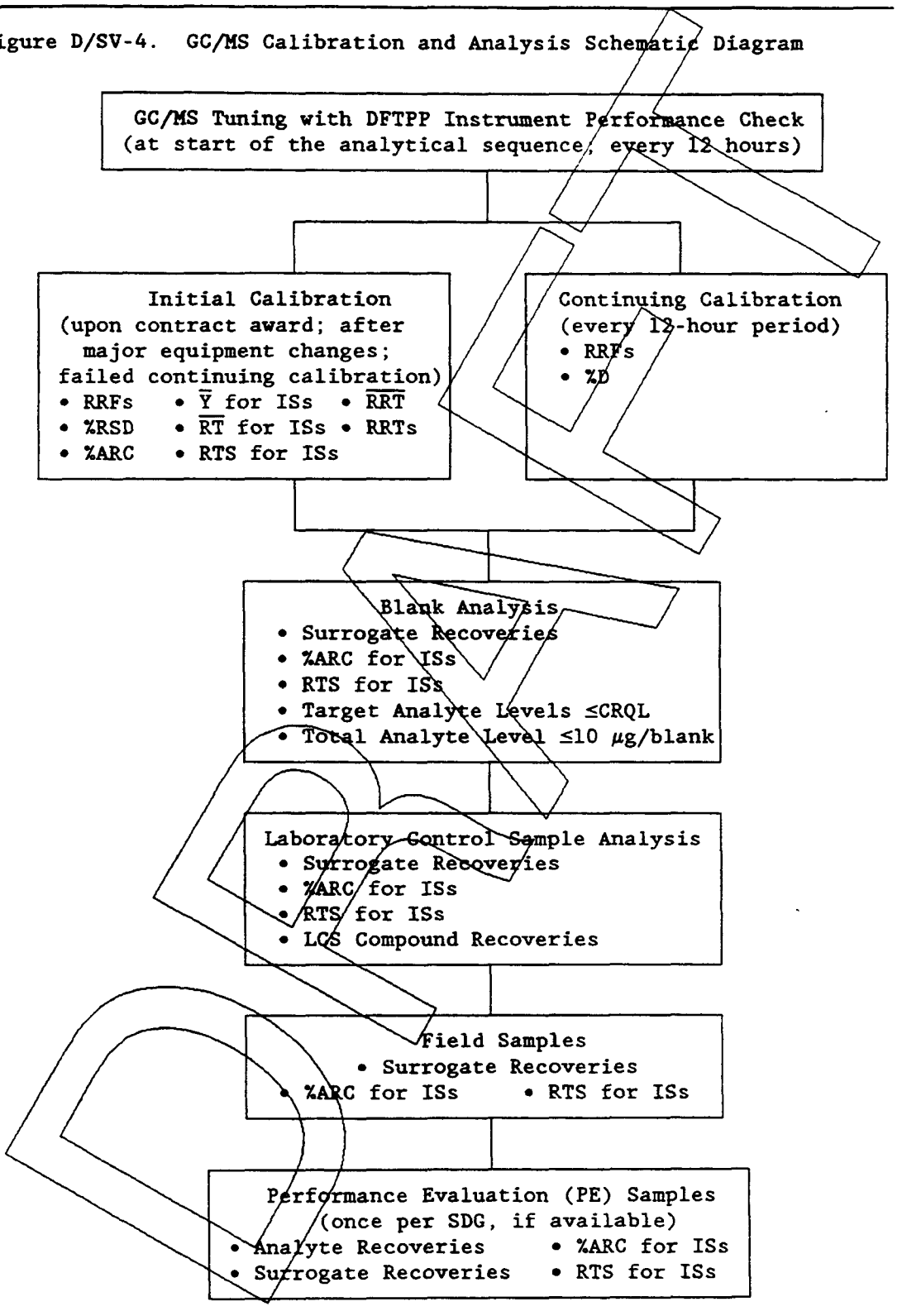

Figure D/SV-5. Semivolatiles Loading in PUF/XAD-2 Cartridges

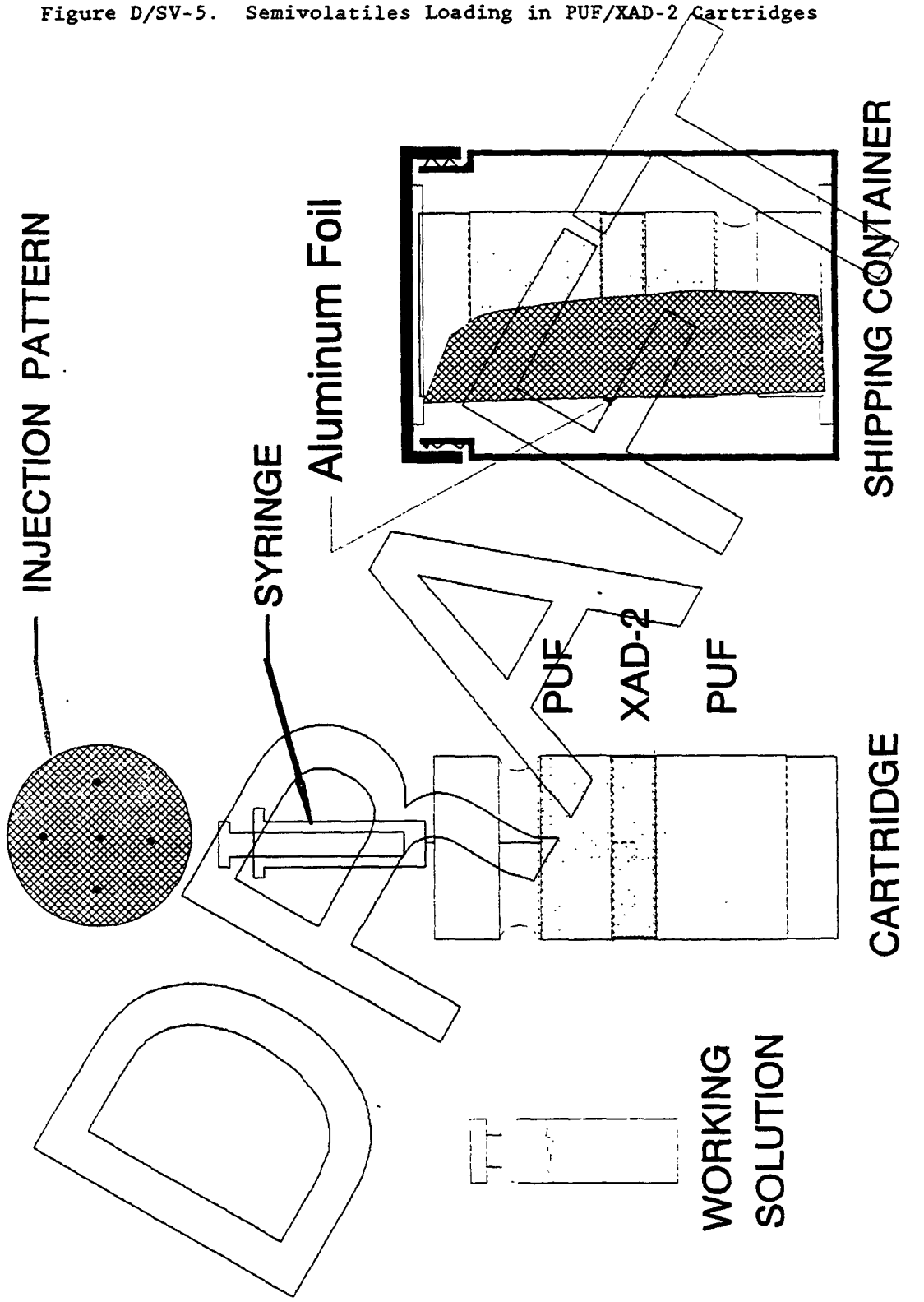

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EXHIBIT E

QUALITY ASSURANCE/QUALITY CONTROL REQUIREMENTS

January, 1992

EXHIBIT E

QUALITY ASSURANCE/QUALITY CONTROL REQUIREMENTS

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SECTION 1

INTRODUCTION

1.1 Quality assurance (QA) and quality control (QC) are integral parts of EPA's Contract Laboratory Program (CLP). The CLP QA program consists of management review and oversight at the planning, implementation, and completion stages of environmental data generation activities, to ensure that data provided are of the quality required. The CLP QC program includes those activities required as part of data generation to ensure that the data are of known and documented quality.

1.2 During the planning of an environmental data collection program, QA activities focus on defining data quality objectives and criteria, and designing a QC system to measure and document the quality of data that will be generated. During the implementation of the data collection effort, QA activities ensure that the QC system is functioning effectively, and that the deficiencies uncovered by the QC system are identified and corrected. After environmental data are generated, QA activities focus on assessing the quality of data obtained to determine its suitability to support enforcement or remedial decisions.

1.3 The purpose of this Exhibit is to describe the overall QA/QC operations and the processes by which the CLP meets the QA/QC objectives defined above. This contract requires a variety of QA/QC activities. These contract requirements are the minimum QA/QC operations necessary to satisfy the analytical requirements associated with the determination of the different method analytes. These operations are designed to facilitate laboratory comparison by providing the EPA with comparable data from all Contractors. These requirements do not release the laboratory from maintaining its own QC checks on method and instrument performance.

1.4 Appropriate use of data generated under the great range of analytical conditions encountered in ambient air analyses requires reliance on the QC procedures and criteria incorporated into the methods. The methods in this contract have been validated on samples typical of those received by the laboratories participating in the CLP. However, the validation of these methods does not guarantee that they perform equally well for all samples collected under actual field conditions. Inaccuracies can result from causes such as sampling artifacts, equipment malfunctions, and human error. Therefore, the QC component of each method is indispensable.

1.5 The data acquired from QC procedures are used to estimate and evaluate analytical results and to determine the necessity for or the effect of corrective actions. The means used for evaluating the analytical results include quantitative and qualitative indicators of quality such as precision, accuracy, detection limit, and other quantitative and qualitative indicators. In addition, QC data give an overview of the activities required in an

integrated program to generate environmental data of known and documented quality required to meet defined objectives.

1.6 Necessary components of a complete QA/QC program include internal QC criteria that demonstrate acceptable levels of performance, as determined by QA review. External review of data and procedures is accomplished by the monitoring activities of the National Program Office, Regional data users, Sample Management Office, NEIC, and EMSL/LV. Each external review accomplishes a different purpose. These reviews are described in specific sections of this Exhibit. Performance evaluation samples provide an external QA reference for the program. A laboratory on-site evaluation system is also part of the external QA monitoring. A feedback loop provides the results of the various review functions to the contract laboratories through direct communications with the Administrative Project Officers (APOs) and Technical Project Officers (TPOs).

1.7 This Exhibit is not a guide to constructing QA project plans, QC systems, or a QA organization. It is, however, an explanation of the QC and QA requirements of the CLP. It outlines some minimum standards for QA/QC programs. It also includes specific items that are required in a QA Plan and by the QA/QC documentation detailed in this contract. Delivery of this documentation provides the Agency with a complete data package which will stand alone, and limits the need for contact with the Contractor or with an analyst, at a later date, if some aspect of the analysis is questioned.

1.8 To ensure that the product delivered by the Contractor meets the requirements of the contract and to improve interlaboratory data comparison, the Agency requires the following from the Contractor.

1.8.1 Development and implementation of a QA program, and documentation of the key elements of that QA program through a written QA Plan, as described in Section 2 of this Exhibit.

1.8.2 Preparation of and adherence to written Standard Operating Procedures (SOPs) as described in Section 5 of this Exhibit.

1.8.3 Adherence to the analytical methods and associated QC requirements specified in the contract.

1.8.4 Verification of analytical standards and documentation of the purity of neat materials and the purity and accuracy of solutions obtained from private chemical houses.

1.8.5 Participation in the analysis of laboratory performance evaluation (PE) samples, including adherence to corrective action procedures.

1.8.6 Participation in on-site laboratory evaluations, including adherence to corrective action procedures.

1.8.7 Submission of all raw data and pertinent documentation for Regional review.

1.8.8 Submission, upon request, of GC/MS tapes and applicable documentation for tape audits.

1.8.9 Submission for Agency review of all original documentation generated during sample analyses.

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SECTION 2

QUALITY ASSURANCE PLANS

2.1 The Contractor shall establish a QA program with the objective of providing sound analytical chemical measurements. This program shall incorporate the QC procedures, any necessary corrective action, and all documentation required during data collection as well as the quality assessment measures performed by management to ensure acceptable data production.

2.2 As evidence of such a program, the Contractor shall prepare a written Quality Assurance Plan (QAP) which describes the procedures that are implemented to achieve the following:

2.2.1 Maintain data integrity, validity, and usability.

2.2.2 Ensure that analytical measurement systems are maintained in an acceptable state of stability and reproducibility .

2.2.3 Detect problems through data assessment and establish corrective action procedures which keep the analytical process reliable.

2.2.4 Document all aspects of the measurement process in order to provide data that are technically sound and legally defensible.

2.3 The QAP must present, in specific terms, the policies, organization, objectives, and specific QA and QC activities designed to achieve the data quality requirements in this contract. Where applicable, SOPs pertaining to each element shall be included or referenced as part of the QAP. The QAP must be available during On-Site Laboratory evaluation and upon written request by the Administrative Project Officer. Additional information relevant to the preparation of a QAP can be found in EPA and ASTM publications[2,4].

2.4 ELEMENTS OF A QUALITY ASSURANCE PLAN

2.4.1 The following key elements of the Contractor's quality assurance program shall be addressed in the QAP:

2.4.1.1 Contractor QA Policy and Objectives

2.4.1.2 Organization and Personnel

- QA Management;
  - Organization;
  - Assignment of QC and QA responsibilities; and

- Reporting relationships.

- Personnel;
  - Staff resumes;
  - Education and experience requirements pertinent to this Contract; and
  - Training progress.
- Facilities and Equipment;
  - Instrumentation and backup alternatives; and
  - Maintenance activities and schedules.
- Document Control;
  - Laboratory notebook policy;
  - Sample and data tracking/custody procedures and documentation requirements;
  - Logbook maintenance and archiving procedures;
  - Case file organization, preparation, and review procedures; and
  - Procedures for preparation, approval, review, revision, and distribution of SOPs.
- Analytical Methodology;
  - Calibration procedures and frequency;
  - Sample handling and storage procedures;
  - Sample preparation procedures;
  - Sample analysis procedures; and
  - Standards preparation procedures.

Data Generation;

- Data collection procedures;
- Data reduction procedures;

- Data review procedures;
- Data reporting and authorization procedures; and
- Data management procedures.

• Quality Control Program; and

- Solvent, reagent, and adsorbent check analysis;
- Reference material analysis;
- Internal QC checks; and
- Corrective action and determination of QC limit procedures.

• Quality Assurance Program Assessment.

- Data audits;
- Systems audits;
- Performance audits;
- Corrective action procedures; and
- QA reporting procedures.

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SECTION 3

STANDARD OPERATING PROCEDURES

3.1 In order to obtain reliable results, adherence to prescribed analytical methodology is imperative. In any operation that is performed on a repetitive basis, reproducibility is best accomplished through the use of Standard Operating Procedures (SOPs). As defined by the EPA, an SOP is a written document that provides directions for the step-by-step execution of an operation, analysis, or action which is commonly accepted as the method for performing certain routine or repetitive tasks.

3.2 SOPs prepared by the Contractor must be functional, i.e., clear, comprehensive, up-to-date, and sufficiently detailed to permit duplication of results by qualified analysts. All SOPs, as presented to the Agency, must reflect activities as they are currently performed in the laboratory. In addition, all SOPs must:

3.2.1 Be consistent with current EPA regulations, guidelines, and the CLP contract's requirements;

3.2.2 Be consistent with instrument manufacturer's specific instruction manuals;

3.2.3 Be available to the EPA during an On-Site Laboratory Evaluation. A complete set of SOPs shall be bound together and available for inspection at such evaluations. During On-Site evaluations, laboratory personnel may be asked to demonstrate the application of the SOPs;

3.2.4 Provide for the development of documentation that is sufficiently complete to record the performance of all tasks required by the protocol;

3.2.5 Describe the mechanism for demonstrating the validity of data reported by the Contractor and explaining the cause of missing or inconsistent results;

3.2.6 Describe the corrective measures and feedback mechanism used when analytical results do not meet protocol requirements;

3.2.7 Be reviewed regularly and updated as necessary when contract, facility, or Contractor procedural modifications are made;

3.2.8 Be archived for future reference in usability or evidentiary situations;

3.2.9 Be available at specific work stations as appropriate; and

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3.2.10 Be subject to a document control procedure which precludes the use of outdated or inappropriate SOPs.

3.3 SOP SPECIFICATIONS AND FORMAT

3.3.1 An SOP is defined as a written narrative step-by-step description of laboratory operating procedures including examples of laboratory documentation. The SOPs must accurately describe the actual procedures used in the laboratory, and copies of the written SOPs shall be available to ensure that analytical data produced under this contract are acceptable for use in EPA enforcement case preparation and litigation. The Contractor's SOPs shall provide mechanisms and documentation to meet each of the following specifications and shall be used by EPA sa the basis for laboratory evidence audits.

3.3.2 The format for SOPs may vary depending upon the kind of activity for which they are prepared. However, at a minimum, the following sections must be included.

3.3.2.1 Title page.

3.3.2.2 Scope and application.

3.3.2.3 Definitions.

3.3.2.4 Procedures.

3.3.2.5 QC acceptance criteria.

3.3.2.6 Corrective Action Procedures, including procedures for secondary review of information being generated.

3.3.2.7 Documentation Description and example forms.

3.3.2.8 Miscellaneous notes and precautions.

3.3.2.9 References.

3.4 REQUIRED SOPS

3.4.1 Evidentiary SOPs

The Contractor shall develop and use adequate written SOPs to ensure sample and data accountability. Evidentiary SOPs shall include specific procedures for the following processes as they are performed by the Contractor:

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3.4.1.1 **Sample receipt and logging**

3.4.1.1.1 The Contractor shall have written SOPs for receiving and logging in the samples. The procedures shall include, documentation of the following information:

- Presence or absence of EPA chain-of-custody forms;
- Presence or absence of airbills or airbill stickers;
- Presence or absence of EPA Traffic Reports or SAS packing lists;
- Presence or absence of custody seals on shipping and/or sample containers and their condition;
- Custody seal numbers, when present;
- Presence or absence of sample tags;
- Sample tag ID numbers;
- Condition of the shipping container;
- Condition of the sample container;
- Verification of agreement or nonagreement of information on receiving documents and sample containers;
- Resolution of problems or discrepancies with SMO; and
- The definition of any terms used to describe sample condition upon receipt.

3.4.1.1.2 The Contractor shall have a designated sample custodian responsible for receipt of samples and have written SOPs describing his/her duties and responsibilities.

3.4.1.2 **Sample identification**

3.4.1.2.1 The Contractor shall have written SOPs for maintaining identification of EPA samples throughout the laboratory.

3.4.1.2.2 If the Contractor assigns unique laboratory identifiers, written SOPs shall include a description of the method used to assign the unique laboratory identifier and cross-reference to the EPA sample number.

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3.4.1.2.3 If the Contractor uses prefixes or suffixes in addition to sample identification numbers, the written SOPs shall include their definitions.

3.4.1.3 Sample security

The Contractor shall have written SOPs for maintenance of the security of samples after log-in and shall demonstrate security of the sample storage and laboratory areas. The SOPs shall specifically include descriptions of all storage areas for EPA samples in the laboratory, and steps taken to prevent sample contamination. The SOPs shall include a list of authorized personnel who have access to secure storage areas.

3.4.1.4 Internal chain-of-custody of samples and data.

The Contractor shall have written SOPs for the chain-of-custody consisting of sample identification, chain-of-custody procedures, sample receiving procedures, and sample tracking procedures. For more information concerning the chain-of-custody procedures see Section 4 of this Exhibit.

3.4.1.5 Internal tracking of samples and data.

The Contractor shall have written SOPs for tracking the work performed on any particular sample. The tracking SOP shall include the following:

- A description of the documentation used to record sample receipt, sample storage, sample transfers, sample preparations, and sample analyses;
- A description of the documentation used to record instrument calibration and other QA/QC activities; and
- Examples of the document formats and laboratory documentation used in the sample receipt, sample storage, sample transfer, and sample analyses.

3.4.1.6 Laboratory document and information control

3.4.2 Analytical SOPs

The Contractor shall develop and use adequate written SOPs to ensure that all data generated for the CLP are of known, documented, and acceptable quality. Analytical SOPs shall include specific procedures for the following processes as they are performed by the Contractor:

3.4.2.1 The Contractor shall have written SOPs for preventing sample contamination, during sample preparation, cleaning of glassware, storage, and analysis.

3.4.2.2 The Contractor shall have SOPs to ensure traceability of standards used in sample analysis QA/QC.

3.4.3 **Quality Management SOPs**

3.4.3.1 The Contractor shall have written SOPs for technical and managerial review of laboratory operation and data package preparation, laboratory data review/laboratory self inspection system. The procedures shall include but not be limited to documenting the following information:

3.4.3.1.1 Data flow and chain-of-command for data review;

3.4.3.1.2 Procedures for measuring precision and accuracy.

3.4.3.1.3 Evaluation of parameters for identifying systematic errors.

3.4.3.1.4 Procedures to assure that hardcopy deliverables are complete and compliant with the requirements in Exhibit B.

3.4.3.1.5 Demonstration of internal QA inspection procedure (demonstrated by supervisory sign-off on personal notebooks, internal PE samples, etc.).

3.4.3.1.6 Frequency and type of internal audits (e.g., random, quarterly, spot checks, perceived trouble areas).

3.4.3.1.7 Demonstration of problem identification, corrective actions, and resumption of analytical processing. Sequence resulting from internal audit (i.e., QA feedback).

3.4.3.1.8 Documentation of audit reports, (internal and external), response, corrective action, etc.

3.4.3.2 The Contractor shall have written SOPs for organization and assembly of all documents relating to each EPA Case, including technical and managerial review. Documents shall be filed on a Case-specific basis. The procedures must ensure that all documents including logbook pages, sample tracking records, chromatographic charts, computer printouts, raw data summaries, correspondence, and any other written documents having reference to the Case are compiled in one location for submission to EPA. The system must include a document numbering and inventory procedure. For more information

concerning document control and case file preparation, see Section 5 of this Exhibit.

3.4.3.3 The Contractor shall have written SOPs for sample analysis, management and handling, and reporting of data. The procedures shall include but not be limited to documenting the following information:

3.4.3.3.1 Procedures for controlling and estimating data entry errors.

3.4.3.3.2 Procedures for reviewing changes to data and deliverables and ensuring traceability of updates.

3.4.3.3.3 Life cycle management procedures for testing, modifying and implementing changes to existing computing systems including hardware, software, and documentation or installing new systems.

3.4.3.3.4 Database security, backup and archival procedures including recovery from system failures.

3.4.3.3.5 System maintenance procedures and response time.

3.4.3.3.6 Individual(s) responsible for system operation, maintenance, data integrity and security.

3.4.3.3.7 Specifications for staff training procedures.

3.4.3.4 The Contractor shall have written SOPs for laboratory safety.

3.5 HANDLING OF CONFIDENTIAL INFORMATION

3.5.1 A Contractor conducting work under this contract may receive EPA-designated confidential information from the Agency. Confidential information must be handled separately from other documentation developed under this contract. To accomplish this, the following procedures for the handling of confidential information have been established.

3.5.2 All confidential documents shall be under the supervision of a designated Document Control Officer (DCO).

3.5.3 Any samples or information received with a request of confidentiality shall be handled as "confidential." A separate locked file shall be maintained to store this information and shall be segregated from other nonconfidential information. Data generated from confidential samples shall be treated as confidential. Upon receipt of confidential information, the DCO logs these documents into a Confidential Inventory Log. The information is then made available to authorized personnel but only after it has been signed out to that person by the DCO. The documents shall be returned to the locked file at the conclusion of each

working day. Confidential information may not be reproduced except upon approval by the EPA Contracting Officer. The DCO will enter all copies into the document control system. In addition, this information may not be disposed of except upon approval by the EPA Contracting Officer. The DCO shall remove and retain the cover page of any confidential information disposed of for one year and shall keep a record of the disposition in the Confidential Inventory Log.

3.6 SOPS DELIVERY REQUIREMENTS

Within forty-five (45) days of contract receipt, a complete set of SOPs relevant to this contract shall be sent to the TPO, SMO and EMSL/LV. Also, during the term of performance of the contract, copies of SOPs which have been amended or new SOPs which have been written shall be sent to the TPO, EMSL/LV (quality assurance SOPs) and NEIC (evidentiary SOPs).

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SECTION 4

CHAIN-OF-CUSTODY

A sample is physical evidence collected from a facility or from the environment. An essential part of hazardous waste investigation effort is that the evidence gathered be controlled. To accomplish this, the following sample identification, chain-of-custody, sample receiving, and sample tracking procedures have been established.

4.1 SAMPLE IDENTIFICATION

4.1.1 To ensure traceability of samples while in possession of the Contractor, the Contractor shall have a specified method for maintaining identification of samples throughout the laboratory.

4.1.2 Each sample and sample preparation container shall be labeled with the EPA number or a unique laboratory identifier. If a unique laboratory identifier is used, it shall be cross-referenced to the EPA number.

4.2 CHAIN-OF-CUSTODY PROCEDURES

Because of the nature of the data being collected, the custody of EPA samples must be traceable from the time the samples are collected until they are introduced as evidence in legal proceedings. The Contractor shall have procedures ensuring that EPA sample custody is maintained and documented. A sample is under custody if the following applies:

4.2.1 It is in your possession, or

4.2.2 It is in your view after being in your possession, or

4.2.3 It was in your possession and you locked it up, or

4.2.4 It is in a designated secure area (secure areas shall be accessible to authorized personnel only).

4.3 SAMPLE RECEIVING PROCEDURES

4.3.1 The Contractor shall designate a sample custodian responsible for receiving all samples.

4.3.2 The Contractor shall designate a representative to receive samples in the event that the sample custodian is not available.

4.3.3 The condition of the shipping containers and sample bottles shall be inspected upon receipt by the sample custodian or his/her representative.

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4.3.4 The condition of the custody seals (intact/not intact) shall be inspected upon receipt by the sample custodian or his/her representative.

4.3.5 The sample custodian or his/her representative shall check for the presence or absence of the following documents accompanying the sample shipment.

4.3.5.1 Airbills or airbill stickers.

4.3.5.2 Custody seals.

4.3.5.3 EPA custody records.

4.3.5.4 EPA traffic reports or SAS packing lists.

4.3.5.5 Sample tags.

4.3.6 The sample custodian or his/her representative shall sign and date all forms (e.g., custody records, traffic reports or packing lists, and airbills) accompanying the samples at the time of sample receipt.

4.3.7 The Contractor shall contact SMO to resolve discrepancies and problems such as absent documents, conflicting information, broken custody seals, and unsatisfactory sample condition (e.g., leaking sample bottle).

4.3.8 The Contractor shall record the resolution of discrepancies and problems on Telephone Contact Logs.

4.3.9 The following information shall be recorded on appropriate Form AADC-1 by the sample custodian or his/her representative as samples are received and inspected.

4.3.9.1 Condition of the shipping container.

4.3.9.2 Presence or absence and condition of custody seals on shipping and/or sample containers.

4.3.9.3 Custody seal numbers, when present.

4.3.9.4 Condition of the sample bottles.

4.3.9.5 Presence or absence of airbills or airbill stickers.

4.3.9.6 Airbill or airbill sticker numbers.

4.3.9.7 Presence or absence of EPA custody records.

4.3.9.8 Presence or absence of EPA traffic reports or SAS packing lists.

4.3.9.9 Presence or absence of sample tags.

4.3.9.10 Sample tag identification numbers cross-referenced to the EPA sample numbers.

4.3.9.11 Verification of agreement or non-agreement of information recorded on shipping documents and sample containers.

4.3.9.12 Problems or discrepancies.

4.4 SAMPLE TRACKING PROCEDURES

The Contractor shall maintain records documenting all phases of sample handling from receipt to final analysis. The records shall include documentation of the movement of samples and prepared samples into and out of designated laboratory storage areas.

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SECTION 5

DOCUMENT CONTROL

The goal of the laboratory document control program is to assure that all documents for a specified Sample Delivery Group (SDG) will be accounted for when the project is completed. Accountable documents used by contract laboratories shall include but not be limited to logbooks, chain-of-custody records, sample work sheets, bench sheets, and other documents relating to the sample or sample analyses. The following document control procedures have been established to assure that all laboratory records are assembled and stored for delivery to the EPA or are available upon request from the EPA prior to the delivery schedule.

5.1 PREPRINTED LABORATORY FORMS AND LOGBOOKS

5.1.1 All documents produced by the Contractor which are directly related to the preparation and analysis of EPA samples shall become the property of the EPA and shall be placed in the complete sample delivery group file (CSF). All observations and results recorded by the laboratory but not on preprinted laboratory forms shall be entered into permanent laboratory logbooks. When all data from a SDG are compiled, all original laboratory forms and copies of all SDG-related logbook entries shall be included in the documentation package.

5.1.2 The Contractor shall identify the activity recorded on all laboratory documents which is directly related to the preparation and analysis of EPA samples.

5.1.3 Pre-printed laboratory forms shall contain the name of the laboratory and be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

5.1.4 Logbook entries shall be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

5.1.5 Logbook entries shall be in chronological order. Entries in logbooks, with the exception of instrument run logs and extraction logs, shall include only one SDG per page.

5.1.6 Pages in both bound and unbound logbooks shall be sequentially numbered.

5.1.7 Instrument run logs shall be maintained so as to enable a reconstruction of the run sequence of individual instruments. Because the laboratory must provide copies of the instrument run logs to the EPA, the

laboratory may exercise the option of using only laboratory or EPA sample identification numbers in the logs for sample ID rather than government agency or commercial client names to preserve the confidentiality of commercial clients.

5.1.8 Corrections to supporting documents and raw data shall be made by drawing a single line through the error and entering the correct information. Corrections and additions to supporting documents and raw data shall be dated and initialed. No information shall be obliterated or rendered unreadable. All notations shall be recorded in ink. Unused portions of documents shall be crossed out.

5.2 CONSISTENCY OF DOCUMENTATION

5.2.1 The Contractor shall assign a document control officer responsible for the organization and assembly of the CSF.

5.2.2 All copies of laboratory documents shall be complete and legible.

5.2.3 Original documents which include information relating to more than one SDG shall be filled in the CSF of the lowest SDG number. The copy(s) shall be placed in the other CSF(s) and the Contractor shall record the following information on the copy(ies) in red ink.

"COPY

ORIGINAL IS FILED IN CSF _____"

The Contractor shall sign and date this addition to the copy(ies).

5.2.4 Before releasing analytical results, the document control officer shall assemble and cross-check the information on sample tags, custody records, lab bench sheets, personal and instrument logs, and other relevant data to ensure that data pertaining to each particular sample or sample delivery group is consistent throughout the CSF.

5.3 DOCUMENT NUMBERING AND INVENTORY PROCEDURE

5.3.1 In order to provide document accountability of the completed analysis records, each item in a CSF shall be inventoried and assigned a serialized number as described in Exhibit B.

CSF # - Region - Serialized number (For example: 75-2-0240).

5.3.2 All documents relevant to each sample delivery group, including logbook pages, bench sheets, mass spectra, chromatograms, screening records, re-preparation records, re-analysis records, records of failed or attempted analysis, custody records, library research results, etc., shall be inventoried.

5.3.3 The Document Control Officer (DCO) shall be responsible for ensuring that all documents generated are placed in the CSF for inventory and are delivered to the EPA. The DCO shall place the sample tags in plastic bags in the file. Figure E-1 is an example of a document inventory.

Figure E-1

Example

DOCUMENT INVENTORY

Document Control #*	Document Type	# Pages
232-2-0001	Case File Document Inventory Sheet	1
232-2-0002	Chain-of-Custody Records	2
232-2-0003	Shipping Manifests	2
232-2-0004	Sample Tags	50
232-2-0005	SMO Organics Traffic Reports	10
232-2-0006	Analysis Data Sheets	41
232-2-0007	Analysts' Organics Notebook Pages	14
232-2-0008	GC/MS and GC Instrument Logbook Pages	12
etc.	etc.	etc.

*This number is to be recorded on each set of documents.

5.4 STORAGE OF EPA FILES

The Contractor shall maintain EPA laboratory documents in a secure location.

5.5 SHIPPING DATA PACKAGES AND CSF

5.5.1 The Contractor shall document shipment of deliverables packages to the recipients. These shipments require custody seals on the containers placed such that they cannot be opened without damaging or breaking the seal. The Contractor shall document what was sent, to whom, the date, and the method (carrier) used.

5.5.2 The Contractor shall purge the CSF deliverable to the appropriate EPA Region 180 days after the report submission.

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5.5.3 A copy of the transmittal letter for the CSF will be sent to the NEIC and the SMO.

5.5.4 The Document Control form is used to document the receipt and inspection of shipping containers and samples. The Contractor shall submit one (1) original FORM AADC-1 for each shipping container.

5.5.5 The Contractor shall sign and date the airbill (if present), examine the shipping containers, record the presence or absence of custody seals and their conditions.

5.5.6 The Contractor shall note any problems with the samples and follow the instructions explained in Exhibit B, Sample Log-In Sheet.

5.5.7 The Contractor shall submit a completed Document Control Form with each SDG package.

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SECTION 6

ANALYTICAL STANDARDS REQUIREMENTS

The U.S. Environmental Protection Agency will not supply analytical reference standards either for direct analytical measurements or for the purpose of traceability. All contract laboratories will be required to prepare from neat materials, from cylinders of compressed gases traceable to NIST Standard Reference Materials or NIST/EPA approved certified reference material, or purchase from private chemical supply houses those standards necessary to successfully and accurately perform the analyses required in this protocol.

6.1 PREPARATION OF CHEMICAL STANDARDS FROM THE NEAT HIGH PURITY BULK MATERIAL

6.1.1 A laboratory may prepare their chemical standards from neat materials. Commercial sources for neat chemical standards pertaining to analytes listed on the TCL are given in Appendix C of the "Quality Assurance Materials Bank: Analytical Reference Standards," Seventh Edition, January 1988. Laboratories should obtain the highest purity possible when purchasing neat chemical standards; standards purchased at less than 98% purity must be documented as to why a higher purity could not be obtained.

6.1.2 Neat chemical standards must be kept refrigerated when not being used in the preparation of standard solutions. Proper storage of neat chemicals is essential in order to safeguard them from decomposition.

6.1.3 The purity of a compound can sometimes be misrepresented by a chemical supply house. Since knowledge of purity is needed to calculate the concentration of solute in a solution standard, it is the contract laboratory's responsibility to have analytical documentation ascertaining that the purity of each compound is correctly stated. Purity confirmation, when performed, should use either differential scanning calorimetry, gas chromatography with flame ionization detection, high performance liquid chromatography, infrared spectrometry, or other appropriate techniques. Use of two or more independent methods is recommended. The correction factor for impurity when weighing neat materials in the preparation of solution standards is:

$$\frac{\text{Wt. of impure compound}}{\left(\frac{\text{percent purity}}{100}\right)} = \text{Wt. of pure compound} \qquad \text{Eq. E-1}$$

where "weight of pure compound" is that required to prepare a specific volume of a solution standard of a specified concentration.

6.1.4 Mis-identification of compounds occasionally occurs and it is possible that a mislabeled compound may be received from a chemical supply house. It is the contract laboratory's responsibility to have analytical documentation confirming that all compounds used in the preparation of solution standards are correctly identified. Identification confirmation, when performed, should use GC/MS analysis on at least two different analytical columns, or other appropriate techniques.

6.1.5 Calculate the weight of material to be weighed out for a specified volume taking into account the purity of the compound and the desired concentration. A second person must verify the accuracy of the calculations. Check balances for accuracy with a set of standard weights. All weighing should be performed on an analytical balance to the nearest 0.1 mg and verified by a second person. The solvent used to dissolve the solute should be compatible with the protocol in which the standard is to be used; the solute should be soluble, stable, and nonreactive with the solvent. In the case of a multicomponent solution, the components must not react with each other.

6.1.6 Log notebooks are to be kept for all weighing and dilutions. All subsequent dilutions from the primary standard and the calculations for determining their concentrations are to be recorded and verified by a second person. All solution standards are to be refrigerated when not in use. All solution standards are to be clearly labeled as to the identity of the compound or compounds, concentration, date prepared, solvent, and initials of the preparer.

6.2 PURCHASE OF CHEMICAL STANDARDS IN SOLUTION

6.2.1 Solutions of analytical reference standards can be purchased by Contractors provided they meet the following criteria.

6.2.1.1 Contract laboratories must maintain the following documentation to verify the integrity of the standard solutions they purchase:

- Mass spectral identification confirmation of the neat material;
- Purity confirmation of the neat material; and
- Chromatographic and quantitative documentation that the solution standard was QC checked according to the following section.

6.2.1.2 The Contractor must purchase standards for which the quality is demonstrated statistically and analytically by a method of the supplier's choice. One way this can be demonstrated is to prepare and analyze three solutions, a high standard, a low standard, and a standard at the target concentration (see sections 6.2.1.3 and 6.2.1.4 below). The supplier must then demonstrate that the analytical

results for the high standard and low standard are consistent with the difference in theoretical concentrations. This is done by the Student's t-test in part 6.3.1.3 which follows. If this is achieved, the supplier must then demonstrate that the concentration of the target standard lies midway between the concentrations of the low and high standards. This is done by the Student's t-test. The standard is certified to be within 10 percent of the target concentration.

6.2.1.3 If the procedure above is used, the supplier must document that the following have been achieved.

- Two solutions of identical concentration must be prepared independently from neat materials. An aliquot of the first solution must be diluted to the intended concentration (the "target standard"). One aliquot is taken from the second solution and diluted to a concentration ten percent greater than the target standard. This is called the "high standard". One further aliquot is taken from the second solution and diluted to a concentration 10 percent less that the target standard. This is called the "low standard";

- Six replicate analyses of each standard (a total of 18 analyses) must be performed in the following sequence: low standard, target, high standard, low standard, target standard, high standard; and

- The mean and variance of the six results for each solution must be calculated.

$$Mean = \frac{Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6}{6} \qquad \text{Eq. E-2}$$

$$Variance = \frac{Y_{12} + Y_{22} + Y_{32} + Y_{42} + Y_{52} + Y_{62} - (6 \times Mean)_2}{5} \qquad \text{Eq. E-3}$$

The values Y_1, Y_2, Y_3, ..., represent the results of the six analyses of each standard. The means of the low, target, and high standards are designated M_1, M_2, and M_3, respectively. The variances of the low, target, and high standards are designated V_1, V_2, and V_3, respectively. Additionally, a pooled variance, V_p, is calculated.

$$V_p = \frac{\frac{V_1}{0.81} + V_2 + V_3}{\frac{1.21}{3}} \qquad \text{Eq. E-4}$$

If the square root of Vp is less than one percent of M_2, then $M_2^2/10,000$ is to be used as the value of Vp in all subsequent calculations.

- The test statistic must be calculated:

$$TEST\ STATISTIC = \frac{\left| \frac{M_2}{1.1} - \frac{M_1}{0.9} \right|}{\left(\frac{V_p}{3} \right)^{0.5}} \qquad \text{Eq. E-5}$$

If the test statistic exceeds 2.13 then the supplier has failed to demonstrate a twenty percent difference between the high and low standards. In such a case, the standards are not acceptable.

- The test statistic must be calculated:

$$TEST\ STATISTIC = \frac{\left| M_2 - \left(\frac{M_1}{1.8} \right) - \left(\frac{M_3}{2.2} \right) \right|}{\left(\frac{V_p}{4} \right)^{0.5}} \qquad \text{Eq. E-6}$$

If the test statistic exceeds 2.13, the supplier has failed to demonstrate that the target standard concentration is midway between the high and low standards. In such a case, the standards are not acceptable.

- The 95 percent confidence intervals for the mean result of each standard must be calculated:

$$INTERNAL\ FOR\ LOW\ STANDARD = M_1 \pm (2.13) \left(\frac{V_p}{6} \right)^{0.5} \qquad \text{Eq. E-7}$$

$$INTERNAL\ FOR\ TARGET\ STANDARD = M_2 \pm (2.13) \left(\frac{V_p}{6} \right)^{0.5} \qquad \text{Eq. E-8}$$

$$INTERNAL\ FOR\ HIGH\ STANDARD = M_3 \pm (2.13) \left(\frac{V_p}{6} \right)^{0.5} \qquad \text{Eq. E-9}$$

These intervals must not overlap. If overlap is observed, then the supplier has failed to demonstrate the ability to discriminate

the 10 percent difference in concentrations. In such a case, the standards are not acceptable. In any event, the laboratory is responsible for the quality of the standards employed for analyses under this contract.

6.3 REQUESTING STANDARDS FROM THE EPA STANDARDS REPOSITORY

Solutions of analytical reference materials can be ordered from the U.S. EPA Chemical Standards Repository, depending on availability. The Contractor can place an order for standards only after demonstrating that these standards are not available from commercial vendors either in solution or as a neat material.

6.4 DOCUMENTATION OF THE VERIFICATION AND PREPARATION OF CHEMICAL STANDARDS

It is the responsibility of each laboratory to maintain the necessary documentation to show that the chemical standards they have used in the performance of CLP analysis conform to the requirements previously listed. Weighing logbooks, calculations, chromatograms, mass spectra, etc, whether produced by the laboratory or purchased from chemical supply houses, must be maintained by the laboratory and may be subject to review during on-site inspection visits. Documentation of standards preparation may be required to be sent to EPA for verification of contract compliance. In those cases where the documentation is supportive of the analytical results of data packages sent to EPA, such documentation is to be kept on file by the laboratories for a period of one year.

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SECTION 7

METHOD SPECIFIC QA/QC REQUIREMENTS

7.1 The purpose of this section is to outline the minimum quality control (QC) operations necessary to satisfy the analytical requirements associated with the determination of the semivolatile organic compounds listed in Exhibit C, using the procedures in Exhibit D. This section is not intended as a comprehensive quality control document, but rather as a guide to the specific QC operations that must be addressed during analysis of semivolatiles captured on PUF/XAD-2. The laboratory is expected to address these operations in preparing the quality assurance plan and Standard Operating Procedures discussed in Sections 2 and 3.

7.2 The specific QC operations that must be considered for semivolatile organics analysis include the following:

7.2.1 Testing and Spiking of PUF/XAD-2 cartridges;

7.2.2 GC/MS Instrument Performance Check and Ion Abundance Patterns;

7.2.3 GC/MS Initial and Continuing Calibration;

7.2.4 Internal Standard Area and Retention Time;

7.2.5 Blank Analysis;

7.2.6 Surrogate Compound Recoveries; and

7.2.7 Performance Evaluation (PE) Samples.

7.2.8 Testing and Spiking of PUF/XAD-2 Cartridges

7.2.8.1 As part of the procedure for preparing PUF/XAD-2 cartridges for sampling and subsequent analysis, the laboratory is required to analyze by GC/MS or GC/ECD one cartridge or 10 percent, whichever is greater, of the cartridges from each batch of prepared PUF/XAD-2 cartridges, and confirm that the total level of semivolatiles per cartridge assembly (filter and PUF/XAD-2 sandwich) is less than 10 μg. If the total semivolatiles exceed 10 μg, the entire batch shall be rejected or cleaned until acceptable.

7.2.8.2 The laboratory is also required to spike each cartridge with surrogate compounds as discussed in Exhibit D.

7.2.9 GC/MS Performance Checking the Mass Spectrometer and Ion Abundance Patterns

7.2.9.1 Prior to initiating any data collection activities involving QC or field samples, it is necessary to establish that a given GC/MS system

meets the instrument performance criteria specified in Exhibit D. The purpose of this instrument performance check is to ensure correct mass calibration, mass resolution, and mass transmission. This is accomplished through the analysis of decafluorotriphenylphosphine (DFTPP).

7.2.9.2 The required frequency of DFTPP analysis (once every 12 hours on each GC/MS system) is described in detail in Exhibit D.

7.2.9.3 The key ions produced during the analysis of DFTPP and their respective ion abundance criteria are given in Exhibit D, Table D\SV-5.

7.2.9.4 The documentation includes Form IV-AASV.

7.2.10 **Initial Calibration of the GC/MS System**

7.2.10.1 Prior to the analysis of samples and required blanks and after instrument performance criteria have been met, the GC/MS system must be initially calibrated using calibration standards containing the target compounds, surrogates, and internal standards.

7.2.10.2 The detailed procedure is given in Exhibit D.

7.2.10.3 The GC/MS is calibrated by analyzing standards spiked onto the PUF/XAD-2 cartridge assemblies, and calculating concentrations by the relative response factor (RRF) method.

7.2.10.4 Calibration standards containing the target compounds of interest are prepared as outlined in Exhibit D and spiked onto the PUF/XAD-2 cartridges.

7.2.10.5 The PUF/XAD-2 cartridges are spiked with known concentrations of internal standards and surrogate standards as described in Exhibit D.

7.2.10.6 The cartridges are then analyzed as described in Exhibit D.

7.2.10.7 Relative response factors (RRFs) are calculated as described in Exhibit D.

7.2.10.8 The documentation includes Form V-AASV, Form VII-AASV, a GC/MS data system printout for the analysis of each semivolatile calibration standard, and the mass spectrum of each target and surrogate compound.

7.2.11 **GC/MS Continuing Calibration**

7.2.11.1 Once the GC/MS system has been calibrated, the calibration must be verified each 12-hour time period for each GC/MS system.

7.2.11.2 The standard is to be analyzed according to the procedures and at the frequency given in Exhibit D.

7.2.11.3 The continuing calibration of the GC/MS system is evaluated on the basis of the magnitude of the response factors and the percent difference between the average RRF of each compound from the initial calibration and the RRF of that compound in the continuing calibration standard. The minimum response factors of each compound with minimum RRFs in the continuing calibration and the percent difference must meet the criteria given in Exhibit D.

7.2.11.4 The documentation includes, Form VI-AASV, Form VII-AASV, a GC/MS data system printout for the analysis of the semivolatile calibration standard, and the mass spectrum of each target compound.

7.2.12 Internal Standard Area and Retention Times

7.2.12.1 The response of each of the internal standards in all calibration standards, samples, and blanks is crucial to the provision of reliable analytical results, because the quantitative determination of semivolatile compounds by these procedures is based on the use of internal standards added immediately prior to analysis.

7.2.12.2 The specific compounds used as internal standards are given in Exhibit D. Each internal standard is spiked on the PUF/XAD-2 cartridge at the level specified in Exhibit D.

7.2.12.3 The retention time and the area response of the primary quantitation ion of each internal standard must be monitored for all analyses.

7.2.12.4 The area response and retention times of each internal standard are evaluated for stability, according to the procedures in Exhibit D. The area of the internal standard in a sample must be within ±40 percent of the area of the same internal standard in the associated initial or continuing calibration standard. Likewise, the retention time of an internal standard in a sample must be within ±0.06 RRT units of its retention time in the associated initial or continuing calibration standard, as described in Exhibit D.

7.2.12.5 Requirements for analysis of samples when internal standards do not meet specifications are given in Exhibit D.

7.2.12.6 The documentation includes Form VII-AASV; and a GC/MS data system printout for the analysis of each semivolatile sample, blank, and calibration standard.

7.2.13 Blank Analysis

7.2.13.1 A blank is a certified clean PUF/XAD-2 cartridge carried through the entire analytical procedure. The field blank is spiked with the surrogates and sent out to the field along with cartridges used for air

sampling. The laboratory method blank cartridge never leaves the laboratory. The purpose of a laboratory method blank is to determine the levels of contamination associated with the processing and analysis of samples at the laboratory, while the field blank monitors contamination due to cartridge handling during sampling.

7.2.13.2 A laboratory method blank shall be analyzed once every 12 hours on each GC/MS system while a field blank must be analyzed at least once per SDG, as described in detail in Exhibit D.

7.2.13.3 For the purposes of this protocol, an acceptable blank must contain less than or equal to the Contract Required Quantitation Limit (see Exhibit C) of any single target compound, or less than 10 μg/cartridge for total semivolatiles, whichever is less.

7.2.13.4 If a laboratory blank exceeds the limits for contamination above, the Contractor shall consider the analytical system out of control. The source of the contamination must be investigated and appropriate corrective actions taken and documented before further sample analysis proceeds. The requirements for reanalysis of associated samples are given in Exhibit D.

7.2.13.5 The documentation includes Form II-AASV Blank Summary Form, Form I-AASV for the blank analysis, Form VII-AASV for internal standards in the blank, Form IX for surrogate recoveries in the blank, and a GC/MS data system printout for the analysis of the blank.

7.2.14 **Surrogate Compound Recoveries**

7.2.14.1 The recoveries of the surrogate compounds are calculated from the analysis of each sample and blank. The purpose of the surrogate compounds is to evaluate the performance of the entire PUF/XAD-2 cartridge and GC/MS system. Poor extraction efficiency, leaks, and cold spots in transfer lines are only a few of the potential causes of poor recovery of these compounds.

7.2.14.2 Three surrogate compounds are added to each PUF/XAD-2 cartridge assembly prior to field sampling at the concentrations described in Exhibit D. Five additional surrogate compounds are added to the cartridges just prior to extraction.

7.2.14.3 The recoveries of the surrogate compounds are calculated according to the procedures in Exhibit D. The recoveries must be within the quality control limits given in Exhibit D. If the recovery of any one surrogate compound is outside these limits, the Contractor shall follow the steps outlined in Exhibit D.

7.2.14.4 The documentation includes Form IX-AASV and a GC/MS data system printout for the analysis of each sample and blank.

7.2.15 **Performance Evaluation (PE) Samples**

7.2.15.1 Performance evaluation samples are intended to assist the Agency in monitoring Contractor performance. The laboratory will not be informed as to which compounds are contained in the PE samples or the concentrations.

7.2.15.2 The Laboratory shall extract, analyze, and report the results of the PE sample once per sample delivery group, if available.

7.2.15.3 The laboratory will receive PE samples on PUF/XAD-2 cartridges from the Agency. The samples will come with instructions concerning the extraction procedure required for the PE samples. The Laboratory shall add internal and surrogate compounds to the PE sample, following procedures in Exhibit D.

7.2.15.4 Each laboratory shall extract and concentrate the PE sample using the procedure described in Exhibit D for those semivolatile target compounds listed in Exhibit C.

7.2.15.5 The laboratory shall meet the following PE sample technical acceptance criteria as detailed in Exhibit D:

7.3.8.5.1 The PE sample must be analyzed on a GC/MS system meeting the DFTPP tuning and initial calibration or continuing calibration technical acceptance criteria at the frequency described in Exhibit D.

7.3.8.5.2 The PE sample must be desorbed according to Exhibit D.

7.3.8.5.3 The PE sample must be prepared and analyzed with a laboratory method blank that meets the blank technical acceptance criteria.

7.3.8.5.4 The percent recovery for each of the surrogates in the PE sample must be within acceptable windows as outlined in Exhibit D.

7.3.8.5.5 The area response change between the PE sample and the most recent calibration standard analysis for each of the internal standards must be within 40 percent.

7.3.8.5.5 The retention time shift between the PE sample and the most recent calibration standard analysis for each of the internal standards must be within 20 seconds.

7.3.8.5.6 The percent recovery for each of the target compounds must be within replicate precision and audit accuracy, as outlined in Exhibit D.

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SECTION 8

REGIONAL DATA REVIEW

8.1 Contract laboratory data are generated to meet the specific needs of the Regions. In order to verify the useability of data for the intended purpose, each Region reviews data from the perspective of end-user, based upon functional aspects of data quality. General guidelines for data review have been developed jointly by the Region and the National Program Office. Each Region uses these guidelines as the basis for data evaluation. Individual Regions may augment the basic guideline review process with additional review based on Region-specific or site-specific concerns. Regional reviews, like the sites under investigation, vary based on the nature of the problems under investigation and the Regional response appropriate to the specific circumstances.

8.2 Regional data reviews relating useability of the data to a specific site are part of the collective assessment process. They complement the review done at the Sample Management Office, which is designed to identify contractual discrepancies, and the review done at EMSL/LV, which is designed to evaluate Contractor and method performance. These individual evaluations are integrated into a collective review that is necessary for program and laboratory administration and management and may be used to take appropriate action to correct deficiencies in the Contractor's performance.

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SECTION 9

LABORATORY EVALUATION SAMPLES

9.1 Although intralaboratory QC may demonstrate Contractor and method performance that can be tracked over time, an external performance evaluation program is an essential feature of a QA program. As a means of measuring Contractor and method performance, Contractors participate in interlaboratory comparison studies conducted by the EPA. Results from the analysis of these laboratory evaluation samples will be used by the EPA to verify the Contractor's continuing ability to produce acceptable analytical data. The results are also used to assess the precision and accuracy of the analytical methods for specific analytes.

9.2 Sample sets may be provided to participating Contractors as frequently as on an SDG-by-SDG basis as a recognizable QC sample of known composition; as a recognizable QC sample of unknown composition; or not recognizable as a QC material. The laboratory evaluation samples may be sent either by the Regional client or the National Program Office, and may be used for contract action.

9.3 Contractors are required to analyze the samples and return the data package and all raw data within the contract required turnaround time.

9.4 At a minimum, the results are evaluated for compound identification, quantification, and sample contamination. Confidence intervals for the quantification of target compounds are based on reported values using population statistics. EPA may adjust the scores on any given laboratory evaluation sample to compensate for unanticipated difficulties with a particular sample. Normally, a fraction of the compounds spiked into the sample are not specifically listed in the contract. Contractors are required to use the NIST/EPA/MSDC mass spectral library to tentatively identify a maximum number of non-target compounds in each fraction that are present above a minimal response. Tentative identification of these compounds based on contractually described spectral interpretation procedures is evaluated and integrated into the evaluation process.

9.5 A Contractor's results on the laboratory evaluation samples will determine the Contractor's performance as follows:

9.5.1 No response is required for a score of 90 percent or above.

9.5.2 For a score of 75 to 89, the Contractor shall describe the deficiency(ies) and the corrective action(s) taken in a letter to the APO, TPO, and EMSL/LV, within 14 days of receipt of notification from EPA.

9.5.3 For a score less than 75, the Contractor shall be notified by the APO or TPO concerning the remedy for its unacceptable performance. The

Contractor may expect, but EPA is not limited to, the following actions: reduction of the number of samples sent under the contract, suspension of sample shipment to the Contractor, a site visit, a full data audit, analysis of remedial PE samples, and/or a contract sanction, such as a Cure Notice.

NOTE: A Contractor's prompt response demonstrating that corrective action has been taken to ensure the Contractor's capability to meet contract requirements will facilitate continuation of full sample delivery.

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SECTION 10

GC/MS TAPE AUDITS

10.1 Periodically, EPA requests from Contractors the GC/MS magnetic tapes corresponding to a specific Case in order to accomplish tape audits. Generally, tape submissions and audits are requested for the following reasons.

10.1.1 Program overview;

10.1.2 Indication of data quality problems from EMSL/LV, SMO, or Regional data reviews;

10.1.3 Support for on-site audits; and

10.1.4 Specific Regional requests.

10.2 Depending upon the reason for an audit, the tapes from a recent Case, a specific Case, or a laboratory evaluation sample may be requested. Tape audits provide a mechanism to assess adherence to contractual requirements and to ensure the consistency of data reported on the hardcopy with that generated on the GC/MS tapes. This function provides external monitoring of Program QC requirements and checks adherence of the Contractor to internal QA procedures. In addition, tape audits enable EPA to evaluate the utility, precision, and accuracy of the analytical methods.

10.3 The GC/MS tape shall include raw data and quantitation reports for samples, blanks, laboratory evaluation samples, initial calibrations, continuing calibration, and DFTPP tuning associated with the Case requested. The specific requirements for submissions of GC/MS tapes are discussed in Exhibit B.

10.4 Upon request of the Administrative Project Officer or EMSL/LV, the required tapes and all necessary documentation shall be submitted to EPA within seven (7) days of notification.

SECTION 11

ON-SITE LABORATORY EVALUATIONS

11.1 At a frequency dictated by a contract laboratory's performance, the Administrative Project Officer(APO)/Technical Project Officer(TPO) or their authorized representative will conduct an on-site laboratory evaluation. On-site laboratory evaluations are carried out to monitor the Contractor's ability to meet selected terms and conditions specified in the contract. The evaluation process incorporates two separate categories: Quality Assurance Evaluation and an Evidentiary Audit.

11.2 QUALITY ASSURANCE ON-SITE EVALUATION

11.2.1 Quality assurance evaluators inspect the Contractor's facilities to verify the adequacy and maintenance of instrumentation, the continuity of personnel meeting experience or education requirements, and the acceptable performance of analytical and QC procedures. The Contractor should expect that items to be monitored will include but not be limited to the following items:

- Size and appearance of the facility;
- Quantity, age, availability, scheduled maintenance and performance of instrumentation;
- Availability, appropriateness, and utilization of SOPs;
- Staff qualifications, experience, and personnel training programs;
- Reagents, standards, and sample storage facilities;
- Standard preparation logbooks and raw data;
- Bench sheets and analytical logbook maintenance and review, and
- Review of the Contractor's sample analysis/data package inspection procedures.

11.2.2 Prior to an on-site evaluation, various documentation pertaining to performance of the specific Contractor is integrated in a profile package for discussion during the evaluation. Items that may be included are previous on-site reports, laboratory evaluation sample scores, Regional review of data, Regional QA materials, GC/MS tape audit reports, and data trend reports.

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11.3 EVIDENTIARY AUDIT

11.3.1 Evidence auditors conduct an on-site laboratory evaluation to determine if laboratory policies and procedures are in place to satisfy evidence handling requirements as stated. The evidence audit is comprised of the following three activities.

11.3.1.1 Procedural Audit

The procedural audit consists of review and examination of actual standard operating procedures and accompanying documentation for the following laboratory operations:

- Sample receiving;
- Sample storage;
- Sample identification;
- Sample security;
- Sample tracking (from receipt to completion of analysis); and
- Analytical project file organization and assembly.

11.3.1.2 Written SOPs Audit

The written SOPs audit consists of review and examination of the written SOPs to determine if they are accurate and complete for the following laboratory operations: sample receiving, sample storage, sample identification, sample security, sample tracking (from receipt to completion of analysis), and analytical project file organization and assembly.

11.3.1.3 Analytical Project File Evidence Audit

The analytical project file evidence audit consists of review and examination of the analytical project file documentation. The auditors review the files to determine:

- Accuracy of the document inventory;
- Completeness of the file;
- Adequacy and accuracy of the document numbering system;
- Traceability of sample activity;
- Identification of activity recorded on the documents; and

- Error correction methods.

11.4 DISCUSSION OF THE ON-SITE TEAM'S FINDINGS

The QA and evidentiary auditors discuss their findings with the Administrative Project Officer (APO)/Technical Project Officer (TPO) prior to debriefing the Contractor. During the debriefing, the auditors present their findings and recommendations for corrective actions necessary to the Contractor personnel.

11.5 CORRECTIVE ACTION REPORTS FOR FOLLOW-THROUGH TO QUALITY ASSURANCE AND EVIDENTIARY AUDIT REPORTS

11.5.1 Following an on-site evaluation, QA and evidentiary audit reports which discuss deficiencies found during the on-site evaluation will be forwarded to the Contractor. The Contractor must discuss the corrective actions taken to resolve the deficiencies discussed during the on-site visit and discussed in the on-site reports in a letter to the APO/TPO, EMSL/LV (response to the QA report) and NEIC (response to the evidentiary report) within 14 days of receipt of the finding or within the time agreed upon between APO/TPO and the Contractor. If SOPs are required to be written or SOPs are required to be amended, the Contractor must provide the SOPs to the TPO, EMSL/LV (QA/technical SOPs) and NEIC (evidentiary SOPs) within 30 days of receipt of the finding or within the time agreed upon between the APO/TPO and the Contractor.

11.5.2 If the Contractor fails to take appropriate corrective action to resolve the deficiencies discussed in the on-site reports, a Contractor may expect, but the Agency is not limited to, the following actions:

- reduction of the number of samples sent under the contract;
- suspension of sample shipment to the Contractor;
- a follow-up site visit, a full data audit; and
- analysis of remedial PE samples and/or contract sanction, such as a Cure Notice.

SECTION 12

QUALITY ASSURANCE AND DATA TREND ANALYSIS

12.1 Data submitted by laboratories are subject to review from several aspects: compliance with contract-required QC, usability, and full data package evaluation. Problems resulting from any of these reviews may determine the need for a GC/MS tape audit, an on-site laboratory evaluation and/or a remedial laboratory evaluation sample. In addition, QC prescribed in the methods provides information that is continually used by the Agency to assess sample data quality, Contractor data quality and Program data quality via data trend analysis. Trend analysis is accomplished by entering data into a computerized data base. Statistical reports that evaluate specific anomalies or disclose trends in many areas, including the following, are generated from this data base:

12.1.1 Laboratory Control Sample;

12.1.2 Blanks;

12.1.3 GC/MS Instrument Performance Checks;

12.1.4 Initial and Continuing Calibration Data; and

12.1.5 Other QC and Method Parameters.

12.2 Program-wide statistical results are used to rank laboratories in order to observe the relative performance of each Contractor using a given protocol against its peers. The reports are also used to identify trends within laboratories. The results of many of these trends analyses are included in overall evaluation of a Contractor's performance, and are reviewed to determine if corrective action or an on-site laboratory evaluation is indicated in order to meet the QA/QC requirements of the contract.

12.3 Contractor performance over time is monitored using these trend analysis techniques to detect departures of Contractor output from required or desired levels of QC, and to provide an early warning of Contractor QA/QC problems which may not be apparent from the results of an individual case.

12.4 As a further benefit to the Program, the data base provides the information needed to establish performance-based criteria in updated analytical protocols, where advisory criteria have been previously used. The vast empirical data set produced by contract laboratories is carefully analyzed, with the results augmenting theoretical and research-based performance criteria. The result is a continuously monitored set of QC and performance criteria specifications of what is routinely achievable and expected of environmental chemistry laboratories in mass production analysis

of environmental samples. This, in turn, assists the Agency in meeting its objectives of obtaining data of known and documented quality.

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SECTION 13

DATA MANAGEMENT

13.1 Data management procedures are defined as procedures specifying the acquisition or entry, update, correction, deletion, storage and security of computer readable data and files. These procedures should be in written form and contain a clear definition for all databases and files used to generate or resubmit deliverables. Key areas of concern include: system organization (including personnel and security), documentation operations, traceability and quality control.

13.2 Data manually entered from hard-copy must be quality controlled and the error rates estimated. Systems should prevent entry of incorrect or out-of-range data and alert data entry personnel of errors. In addition, data entry error rates must be estimated and recorded on a monthly basis by reentering a statistical sample of the data entered and calculating discrepancy rates by data element.

13.3 The record of changes in the form of corrections and updates to data originally generated, submitted, and/or resubmitted must be documented to allow traceability of updates. Documentation must include the following for each change:

13.3.1 Justification or rationale for the change;

13.3.2 Initials of the person making the change or changes. Data changes must be implemented and reviewed by a person or group independent of the source generating the deliverable;

13.3.3 Change documentation must be retained according to the schedule of the original deliverable;

13.3.4 Resubmitted diskettes or other deliverables must be reinspected as a part of the laboratory's internal inspection process prior to resubmission. The entire deliverable, not just the changes, must be inspected;

13.3.5 The Laboratory Manager must approve changes to originally submitted deliverables; and

13.3.6 Documentation of data changes may be requested by laboratory auditors.

13.4 Lifecycle management procedures must be applied to computer software systems developed by the laboratory to be used to generate and edit contract deliverables. Such systems must be thoroughly tested and documented prior to utilization

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13.4.1 A software test and acceptance plan including test requirements, test results and acceptance criteria must be developed, followed, and available in written form.

13.4.2 System changes must not be made directly to production systems generating deliverables. Changes must be made first to a development system and tested prior to implementation.

13.4.3 Each version of the production system will be given an identification number, date of installation, date of last operation and archived.

13.4.4 System and operations documentation must be developed and maintained for each system. Documentation must include a user's manual and an operations and maintenance manual.

13.5 Individual(s) responsible for the following functions must be identified:

13.5.1 System operation and maintenance including documentation and training;

13.5.2 Database integrity, including data entry, data updating and quality control; and

13.5.3 Data and system security, backup and archiving.

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SECTION 14

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EXHIBIT F

EVIDENTIARY REQUIREMENTS

January, 1992

EXHIBIT F

EVIDENTIARY REQUIREMENTS

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SECTION 1

SAMPLE CHAIN-OF-CUSTODY

A sample is physical evidence collected from a facility or from the environment. An essential part of hazardous waste investigation effort is that the evidence gathered be controlled. To accomplish this, the following sample identification, chain-of-custody, sample receiving, and sample tracking procedures have been established.

1.1 SAMPLE IDENTIFICATION

1.1.1 To assure traceability of samples while in possession of the Contractor, the Contractor shall have a specified method for maintaining identification of samples throughout the laboratory.

1.1.2 Each sample and sample preparation container shall be labeled with the EPA sample number or a unique laboratory identifier. If a unique laboratory identifier is used, it shall be cross-referenced to the EPA sample number.

1.2 CHAIN-OF-CUSTODY PROCEDURES

1.2.1 Because of the nature of the data being collected, the custody of EPA samples must be traceable from the time the samples are collected until they are introduced as evidence in legal proceedings. The Contractor shall have procedures ensuring that EPA sample custody is maintained and documented.

1.2.2 A sample is under custody if the following applies:

1.2.2.1 It is in your possession.

1.2.2.2 It is in your view after being in your possession.

1.2.2.3 It was in your possession and you locked it up.

1.2.2.4 It is in a designated secure area (secure areas shall be accessible to authorized personnel only).

1.3 SAMPLE RECEIVING PROCEDURES

1.3.1 The Contractor shall designate a sample custodian responsible for receiving all samples.

1.3.2 The Contractor shall designate a representative to receive samples in the event that the sample custodian is not available. The condition of the shipping containers and sample bottles shall be

inspected upon receipt by the sample custodian or his/her representative.

1.3.3 The condition of the custody seals (intact/not intact) shall be inspected upon receipt by the sample custodian or his/her representative.

1.3.4 The sample custodian or his/her representative shall check for the presence or absence of the following documents accompanying the sample shipment:

1.3.4.1 Airbills or airbill stickers.

1.3.4.2 Custody seals.

1.3.4.3 EPA custody records.

1.3.4.4 EPA traffic reports or SAS packing lists.

1.3.4.5 Sample tags

1.3.5 The sample custodian or his/her representative shall sign and date all forms (e.g., custody records, traffic reports or packing lists, and airbills) accompanying the samples at the time of sample receipt.

1.3.6 The Contractor shall contact SMO to resolve discrepancies and problems such as absent documents, conflicting information, broken custody seals, and unsatisfactory sample condition (e.g., leaking sample bottle).

1.3.7 The Contractor shall record the resolution of discrepancies and problems on Telephone Contact Logs.

1.3.8 The following information shall be recorded on Form AADC-1 by the sample custodian or his/her representative as samples are received and inspected:

1.3.8.1 Condition of the shipping container.

1.3.8.2 Presence or absence and condition of custody seals on shipping and/or sample containers.

1.3.8.3 Custody seal numbers, when present.

1.3.8.4 Condition of the sample bottles.

1.3.8.5 Presence or absence of airbills or airbill stickers.

1.3.8.6 Airbill or airbill sticker numbers.

1.3.8.7 Presence or absence of EPA custody records.

1.3.8.8 Presence or absence of EPA traffic reports or SAS packing lists.

1.3.8.9 Presence or absence of sample tags.

1.3.8.10 Sample tag identification numbers cross-referenced to the EPA sample numbers.

1.3.8.11 Verification of agreement or non-agreement of information recorded on shipping documents and sample containers.

1.3.8.12 Problems or discrepancies.

1.4 SAMPLE TRACKING PROCEDURES

The Contractor shall maintain records documenting all phases of sample handling from receipt to final analysis. The records shall include documentation of the movement of samples and prepared samples into and out of designated laboratory storage areas.

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SECTION 2

DOCUMENT CONTROL PROCEDURES

The goal of the laboratory document control program is to assure that all documents for a specified SDG will be accounted for when the project is completed. Accountable documents used by contract laboratories shall include but not be limited to logbooks, chain-of-custody records, sample work sheets, bench sheets, and other documents relating to the sample or sample analyses. The following document control procedures have been established to assure that all laboratory records are assembled and stored for delivery to the EPA or are available upon request from the EPA prior to the delivery schedule.

2.1 PREPRINTED LABORATORY FORMS AND LOGBOOKS

2.1.1 All documents produced by the Contractor which are directly related to the preparation and analysis of EPA samples shall become the property of the EPA and shall be placed in the complete sample delivery group file (CSF). All observations and results recorded by the laboratory but not on preprinted laboratory forms shall be entered into permanent laboratory logbooks. When all data from a SDG are compiled, all original laboratory forms and copies of all SDG-related logbook entries shall be included in the documentation package.

2.1.2 The Contractor shall identify the activity recorded on all laboratory documents which is directly related to the preparation and analysis of EPA samples.

2.1.3 Pre-printed laboratory forms shall contain the name of the laboratory and be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

2.1.4 Logbook entries shall be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

2.1.5 Logbook entries shall be in chronological order. Entries in logbooks, with the exception of instrument run logs and extraction logs, shall include only one SDG per page.

2.1.6 Pages in both bound and unbound logbooks shall be sequentially numbered.

2.1.7 Instrument run logs shall be maintained so as to enable a reconstruction of the run sequence of individual instruments. Because the laboratory must provide copies of the instrument run logs to the EPA, the laboratory may exercise the option of using only laboratory or EPA

sample identification numbers in the logs for sample ID rather than government agency or commercial client names to preserve the confidentiality of commercial clients.

2.1.8 Corrections to supporting documents and raw data shall be made by drawing a single line through the error and entering the correct information. Corrections and additions to supporting documents and raw data shall be dated and initialed. No information shall be obliterated or rendered unreadable. All notations shall be recorded in ink. Unused portions of documents shall be crossed out.

2.2 CONSISTENCY OF DOCUMENTATION

2.2.1 The Contractor shall assign a document control officer responsible for the organization and assembly of the CSF.

2.2.2 All copies of laboratory documents shall be complete and legible.

2.2.3 Before releasing analytical results, the document control officer shall assemble and cross-check the information on sample tags, custody records, laboratory bench sheets, personal and instrument logs, and other relevant data to ensure that data pertaining to each particular sample or sample delivery group is consistent throughout the CSF.

2.3 DOCUMENT NUMBERING AND INVENTORY PROCEDURES

2.3.1 In order to provide document accountability of the completed analysis records, each item in a CSF shall be inventoried and assigned a serialized number as described in Exhibit B, Section 2.

CSF # - Region - Serialized number (For example: 75-2-0240).

2.3.2 All documents relevant to each SDG, including logbook pages, bench sheets, mass spectra, chromatograms, screening records, re-preparation records, re-analysis records, records of failed or attempted analysis, custody records, library research results, etc., shall be inventoried.

2.3.3 The Document Control Officer (DCO) shall be responsible for ensuring that all documents generated are placed in the CSF for inventory and are delivered to the EPA. The DCO shall place the sample tags in plastic bags in the file. Figure E-1 of Exhibit E is an example of a document inventory.

2.4 STORAGE OF EPA FILES

The Contractor shall maintain EPA laboratory documents in a secure location.

2.5 SHIPPING DATA PACKAGES AND CSF

2.5.1 The Contractor shall document shipment of deliverables packages to the recipients. These shipments require custody seals on the containers placed such that they cannot be opened without damaging or breaking the seal. The Contractor shall document what was sent, to whom, the date, and the method (carrier) used.

2.5.2 The Contractor shall purge the CSF deliverable to the appropriate EPA Region 180 days after the report submission.

2.5.3 A copy of the transmittal letter for the CSF will be sent to NEIC and SMO.

2.5.4 The Document Control form is used to document the receipt and inspection of shipping containers and samples. The Contractor shall submit one original FORM AADC-1 for each shipping container.

2.5.5 The Contractor shall sign and date the airbill (if present), examine the shipping containers, record the presence or absence of custody seals and their conditions.

2.5.6 The Contractor shall note any problems with the samples and follow the instructions explained in Exhibit B, Sample Log-In Sheet.

2.5.7 The Contractor shall submit a completed Document Control Form with each SDG package.

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SECTION 3

STANDARD OPERATING PROCEDURES

The Contractor must have written standard operating procedures (SOPs) for receipt of samples, maintenance of custody, sample identification, sample storage, tracking the analysis of samples, and assembly of completed data.

3.1 SPECIFICATIONS FOR WRITTEN STANDARD OPERATING PROCEDURES

3.1.1 An SOP is defined as a written narrative step-by-step description of laboratory operating procedures including examples of laboratory documentation. The SOPs must accurately describe the actual procedures used in the laboratory, and copies of the written SOPs shall be available to the appropriate laboratory personnel. These procedures are necessary to ensure that analytical data produced under this contract are acceptable for use in EPA enforcement case preparation and litigation.

3.1.2 The Contractor's SOPs shall provide mechanisms and documentation to meet each of the following specifications and shall be used by EPA as the basis for laboratory evidence audits. The Contractor must have written standard operating procedures (SOPs) for:

3.1.2.1 Sample receipt and logging.

3.1.2.2 Sample storage.

3.1.2.3 Preventing sample contamination.

3.1.2.4 Security for laboratory and samples.

3.1.2.5 Traceability of standards.

3.1.2.6 Maintaining instrument records and logbooks.

3.1.2.7 Sample analysis and data control systems.

3.1.2.8 Glassware cleaning.

3.1.2.9 Technical and managerial review of laboratory operation and data package preparation.

3.1.2.10 Internal review of contractually-required quality assurance and quality control data for each individual data package.

3.1.2.11 Sample analysis, data handling, and reporting.

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3.1.2.12 Chain-of-Custody.

3.1.2.13 Document control, including Case file preparation.

3.1.3 The Contractor shall have a designated sample custodian responsible for receipt of samples and have written SOPs describing his/her duties and responsibilities.

3.1.4 The Contractor shall have written SOPs for receiving and logging in of the samples. The procedures shall include but not be limited to documenting the following information:

3.1.4.1 Presence or absence of EPA chain-of-custody forms.

3.1.4.2 Presence or absence of airbills or airbill stickers.

3.1.4.3 Presence or absence of EPA Traffic Reports or SAS packing lists.

3.1.4.4 Presence or absence of custody seals on shipping and/or sample containers and their condition.

3.1.4.5 Custody seal numbers, when present.

3.1.4.6 Presence or absence of sample tags.

3.1.4.7 Sample tag ID numbers.

3.1.4.8 Condition of the shipping container.

3.1.4.9 Condition of the sample container.

3.1.4.10 Verification of agreement or nonagreement of information on receiving documents and sample containers.

3.1.4.11 Resolution of problems or discrepancies with SMO.

3.1.4.12 The definition of any terms used to describe sample condition upon receipt.

3.1.5 The Contractor shall have written SOPs for maintenance of the security of samples after log-in and shall demonstrate security of the sample storage and laboratory areas. The SOPs shall specifically include descriptions of all storage areas for EPA samples in the laboratory, and steps taken to prevent sample contamination. The SOPs shall include a list of authorized personnel who have access or keys to secure storage areas.

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3.1.6 The Contractor shall have written SOPs for tracking the work performed on any particular sample. The tracking SOP shall include the following:

3.1.6.1 A description of the documentation used to record sample receipt, sample storage, sample transfers, sample preparations, and sample analyses.

3.1.6.2 A description of the documentation used to record instrument calibration and other QA/QC activities.

3.1.6.3 Examples of the document formats and laboratory documentation used in the sample receipt, sample storage, sample transfer, and sample analyses.

3.1.7 The Contractor shall have written SOPs for maintaining identification of EPA samples throughout the laboratory.

3.1.8 If the Contractor assigns unique laboratory identifiers, written SOPs shall include a description of the method used to assign the unique laboratory identifier and cross-reference to the EPA sample number.

3.1.9 If the Contractor uses prefixes or suffixes in addition to sample identification numbers, the written SOPs shall include their definitions. The Contractor shall have written SOPs describing the method by which the laboratory maintains samples under custody.

3.1.10 The Contractor shall have written SOPs for organization and assembly of all documents relating to each EPA Case, including technical and managerial review. Documents shall be filed on a Case-specific basis. The procedures must ensure that all documents including logbook pages, sample tracking records, chromatographic charts, computer printouts, raw data summaries, correspondence, and any other written documents having reference to the Case are compiled in one location for submission to EPA. The system must include a document numbering and inventory procedure.

3.1.11 The Contractor shall have written SOPs for laboratory safety.

3.1.12 The Contractor shall have written SOPs for cleaning of glassware used in preparing and analyzing samples under this contract.

3.1.13 The Contractor shall have SOPs for traceability of standards used in sample analysis QA/QC.

3.2 HANDLING OF CONFIDENTIAL INFORMATION

3.2.1 A Contractor conducting work under this contract may receive

EPA-designated confidential information from the Agency. Confidential information must be handled separately from other documentation developed under this contract. To accomplish this, the following procedures for the handling of confidential information have been established.

3.2.2 All confidential documents shall be under the supervision of a designated Document Control Officer (DCO).

3.2.3 Any samples or information received with a request of confidentiality shall be handled as "confidential." A separate locked file shall be maintained to store this information and shall be segregated from other nonconfidential information. Data generated from confidential samples shall be treated as confidential. Upon receipt of confidential information, the DCO logs these documents into a Confidential Inventory Log. The information is then made available to authorized personnel but only after it has been signed out to that person by the DCO. The documents shall be returned to the locked file at the conclusion of each working day. Confidential information may not be reproduced except upon approval by the EPA Contracting Officer. The DCO will enter all copies into the document control system. In addition, this information may not be disposed of except upon approval by the EPA Contracting Officer. The DCO shall remove and retain the cover page of any confidential information disposed of for one year and shall keep a record of the disposition in the Confidential Inventory Log.

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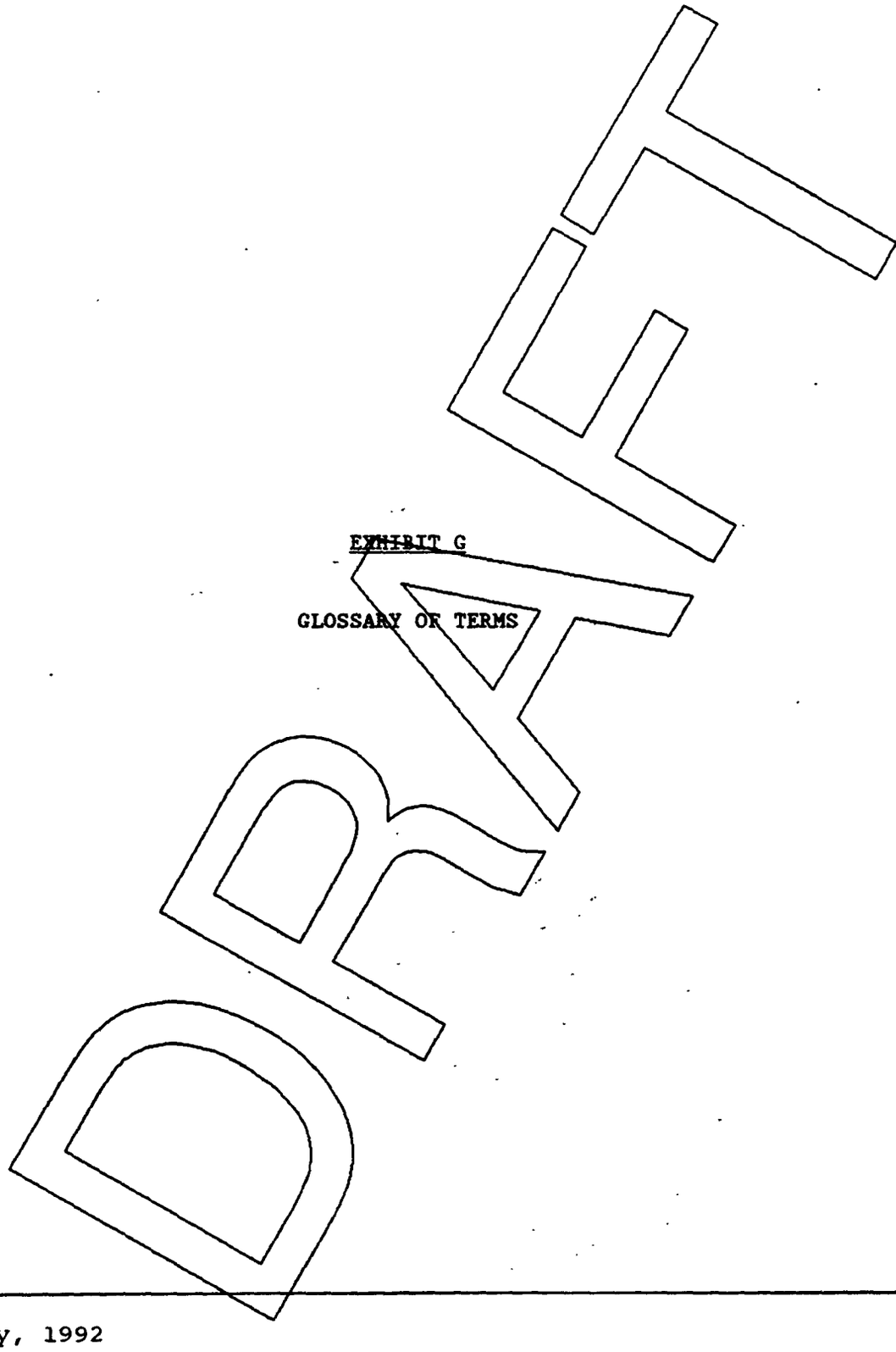

EXHIBIT G

GLOSSARY OF TERMS

January, 1992

EXHIBIT G

GLOSSARY OF TERMS

Aliquot - A measured portion of a field sample taken for analysis.

Analysis Date/Time - The date and military time (24 hour clock) of the introduction of the sample, standard, or blank into the GC/MS system.

Analysis Group - An analysis group is a set of no more than twenty analytical samples (as defined below) for the purpose of method Quality Assurance/Quality Control (QA/QC), such that the QA/QC required by Exhibit E is, at a minimum, prepared and analyzed at a frequency of once per twenty analytical samples.

Analysis Run - The actual instrumental analysis of the sample preparations from the time of instrument calibration through the running of the final sample. All sample preparation analyses during the analysis run are subject to the QC protocols set forth in Exhibit E of this contract unless otherwise specified in the individual methods.

Analytical Preparation Method - A method (i.e, extraction) used to dissolve or otherwise release the compound(s) of interest from its matrix and provide a final solution containing the compound(s) which is suitable for instrumental or other analysis methods.

Analytical Sample - Any solution or media introduced into an instrument on which an analysis is performed excluding initial calibration and continuing calibration standards. Note the following are all defined as analytical samples: undiluted and diluted samples (EPA and non-EPA), duplicate samples, laboratory control sample (LCS), and blanks.

ASTM Type II Water - Distilled water with a conductivity of less than 1.0 μmho/cm at 25°C. For additional specifications refer to ASTM D1193-77, "Standard Specification for Reagent Water".

Background Correction - A technique to compensate for variable background contribution to the instrument signal in the determination of target compounds.

Batch - A group of samples prepared at the same time.

Breakthrough volume (V_B) - Sample volume at which point a particular component will be initially detected in the eluate from the PUF/XAD-2 cartridge.

Calibration - The establishment of an analytical curve based on the response

or other measured characteristic of known standards.

Calibration Standards - A series of known standard solutions used to determine instrument stability and reliability (preparation of the analytical curve).

Case - A finite, usually predetermined number of samples collected over a given time period from a particular site. Case numbers are assigned by the Sample Management Office. A Case consists of one or more Sample Delivery Groups.

Coefficient of Variation (CV) - The standard deviation as a percent of the arithmetic mean.

Continuing Calibration - Analytical standard run at least every 12 hours to verify the initial calibration of the analytical system.

Contract Required Quantitation Limit (CRQL) - Minimum level of quantitation acceptable under the contract. Generally defined as 3.3 (or more) times the standard deviation of seven replicate analyses of the method blank.

Control Limits - A range within which specified measurement results must fall to be compliant. Control limits may be mandatory, requiring corrective action if exceeded, or advisory, requiring that noncompliant data be flagged.

Correlation Coefficient - A number (r) which indicates the degree of dependence between two variables (e.g., concentration - absorbance). The more dependent they are the closer the value to one. Determined on the basis of the least squares line.

Cryogen - A liquified gas used to obtain very low temperatures in the cryogenic trap of the analytical system. A typical cryogen is liquid nitrogen (bp - 195.8°C).

Data System - For the purpose of this contract, computer system that allows the continuous acquisition and printout of time vs. intensity data throughout the chromatographic program.

Day - Unless otherwise specified, day shall mean calendar day.

DDI - Deionized Distilled water.

Deuterated Chemicals - Those chemicals which contain deuterium (hydrogen isotope that is twice the mass of hydrogen); used as tracers for system quality assurance.

Duplicate - A second aliquot of a sample that is treated the same as the original sample in order to determine the precision of the method.

EBCDIC - Extended Binary Coded Decimal Interchange Code.

External Standards - Target analytes analyzed at a known concentration prior to sample analysis, to determine calibration factors.

Extractable - A compound that can be partitioned into an organic solvent from the sample matrix and is amenable to gas chromatography. Extractables include semivolatile organic compounds.

Field Blank - Any blank PUF/XAD-2 cartridges spiked with the same surrogates and sent to the field, along with cartridges for field sampling, but through which ambient air is not sampled.

Field Sample - Material received to be analyzed that is contained in single or multiple containers and identified by a unique EPA Sample Number.

Holding Time - The elapsed time expressed in days from the date of receipt of the sample by the Contractor until the date of its analysis.

In-House - At the Contractor's facility.

Initial Calibration - Analysis of analytical standards for a series of different specified concentrations; used to define the linearity and dynamic range of the response of the analytical instrument to the target analytes.

Instrument Detection Limit (IDL) - Determined by multiplying by three the standard deviation obtained for the analysis of a standard solution (each analyte in reagent water) at a concentration of 3x-5x IDL on three nonconsecutive days with seven consecutive measurements per day.

Interferents - Substances which affect the analysis for the compound of interest.

Internal Standards - Analytes added to every standard, blank, and sample extract at a known concentration prior to analysis. Internal standards are used as the basis for quantitation of the target and surrogate compounds.

Laboratory - Synonymous with Contractor as used herein.

Laboratory Control Sample (LCS) - Aliquot spiked with known concentration of specific analytes and subjected to the entire analytical procedure in order to monitor method and contractor performance.

Laboratory Method Blank (LMB) - A solution produced by performing the analytical preparation method without the addition of a sample. The solution thus contains the same concentrations of reagents as all other analytical preparations plus any impurities derived from the preparation process. For preparations containing reagents of variable concentrations, the LMB should

match the maximum reagent concentration used in the sample extraction.

Laboratory Receipt Date - The date on which a sample is received at the Contractor's facility, as recorded on the shipper's delivery receipt and sample Traffic Report. Also referred to as VTSR (validated time of sample receipt).

Linear Range - The concentration range over which the analytical curve remains linear.

Mass Spectral Interference - Defined as the inability to detect the internal standard quantification ion due to presence of high levels of mass spectral "noise" at the same mass.

Matrix - The predominant material of which the sample to be analyzed is composed.

Megabore® Column - One of two types of capillary columns, the other being the narrow bore, for the analysis of target compounds under this contract.

Method Detection Limit (MDL) - The chemical concentration that produces a signal, due to an analyte, which is equal to the student $t_{.99}$ times the standard deviation of a series of measurements on at least seven separate method blanks. In practice, a method detection limit will be substantially higher than an instrumental detection limit.

MS-SCAN - The gas chromatograph (GC) is coupled to a mass selective detector where the instrument is programmed to acquire all mass for target analytes and to disregard all others.

Narrative (SDG Narrative) - Portion of the data package which includes laboratory, contract, SDG and sample number identification, and descriptive documentation of any problems encountered in processing the samples, along with corrective action taken and problem resolution. Complete SDG Narrative specifications are included in Exhibit B.

Narrow-Bore Capillary Column - One of two capillary columns, the other being the wide-bore (Megabore®) capillary column, for the analysis of compounds under this contract.

Performance Evaluation (PE) Sample - A sample of known composition provided by EPA for Contractor analysis. Used by EPA to evaluate Contractor performance.

Protocol - A compilation of the procedures to be followed with respect to sample receipt and handling, analytical methods, data reporting and deliverables, and document control.

Qualitative Accuracy - The ability of an analytical system to correctly identify compounds.

Quantitative Accuracy - The ability of an analytical system to correctly measure the concentration of an identified compound.

Reconstructed Ion Chromatogram (RIC) - A mass spectral graphical representation of the separation achieved by a gas chromatograph; a plot of total ion current versus retention time.

Recovery - A determination of the accuracy of the analytical procedure made by comparing measured values for a fortified (spiked) sample against the known spike values. Recovery is determined by the following equation:

$$\%\text{Surrogate Recovery} = \frac{\text{measured value}}{\text{spiked value}} \times 100\%$$

Relative Response Factor (RRF) - A measure of the relative mass spectral response of an analyte compared to its internal standard. Relative Response Factors are determined by analysis of standards and are used in the calculation of concentrations of analytes in samples. RRF is determined by the following equation:

$$RRF = \frac{A_x}{A_{is}} \times \frac{C_{is}}{C_x}$$

where:
- A = area of the characteristic ion measured;
- C = concentration;
- is = internal standard; and
- x = compound of interest.

Resolution - Also termed separation, the separation between peaks on a chromatogram, calculated by dividing the height of the valley between the peaks by the peak height of the smaller peak being resolved, multiplied by 100.

Retention Time (RT) - The time to elute a specific chemical from a chromatographic column for a specific carrier gas flow rate, measured from the time the chemical is injected into the gas stream until its maximum concentration appears at the detector.

Retention Time Window - Retention time window is determined for each analyte of interest and is the time from injection to elution of a specific chemical from a chromatographic column. The window is determined by three injections of a single component standard over a 24-hour period as plus or minus three times the standard deviation of the absolute retention time for that analyte.

Rounding Rules - The following are the rules for rounding off numbers.

If the figure following those to be retained is less than 5, the figure is dropped, and the retained figures are kept unchanged. As an example, 11.443 is rounded off to 11.44.

If the figure following those to be retained is greater than 5, the figure is dropped, and the last retained figure is raised by 1. As an example, 11.446 is rounded off to 11.45.

If the figure following those to be retained is 5, and if there are no figures other than zeros beyond the five, the figure 5 is dropped, and the last-place figure retained is increased by one if it is an odd number or it is kept unchanged if an even number. As an example, 11.435 is rounded off to 11.44, while 11.425 is rounded off to 11.42.

If a series of multiple operations is to be performed (add, subtract, divide, multiply), all figures are carried through the calculations. Then the final answer is rounded to the proper number of significant figures.

See forms instructions guide (Exhibit B) for exceptions.

Run - A continuous analytical sequence consisting of prepared samples and all associated quality assurance measurements as required by this contract.

Sample Delivery Group (SDG) - A unit within a sample Case that is used to identify a group of samples for delivery. An SDG is a group of 20 or fewer samples within a Case, received over a period of up to 14 calendar days. Data from all samples in an SDG are due concurrently. A Sample Delivery Group is defined by one of the following, whichever occurs first:

- Case; or
- Each 20 samples within a Case; or
- Each 14-day calendar period during which samples in a Case are received, beginning with receipt of the first sample in the Case or SDG.

Samples may be assigned to Sample Delivery Groups by sample collection method.

Sample Number (EPA Sample Number) - A unique identification number designated by EPA for each sample. The EPA Sample Number appears on the sample Traffic Report which documents information on that sample.

Selected Ion Current Profile (SICP) - A plot of ion abundance vs. time or scan

number for ions of a specified mass.

Semivolatile Organic Compounds - Target compounds with normal vapor pressures between 1 x 10^{-1} and 1 x 10^{-7} mm Hg, and which are amenable to analysis by this method.

Standard Analysis - An analytical determination made with known quantities of target compounds; used to determine response factors.

Static Calibration - Calibration of an analytical system with known concentrations of calibration gas, obtained from a source such as gas cylinders or prepared from standard stock solutions.

Stock Solution - A standard solution which can be diluted to derive other standards.

Surrogates Compounds - Compounds added to every blank, sample, and standard; used to evaluate analytical efficiency by measuring recovery. Surrogates are brominated, fluorinated, or isotopically labelled compounds not expected to be detected in environmental media.

Target compound - The semivolatile organic compound an analysis seeks to determine; the compound of interest.

Tentatively Identified Compounds (TIC) - Compounds detected in samples that are not target compounds, internal standards or surrogate standards. Up to 10 peaks are subjected to mass spectral library searches for tentative identification.

Time - When required to record time on any deliverable item, time shall be expressed as Military Time, i.e., a 24-hour clock.

Traffic Report (TR) - An EPA sample identification form filled out by the sampler, which accompanies the sample during shipment to the laboratory and which is used for documenting sample condition and receipt by the laboratory.

Twelve-Hour Time Period - The twelve (12) hour time period for GC/MS system tuning, standards calibration (initial or continuing calibration) begins at the moment of injection of the DFTPP analysis that the laboratory submits as documentation of compliant tune. The time period ends after 12 hours has elapsed according to the system clock.

Validated Time of Sample Receipt (VTSR) - The date on which a sample is received at the Contractor's facility, as recorded on the shipper's delivery receipt and Sample Traffic Report.

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ATTACHMENT VI

USEPA CONTRACT LABORATORY PROGRAM

METAL

ANALYSIS

OF

AMBIENT AIR

(MAA)

December, 1991

Revision MAA01.0

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USEPA CONTRACT LABORATORY PROGRAM

METAL ANALYSIS OF AMBIENT AIR (MAA)

December, 1991

Revision MAA01.0

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DRAFT

PREFACE

The purpose of this contract is to provide the U.S. Environmental Protection Agency (EPA) with chemical analytical services, quality control procedures, and an analysis structure which will generate data of known and documented quality. The methods for the analysis of ambient air was developed with the guidance of the air toxics workgroup to ensure that the needs of regional, state and local air pollution programs were addressed.

The samples to be analyzed are of ambient air collected at or in the vicinity of known or suspected hazardous waste sites and may contain potentially hazardous organic and/or inorganic material in high concentrations. The Contractor should be aware of the potential hazards associated with the handling and analyses of these samples. It is the Contractor's responsibility to take all necessary measures and precautions to ensure the health and safety of its employees. The Contractor is responsible for providing a safe working environment and making its employees aware of the potential hazards of working with and analyzing these samples.

Procedures specified herein shall be used in the preparation and analysis of air samples for the presence and quantitation of inorganic parameters. The Contractor shall employ safe handling procedures and generally accepted laboratory practices in the performance of contract requirements and shall follow the quality assurance and quality control (QA/QC) program specified herein.

The data obtained under this contract will be used by EPA to determine the existence and extent of risk posed by hazardous waste disposal sites to the public, individuals involved in Superfund site cleanups, and the environment. The data may be used in civil and/or criminal litigation which requires the strictest adherence to chain-of-custody protocol, document control, and quality assurance procedures.

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EXHIBIT A

SUMMARY OF REQUIREMENTS FOR METAL ANALYSIS OF AMBIENT AIR

DRAFT

December, 1991

EXHIBIT A

SUMMARY OF REQUIREMENTS FOR METAL ANALYSIS OF AMBIENT AIR

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SECTION 1

GENERAL REQUIREMENTS

The Contractor shall employ procedures specified in this Contract in the preparation and analysis of the ambient air samples for the presence and quantitation of the metal parameters indicated in Exhibit C.

The Contractor shall employ proven techniques to identify and measure the metal parameters presented in the Target Compound List (TCL) as specified in Exhibit C. The Contractor shall perform sample preparation, analysis procedures, and quailty control procedures as prescribed in Exhibit D, and meet specified sample preservation and holding time requirements.

For all samples analyzed under this contract, the Contractor shall adhere to the quality assurance/quality control (QA/QC) protocols specified in Exhibit E and abide by the evidentiary protocols specified in Exhibit F.

Following sample analysis, the Contractor shall perform data reduction and shall report analytical activities, sample data, and quality control documentation as designated in Exhibit B. Exhibit B contains all reporting and deliverables requirements for this contract, including copies of the data reporting forms and forms instruction guide.

To ensure proper understanding of the language in this contract, Exhibit G contains a glossary of terms. When a term is used in the text without explanation, the glossary meaning shall be applicable. Glossary definitions do not replace or take precedence over specific information included in the Contract text.

The samples to be analyzed by the Contractor are from known or suspected hazardous waste sites and may contain hazardous organic and/or metal materials at high concentration levels. The Contractor should be aware of the potential hazards associated with the handling and analysis of these samples. It is the Contractor's responsibility to take all necessary measures to ensure the health and safety of its employees.

In addition, the Contractor must be aware of the importance of maintaining the integrity of the data generated under this contract, as it is used to make major decisions regarding public health or welfare and the environment. In addition, data generated under this contract may be used in litigation against potentially responsible parties in the enforcement of Superfund legislation.

SECTION 2

SPECIFIC REQUIREMENTS

For each sample, the Contractor shall perform the following tasks:

2.1 TASK I: RECEIVE AND PREPARE AMBIENT AIR SAMPLES

2.1.1 The Contractor shall receive and handle samples under the chain-of-custody and document control procedures described in Exhibit F.

2.1.2 The Contractor shall provide the required analytical expertise and instrumentation for analyses of the TCL analytes equal to or lower than the quantitation limits specified in Exhibit C. In Exhibit D, EPA provides the Contractor with the specific sample preparation techniques for ambient air samples and an appropriate set of analytical procedures that shall be used.

2.1.3 The Contractor shall prepare and analyze samples within the maximum holding time specified in Exhibit D, even if these times are less than the maximum data submission time allowed in this contract.

2.1.4 The Contractor is advised that the samples received under this contract are usually from known or suspected hazardous waste sites and may contain high levels of organic and metal materials of a potentially hazardous nature and of unknown structure and concentration, and should be handled throughout the preparation and analysis with appropriate caution. The Contractor shall be responsible for all necessary measures and precautions to ensure the health and safety of laboratory employees.

2.2 TASK II: ANALYZE SAMPLES FOR THE IDENTIFICATION AND QUANTITATION OF SPECIFIC PARAMETERS

2.2.1 For each sample received, the Contractor shall be required to perform the analyses described as follows. The documentation that accompanies the sample(s) to the Contractor facility shall indicate specific analytical requirements for that sample or set of samples.

2.2.2 Exhibit D specifies the analytical procedures that shall be used. Exhibit D contains instructions and references for preparation of ambient air samples containing low-to-medium concentrations of metals for ICP, ICP/MS, or AA analysis.

2.2.3 All samples must initially be run undiluted (i.e., final product of sample preparation procedure). When an analyte concentration exceeds the calibrated or linear range, appropriate dilution [but not below the contract required quantitation limit (CRQL)] and reanalysis of the prepared sample is required, as specified in Exhibit D.

2.2.4 For the purpose of this contract, a full sample analysis is defined as analysis for all of the TCL constituents identified in Exhibit C in accordance with the methods and quality control (QC) procedures in Exhibit D and performance of related QA/QC as specified in Exhibit E. Laboratory Control Samples (LCS) and spike sample analyses shall each be considered a separate full sample analysis. All other QA/QC requirements are considered an inherent part of this Contract and are included in the contract sample unit price.

2.3 TASK III: PERFORM REQUIRED QUALITY ASSURANCE AND QUALITY CONTROL PROCEDURES

2.3.1 All specific QA procedures prescribed in Exhibits E and QC procedures prescribed in Exhibit D shall be strictly adhered to by the Contractor. Records documenting the use of the protocol shall be maintained in accordance with the document control procedures prescribed in Exhibit F, and shall be reported in accordance with Exhibit B requirements.

2.3.2 The Contractor shall establish and use on a continuing basis QA/QC procedures, including the daily or (as required) more frequent use of standard reference solutions from EPA, NIST, or secondary standards traceable thereto, where available at appropriate concentrations (i.e., standard solutions designed to ensure that operating parameters of equipment and procedures, from sample receipt through identification and quantitation, produce reliable data). Exhibits D and E provide specific QA/QC requirements.

2.3.3 Additional QA/QC shall be required quarterly or more frequently; i.e., with each Case or Sample Delivery Group (SDG), in the form of Laboratory Control Samples (LCS) and Performance Evaluation Samples (PES) for metals submitted to EPA for Contractor analysis, and in the form of verification of instrument parameters, as described in Exhibit D and E.

2.3.3.1 EPA has provided to the Contractor formats for the reporting of data (Exhibit B). The Contractor shall be responsible for completing and returning analysis data sheets in the format specified in this Contract and within the time specified in the Contract Performance/ Delivery Schedule.

2.3.3.2 Use of formats other than those designated by EPA will be deemed as noncompliant. Such data are unacceptable. Resubmission in the specified format at no additional cost to the Government will be required.

2.3.3.3 Computer generated forms may be submitted in the hardcopy data package(s) provided that the forms are in exact EPA format. This means that the order of data elements is the same as on each EPA required form, including form numbers and titles, page numbers and header information, columns, and lines.

2.3.4 The Contractor shall provide analytical equipment and technical expertise for this contract as specified by the following.

2.3.4.1 Inductively coupled plasma (ICP) emission spectrometer with the capability to analyze metals sequentially or simultaneously.

2.3.4.2 Inductively coupled plasma-mass spectrometer (ICP-MS) with the capability to analyze metals (optional).

2.3.4.3 Atomic absorption (AA) spectrometer equipped with graphite furnace and flame analysis capabilities.

2.3.4.4 The Contractor shall have, in-house, the appropriate standards for all target compounds listed in Exhibit C prior to accepting any samples from the Sample Management Office (SMO). Standards provided by EPA for use in the Preaward Performance Evaluation may not contain all the target compounds and thus shall not be used for routine analyses unless or until they have been supplemented with commercially-available standard materials.

2.3.5 The minimum functional requirements necessary to meet the terms and conditions of this contract are listed below. The Contractor shall designate and use qualified key personnel to perform these functions. The EPA reserves the right to review personnel qualifications and experience.

2.3.5.1 Project Manager.

2.3.5.2 Inorganic Laboratory Supervisor.

2.3.5.3 Quality Assurance Officer.

2.3.5.4 Systems Manager.

2.3.5.5 Programmer Analyst.

2.3.5.6 Inductively Coupled Plasma (ICP) Operators.

2.3.5.7 Inductively Coupled Plasma (ICP) Spectroscopist.

2.3.5.8 Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) Operators.

2.3.5.9 Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) Spectroscopist.

2.3.5.10 Graphite Furnace Atomic Absorption (GFAA) Operators.

2.3.5.11 Sample Preparation Laboratory Supervisor.

2.3.5.12 Sample Preparation Specialists.

2.3.5.13 Chemist (back-up).

NOTE: The Contractor shall designate a Sample Custodian and a Document Control Officer.

2.3.6 The Contractor shall respond within 10 days to requests from data recipients for additional information or explanations that result from the Government's inspection activities.

2.3.7 The Contractor is required to retain unused sample volumes and used sample containers for a period of 60 days after data submission unless otherwise instructed in Exhibit B or Exhibit D.

2.3.8 The Contractor shall adhere to the chain-of-custody and document control procedures described in Exhibit F. Documentation, as described therein, shall be required to show that all procedures are being strictly followed. This documentation shall be reported in the Complete Case File Purge (Exhibit B).

2.3.9 Sample shipments to the Contractor's facility will be scheduled and coordinated by SMO, acting on behalf of the Administrative Project Officer (APO). The Contractor shall communicate with SMO personnel by telephone as necessary throughout the process of sample scheduling, shipment, analysis, and data reporting, to ensure that samples are properly processed.

2.3.9.1 If there are problems with the samples (e.g., mixed media, containers broken) or sample documentation/paperwork (e.g., Traffic Reports not with shipment, or sample and Traffic Report numbers do not correspond) the Contractor shall immediately contact SMO for resolution. The Contractor shall immediately notify SMO regarding any problems and laboratory conditions that affect the timeliness of analyses and data reporting. In particular, the Contractor shall notify SMO personnel in advance regarding sample data that will be delivered late and shall specify the estimated delivery date.

2.3.10 Sample analyses will be scheduled by groups of samples, each defined as a Case and identified by a unique EPA Case number assigned by SMO. A Case signifies a group of samples collected at one site or geographical area over a finite time period, and will include one or more field samples with associated blanks. Samples may be shipped to the Contractor in a single shipment or multiple shipments over a period of time, depending on the size of the Case. A Case consists of one or more SDG(s). An SDG is defined by the following:

2.3.10.1 Each Case of field samples received; or

2.3.10.2 Each 20 field samples within a Case; or

2.3.10.3 Each seven calendar day period during which field samples in a Case are received (said period beginning with the receipt of the first sample in the SDG).

2.3.11 Data for all samples in an SDG must be submitted together (in one package) in the order specified in Exhibit B. The SDG number is the EPA number of the first sample received in the SDG. When several samples are received together in the first SDG shipment, the SDG number is the lowest sample number (considering both alpha and numeric designations) in the first group of samples received under the SDG. The SDG number is reported on all data reporting forms. The SDG Receipt Date is the day that the last sample in the SDG is received.

2.3.12 The Contractor is responsible for identifying each SDG as samples are received, through proper sample documentation (see Exhibit B) and communication with SMO personnel.

2.3.13 Each sample received by the Contractor will be labeled with an EPA sample number, and accompanied by a Traffic Report (TR) form bearing the sample number and descriptive information regarding the sample. The Contractor shall complete and sign the TR, recording the date of sample receipt and sample condition on receipt for each sample container.

2.3.14 The Contractor shall submit signed copies of TRs for all samples in an SDG to SMO within three calendar days following receipt of the last sample in the SDG. TRs shall be submitted in SDG sets (i.e., all TRs for a SDG shall be clipped together) with an SDG Cover Sheet containing information regarding the SDG, as specified in Exhibit B.

2.3.15 EPA Case numbers (including SDG numbers) and EPA sample numbers shall be used by the Contractor in identifying samples received under this contract both verbally and in reports/correspondence.

2.3.16 Samples will be routinely shipped directly to the Contractor through a delivery service. The Contractor shall be available to receive sample shipments at any time the delivery service is operating, including Saturdays and holidays. As necessary, the Contractor shall be responsible for any handling or processing required for the receipt of sample shipments, including pick-up of samples at the nearest servicing airport, bus station, or other carrier service within the Contractor's geographical area.

2.3.17 The Contractor shall accept all samples scheduled by SMO, provided that the total number of samples received in any calendar month does not exceed the monthly limitation expressed in the contract. Should the Contractor elect to accept additional samples, the Contractor shall remain bound by all contract requirements for analysis of those samples accepted.

SECTION 3

DETAILED TECHNICAL & MANAGEMENT REQUIREMENTS

The Contractor shall have the following technical and management capabilities:

3.1 PERSONNEL

3.1.1 Project Manager

3.2.1.1 Responsible for all technical efforts of the laboratory to meet all terms and conditions of the contract.

3.1.1.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.1.3 Experience: Minimum of three years of laboratory experience, including at least one year in a supervisory position.

3.1.2 Inorganic Laboratory Supervisor

3.1.2.1 Responsible for all technical efforts of the Inorganic laboratory to meet all terms and conditions of the contract.

3.1.2.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.2.3 Experience: Minimum of three years of laboratory experience in operating a ICP, ICP-MS, or AA, including at least one year in a supervisory position.

3.1.3 Quality Assurance Officer

3.1.3.1 Responsible for overseeing the quality assurance aspects of data generation and reporting directly to upper management.

3.1.3.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.3.3 Experience: Minimum of three years of laboratory experience, including at least one year of applied experience with QA principles and practices in an analytical laboratory.

3.1.4 Systems Manager

3.1.4.1 Responsible for the management and quality control of all computing systems (hardware, software, documentation, and procedures), generating, updating, and performing quality control on automated deliverables.

3.1.4.2 Education: Minimum of Bachelor's degree with four or more intermediate courses in programming, information management, database management systems, or systems requirements analysis.

3.1.4.3 Experience: Minimum of three years experience in data or systems management or programming including one year experience with software used for data management and generation of deliverables.

3.1.5 Program Analyst

3.1.5.1 Responsible for the installation, operation, and maintenance of software and programs; generating, updating, and performing quality control procedures on analytical databases and automated deliverables.

3.1.5.2 Education: Minimum of Bachelor's degree with four or more intermediate courses in programming, information management, information systems, or systems requirements analysis.

3.1.5.3 Experience: Minimum of two years experience in systems or applications programming including one year of experience with software used for data management and generation of deliverables.

3.1.6 Inductively Coupled Plasma (ICP) Spectroscopist

3.1.6.1 Responsible for the operation, interpretation, and maintenance of the ICP spectrometer(s) to meet all terms and conditions of the contract.

3.1.6.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline and specialized training in ICP spectroscopy.

3.1.6.3 Experience: Minimum of two years of applied experience with ICP analysis of environmental samples.

3.1.7 ICP Operator

3.1.7.1 Responsible for the operation and maintenance of the ICP spectrometer(s) to meet all terms and conditions of the contract.

3.1.7.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.7.3 Experience: Minimum of one year of applied experience with ICP analysis of environmental samples; or in lieu of educational requirement, three additional years of experience operating and maintaining ICP instrumentation.

3.1.8 **ICP-MS Spectroscopist (Required if ICP-MS is to be used.)**

3.1.8.1 Responsible for the operation, interpretation, and maintenance of the ICP-MS spectrometer(s) to meet all terms and conditions of the contract.

3.1.8.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline and specialized training in ICP and ICP-MS spectroscopy.

3.1.8.3 Experience: Minimum of one year of applied experience with ICP-MS analysis of environmental samples and a minimum of two years of applied experience with ICP analysis of environmental samples.

3.1.9 **ICP-MS Operator (Required if ICP-MS is to be used.)**

3.1.9.1 Responsible for the operation and maintenance of the ICP-MS spectrometer(s) to meet all terms and conditions of the contract.

3.1.9.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.9.3 Experience: Minimum of one year of applied experience with ICP and ICP-MS analysis of environmental samples; or in lieu of educational requirement, three additional years of experience operating and maintaining ICP instrumentation including ICP-MS techniques.

3.1.10 **Graphite Furnace Atomic Absorption (GFAA) Operator**

3.1.10.1 Responsible for the operation and maintenance of the GFAA spectrometer(s) to meet all terms and conditions of the contract.

3.1.10.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.10.3 Experience: Minimum of one year of applied experience with AA analysis of environmental samples; or in lieu of educational requirement, three additional years of experience operating and maintaining AA instrumentation.

3.1.11 **Sample Preparation Laboratory Supervisor**

3.1.11.1 Responsible for all technical efforts of sample preparations to meet all terms and conditions of the EPA contract.

3.1.11.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.11.3 Experience: Minimum of three years of laboratory experience, including at least one year of supervisory experience.

3.1.12 **Sample Preparation Specialist**

3.1.12.1 Responsible for all aspects of sample preparations to meet all terms and conditions of the EPA contract.

3.1.12.2 Education: Minimum of high school diploma and a college level course in general chemistry or equivalent.

3.1.12.3 Experience: Minimum of six months of applied experience in an analytical laboratory.

3.1.13 **Technical Staff Redundancy**

3.1.13.1 In order to ensure continuous operations to accomplish the required work as specified by the contract, the bidder shall have a minimum of one chemist available at all times as a back-up technical person with the following qualifications.

3.1.13.2 Education: Minimum of Bachelor's degree in chemistry or any scientific/engineering discipline.

3.1.13.3 Experience: Minimum of one year of experience in each of the following areas: ICP and ICP-MS operation and maintenance; AA operation and maintenance; classical chemistry analytical procedures; and sample preparation for metals analysis.

3.2 **FACILITIES**

The adequacy of the facilities and equipment is as important as the technical staff for accomplishing the required work as specified by the EPA contract.

3.2.1 **Sample Receipt Area**

Adequate, contamination-free, well-ventilated work space with chemical resistant bench top shall be available for receipt and safe handling of EPA samples.

3.2.2 **Storage Area**

Sufficient refrigerator space to maintain unused EPA sample volume for up to 60 days after data submission shall be provided. Volatile samples must be stored in a refrigerator used only for storage of volatile samples from this contract. Samples must be stored in an atmosphere demonstrated to be free from all potential contaminants. Samples, extracts, and standards must be stored separately.

3.2.3 **Sample Preparation Area**

Adequate, contamination-free, well-ventilated work space shall be provided with:

3.2.3.1 Benches with chemical resistant tops.

3.2.3.2 Exhaust hoods.

3.2.3.3 Glove box or isolated area in which to prepare standard materials.

3.2.3.4 Source of distilled or demineralized organic-free water.

3.2.3.5 Analytical balance(s) located away from draft and rapid change in temperature.

3.3 INSTRUMENTATION

At a minimum, the Contractor shall have the following instruments operative at the time of the Preaward Site Evaluation and committed for the full duration of the contract.

3.3.1 100 Samples/Month Capacity Requirements

Fraction	No. of Instrument(s)	Type of Instrument
ICP Metals	1	ICP Emission Spectrometer with MS Dectector (if appropriate)
GFAA Metals	1	Atomic Absorption Spectrometer with Graphite Furnace Atomizer

NOTE: The Contractor shall have the following instruments available (operational) at all times as a back-up system:

Quantity	Instruments
1	GFAA

These instruments must be included in the bidder's inventory of equipment. In addition, the Contractor shall have an in-house stock of instrument parts and circuit boards to ensure continuous operation to meet contract-specified holding and turnaround times.

3.3.2 200 Samples/Month Capacity Requirements

Fraction	No. of Instrument(s)	Type of Instrument
ICP Metals	1	ICP Emission Spectrometer with MS Dectector (if appropriate)
GFAA Metals	1	Atomic Absorption Spectrometer with Graphite Furnace Atomizer

NOTE: The Secondary Instrument Requirement for 200 Samples/Month Capacity is one GFAA.

These instruments must be included in the bidder's inventory of equipment. In addition, the Contractor shall have an in-house stock of instrument parts and circuit boards to ensure continuous operation to meet contract-specified holding and turnaround times.

3.3.3 Instrument Specifications

Further information on instrument specifications and required ancillary equipment may be found in Exhibit D and other Exhibits in this Contract.

3.4 DATA HANDLING AND PACKAGING

The Contractor shall be able to submit reports and data packages as specified in Exhibit B. To complete this task, the Contractor shall be required to:

- Provide space, tables, and copy machines to meet the contract requirements; and
- Designate personnel responsible for report preparations and submission.

3.5 LABORATORY MANAGEMENT CAPABILITY

The Contractor shall have an organization with well-defined responsibilities for each individual in the management system to ensure sufficient resources for EPA contract(s) and to maintain a successful operation. To establish this capability, the Contractor shall designate personnel to carry out the following responsibilities for the EPA contract. Functions include, but are not limited to, the following:

3.5.1 Technical Staff

Responsible for all technical efforts for the EPA contract such as sample preparation, sample analysis, sample validation, and trouble-shooting of all instruments.

3.5.2 **Project Manager**

Responsible for overall aspects of EPA contract(s) (from sample receipt through data delivery) and shall be the primary contact for EPA Headquarters APO and Regional Technical Project Officers (TPO).

3.6.3 **Sample Custodian**

Responsible for receiving the EPA samples (logging, handling, and storage).

3.6.4 **Quality Assurance Officer**

Responsible for overseeing the quality assurance aspects of the data and reporting directly to upper management.

3.6.5 **Document Control Officer**

Responsible for ensuring that all documents generated are placed in the Complete SDG File for inventory and are delivered to the appropriate EPA Region or other receiver as designated by EPA.

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EXHIBIT B

REPORTING

AND

DELIVERABLES REQUIREMENTS

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December, 1991

EXHIBIT B

REPORTING AND DELIVERABLES REQUIREMENTS

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SECTION 1

CONTRACT REPORTS/DELIVERABLES DISTRIBUTION

The following table summarizes the contract reporting and deliverables requirements specified in the Contract Schedule and includes the distribution of each deliverable. **NOTE:** Specific recipient names and addresses are subject to change during the term of the contract. The EPA APO or SMO will notify the Contractor in writing of such changes when they occur.

Item	No. of Copies	Schedule and Delivery	Distribution		
			(1)	(2)	(3)
Updated Standard Operating Procedures (SOPs)	2	45 days after contract award.		X	X
*Sample Traffic Reports	1	***3 days after receipt of last sample in Sample Delivery Group (SDG).	X		
**Sample Data Package including the Performance Evaluation Sample (PES)	3	35 days after receipt of last sample in SDG	X	X	X
Results of Intercomparison Study/Preaward Performance Evaluation (PPE) Sample	2	35 days after receipt of last sample in SDG	X	X	
Complete SDG File	1	35 days after data receipt of last sample in SDG.		X	
*Verification of Parameters	1	15th day of January, April, July, and October.		X	
****Quality Assurance Plan	1	Submit copy within 7 days by written request by APO.	As Directed		

Distribution

(1) Sample Management Office
(2) Environmental Monitoring Systems Laboratory-Las Vegas
(3) USEPA Region

* Also required in each Sample Data Package.

** Concurrent delivery of these items to all recipients is required.

*** An SDG is a group of samples within a Case, received over a period of seven days or less and not exceeding 20 samples. Data for all samples in the SDG are due concurrently. (See Exhibit A, Task III, for further description).

**** See Exhibit E for description.

NOTE: As specified in the Contract Schedule in the IFB (Government Furnished Supplies and Materials), unless otherwise instructed by SMO, the Contractor shall dispose of unused sample volume and used sample bottles/containers no earlier than 60 days following submission of analytical data.

Address

(1) USEPA Contract Laboratory Program
Sample Management Office
P.O. Box 818
Alexandria, VA 22313

For overnight delivery service, use street address:

300 North Lee Street
Alexandria, VA 22313

(2) USEPA Environmental Monitoring Systems Laboratory
P.O. Box 93478
Las Vegas, NV 89193-3478
ATTN: Data Audit Staff

For overnight delivery service, use street address:

944 E. Harmon, Executive Center
Las Vegas, NV 89109
ATTN: Data Audit Staff

(3) USEPA REGIONS:

SMO, acting on behalf of the EPA APO, will provide the Contractor with the list of addresses for the 10 EPA Regions. SMO will provide the Contractor with updated Regional name/address lists as necessary throughout the period of the contract and identify other client recipients on a case-by-case basis.

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SECTION 2

REPORT DESCRIPTIONS AND ORDER OF DATA DELIVERABLES

The Contractor shall provide reports and other deliverables according to the schedule specified in Section F of the IFB, "SCHEDULE INFORMATION." The required content and form of each deliverable is described in this Exhibit.

All reports and documentation shall be:

- Legible;
- Clearly labeled and completed in accordance with instructions in this Exhibit;
- Arranged in the order specified in this section;
- Paginated; and
- Single-sided.

If submitted documentation does not conform to the above criteria, the Contractor will be required to resubmit such documentation with deficiency(ies) corrected, at no additional cost to the Government.

Whenever the Contractor is required to submit or resubmit data as a result of an on-site laboratory evaluation or through an APO/TPO action, the data shall be clearly marked as "ADDITIONAL DATA" and shall be sent to all three contractual data recipients (SMO, EMSL-LV, and Region). A cover letter shall be included that describes which data are being delivered, to which EPA Case(s) the data pertain, and who requested the data.

Section 3 of this Exhibit contains instructions to the Contractor for properly completing all data reporting forms to provide the EPA with the required documentation and contains the required data forms in EPA-specified format.

Descriptions of the requirements for each deliverable item cited in the Contract Performance/Delivery Schedule (see Section F of the IFB "SCHEDULE INFORMATION") are specified as follows in this Section. Items submitted concurrently must be arranged in the order listed. Additionally, the components of each item must be arranged in the order presented herein.

2.1 UPDATED STANDARD OPERATING PROCEDURES

2.1.1 The Contractor shall submit updated copies of all required Standard Operating Procedures (SOPs) that were submitted with the Prebid Performance Evaluation (PPE) sample results. The updated SOPs must address any and all

issues of laboratory performance and operation identified by the Contractor in the review of the PPE sample data and the evaluation of Bidder-Supplied Documentation.

2.1.2 The Contractor must supply SOPs for the following.

2.1.2.1 Evidentiary SOPs.

2.1.2.2 Sample receipt and logging.

2.1.2.3 Sample and extract storage area.

2.1.2.4 Preventing sample contamination.

2.1.2.5 Security for laboratory and samples.

2.1.2.6 Traceability/equivalency of standards.

2.1.2.7 Maintaining instrument records and bound logbooks.

2.1.2.8 Glassware cleaning.

2.1.2.9 Technical and managerial review of laboratory operation and data package preparation.

2.1.2.10 Internal review of contractually-required QA/QC data for each individual data package.

2.1.2.11 Sample analysis, data handling, and data reporting.

2.1.2.12 Chain-of-custody and document control, including case file preparation.

2.1.2.13 Sample data validation/self-inspection system, including:

- Data flow and chain-of-command for data review;
- Procedures for measuring precision and accuracy;
- Evaluation parameters for identifying systematic errors;
- Procedures to ensure that hardcopy data are complete and compliant with the requirements in Exhibit B;
- Demonstration of internal QA inspection procedure (demonstrated by supervisory sign-off on personal notebooks, internal PE samples, etc.);

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- Frequency and type of internal audits (e.g., random, quarterly, spot checks, perceived trouble areas);
- Demonstration of problem identification, corrective actions, and resumption of analytical processing resulting from internal audit (i.e., QA feedback); and
- Documentation of audit reports (internal and external), response, corrective action, etc.

2.1.2.14 Data Handling.

2.1.2.14.1 Data Management procedures defined as written procedures that are clearly defined for all databases and files used to generate or re-submit deliverables specifying the acquisition or entry, update, correction, deletion, storage, and security of computer readable data and files. Key areas of concern include: system organization including personnel and security, demonstration, operations, traceability, and quality control.

2.1.2.14.2 Data manually entered from hardcopy must be subjected to quality control procedures and error rates estimated.

2.1.2.14.3 The record of changes in the form of corrections and updates to data originally generated, submitted, and/or resubmitted must be documented to allow traceability of updates. Documentation must include the following information for each change:

- Justification or rationale for the change;
- Initials of the person making the changes or changes. Data changes must be identified when generating the deliverables;
- Changed documentation must be retained according to the schedule of the original deliverable;
- Resubmitted deliverables must be reinspected as a part of the laboratory's internal inspection process prior to submission. The entire deliverable and not just the changes must be reinspected;
- The laboratory manager must approve changes to originally submitted deliverables; and
- Documentation of data changes may be requested by laboratory auditors.

2.1.2.14.4 Life Cycle Management procedures must be applied to computer systems used to generate and edit contract deliverables. Such systems must be thoroughly tested and documented prior to utilization.

2.1.2.14.5 A software test and acceptance plan including test requirements, test results, and acceptance criteria must be developed, followed, and available in written form.

2.1.2.14.6 System changes shall not be made directly to production systems generating deliverables. Changes must be made first to a development system and tested prior to implementation.

2.1.2.14.7 Each version of the production system will be given an identification number, date of installation, date of last operation, and archived.

2.1.2.14.8 System and operations documentation shall be developed and maintained for each system. Documentation must include a user's manual and an operations and maintenance manual.

2.1.2.14.9 Individual(s) responsible for the following functions shall be identified:

- System operation and maintenance including documentation and training; and
- Database integrity including data entry, data updating and QC.

2.1.2.14.10 Data and system security, backup, and archiving.

2.2 SAMPLE TRAFFIC REPORTS

2.2.1 The original sample TR page marked "Lab Copy for Return to SMO" shall be submitted to SMO with laboratory receipt information and signed in original Contractor signature, for each sample in the SDG.

2.2.2 TRs shall be submitted in SDG sets (i.e., TRs for all samples in an SDG shall be clipped together), with an SDG Cover Sheet attached.

2.2.3 The SDG Cover Sheet shall contain the following items:

- Laboratory name;
- Contract number;
- Sample analysis price - full sample price from contract;

- Case number; and
- List of EPA sample numbers of all samples in the SDG, identifying the first and last samples received, and their dates of receipt.

NOTE: When more than one sample is received in the first or last SDG shipment, the "first" sample received would be the lowest sample number (considering both alpha and numeric designations), and the "last" sample received would be the highest sample number (considering both alpha and numeric designations).

2.2.4 Each TR shall be clearly marked with the SDG Number and the EPA sample number of the first sample in the SDG. This information shall be entered below the laboratory receipt date on the TR. The TR for the last sample received in the SDG shall be clearly marked "SDG - FINAL SAMPLE."

2.2.5 If samples are received at the laboratory with multi-sample TRs, all the samples on one multi-sample TR may not necessarily be in the same SDG. In this instance, the laboratory shall make the appropriate number of photocopies of the TR, and submit one copy with each SDG cover sheet.

2.3 SAMPLE DATA PACKAGE

2.3.1 The sample data package shall be complete, consecutively paginated, and shall include data for analysis of all samples in an SDG. These samples include analytical and field samples, sample reanalyses, blanks, spikes, duplicates, and laboratory control samples.

2.3.2 The sample data package is divided into six units as follows:

- Cover page;
- Sample data (Results);
- Quality control summary;
- Raw data;
- Preparation logs; and
- Sample TRs.

2.3.2.1 Cover Page

This document shall be clearly labeled "Cover Page." The Cover Page shall contain: laboratory name; laboratory code; contract number; Case Number; SDG Number; SAS number (appears on cover page of SAS); EPA

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sample numbers in alphanumeric order, showing EPA sample number cross-referenced with laboratory ID numbers; and comments, describing in detail any problems encountered in processing the samples in the data package.

The Cover Page shall contain the following statement, verbatim:

"I certify that this data package is in compliance with the terms and conditions of the contract, both technically and for completeness, for other than the conditions detailed above. Release of the data contained in this hardcopy data package has been authorized by the Laboratory Manager or the Manager's designee, as verified by the following signature."

This statement shall be directly followed by the signature of the Laboratory Manager or his designee with a typed line below it containing the signer's name and title, and the date of signature.

In the event that the Laboratory Manager cannot validate all data reported for each sample, he/she must provide a detailed description of the problems associated with the sample(s) on the Cover Page.

2.3.2.2 **Sample Data**

Sample data shall be submitted with FORM I - Analysis Data Sheet, for all samples in the SDG, arranged in increasing alphanumeric EPA sample number order.

2.3.2.3 **Quality Control Summary**

The quality control summary shall contain the following forms:

NOTE: If more than one form is necessary, duplicate forms must be arranged in chronological order.

- Initial and Continuing Calibration Verification [FORM II - AAIN];
- CRQL Standards/Linear Range Standards (Quarterly) [FORM III - AAIN];
- Blanks [FORM IV - AAIN];
- ICP and ICP-MS Interference Check Sample [FORM V - AAIN];
- Spike Sample Recovery [FORM VI - AAIN];
- Duplicates [FORM VII - AAIN];
- Laboratory Control Sample [FORM VIII - AAIN];
- Method of Standard Additions [FORM IX - AAIN];

- ICP and ICP-MS Serial Dilutions [FORM X - AAIN];
- Method Quantitation Limits (Quarterly) [FORM XI - AAIN];
- ICP and ICP-MS Interelement Correction Factors (Annual) [FORM XII - AAIN];
- ICP-MS Tuning and Response Factor Criteria [FORM XIII - AAIN];
- ICP-MS Internal Standards Summary [FORM XIV - AAIN];
- Preparation Log [FORM XV - AAIN];
- Analysis Run Log [FORM XVI - AAIN]; and
- Standard Solutions Source [FORM XVII - AAIN].

2.3.2.4 **Raw Data**

2.3.2.4.1 For each reported value, the Contractor shall include all raw data from the instrument used to obtain the sample values (except for raw data for quarterly verifications of instrument parameters). Raw data shall contain all instrument readouts used for the sample results, including those readouts that may fall below the Method Quantitation Limit (MQL). All ICP, ICP-MS, and GFAA instruments must provide legible hard copy of the direct real-time instrument readout (i.e., stripcharts, printer tapes, etc.). A photocopy of the direct sequential instrument readout must be included.

2.3.2.4.2 The order of raw data in the data package shall be: ICP, ICP-MS, and GFAA. All raw data shall include concentration units for ICP and ICP-MS (if appropriate) and absorbencies or concentration units for GFAA.

2.3.2.4.3 Metal raw data must be labeled with EPA sample number and appropriate codes as shown in Table B-1, to identify unequivocally the following:

- Calibration standards, including source and preparation date;
- Initial and continuing calibration blanks and preparation blanks;
- Initial and continuing calibration verification standards, interference check samples, CRQL standard, and linear range standard;
- Diluted and undiluted samples (by EPA sample number) and all weights, dilutions, and volumes used to obtain the reported values. If the volumes, weights, and dilutions are consistent for all samples in a given SDG, a general statement outlining these parameters is sufficient;
- Duplicates;

- Spikes (indicating standard solutions used, final spike concentrations, volumes involved). If spike information (source, concentration, volume) is consistent for a given SDG, a general statement outlying these parameters is sufficient;

- Instrument used, any instrument adjustments, data corrections or other apparent anomalies on the measurement record, including all data voided or data not used to obtain reported values and a brief written explanation;

- Data and EPA sample number for ICP, ICP-MS, and GFAA analyses clearly and sequentially identified on the raw data;

- All calculations for sample and analytical spike data, including percent recovery, coefficient of variation, slope and y-intercept of linear fit;

- Time and date of each analysis. Instrument run logs can be submitted if they contain this information. If the instrument does not automatically provide time of analysis, these must be manually entered on all raw data for initial and continuing calibration verification and blanks, as well as interference check samples and linear range analysis standards; and

- Integration times for GFAA analysis.

2.3.2.5 **Preparation Logs**

These logs must include the following:

- Date;

- Sample weights and volumes;

- Sufficient information to identify unequivocally which QC samples (i.e., laboratory control sample, preparation blank) correspond to each batch prepared; and

- Comments describing any significant sample changes or reactions which occur during preparation.

2.3.2.6 **Sample Traffic Report**

A legible copy of the sample TRs and SDG Cover Sheet shall be submitted as described in part 2.2 of this Exhibit for all of the samples in the SDG. The TRs shall be arranged in increasing EPA sample number order, considering both alpha and numeric designations.

TABLE B-1

Codes for Labelling Metal Data

Sample	XXXXXX
Duplicate	XXXXXXD
Sample Spike	XXXXXXS
Instrument Calibration Standards:	
ICP and ICP-MS	S or S0 for blank standard
Atomic Absorption	S0, S10, etc.
Initial Calibration Verification	ICV
Initial Calibration Blank	ICB
Continuing Calibration Verification	CCV
Continuing Calibration Blank	CCB
Interference Check Samples:	
Solution A	ICSA
Solution AB	ICSAB
CRQL Standard for AA	CRA
CRQL Standard for ICP and ICP-MS	CRI
Laboratory Control Samples	LCS
Preparation Blank	PB
Linear Range Analysis Standard	LRS

NOTES:

1. When an MSA is performed on samples other than field samples, the "0", "1", "2" or "3" suffixes must be the last to be added to the EPA Sample Number. For instance, an MSA spike of a duplicate must be formatted "XXXXXXD0".

2. The numeric suffix that follows the "S" suffix for the standards indicates the true value of the concentration of the standard in µg/L.

3. ICP and ICP-MS calibration standards usually consist of several analytes at different concentrations. Therefore, no numeric suffix can follow the ICP and ICP-MS calibration standards unless all the analytes in the standard are prepared at the same concentrations.

4. The CRQL standard for AA is considered to be a calibration standard if it was a part of the calibration curve, thus it must be formatted like any other standard. The "CRA" format must be used if the CRQL standard for AA is not used to establish the calibration curve.

2.4 RESULTS OF INTERCOMPARISON/PERFORMANCE EVALUATION SAMPLE ANALYSES

The reporting of analytical results for Intercomparison Study/Preaward Performance Evaluation (PPE) sample analyses includes all requirements specified in part 2.3 for reporting of sample data. The PPE sample shall be carried through the exact same process as an analytical and field sample.

2.5 COMPLETE CASE FILE PURGE

2.5.1 The Complete SDG File package includes all laboratory records received or generated for a specific Case that have not been previously submitted to EPA as a deliverable. These items shall be submitted to EPA as a deliverable. These items shall be submitted along with their Document Inventory Sheet FORM AADC-2 (see Exhibit E for description of document numbering and inventory procedure). These items include, but are not limited to, sample tags, custody records, sample tracking records, analysts' logbook pages, bench sheets, instrument readout records, computer printouts, raw data summaries, instrument logbook pages (including instrument conditions), correspondence, and the document inventory.

2.5.2 Shipment of the Complete SDG File package by first class mail, overnight courier, priority mail or equivalent is acceptable. Custody seals, which are provided by EPA, shall be placed on shipping containers and a document inventory and transmittal letter included. The Contractor is not required to maintain any documents for a sample Case after submission of the Complete SDG File package; however, the Contractor should maintain a copy of the document inventory and transmittal letter.

2.6 VERIFICATION OF INSTRUMENT PARAMETERS

The Contractor shall perform and report quarterly verification of MQLs by methods specified in Exhibit D and E for each type and model number of instrument used under this contract. For ICP and ICP-MS instrumentations and methods, the Contractor shall also report annual interelement correction factors (including method of determination), wavelengths used, and integration times. Annual Verification of Instrument Parameters forms for the current year shall be submitted in each SDG data package, using appropriate forms. Submission of Quarterly Verification of Instrument Parameters shall include the raw data used to determine those values reported.

2.7 QUALITY ASSURANCE PLAN (QAP)

2.7.1 The Contractor shall prepare a written Quality Assurance Plan (QAP) which describes the procedures that are implemented to achieve the following: maintain data integrity, validity, and useability; ensure that analytical measurement systems are maintained in an acceptable state of stability and reproducibility; detect problems through data assessment and established corrective action procedures which keep the analytical process

reliable; and document all aspects of the measurement process in order to provide data which are technically sound and legally defensible.

2.7.2 The QAP must present, in specific terms, the policies, organization, objectives, functional guidelines, and specific QA/QC activities designed to achieve the data quality requirements in this contract. Where applicable, SOPs pertaining to each parameter shall be included or referenced as part of the QAP. The QAP must be available during on-site laboratory evaluation and upon written request by the APO.

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SECTION 3

FORM INSTRUCTIONS GUIDE

This section contains specific instructions for the completion of all required Data Reporting Forms for analysis of metal constituents in ambient air. This section is organized into the following parts:

- General Information and Header Information
- Cover Page - [COVER PAGE - AAIN]
- Analysis Data Sheet [FORM I - AAIN]
- Initial and Continuing Calibration Verification [FORM II - AAIN]
- CRQL Standards/Linear Range Standards (Quarterly) [FORM III - AAIN]
- Blanks [FORM IV - AAIN]
- ICP Interference Check Sample [FORM V - AAIN]
- Spike Sample Recovery [FORM VI - AAIN]
- Duplicates [FORM VII - AAIN]
- Laboratory Control Sample [FORM VIII - AAIN]
- Method of Standard Additions [FORM IX - AAIN]
- ICP Serial Dilution [FORM X - AAIN]
- Method Quantitation Limits (Quarterly) [FORM XI - AAIN]
- ICP and ICP-MS Interelement Correction Factors (Annual) [FORM XII - AAIN]
- ICP-MS Tuning and Response Factor Criteria [FORM XIII - AAIN]
- ICP-MS Internal Standards Summary [FORM XIV - AAIN]
- Preparation Log [FORM XV - AAIN]
- Analysis Run Log [FORM XVI - AAIN]
- Standard Solutions Sources [FORM XVII - AAIN]
- Sample Log-In Sheet [FORM AADC-IN-1]
- Document Inventory Sheet [FORM AADC-IN-2]

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3.1 GENERAL INFORMATION AND HEADER INFORMATION

3.1.1 Values must be reported on the hardcopy forms according to the individual form instructions in this Section. Each form submitted must be filled out completely for all analytes. Multiple forms cannot be submitted in place of one form if the information on those forms can be submitted on one form.

3.1.2 For rounding off numbers to the appropriate level of precision, observe the following common rules. If the figure following those to be retained is less than 5, drop it (round down). If the figure is greater than 5, drop it and increase the last digit to be retained by 1 (round up). If the figure following the last digit to be retained equals 5 and there are no digits to the right of the 5 or all digits to the right of the 5 equals zero, then round up if the digit to be retained is odd, or round down if that digit is even.

3.1.3 All characters which appear on the data reporting forms presented in the contract must be reproduced by the Contractor when submitting data, and the format of the forms submitted must be identical to that shown in the contract. No information may be added, deleted, or moved from its specified position without prior written approval of the EPA APO. The names of the various fields and analytes (i.e., "Lab Code", "Aluminum") on the forms must appear as they do on the forms, except that the use of uppercase and lowercase letters is optional.

3.1.4 All alphabetic entries made onto the forms by the Contractor must be in ALL UPPERCASE letters (i.e., "LOW", not "Low" or "low").

3.1.5 Six pieces of information are common to the header sections of each data reporting form. These are: Lab Name, Contract, Lab Code, Case No., SAS No., and SDG No. This information must be entered on every form and must match on all forms.

3.1.5.1 The "Lab Name" is the name chosen by the Contractor to identify the laboratory. It may not exceed 25 characters.

3.1.5.2 The "Contract" is the number of the EPA contract, including hyphens, under which the analyses were performed.

3.1.5.3 The "Lab Code" is an alphabetic abbreviation of up to 6 characters, assigned by the EPA, to identify the laboratory and aid in data processing. This lab code shall be assigned by the EPA at the time a contract is awarded, and must not be modified by the Contractor, except at the direction of EPA. If a change of name or ownership occurs at the laboratory, the lab code will remain the same until the Contractor is directed by the EPA to use another lab code assigned by the EPA.

3.1.5.4 The "Case No." is the EPA-assigned Case number (up to 5 characters) associated with the sample and recorded on the TR.

3.1.5.5 The "SAS No." is the EPA-assigned number for analyses performed under Special Analytical Services (SAS). If samples are to be analyzed under SAS only and reported on these forms, then enter SAS No. and leave Case No. blank. If samples are analyzed according to this Contract and have additional SAS requirements, then list both Case No. and SAS No. on all forms. If the analyses have no SAS requirements, leave "SAS No." blank.

NOTE: Some samples in an SDG may have a SAS No., while others may not.

3.1.5.6 The "SDG No." is the Sample Delivery Group number. The SDG number is the EPA sample number of the first sample received in the SDG. When several samples are received together in the first SDG shipment, the SDG number must be the lowest sample number (considering both alpha and numeric designations) in the first group of samples received under the SDG.

3.1.6 The EPA sample number is the unique identifying number given in the TR that accompanied that sample. This number is assigned by the EPA and it must be used exactly as assigned.

3.1.6.1 The "EPA SAMPLE No." must be entered on several of the forms. This number appears either in the upper right hand corner of the form, or as the left column of a table summarizing data from a number of samples. When the "EPA SAMPLE No." is entered into the triple-spaced box in the upper right hand corner of a form, it must be centered on the middle line of the three lines that comprise the box.

3.1.6.2 All field samples and quality control samples associated with field samples must be identified with an EPA sample number. In addition, the sample suffix and quality control sample abbreviations listed in Table B-1, Section 2 of this Exhibit must be used as appropriate.

3.1.7 All results must be transcribed to FORMs II-XV in the raw data with the specified number of decimal places that are described in Exhibit B. The raw data result is to be rounded only when the number of figures in the raw data result exceeds the maximum number of figures specified for that result entry for that form. If there are not enough figures in the raw data result to enter in the specified space for that result, then zeros must be used for decimal places to the specified number of reporting decimals for that result for a specific form. The following examples are provided:

Raw Data Result	Specified Format	Correct Entry on Form
5.9	6.3 (to three decimal places)	5.900
5.99653	6.3 (to three decimal places)	5.997
95.99653	6.3 (to three decimal places)	95.997
995.99653	6.3 (to three decimal places)	996.0
9995.996	6.3 (to three decimal places)	9996.0
99995.9	6.3 (to three decimal places)	99996.0
999995.9	6.3 (to three decimal places)	invalid

NOTE: 6.3 stands for a maximum of six significant figures and up to three decimal places.

3.1.8 Before evaluating a number for being in control or out of control in relationship to a certain limit, the number evaluated must be rounded using EPA rounding rules to the significance reported for that limit. For instance, the control limit for an ICV is ± 10 percent of the true value. A percent recovery value of 110.4 would be considered in control while a value of 110.6 would be considered out of control. In addition, a calculated value of 110.50 would be in control while a calculated value of 110.55 would be out of control.

3.2 COVER PAGE [Cover Page - AAIN]

3.2.1 This form is used to list all billable samples analyzed within an SDG, and to provide certain analytical information and general comments. It is also the document which is signed by the Laboratory Manager to authorize and release all data and deliverables associated with the SDG.

3.2.2 Under "EPA Sample No.," enter up to seven characters for the EPA sample number (including spikes and duplicates) for each required analysis within the SDG. Samples spikes must contain an "S" suffix and duplicates a "D" suffix. Other spikes (analytical, post digestion/distillation) must have an "A" suffix. These sample numbers must be listed on the form in ascending alphanumeric order using the Extended Binary Coded Decimal Interchange Code convention. Thus, if MAB123A is the lowest (considering both alpha and numeric characters) EPA sample number within the SDG, it would be entered in the first EPA sample number field. Samples listed below it would be in ascending sequence - MAB124A, MAB124B, MAB125A, MAC111A, MA1111A, MA1111AD, etc.

3.2.3 All EPA sample numbers must be listed in ascending alphanumeric order, continuing to the following Cover Page if applicable.

3.2.4 Under "Lab Sample ID," a laboratory sample identification (up to ten characters) may be entered for each associated EPA sample number. If a laboratory sample ID is entered, it must be entered identically (for each EPA Sample No.) on all associated data.

3.2.5 Enter "Y" or "N" for "YES" or "NO," respectively, in answer to each of the two questions concerning ICP and ICP-MS corrections. Each question must be explicitly answered with a "Y" or an "N." The third question must be answered with a "Y" or "N" if the answer to the second question is "Y." It should be left blank if the answer to the second question is "N."

3.2.6 Under "Comments," enter any problems encountered, both technical and administrative, the corrective action taken, and resolution performed for all of the samples in the SDG.

3.2.7 Each Cover Page must be signed, in original, by the Laboratory Manager or the Manager's designee, and dated to authorize the release and verify the contents of all data and deliverables associated with an SDG.

3.3 ANALYSIS DATA SHEET [FORM I - AAIN]

3.3.1 This form is used to tabulate and report sample analysis results for target analytes (Exhibit C).

3.3.2 Complete the header information according to the header instructions and as follows.

3.3.3 For "Lab Sample ID," enter the laboratory sample identification for the sample, as listed on the Cover Page.

3.3.4 For "Date Received," enter the date (formatted MM/DD/YY) the sample was received at the laboratory, as recorded on the TR [i.e., the Validated Time of Sample Receipt (VTSR)].

3.3.5 For "Air Volume Sampled, Std. m^3," enter the air volume sampled (to two decimal places), as recorded on the TR.

3.3.6 For "Date Analyzed," enter the date (formatted MM/DD/YY) the sample was analyzed by the laboratory.

3.3.7 Under "CAS No.," enter the chemical abstract services register number for the analysis if applicable. If a case number doesn't exist, enter "NA" in the space provided.

3.3.8 Under the column labeled "CONCENTRATION," if the analytical result is greater than or equal to the MQL, report the result. If the result is lower than the MQL, report the CRQL value.

NOTE: Analytical results must be reported to two significant figures if the result value is less than ten, and to three significant figures if the result value is greater than or equal to ten.

NOTE: The requirement for reporting results to two or three significant figures applies to FORM I-AAIN only. Follow the specific instructions for reporting all other results on required forms as described in this Exhibit.

3.3.8.1 Under "µg/L," enter the value obtained (to two significant figures if the result value is less than ten, and to three significant figures if the result value is greater than or equal to ten) for the analyte.

3.3.8.2 Under "µg/m³," enter the value obtained (to two significant figures if the result value is less than ten, and to three significant figures if the result value is greater than or equal to ten) from the following equation:

$$\text{Analyte Conc. air, } \mu g/m^3 = \frac{9 \times \text{Interference-Corrected Analyte Value, } \mu g/L \times \text{Extract Volume, L}}{\text{no. of strips digested} \times \text{air volume sampled, std. } m^3} \qquad \text{Eq. B-1}$$

3.3.9 Under the columns labeled "C," "Q," and "M" enter result qualifiers as identified in the following paragraphs. If additional qualifiers are used, their explicit definitions must be included on the Cover Page in the Comments section.

3.3.10 FORM I-AAIN includes fields for three types of result qualifiers. These qualifiers must be completed as follows:

3.3.10.1 C (Concentration) qualifier: Enter "B" if the reported value was obtained from a reading that was less than the CRQL but greater than or equal to the MQL. Enter "U" if the reported value was obtained from a reading that was less than the MQL.

3.3.10.2 Q (Quality Control) qualifier: Specified entries and their meanings are as follows:

- E - The reported value is estimated because of the presence of interference;
- I - The sum of the values of the interference correction(s) is greater than the result concentration;
- M - Duplicate injection/exposure precision not met;
- N - Spiked sample recovery not within control limits;

- S - The reported value was determined by the Method of Standard Additions (MSA);
- * - Duplicate analysis not within control limits; and
- + - Correlation coefficient for the MSA is less than 0.995.

NOTE: Entering "S," or "+" is mutually exclusive. No combination of these qualifiers can appear in the same field for an analyte.

3.3.10.3 M (Method) qualifier: Enter, as appropriate, the following:

- "P" for ICP;
- "PM" for ICP-MS;
- "A" for Flame Atomic Absorption;
- "F" for Graphite Furnace Atomic Absorption; or
- NR if the analyte is not required to be analyzed.

3.3.11 Under "Comments," enter any sample-specific comments concerning the analyte results and note any significant changes that occurred during sample analysis (e.g., MSA determination, interferences), both technical and administrative, the corrective action taken, and resolution performed for the sample in the SDG.

3.4 **INITIAL AND CONTINUING CALIBRATION VERIFICATION [FORM II - AAIN]**

3.4.1 This form is used to report analyte recoveries from analyses of calibrations solutions.

3.4.2 Complete the header information according to the header instructions and as follows.

3.4.3 Enter the "Initial Calibration Source" (twelve characters maximum) and the "Continuing Calibration Source" (twelve characters maximum). Enter "EPA-LV" or "EPA-CI" to indicate EPA EMSL-Las Vegas or EMSL-Cincinnati, respectively, as the source of EPA standards. When additional EPA supplied solutions are prepared in the future, the Contractor must use the codes supplied with those solutions for identification. If other sources were used, enter sufficient information in the available twelve spaces to identify the manufacturer and the solution used.

3.4.4 Use additional copies of FORM II-AAIN if more calibration sources were used.

3.4.5 Under "WOMN," enter the number of the wavelength or mass number for which the results of each analyte are reported on the form. The wavelength number is a number assigned to each wavelength used when more

than one wavelength is used to obtain data for analyte in the SDG. A wavelength number of "1" is assigned to the longest wavelength used for the analyte in the SDG. A wavelength number of "2" is assigned to the second longest wavelength and so on. A mass number of "1" is assigned to the greatest mass used for the analyte in the SDG. A mass number "2" is assigned to the second greatest mass and so on. The field must be left blank if a single wavelength or mass is used to obtain data for an analyte in the SDG.

3.4.6 Under "INITIAL CALIBRATION True," enter the true concentration (in µg/L, to three decimal places) of each analyte in the Initial Calibration Verification Solution.

3.4.7 Under "INITIAL CALIBRATION Found," enter the most recent found concentration (in µg/L, to three decimal places) of each analyte measured in the Initial Calibration Verification Solution.

3.4.8 Under "INITIAL CALIBRATION %R," enter the value (to the nearest whole number) of the percent recovery computed according to the following equation:

$$\%R = \frac{Found\,(ICV)}{True\,(ICV)} \times 100 \qquad \text{Eq. B-2}$$

Where True (ICV) is the true concentration of the analyte in the Initial Calibration Verification solution and Found (ICV) is the found concentration of the analyte in the Initial Calibration Verification Solution.

3.4.9 Under "CONTINUING CALIBRATION True," enter the true concentration (in µg/L, to three decimal places) of each analyte in the Continuing Calibration Verification Solution.

3.4.10 Under "CONTINUING CALIBRATION Found," enter the found concentration (in µg/L, to three decimal places) of each analyte measured in the Continuing Calibration Verification Solution.

NOTE: The form contains two "CONTINUING CALIBRATION Found" columns. The column to the left must contain values for the first Continuing Calibration Verification and the column to the right must contain values for the second Continuing Calibration Verification. The column to the right should be left blank if no second Continuing Calibration Verification was performed.

3.4.11 If more than one FORM II-AAIN is required to report multiple Continuing Calibration Verifications, then the column to the left on the second form must contain values for the third Continuing Calibration Verification, the column to the right must contain values for the fourth Continuing Calibration Verification, and so on.

3.4.12 Under "CONTINUING CALIBRATION %R," enter the value (to the nearest whole number) of the percent recovery computed according to the following equation:

$$\%R = \frac{Found\,(CCV)}{True\,(CCV)} \times 100 \qquad \text{Eq. B-3}$$

Where True (CCV) is the true concentration of each analyte, and Found (CCV) is the found concentration of the analyte in the Continuing Calibration Verification Solution.

NOTE: The form contains two "CONTINUING CALIBRATION %R" columns. Entries to these columns must follow the sequence detailed above for entries to the "Continuing Calibration Found" columns.

3.4.13 Under "M," enter the method used, as in part 3.3.10.3.

3.4.14 If more than one wavelength or mass is used to analyze an analyte, then submit additional copies of FORM II-AAIN as appropriate.

3.4.15 The order of reporting ICVs and CCVs for each analyte must follow the chronological order in which the standards were run starting with the first FORM II-AAIN and moving from the left to the right, continuing to the following FORM II-AAIN as appropriate. For instance, the first ICV for all analytes must be reported on the first FORM II-AAIN. In a run where three CCVs were analyzed, the first CCV must be reported in the left CCV column on the first FORM II-AAIN and the second CCV must be reported in the right column of the same form. The third CCV must be reported in the left CCV column of the second FORM II-AAIN. On the second FORM II-AAIN, the ICV column and the right CCV column must be left empty in this example. In the previous example, if a second run for an analyte was needed, the ICV of that run must be reported on a third FORM II-AAIN and the CCVs follow in the same fashion as explained before.

3.4.16 In the case where more than one wavelength or mass is used for an analyte in the SDG, all ICV and CCV results of the longest wavelength from all runs must be reported before proceeding to report the results of the second wavelength or mass used and so on.

3.4.17 Under "Comments," enter any ICV and CCV specific comments concerning the analyte results, any significant problems encountered during the ICV and CCV analysis (i.e., percent recovery outside the control limits, interferences), both technical and administrative, the corrective action taken, and resolution performed for the ICV and CCV.

3.5 CONTRACT REQUIRED QUANTITATION LIMIT STANDARDS/LINEAR RANGE STANDARDS (Quarterly) [FORM III - AAIN]

3.5.1 Contract Required Quantitation Limit Standards (CRQL)

3.5.1.1 This form is used to report analyte recoveries from analyses of the CRQL Standards.

3.5.1.2 Complete the header information according to the header instructions and as follows.

3.5.1.3 Under "CRQL," enter the sources of the CRQL Standards for "ICP Source," "ICP-MS Source," and "GFAA Source" analyses in their respective fields (twelve characters maximum each), as explained in part 3.4.3.

3.5.1.4 Under "WOMN," enter the wavelength or mass number as explained in part 3.4.5.

3.5.1.5 Under "True," enter the true concentration (in µg/L, to three decimal places) of each analyte in the CRQL Standard Source Solution that was analyzed for analytical samples associated with the SDG.

3.5.1.6 Under "INITIAL Found," enter the found concentration (in µg/L, to three decimal places) of each analyte measured in the CRQL Standard Solution analyzed at the beginning of each run.

3.5.1.7 Under "INITIAL %R," enter the value (to the nearest whole number) of the percent recovery computed according to the following equation:

$$\%R = \frac{\textit{CRQL Standard Initial Found}}{\textit{CRQL Standard True}} \times 100 \qquad \text{Eq. B-4}$$

3.5.1.8 Under "FINAL Found," enter the found concentration (in µg/L, to three decimal places) of each analyte measured in the CRQL Standard Solution analyzed at the end of each run.

3.5.1.9 Under "FINAL %R," enter the value (to the nearest whole number) of the percent recovery computed according to the following equation:

$$\%R = \frac{\textit{CRQL Standard Final Found}}{\textit{CRQL Standard True}} \times 100 \qquad \text{Eq. B-5}$$

NOTE: For every initial solution reported there must be a final one. However, the opposite is not true. If a CRQL Standard was required to be analyzed in the middle of a run (to avoid exceeding the 8-hour limit), it must be reported in the "FINAL Found" section of this form.

3.5.1.10 If more CRQL standards analyses were required or analyses were performed using more than one wavelength or mass per analyte, submit additional copies of FORM III-AAIN in the appropriate order.

3.5.1.11 The order of reporting CRQL standards for each analyte must follow the chronological order in which the standards were run starting with the first FORM III-AAIN and continuing to the following FORM III-AAIN as appropriate. When multiple wavelengths and masses are used for

one analyte, all the results of one wavelength must be reported before proceeding to the next wavelength or mass.

3.5.1.12 Under "Comments," enter any CRQL-specific comments concerning the analyte results, any significant problems encountered during the CRQL standard analysis (e.g., percent recovery outside the control limits), both technical and administrative, the corrective action taken, and resolution performed for the standard.

3.5.2 **Linear Range Standards (LRS) (Quarterly)**

3.5.2.1 FORM III-AAIN is also used to report analyte recoveries from the quarterly analyses of the Linear Range Standards (LRSs).

3.5.2.2 Complete the header information according to the header instructions and as follows.

3.5.2.3 Under "LRS," enter the source of the LRSs for "ICP Source", "ICP-MS Source", and "GFAA Source" analyses in their respective fields (12 characters maximum each), as explained in part 3.4.3.

3.5.2.4 Under "INITIAL True," enter the true concentration (in µg/L, to three decimal places) of each analyte in the LRS Source Solution that was analyzed for the analytical samples associated with the SDG.

3.5.2.5 Under "INITIAL Found," enter the found concentration (in µg/L, to three decimal places) of each analyte measured in the LRS Solution analyzed at the beginning of each run.

3.5.2.6 Under "INITIAL %R," enter the value (to the nearest whole number) of the percent recovery computed according to the following equation:

$$\%R = \frac{\textit{LRS Initial Found}}{\textit{LRS True}} \times 100 \qquad \text{Eq. B-6}$$

3.5.2.7 Under "FINAL Found," enter the found concentration (in µg/L, to three decimal places) of each analyte measured in the LRS Solution analyzed at the end of each run.

3.5.2.8 Under "FINAL %R," enter the value (to the nearest whole number) of the percent recovery computed according to the following equation:

$$\%R = \frac{\textit{LRS Final Found}}{\textit{LRS True}} \times 100 \qquad \text{Eq. B-7}$$

3.5.2.9 If more LRS analyses were required or analyses were performed using more than one wavelength per analyte, submit additional copies of FORM III-AAIN in the appropriate order.

3.5.2.10 The order of reporting the LRS for each analyte must follow the chronological order in which the standards were run starting with the first FORM III-AAIN and continuing to the following FORM III-AAIN as appropriate. If multiple wavelengths or masses are used for one analyte, all the results of one wavelength or mass must be reported before proceeding to the next wavelength or mass.

3.5.2.11 Under "Comments," enter any LRS-specific comments concerning the analytes results, any significant problems encountered during the LRS analysis (e.g., percent recovery outside the control limits), both technical and administrative, the corrective action taken, and resolution performed for the standard.

3.6 BLANKS [FORM IV - AAIN]

3.6.1 This form is used to report analyte concentrations found in the Initial Calibration Blank (ICB), the Continuing Calibration Blanks (CCB), and the Preparation Blank (PB).

3.6.2 Complete the header information according to the header instructions and as follows.

3.6.3 Under "WOMN," enter the wavelength or mass number for which the results of each analyte are reported on the form. The wavelength or mass number is a number assigned to each wavelength or mass used when more than one wavelength or mass is used to obtain data for an analyte in the SDG. A wavelength number of "1" is assigned to the longest wavelength used for the analyte in the SDG. A wavelength number of "2" is assigned to the second longest wavelength and so on. A mass number of "1" is assigned to the greatest mass used for the analyte in the SDG. A mass number of "2" is assigned to the second greatest mass and so on. The field must be left blank if a single wavelength or mass is used to obtain data for an analyte in the SDG.

3.6.4 Under "INITIAL CALIB. BLANK (ICB)," enter the concentration (in µg/L, to three decimal places) of each analyte in the most recent Initial Calibration Blank (ICB).

3.6.5 For all blanks, enter the concentration of each analyte (positive or negative) measured above the MQL or below the negative value of the MQL.

3.6.6 Under the "C" qualifier field, for any analyte enter "B" if the absolute value of the analyte concentration is less than the CRQL but greater than or equal to the MQL. Enter "U" if the absolute value of the analyte in the blank is less than the MQL.

3.6.7 Under "CONTINUING CALIBRATION BLANK 1," enter the concentration (in µg/L, to three decimal places) of each analyte detected for the first CCB analyzed after the ICB. Enter any appropriate qualifier, as

explained for the "Initial Calibration Blank," in the "C" qualifier column immediately following the "CONTINUING CALIBRATION BLANK (CCB)" column.

3.6.8 If only one CCB was analyzed, then leave the columns labeled "Conc. 2" and "Conc. 3" blank. If up to three CCBs were analyzed, complete the columns labeled "Conc. 2" and "Conc. 3," in accordance with the instructions for the "CONTINUING CALIBRATION BLANK (CCB)" column. If more than three CCBs were analyzed, then complete additional copies of FORM IV-AAIN as appropriate.

3.6.9 Under "PREPARATION BLANK (PB)," enter the concentration (in µg/L, to three decimal places) of each analyte in the PB. Enter any appropriate qualifier, as explained for the ICB, in the "C" qualifier column immediately following the "PREPARATION BLANK" column.

3.6.10 Under "M," enter the method used, as explained in part 3.3.10.3.

3.6.11 If more than one wavelength or mass is used to analyze an analyte, submit additional copies of FORM IV-AAIN as appropriate.

3.6.12 The order of reporting ICBs and CCBs for each analyte must follow the chronological order in which the blanks were run starting with the first FORM IV-AAIN and moving from left to right and continuing to the following FORM IV-AAIN as explained previously. When multiple wavelengths or mass are used for the analysis of one analyte, all the results of one wavelength or mass must be reported before proceeding to the next wavelength or mass.

3.6.13 Under "Comments," enter any ICB and CCB specific comments concerning the analyte results, any significant problems encountered during the ICB, CCB and PB analysis (e.g., blanks outside the control limits), both technical and administrative, the corrective action taken, and resolution performed for the sample.

3.7 ICP INTERFERENCE CHECK SAMPLE [FORM V - AAIN]

3.7.1 This form is used to report ICP Interference Check Sample (ICS) results for each ICP and/or ICP-MS instruments used in SDG analyses.

3.7.2 Complete the header information according to the header instructions and as follows.

3.7.3 For "ICP ID No.," enter an identifier that uniquely identifies the specific instrument within the Contractor laboratory. No two ICP instruments within a laboratory may have the same ICP ID Number. If ICP-MS is used, leave blank.

3.7.4 For "ICP-MS ID No.," enter an identifier that uniquely identifies the specific instrument within the Contractor laboratory. No

two ICP-MS instruments within a laboratory may have the same ICP-MS ID Number. If ICP is used leave blank.

3.7.5 For "ICS Source," enter the ICS source (twelve characters maximum each), as previously explained in part 3.4.3. For EPA solutions, include the name and number identifying it (e.g., EPA-LV87). The laboratory must use the identification supplied by the EPA.

3.7.6 Under "WOMN," enter the wavelength or mass number for which the results of each analyte are reported on the form. The wavelength number is a number assigned to each wavelength used when more than one wavelength is used to obtain data for an analyte in the SDG. A wavelength number of "1" is assigned to the longest wavelength used for the analyte in the SDG. A wavelength number of "2" is assigned to the second longest wavelength and so on. A mass number of "1" is assigned to the greatest mass used for the analyte in the SDG. A mass number of "2" is assigned to the second greatest mass and so on. The field must be left blank if a single wavelength or mass is used to obtain data for an analyte in the SDG.

3.7.7 Under "TRUE Sol. A," enter the true concentration (in µg/L, to three decimal places) of each analyte present in Solution A.

3.7.8 Under "TRUE Sol. AB," enter the true concentration (in µg/L, to three decimal places) of each analyte present in Solution AB.

3.7.9 Under "INITIAL FOUND Sol. A," enter the found concentration (in µg/L to three decimal places) of each analyte measured in the initial analysis of Solution A as required in Exhibit E.

3.7.10 Under "INITIAL FOUND Sol. AB," enter the found concentration (in µg/L to three decimal places) of each analyte measured in the initial analysis of Solution AB as required in Exhibit E.

3.7.11 Under initial found "%R," enter the value (to the nearest whole number) of the percent recovery computed according to the following equation:

$$\%R = \frac{\textit{Initial Found Solution AB}}{\textit{True Solution AB}} \times 100 \qquad \text{Eq. B-8}$$

3.7.12 Under "FINAL FOUND," enter the found concentration (in µg/L, to three decimal places) of each analyte measured in the final analysis as required in Exhibit E.

3.7.13 For all found values, enter the concentration (positive, negative, or zero) of each analyte at each wavelength or mass used for analysis by ICP or ICP-MS.

3.7.14 Under "FINAL FOUND %R," enter the value (to the nearest whole number) of the percent recovery computed according to the following equation:

$$\%R = \frac{\textit{Final Found Solution AB}}{\textit{True Solution AB}} \times 100 \qquad \text{Eq. B-9}$$

NOTE: For every initial solution reported there must be a final one. However, the opposite is not true. If an ICS was required to be analyzed in the middle of a run (to avoid exceeding the 8-hour limit), it must be reported in the "FINAL FOUND" section of this form.

3.7.15 If more ICS analyses were required, submit additional copies of FORM V-AAIN as appropriate.

3.7.16 The order of reporting ICSs for each analyte must follow the temporal order in which the standards were run starting with the first FORM V-AAIN and continuing to the following FORM V-AAIN as appropriate. When multiple wavelengths or masses are used for one analyte, all the results of one wavelength must be reported before proceeding to the next wavelength in the same manner.

3.7.17 Under "Comments," enter any ICS specific comments concerning the analyte results, any significant problems encountered during the ICS analysis (e.g., percent recovery outside the control limits), both technical and administrative, the corrective action taken, and resolution performed for the sample.

3.8 SPIKE SAMPLE RECOVERY [FORM VI - AAIN]

3.8.1 This form is used to report results for the spike sample recovery which is based on the addition of a known quantity of analyte to the pre-digest sample.

3.8.2 Complete the header information according to the header instructions and as follows.

3.8.3 In the "EPA SAMPLE No." box, enter the EPA sample number (7 characters maximum) of the sample from which the spike results on this form were obtained. The number must be centered in the box. Note that the EPA sample number must include the spike sample suffix for which the spike analyses are reported.

3.8.4 Under "WOMN," enter the wavelength or mass number for which the results of each analyte are reported on the form. The wavelength or mass number is a number assigned to each wavelength or mass used when more than one wavelength or mass is used to obtain data for an analyte in the SDG. A wavelength number of "1" is assigned to the longest wavelength used for the analyte in the SDG. A wavelength number of "2" is assigned to the second longest wavelength and so on. A mass number of "1" is

assigned to the greatest mass used for the analyte in the SDG. A mass number of "2" is assigned to the second greatest mass and so on. The field must be left blank if a single wavelength or mass is used to obtain data for an analyte in the SDG.

3.8.5 Under "CONTROL LIMIT %R," enter "75-125" if the spike added value was greater than or equal to one-fourth of the sample result value. If not, leave the field empty.

3.8.6 Under "SPIKED SAMPLE RESULT (SSR)," enter the concentration (in µg/L, to three decimal places) of each analyte in the spike sample. Enter any appropriate qualifier in the "C" qualifier column immediately following the Spiked Sample Result (SSR) column.

3.8.7 Under "SAMPLE RESULT (SR)," enter the concentration (in µg/L, to three decimal places) of each analyte measured in the sample (reported in the EPA sample number box) on which the matrix spike was performed. Enter any appropriate qualifier in the "C" qualifier column immediately following the Sample Result (SR) column.

3.8.8 Under "SPIKE ADDED (SA)," enter the concentration (in µg/L, to three decimal places) of each analyte added to the sample. If the spike added concentration is specified in the contract, the value added and reported must be that specific concentration in µg/L.

3.8.9 Under "%R," enter the value (to the nearest whole number) of the percent recovery computed according to the following equation:

$$\%R = \frac{SSR - SR}{SA} \times 100 \qquad \text{Eq. B-10}$$

NOTE: %R must be reported, whether it is negative, positive or zero. A value of zero must be used for SSR or SR if the analyte value is less than the MQL.

3.8.10 Under "Q," enter "N" if the spike recovery (%R) is out of the control limits (75-125%) and the spiked added is greater than or equal to one-fourth of the sample result.

3.8.11 Under "M," enter the method used or enter "NR" if the analyte is not required in the spike.

NOTE: If different samples were used for spike sample analysis of different analytes, additional copies of FORM VI-AAIN must be submitted for each sample as appropriate.

3.8.12 Use additional copies of FORM VI-AAIN for each sample on which a required spike sample analysis was performed.

3.8.13 Under "Comments," enter any spike sample specific comments concerning the analyte results, any significant problems encountered during the spike sample analysis (e.g , percent recovery outside the control limits), both technical and administrative, the corrective action taken, and resolution performed for the sample.

3.9 DUPLICATES [FORM VII - AAIN]

3.9.1 This form is used to report results of duplicate analyses for determining the precision of the method.

3.9.2 Complete the header information according to the header instructions and as follows.

3.9.3 In the "EPA SAMPLE No." box, enter the EPA sample number (7 characters maximum) of the sample from which the duplicate results on this form were obtained. The number must be centered in the box.

3.9.4 Under "WOMN," enter the wavelength or mass number for which the results of each analyte are reported on the form. The wavelength or mass number is a number assigned to each wavelength or mass used when more than one wavelength or mass is used to obtain data for an analyte in the SDG. A wavelength number of "1" is assigned to the longest wavelength used for the analyte in the SDG. A wavelength number of "2" is assigned to the second longest wavelength and so on. A mass number of "1" is assigned to the greatest mass used for the analyte in the SDG. A mass number of "2" is assigned to the second greatest mass and so on. The field must be left blank if a single wavelength is used to obtain data for an analyte in the SDG.

3.9.5 Under "CONTROL LIMIT," enter the CRQL (in appropriate units, µg/L) for the analyte if the sample or duplicate values were less than five times CRQL and greater than or equal to the CRQL. If the sample and duplicate values were less than the CRQL or greater than or equal to five times CRQL, leave the field empty.

3.9.6 Under "SAMPLE (S)," enter the concentration (in the required concentration units, to three decimal places) of each analyte in the original sample (reported in the EPA sample number box) on which a duplicate analysis was performed. Enter any appropriate qualifier in the "C" qualifier column immediately following the "SAMPLE (S)" column.

3.9.7 Under "DUPLICATE (D)," enter the concentration (in the required concentration units, to three decimal places) of each analyte measured in the Duplicate sample (reported in the EPA sample number box). Enter any appropriate qualifier in the "C" qualifier column immediately following the "DUPLICATE (D)" column.

3.9.8 Under "RPD," enter the absolute value (to one decimal place) of the Relative Percent Difference for all analytes detected above the MQL

in either the sample or the duplicate, computed according to the following equation:

$$RPD = \frac{|S - D|}{\frac{S + D}{2}} \times 100 \qquad \text{Eq. B-11}$$

3.9.9 A value of zero must be substituted for S or D if the analyte concentration is less than the MQL in either one. If the analyte concentration is less than the MQL in both S and D, leave the RPD field empty.

3.9.10 Under "Q," enter "*" if the duplicate analysis for the analyte is out of the control limits. If both sample and duplicate values are greater than or equal to five times CRQL, then the RPD must be less than or equal to 20 percent to be in control. If either sample or duplicate values are less than five times CRQL, then the absolute difference between the two values must be less than or equal to the CRQL to be in control. If both values are below the CRQL, then no control limit is applicable.

3.9.11 Under "M," enter the method used.

3.9.12 If different samples were used for duplicate sample analysis of different analytes, then additional copies of FORM VII-AAIN must be submitted for each sample as appropriate.

3.9.13 Use additional copies of FORM VII-AAIN for each sample on which a required duplicate sample analysis was performed.

3.9.14 Under "Comments," enter any duplicate sample specific comments concerning the analyte results, any significant problems encountered during the duplicate sample analysis (i.e., percent recovery outside the control limits), both technical and administrative, the corrective action taken, and resolution performed for the sample.

3.10 LABORATORY CONTROL SAMPLE [FORM VIII-AAIN]

3.10.1 This form is used to report results for the Laboratory Control Sample (LCS).

3.10.2 Complete the header information according to the header instructions and as follows.

3.10.3 For "LCS USED," enter the appropriate source solution identifier (12 characters maximum) provided by the EPA for the LCS solution that was analyzed by the methods in Exhibit D.

3.10.4 If no analyte was analyzed by a certain method or if the analyte was not required to be analyzed, then leave the appropriate spaces empty.

3.10.5 Under "WOMN," enter the wavelength or mass number for which the results of each analyte are reported on the form. The wavelength or mass number is a number assigned to each wavelength or mass used when more than one wavelength or mass is used to obtain data for an analyte in the SDG. A wavelength number of "1" is assigned to the longest wavelength used for the analyte in the SDG. A wavelength number of "2" is assigned to the second longest wavelength and so on. A mass number of "1" is assigned to the greatest mass used for the analyte in the SDG. A mass number of "2" is assigned to the second greatest mass and so on. The field must be left blank if a single wavelength or mass is used to obtain data for an analyte in the SDG.

3.10.6 Under "M," enter the method used.

3.10.7 Under "LIMITS," enter the lower limit concentration value (to the nearest whole number) in the left column, and the upper limit concentration value (to the nearest whole number) in the right column for each analyte in the LCS according to the ± 20 percent criteria.

3.10.8 Under "TRUE," enter the true concentration (to three decimal places) of each analyte in the LCS.

3.10.9 Under "FOUND," enter the found concentration (to three decimal places) of each analyte measured in the LCS.

3.10.10 Under "C," enter "B" or "U" or leave empty to describe the found value of the LCS.

3.10.11 Under "%R," enter the value (to the nearest whole number) of the percent recovery computed according to the following equation:

$$\%R = \frac{LCS\ FOUND}{LCS\ TRUE} \times 100 \qquad \text{Eq. B-12}$$

3.10.12 If the analyte concentration is less than the MQL, a value of zero must be substituted for the LCS Found.

3.10.13 Submit additional copies of FORM VIII-AAIN as appropriate, if more than one LCS was required. In addition, submit additional copies of FORM VIII-AAIN if more than one wavelength was used to determine an analyte for a sample.

3.10.14 Under "Comments," enter any LCS specific comments concerning the analyte results, any significant problems encountered during the LCS analysis (e.g., percent recovery outside the control limits), both technical and administrative, the corrective action taken, and resolution performed for the sample.

3.11 METHOD OF STANDARD ADDITIONS [FORM IX - AAIN]

3.11.1 This form is used to report the results of samples analyzed using the Method of Standard Additions (MSA) for GFAA analysis.

3.11.2 Complete the header information according to the header instructions and as follows.

3.11.3 Under "EPA SAMPLE No.," enter the EPA sample numbers (nine characters maximum) of the sample from which the standard additions results on this form were obtained.

NOTE: Only field samples and duplicates may be reported on this form, thus the EPA sample number usually has no suffix or a "D".

3.11.4 A maximum of 32 samples can be entered on this form. If additional samples required MSA, submit additional FORMs IX-AAIN. Samples are listed in alphanumeric order per analyte. Submit additional FORMs IX-AAIN as appropriate.

3.11.5 Under "An," enter the chemical symbol (two characters maximum) for each parameter for which MSA was required for each sample listed. The parameters must be in alphabetic listing of the chemical symbols.

NOTE: Results for different samples for each parameter must be reported sequentially, with the analytes ordered according to the alphabetic listing of their chemical symbols. For instance, results for Al (Aluminum) in samples BBB120, BBB121, and BBB122 would be reported in sequence, followed by the results for Ca (Calcium) in BBB120 etc.

3.11.6 Under "ADDITIONS," enter the "ZERO," "FIRST," "SECOND," "THIRD," observed value in absorbance units (to three decimal places) of the analyte before addition is performed.

3.11.6.1 Under "ZERO, Found," enter the concentration in µg/L (to three decimal places) of the analyte (excluding sample contribution) after first addition to the sample analyzed by MSA.

3.11.6.2 Under "FIRST, Added, Found," enter the concentration in µg/L (to three decimal places) of the analyte added in the left column and the found value in µg/L (to three decimal places) of the analyte (excluding sample contribution) after the first addition to the sample analyzed by MSA in the right column.

3.11.6.3 Under "SECOND, Added, Found," enter the concentration in µg/L (to three decimal places) of the analyte added in the left column and the found value in µg/L (to three decimal places) of the analyte (excluding sample contribution) after second addition to the sample analyzed by MSA in the right column.

3.11.6.4 Under "THIRD, Added, Found," enter the concentration in µg/L (to three decimal places) of the analyte added in the left column and the found value in µg/L (to three decimal places) of the analyte (excluding sample contribution) after third addition to the sample analyzed by MSA in the right column.

NOTE: The "ZERO, Found," "FIRST, Found," "SECOND, Found," and "THIRD, Found" must have the same dilution factor.

3.11.7 Under "Final Conc.," enter the final analyte concentration (in µg/L to two decimal places) in the sample as determined by MSA computed according to the following formula:

$$Final\ Conc. = (-1) \times (x\text{-}intercept) \qquad \text{Eq. B-13}$$

NOTE: The final concentration of a parameter does not have to equal the value for that parameter which is reported on FORM I-AAIN for that sample.

3.11.8 Under "r," enter the correlation coefficient (to four decimal places) this obtained for the least squares regression line representing the following points (x,y):(0.0, "ZERO, Found"), ("FIRST, Added," "FIRST, Found"), ("SECOND, Added," "SECOND, Found"), and ("THIRD, Added," "THIRD, Found"). The correlation coefficient must be calculated using the ordinary least square linear regression (unweighted) according to the following formula:

$$r = \frac{N\Sigma x_i y_i - \Sigma x_i \Sigma y_i}{[N\Sigma x_i^2 - (\Sigma x_i)^2]^{\frac{1}{2}} [N\Sigma y_i^2 - (\Sigma y_i)^2]^{\frac{1}{2}}} \qquad \text{Eq. B-14}$$

3.11.16 Under "Q," enter "+" if r is less than 0.995. If r is greater than or equal to 0.995, then leave the field empty.

3.11.17 Under "Comments," enter any significant problems encountered during the method of standard addition analysis, both technical and administrative, the corrective action taken, and resolution performed for the sample.

3.12 ICP SERIAL DILUTION [FORM X - AAIN]

3.12.1 This form is used to report results for ICP serial dilution.

3.12.2 Complete the header information according to the header instructions and as follows.

3.12.3 In the "EPA SAMPLE No." box, enter the EPA sample number (seven characters maximum) of the sample from which the serial dilution analysis results on this form were obtained. The number must be centered in the box.

3.12.4 Under "WOMN," enter the wavelength number for which the results of each analyte are reported on the form. The wavelength number is a number assigned to each wavelength used when more than one wavelength is used to obtain data for an analyte in the SDG. A wavelength number of "1" is assigned to the longest wavelength used for the analyte in the SDG. A wavelength number of "2" is assigned to the second longest wavelength and so on. The field must be left blank if a single wavelength is used to obtain data for an analyte in the SDG.

3.12.5 Under "Initial Sample Result (I)," enter the concentration (in µg/L, to three decimal places) of each analyte in the original sample (reported in the EPA sample number box) on which a serial dilution analysis was performed. Enter any appropriate qualifier in the "C" qualifier column immediately following the "Initial Sample Result (I)" column.

NOTE: The Initial Sample Concentration for an analyte does <u>not</u> have to equal the value for that analyte reported on FORM I-AAIN for that sample. It is the value of the analyte concentration (uncorrected for dilution) that is within the linear range of the instrument.

3.12.6 Under "Serial Dilution Result (S)," enter the concentration (in µg/L, to three decimal places) of each analyte in the diluted sample (reported in the EPA sample number box) on which a serial dilution analysis was performed. Enter any appropriate qualifier in the "C" qualifier column immediately following the "Serial Dilution Result (S)" column.

NOTE: The Serial Dilution Result (S) is obtained by multiplying by five the instrument measured concentration value (in µg/L) of the serial diluted sample and that the "C" qualifier for the serial dilution must be established based on the serial dilution result before correcting it for the dilution regardless of the value reported on the form.

3.12.7 Under "%Difference," enter the absolute value (to one decimal place) of the percent difference in concentration of required analytes, between the original sample and the diluted sample (adjusted for dilution) according to the following equation:

$$\%\ Difference = \frac{|I - S|}{I} \times 100 \qquad \text{Eq. B-15}$$

NOTE: The values for I and S used to calculate % Difference in the equation must be exactly those reported on this form. A value of zero must be substituted for S if the analyte concentration is less that the MQL. If the analyte concentration in (I) is less than the MQL concentration, leave the "% Difference" field empty.

3.12.8 Under "Q," enter "E" if the percent difference is greater than 10 percent and the original sample concentration (reported on FORM I-AAIN) is greater than 50x the MQL reported on FORM XII-AAIN.

3.12.9 Under "M," enter the method used.

3.13 METHOD QUANTITATION LIMITS [FORM XI - AAIN]

3.13.1 This form documents the Method Quantitation Limit (MQL) for each instrument that the laboratory used to obtain data for the SDG. Only the instrument and wavelengths or masses used to generate data for the SDG must be included.

3.13.2 Complete the header information according to the header instructions and as follows.

3.13.3 For "Date," enter the date (formatted MM/DD/YY) on which the MQL values were determined (or became effective).

3.13.4 Enter the instrument ID numbers for the fields "ICP ID No.," "ICP-MS ID No.," and "GFAA ID No." (twelve characters maximum each). These ID Numbers are used to uniquely identify each instrument that the laboratory uses for CLP analyses.

3.13.5 Under "WOMN," enter the wavelength or mass number for which the results of each analyte are reported on the form. The wavelength or mass number is a number assigned to each wavelength used when two or more wavelengths or masses are used to obtain data for an analyte in the SDG. A wavelength number of "1" is assigned to the longest wavelength used for the analyte in the SDG. A wavelength number of "2" is assigned to the second longest wavelength and so on. A mass number of "1" is assigned to the greatest mass used for the analyte in the SDG. A mass number of "2" is assigned to the second greatest mass and so on. The field must be left blank if a single wavelength or mass is used to obtain data for an analyte in the SDG.

3.13.6 Under "WAVELENGTH (nm)," enter the wavelength in nanometers (to two decimal places) for each analyte for which an MDL has been established and is listed in the MQL column. If more than one wavelength is used for an analyte, use other copies of FORM XI-AAIN as appropriate to report the MDL.

3.13.7 Under "Mass," enter the mass to charge ratio (m/z, to four decimal places) for each analyte for which an MDL has been established and is listed in the MDL column. If more than one wavelength is used for an analyte, use other copies of FORM XI-AAIN as appropriate to report the MDL.

3.13.8 Under "INTEG. TIME," enter the integration time (in seconds, to two decimal places) used for each measurement taken from each instrument.

3.13.9 Under "BACKGROUND," enter the type of background correction used to obtain GFAA data. Enter "BS" for Smith Hieftje, "BD" for Deuterium Arc, or "BZ" for Zeeman background correction.

3.13.10 The Contract Required Quantitation Limits (in µg/L) in Exhibit C must appear in the column headed "CRQL".

3.13.11 Under "MQL," enter the MQL (in µg/L to three decimal places) as determined by the laboratory for each analyte analyzed by the instrument for which the ID Number is reported on this form. MQLs shall be reported to two significant figures if the MQL value is less than 100 and to three significant figures for values above or equal to 100.

3.13.12 Under "M," enter the method used to determine the MQL for each wavelength or mass used.

3.13.13 Use additional copies of FORM XI-AAIN if more instruments and wavelengths are used. Note that the data on this form must not exceed the analysis dates in the SDG data package or precede them by more than three months.

3.13.14 Under "Comments," enter alternative wavelengths or masses and the conditions under which they are used, any significant problems encountered during the MQL analysis, the corrective action taken, and resolution performed for the sample.

3.14 ICP AND ICP-MS INTERELEMENT CORRECTION FACTORS (Annual) [FORM XII - AAIN]

3.14.1 This form documents the ICP and ICP-MS Interelement Correction Factors for each ICP and/or ICP-MS instruments that the laboratory used to obtain data for the SDG. Only the instrument and wavelengths or masses used to generate data for the SDG must be included.

3.14.2 The correction factors are determined annually (every twelve months). A copy of the results of the annual interelement correction factors must be included with each SDG data package on FORM XII-AAIN.

3.14.3 Complete the header information according to the header instructions and as follows.

3.14.4 For "Date," enter the date (formatted as MM/DD/YY) on which these correction factors were determined for use. This date must not exceed the ICP and/or ICP-MS analyses dates in the SDG data package. Also, it must not precede them by more than twelve calendar months.

3.14.5 For "ICP ID No.," enter the instrument ID number (twelve characters maximum) used to produce the data for the SDG. If more than one ICP instrument is used, submit additional FORMs XII-AAIN as appropriate.

3.14.6 For "ICP-MS ID No.," enter the instrument ID number (twelve characters maximum) used to produce the data for the SDG. If more than

one ICP-MS instrument is used, submit additional FORMs XII-AAIN as appropriate.

3.14.7 Under "WOMN," list the wavelength in nanometers (to two decimal places) for ICP or the mass to charge ratio (m/z, to four decimal places) for ICP-MS used for each analyte. If more than one wavelength or mass is used, submit additional copies of FORM XII-AAIN as appropriate.

3.14.8 In the "INTERELEMENT CORRECTION FACTORS FOR:" column, enter the correction factor (negative, positive or zero, to seven decimal places, 10 characters maximum) for each corrected analyte analyzed by ICP and/or ICP-MS. If an analyte was not corrected for an analyte that is listed in the header of a column, a zero must be entered to indicate that the correction was determined to be zero.

3.14.9 Use additional copies of FORM XII-AAIN as appropriate if correction factors for more than six analytes were applied.

3.14.10 Columns of correction factors for analytes requiring interelement correction must be entered left to right starting on FORM XII-AAIN according to the alphabetic order of their chemical symbols starting on the first FORM XII-AAIN and proceeding to the following FORM XII-AAIN as appropriate.

3.14.11 Under "Comments," enter alternative wavelengths or masses and the conditions under which they are used, any significant problems encountered during the interelement correction analysis, both technical and administrative, the corrective action taken, and resolution performed for the sample.

3.15 ICP-MS TUNING AND RESPONSE FACTOR CRITERIA [FORM XIII - AAIN]

3.15.1 This form documents the tuning and response factor, and mass calibration results for each ICP-MS used to obtain data for the SDG.

3.15.2 Complete the header information according to the header instructions and as follows

3.15.3 For "Method," enter the method code (two characters maximum) according to 3.3.10.3. If more instruments or analyte masses are used, submit additional FORMS XIII-AAIN as appropriate.

3.15.4 For "Date," enter the date (formatted as MM/DD/YY) on which the initial tuning solution were determined for use. This date must not exceed the ICP-MS analysis dates in the SDG data package.

3.15.5 For "ICP-MS ID No.," enter the instrument ID number (twelve characters maximum) used to produce the data for the SDG. If more than one ICP-MS instrument is used, submit additional FORMs XIII-AAIN as appropriate.

3.15.6 For "Run No.," enter the run number (two characters maximum) which is the number that applies to a continuous analytical sequence consisting of prepared samples and all associated quality assurance measurements as required by the contract.

3.15.7 Under "Analysis Time," enter the initial and final time according to the following:

3.15.7.1 For "Initial Time," enter the time (in military format - HH:MM) at which each initial tuning solution analysis was performed.

3.15.7.2 For "Final Time," enter the time (in military format - HH:MM) at which each final tuning solution analysis was performed.

3.15.8 For "% Relative Abundance," enter the initial and final percent relative abundance according to the following:

3.15.8.1 Under "Initial," enter the percent relative abundance (to two decimal places) calculated from the intensities measured, for each of the isotopes listed, as a result of analyzing the 100 ppb tuning solution at the beginning of each ICP-MS run. The isotopes are listed in the first column from the left in the Tuning Section of the Form.

3.15.8.2 Under "Final," enter the percent relative abundance (to two decimal places) calculated from the intensities measured, for each of the isotopes listed, as a result of analyzing the 100 ppb tuning solution at the end of each ICP-MS run. The isotopes are listed in the first column from the left in the Tuning Section of the Form.

3.15.9 For "RF100 (1) Response," enter the initial and final percent relative abundance according to the following:

3.15.9.1 Under "Initial," enter the measured response factor (in counts per second, to the nearest whole number) in the 100 ppb tuning solution at the at the beginning of each ICP-MS run, for each mass to charge ratio listed in the first column from the left in the Response Factor Section of the Form.

3.15.9.2 Under "Final," enter the measured response factor (in counts per second, to the nearest whole number) in the 100 ppb tuning solution at the at the end of each ICP-MS run, for each mass to charge ratio listed in the first column from the left in the Response Factor Section of the Form.

3.15.10 Under "Observed Mass," enter the observed mass (to four decimal places) in the 100 ppb tuning solution at the beginning of each ICP-MS run, for each mass to charge ratio listed in the first column from the left in the Mass Calibration Section of the Form.

NOTE: The values measured and reported in the Tuning, Response Factor, and Mass Calibration Sections of the Form must be within the control limits listed in the second column from the left in each of the Sections.

NOTE: For every initial solution reported there must be a final one. However, the opposite is not true. If a tuning solution was required to be analyzed in the middle of a run (to avoid exceeding the 8-hour limit), it must be reported in the "Final" section of this form.

3.16 ICP-MS INTERNAL STANDARDS SUMMARY [FORM XIV -AAIN]

3.16.1 This form is used to report the internal standards intensity levels for ICP-MS. The relative intensity of each of the internal standards in all analyses performed in each ICP-MS must be reported on the FORM XIV-AAIN.

NOTE: A run is defined as the continuous totality of analyses performed by an instrument throughout the sequence initiated by, and including, the initial and the final tuning solution, the first required calibration standard and terminated by, and including, the CCV and blank following the last required analytical sample. For example, all field samples and all quality control analyses (including tuning solutions, calibration standards, ICVs, CCVs, ICBs, CCBs, MTS, CRIs, ICSs, IRSs, LCSs, PBs, duplicates, and matrix spikes) associated with the SDG must be reported on FORM XIV-AAIN. The run must be continuous and inclusive of all analyses performed on the particular instrument during the run.

3.16.3 Submit one FORM XIV-AAIN per run if no more than 32 analyses including instrument calibration were performed. If more than 32 analyses per run were performed, then submit additional copies of FORM XIV-AAIN as appropriate. Each new run must be started on the first line of FORM XIV-AAIN.

3.16.4 Complete the header information according to the header instructions and as follows.

3.16.5 For "Method," enter the method code (two characters maximum) according to 3.3.10.3. If more instruments or analyte masses are used, submit additional FORMS XIV-AAIN as appropriate.

3.16.6 For "Run No.," enter the run number (two characters maximum) which is the number that applies to a continuous analytical sequence consisting of prepared samples and all associated quality assurance measurements as required by the contract.

3.16.7 For "ICP-MS ID No.," enter the instrument ID number (twelve characters maximum) used to produce the data for the SDG. If more than one ICP-MS instrument is used, submit additional FORMs XIV-AAIN as appropriate.

3.16.8 For "Start Date," enter the start date (formatted as MM/DD/YY) on which the analyses was started. This date must not exceed the ICP-MS analysis dates in the SDG data package.

3.16.9 For "End Date," enter the end date (formatted as MM/DD/YY) on which the analyses run was ended. This date must not exceed the ICP-MS analysis dates in the SDG data package.

3.16.10 Under "EPA SAMPLE No.," enter the EPA sample number of each sample in the SDG and of all other preparations, such as duplicates, spikes, LCSs, PBs, and repreparations (all formatted according to Table B-2 of this Exhibit). All EPA Sample Numbers must be listed in increasing temporal (date and time) order of analysis, continuing to the next FORM XV-AAIN if applicable. The analysis date and time of other analyses not associated with the SDG, but analyzed by the instrument in the reported analytical run, must be reported. Those analyses must be identified with the EPA SAMPLE NUMBER of "ZZZZZZ". Samples identified as "ZZZZZZ" need not have intensities reported for internal standards.

3.16.11 Under "Time," enter the time (in military format - HH:MM) at which the analysis was performed.

NOTE: For any particular ICP-MS run, the EPA sample number and time sequence on FORM XIV-AAIN and XVI-AAIN must be identical.

3.16.12 Under "Internal Standards %D For:," enter the chemical symbol of the internal standard in the two spaces header field provide to indicate the internal standard for which the percent differences in that column were reported.

3.16.12.1 In the column, enter the percent difference (to the nearest whole number) between the intensity of the internal standard in the blank calibration standard (SO) and the intensity of the internal standard in the EPA sample number for each sample analyze listed on the form (excluding "ZZZZZZ"). The percent difference (%D) is calculated using the following equation:

$$\%D = \frac{|SO_I - S_I|}{SO_I} \times 100 \qquad \text{Eq. B-16}$$

where:

SO_I = The intensity of the internal standard in the blank calibration; and

S_I = The intensity of internal standard in the EPA sample number in the same units.

3.16.13 Under "Q", enter an "E" if the %D for a field sample, duplicate, or spike is greater than 50% for the second time after being run at a five fold dilution. If the percent relative intensity is less than or equal to 50%, then leave the field empty.

NOTE: A comment on the appropriate FORMs I-AAIN, VI-AAIN, or VII-AAIN explaining which analytes are affected by this flag must be included.

NOTE: Columns of internal standard %D must be entered left to right starting with the internal standards of the lower mass on the first FORM XIV-AAIN and proceeding to the following FORM XIV-AAIN as appropriate.

3.17 Preparation Log [FORM XV - AAIN]

3.17.1 This form is used to report the sample analysis log for ICP and ICP-MS analyses only. In addition, the samples reported on this form must have been prepared in the same manner using no pre-preparation dilution or concentration steps. The results reported on FORM I-AAIN for the samples listed on this form for each analyte must be obtained by multiplying each analyte's concentration (in µg/L) from the instrument by the dilution factor (DF) listed on the form.

3.17.2 All field samples and all quality control preparations (including duplicates, spikes, LCS's, PB's and reprepared samples) associated with the SDG must be reported on FORM XV-AAIN. Only the preparations associated with the SDG may be submitted on this form.

3.17.3 Submit one FORM XV-AAIN per method if no more than 32 preparations including quality control preparations were performed. In more than 32 preparations per method were performed, then submit additional copies of FORM XV-AAIN as appropriate.

3.17.4 Complete the header information according to the header instructions and as follows.

3.17.5 For "Analyte," enter the name of the analyte as identified in the Target Analyte List in Exhibit C.

3.17.6 For "Run No.," enter the run number (two characters maximum) which is the number that applies to a continuous analytical sequence consisting of prepared samples and all associated quality assurance measurements as required by the contract.

3.17.7 For "Instrument ID No.," enter the instrument ID number (12 characters maximum) which is the identifier that distinguishes each instrument used for analysis in the SDG. If more than one instrument is used, submit additional copies of FORM XV-AAIN as appropriate.

3.17.8 For "Start Date," enter the date (formatted MM/DD/YY) on which the analysis run was started.

3.17.9 For "End Date," enter the date (formatted MM/DD/YY) on which the analysis run was ended.

3.17.10 Under "EPA SAMPLE No.," enter the EPA sample number of each sample in the SDG and of all other preparations, such as duplicates, spikes, LCSs, PBs, and repreparations (all formatted according to Table B-2 of this Exhibit). All EPA sample numbers must be listed in ascending alphanumeric order, continuing to the next FORM XV-AAIN if applicable. If a sample was reprepared, list the same EPA sample number in the order of increasing preparation date.

3.17.11 Under "PREP. DATE," enter the date (formatted MM/DD/YY) on which each sample was prepared for analysis by the method indicated in the header section of the form.

3.17.12 Under "Final Volume," enter the final volume (in mL, to the nearest whole number) of the preparation for each sample prepared for analysis by the method indicated in the header section of the form. This field must have a value for each sample listed.

3.17.13 Under "Time," enter the time (in military format - HH:MM) at which each analysis was performed.

3.17.14 Under "DF," enter the dilution factor (to two decimal places) by which the final product of preparation needed to be diluted for each analysis performed.

NOTE: A DF of "1" must be entered if the preparation product was analyzed without adding any further volume of dilutant or any other solutions to the sample or an aliquot of that sample taken for preparation.

NOTE: For EPA supplied solutions such as ICVs, ICSs, and LCSs, a DF must be entered if the supplied solution was used at a dilution different from that specified by the instructions provided with the solution. The DF reported in such a case must be that which would make the reported true values on the appropriate form for the solution equal those that were supplied with the solution by the EPA. For instance, if the ICV has a true value of 2500.0 µg/L for aluminum at a 20 fold dilution, and if the solution is prepared at a 40 fold dilution, a DF of "2" must be entered on FORM XIV-AAIN and the uncorrected instrument reading is compared to a true value of 1250 µg/L. In this example, FORM III-AAIN will have a true value of 2500.0 regardless of the dilution used. The found value for the ICV must be corrected for the dilution listed on FORM XV-AAIN using the following formula:

$$\textit{Found value on FORM II-AAIN} = \textit{Instrument readout in µg/L} \times DF \qquad \text{Eq. B-17}$$

3.17.15 Under "%R," enter the percent recovery (to two decimal places) for each analytical spike analyzed. Leave the field blank if the analysis reported is not an analytical spike.

3.18 Analysis Run Log [FORM XVI - AAIN]

3.18.1 This form is used to report the sample analysis run log for each instrument used for analyses in the SDG. This includes any analysis run where conditions for reporting on FORM XV-AAIN were not met. FORM XV-AAIN is analyte and method specific.

3.18.2 A run is defined as the totality of analyses performed by an instrument throughout the sequence initiated by, and including, the first required calibration standard and terminated by, and including, the continuing calibration verification and blank analyses following the last required field sample.

3.18.3 All field samples and all quality control preparations (including tuning solutions, calibration standards, ICVs, CCVs, ICBs, CCBs, MTSs, CRIs, ICSs, LRSs, LCSs, PBs, duplicates, pre-digestion spikes, analytical spikes, and spike addition analyzed by the MSA) associated with the SDG must be reported on FORM XVI-AAIN. The run must be continuous and inclusive of all analyses performed on the particular instrument during the run.

3.18.4 Submit one FORM XVI-AAIN per run if no more than 32 analyses including instrument calibration were analyzed in the run. If more than 32 analyses were performed in the run, submit additional copies of FORM XVI-AAIN as appropriate.

3.18.5 Complete the header information according to the header instructions and as follows:

3.18.6 For "Run No.," enter the run number (two characters maximum) which is the number that applies to a continuous analytical sequence consisting of prepared samples and all associated quality assurance measurements as required by the contract.

3.18.7 For "Start Date," enter the date (formatted MM/DD/YY) on which the analysis run was started.

3.18.8 For "Method," enter the method code (two characters maximum).

3.18.9 For "End Date," enter the date (formatted MM/DD/YY) on which the analysis run was ended.

3.18.10 For "Instrument ID No.," enter the instrument identification number (twelve characters maximum) which is the identifier that distinguishes each instrument used for analysis in the SDG. If more than one instrument is used, submit additional copies of FORM XVI-AAIN as appropriate.

3.18.11 Under "EPA SAMPLE No.," enter the EPA sample number, including the QC suffix of each sample (formatted according to Table B-2 of this

Exhibit). All EPA sample numbers must be listed in increasing temporal (date and time) order of analysis, continuing to the next FORM XV-AAIN for the instrument run if applicable. The analysis date and time of other analyses not associated with the SDG but analyzed by the instrument in the reported analytical run must be reported. Those analyses must be identified with the EPA Sample No. of "ZZZZZ".

3.18.12 Under "PREP. DATE," enter the date (formatted MM/DD/YY) on which each sample was prepared for analysis by the method indicated in the header section of the form.

3.18.13 Under "VOLUME," enter the final volume (in mL, to the nearest whole number) of the preparation for each sample prepared for analysis by the method indicated in the header section of the form. This field must have a value for each field listed.

3.18.14 Under "TIME," enter the time (in military format - HH:MM) at which each analysis was performed. If an autosampler is used with equal analysis time and intervals between analyses, then only the start time of the run (the time of analysis of the first calibration standard) and end time of the run (the time of analysis of the final CCV or CCB, whichever is later) needs to be reported.

3.18.15 Under "DF," enter the dilution factor (to three decimal places) by which the final product of the preparation procedure (digestate or distillate) can be analyzed within the instrument standard range. The DF does not include the dilution inherent in the preparation as specified by the preparation procedures in Exhibit D.

NOTE: A "1" must be entered if the preparation product was analyzed without adding any further volume of dilutant or any other solutions to the "Volume" or an aliquot of the "Volume" listed on FORM XV-AAIN for that sample.

NOTE: For EPA supplied solutions such as ICVs, ICSs, and LCSs, a DF must be entered if the supplied solution was used at a dilution different from that specified by the instructions provided with the solution. The DF reported in such a case must be that which would make the reported true values on the appropriate form for the solution equal those that were supplied with the solution by the EPA. For instance, if the ICV has a true value of 2500.0 µg/L for aluminum at a 20 fold dilution, and if the solution is prepared at a 40 fold dilution, a DF of "2" must be entered on FORM XIV-AAIN and the uncorrected instrument reading is compared to a true value of 1250 µg/L. In this example, FORM II-AAIN will have a true value of 2500.0 regardless of the dilution used. The found value for the ICV must be corrected for the dilution listed on FORM XV-AAIN using the following formula:

$$\text{Found value on FORM II-AAIN} = \text{Instrument readout in mg/L} \times DF \qquad \text{Eq. B-18}$$

3.18.16 Under "ANALYTES," enter "X" in the column of the designated analyte to indicate that the analyte value was used from the reported analysis to report data on any of the forms in the SDG. Leave the column empty for each analyte if the analysis was not used to report the particular analyte.

3.19 STANDARD SOLUTIONS SOURCES [FORM XVII - AAIN]

3.19.1 This form is used to report the source of each standard solution on an analyte-by-analyte basis for ICVs, CCVs, CRQLs, LRSs, ICSs, and LCSs standards used for QC analyses in the SDG.

3.19.2 For EPA supplied solutions, entering "EPA" is not sufficient. EPA solutions must be identified using the codes EPA supplied with the solutions identification.

3.19.3 For non-EPA supplied solutions, enter sufficient information in the available twelve spaces to unequivocally identify the manufacturer and the solution used.

3.19.4 Complete the header information according to the instructions and as follows:

3.19.5 Under "ICV Standard Source," enter the initial calibration source (twelve spaces maximum) for each analyte for which the ICV results were reported on FORM II-AAIN.

3.19.6 Under "CCV Standard Source," enter the continuing calibration source (twelve spaces maximum) for each analyte for which the CCV results were reported on FORM II-AAIN.

3.19.7 Under "CRQL Standard Source," enter the contract required quantitation limit source (twelve spaces maximum) for each analyte for which the CRI results were reported on FORM III-AAIN.

3.19.8 Under "LRS Standard Source," enter the linear range standard source (twelve spaces maximum) for each analyte for which the LRS results were reported on FORM III-AAIN.

3.19.9 Under "ICS Standard Source," enter the interference check sample standard source (twelve spaces maximum) for each analyte for which the ICS results were reported on FORM V-AAIN.

3.19.10 Under "LCS Standard Source," enter the laboratory control sample standard source (twelve spaces maximum) for each analyte for which ICS results were reported on FORM VIII-AAIN.

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3.20 SAMPLE LOG-IN SHEET [FORM AADC - IN - 1]

3.20.1 This form is used to document the receipt and inspection of shipping containers and samples. One original FORM AADC-IN-1 is required for each shipping container.

3.20.2 If the samples in a single shipping container must be assigned to more than one SDG, then the original FORM AADC-IN-1 shall be placed with the deliverables for the SDG of the lowest alphanumeric number and a copy of FORM AADC-IN-1 must be placed with the deliverables for the other SDG(s). The copies should be identified as "copy(ies)," and the location of the original should be noted on the copies.

3.20.3 Sign and date the airbill (if present). Examine the shipping container and record the presence/absence of custody seals and their condition (i.e., intact, broken) in item 1 on FORM AADC-IN-1. Record the custody seal numbers in item 2.

3.20.4 Open the shipping container, remove the enclosed sample documentation, and record on FORM AADC-IN-1, items 3-5, the presence/absence of chain-of-custody record(s), SMO forms (i.e., TRs, Packing Lists), and airbills or airbill stickers. Specify if there is an airbill or an airbill sticker present in item 5 on FORM AADC-IN-1. Record the airbill or sticker number in item 6.

3.20.5 Remove the samples from the shipping container(s), examine the samples and the sample tag (if present), and record the condition of the sample bottles (i.e., intact, broken, leaking), and the presence or absence of sample tags in items 7 and 8 on FORM AADC-IN-1.

3.20.6 Review the sample shipping documents and complete the header information. Compare the information recorded on all the documents and samples, and circle the appropriate answer in item 9 on FORM AADC-IN-1.

3.20.7 If there are no problems observed during receipt, sign and date (include time) FORM AADC-IN-1, the chain-of-custody record, the TR, and write the sample numbers on FORM AADC-IN-1. For each sample number entered, enter the corresponding air volume sampled in standard cubic meters (std. m^3) in the appropriate column. Record the appropriate sample tags and assigned laboratory numbers if applicable. The log-in date should be recorded at the top of FORM AADC-IN-1, and the date and time of sample receipt at the laboratory should be recorded in items 10 and 11. Cross out unused columns and spaces.

3.20.8 If there are problems observed during receipt (e.g., data on air volume sampled is missing for one or more samples) or if an answer marked with an asterisk (i.e., "absent*") was circled, then contact SMO and document the resolution of the problem on a CLP Communication Log. Following resolution, sign and date the forms as specified in the

preceding paragraph and note, where appropriate, the resolution of the problem.

3.20.9 For "Sample Transfer," enter the fraction designation (if appropriate) and the specific area designation (e.g., refrigerator number) in the Sample Transfer block located in the bottom left corner of FORM AADC-IN-1. Sign and date the sample transfer block.

3.21 DOCUMENT INVENTORY SHEET [FORM AADC - IN - 2]

3.21.1 This form is used to record the inventory of the Complete Sample Delivery Group Case file (CSF) documents which are sent to the Region.

3.21.2 Organize all EPA-CSF documents as described in Exhibit B. Assemble the documents in the order specified on FORM AADC-IN-2 and Exhibit B, and stamp each page with the consecutive numbers (Do not number the DC-IN-2 form). Inventory the CSF by reviewing the document numbers and recording page number ranges in the column provided on FORM AADC-IN-2. If there are no documents for a specific document type, enter "NA" in the empty space.

3.21.3 Certain laboratory specific documents related to the CSF may not fit into a clearly defined category. The laboratory should review DC-IN-2 to determine if it is most appropriate to place them under items 25, 26, 27, or 28. Item 28 should be used if there is no appropriate item. These types of documents should be described or listed in the blanks under each appropriate item.

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SECTION 4

DATA REPORTING FORMS

PAGE NO.

1. Cover Page - [COVER PAGE - AAIN] B-50
2. Analysis Data Sheet [FORM I - AAIN] B-51
3. Initial and Continuing Calibration Verification [FORM II - AAIN] . . B-52
4. CRQL Standards/Linear Range Standards (Quarterly) [FORM III - AAIN] B-53
5. Blanks [FORM IV - AAIN] B-54
6. ICP Interference Check Sample [FORM V - AAIN] B-55
7. Spike Sample Recovery [FORM VI - AAIN] B-56
8. Duplicates [FORM VII - AAIN] B-57
9. Laboratory Control Sample [FORM VIII - AAIN] B-58
10. Method of Standard Additions [FORM IX - AAIN] B-59
11. ICP Serial Dilution [FORM X - AAIN] B-60
12. Method Quantitation Limits (Quarterly) [FORM XI - AAIN] B-61
13. ICP and ICP-MS Interelement Correction Factors (Annual) [FORM XII- AAIN] B-62
14. ICP-MS Tuning and Response Factor Criteria [FORM XIII - AAIN] . . . B-63
15. ICP-MS Internal Standards Summary [FORM XIV - AAIN] B-64
16. Preparation Log [FORM XV - AAIN] B-65
17. Analysis Run Log [FORM XVI - AAIN] B-66
18. Standard Solutions Sources [FORM XVII - AAIN] B-67
19. Sample Log-In Sheet [FORM AADC-IN-1] B-68
20. Document Inventory Sheet [FORM AADC-IN-2] B-69

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

COVER PAGE

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

EPA Sample No.	Lab Sample ID

Enter a "Y" for Yes or an "N" for No

ICP and ICP-MS interelement corrections applied? _____

ICP and ICP-MS background corrections applied? _____

If yes, were raw data generated before application of background corrections? _____

Comments: _____

I certify that this data package is in compliance with the terms and conditions of the contract, both technically and for completeness, excluding the conditions detailed above. Release of the data contained in this hardcopy data package and in the computer-readable data submitted on floppy diskette has been authorized by the Laboratory Manager or the Manager's designee, as verified by the following signature.

Signature: _____ Name: _____

Date: _____ Title: _____

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM
Metals in Ambient Air

EPA SAMPLE NO.

ANALYSIS DATA SHEET

Lab Name: _____ Contract: _____

Lab Code: _____ Lab Sample ID: _____

Case No.: _____ Date Received: _____

SAS No.: _____ Air Volume Sampled, Std. m^3: _____

SDG No.: _____ Date Analyzed: _____

CAS No.	ANALYTE	CONCENTRATION		C	Q	M
		µg/L	µg/m^3			
7429-90-5	Aluminum					
7440-36-0	Antimony					
7440-38-2	Arsenic					
7440-39-3	Barium					
7440-41-7	Beryllium					
7440-43-9	Cadmium					
7440-70-2	Calcium					
7440-47-3	Chromium					
7440-48-4	Cobalt					
7440-50-8	Copper					
7439-89-6	Iron					
7439-92-1	Lead					
7439-95-4	Magnesium					
7439-96-5	Manganese					
7439-97-6	Molybdenum					
7440-02-0	Nickel					
7440-09-7	Potassium					
7782-49-2	Selenium					
7440-22-4	Silver					
7440-23-5	Sodium					
7440-28-0	Thallium					
7440-31-5	Tin					
7440-62-2	Vanadium					
7440-66-6	Zinc					

Comments: _____

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

INITIAL AND CONTINUING CALIBRATION VERIFICATION

Lab Name: _____ Contract: _____

Lab Code: _____ Case No.: _____

SAS No.: _____ Initial Calibration Source: _____

SDG No.: _____ Continuing Calibration Source: _____

Concentration Units: µg/L

ANALYTE	WOMN	INITIAL CALIBRATION (ICV)			CONTINUING CALIBRATION (CCV) CCV No.: ____			CCV No.: ____			M
		True	Found	%R	True	Found	%R	True	Found	%R	
Aluminum											
Antimony											
Arsenic											
Barium											
Beryllium											
Cadmium											
Calcium											
Chromium											
Cobalt											
Copper											
Iron											
Lead											
Magnesium											
Manganese											
Molybdenum											
Nickel											
Potassium											
Selenium											
Silver											
Sodium											
Thallium											
Tin											
Vanadium											
Zinc											

Comments: _____

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

CRQL STANDARDS/LINEAR RANGE STANDARDS

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

CRQL: LRS:

ICP Source: _____ ICP Source: _____

ICP-MS Source: _____ ICP-MS Source: _____

GFAA Source: _____ GFAA Source: _____

Concentration Units: µg/L

ANALYTE	WOMN	CRQL STANDARDS						LINEAR RANGE STANDARDS (LRS)					
		INITIAL			FINAL			INITIAL			FINAL		
		True	Found	%R	Found	%R	M	True	Found	%R	Found	%R	M
Aluminum													
Antimony													
Arsenic													
Barium													
Beryllium													
Cadmium													
Calcium													
Chromium													
Cobalt													
Copper													
Iron													
Lead													
Magnesium													
Manganese													
Molybdenum													
Nickel													
Potassium													
Selenium													
Silver													
Sodium													
Thallium													
Tin													
Vanadium													
Zinc													

Comments: _____

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

BLANKS

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

Concentration Units: µg/L

ANALYTE	WOMN	INITIAL CALIB. BLANK (ICB)		CONTINUING CALIBRATION BLANK (CCB)						PREPARATION BLANK (PB)		M
		Conc.	C	Conc. 1	C	Conc. 2	C	Conc. 3	C	Conc.	C	
Aluminum												
Antimony												
Arsenic												
Barium												
Beryllium												
Cadmium												
Calcium												
Chromium												
Cobalt												
Copper												
Iron												
Lead												
Magnesium												
Manganese												
Molybdenum												
Nickel												
Potassium												
Selenium												
Silver												
Sodium												
Thallium												
Tin												
Vanadium												
Zinc												

Comments: _____

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

ICP INTERFERENCE CHECK SAMPLE

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

ICP ID No.: _____ ICS Source: _____

Concentration Units: µg/L ICP-MS ID No.: _____

ANALYTE	WOMN	TRUE		INITIAL FOUND			FINAL FOUND			M
		Sol. A	Sol. AB	Sol. A	Sol. AB	%R	Sol. A	Sol. AB	%R	
Aluminum										
Antimony										
Arsenic										
Barium										
Beryllium										
Cadmium										
Calcium										
Chromium										
Cobalt										
Copper										
Iron										
Lead										
Magnesium										
Manganese										
Molybdenum										
Nickel										
Potassium										
Selenium										
Silver										
Sodium										
Thallium										
Tin										
Vanadium										
Zinc										

Comments: _____

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

SPIKE SAMPLE RECOVERY

EPA SAMPLE NO.

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

Concentration Units: µg/L

ANALYTE	WOMN	CONTROL LIMIT %R	SPIKED SAMPLE RESULT (SSR)		SAMPLE RESULT (SR)		SPIKE ADDED (SA)			
			Conc.	C	Conc.	C	Conc.	%R	Q	M
Aluminum										
Antimony										
Arsenic										
Barium										
Beryllium										
Cadmium										
Calcium										
Chromium										
Cobalt										
Copper										
Iron										
Lead										
Magnesium										
Manganese										
Molybdenum										
Nickel										
Potassium										
Selenium										
Silver										
Sodium										
Thallium										
Tin										
Vanadium										
Zinc										

Comments: _____

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM
Metals in Ambient Air

DUPLICATES

EPA SAMPLE NO.

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

Concentration Units: µg/L

ANALYTE	WOMN	CONTROL LIMIT	SAMPLE (S)		DUPLICATE (D)		RPD	Q	M
			Conc.	C	Conc.	C			
Aluminum									
Antimony									
Arsenic									
Barium									
Beryllium									
Cadmium									
Calcium									
Chromium									
Cobalt									
Copper									
Iron									
Lead									
Magnesium									
Manganese									
Molybdenum									
Nickel									
Potassium									
Selenium									
Silver									
Sodium									
Thallium									
Tin									
Vanadium									
Zinc									

Comments: _____

U. S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Metals in Ambient Air

LABORATORY CONTROL SAMPLE

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

GFAA Source: _____ ICP Source: _____

ICP-MS Source: _____ Concentration Units: µg/L

ANALYTE	LCS USED	WOMN	LIMITS		TRUE	FOUND	C	%R	M
			LOWER	UPPER					
Aluminum									
Antimony									
Arsenic									
Barium									
Beryllium									
Cadmium									
Calcium									
Chromium									
Cobalt									
Copper									
Iron									
Lead									
Magnesium									
Manganese									
Molybdenum									
Nickel									
Potassium									
Selenium									
Silver									
Sodium									
Thallium									
Tin									
Vanadium									
Zinc									

Comments: _____

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

STANDARD ADDITION RESULTS

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

Concentration Units: µg/L

				A D D I T I O N S									
			ZERO	FIRST		SECOND		THIRD		FINAL			
			Found	Added	Found	Added	Found	Added	Found	CONC.	r	Q
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
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32													

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

ICP and ICP–MS SERIAL DILUTION

EPA SAMPLE NO.

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

Concentration Units: µg/L

Analyte	WOMN	Initial Sample Result (I)	C	Serial Dilution Result (S)	C	%Difference	Q	M
Aluminum								
Antimony								
Arsenic								
Barium								
Beryllium								
Cadmium								
Calcium								
Chromium								
Cobalt								
Copper								
Iron								
Lead								
Magnesium								
Manganese								
Molybdenum								
Nickel								
Potassium								
Selenium								
Silver								
Sodium								
Thallium								
Tin								
Vanadium								
Zinc								

Comments: _____

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

METHOD QUANTITATION LIMIT

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

Date: _____ ICP ID No.: _____

GFAA ID No.: _____ Concentration Units: µg/L

ANALYTE	WOMN	WAVE-LENGTH (nm)	MASS (m/z)	INTEG. TIME (sec)	BACK-GROUND	CRQL (µg/L)	MQL (µg/L)	M
Aluminum						226		
Antimony						92		
Arsenic						92		
Barium						11		
Beryllium						7		
Cadmium						18		
Calcium						381		
Chromium						44		
Cobalt						55		
Copper						37		
Iron						126		
Lead						118		
Magnesium						89		
Manganese						15		
Molybdenum						33		
Nickel						52		
Potassium						758		
Selenium						577		
Silver						229		
Sodium						592		
Thallium						562		
Tin						155		
Vanadium						26		
Zinc						444		

Comments: _____

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

ICP AND ICP-MS INTERELEMENT CORRECTION FACTORS (ANNUAL)

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

ICP ID No.: _____ Date: _____

ICP-MS ID No.: _____

ANALYTE	W O M N	INTERELEMENT CORRECTION FACTORS FOR:				
		___	___	___	___	___
Aluminum						
Antimony						
Arsenic						
Barium						
Beryllium						
Cadmium						
Calcium						
Chromium						
Cobalt						
Copper						
Iron						
Lead						
Magnesium						
Manganese						
Molybdenum						
Nickel						
Potassium						
Selenium						
Silver						
Sodium						
Thallium						
Tin						
Vanadium						
Zinc						

Comments: _____

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

ICP–MS TUNING AND RESPONSE FACTOR CRITERIA

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

Date: _____ ICP-MS ID No.: _____

Run No.: _____ Method: _____

Analysis Times:

Initial: _____

Final: _____

TUNING

m/z	Ion Abundance Criteria	% Relative Abundance	
		Initial	Final
$^{7}Li/^{59}Co$	(0.20 - 1.00)		
$^{56}Co/^{59}Co$	(1.00)		
$^{115}In/^{59}Co$	(0.75 - 2.00)		
$^{205}Tl/^{59}Co$	(0.50 - 1.20)		

RESPONSE FACTOR (counts per second)

m/z	Response Factor Criteria	RF100 (1) Response	
		Initial	Final
^{7}Li	(> 2,000)		
^{59}Co	(> 20,000)		
^{115}In	(> 10,000)		
^{102}Ru	(> 25)		
^{205}Tl	(> 1,000)		

(1) Background (RF0) for ^{102}Ru.

MASS CALIBRATION

m/z	Acceptable Mass Range	Observed Mass
^{7}Li	(6.9160 - 7.1160)	
^{59}Co	(58.8332 - 59.0332)	
^{115}In	(114.8040 - 115.0040)	
^{205}Tl	(204.8744 - 205.0744)	

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

ICP-MS INTERNAL STANDARDS SUMMARY

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

Run No.: _____ Method: _____

Start Date: _____ ICP-MS ID No.: _____

End Date: _____

	EPA SAMPLE NUMBER	Time	Internal Standards %D For:									
			___	Q	___	Q	___	Q	___	Q	___	Q
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
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32												

U. S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

PREPARATION LOG

Lab Name: _____ Contract: _____

Lab Code: _____ SAS No.: _____

Case No.: _____ SDG No.: _____

Run No.: _____ Analyte: _____

Start Date: _____ Instrument ID No.: _____

End Date: _____

	EPA SAMPLE No.	PREP. DATE	Final Volume (mL)	Time	DF	%R
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
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31						
32						

U.S. ENVIRONMENTAL PROTECTION AGENCY

CONTRACT LABORATORY PROGRAM

Metals in Ambient Air

ANALYSIS RUN LOG

Lab Name: _____ Contract: _____

Lab Code: _____ SDG No.: _____

Case No.: _____ SAS No.: _____

Start Date: _____ Run No.: _____

End Date: _____ Method: _____

Instrument ID No.: _____

	EPA SAMPLE No.	PREP. DATE	VOLUME (mL)	TIME	DF	ANALYTES																								
						AL	SB	AS	BA	BE	CD	CA	CR	CO	CU	FE	PB	MG	MN	MO	NI		SE	AG	AA	TL	SN	V	ZN
1																														
2																														
3																														
4																														
5																														
6																														
7																														
8																														
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31																														
32																														

U.S. ENVIRONMENTAL PROTECTION AGENCY
CONTRACT LABORATORY PROGRAM
Metals in Ambient Air

STANDARD SOLUTIONS SOURCES

Lab Name: _____ Contract: _____

Lab Code: _____ SDG No.: _____

Case No.: _____ SAS No.: _____

Analyte	ICV Standard Source	CCV Standard Source	CRQL Standard Source	LRS Standard Source	ICS Standard Source	LCS Standard Source
Aluminum						
Antimony						
Arsenic						
Barium						
Beryllium						
Cadmium						
Calcium						
Chromium						
Cobalt						
Copper						
Iron						
Lead						
Magnesium						
Manganese						
Molybdenum						
Nickel						
Potassium						
Selenium						
Silver						
Thallium						
Tin						
Vanadium						
Zinc						

Comments: _____

SAMPLE LOG-IN SHEET

Lab Name: ______________________ Page: ________ of ________

Received By (Print Name): ______________________ Log-in Date: ______________

Received by (Signature): ______________________

Case Number: ______________

Sample Delivery Group No.: ______________

SAS Number: ______________

CIRCLE THE APPROPRIATE RESPONSE:

1. Custody Seal(s) — Present/Absent* — Intact/Broken
2. Custody Seal Nos.: ______________ ______________
3. Chain-of-Custody Records — Present/Absent*
4. Traffic Reports or Packing List — Present/Absent*
5. Airbill — Airbill/Sticker Present/Absent*
6. Airbill No.: ______________
7. Sample Tags — Present/Absent* — Sample Tag Numbers — Listed/Not Listed on Chain-of-Custody
8. Sample Condition: — Intact/Broken*/ Leaking
9. Does information on custody records traffic reports, an sample tags agree. — Yes/No*
10. Date Received at Lab: ______________
11. Time Received: ______________

EPA SAMPLE #	SAMPLE TAG #	ASSIGNED LAB #	AIR VOLUME SAMPLED STD. m^3	REMARKS: CONDITION OF SAMPLE SHIPMENT ETC.

Sample Transfer

Fraction: ________ ________

Area #: ________ ________

By: ________ ________

On: ________ ________

*If Circled, contact SMO and attach record of resolution

Reviewed by: ______________ Logbook No.: ______________

Date: ______________ Logbook Page No.: ______________

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METAL IN AMBIENT AIR ANALYTES
COMPLETE SDG FILE (CSF)
INVENTORY SHEET

Lab Name: _____ City/State: _____

Case No.: _____ SDG No.: _____ SDG Nos. to Follow: ____ - ____ - ____ - ____

SAS No.: _____ Contract No.: _____

All documents delivered in the complete SDG file must be original documents where possible. (Reference Exhibit B, Section 3)

	Page Nos.		(Please Check:)	
	From	To	Lab	Region
1. Inventory Sheet (AADC-2) (Do not number)				
2. Cover Page				
3. Inorganic Analysis Data Sheet (FORM I-AAIN)				
4. Initial & Continuing Calibration Verification (FORM II-AAIN)				
5. CRQL Standards/Linear Range Standards (Quarterly) (FORM III-AAIN)				
6. Blanks (FORM IV-AAIN)				
7. ICP and ICP-MS Interference Check Sample (FORM V-AAIN)				
8. Spike Sample Recovery (FORM VI-AAIN)				
9. Duplicates (FORM VII-AAIN)				
10. Laboratory Control Sample (FORM VIII-AAIN)				
11. Method of Standard Addition Results (FORM IX-AAIN)				
12. ICP and ICP-MS Serial Dilution (FORM X-AAIN)				
13. Method Detection Limit (FORM XI-AAIN)				
14. ICP and ICP-MS Interelement Correction Factors (Annual) (FORM XII-AAIN)				
15. ICP-MS Tuning and Response Factor Criteria (FORM XIII-AAIN)				
16. ICP-MS Internal Standards Summary (FORM XIV-AAIN)				
17. Preparation Log (FORM XV-AAIN)				
18. Analysis Run Log (B) (FORM XVI-AAIN)				
19. ICP Raw Data				
20. ICP-MS Raw Data				
21. GFAA Raw Data				
22. Traffic Report				

DRAFT

METAL IN AMBIENT AIR ANALYTES
COMPLETE SDG FILE (CSF)
INVENTORY SHEET

	From	To	Lab	Region
23. EPA Shipping/Receiving Documents				
Airbill (No. of Shipments ____)				
Chain-of-custody Records				
Sample Tags				
Sample Log-In Sheet (Lab & HDC-1)				
SDG Cover Sheet				
24. Misc. Shipping/Receiving Records				
(list all individual records)				
Telephone Logs				
_____				
_____				
25. Internal Lab Sample Transfer Records & Tracking Sheets (describe or list)				
26. Internal Originial Sample Preparation & Analysis Records (describe or list)				
Preparation Records _____				
Analysis Records _____				
Description _____				
27. Other Records (describe or list)				
Telephone Communication Log				
_____				
_____				

28. Comments: _____

_____

_____

_____

Completed by (CLP Lab):

_____ _____ _____

(Signature) (Print Name & Title) (Date)

Audited by (EPA):

_____ _____ _____

(Signature) (Print Name & Title) (Date)

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EXHIBIT C

TARGET COMPOUND LISTS

TABLE 1

METALS IN AMBIENT AIR
TARGET ANALYTE LIST (TAL) AND
CONTRACT REQUIRED QUANTITATION LIMITS (CRQL)

Analyte	CAS RN	Contract Required Quantitation Limit[1,2,3] ng/m³	µg/L
Aluminum	7429-90-5	33	226
Antimony	7440-36-0	13	92
Arsenic	7440-36-2	13	92
Barium	7440-39-3	2	11
Beryllium	7440-41-7	1	7
Cadmium	7440-43-9	3	18
Calcium	7440-70-2	55	381
Chromium	7440-47-3	6	44
Cobalt	7440-48-4	8	55
Copper	7440-50-8	5	37
Iron	7439-89-6	18	126
Lead	7439-92-1	17	118
Magnesium	7439-95-4	13	89
Manganese	7439-96-5	2	15
Molybdenum	7439-98-7	5	33
Nickel	1313-99-1	8	52
Potassium	7440-09-7	109	758
Selenium	7782-49-2	83	577
Silver	7440-22-4	33	229
Sodium	7440-23-5	85	592
Thallium	7440-28-0	81	562
Tin	7440-31-5	22	155
Vanadium	7440-62-2	4	26
Zinc	7440-66-6	64	444

(1) The analytical methods specified in Exhibit D, Sections 3 and 5 must be utilized and the achieved instrument detection limits must meet the Contract Required Quantitation Limits (CRQL) requirements. Higher detection levels may only be used in the following circumstance:

- If the sample concentration exceeds two times the detection limit of the instrument or method in use, the value may be reported even though the instrument or instrument detection limit may not equal the contract required quantitation limit. The method detection limit must be documented as described in Exhibits D.

(2) These CRQL's are the method detection limits obtained from actual method blank preparations that must be met using the procedure in Exhibits D.

(3) Assume 2500 m³ air volume per Hi-Vol filter and 40 mL final extract volume. See Exhibit D, Sections 3.9.4 and 5.11.2 for calculations.

TABLE 2

METALS IN AMBIENT AIR
TARGET ANALYTE LIST (TAL) AND
CONTRACT REQUIRED QUANTITATION LIMITS (CRQL)
FOR ICP-MS ANALYSES

Analyte	CAS RN	Contract Required Quantitation Limit[1,2] ng/m³	µg/L
Aluminum	7429-90-5	33	226
Antimony	7440-36-0	13	92
Arsenic	7440-36-2	13	92
Barium	7440-39-3	2	11
Beryllium	7440-41-7	1	7
Cadmium	7440-43-9	3	18
Chromium	7440-47-3	6	44
Cobalt	7440-48-4	8	55
Copper	7440-50-8	5	37
Iron	7439-89-6	18	126
Lead	7439-92-1	17	118
Manganese	7439-96-5	2	15
Nickel	1313-99-1	8	52
Selenium	7782-49-2	83	577
Silver	7440-22-4	33	229
Thallium	7440-28-0	81	562
Vanadium	7440-62-2	4	26
Zinc	7440-66-6	64	444

(1) The ICP-MS method specified in Exhibit D, Section 4 may be utilized provided the documented method detection limits meet the Contract Required Quantitation Limit (CRQL) requirements.

(2) The CRQL is the method detection limits obtained in pure water that must be met using the procedure in Exhibit D. The method detection limits for samples may be considerably higher depending on the sample matrix.

(3) Assume 2500 m³ air volume per Hi-Vol filter and 40 mL final extract volume. See Exhibit D, Section 4.9.2 for calculations.

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TABLE 3

INTERFERENCE CHECK SAMPLE COMPONENTS AND CONCENTRATIONS FOR ICP AND ICP-MS

Interference Component	Solution A Concentration (mg/L)	Solution AB Concentration (mg/L)
Al	500.0	500.0
Ca	500.0	500.0
Fe	500.0	500.0
Mg	500.0	500.0
Na	500.0	500.0
P	500.0	500.0
K	500.0	500.0
S	500.0	500.0
C	1,000.0	1,000.0
Cl	3,600.0	3,600.0
Mo	10.0	20.0
Ti	10.0	20.0
As	0.0	0.100
Cd	0.0	0.050
Cr	0.0	0.100
Co	0.0	0.200
Cu	0.0	0.100
Mn	0.0	0.100
Ni	0.0	0.200
Se	0.0	0.100
Ag	0.0	0.100
V	0.0	0.200
Zn	0.0	0.100

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TABLE 4

INITIAL AND CONTINUING CALIBRATION VERIFICATION
CRQL STANDARD CONTROL LIMITS, AND LCS STANDARD CONTROL LIMITS
FOR INORGANIC ANALYSES

INITIAL AND CONTINUING CALIBRATION VERIFICATION LIMITS

Analytical Method	Inorganic Species	% of True Value (EPA Set) Low Limit	High Limit
ICP	Metals	90	110
ICP-MS	Metals	90	110
GFAA	Metals	90	110

CRQL STANDARD CONTROL LIMITS

Analytical Method	Inorganic Species	% of True Value (EPA Set) Low Limit	High Limit
ICP	Metals	85	115
ICP-MS	Metals	85	115
GFAA	Metals	85	115

LCS STANDARD CONTROL LIMITS

The LCS Standard Control Limits are the same for all inorganics species. The limits are 80-120 percent.

EXHIBIT D

ANALYTICAL METHODS FOR THE DETERMINATION OF METAL COMPOUNDS COLLECTED ON HI-VOL FILTERS AND ANALYZED BY INDUCTIVELY COUPLED PLASMA (ICP) ATOMIC EMISSION SPECTROMETRY, INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY (ICP-MS) OR GRAPHITE FURNACE ATOMIC ABSORPTION (GFAA) SPECTROMETRY

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EXHIBIT D

ANALYTICAL METHODS FOR THE DETERMINATION OF METAL COMPOUNDS COLLECTED ON HI-VOL FILTERS AND ANALYZED BY INDUCTIVELY COUPLED PLASMA (ICP) ATOMIC EMISSION SPECTROMETRY, INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY (ICP-MS) OR GRAPHITE FURNACE ATOMIC ABSORPTION (GFAA) SPECTROMETRY

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SECTION 1

ANALYTICAL METHODS FOR THE DETERMINATION OF METAL COMPOUNDS COLLECTED ON HI-VOL FILTERS AND ANALYZED BY INDUCTIVELY COUPLED PLASMA (ICP) ATOMIC EMISSION SPECTROMETRY, INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY (ICP-MS) OR GRAPHITE FURNACE ATOMIC ABSORPTION (GFAA) SPECTROMETRY

1. INTRODUCTION

1.1 SCOPE AND APPLICATION

1.1.1 The methods specified in Exhibit D must be used and the documented instrument or method detection limits must meet the Contract Required Quantitation Limits (CRQL) (Tables 1 and 2, in Exhibit C). Analytical methods with higher detection limits may be used only if the sample concentration exceeds five times the documented detection limit of the instrument or method.

1.1.2 All samples must initially be run undiluted (i.e., final product of the sample preparation procedure). When an analyte concentration exceeds the calibrated or linear range (as appropriate), reanalysis for that analyte(s) is required after appropriate dilution. The Contractor must use the least dilution necessary to bring the analyte(s) within the valid analytical range (but not below the CRQL) and report the highest valid value for each analyte as measured from the undiluted and diluted analyses. Unless the Contractor can submit proof that dilution was required to obtain valid results, both diluted and undiluted sample measurements must be contained in the raw data. All sample dilutions shall be made with deionized water appropriately acidified to maintain constant acid strength.

1.1.3 The Contractor is reminded and cautioned that Exhibit D is a compendium of required and permitted analytical methods to be used in the performance of analyses under this contract. The quality assurance/quality control (QA/QC) procedures or measurements to be performed in association with these methods or analyses are specified in Exhibit E.

1.1.4 The Contractor is reminded and cautioned that the collection and provision of raw data may or may not be referred to within the individual methods of Exhibit D or the Quality Assurance Protocol of Exhibit E. The Raw Data Deliverables requirements are specified in Exhibit B. Raw data collected and provided in association with the performance of analyses under this contract shall conform to the appropriate provisions of Exhibit B.

1.1.5 Laboratory glassware to be used in metals analysis must be acid cleaned according to EPA's manual "Methods for Chemical Analysis of Water

and Wastes" or an equivalent procedure (see part 2.1.6.3). Samples must be opened and digested in a hood. Stock solutions to be used for preparing instrument or method calibration standards may be purchased or prepared as described in parts 3.6 and 4.6. All other solutions to be used for QA/QC measurements shall conform to the specific requirements of Exhibit E.

1.1.6 Background corrections are required for all GFAA measurements. Each GFAA analysis requires a minimum of two injections (burns) except during full Method of Standard Additions (MSAs). All ICP and ICP-MS measurements shall require a minimum of two replicate exposures. Appropriate hardcopy raw data for each exposure/injection shall be included in the data package in accordance with Exhibit B. The average of each set of exposures/injections shall be used for standardization, sample analysis, and reporting as specified in Exhibit D. All exposures must be reported in the raw data in concentration units.

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SECTION 2

SAMPLE PREPARATION

2.1 MICROWAVE EXTRACTION AND RELATED HANDLING PROCEDURES

2.1.1 Introduction

2.1.1.1 This Section describes a microwave extraction procedure to extract the metals from the particulate loaded glass-fiber filter. Following microwave extraction, target analytes are analyzed by ICP, ICP-MS, or GFAA.

2.1.2 Sample Preservation

2.1.2.1 Ambient air glass-fiber filters should be received folded in half lengthwise with the particulate material inward and enclosed in protective envelopes. These protective envelopes shall be stored at 15 to 30°C until analysis.

2.1.2.2 The maximum sample holding time under this contract is 180 days. To be compliant with this contract, the Contractor must analyze samples within 180 days even if these times are less than the maximum data submission times allowed in this contract.

2.1.3 Summary of Method

2.1.3.1 A 1" x 8" strip is cut from the 8" x 10" filter as described in the Federal Reference Method for Lead (see Figure D-1 and Reference 11). The metals are extracted from the filter strip by a hydrochloric acid/nitric acid solution using a laboratory microwave digestion system. After cooling, the digestate is centrifuged to remove any insoluble material.

2.1.3.2 Microwave extraction is used to prepare samples for ICP analysis. This method (using nitric acid only) or an alternate hot extraction technique may be used to prepare samples for ICP-MS and GFAA analysis.

2.1.4 Apparatus and Materials

2.1.4.1 Microwave digestive system and capping station: With programmable power settings up to 600 watts (see Figure D-2).

NOTE: Commercial kitchen or home-use microwave shall NOT be used for the digestion of samples under this contract. The oven cavity must be corrosion resistant and well ventilated. All electronics must be protected against corrosion for safe operation.

2.1.4.2 PFA Teflon digestion vessels: Capable of withstanding pressures of up to 100 psi. Pressure venting vessels capable of controlled pressure relief at pressures exceeding 100 psi. (60- to 120-mL capacity).

2.1.4.3 Teflon PFA overflow vessel: Double ported (60- to 120-mL capacity).

2.1.4.4 Rotating table: For uniform exposure of samples within the oven.

2.1.4.5 Volumetric glassware: 50- to 100-mL capacity (Class A borosilicate).

2.1.4.6 Bottles: Linear polyethylene or polypropylene with leakproof caps, for storing samples; Teflon bottles for storing multielement standards (500-mL, 125-mL, and 30-mL).

2.1.4.7 Centrifuge tubes: Polypropylene tube with screw tops of polypropylene, 50-mL (Nalgene 3119-0050 or equivalent).

2.1.4.8 Pipette: Automatic dispensing with an accuracy of setting of 0.1 mL or better and repeatability of 20 µL (Grumman Automatic Dispensing Pipette, Model ADP-30DT or equivalent).

2.1.4.9 Rack: Wire (Fisher 14-793-1) or polypropylene (Fisher 14-8090), for holding centrifuge tubes during shaking.

2.1.4.10 Particle mask (3M, No. 8500): To be worn while cutting and handling glass-fiber filters.

2.1.4.11 Centrifuge: Capable of maintaining speeds of 2000 rpm (International Equipment company Model UV or equivalent).

2.1.4.12 Template: To aid in sectioning the glass-fiber filter. Federal Register 1978 43 (Oct. 5), 46258-46261. (See Figure D-1).

2.1.4.13 Pizza cutter: Thin wheel (< 1 mm).

2.1.4.14 Mechanical shaker: Eberbach Corporation Model 6460 or equivalent.

2.1.5 Reagents

2.1.5.1 Hydrochloric acid: American Chemical Society (ACS) reagent grade, concentrated (12.3M) (or equivalent), for preparing samples.

2.1.5.2 Nitric acid: Redistilled spectrographic grade (16M) (or eqivalent), for preparing samples.

2.1.5.3 ASTM Type II water (ASTM D1193).

2.1.6 Microwave Extraction Procedure

2.1.6.1 Microwave Calibration Procedure

2.1.6.1.1 Calibration of the microwave unit is a critical step prior to its use. In order that absolute power settings may be interchanged from one microwave unit to another, the actual delivered power must be determined.

2.1.6.1.2 Calibration of a laboratory microwave unit (see Figure D-2) depends on the type of electronic system used by the manufacturer. If the unit has a precise and accurate linear relationship between the output power and the scale used in controlling the microwave unit, then the calibration can be a single-point calibration at maximum power. If the unit is not accurate or precise for some portion of the controlling scale, then a multiple-point calibration is necessary. If the unit power calibration needs multiple-point calibration, then the point where the linearity begins must be identified. For example, a calibration at 100, 99, 98, 97, 95, 90, 80, 70, 60, and 50 percent power settings can be applied and the data plotted. The nonlinear portion of the calibration curve can be excluded or restricted in use. Each percent is equivalent to approximately 5.5 - 6.5 W and becomes the smallest unit of power that can be controlled. If 20 - 40 W are contained from 99 - 100 percent, that portion of the microwave calibration is not controllable by three to seven times that of the linear portion of the control scale and will prevent duplication of precise power conditions specified in that portion of the power scale.

2.1.6.1.3 The equations in the following paragraph evaluate the power available for heating in a microwave cavity. This is accomplished by measuring the temperature rise in 1 kg of water exposed to electromagnetic radiation for a fixed period of time. Measurements are made on weighed replicates (five replicates) of 1 kg samples of room temperature distilled water in thick-walled microwave transparent (Teflon) vessels. The containers must be circulated continuously through the field for at least two minutes at full power. The vessels are removed from the microwave and the contents are stirred. After stirring, the temperature of the water is measured and recorded for use in the formula below.

2.1.6.2 Calibration Formula

2.1.6.2.1 Measure the initial temperature of the water, (T_i), to within 0.1°C. The starting temperature should be between 22 and 26°C. Irradiate 1 kg of water at full power, 100 percent (99, 98, 97, 95, 90, 80, 70, 60, or 50 percent power setting) for 120 seconds. The container must be circulated through the cavity at a rate of at least

one revolution every 30 seconds during the irradiation. Measure the final temperature of the water, after stirring, (T_f), to within 0.1°C, while stirring the water (an electronic stirrer using a large stir bar works best) within 30 seconds of the end of irradiation. Use the maximum reading. Repeat for a new sample, for a total of five replicates per microwave setting, of distilled room-temperature water using a new, clean container. Calculate the microwave power according to the formula:

$$Power = \frac{K \times C_p \times M \times T}{t} \qquad \text{Eq. D/IN-1}$$

$$34.87 = \frac{K \times C_p \times M}{t} \qquad \text{Eq. D/IN-2}$$

$$Power = 34.87 \times T \qquad \text{Eq. D/IN-3}$$

where:

Power = The apparent power absorbed by the sample in watts (W = joule-sec^{-2});
K = The conversion factor for thermochemical calories-sec^{-1} to W (equal to 4.184);
C_p = The heat capacity, thermal capacity, or specific heat (cal-g^{-1}-°C^{-1} = 1.0 for water);
M = The mass of the sample in grams;
T = $T_f - T_i$ in °C; and
t = Time in seconds.

2.1.6.2.2 Derive an equation for the linear portion of the calibration range and determine the equivalent value in watts of the arbitrary setting scale. Use the actual power in watts to determine the appropriate setting of the particular microwave unit being used. Each microwave unit will have its own setting that corresponds to the actual power delivered to the samples.

2.1.6.3 Cleaning Procedure for RFA Vessels

2.1.6.3.1 Prior to first use, new vessels must be annealed before they are used. A pretreatment/cleaning procedure must be followed. This procedure calls for heating the vessels for 96 hours to 200°C. The vessels must be disassembled during annealing and the sealing surfaces (the top of the vessel or the rim) must not be used to support the vessel during annealing.

2.1.6.3.2 Rinse with distilled water. Immerse in a cleaning bath of 1:1 HCl for a minimum of three hours after the bath temperature has reached a temperature just below boiling. Rinse with distilled water. Immerse in a cleaning bath of 1:1 HNO_3 for a minimum of three hours

after the bath temperature has reached a temperature just below boiling. The vessels are then rinsed with copious amounts of deionized, distilled water prior to use for any analyses under this contract. Between sample digestions, the PFA vessels should be detergent washed and 1:1 HNO_3 rinsed followed by a deionized, distilled water rinse.

2.1.6.4 Digestion Procedure for Microwave Extraction

2.1.6.4.1 Prepare extracting acid (2M HCl, 0.9M HNO_3) for use with ICP analysis. In a 1-L volumetric flask, combine in order and mix well 500 mL of deionized, distilled water, 55.5 mL of concentrated (16M) redistilled spectrographic-grade nitric acid, and 167.5 mL of ACS reagent-grade concentrated hydrochloric acid (12M). Cool and dilute to 1 L with deionized, distilled water.

NOTE: Nitric and hydrochloric acid fumes are toxic. Prepare in a well-ventilated fume hood. Mixing results in an exothermic reaction. Stir slowly.

2.1.6.4.2 Prepare nitric acid (3M HNO_3) for use with ICP-MS and GFAA analyses. In a 1-L volumetric flask combine in order and mix well, 500 mL of deionized distilled water and 192 mL of concentrated nitric acid. Slowly dilute to 1 L.

2.1.6.4.3 Cut a 1" x 8" strip from the folded particulate bearing filter using a template and a pizza cutter as described in the Federal Reference Method for Lead (see Figure D-1 and Reference 11). Using vinyl gloves or plastic forceps, accordion fold or tightly roll the filter strip and place it on its edge in a centrifuge tube.

NOTE: A breathing mask and vinyl gloves are required for safety of personnel handling dry glass-fiber filters. The breathing mask prevents the inhalation of minute glass shards and particulate material. The gloves protect the skin from the same materials and also prevent contamination of the sample by skin secretions.

NOTE: It is suggested that more than one strip from a filter be extracted to ensure adequate sample volume for sample and QC sample analysis.

2.1.6.4.4 Add 10.0 mL of extracting acid for ICP analysis or 10 mL of 3 M nitric acid for GFAA or ICP-MS analysis, using a preset calibrated automatic dispensing pipette or Class A regular pipette. (The acid should cover the strip completely). The sequence of adding the filter strip and acid to the centrifuge tube may be reversed, if more convenient, without affecting the results. Place the centrifuge tube in a Teflon PFA vessel containing 31 mL of deionized water.

2.1.6.4.5 The caps with the pressure release valves are placed on the vessels hand-tight, and then tightened using constant torque to 12 ft./lbs. Connect the sample vessel to the overflow vessel using the Teflon PFA connecting tube. Weigh the two vessel assembly to the nearest 0.01 g. Place the vessels in the microwave carousel. Connect the overflow vessels to the center well of the oven (see Figure D-2).

2.1.6.4.6 Place the 12 vessels on the turntable of the microwave unit. Any vessels containing 10 mL of acid solution for analytical blank purposes are counted as sample vessels. Irradiate the sample vessels at 486 W for 23 minutes. (Based on the calibration of the microwave as previously described).

2.1.6.4.7 At the end of the program, remove the turntable containing the microwave vessels and cool it in tap water for 10 minutes. Open the microwave vessels and discard the water that they contain.

2.1.6.4.8 Add 10 mL of deionized distilled water to the centrifuge tube, using the preset calibrated automatic dispensing pipette or using a Class A regular pipette. Cap the centrifuge tube tightly and mechanically shake for five minutes. Place the tube in the centrifuge and operate for 25 minutes at 2000 rpm. Decant the clear supernatant from the centrifuge tube into an weighed acid-cleaned 20-mL polypropylene bottle (bearing sample ID label), taking care not to disturb the solids in the bottom of the tube and weigh the bottle and contents. The matrix is 0.45M nitric acid, 1.03M hydrochloric acid for ICP analysis or 1.5M nitric acid, for ICP-MS and GFAA analyses and deionized, distilled water. The sample is now ready for analysis.

2.2 ALTERNATE SAMPLE PREPARATION FOR ICP-MS AND GFAA ANALYSIS

2.2.1 Introduction

2.2.1.1 This method describes a hot extraction procedure to extract the metals from the particulate loaded glass-fiber filter, for subsequent analysis by inductively coupled plasma-mass spectrometry (ICP-MS) and graphite furnace atomic absorption (GFAA) spectrometry.

2.2.2 Summary of Method

2.2.2.1 The metals are extracted by hot nitric acid from the filter. After cooling to room temperature, the extract is allowed to settle.

2.2.3 Apparatus and Materials

2.2.3.1 Volumetric glassware: 30- to 150-mL capacity (Class A Borosilicate).

2.2.3.2 Hot plate.

2.2.3.3 Centrifuge: Capable of maintaining speeds of 2000 rpm (International Equipment Company Model UV or equivalent).

2.2.3.4 Centrifuge tubes: Polypropylene tubes and screw tops, 100-mL.

2.2.3.5 Pipette: Automatic dispensing with an accuracy of 0.1 mL or better and repeatability of 20 μL, (Grumman Automatic Dispensing Pipet, Model ADP-30 DT or equivalent).

2.2.3.6 Particle mask: To be worn while cutting and handling glass-fiber filters.

2.2.3.7 Template: To aid in sectioning the glass-fiber filter. Federal Register 1978, 43 (Oct. 5), 46258-46261. See Figure D-1.

2.2.3.8 Pizza cutter: Thin wheel (< 1 mm).

2.2.4 **Reagents**

2.2.4.1 Nitric Acid (HNO_3): Concentrated, 16M, redistilled spectrographic grade.

2.2.4.1.1 Nitric Acid, 3M: Prepare by adding 192 mL of concentrated nitric acid (2.2.4.1) to distilled, deionized water and slowly diluting to 1 L.

NOTE: Nitric acid fumes are toxic. Prepare in a well-ventilated fume hood. Stir slowly.

2.2.4.2 ASTM Type II Water (ASTM D1193): Water must be monitored.

2.2.5 **Sample Preservation and Handling**

2.2.5.1 Exposed Hi-Vol filters should be folded in half with particulate material inward, enclosed in protective envelopes, and stored at 15 to 30°C until analysis.

2.2.6 **Hot Extraction Procedure**

2.2.6.1 Cut a 1" x 8" strip as described in the Federal Reference Method for Lead (see Figure D-1).

2.2.6.2 Fold the strip in half twice, and place in a 150-mL beaker. Add 15 mL of 3M HNO_3 to completely cover the sample. Cover the beaker with a watch glass. It is important to keep the sample covered so that corrosion products (formed on fume hood surface which may contain target analytes) are not deposited in the extract.

NOTE: It is suggested that more than one strip per filter be extracted to ensure adequate volume for sample and QC analysis.

2.2.6.3 Gently boil the sample in a beaker on a hot plate under a fume hood for 30 minutes. Do not let the sample evaporate to dryness.

NOTE: Nitric acid fumes are toxic.

2.2.6.4 After 30 minutes, remove the beaker from the hot plate, and cool to near room temperature. Rinse watch glass and sides of beaker with distilled, deionized water.

2.2.6.5 Decant extract and rinsings into a 100-mL volumetric flask. Add distilled, deionized water to the 40-mL mark on beaker, cover with watch glass and set aside for a minimum of 30 minutes. This is a critical step and cannot be omitted since it allows the HNO_3 trapped in the filter to diffuse into the rinse water.

2.2.6.6 Decant the water from the filter into the volumetric flask, rinse filter and beaker twice with distilled, deionized water, and add the rinse to the volumetric flask until the total volume is 80 to 85 mL.

2.2.6.7 Stopper flask and shake vigorously, and set aside for approximately five minutes or until foam has dissipated.

2.2.6.8 Bring solution to volume with distilled, deionized water, and mix thoroughly. Allow solution to settle for one hour before proceeding with analysis.

NOTE: Do not filter the extracted sample to remove particulate matter because of possible loss of target analytes due to filtration. The final extract can be centrifuged at 2000 RPM for 30 minutes to remove any suspended solids.

2.2.6.9 If sample is to be stored for subsequent analysis, transfer to a polyethylene bottle, being careful not to disturb the settled solids.

2.2.6.10 Samples prepared by hot extraction procedure are now in 0.45M HNO_3.

2.2.6.11 Blank filter samples should be extracted and analyzed, and digestion blanks should be run to ensure low levels of metals in the reagents used.

SECTION 3

SAMPLE ANALYSIS BY INDUCTIVELY COUPLED PLASMA (ICP) ATOMIC EMISSION SPECTROMETRY

3.1 INTRODUCTION

3.1.1 Metals for which this method is applicable are listed in Table 1, Exhibit C, and are determined by ICP after sample preparation by microwave digestion. Appropriate steps must be taken to correct for potential interference effects.

3.1.2 Table D-1 lists analytes along with recommended wavelengths and typical estimated instrumental detection limits using conventional pneumatic nebulization. Actual working detection limits are sample dependent and as the sample matrix varies, these concentrations may also vary. In time, other analytes may be added as more information becomes available.

3.1.3 Because of the differences among various makes and models of satisfactory instruments, no detailed instrumental operating instructions can be provided. Instead, the analyst is referred to the instructions provided by the manufacturer of the particular instrument.

3.2 SUMMARY OF METHOD

3.2.1 The analyte concentrations are determined by ICP atomic emission spectroscopic analysis. The acid extracts are pumped into a pneumatic nebulizer. The aerosol formed is transported into an inductively coupled plasma and the metals are excited into higher electronic states. Atomic and ionic line emission spectra characteristic of the particular metals are produced when the electrons decay back to the lower energy levels. The spectra are dispersed by a spectrometer and the intensity of specific line radiation(s) are monitored simultaneously or sequentially by a photomultiplier tube(s). The photocurrent produced by the photomultiplier tube will increase in direct proportion to the concentration of the element in the sample within the linear range of a specific emission line. The photocurrent is processed by a computer system and related to concentration through a calibration procedure.

3.2.2 Calibration is performed by standardizing the instrument with a series of mixed element standards and a blank that are matrix matched to the acid extract solution. Every solution analyzed, such as a dilution, calibration stability standard, or reference sample must be matrix matched to the sample extract.

3.2.3 Appropriate steps must be taken to ensure that potential interferences are corrected. This is especially important for spectral

interferences. Recommendations for correcting for interferences are briefly summarized below under headings that categorize the type of interference that is being considered.

3.2.3.1 **Recommended Corrections for Physical Interferences**

- The use of peristaltic pump to introduce the acid extract into the nebulizer.
- Frequent (20 percent or better) analysis of the calibration stability standard.
- Adequate rinsing (one minute or more) between sample analyses using ten percent HNO_3 or ten percent HCl, and optional use of humidified argon or a nebulizer tip washer as necessary.

3.2.3.2 **Recommended Corrections for Chemical Interferences**

- Matrix matching between samples and all standards and sample diluting the sample during analysis.

3.2.3.3 **Recommended Corrections for Spectral Interferences**

- Use of calculated interelement corrections in the form of factors or first or second order equations that describe the interference function (on-peak correction).
- Optional use of measurement of background shift on either side or both sides of the analyte line (off-peak correction).
- Optionally, wavelength scans (for each of the analyte element wavelengths) for each of the samples simultaneously plotted with a calibration blank scan and a calibration standard scan may be performed.

3.2.4 Every solution, including calibration standards, calibration and method blanks, and reference samples, must be analyzed using two full exposures (peak scan), each of which is sufficient to meet the method quantitation limit (MQL) for each analyte emission line. All exposure times must be the same for all analyses and all quarterly analyses (i.e., MQL and interelement correction factor.)

3.2.5 Both the off-peak (background) and on-peak (interelement correction coefficients or equations) interference corrections made for all analytes must be calculated and reported with the analysis results.

3.2.6 If the sum of the values of the interference correction(s) made on any analyte is greater than the resulting analyte concentration, the reported value is to be flagged with an "I" on FORM I-AAIN.

3.2.7 If the analyte requiring dilution interferes with another analyte, the interference correction(s) must reflect the actual concentration of the interferent in the undiluted samples.

3.2.8 The specific spectral lines that are employed must be reported.

3.2.9 All reported analyte data must have been obtained within the linear range of the respective analyte emission line. If any analyte concentration results in the linear range of the spectral line being exceeded, the sample must be diluted such that the resulting solution concentration falls within the linear range, but not below the CRQL.

3.3 SAFETY

3.3.1 The toxicity or carcinogenicity of each reagent used in this method has not been precisely defined; however, each chemical compound should be treated as a potential health hazard. The laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of material handling data sheets shall be available to all personnel involved in the chemical analysis.

3.4 INTERFERENCES

3.4.1 ICP emission spectroscopy is prone to interelement effects, which in practice are experienced in two main forms. Interferences that cause a translation of the analytical curve are caused by spectral line overlap or increase in background due to an electron/metal ion recombination continuum and/or scattered light within the spectrometer. For a given matrix and spectral line, a constant additive interference is produced that is independent of the analyte concentration. Rotational interference of the analytical curve, experienced essentially as a change in sensitivity, is due to the combined effects of variations in nebulizer performance produced by the physical properties of the sample solution and changes in the excitation conditions in the plasma caused by the matrix metals. Both forms of interference can operate simultaneously for a particular sample matrix.

3.4.2 Spectral interference from poorly resolved metal spectral lines, such as scattered light, or broad continuum spectral background, will lead to systematic error in the analytical results unless proper corrections are made. Molecular band emission will lead to a deterioration of the quantitation limit and will increase the difficulty of off-peak background correction. Methods of correcting translational interference (other than exact matrix matching of the standards to the sample) include the on-peak correction technique. This method can be applied to both spectral line overlap and background enhancement, but it requires specific knowledge of the metals causing the interference. On-peak correction can only be performed on a quantitative basis if the interfering metals are included

in the multi-metal analysis, although uncertainties may still exist in whether the correction coefficients employed match those required for the particular sample matrix.

3.4.3 Rotational calibration curve interference manifests itself for a given matrix and spectral line as a change in the slope of the analyte calibration. This type of interference includes: sample nebulization and transport effects, often called physical interference including lateral diffusion interferences; and chemical interferences such as solute vaporization interference and ionization interferences. Such interferences can be reduced by matrix matching of the standards and samples and by the method of standard additions, (although standard additions can become quite lengthy and impracticable for multi-metal analyses) and by the use of internal standards. Matrix matching can correct for any of these interferences but the correction is dependent on the accuracy of the matching. Variations in the matrix from sample to sample will cause corresponding inaccuracies in the analyte results.

3.4.4 Listed in Table D-2 are some interference effects for the recommended wavelengths given in Table D-1. The data in Table D-2 are intended for use only as a rudimentary guide for the indication of potential spectral interferences. For this purpose, linear relations between concentration and intensity for the analytes and the interferents can be assumed. The interference information, which was collected at the Ames Laboratory (USOOE, Iowa State University, Ames, Iowa 50011), is expressed as analyte concentration equivalents (i.e., false analyte concentrations) arising from 100 mg/L of the interferent element.

3.5 **APPARATUS AND EQUIPMENT**

3.5.1 Computer-controlled inductively coupled plasma atomic emission spectrometer system with:

- Polychromator with associated dispersion and detector system such that the metals can be determined simultaneously, or a sequential scanning instrument that allows achievement of the quality control requirements for this method;
- Radio frequency generator and coupling system;
- Pneumatic nebulizer; and
- Software capable of performing both off-peak (background correction) and on-peak (coefficients of first or second order regression equations describing expected interference) spectral interference corrections. In addition, the software must be capable of creating a hardcopy output of both types of corrections in either concentration units or analyte raw intensity data along with net calculated concentrations.

3.5.2 Argon gas supply: Welding grade or better.

3.5.3 Assorted laboratory volumetric glassware, pipets and micropipets.

3.5.4 Operating conditions: Because of the differences among various makes and models of satisfactory instruments, no detailed operating instructions can be provided. Instead, the analyst should follow the instructions provided by the manufacturer of the particular instrument. Sensitivity, instrumental detection limit, precision, linear dynamic range, and interference effects must be investigated and established for each individual analyte line on that particular instrument. All measurements must be within the instrument linear range where correction factors are valid. It is the responsibility of the analyst to verify that the instrument configuration and operating conditions used satisfy analytical requirements and to maintain quality control data confirming instrument performance and analytical results.

3.6 REAGENTS AND STANDARDS

3.6.1 In the determination of trace elements, containers can introduce either positive or negative errors in the measurement of trace elements by contributing contaminants through leaching or surface desorption and depleting concentrations through adsorption. Thus the collection and treatment of the samples prior to analysis require particular attention. The following cleaning treatment sequence has been determined to be adequate to minimize contamination in the sample bottles, whether borosilicate glass, linear polyethylene, or Teflon is used: detergent, ASTM Type II water, 1:1 hydrochloric acid, ASTM Type I water, 1:1 nitric acid, and ASTM Type I water.

NOTE: Chromic acid shall not be used because chromium is one of the contract required analytes, and its use may lead to cross contamination.

NOTE: Acids used in the preparation of standards and for sample processing must be below the CRQLs for the analytes of interest for the purpose of this document.

3.6.2 Nitric acid and hydrochloric acid used in the preparation of standards and for sample processing must be of high purity.

3.6.3 Water equivalent to ASTM Type II is used throughout.

3.6.4 Stock standard solutions: Standards must be from ultrapure materials. The stock standard solutions may be the same as the spiking standard solutions, if desired.

3.6.5 Spiking standard solutions: Standards must be made from ultrapure materials. Both multi-metal and single metal solutions will be needed. Because of the limited sample volume (100 mL), multi-metal solutions will be needed to maintain the sample matrix at 95 percent original strength after the addition of the spike volume.

3.6.6 No more than five multi-metal stock standards will be required containing metals in the following concentrations:

Metal	Conc. mg/L
Na, Al, Ca, As, Se	1000
Ba, Co, Mn, Ni, Pb, Ag, Tl, V, K	500
Be, Cd, Cu, Cr, Zn, Sb, Sn, Mo, Fe, Mg	100

3.6.6.1 Using the appropriate metal salts and solution matrices, the following standards have been found to be stable for one year.

Metals Mixes	Matrix
Al, Ba, Be, Fe, Ni, Ag, Na, Tl	20 percent conc. HCl
Ca, Cd, Co, Cu, Pb, Mg, Mn, Zn	10 percent conc. HNO_3
Cr	Water
V	2 percent conc. HNO_3

3.6.7 A single metal stock standard at 1000 mg/L will be needed for each metal.

3.6.8 Calibration standards: Prepare calibration standards by dilution of stock or spiking standard solutions. All calibration standards must be matrix matched with the extracting acid solution according to the preparation procedure used in the analysis. Concentrated hydrochloric acid can be used instead of HNO_3 if required for stabilization of a metal(s).

3.6.9 Calibration blank: Prepare calibration blanks such that the resulting solution is matrix matched with the extracting acid solution according to the preparation procedure used in the analysis.

3.6.10 Initial calibration verification: The initial calibration verification solution shall be from a different source than that used for the calibration standards and shall be approximately in the middle of the respective calibration curve. This verification standard must be in the same acid matrix as the calibration standards.

3.6.11 ICP interference check sample: Prepare by dilution of the stock standards if it is not available from the EPA. If the solution is prepared by the analyst, it shall be made using the concentrations in Table 3, Exhibit C. It shall be run at least five times and the mean standard deviation shall be reported in the raw data.

NOTE: The interference check solution(s) (ICS) is prepared to contain known concentrations of interfering elements that will demonstrate the magnitude of interferences and provide an adequate test of any corrections. The ICS is used to verify that the interference levels are corrected by the data system within quality control limits.

3.7 QUALITY CONTROL

3.7.1 Instrument Calibration

3.7.1.1 Summary

Prior to the analysis of samples and required QC, each ICP system shall be initially calibrated to determine instrument sensitivity.

3.7.1.2 Frequency

Instruments shall be calibrated daily or once every 24 hours and each time the instrument is set up.

3.7.1.3 Procedure

Calibration standards shall be prepared using the same type of matrix and at the same concentration as the preparation blank following sample preparation.

Calibrate according to instrument manufacturer's recommended procedures using at least two standards, one being a blank.

Before beginning the sample run, reanalyze the highest mixed calibration standard as if it were a sample.

3.7.1.4 Calculations

$$\% \ Recovery = \frac{Found \ Concentration}{True \ Concentration} \times 100 \qquad \text{Eq. D-4}$$

3.7.1.5 Technical Acceptance Criteria

Recovery for the highest mixed calibration standard shall be within ± five percent of the true value (i.e., 95-105 percent).

3.7.1.6 Corrective Action

Follow instrument manufacturer's recommendations to correct the problem. Also, baseline correction is acceptable as long as it is performed after every sample or after the continuing calibration verification and blank check; resloping is acceptable as long as it is immediately preceded and immediately followed by a CCV and a CCB.

3.7.1.7 Documentation

The instrument standardized data and time shall be included in the raw data. The final concentration should be in μg/L.

3.7.2 Initial Calibration Verification

3.7.2.1 Summary

Immediately after the ICP system has been calibrated, the accuracy of the initial calibration shall be verified and documented for every analyte by the analysis of EPA Initial Calibration Verification Solution(s) (ICV) at each wavelength used for analysis.

3.7.2.2 Frequency

Each time the instrument is calibrated, the ICV shall be run immediately following the calibration, before any samples are analyzed.

3.7.2.3 Procedure

If the ICV solution(s) are not available from EPA, or where a certified solution of an analyte is not available from any source, analyses shall be conducted on an independent standard at a concentration other than that used for instrument calibration, but within the linear range. An independent standard is defined as a standard composed of the analytes from a different source than those used in the standards for the instrument calibration.

3.7.2.4 Calculations

$$\%\ Recovery = \frac{Found\ Concentration}{True\ Concentration} \times 100 \qquad \text{Eq. D-5}$$

3.7.2.5 Technical Acceptance Criteria

Recovery for the ICV shall be within ± 10 percent of the true value (i.e., 90-110 percent).

3.7.2.6 Corrective Action

When recoveries of the ICV exceed the technical acceptance criteria, the analysis shall be terminated, the problem corrected, the instrument recalibrated, and the calibration reverified.

3.7.2.7 Documentation

Report the ICV found concentration (µg/L), true concentration (µg/L), and percent recovery on FORM II-AAIN.

3.7.3 Continuing Calibration Verification

3.7.3.1 Summary

To ensure calibration accuracy during an analysis run, a continuing calibration verification solution (CCV) is analyzed and reported for every wavelength used for the analysis of each analyte.

3.7.3.2 Frequency

The CCV is run at a frequency of 10 percent or every two hours during an analysis run, whichever is more frequent.

The CCV is also run after the last analytical sample in the analysis run.

3.7.3.3 Procedure

The same CCV shall be used throughout the analysis runs for a Case of samples received. The analyte concentrations in the continuing calibration standard shall be an EPA solution or a Contractor prepared standard solution and should be at or near ± 10 percent of the mid-range levels of the calibration curve.

Each CCV analyzed shall reflect the conditions of analysis for all of the associated analytical samples (the preceding 10 analytical samples or the preceding analytical samples up to the previous CCV). The duration of analysis, rinses and other related operations that may affect the CCV measured result shall not be applied to the CCV to a greater extent than the extent applied to the associated analytical samples. For instance, the difference in time between a CCV analysis and the blank immediately following it as well as the difference in time between the CCV and the analytical sample immediately preceding it shall not exceed the smallest difference in time between any two consecutive analytical samples associated with the CCV.

3.7.3.4 Calculations

$$\%\ Recovery = \frac{Found\ Concentration}{True\ Concentration} \times 100 \qquad \text{Eq. D-6}$$

3.7.3.5 Technical Acceptance Criteria

Recovery for the CCV shall be within ± 10 percent of the true value (i.e., 90-110 percent).

3.7.3.6 Corrective Action

When recoveries of the CCV exceed the technical acceptance criteria, the analysis shall be stopped, the problem corrected, the instrument recalibrated, the calibration reverified, and the preceding 10 analytical samples reanalyzed (or all analytical samples since the last compliant CCV).

3.7.3.7 Documentation

Report the CCV found concentration (µg/L), true concentration (µg/L), and percent recovery on FORM II-AAIN.

3.7.4 CRQL Standard

3.7.4.1 Summary

To verify linearity near the CRQL, the Contractor shall analyze an ICP standard at two times the MQL or two times CRQL, whichever is greater. This standard shall be run for every wavelength used for analysis.

3.7.4.2 Frequency

The CRQL standard shall be run at the beginning and end of each sample analysis run, or a minimum of twice per eight hours, whichever is more frequent.

3.7.4.3 Procedure

The CRQL standard shall not be run before the ICV solution.

3.7.4.4 Calculations

$$\%\ Recovery = \frac{Found\ Concentration}{True\ Concentration} \times 100 \qquad \text{Eq. D-7}$$

3.7.4.5 Technical Acceptance Criteria

Recovery of the CRQL standard shall be within ± 15 percent of the true value for each wavelength used for analysis.

3.7.4.6 Corrective Action

If the CRQL standard does not fall within the control limit, the analysis shall be terminated, the problem corrected and the analytical samples since the last compliant CRQL standard reanalyzed.

3.7.4.7 Documentation

Report the CRQL standard found concentration (µg/L), true concentration (µg/L), and percent recovery on FORM III-AAIN.

3.7.5 **Linear Range Analysis (Quarterly)**

3.7.5.1 Summary

The concentration range over which the ICP calibration curve remains linear must be determined and any values above this linear range shall be diluted and reanalyzed.

3.7.5.2 Frequency

For all ICP analyses, a linear range verification check standard shall be analyzed and reported quarterly (every 3 calendar months) for each element on the target analyte list (Table 1, Exhibit C). The standard shall be analyzed during a routine analytical run performed under this contract. This standard shall be run for all wavelengths used for each analyte reported by ICP.

3.7.5.3 Procedure

The standard shall be analyzed as though it were a separate analytical sample (i.e., each measurement shall be followed by a rinse and/or any other procedure normally performed between the analysis of separate samples).

3.7.5.4 Calculations

$$\% \ Recovery = \frac{Found\ Concentration}{True\ Concentration} \times 100 \qquad \text{Eq. D-8}$$

3.7.5.5 Technical Acceptance Criteria

Recovery for the linear range standard shall be within ± 5 percent of the true value (i.e., 95-105 percent).

3.7.5.6 Corrective Action

If the recovery of the linear range standard does not meet the technical acceptance criteria, then the analysis shall be terminated and successive dilutions of the standard shall be reanalyzed until the control limits are met. The concentration of this standard that meets the control limits is the upper limit of the instrument linear range beyond which results cannot be reported under this contract without dilution of the analytical sample.

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3.7.5.7 Documentation

Report the linear range standard found concentration (in µg/L), true concentration (in µg/L) and percent recovery for each analyte on FORM III-AAIN.

3.7.6 Initial Calibration Blank

3.7.6.1 Summary

To verify that the ICP system is not contaminated, an initial calibration blank (ICB) shall be analyzed after calibration.

3.7.6.2 Frequency

The ICB shall be analyzed each time the system is calibrated and immediately after the ICV.

3.7.6.3 Procedure

If the absolute value of the ICB is greater than the MQL, the result shall be reported.

3.7.6.4 Calculations

Not applicable.

3.7.6.5 Technical Acceptance Criteria

The absolute value of the ICB must be less than the CRQL.

3.7.6.6 Corrective Action

When the ICB concentration does not meet the technical acceptance criteria, terminate analysis, correct the problem, recalibrate, verify the calibration, and reanalyze the ICB.

3.7.6.7 Documentation

Report the ICB values in µg/L on FORM IV-AAIN.

3.7.7 Continuing Calibration Blanks

3.7.7.1 Summary

To ensure that the system is not contaminated during the analysis run, continuing calibration blanks (CCB) are analyzed.

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3.7.7.2 Frequency

Analyze the CCB at a frequency of 10 percent or every two hours, whichever is more frequent.

Analyze the CCB after every CCV.

3.7.7.3 Procedure

A CCB shall be run after the last CCV in the analysis run. If the absolute value of the CCB is greater than the MQL, the result shall be reported.

3.7.7.4 Calculations

Not applicable.

3.7.7.5 Technical Acceptance Criteria

The absolute value of the CCB must be less than the CRQL.

3.7.7.6 Corrective Action

When the CCB concentration does not meet the technical acceptance criteria, terminate analysis, correct the problem, recalibrate, verify the calibration, and reanalyze the preceding 10 analytical samples (or all analytical samples since the last compliant CCB).

3.7.7.7 Documentation

Report the CCB values in µg/L on FORM IV-AAIN.

3.7.8 Preparation Blanks

3.7.8.1 Summary

To ensure against contamination during sample preparation, a preparation blank (PB) is analyzed.

3.7.8.2 Frequency

At least one PB must be prepared and analyzed with every SDG or with each batch of samples digested, whichever is more frequent.

3.7.8.3 Procedure

The PB shall consist of ASTM Type II water processed through each sample preparation and analysis procedure step.

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The first batch of samples in a SDG shall be assigned to PB one, the second batch of samples to PB two, etc.

3.7.8.4 Calculations

Not applicable.

3.7.8.5 Technical Acceptance Criteria

The absolute value of the PB must be less than the CRQL.

3.7.8.6 Corrective Action

If the absolute value of the concentration of the PB is less than or equal to the CRQL, no corrective action is required.

If any analyte concentration in the PB is above the CRQL, the lowest concentration of the analyte in the associated samples must be 10 times the PB concentration. Otherwise, all samples associated with the PB and with the analyte's concentration less than 10 times the PB concentration and above the CRQL shall be redigested and reanalyzed for that analyte. The sample concentration is not to be corrected for the PB value.

If an analyte concentration in the PB is below the negative CRQL, then all samples reported below 10 times CRQL associated with the PB shall be redigested and reanalyzed.

3.7.8.7 Documentation

The values for the PB shall be recorded in µg/L on FORM IV-AAIN.

3.7.9 ICP Interference Check Sample

3.7.9.1 Summary

To verify interelement and background correction factors, an ICP Interference Check Sample (ICS) is analyzed.

3.7.9.2 Frequency

Analyze the ICS at the beginning and end of each analysis run or a minimum of twice per eight hour working shift, whichever is more frequent, but not before the ICV.

3.7.9.3 Procedure

The ICS consists of two solutions: Solution A and Solution AB. Solution A consists of the interferents, and Solution AB consists of

the analytes mixed with the interferents. An ICS analysis consists of analyzing both solutions consecutively (starting with Solution A) for all wavelengths used for each analyte reported by ICP.

The ICP ICS shall be obtained from EPA (EMSL/LV) if available and analyzed according to the instructions supplied with the ICS.

If the ICP ICS is not available from EPA, an independent ICP ICS shall be prepared with interferent and analyte concentrations at the levels specified in Table 3, Exhibit C. The mean value and standard deviation shall be established by initially analyzing the ICS at least five times repetitively for each analyte.

If true values for analytes contained in the ICS and analyzed by ICP are not supplied with the ICS, the mean shall be determined by initially analyzing the ICS at least five times repetitively for the particular analytes. This mean determination shall be made during an analytical run where the results for the previously supplied EPA ICS met all contract specifications. Additionally, the result of this initial mean determination is to be used as the true value for the lifetime of that solution (i.e., until the solution is exhausted).

3.7.9.4 Calculations

$$\% \ Recovery = \frac{Found \ Concentration}{True \ Concentration} \times 100 \qquad \text{Eq. D-9}$$

3.7.9.5 Technical Acceptance Criteria

Recovery for the ICS shall be within ± 20 percent of the true value (i.e., 80-120 percent).

3.7.9.6 Corrective Action

If the ICS recoveries does not meet the technical acceptance criteria, terminate the analysis, correct the problem, recalibrate the instrument, verify the calibration, and reanalyze all of the analytical samples since the last compliant ICS was analyzed.

3.7.9.7 Documentation

Report the ICS found concentration (µg/L), true concentration (µg/L), percent recovery, mean and standard deviation on FORM V-AAIN.

The mean and standard deviation shall be reported in the raw data.

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3.7.10 Spike Sample Analysis

3.7.10.1 Summary

To provide information about the effect of the sample matrix on the digestion, a known amount of analyte is added (spiked) into a sample.

3.7.10.2 Frequency

At least one spike sample analysis shall be performed on each group of samples for each SDG. EPA may require additional spike sample analysis upon special request by the Project Officer, for which the Contractor will be paid.

If two analytical methods are used to obtain the reported values for the same analyte within a SDG (e.g., ICP and GFAA), then spike samples shall be run by each method used.

3.7.10.3 Procedure

The spike is added before the sample preparation (i.e., prior to digestion) at concentration levels in the Spike Sample solution as indicated in Table D-3.

Samples identified as field blanks cannot be used for spiked sample analysis. EPA may require that a specific sample be used for the spike sample analysis. In the instance where there is more than one spike sample per SDG and one spike sample recovery is not within contract criteria, flag all the samples of the same matrix, level, and method in the SDG.

3.7.10.4 Calculations

$$\%\ Recovery = \frac{SSR - SR}{SA} \times 100 \qquad \text{Eq. D-10}$$

where:

SSR = Spiked Sample Result;
SR = Sample Result; and
SA = Spike Added.

If the spike analysis is performed on the same sample that is chosen for the duplicate sample analysis, spike calculations shall be performed using the results of the sample designated as the "original sample" (see part 3.7.11, Duplicate Sample Analysis). The average of the duplicate results cannot be used for the purpose of determining percent recovery.

When the sample concentration is less than the instrument detection limit, use SR = 0 only for purposes of calculating percent recovery.

3.7.10.5 Technical Acceptance Criteria

Recovery for the spike should be within ± 25 percent of the spiked amount (i.e., 75-125 percent).

3.7.10.6 Corrective Action

If the spike recovery is not within the limits of 75-125 percent, the data of all samples received associated with that spike sample and determined by the same analytical method shall be flagged with the letter "N" on FORMs I-AAIN and VI-AAIN.

An exception to this rule is granted in situations where the sample concentration exceeds the spike concentration by a factor of four or more. In such an event, the data shall be reported unflagged even if the percent recovery does not meet the 75-125 percent recovery criteria.

3.7.10.7 Documentation

Report the spiked sample results, sample results, spike added and percent recovery for the spike sample analysis on FORM VI-AAIN.

The units for reporting spike sample results will be in µg/L.

3.7.11 Duplicate Sample Analysis

3.7.11.1 Summary

Duplicate aliquots of a sample are carried through the preparation and analysis steps to provide information about the precision of the analytical methods as well as matrix effects.

3.7.11.2 Frequency

At least one duplicate sample analysis shall be performed on each group of samples for each SDG. EPA may require additional duplicate sample analysis upon special request by the Project Officer, for which the Contractor will be paid.

If two analytical methods are used to obtain the reported values for the same analyte within a SDG (e.g., ICP and GFAA), then duplicate samples shall be run by each method used.

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3.7.11.3 Procedure

Samples identified as field blanks cannot be used for duplicate sample analysis.

EPA may require that a specific sample be used for the duplicate sample analysis.

In the instance where there is more than one duplicate sample per SDG and one duplicate result is not within contract criteria, flag all the samples of the SDG.

Duplicate sample analyses are required for calculations of relative percent difference.

3.7.11.4 Calculations

$$RPD = \frac{|S - D|}{\frac{S + D}{2}} \times 100 \qquad \text{Eq. D-11}$$

where:

RPD = Relative Percent Difference;
S = First Sample Value (original); and
D = Second Sample Value (duplicate).

Duplicates cannot be averaged for reporting on FORM I-AAIN.

3.7.11.5 Technical Acceptance Criteria

A control limit of ± 20 percent for RPD shall be used for original and duplicate sample values greater than or equal to five times CRQL (Exhibit C). A control limit of ± CRQL shall be used for sample values less than five times CRQL.

If one result is above the five times CRQL level and the other is below, use the ± CRQL criteria.

If both sample values are less than the MQL, the RPD is not calculated.

Specific control limits for each analyte will be added to FORM IX-AAIN at a later date, based on precision results.

3.7.11.6 Corrective Action

If the duplicate sample results are outside the control limits, flag with an asterisk all the data for samples received associated with that duplicate sample.

3.7.11.7 Documentation

The results in µg/L of the duplicate sample analyses shall be reported on FORM VIII-AAIN.

The absolute value of the control limit (CRQL) shall be entered in the "CONTROL LIMIT" column on FORM VIII-AAIN.

3.7.12 Laboratory Control Samples

3.7.12.1 Summary

A laboratory control sample (LCS) is digested and analyzed to ensure against analyte loss in the sample preparation.

3.7.12.2 Frequency

One LCS shall be prepared and analyzed for every group of samples in a SDG, or for each batch of samples, whichever is more frequent.

3.7.12.3 Procedure

A LCS shall be analyzed for each analyte using the same sample preparations, analytical methods and QA/QC procedures employed for the EPA samples received.

The LCS solution shall be obtained from EPA. (If unavailable, other EPA Quality Assurance Check samples or other certified materials may be used.)

3.7.12.4 Calculations

$$\% \ Recovery = \frac{Found \ Concentration}{True \ Concentration} \times 100 \qquad \text{Eq. D-12}$$

3.7.12.5 Technical Acceptance Criteria

Recovery for the LCS shall be within ± 20 percent of the true value (i.e., 80-120 percent), with the exception of Ag and Sb.

3.7.12.6 Corrective Action

If the percent recovery for the LCS falls outside the technical acceptance criteria, then the analyses shall be terminated, the problem corrected, and the samples associated with that LCS reprepared and reanalyzed.

3.7.12.7 Documentation

Report the LCS found concentration (µg/L), true concentration (in µg/L), and percent recovery on FORM IX-AAIN.

3.7.13 Performance Evaluation Sample (PES)

3.7.13.1 Summary

The performance evaluation sample (PES) assists the Agency in monitoring the laboratory performance for analyte identification and quantification.

3.7.13.2 Frequency

One PES shall be delivered, prepared, and analyzed for every group of samples in a SDG, or for each batch of samples, whichever is more frequent.

3.7.13.3 Procedure

A PES shall be analyzed for each analyte using the same sample preparations, analytical methods and QA/QC procedures employed for the EPA samples received.

The PES solution shall be obtained from EPA. (If unavailable, the contractor must contact the Agency and SMO for instructions.)

3.7.13.4 Calculations

Not applicable.

3.7.13.5 Technical Acceptance Criteria

Recovery for the PES shall be within 75 percent of the true value of analyte.

3.7.13.6 Corrective Action

If the percent recovery for the PES falls below 75 percent, the Agency may take, but is not limited to the following actions:

- Show Cause and/or Cure Notice for unacceptable performance;
- Reduction of the number of samples shipped to the laboratory;
- Suspension of sample shipment;

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- A site visit;
- A full data audit; or
- Require the laboratory to analyze remedial PES.

In addition to the above cited actions, the laboratory shall also provide the Technical and Administrative Project Officers a written correction action report on every unacceptable (less than 75 percent) PES score within seven days of written or verbal request by Agency personnel.

3.7.13.7 Documentation

Report the PES on Form I-AAIN (in µg/L) for all analytes.

3.7.14 Method Quantitation Limits

3.7.14.1 Summary

Prior to sample analysis, the method quantitation limit (MQL) shall be determined for each instrument that will be used.

3.7.14.2 Frequency

MQLs shall be determined within 30 days of the start of the contract and at least quarterly (every three calendar months) until the end of the contract.

3.7.14.3 Procedure

MQLs (in µg/L) shall be determined by multiplying by three, the average of the standard deviations (σ_{n-1}) obtained on three nonconsecutive days from the consecutive analysis of seven different PB extracts. Each measurement must be performed as though it were a separate analytical sample (i.e., each measurement must be followed by a rinse and/or any other procedure normally performed between the analysis of separate samples). MQLs shall be determined and reported for each wavelength used in the analysis of the samples.

The quarterly determined MQL for an instrument shall always be used as the MQL for that instrument during that quarter. If the instrument is adjusted in anyway that may affect the MQL, the MQL for that instrument shall be redetermined and the results submitted for use as the established MQL for that instrument for the remainder of the quarter.

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3.7.14.4 Calculations

$$MQL = 3 \times (\sigma_{n-1}) \qquad \text{Eq. D-13}$$

3.7.14.5 Technical Acceptance Criteria

The MQLs shall be ≤ the CRQLs in Exhibit C.

3.7.14.6 Corrective Action

If an instrument's MQL exceeds the CRQL for an analyte, that instrument cannot be used in this document unless the analyte concentration is greater than or equal to five times the reported MQL.

3.7.14.7 Documentation

MQLs shall be submitted with each data package and reported on FORM XI-AAIN for each instrument used. If multiple instruments are used for the analysis of an analyte within an SDG, the highest MQL for the analyte shall be used for reporting concentration values for that SDG.

3.7.15 ICP Serial Dilution

3.7.15.1 Summary

The serial dilution shall be performed to check for the presence of matrix interference.

3.7.15.2 Frequency

One serial dilution shall be performed for each SDG.

3.7.15.3 Procedure

The serial dilution shall be performed by diluting a prepared sample aliquot five fold (1:4). The dilution must be performed on an analyte by analyte bases. The serial dilution is the dilution of the sample, or an aliquot of the sample, that contains a concentration level of the analyte within the linear range.

3.7.15.4 Calculations

$$\%D = \frac{|I - S|}{I} \times 100 \qquad \text{Eq. D-14}$$

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where:

I = Initial Sample Result; and
S = Serial Dilution Result.

3.7.15.5 Technical Acceptance Criteria

If the original sample concentration is greater than 50 times the MQL, the %D should be within ± 10 percent of the initial sample result.

3.7.15.6 Corrective Action

If the serial dilution results are outside the control limits, flag all the data for the affected analytes in the samples received associated with that serial dilution with an "E" on FORM XI-AAIN and FORM I-AAIN.

3.7.15.7 Documentation

The values for the serial dilution shall be recorded in µg/L on FORM XI-AAIN.

3.7.16 Interelement Correction Factors

3.7.16.1 Summary

To ensure against spectral interferences, interelement correction factors are determined for all wavelengths used for each analyte reported by ICP.

3.7.16.2 Frequency

Before any field samples are analyzed under this contract, the ICP interelement correction factors shall be determined within three months prior to the start of contract analyses and at least annually thereafter.

3.7.16.3 Procedure

Correction factors for spectral interference due to Al, Ca, Fe, K, Na, and Mg shall be determined for all ICP instruments at all wavelengths used for each analyte reported by ICP. Correction factors for spectral interference due to analytes other than Al, Ca, Fe, K, Na, and Mg shall be reported if they were applied.

If the instrument was adjusted in any way that may affect the ICP interelement correction factors, the factors shall be redetermined and the results submitted for use.

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Follow the instrument manufacturer's recommendations for applying interelement correction factors.

3.7.16.4 Calculations

Not applicable

3.7.16.5 Technical Acceptance Criteria

Not applicable

3.7.16.6 Corrective Action

Not applicable

3.7.16.7 Documentation

Results from interelement correction factors determination shall be reported on FORM XI-AAIN for all ICP parameters.

3.8 INSTRUMENT OPERATION

3.8.1 No detailed operating instructions as to the optimization of the plasma power, argon flows, torch and coil configuration, etc. will be given. The analyst should follow the instructions provided by the manufacturer of the particular instrument.

3.8.2 The sample introduction system is to be of a pneumatic type. The use of a peristaltic pump instead of direct aspiration is required. A tip washer is a very useful aid and can be easily inserted into the sample flow system by placing a "tee connector" on the carrier argon flow line just before entering the nebulizer. One arm of the "tee connector" runs to the nebulizer, another to the carrier argon flow line and the third is connected to a line from the peristaltic pump. When a drop in the carrier flow is observed, a small pulse of water is pumped into the carrier argon flow and blown through the nebulizer orifice, dissolving the salt buildup and restarting the original carrier argon flow.

3.8.3 Changes in the carrier argon flow may change the emission characteristics of the analyte. The use of a digital mass flow controller is recommended to control the carrier argon flow.

3.8.4 For direct reading instruments, every solution, including calibration standards, calibration and method blanks, reference samples, and samples shall be analyzed using two full exposures (peak scan), each of which is sufficient to meet the MQL (at each analyte emission line). All exposure times shall be the same for all analyses and all quarterly analyses (i.e., LRS, MQL, and interelement correction factor). Each

background spectral region shall have an exposure time equivalent to a full exposure time for direct reading instruments.

3.8.5 Selection of the appropriate background spectral region for each analyte shall account for the major interferents within that region and for the possibility of analyte line broadening at high concentrations. One of the best ways to select the appropriate background spectral region is to perform a wavelength scan around the analyte wavelengths in the presence of metals frequently encountered at high levels in the samples. Alternately, if the instrument does not have automatic scanning capability, selection of the background spectral region will have to be determined on the basis of manual scans and experience.

3.8.6 A calibration blank rinse between each sample aspiration should be sufficient to prevent carry-over between samples.

3.8.7 The determination of the linear range of each analyte line, interference effects, and any type of detection limit or precision measurement shall be established under the same conditions used for the analysis of the samples, including the background correction scheme.

3.9 PROCEDURE

3.9.1 Calibration

3.9.1.1 Set up the instrument with proper operating parameters. The instrument shall be allowed to become thermally stable before beginning analysis. This requires at least 30 minutes of operation with the plasma lit prior to calibrations.

3.9.1.2 Initiate appropriate operating configuration of the instrument computer.

3.9.1.3 Perform the appropriate steps recommended by the manufacturer to align the exit slits with the entrance slit. These steps are commonly called the profile or wavelength calibration procedure.

3.9.2 Analysis Sequence

3.9.2.1 Before beginning the sample analysis run, analyze the initial calibration blank (ICB), initial calibration verifications (ICV), interference check sample, and the CRQL standard (CRI). The ICV and LRS concentration values shall not deviate from the actual values by more than 10 percent, while the CRI shall not deviate from its actual values by more than 15 percent. The calibration blank values shall not exceed the CRQL. The interference check sample found values shall not deviate by more than 20 percent of the true values. If these conditions are not met for any analyte, discontinue the analysis and refer to Exhibits D

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(Quality Control - Initial and Continuing Calibration Blanks) and E for additional information.

3.9.2.2 Upon successful analysis of the ICV, ICB, CRI, and ICS, analyze all PB extract(s) prepared with the samples. If any of the blank(s) values are not less than or equal to the CRQL, see Exhibits D and E for the appropriate action.

3.9.2.3 If the PB and LCS values are within the acceptable ranges, analyze the spike sample. If the recovery of any analyte deviates from the acceptable ranges, see Exhibit E for the appropriate action. Proceed to the analysis of samples if the recoveries are acceptable or after consulting Exhibits D and E.

3.9.2.4 The continuing calibration verification standard (ICV) and the continuing calibration blank (CCB) shall be analyzed after every 10 analytical sample analyses. The analyst shall run CCV and CCB samples after the analysis of the previous sample, but prior to use of a tip wash or other clean out device. CCV concentration values shall not deviate from the actual values by more than 10 percent. In addition, the absolute values for the CCB shall be lower than the CRQLs. If these conditions are not met at any time during samples analysis, discontinue the analysis and see Exhibits D and E for the appropriate action.

3.9.2.5 At the end of the sample analysis run, analyze the ICS, CRI, and CCB. If the values for any of these samples deviates from the required limits, see Exhibits D and E for additional information.

3.9.3 **Sample Analyses**

3.9.3.1 All sample extracts shall first be analyzed without any dilution. Diluting sample extracts is permissible if necessary, provided that the dilution does not produce results below CRQL.

3.9.3.2 All concentrations within the linear range of the analyte shall be reported. All concentrations reported shall be obtained within the established linear range for that analysis run, and interference corrections shall be made based on the actual concentration of the interferent and not the apparent concentration obtained when the interferent concentration is above the linear range.

3.9.4 **Calculations**

3.9.4.1 To obtain the analyte air concentration (in $\mu g/m^3$), multiply the interference-corrected analyte values (in $\mu g/L$) by nine times the appropriate volume (in liters) used in the extraction and divide by the volume of air (in standard m^3) sampled and the number of 1"x 8" strips digested for the sample. The factor "9" represents the total area (63

in^2) of the Hi-Vol filter exposed to the air stream divided by the exposed area (7 in^2) in one 1"x 8" strip.

$$\text{Analyte Conc. air, } \mu g/m^3 = \frac{9 \times \text{Interference-Corrected Analyte Value, } \mu g/L \times \text{Extract Volume, L}}{\text{no. of strips digested} \times \text{air volume sampled, std. } m^3} \quad \text{Eq. D-15}$$

3.9.5 Documentation

3.9.5.1 Report the air concentration values in $\mu g/m^3$ and the interference-corrected analyte value in $\mu g/L$ on FORM I-AAIN.

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SECTION 4

SAMPLE ANALYSIS BY INDUCTIVELY COUPLED PLASMA-MASS SPECTROMETRY (ICP-MS)

4.1 SCOPE AND APPLICATION

4.1.1 Metals for which this method is applicable are listed in Table 2, Exhibit C in are determined by ICP-MS after sample preparation by microwave digestion (Section 2 of this Exhibit). Instrument quantitation limits, sensitivities, and linear ranges for these elements will vary with the matrices, instrumentation, and operating conditions. Use of this method is restricted to spectroscopists who are knowledgeable in the recognition and the correction of spectral, chemical, and physical interferences in ICP-MS. The experience requirement is one year on a commercially available ICP-MS.

4.2 SUMMARY OF METHOD

4.2.1 The method describes the multi-elemental determination of analytes by ICP-MS. The method measures ions produced by a radio-frequency inductively coupled plasma. Analyte species originating in a liquid are nebulized and the resulting aerosol transported by argon gas into the plasma torch. The ions produced are entrained in the plasma gas and by means of a water cooled interface, introduced into a quadrupole mass spectrometer, capable of providing a resolution better than or equal to 1 amu peak width at 10 percent of the peak height. The water-cooled interface consisting of tandem skimmers, is differentially pumped and leads into the high vacuum chamber of the mass spectrometer. The ions and ion clusters produced in the plasma and those formed during the introduction of the ion beam into the mass spectrometer, are sorted according to their mass-to-charge ratios and quantified with a channel electron multiplier. Interferences must be assessed and valid corrections applied or the data flagged to indicate problems. Use of the internal standard technique is required to compensate for suppressions and enhancements caused by sample matrices.

4.3 INTERFERENCES

4.3.1 Isobaric elemental interferences in ICP-MS are caused by isotopes of different elements forming ions with the same nominal mass-to-charge ratio (m/z). Table D-10, shows isobaric interferences and the secondary masses which would be analyzed to correct for these interferences. A data system must be used to correct for these interferences. This involves determining the signal for another isotope of the interfering element and subtracting out the appropriate signal from the isotope of interest. Data that is corrected must be noted in the report along with the exact calculations used. Commercial ICP-MS instruments nominally provide unit

resolution at 10 percent of the peak height, and very high ion currents at adjacent masses can contribute to ion signals at the mass of interest. Table D-9 shows approximate concentrations at which adjacent masses give rise to a contribution of 10 µg/L to the analyte of interest at a resolution of 1 amu at 10 percent peak height, if the mass were chosen for quantitation. It should be noted that the information described in Table D-9, was experimentally derived and the interferences which are described occur from several different sources. One interference is the effect of resolution on adjacent peaks. This has a larger effect at 1 amu less than the interferant than at one amu greater than the interferant's mass due to the trapezoidal peak shape associated with a quadrupole mass spectrometer. Another interference which would be observed is the formation of a hydride ion. These interferences only cause an interference at 1 amu greater than the interferant's mass. It should also be remembered that these interferences are not necessarily linear and attempts should not be made to extrapolate the values to a particular data set. The table has been included for its informational content alone.

4.3.2 Isobaric molecular and doubly charged ion interferences in ICP-MS are caused by ions consisting of more than one atom or charge. Table D-10, lists isobaric molecular-ion interferences which could affect the analytes. It should be noted that many of these interferences are extremely rare, but adverse effects on data quality could occur if the individual constituents occurred in the sample at sufficiently high concentrations. When the interferences cannot be avoided by the use of another isotope with sufficient natural abundance, corrections to the data must be applied. Corrections for molecular-ion interferences may either be based upon the natural isotope ratios of the molecular ion or a determination of the actual amount of interference which occurs when the interferant is present.

If a correction for an oxide ion is used, the correction may be normalized to the extent of oxide formation of an appropriate internal standard previously demonstrated to form the same level of oxide as the interferant. This second type of correction has been reported for oxide ion corrections using ThO/Th for use on rare earth elements. Most isobaric interferences that could affect ICP-MS determinations have been identified in the literature.

4.3.3 Physical interferences are effects associated with the sample nebulization and transport processes as well as ion-transmission efficiencies. Nebulization and transport processes are those in which the matrix component causes a change in surface tension or viscosity in a manner different from the standards used in performing calibration. Internal standards have been used to correct for these interferences. The interferences are primarily suppressions and are seen by the lighter elements more than the heavier elements. The effects are greater for matrix components with heavier atomic mass than for matrix components with lighter atomic mass. Changes in matrix composition therefore can cause

significant suppressions and enhancements. Dissolved-solid levels can contribute deposits on the nebulizer tip of a pneumatic nebulizer and on the interface skimmers (reducing the orifice size and the instrument performance). Total solid levels below 0.2 percent (2,000 ppm) have been recommended to minimize solid deposition. Internal standards must be affected to the same degree as the analyte to demonstrate that they compensate for these interferences. A minimum of three internal standards, listed in Table D-7, bracketing the mass range, must be used. When the intensity level of an internal standard is less than 30 percent or greater than 125 pecent of the intensity of the first standard used during calibration, the sample must be reanalyzed after performing a five fold (1:4) dilution. The intensity levels of the internal standards for the CCB and CCV solutions must agree within ± 20 percent of the intensity level of the internal standard of the ICB solution. If they do not agree, terminate the analysis, correct the problem, recalibrate, and reanalyze the previous 10 samples at no additional cost.

4.3.4 Memory interferences are effects which are dependant upon the relative concentration differences between samples or standards which are analyzed sequentially. Sample deposition on the sampler and skimmer cones, spray chamber design, and the type of nebulizer used, affect the extent of the memory interferences which are present. To verify that memory effects do not have an adverse impact on data quality, the memory test must be performed on the tuned and calibrated instrument before any analyses are performed. A multielement memory test solution containing levels of analytes as specified in Table D-6, is aspirated into the system for a normal sample exposure period. A blank solution is then introduced, noting the time when the uptake tube is switched to the blank solution. After the normal routine rinse time has elapsed, begin a routine analysis of the blank solution. Inspect the resulting data to see if any analytes are in excess of the MQL. If there are, reanalyze the blank to eliminate the possibility of actual blank contamination. A decreased value on the second analysis indicates a memory problem rather than blank contamination. If a memory problem does exist (see Exhibit E) for a given analyte, increase the rinse time until the system passes the memory test. If the increased rinse time is not feasible from a sample throughput standpoint, a hardware change may be necessary.

4.4 Apparatus and Materials

4.1 Inductively coupled plasma - mass spectrometer: System capable of 1 amu resolution from 6-253 amu with a data system that allows corrections for isobaric interferences and the application of the internal standard technique. Use of a mass-flow controller for the nebulizer argon and a peristaltic pump for the sample solution are recommended.

4.4.2 Argon gas supply: High-purity grade (99.99%)

4.5 OPERATIONAL REQUIREMENTS

4.5.1 System configuration: Because of the differences between various makes and models of satisfactory instruments, no detailed operating instruction can be provided. Instead, the analyst should follow the instructions provided by the manufacturer of the particular instrument. Sensitivity, method quantitation limits (MQL's), precision, linear dynamic range and interference effects must be established for each analyte on a particular instrument. All reported measurements must be within the instrumental linear ranges. The analyst must maintain quality control data confirming instrument performance and analytical results.

IT IS THE RESPONSIBILITY OF THE ANALYST TO VERIFY THAT THE INSTRUMENT CONFIGURATION AND OPERATING CONDITIONS USED SATISFY THE ANALYTICAL REQUIREMENTS SET FORTH IN THIS DOCUMENT AND TO MAINTAIN QUALITY CONTROL DATA CONFIRMING INSTRUMENT PERFORMANCE AND ANALYTICAL RESULTS.

The data must include hardcopies and computer readable storage media which can be readily examined by an EPA audit team. The data must demonstrate defendable choices of instrument operating conditions which mimimize interferences such as oxides.

4.5.2 Precautions must be taken to protect the channel electron multiplier from high ion currents. The channel electron multiplier suffers from fatigue after being exposed to high ion currents. This fatigue can last from several seconds to hours depending on the extent of exposure. During this time period, response factors are constantly changing which invalidates the calibration curve, causes instability, and invalidates sample analyses. Samples run during such periods are required reruns at no additional cost to the Government under this contract.

4.5.3 Sensitivity, MQL's, precision, linear dynamic range, and interference effects must be established for each analyte on a particular instrument. These parameters must be determined for each configuration used if an instrument is equipped with dual detector hardware. All reported measurements must be within the instrumental linear dynamic ranges. All reported measurements from a less sensitive detector configuration must exceed five times the documented instrumental detection limit for that detector configuration. The analyst must maintain quality control data confirming instrument performance and analytical results.

4.6 REAGENTS AND STANDARDS

4.6.1 Acids used in the preparation of standards and for sample processing must be below the MQL's for the analytes of interest. Redistilled acids or ultra-pure acids are required for use with ICP-MS because of the high sensitivity of ICP-MS. Nitric acid at less than two percent (v/v) is preferred for ICP-MS to minimize damage to the interface and to minimize isobaric molecular-ion interferences with the analytes.

Many more molecular-ion interferences are observed on the analytes when hydrochloric and sulfuric acids are used, as demonstrated in Table D-10. Concentrations of antimony and silver above 300 µg/L require one percent (v/v) HCl for stability.

4.6.2 Internal standards must be used to monitor and correct for changes that occur from differences between standards and samples. This information must be clearly reported in the raw data. The changes for which internal standards correct, are primarily physical interferences. Internal standards must be present in all standards and samples at identical levels by mixing the internal standard to the solution being nebulized prior to the nebulizer. This may be accomplished by using a second channel of the peristaltic pump to add the internal standard to the uptake tube. If adding the solution to the uptake tube is not used then the internal standard must be added in two separate aliquots to the samples and standards to prevent the possibility of improperly spiking the internal standard levels. The double spiking ensures that misquantitation will not occur based upon a single internal standard spike. Double spiking may occur either by adding a constant volume of internal standard concentrate to identical volumes of the standards and prepared samples, or by diluting the internal standard to the appropriate level for its use in the analyses. One typical example is to measure out 10.0 mL of all standards and samples into individual containers, then 0.100 mL of a 10 mg/L solution of the internal standard is added to each of the containers. This adds identical amounts of the internal standard to each solution for analysis. The concentrations of the analyte levels in the standards do not have to be corrected for the dilution which occurs because the dilution is canceled out when corrections to the samples are made for their dilution.

4.6.2.1 Bismuth internal standard solution, stock, 1 mL = 100 µg Bi: Dissolve 0.1115 g Bi_2O_3 in a minimum amount of dilute HNO_3. Add 10 mL conc. HNO_3 and dilute to 1,000 mL with ASTM Type I water.

4.6.2.2 Holmium internal standard solution, stock, 1 mL = 100 µg Ho: Dissolve 0.1757 g $Ho_2(CO_3)_3 \cdot 5H_2O$ in 10 mL ASTM Type I water and 10 mL HNO_3. After dissolution is complete, warm the solution to degas. Add 10 mL conc. HNO_3 and dilute to 1,000 mL with ASTM Type I water.

4.6.2.3 Indium internal standard solution, stock, 1 mL = 100 µg In: Dissolve 0.1000 g indium metal in 10 mL conc. HNO_3. Dilute to 1,000 mL with ASTM Type I water.

4.6.2.4 Lithium internal standard solution, stock, 1 mL = 100 µg ^6Li: Dissolve 0.6312 g 95 atom percent enriched ^6Li, Li_2CO_3 in 10 mL of ASTM Type I water and 10 mL HNO_3. After dissolution is complete, warm the solution to degas. Add 10 mL conc. HNO_3 and dilute to 1,000 mL with ASTM Type I water.

4.6.2.5 Rhodium internal standard solution, stock, 1 mL = 100 μg Rh: Dissolve 0.3593 g $(NH_4)_3RhCl_6$ in 10 mL ASTM Type I water. Add 100 mL conc. HCl and dilute to 1,000 mL with ASTM Type I water.

4.6.2.6 Scandium internal standard solution, stock, 1 mL = 100 μg Sc: Dissolve 0.15343 g Sc_2O_3 in 10 mL (1:1) hot HNO_3. Add 5 mL conc. HNO_3 and dilute to 1,000 mL with ASTM Type I water.

4.6.2.7 Terbium internal standard solution, stock, 1 mL = 100 μg Tb: Dissolve 0.1828 g $Tb_2(CO_3)_3 \cdot 5H_2O$ in 10 mL (1:1) HNO_3. After dissolution is complete, warm the solution to degas. Add 5 mL conc. HNO_3 and dilute to 1,000 mL with ASTM Type I water.

4.6.2.8 Yttrium internal standard solution, stock, 1 mL = 100 μg Y: Dissolve 0.2316 g $Y_2(CO_3)_3 \cdot 3H_2O$ in 10 mL (1:1) HNO_3. Add 5 mL conc. HNO_3 and dilute to 1,000 mL with ASTM Type I water.

4.6.3 Mixed calibration standard solutions: Dilute the stock-standard solutions to levels in the linear range for the instrument in a solvent consisting of one percent (v/v) HNO_3 in ASTM Type I water along with the selected concentration of internal standards such that there is an appropriate internal standard element for each of the analytes (see Table D-7). Prior to preparing the mixed standards, each stock solution must be analyzed separately to determine possible spectral interferences or the presence of impurities. Care must be taken when preparing the mixed standards that the elements are compatible and stable. Transfer the mixed standard solutions to freshly acid-cleaned not previously used FEP fluorocarbon bottles for storage. Fresh mixed standards must be prepared as needed with the realization that concentrations can change on aging. Calibration standards must be initially verified using a quality control sample and monitored weekly for stability. Although not specifically required, some typical calibration standard combinations follow.

4.6.3.1 Mixed standard solution I: Manganese, beryllium, cadmium, lead, silver, barium, copper, cobalt, nickel and zinc.

4.6.3.2 Mixed standard solution II: Arsenic, chromium, thallium, and aluminum.

4.6.3.3 Mixed standard solution III: Antimony, vanadium, iron.

4.6.3.4 Mixed standard solution IV: Bismuth, holmium, indium, scandium, yttrium, and terbium.

4.6.3.5 Mixed standard solution V: Rhodium.

NOTE: If the addition of silver to the recommended acid combination results in an initial precipitation, add 15 mL of ASTM Type I water and

warm the flask until the solution clears. Cool and dilute to 100 mL with ASTM Type I water. For this acid combination the silver concentration must be limited to 2 mg/L. Silver under these conditions is stable in a tap water matrix for 30 days.

4.6.4 Three types of blanks are required for the analysis. The calibration blank is used in establishing and monitoring the calibration curve, the preparation blank is used to monitor the blank standard solution (SO), ICB, and CCB for possible contamination resulting from the sample preparation procedure, and the rinse blank is used to flush the system between all samples and standards.

4.6.4.1 The calibration blank consists of one percent HNO_3 (v/v) in ASTM Type I water along with the selected concentration of internal standards such that there is an appropriate internal standard element for each of the analytes (see Table D-7).

4.6.4.2 The preparation blank must contain all the reagents in the same volumes as used in processing the samples. The preparation blank must be carried through the complete procedure and contain the same acid concentration in the final solution as the sample solutions used for analysis (see Exhibit E).

4.6.4.3 The rinse blank consists of two percent HNO_3 (v/v) in ASTM Type I water. Prepare a sufficient quantity to flush the system between standards and samples.

4.6.5 The Interference Check Solution(s) (ICS) is prepared to contain known concentrations of interfering elements that will demonstrate the magnitude of interferences and provide an adequate test of any corrections. The ICS solution is detailed in Table 3, Exhibit C. The chloride concentration provides a means to evaluate software corrections for chloride-related interferences such as $^{35}Cl^{16}O^{+}$ on $^{51}V^{+}$ and $^{40}Ar^{35}Cl^{+}$ on $^{75}As^{+}$. Since the natural abundance of ^{35}Cl at 75.8 percent is 3.13 times the ^{37}Cl abundance of 24.2 percent, the ion corrections can be calculated with adjustments for isobaric contributions. Iron is used to demonstrate adequate resolution of the spectrometer on manganese. Molybdenum serves to indicate oxide effects on cadmium isotopes. The other components are present to evaluate the ability of the measurement scheme to correct for various molecular-ion isobaric interferences. The ICS is used to verify that the interference levels are corrected by the data system within quality control limits.

4.6.5.1 Stock solutions for preparing ICS solutions A and AB may be provided if available from EPA. Otherwise, refer to Table 3, Exhibit C. They must be diluted before use according to the instruction provided. The prepared ICS solutions A and AB must be prepared weekly.

4.6.5.2 Mixed ICS solution I may be prepared by adding 13.903 g $Al(NO_3)_3 \cdot 9H_2O$, 2.498 g $CaCO_3$ dried at 180°C for 1 hour before weighing, 1.000 g Fe, 1.658 g MgO, 2.305 g Na_2CO_3, and 1.767 g K_2CO_3 to 25 mL of ASTM Type I water. Slowly add 40 mL of (1:1) HNO_3. After dissolution is complete, warm the solution to degas. Cool and dilute to 1,000 mL with ASTM Type I water.

4.6.5.3 Mixed ICS solution II may be prepared by slowly adding 7.444 g 85 percent H_3PO_4, 6.373 g 96 percent H_2SO_4, 40.024 g 37 percent HCl, and 10.664 g $C_6O_7H_8$ to 100 mL of ASTM Type I water. Dilute to 1,000 mL with ASTM Type I water.

4.6.5.4 Mixed ICS solution III may be prepared by adding 5 mL each of arsenic stock solution, chromium stock solution, copper stock solution, and zinc stock solution, 10 mL each of cobalt stock solution, nickel stock solution, and vanadium stock solution, and 2.5 mL of cadmium stock solution. Dilute to 100 mL with two percent HNO_3.

4.6.5.5 ICS A may be prepared by adding 10 mL of mixed ICS solution I, 10 mL each of titanium stock solution, and molybdenum stock solution, and 5 mL of mixed ICS solution II. Dilute to 100 mL with ASTM Type I water. ICS solution A must be prepared fresh weekly.

4.6.5.6 ICS AB may be prepared by adding 10 mL of mixed ICS solution I, 10 mL each of titanium stock solution and molybdenum stock solution, 5 mL of mixed ICS solution II, and 2 mL of mixed ICS solution III. Dilute to 100 mL with ASTM Type I water. ICS solution AB must be prepared fresh weekly.

4.7 QUALITY CONTROL

To obtain analyte data of known quality, it is necessary to measure for more than the analytes of interest in order to know the required interference corrections. If the concentrations of interference sources (such a C, Cl, Mo, Zr, W) are below the levels that show an effect on the analyte level, uncorrected equations may be used provided all QA criteria are met. It should be noted that monitoring the interference sources does not necessarily require monitoring the interference itself, but that a molecular species may be monitored to indicate the presence of the interference. When corrected equations are used all QA criteria must also be met. Extensive QC for interference corrections are required at all times. The monitored masses must include those elements whose oxygen, hydroxyl, chloride, nitrogen, carbon and sulfur molecular ions which could impact the analytes of interest. When an interference source is present, the sample elements impacted must be flagged to indicate (a) the percentage interference correction applied to the data or (b) an uncorrected interference. The isotope proportions for an element or molecular-ion cluster provide information useful for quality assurance. These tests will enable the analyst to detect positive or negative interferences that distort the accuracy of the reported values.

4.7.1 Instrument Calibration

4.7.1.1 Summary

Prior to the analysis of samples and required QC, each ICP-MS system shall be initially calibrated to determine instrument sensitivity.

4.7.1.2 Frequency

Instruments shall be calibrated daily or once every 24 hours and each time the instrument is set up.

4.7.1.3 Procedure

Calibration standards shall be prepared using the same type of matrix and at the same concentration as the preparation blank following sample preparation.

Calibrate according to instrument manufacturer's recommended procedures using at least two standards, one being a blank.

Before beginning the sample run, reanalyze the highest mixed calibration standard as if it were a sample.

4.7.1.4 Calculations

$$\% \ Recovery = \frac{Found \ Concentration}{True \ Concentration} \times 100 \qquad \text{Eq. D-16}$$

4.7.1.5 Technical Acceptance Criteria

Recovery for the highest mixed calibration standard shall be within ± five percent of the true value (i.e., 95-105 percent).

4.7.1.6 Corrective Action

Follow instrument manufacturer's recommendations to correct the problem. Also, baseline correction is acceptable as long as it is performed after every sample or after the continuing calibration verification and blank check; resloping is acceptable as long as it is immediately preceded and immediately followed by a CCV and a CCB.

4.7.1.7 Documentation

The instrument standardized data and time shall be included in the raw data. The final concentration should be in µg/L.

4.7.2 Initial Calibration Verification

4.7.2.1 Summary

Immediately after the ICP-MS system has been calibrated, the accuracy of the initial calibration shall be verified and documented for every analyte by the analysis of EPA Initial Calibration Verification Solution(s) (ICV) at each mass used for analysis.

4.7.2.2 Frequency

Each time the instrument is calibrated, the ICV shall be run immediately following the calibration, before any samples are analyzed.

4.7.2.3 Procedure

If the ICV solution(s) are not available from EPA, or where a certified solution of an analyte is not available from any source, analyses shall be conducted on an independent standard at a concentration other than that used for instrument calibration, but within the linear range. An independent standard is defined as a standard composed of the analytes from a different source than those used in the standards for the instrument calibration.

4.7.2.4 Calculations

$$\% \ Recovery = \frac{Found \ Concentration}{True \ Concentration} \times 100 \qquad \text{Eq. D-17}$$

4.7.2.5 Technical Acceptance Criteria

Recovery for the ICV shall be within ± 10 percent of the true value (i.e., 90-110 percent).

4.7.2.6 Corrective Action

When recoveries of the ICV exceed the technical acceptance criteria, the analysis shall be terminated, the problem corrected, the instrument recalibrated, and the calibration reverified.

4.7.2.7 Documentation

Report the ICV found concentration (µg/L), true concentration (µg/L), and percent recovery on FORM II-AAIN.

4.7.3 Continuing Calibration Verification

4.7.3.1 Summary

To ensure calibration accuracy during an analysis run, a continuing calibration verification solution (CCV) is analyzed and reported for every mass used for the analysis of each analyte.

4.7.3.2 Frequency

The CCV is run at a frequency of 10 percent or every two hours during an analysis run, whichever is more frequent.

The CCV is also run after the last analytical sample in the analysis run.

4.7.3.3 Procedure

The same CCV shall be used throughout all analysis runs for a Case of samples received. The analyte concentrations in the continuing calibration standard shall be an EPA solution or a Contractor prepared standard solution and should be at or near ± 10 percent of the mid-range levels of the calibration curve.

Each CCV analyzed shall reflect the conditions of analysis for all of the associated analytical samples (the preceding 10 analytical samples or the preceding analytical samples up to the previous CCV). The duration of analysis, rinses and other related operations that may affect the CCV measured result shall not be applied to the CCV to a greater extent than the extent applied to the associated analytical samples. For instance, the difference in time between a CCV analysis and the blank immediately following it as well as the difference in time between the CCV and the analytical sample immediately preceding it shall not exceed the smallest difference in time between any two consecutive analytical samples associated with the CCV.

4.7.3.4 Calculations

$$\%\ Recovery = \frac{Found\ Concentration}{True\ Concentration} \times 100 \qquad \text{Eq. D-18}$$

4.7.3.5 Technical Acceptance Criteria

Recovery for the CCV shall be within ± 10 percent of the true value (i.e., 90-110 percent).

4.7.3.6 Corrective Action

When recoveries of the CCV exceed the technical acceptance criteria, the analysis shall be stopped, the problem corrected, the instrument recalibrated, the calibration reverified, and the preceding 10 analytical samples reanalyzed (or all analytical samples since the last compliant CCV).

4.7.3.7 Documentation

Report the CCV found concentration (µg/L), true concentration (µg/L), and percent recovery on FORM II-AAIN.

4.7.4 **CRQL Standard**

4.7.4.1 Summary

To verify linearity near the CRQL, the Contractor shall analyze an ICP-MS standard at two times the MQL or two times CRQL, whichever is greater. This standard shall be run for every mass used for analysis.

4.7.4.2 Frequency

The CRQL standard shall be run at the beginning and end of each sample analysis run, or a minimum of twice per eight hours, whichever is more frequent.

4.7.4.3 Procedure

The CRQL standard shall not be run before the ICV solution.

4.7.4.4 Calculations

$$\% \text{ Recovery} = \frac{\text{Found Concentration}}{\text{True Concentration}} \times 100 \qquad \text{Eq. D-19}$$

4.7.4.5 Technical Acceptance Criteria

Recovery of the CRQL standard shall be within ± 15 percent of the true value for each mass used for analysis.

4.7.4.6 Corrective Action

If the CRQL standard does not fall within the control limit, the analysis shall be terminated, the problem corrected and the analytical samples since the last compliant CRQL standard reanalyzed.

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4.7.4.7 Documentation

Report the CRQL standards found concentration (µg/L), true concentration (µg/L), and percent recovery on FORM III-AAIN.

4.7.5 Linear Range Analysis (Quarterly)

4.7.5.1 Summary

The concentration range over which the ICP-MS calibration curve remains linear must be determined and any values above this linear range shall be diluted and reanalyzed.

4.7.5.2 Frequency

For all ICP-MS analyses, a linear range verification check standard shall be analyzed and reported quarterly (every 3 calendar months) for each element on the target analyte list (Table 2, Exhibit C). The standard shall be analyzed during a routine analytical run performed under this contract. This standard shall be run for all masses used for each analyte reported by ICP-MS.

4.7.5.3 Procedure

The standard shall be analyzed as though it were a separate analytical sample (i.e., each measurement shall be followed by a rinse and/or any other procedure normally performed between the analysis of separate samples).

4.7.5.4 Calculations

$$\%\ Recovery = \frac{Found\ Concentration}{True\ Concentration} \times 100 \qquad \text{Eq. D-20}$$

4.7.5.5 Technical Acceptance Criteria

Recovery for the linear range standard shall be within ± 5 percent of the true value (i.e., 95-105 percent).

4.7.5.6 Corrective Action

If the recovery of the linear range standard does not meet the technical acceptance criteria, then the analysis shall be terminated and successive dilutions of the standard shall be reanalyzed until the control limits are met. The concentration of this standard that meets the control limits is the upper limit of the instrument linear range beyond which results cannot be reported under this contract without dilution of the analytical sample.

4.7.5.7 Documentation

Report the linear range standards found concentration (in µg/L), true concentration (in µg/L) and percent recovery for each analyte on FORM III-AAIN.

4.7.6 Initial Calibration Blank

4.7.6.1 Summary

To verify that the ICP-MS system is not contaminated, an initial calibration blank (ICB) shall be analyzed after calibration.

4.7.6.2 Frequency

The ICB shall be analyzed each time the system is calibrated and immediately after the ICV.

4.7.6.3 Procedure

If the absolute value of the ICB is greater than the MQL, the result shall be reported.

4.7.6.4 Calculations

Not applicable.

4.7.6.5 Technical Acceptance Criteria

The absolute value of the ICB must be less than the CRQL.

4.7.6.6 Corrective Action

When the ICB concentration does not meet the technical acceptance criteria, terminate analysis, correct the problem, recalibrate, verify the calibration, and reanalyze the ICB.

4.7.6.7 Documentation

Report the ICB values in µg/L on FORM IV-AAIN.

7.7 Continuing Calibration Blanks

4.7.7.1 Summary

To ensure that the system is not contaminated during the analysis run, continuing calibration blanks (CCB) are analyzed.

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4.7.7.2 Frequency

Analyze the CCB at a frequency of 10 percent or every two hours, whichever is more frequent.

Analyze the CCB after every CCV.

4.7.7.3 Procedure

A CCB shall be run after the last CCV in the analysis run. If the absolute value of the CCB is greater than the MQL, the result shall be reported.

4.7.7.4 Calculations

Not applicable.

4.7.7.5 Technical Acceptance Criteria

The absolute value of the CCB must be less than the CRQL.

4.7.7.6 Corrective Action

When the CCB concentration does not meet the technical acceptance criteria, terminate analysis, correct the problem, recalibrate, verify the calibration, and reanalyze the preceding 10 analytical samples (or all analytical samples since the last compliant CCB).

4.7.7.7 Documentation

Report the CCB values in µg/L on FORM IV-AAIN.

4.7.8 Preparation Blanks

4.7.8.1 Summary

To ensure against contamination during sample preparation, a preparation blank (PB) is analyzed.

4.7.8.2 Frequency

At least one PB must be prepared and analyzed with every SDG or with each batch of samples digested, whichever is more frequent.

4.7.8.3 Procedure

The PB shall consist of ASTM Type I water processed through each sample preparation and analysis procedure step.

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The first batch of samples in a SDG shall be assigned to PB one, the second batch of samples to PB two, etc.

4.7.8.4 Calculations

Not applicable.

4.7.8.5 Technical Acceptance Criteria

The absolute value of the PB must be less than the CRQL.

4.7.8.6 Corrective Action

If the absolute value of the concentration of the PB is less than or equal to the CRQL, no corrective action is required.

If any analyte concentration in the PB is above the CRQL, the lowest concentration of the analyte in the associated samples must be 10 times the PB concentration. Otherwise, all samples associated with the PB and with the analyte's concentration less than 10 times the PB concentration and above the CRQL shall be redigested and reanalyzed for that analyte. The sample concentration is not to be corrected for the PB value.

If an analyte concentration in the PB is below the negative CRQL, then all samples reported below 10 times CRQL associated with the PB shall be redigested and reanalyzed.

4.7.8.7 Documentation

The values for the PB shall be recorded in µg/L on FORM IV-AAIN.

7.9 ICP Interference Check Sample

4.7.9.1 Summary

To verify interelement and background correction factors, an ICP Interference Check Sample (ICS) is analyzed.

4.7.9.2 Frequency

Analyze the ICS at the beginning and end of each analysis run or a minimum of twice per eight hour working shift, whichever is more frequent, but not before the ICV.

4.7.9.3 Procedure

The ICS consists of two solutions: Solution A and Solution AB. Solution A consists of the interferents, and Solution AB consists of

the analytes mixed with the interferents. An ICS analysis consists of analyzing both solutions consecutively (starting with Solution A) for all masses used for each analyte reported by ICP-MS.

The ICS shall be obtained from EPA (EMSL/LV) if available and analyzed according to the instructions supplied with the ICS.

If the ICP ICS is not available from EPA, an independent ICP ICS shall be prepared with interferent and analyte concentrations at the levels specified in Table 3, Exhbit C. The mean value and standard deviation shall be established by initially analyzing the ICS at least five times repetitively for each analyte.

If true values for analytes contained in the ICS and analyzed by ICP-MS are not supplied with the ICS, the mean shall be determined by initially analyzing the ICS at least five times repetitively for the particular analytes. This mean determination shall be made during an analytical run where the results for the previously supplied EPA ICS met all contract specifications. Additionally, the result of this initial mean determination is to be used as the true value for the lifetime of that solution (i.e., until the solution is exhausted).

4.7.9.4 Calculations

$$\% \textit{ Recovery} = \frac{\textit{Found Concentration}}{\textit{True Concentration}} \times 100 \qquad \text{Eq. D-21}$$

4.7.9.5 Technical Acceptance Criteria

Recovery for the ICS shall be within ± 20 percent of the true value (i.e., 80-120 percent).

4.7.9.6 Corrective Action

If the ICS recoveries does not meet the technical acceptance criteria, terminate the analysis, correct the problem, recalibrate the instrument, verify the calibration, and reanalyze all of the analytical samples since the last compliant ICS was analyzed.

4.7.9.7 Documentation

Report the ICS found concentration (µg/L), true concentration (µg/L), percent recovery, mean and standard deviation on FORM V-AAIN.

The mean and standard deviation shall be reported in the raw data.

4.7.10 Spike Sample Analysis

4.7.10.1 Summary

To provide information about the effect of the sample matrix on the digestion, a known amount of analyte is added (spiked) into a sample.

4.7.10.2 Frequency

At least one spike sample analysis shall be performed on each group of samples for each SDG. EPA may require additional spike sample analysis upon special request by the Project Officer, for which the Contractor will be paid.

If two analytical methods are used to obtain the reported values for the same analyte within a SDG (e.g., ICP-MS and GFAA), then spike samples shall be run by each method used.

4.7.10.3 Procedure

The spike is added before the sample preparation (i.e., prior to digestion) at concentration levels in the Spike Sample solution as indicated in Table D-3.

Samples identified as field blanks cannot be used for spiked sample analysis. EPA may require that a specific sample be used for the spike sample analysis. In the instance where there is more than one spike sample per SDG and one spike sample recovery is not within contract criteria, flag all the samples of the same matrix, level, and method in the SDG.

4.7.10.4 Calculations

$$\% \ Recovery = \frac{SSR - SR}{SA} \times 100 \qquad \text{Eq. D/IN-22}$$

where:

SSR = Spiked Sample Result;
SR = Sample Result; and
SA = Spike Added.

If the spike analysis is performed on the same sample that is chosen for the duplicate sample analysis, spike calculations shall be performed using the results of the sample designated as the "original sample" (see part 4.7.11, Duplicate Sample Analysis). The average of the duplicate results cannot be used for the purpose of determining percent recovery.

When the sample concentration is less than the instrument detection limit, use SR = 0 only for purposes of calculating percent recovery.

4.7.10.5 Technical Acceptance Criteria

Recovery for the spike should be within ± 25 percent of the spiked amount (i.e., 75-125 percent).

4.7.10.6 Corrective Action

If the spike recovery is not within the limits of 75-125 percent, the data of all samples received associated with that spike sample and determined by the same analytical method shall be flagged with the letter "N" on FORMs I-AAIN and VI-AAIN.

An exception to this rule is granted in situations where the sample concentration exceeds the spike concentration by a factor of four or more. In such an event, the data shall be reported unflagged even if the percent recovery does not meet the 75-125 percent recovery criteria.

4.7.10.7 Documentation

Report the spiked sample results, sample results, spike added and percent recovery for the spike sample analysis on FORM VI-AAIN.

The units for reporting spike sample results will be in µg/L.

7.11 Duplicate Sample Analysis

4.7.11.1 Summary

Duplicate aliquots of a sample are carried through the preparation and analysis steps to provide information about the precision of the analytical methods as well as matrix effects.

4.7.11.2 Frequency

At least one duplicate sample analysis shall be performed on each group of samples for each SDG. EPA may require additional duplicate sample analysis upon special request by the Project Officer, for which the Contractor will be paid.

If two analytical methods are used to obtain the reported values for the same analyte within a SDG (e.g., ICP-MS and GFAA), then duplicate samples shall be run by each method used.

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4.7.11.3 Procedure

Samples identified as field blanks cannot be used for duplicate sample analysis.

EPA may require that a specific sample be used for the duplicate sample analysis.

In the instance where there is more than one duplicate sample per SDG and one duplicate result is not within contract criteria, flag all the samples of the SDG.

Duplicate sample analyses are required for calculations of relative percent difference.

4.7.11.4 Calculations

$$RPD = \frac{|S - D|}{\frac{S + D}{2}} \times 100 \qquad \text{Eq. D/IN-23}$$

where:

RPD = Relative Percent Difference;
S = First Sample Value (original); and
D = Second Sample Value (duplicate).

Duplicates cannot be averaged for reporting on FORM I-AAIN.

4.7.11.5 Technical Acceptance Criteria

A control limit of ± 20 percent for RPD shall be used for original and duplicate sample values greater than or equal to five times CRQL (Exhibit C). A control limit of ± CRQL shall be used for sample values less than five times CRQL.

If one result is above the five times CRQL level and the other is below, use the ± CRQL criteria.

If both sample values are less than the MQL, the RPD is not calculated.

Specific control limits for each analyte will be added to FORM IX-AAIN at a later date, based on precision results.

4.7.11.6 Corrective Action

If the duplicate sample results are outside the control limits, flag with an asterisk all the data for samples received associated with that duplicate sample.

4.7.11.7 Documentation

The results in µg/L of the duplicate sample analyses shall be reported on FORM VIII-AAIN.

The absolute value of the control limit (CROL) shall be entered in the "CONTROL LIMIT" column on FORM VIII-AAIN.

4.7.12 Laboratory Control Samples

4.7.12.1 Summary

A laboratory control sample (LCS) is digested and analyzed to ensure against analyte loss in the sample preparation.

4.7.12.2 Frequency

One LCS shall be prepared and analyzed for every group of samples in a SDG, or for each batch of samples, whichever is more frequent.

4.7.12.3 Procedure

A LCS shall be analyzed for each analyte using the same sample preparations, analytical methods and QA/QC procedures employed for the EPA samples received.

The LCS solution shall be obtained from EPA. (If unavailable, other EPA Quality Assurance Check samples or other certified materials may be used.)

4.7.12.4 Calculations

$$\% \text{ Recovery} = \frac{\text{Found Concentration}}{\text{True Concentration}} \times 100 \qquad \text{Eq. D/IN-24}$$

4.7.12.5 Technical Acceptance Criteria

Recovery for the LCS shall be within ± 20 percent of the true value (i.e., 80-120 percent), with the exception of Ag and Sb.

4.7.12.6 Corrective Action

If the percent recovery for the LCS falls outside the technical acceptance criteria, then the analyses shall be terminated, the problem corrected, and the samples associated with that LCS reprepared and reanalyzed.

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4.7.12.7 Documentation

Report the LCS found concentration (µg/L), true concentration (in µg/L), and percent recovery on FORM IX-AAIN.

4.7.13 Performance Evaluation Sample (PES)

4.7.13.1 Summary

The performance evaluation sample (PES) assists the Agency in monitoring the laboratory performance for analyte identification and quantification.

4.7.13.2 Frequency

One PES shall be delivered, prepared, and analyzed for every group of samples in a SDG, or for each batch of samples, whichever is more frequent.

4.7.13.3 Procedure

A PES shall be analyzed for each analyte using the same sample preparations, analytical methods and QA/QC procedures employed for the EPA samples received.

The PES solution shall be obtained from EPA. (If unavailable, the contractor must contact the Agency and SMO for instructions.)

4.7.13.4 Calculations

Not applicable.

4.7.13.5 Technical Acceptance Criteria

Recovery for the PES shall be within 75 percent of the true value of analyte.

4.7.13.6 Corrective Action

If the percent recovery for the PES falls below 75 percent, the Agency may take, but is not limited to the following actions:

- Show Cause and/or Cure Notice for unacceptable performance;
- Reduction of the number of samples shipped to the laboratory;
- Suspension of sample shipment;
- A site visit;

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- A full data audit; or
- Require the laboratory to analyze remedial PES.

In addition to the above cited actions, the laboratory shall also provide the Technical and Administrative Project Officers a written correction action report on every unacceptable (less than 75 percent) PES score within seven days of written or verbal request by Agency personnel.

4.7.13.7 Documentation

Report the PES results on Form I-AAIN (in µg/L) for all analytes.

4.7.14 Internal Standards for ICP-MS

4.7.14.1 Summary

A minimum of three internal standards, bracketing the mass range, shall be used to check and correct the ICP-MS system for the presence of physical interferences.

4.7.14.2 Frequency

Analyze with each sample, duplicate, spike analysis, PES, CCV, and CCB.

4.7.14.3 Procedure

Each sample, blank, and QA/QC sample must be spiked with the internal standard and shall be analyzed for each analyte using the same sample preparations, analytical methods and QA/QC procedures employed for the EPA samples received.

4.7.14.4 Calculations

$$\%D = \frac{|(SO_I) - (S_I)|}{SO_I} \times 100 \qquad \text{Eq. D/IN-25}$$

where:

SO_I = Intensity of the internal standard in the blank calibration standard;
S_I = Intensity of internal standard in the EPA Sample No.; and
%D = Percent difference.

4.7.14.5 Technical Acceptance Criteria

The intensity level of an internal standard for each sample, duplicate, spike sample, and PES shall agree within ± 50 percent of

the intensity level of the internal standard of the initial calibration blank standard solution (SO_I). MQLs shall be ≤ the CRQLs in Exhibit C.

The intensity levels of the internal standard for the ICV, ICB, CCV, and CCB solutions must agree within ± 20 percent of the instensity level of the internal standard of the initial calibration blank solution (SO_I).

4.7.14.6 Corrective Action

If the internal standard intensity level does not agree ± 50 percent of the sample, the sample must be analyzed after performing a five fold (1:4) dilution and reanalyzed. If the intensity level percent difference (%D) remains greater than 50 percent, a physical interference must be suspected, and the data on FORM XV-AAIN must be flagged with an "E." The analytes affected by the interferences must be listed in the comment section on the appropriate FORM I-AAIN, VII-AAIN, and VIII-AAIN.

If the internal standard intensity level does not agree within ± 20 percent for the ICV and ICB, the analysis shall be terminated, the problem corrected, and a new analytical run shall be started.

If the internal standard intensity level does not agree within ± 20 percent for the CCV and CCB, terminated the analysis, correct the problem, and reanalyze the CCV/CCB only once. If the first CCV/CCB reanalysis yields a %D value within the control limits, then the preceding 10 analytical samples or all analytical samples analyzed since the last compliant calibration verification may be reanalyzed for the analytes affected. Otherwise, the instrument shall be recalibrated, the calibration verified and the affected analytical samples rerun in the context of a new run.

4.7.14.7 Documentation

The internal standard percent difference (%D) shall be reported for each ICP-MS analysis on FORM XV-AAIN.

4.7.15 **Method Quantitation Limits**

4.7.15.1 Summary

Prior to sample analysis, the method quantitation limit (MQL) shall be determined for each instrument that will be used.

4.7.15.2 Frequency

MQLs shall be determined within 30 days of the start of the contract and at least quarterly (every three calendar months) until the end of the contract.

4.7.15.3 Procedure

MQLs (in $\mu g/L$) shall be determined by multiplying by three, the average of the standard deviations (σ_{n-1}) obtained on three nonconsecutive days from the consecutive analysis of seven different PB extracts. Each measurement must be performed as though it were a separate analytical sample (i.e., each measurement must be followed by a rinse and/or any other procedure normally performed between the analysis of separate samples). MQLs shall be determined and reported for each mass and mass number used in the analysis of the samples.

The quarterly determined MQL for an instrument shall always be used as the MQL for that instrument during that quarter. If the instrument is adjusted in anyway that may affect the MQL, the MQL for that instrument shall be redetermined and the results submitted for use as the established MQL for that instrument for the remainder of the quarter.

4.7.15.4 Calculations

$$MQL = 3 \times (\sigma_{n-1}) \qquad \text{Eq. D/IN-26}$$

4.7.15.5 Technical Acceptance Criteria

The MQLs shall be ≤ the CRQLs in Table 2, Exhibit C.

4.7.15.6 Corrective Action

If an instrument's MQL exceeds the CRQL for an analyte, that instrument cannot be used in this document unless the analyte concentration is greater than or equal to five times the reported MQL.

4.7.15.7 Documentation

MQLs shall be submitted with each data package and reported on FORM XI-AAIN for each instrument used. If multiple instruments are used for the analysis of an analyte within a SDG, the highest MQL for the analyte shall be used for reporting concentration values for that SDG.

4.7.16 Interelement Correction Factors

4.7.16.1 Summary

To ensure against spectral and isobaric interferences, interelement correction factors are determined for all masses used for each analyte reported by ICP-MS.

4.7.16.2 Frequency

Before any field samples are analyzed under this contract, the ICP interelement correction factors shall be determined within three months prior to the start of contract analyses and at least annually thereafter.

4.7.16.3 Procedure

Correction factors shall be determined under the same instrument conditions used for sample analysis. If the instrument was adjusted in any way that may affect the interelement correction factors, the factors shall be redetermined and the results submitted for use.

Follow the instrument manufacturer's recommendations for applying interelement correction factors.

4.7.16.4 Calculations

Not applicable.

4.7.16.5 Technical Acceptance Criteria

Not applicable.

4.7.16.6 Corrective Action

Not applicable.

4.7.16.7 Documentation

Results from interelement correction factors determination shall be reported on FORM XI-AAIN for all ICP-MS parameters.

4.8 PROCEDURE

4.8.1 Initiate appropriate operating configuration of instrument computer.

4.8.2 Set up the instrument with the proper operating parameters. Allow at least 30 minutes for the instrument to equilibrate before analyzing any samples. Instrument calibration is verified by running the tuning solution (Table D-5) at least four times with relative standard deviations of less than 10 percent for the analytes contained in the tuning solution.

4.8.3 Conduct mass calibration and resolution checks using the tuning solution (100 ppb of the elements Li, Co, In, and Tl). The intensities on the forms in Exhibit B (see Table D-6) for the response factor criteria

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are recommendations which might be helpful when setting up the instruments but are not required criteria. The mass calibration must meet the criteria specified in Table D-6, if mass calibration exceed those criteria then the mass calibration must be adjusted to the correct values. The resolution must also be verified to be less than 1.0 amu full width at 10 percent peak height. To verify, the tuning solution must be analyzed at the beginning and end of each eight hour shift, and pass the tuning criteria.

4.8.4 Calibration and Sample Analysis

4.8.4.1 Calibrate the instrument for the analytes of interest using the calibration blank and at least a single standard according to the manufacturer's recommended procedure for each detector configuration which will be used in analysis. Flush the system with the rinse blank between each standard solution. Report each integration during the calibration and sample analysis and use the average of the multiple integrations for both standardization and sample analysis. A minimum of two replicate integrations are required for both calibration and sample analysis. The raw data must include the concentrations of elements in each integration as well as the average. Additionally, if different detector configurations are used, the raw data must indicate which detector configuration is being used.

NOTE: Some elements (such as Hg, W, and Mo) require extended flushing times which need to be determined for each instrumental system. Run the memory tests on the solution in Table D-7 to verify that memory problems will not affect the data quality.

4.8.5 As a minimum, all masses which would affect data quality must be monitored to determine potential effects from matrix components on the analyte peaks. This information is to be used to assess data quality and as a minimum must include the masses which are boldfaced and underlined, listed in Table D-12, for each element. These masses must be monitored simultaneously in a separate scan or at the time quantification occurs.

4.8.6 Flush the system with the rinse blank solution for a least 30 seconds before the analysis of each sample. Aspirate each sample for at least 30 seconds before collecting data.

4.8.7 Dilute and reanalyze samples that are more concentrated than the linear range for an analyte.

4.9 CALCULATIONS

4.9.1 If dilutions were performed, the appropriate corrections must be applied to the sample values.

4.9.2 To obtain the analyte air concentration (in $\mu g/m^3$), multiply the interference-corrected analyte values (in $\mu g/L$) by nine times the

appropriate volume (in liters) used in the extraction and divide by the volume of air (in standard m^3) sampled and the number of 1" x 8" strips digested for the sample. The factor "9" represents the total area (63 in^2) of the Hi-Vol filter exposed to the air stream divided by the exposed area (7 in^2) in one 1" x 8" strip.

$$\text{Analyte Conc. In air, } \mu g/m^3 = \frac{(9)\left(\text{Interference-Corrected Value, } \mu g/L\right)\left(\text{Extract Volume, } L\right)}{\text{no. of strips digested} \times \text{air volume sampled, std. } m^3} \qquad \text{Eq. D-27}$$

4.10 DOCUMENTATION

4.10.1 Report the air concentration values in $\mu g/m^3$ and the interference-corrected analyte value in $\mu g/L$ om FORM I-AAIN.

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SECTION 5

SAMPLE ANALYSIS BY GRAPHITE FURNACE ATOMIC ABSORPTION (GFAA) SPECTROMETRY

5.1 INTRODUCTION

5.1.1 GFAA analysis procedures are provided to achieve lower quantitation limits (where required) for the analysis of metal analytes listed in Table 1 the Target Analyte List in Exhibit C.

5.1.2 Because of the differences among various makes and models of satisfactory instruments, no detailed instrument operating instructions can be provided. Instead, the analyst is referred to the instructions provided by the manufacturer of that instrument.

5.2 SUMMARY OF METHOD

5.2.1 Using the furnace technique in conjunction with an atomic absorption spectrophotometer, a representative aliquot of a sample is placed in a graphite tube in the furnace, evaporated to dryness, charred, and atomized. Radiation from a given excited element is passed through the vapor containing ground state atoms of that element. The intensity of the transmitted radiation decreases in proportion to the amount of the ground state element in the vapor. The metal atoms to be measured are placed in the beam of radiation by increasing the temperature of the furnace thereby causing the injected specimen to be volatilized. A monochromator isolates the characteristic radiation from a hollow cathode lamp or an electrodless furnace lamp, and a photosensitive device measures the attenuated transmitted radiation.

5.3 INTERFERENCES

5.3.1 The composition of the sample matrix can have a major effect on the analysis. By modifying the sample matrix, either to remove interferences or to stabilize the analyte, interferences can be minimized. Examples are the addition of ammonium nitrate to remove alkali chlorides and the addition of ammonium phosphate to retain cadmium.

5.3.2 Gases generated in the furnace during atomization may have molecular absorption bands encompassing the analytical wavelength. Therefore the use of background correction is required for all furnace analysis.

5.3.3 Continuum background correction cannot correct for all types of background interference. When the background interference cannot be compensated for, choose an alternate wavelength, chemically separate the

analyte from the interferant, or use an alternate form of background correction (e.g., Zeeman background correction).

5.3.4 Interferences from a smoke producing sample matrix can sometimes be reduced by extending the charring time at a higher temperature or utilizing an ashing cycle in the presence of air. Care must be taken to prevent loss of analyte.

5.4 APPARATUS

5.4.1 Atomic absorption spectrophotometer: Single or dual channel, single or double beam instrument having a grating monochromator, photomultiplier detector, adjustable slits, a wavelength range of 190- to 800-nm, background correction, and provisions for interfacing with a recording device.

5.4.2 Graphite furnace: Any furnace device capable of reaching the specified temperatures is satisfactory.

5.4.3 Operational requirements: Because of the differences between various makes and models of satisfactory instruments, no detailed operating instructions can be provided. Instead, the analyst should follow the instructions provided by the manufacturer of the particular instrument. Sensitivity, instrument detection limit, precision, linear dynamic range, and interference effects must be investigated and established for each individual analyte on that particular instrument. It is the responsibility of the analyst to verify that the instrument configuration and operating conditions used satisfy the analytical requirements set forth in this document and to maintain quality control data confirming instrument performance and analytical results.

5.5 Reagents and Standards

5.5.1 Matrix matching with the samples is mandatory for all blanks, standards, and quality control samples, to avoid inaccurate concentration values due to possible standard curve deviations.

5.5.2 Calibration standards are prepared by diluting stock metal solutions at the time of analysis and are discarded after use. Prepare at least three calibration standards in graduated amounts in the appropriate range by combining an appropriate volume of stock solution in a volumetric flask. The calibration standards must be prepared using the same type of acid or combination of acids at the same concentration.

5.5.3 Two types of blanks are required for GFAA analysis; the calibration blank is used in establishing the analytical curve while the preparation blank is used to indicate possible contamination resulting from the reagents or apparatus used in the sample processing.

5.6 QUALITY CONTROL

5.6.1 Instrument Calibration

5.6.1.1 Summary

Prior to the analysis of samples and required QC, each GFAA system shall be initially calibrated to determine instrument sensitivity.

5.6.1.2 Frequency

Instruments shall be calibrated daily or once every 24 hours and each time the instrument is set up.

5.6.1.3 Procedure

Calibration standards shall be prepared by diluting the stock solutions at the time of analysis, and are discarded after use.

Calibration standards shall be prepared using the same type of acid or combination of acids, and at the same concentration as will result in the samples following sample preparation.

The instrument shall be calibrated according to instrument manufacturer's recommended procedures using at least four calibration points. Beginning with a calibration blank and working towards the highest standard, run at least three other standards. One calibration standard shall be a blank, and another shall be at the CRQL.

Baseline correction is acceptable as long as it is performed after each and every sample, or after the CCV and CCB, respectively.

Resloping is acceptable as long as it is immediately preceded and immediately followed by a CCV and CCB.

5.6.1.4 Calculations

Not applicable.

5.6.1.5 Technical Acceptance Criteria

Not applicable.

5.6.1.6 Corrective Action

Not applicable.

5.6.1.7 Documentation

The instrument standardization date and time shall be included in the raw data. Concentrations shall be in $\mu g/L$.

5.6.2 Initial Calibration Verification

5.6.2.1 Summary

Immediately after the GFAA system has been calibrated, the accuracy of the initial calibration shall be verified and documented for every analyte by the analysis of EPA Initial Calibration Verification Solutions(s) (ICV) at each wavelength used for analysis.

5.6.2.2 Frequency

Each time the instrument is calibrated, the ICV shall be run immediately following the calibration and before any samples are analyzed.

5.6.2.3 Procedure

If the ICV solution(s) are not available from EPA, or where a certified solution of an analyte is not available from any source, analyses shall be conducted on an independent standard at a concentration other than that used for instrument calibration, but within the calibration range. An independent standard is defined as a standard composed of the analytes from a different source than those used in the standards for the instrument calibration.

5.6.2.4 Calculations

$$\% \ Recovery = \frac{Found\ Concentration}{True\ Concentration} \times 100 \qquad \text{Eq. D-28}$$

5.6.2.5 Technical Acceptance Criteria

Recovery for the ICV shall be within ± 10 percent of the true value (i.e., 90-110 percent).

5.6.2.6 Corrective Action

When recoveries of the ICV exceed the technical acceptance criteria, the analysis shall be terminated, the problem corrected, the instrument recalibrated, and the calibration reverified.

5.6.2.7 Documentation

Report the ICV found concentration (in µg/L), true concentration (in µg/L), and percent recovery on FORM II-AAIN.

5.6.3 Continuing Calibration Verification

5.6.3.1 Summary

To ensure calibration accuracy during an analysis run, a continuing calibration verification solution (CCV) is analyzed and reported for every wavelength used for the analysis of each analyte.

5.6.3.2 Frequency

The CCV is run at a frequency of 10 percent or every two hours during an analysis run, whichever is more frequent.

The CCV is also run after the last analytical sample in the analysis run.

5.6.3.3 Procedure

The CCV shall contain the analytes at a concentration at or near the mid-range of the calibration curve.

The same CCV shall be used throughout all analysis runs for a Case of samples received.

If the ICV solution(s) are not available from EPA, or where a certified solution of an analyte is not available from any source, analyses shall be conducted on an independent standard at a concentration other than that used for instrument calibration, but within the calibration range. An independent standard is defined as a standard composed of the analytes from a different source than those used in the standards for the instrument calibration.

Each CCV analyzed shall reflect the conditions of analysis for all the associated analytical samples (the preceding 10 analytical samples or the preceding analytical samples up to the previous CCV). The duration of analysis, rinses and other related operations that may affect the CCV measured result shall not be applied to the CCV to a greater extent than the extent applied to the associated analytical samples. For instance, the difference in time between a CCV analysis and the blank immediately following it as well as the difference in time between the CCV and the analytical sample immediately preceding it shall not exceed the lowest difference in time between any two consecutive analytical samples associated with the CCV.

5.6.3.4 Calculations

$$\%\ Recovery = \frac{Found\ Concentration}{True\ Concentration} \times 100 \qquad \text{Eq. D-29}$$

5.6.3.5 Technical Acceptance Criteria

Recovery for the CCV shall be within ± 10 percent of the true value (i.e., 90-110 percent).

5.6.3.6 Corrective Action

When recoveries of the CCV exceed the technical acceptance criteria, the analysis shall be stopped, the problem corrected, the

instrument recalibrated, the calibration reverified, and the preceding 10 analytical samples reanalyzed (or all analytical samples since the last compliant CCV).

5.6.3.7 Documentation

Report the CCV found concentration (in µg/L), true concentration (in µg/L), and percent recovery on FORM II-AAIN.

5.6.4 CRQL Standard

5.6.4.1 Summary

To verify linearity near the CRQL, the Contractor shall analyze a GFAA standard at two times the CRQL or two times the MQL, whichever is greater. This standard shall be run for every wavelength used for analysis.

5.6.4.2 Frequency

The CRQL standard shall be run at the beginning and end of each sample analysis run, or a minimum of twice per eight hours, whichever is more frequent.

5.6.4.3 Procedure

The CRQL standard is not to be run before the ICV solution.

5.6.4.4 Calculations

$$\% \text{ Recovery} = \frac{\text{Found Concentration}}{\text{True Concentration}} \times 100 \qquad \text{Eq. D-30}$$

5.6.4.5 Technical Acceptance Criteria

Recovery of the CRQL standard shall be within ± 15 percent of the true value for each wavelength used for analysis.

5.6.4.6 Corrective Action

If the CRQL standard recovery does not fall within the technical acceptance criteria, terminate the analysis, correct the problem and reanalyze all analytical samples since the last compliant CRQL standard.

5.6.4.7 Documentation

Report the CRQL standard's found concentration (in µg/L), true concentration (in µg/L), and percent recovery on FORM III-AAIN.

5.6.5 Initial Calibration Blank

5.6.5.1 Summary

To verify that the GFAA system is not contaminated, an initial calibration blank (ICB) shall be analyzed after calibration.

5.6.5.2 Frequency

The ICB shall be analyzed each time the system is calibrated and immediately after the ICV.

5.6.5.3 Procedure

If the absolute value of the ICB is greater than the MQL, the result shall be reported.

5.6.5.4 Calculations

Not applicable.

5.6.5.5 Technical Acceptance Criteria

The absolute value of the ICB must be less than the CRQL.

5.6.5.6 Corrective Action

When the ICB concentration does not meet the technical acceptance criteria, terminate analysis, correct the problem, recalibrate, verify the calibration, and reanalyze the ICB.

5.6.5.7 Documentation

Report the ICB values in µg/L on FORM IV-AAIN.

5.6.6 Continuing Calibration Blanks

5.6.6.1 Summary

To ensure that the system is not contaminated during the analysis run, continuing calibration blanks (CCB) are analyzed.

5.6.6.2 Frequency

Analyze the CCB at a frequency of 10 percent or every two hours, whichever is more frequent.

Analyze the CCB after every CCV.

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5.6.6.3 Procedure

A CCB shall be run after the last CCV in the analysis run.

If the absolute value of the CCB is greater than the MQL, the result shall be reported.

5.6.6.4 Calculations

Not applicable.

5.6.6.5 Technical Acceptance Criteria

The absolute value of the CCB must be less than the CRQL.

5.6.6.6 Corrective Action

When the CCB concentration does not meet the technical acceptance criteria, terminate analysis, correct the problem, recalibrate, verify the calibration, and reanalyze the preceding 10 analytical samples (or all analytical samples since the last compliant CCB).

5.6.6.7 Documentation

Report the ICB values in µg/L on FORM IV-AAIN.

5.6.7 **Preparation Blanks**

5.6.7.1 Summary

To ensure against contamination during sample preparation, a preparation blank (PB) is analyzed.

5.6.7.2 Frequency

At least one PB shall must be prepared and analyzed with every SDG or with each batch of samples digested, whichever is more frequent.

5.6.7.3 Procedure

The PB shall consist of ASTM Type II water processed through each sample preparation and analysis procedure step (see Exhibit D).

The first batch of samples in an SDG is to be assigned to PB one, the second batch of samples to PB two, etc.

5.6.7.4 Calculations

Not applicable.

5.6.7.5 Technical Acceptance Criteria

The absolute value of the PB must be less than the CRQL.

5.6.7.6 Corrective Action

If the absolute value of the PB concentration is less than or equal to the CRQL, no corrective action is required.

If any analyte concentration in the blank is above the CRQL, the lowest concentration of that analyte in the associated samples must be 10 times the blank concentration. Otherwise, all samples associated with the blank and with the analyte's concentration less than 10 times the blank concentration and above the CRQL shall be redigested and reanalyzed for that analyte. The sample concentration is not to be corrected for the blank value.

If the concentration of the blank is below the negative CRQL, then all samples reported below 10 times CRQL associated with the blank shall be redigested and reanalyzed.

5.6.7.7 Documentation

The values for the PB shall be recorded in µg/L on FORM IV-AAIN.

5.6.8 Spike Sample Analysis

5.6.8.1 Summary

To provide information about the effect of the sample matrix on the digestion, a known amount of analyte is added (spiked) into a sample.

5.6.8.2 Frequency

At least one spike sample analysis shall be performed on each group of samples for each SDG. (EPA may require additional spike sample analysis upon special request by the Project Officer, for which the Contractor will be paid.)

If two analytical methods are used to obtain the reported values for the same metal within a SDG (e.g., ICP and GFAA), then spike samples shall be run by each method used.

5.6.8.3 Procedure

The spike is added before the sample preparation (i.e., prior to digestion) at the concentration levels in the Spike Sample solution as indicated in Table D-3.

Samples identified as field blanks cannot be used for spiked sample analysis.

EPA may require that a specific sample be used for the spike sample analysis.

In the instance where there is more than one spike sample per method per SDG and one spike sample recovery is not within contract criteria, flag all the samples for the same method in the SDG.

5.6.8.4 Calculations

$$\% \ Recovery = \frac{SSR - SR}{SA} \times 100 \qquad \text{Eq. D-31}$$

where:

SSR = Spiked Sample Result, µg/L;
SR = Sample Result, µg/L; and
SA = Spike Added, µg/L.

If the spike analysis is performed on the same sample that is chosen for the duplicate sample analysis, spike calculations shall be performed using the results of the sample designated as the "original sample" (see 5.6.9 Duplicate Sample Analysis). The average of the duplicate results cannot be used for the purpose of determining percent recovery.

When the sample concentration is less than the instrument detection limit, use SR = 0 only for purposes of calculating percent recovery.

5.6.8.5 Technical Acceptance Criteria

Recovery for the spike should be within ± 25 percent of the spiked amount (i.e., 75-125 percent).

5.6.8.6 Corrective Action

If the spike recovery is not at or within the limits of 75-125 percent, the data of all samples received associated with that spike sample and determined by the same analytical method shall be flagged with the letter "N" on FORMs I-AAIN and VII-AAIN.

An exception to this rule is granted in situations where the sample concentration exceeds the spike concentration by a factor of four or more. In such an event, the data shall be reported unflagged even if the percent recovery does not meet the 75-125 percent recovery criteria.

When the digestion spike recovery falls outside the technical acceptance criteria and the sample result does not exceed four times the spike added, an analytical spike must be performed for those metals that do not meet the specified criteria (exception: Ag). Spike the unspiked aliquot of the sample at two times the indigenous level or two times CRQL, whichever is greater.

5.6.8.7 Documentation

Report the spiked sample results, sample results, spike added and percent recovery for the digestion spike sample analysis on FORM VI-AAIN.

The units for reporting spike sample results are µg/L.

5.6.9 Duplicate Sample Analysis

5.6.9.1 Summary

Duplicate aliquots of a sample are carried through the preparation and analysis steps to provide information about the precision of the analytical methods as well as matrix effects.

5.6.9.2 Frequency

At least one duplicate sample analysis shall be performed on each group of samples for each SDG. (EPA may require additional duplicate sample analysis upon special request by the Project Officer, for which the Contractor will be paid.)

If two analytical methods are used to obtain the reported values for the same metal within a SDG (e.g., ICP and GFAA), then duplicate samples shall be run for each method used.

5.6.9.3 Procedure

Samples identified as field blanks cannot be used for duplicate sample analysis.

EPA may require that a specific sample be used for the duplicate sample analysis.

In the instance where there is more than one duplicate sample per method per SDG and one duplicate result is not within contract criteria, then flag all the samples for the method in the SDG.

Duplicate sample analyses are required for calculation of relative percent difference.

Duplicates cannot be averaged for reporting on FORM I-AAIN.

5.6.9.4 Calculations

$$RPD = \frac{|S - D|}{\frac{S + D}{2}} \times 100 \qquad \text{Eq. D-32}$$

where:

RPD = Relative Percent Difference;
S = First Sample Value (original), µg/L; and
D = Second Sample Value (duplicate), µg/L.

5.6.9.5 Technical Acceptance Criteria

A control limit of ± 20 percent for RPD shall be used for original and duplicate sample values greater than or equal to five times CRQL (Exhibit C). A control limit of ± CRQL shall be used for sample values less than five times CRQL.

If one result is above the five times CRQL level and the other is below, use the ± CRQL criteria.

For duplicate results less than five times CRQL, enter the absolute value of the CRQL in the "CONTROL LIMIT" column of FORM VIII-AAIN.

If both sample values are less than the MQL, the RPD is not calculated.

Specific control limits for each metal will be added to FORM VIII-AAIN at a later date based on precision results.

5.6.9.6 Corrective Action

If the duplicate sample results are outside the control limits, flag all the data for samples received associated with that duplicate sample with an asterisk "*."

5.6.9.7 Documentation

The results of the duplicate sample analyses must be reported on FORM VIII-AAIN in µg/L.

The absolute value of the control limit (CRQL) shall be entered in the "CONTROL LIMIT" column of FORM VIII-AAIN.

5.6.10 Laboratory Control Samples

5.6.10.1 Summary

A laboratory control sample (LCS) is digested and analyzed to ensure against analyte loss in the sample preparation.

5.6.10.2 Frequency

One LCS shall be prepared and analyzed for every group of samples in a SDG or for each batch (i.e., a group of samples prepared at the same time) of samples, whichever is more frequent.

5.6.10.3 Procedure

The LCS shall be analyzed for each analyte using the same sample preparations, analytical methods and QA/QC procedures employed for the EPA samples received.

The LCS solution shall be obtained from EPA (if unavailable, the ICV solutions may be used).

If the EPA LCS is unavailable, other EPA Quality Assurance Check samples or other certified materials may be used.

5.6.10.4 Calculations

$$\% \text{ Recovery} = \frac{\text{Found Concentration}}{\text{True Concentration}} \times 100 \qquad \text{Eq. D-33}$$

5.6.10.5 Technical Acceptance Criteria

Recovery for the LCS shall be within ± 20 percent of the true value (i.e., 80-120 percent) with exception of Ag and Sb.

Technical acceptance criteria for Ag and Sb in the LCS will be determined at a later date.

5.6.10.6 Corrective Action

If the percent recovery for the LCS falls outside the technical acceptance criteria, the analyses shall be terminated, the problem corrected, and all samples associated with that LCS reprepared and reanalyzed.

5.6.10.7 Documentation

Report the LCS found concentration (µg/L), true concentration (µg/L), and percent recovery on FORM IX-AAIN.

5.6.11 Performance Evaluation Sample (PES)

5.6.11.1 Summary

The performance evaluation sample (PES) assists the Agency in monitoring the laboratory performance for analyte identification and quantification.

5.6.11.2 Frequency

One PES shall be delivered, prepared, and analyzed for every group of samples in a SDG, or for each batch of samples, whichever is more frequent.

5.6.11.3 Procedure

A PES shall be analyzed for each analyte using the same sample preparations, analytical methods and QA/QC procedures employed for the EPA samples received.

The PES solution shall be obtained from EPA. If unavailable, the contractor must contact the Agency and SMO for instructions.

5.6.11.4 Calculations

Not applicable.

5.6.11.5 Technical Acceptance Criteria

Recovery for the PES shall be within 75 percent of the true value of analyte.

5.6.11.6 Corrective Action

If the percent recovery for the PES falls below 75 percent, the Agency may take, but is not limited to the following actions:

- Show Cause and/or Cure Notice for unacceptable performance;
- Reduction of the number of samples shipped to the laboratory;
- Suspension of sample shipment;
- A site visit;
- A full data audit; or
- Require the laboratory to analyze a remedial PES.

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In addition to the above cited actions, the laboratory shall also provide the Technical and Administrative Project Officers a written correction action report on every unacceptable (less than 75 percent) PES score within seven days of written or verbal request by Agency personnel.

5.6.11.7 Documentation

Report the PES on Form I-AAIN (in µg/L) for all analytes.

5.6.12 Analytical Spike Sample Analysis/Method of Standard Additions

5.6.12.1 Summary

To ensure against bias resulting from interference effects in GFAA analyses, the Method of Standard Additions (MSA) is utilized. The special procedures summarized in Figure D-3 will be required for quantitation.

5.6.12.2 Frequency

All GFAA analyses for each analytical sample will require at least one analytical spike.

The frequency of MSA will depend on the recovery of the analytical spike.

A maximum of 10 full sample analyses to a maximum of 20 injections may be performed between consecutive calibration verifications and blanks. Each full MSA counts as two analytical samples towards determining 10 percent CCV/CCB frequency (i.e., five full MSAs can be performed between calibration verifications).

5.6.12.3 Procedure

All GFAA analyses including MSA shall fall within the calibration range.

Except during full MSA, all analyses require duplicate injections. Only single injections are required for MSA quantitation. Average concentration values are used for reporting purposes.

The analytical spike (at two times CRQL) of a sample must be run immediately after that sample. The percent recovery of the analytical spike will determine the method of quantitation for the sample.

The requirement for an analytical spike will include the LCS and the preparation blank. The LCS must be quantitated from the calibration curve and corrective action, if needed, taken accordingly.

MSAs are not to be performed on the LCS or preparation blank, regardless of spike recovery results. If the preparation blank analytical spike recovery is out of the control limits 85-115 percent, the spiking solution must be verified by respiking and rerunning the preparation blank once. If the preparation blank analytical spike recovery is still out of control, correct the problem and respike and reanalyze all analytical samples associated with the blank. An analytical spike is not required for the pre-digestion spike sample.

If the spike recovery is < 40 percent, the sample must be diluted by a factor of five to ten and rerun with another spike. This step must only be performed once. If after the dilution the spike recovery is still < 40 percent, report data from the initial undiluted analysis and flag with an "E" to indicate interference problems.

If the spike recovery is ≥ 40 percent and the sample absorbance or concentration is < 50 percent of the spike, report the sample results to the MQL. If the spike is less than 85 percent or greater than 115 percent, flag the result with a "W."

If the sample absorbance or concentration is < 50 percent of the spike and the spike recovery is at or between 85 percent and 115 percent, the sample must be quantitated directly from the calibration curve and reported down to the MQL.

If the sample absorbance or concentration is ≤ 50 percent of the spike and the spike recovery is > 85 percent or greater than 115 percent, the sample must be quantitated by MSA.

For analytical runs containing only MSAs, single injections can be used for QC samples during that run. For instruments that operate in an MSA mode only, MSA can be used to determine QC samples during that run.

The sample and three spikes must be analyzed consecutively for MSA quantitation (the "initial" spike run data is specifically excluded from use in the MSA quantitation).

MSA spikes shall be prepared such that:

a) Spike 1 is approximately 50 percent of the sample concentration;

b) Spike 2 is approximately 100 percent of the sample concentration; and

c) Spike 3 is approximately 150 percent of the sample concentration (all concentrations expressed in μg/L).

5.6.12.4 Calculations

$$\% \ Recovery = \frac{SSR - SR}{SA} \times 100 \qquad \text{Eq. D-34}$$

where:
SSR = Spiked Sample Result;
SR = Sample Result; and
SA = Spike Added.

$$RSD = \frac{\sigma_{n-1}}{\bar{x}} \times 100 \qquad \text{Eq. D-35}$$

where:
RSD = Relative Standard Deviation
σ_{n-1} = Standard deviation; and
$\bar{x}$ = Mean

5.6.12.5 Technical Acceptance Criteria

For concentrations ≥ CRQL, the duplicate injections must agree within ± 20 percent of RSD or CV.

The analytical spike recoveries for the LCS and PB shall be within control limits of ± 15 percent (i.e., MSA is NOT performed on the LCS or PB).

5.6.12.6 Corrective Action

If the RSD (CV) technical acceptance criteria are not met, rerun the sample once. If the criteria are still not met, flag the value reported on FORM I-AAIN with the letter "M".

NOTE: The "M" flag is required for the analytical spike as well as the sample.

If the PB analytical spike technical acceptance criteria are not met, verify the spiking solution by respiking and rerunning the PB once. If the criteria are still not met, correct the problem and reanalyze all analytical samples associated with the blank.

If the LCS analytical spike technical acceptance criteria are not met, correct the problem and reanalyze all analytical samples associated with that LCS.

5.6.12.7 Documentation

If the spike recovery is < 40 percent, the sample must be diluted by a factor of five to ten and rerun with another spike. This step

must only be performed once. If after the dilution the spike recovery is still < 40 percent, report data from the initial undiluted analysis and flag with an "E" to indicate interference problems.

If the spike recovery is ≥ 40 percent and the sample absorbance or concentration is < 50 percent of the spike, report the sample results to the MQL. If the spike is less than 85 percent or greater than 115 percent, flag the result with a "W."

If the sample absorbance or concentration is < 50 percent of the spike and the spike recovery is at or between 85 percent and 115 percent, the sample must be quantitated directly from the calibration curve and reported down to the MQL.

The raw data package must include absorbance and concentration values for both injections, the average value, and the coefficient of variation (or RSD).

The data for each MSA analysis must be clearly identified in the raw data documentation (using added concentration as the x-variable and absorbance as the y-variable) along with the slope, x-intercept, y-intercept, and correlation coefficient (r) for the least squares fit of the data.

Reported values obtained by MSA must be flagged with the letter "S" on FORM I-AAIN if the correlation coefficient is ≥ 0.995. If the correlation coefficient is ≤ 0.995, flag the data on FORMs I-AAIN and XII-AAIN with a "+".

5.6.13 Method Quantitation Limits

5.6.13.1 Summary

The method quantitation limit (MQL) shall be determined before any samples are analyzed for every instrument that will be used.

5.6.13.2 Frequency

MQLs must be determined within 30 days of the start of the contract and at least quarterly (every three calendar months).

5.6.13.3 Procedure

MQLs (in μg/L) shall be determined by multiplying by three the average of the standard deviations (σ_{n-1}) obtained on three nonconsecutive days from the analysis of a standard solution (each analyte in reagent water) at a concentration three times to five times of the instrument manufacturer's suggested instrument detection limit (IDL), with seven consecutive measurements per day. Each measurement

must be performed as though it were a separate analytical sample (i.e., each measurement shall be followed by a rinse and/or any other procedure normally performed between the analysis of separate samples). MQLs shall be determined and reported for each wavelength used in the analysis of the samples.

The quarterly determined MQL for an instrument shall always be used as the MQL for that instrument during that quarter. If the instrument is adjusted in any way that may affect the MQL, the MQL for that instrument shall be redetermined and the results submitted for use as the established MQL for that instrument for the remainder of the quarter.

MQL must be determined in μg/L.

5.6.13.4 Calculations

$$MQL = 3 \times \sigma_{n-1} \qquad \text{Eq. D-36}$$

where:

σ_{n-1} = Standard Deviation

5.6.13.5 Technical Acceptance Criteria

The MQL shall meet the CRQLs established in Exhibit C.

5.6.13.6 Corrective Action

If an instrument's MQL cannot meet the CRQL for an analyte, that instrument cannot be used to quantitate an analyte unless the sample concentration exceeds five times the MQL.

5.6.13.7 Documentation

For each instrument used, MQLs shall be reported on FORM XV-AAIN and submitted with each data package. If multiple GFAA instruments are used for the analysis of a metal within a SDG, the highest MQL for the GFAAs shall be used for reporting concentration values for that SDG.

5.7 INSTRUMENT OPERATION

5.7.1 Set up the instrument with the proper operating parameters established by the instrument manufacturer. The individual steps (drying, charring and atomization) require careful consideration to ensure each process is carried out effectively. The instrument shall be allowed to become thermally stable before beginning any analysis. This usually requires at least 30 minutes of operation prior to calibration. Background correction shall be used.

5.7.2 Calibrate the instrument according to the manufacturer's recommended procedures using calibration standard solutions.

5.7.3 In order to determine if the sample result is to be calculated by MSA, an analytical spike at two times CRQL shall be performed and analyzed after each sample analysis. The analytical spike recovery shall be used to determine the need for MSA as explained in 5.6.12. The spiking solution volume shall not exceed 10 percent of the sample volume.

5.7.4 Dilute and reanalyze samples that are more concentrated than the linear range (i.e., top calibration standard) for an analyte.

5.8 **PROCEDURE**

5.8.1 **Calibration**

5.8.1.1 Set up the instrument with proper operating parameters. The instrument shall be allowed to become thermally stable before beginning analysis. This requires at least 30 minutes of operation with the lamp lit prior to calibration.

5.8.1.2 Initiate appropriate operating configuration of the computer, if used.

5.8.1.3 Calibrate the instrument using the appropriate matrix matched calibration standard solution(s). The number of standards utilized is left to the discretion of the operator but shall include a minimum of a calibration blank and at least three standards. The operator should be aware of the requirements in Exhibits D and E that provide for the assurance that all sample values are within the calibration range.

5.8.1.4 All standards, blanks, and sample solutions shall be matrix matched. A change in the acid strength changes the slope of the calibration curve and can cause inaccurate results.

5.9 **Analysis Sequence**

5.9.1 Before beginning the sample analysis run, analyze the ICB ICV, and CRA under the same operating conditions intended for sample analyses. The ICV found concentration values shall not deviate from the true values by more than 10 percent. The CRA recovery values must be within ± 15 percent of the true values. The calibration blank values may not exceed the CRQL. If these conditions are not met for any element, the analysis shall be discontinued and corrective action applied until the conditions are met (see Exhibits D and E for additional information).

5.9.2 Upon successful analysis of the ICV and ICB, analyze all method PB extract(s) prepared with the digested samples. If any of the

blank(s) are not less than or equal to the CRQL, see Exhibits D and E for the appropriate action.

5.9.3 If the method blank(s) values are acceptable, analyze the LCS. If any LCS values deviate from the acceptable ranges, see Exhibits D and E for the appropriate action.

5.9.4 If the LCS values are within the acceptable ranges, analyze the method spike sample. If the recovery of any element deviates from the acceptable ranges, see Exhibits D and E for the appropriate action. Proceed to the analysis of samples if the recoveries are acceptable or after consulting Exhibits D and E.

5.9.5 The CCV and the CCB must be analyzed after every 10 analytical sample analyses. CCV values shall not deviate from the actual values by more than ± 10 percent. In addition, the absolute values for the calibration blank shall be lower than the required quantitation limits. If these conditions are not met at any time during samples analysis, discontinue the analysis and see Exhibits D and E for the appropriate action.

5.9.6 At the end of the sample analysis run, analyze the CRA, CCB, and CCV. If the values for any of these samples deviates from the required limits, see Exhibits D and E.

5.10 **Sample Analyses**

5.10.1 All sample extracts must first be analyzed without any dilution. Diluting sample extracts is permissible if necessary provided that the dilution does not result in a sample concentration below CRQL.

5.10.2 All concentrations reported shall be obtained within the established calibration range for that analysis run. All concentrations within the calibration range of the analyte are to be reported.

5.10.3 In order to determine if the sample result is to be calculated by MSA, an analytical spike at two times CRQL shall be performed and analyzed immediately after each sample analysis. The analytical spike recovery is used to determine the need for MSA as explained in part 5.6.12 and Exhibit E. The spiking solution volume shall not exceed 10 percent of the sample volume.

5.10.4 Add appropriate volumes of the spiking standard to the remaining three aliquots that result in concentrations of 50 percent, 100 percent, and 150 percent of the sample concentration. The spiking standard solution volume added to each aliquot shall not exceed 10 percent of the volume of the aliquot. Add the appropriate amount of blank solution to each aliquot to make the total of spike plus blank volumes added equal.

5.10.5 Using a calculator or a statistical package on a computer, determine the slope, the intercepts of the ordinate (y-axis) and the abscissa (x-axis), and the correlation coefficient using the found concentration as the ordinate and the standard addition concentration as the abscissa. The absolute value of the intercept of the abscissa is the concentration of the analyte in the dilute solution. If the correction coefficient is less than 0.995, then the analyses shall be repeated. If the second analysis correlation coefficient is less than 0.995, then repeat the analysis using a smaller aliquot of the sample digest. Be certain to correct for the difference in volume created by using a smaller sample digest aliquot. If the correlation coefficient is still less than 0.995, flag the sample data with a "+."

5.11 Calculations

5.11.1 Determine the method detection limit (MQL) from the standard deviation of the method blank analyte analyses, based on the standard addition plot.

5.11.2 Calculate sample extract concentrations (µg/L) by multiplying the analyte concentration calculated by the appropriate dilution factors used in Sections 5.8.1. Calculate the air concentration for each analyte in µg/m³ by multiplying the analyte concentration in µg/L by the extract volume (liters) times 9 and dividing by the volume of the air sampled (standard m³) per filter and the number of filter strips digested. The factor "9" represents the area (63 in²) of the Hi-Vol filter exposed to the air stream divided by the exposed area (7 in²) in one 1"x8" strip.

$$\text{Analyte Conc. In air, } \mu g/m^3 = \frac{(9)\left(\text{Interference-Corrected Value, } \mu g/L\right)\left(\text{Extract Volume, } L\right)}{\text{no. of strips digested} \times \text{air volume sampled, std. } m^3} \quad \text{Eq. D-37}$$

Calculate all method spike levels relative to the corresponding unspiked sample concentration in units of µg/L.

Calculate the relative percent difference (RPD) for both the method and analysis duplicates. Calculate the RPD by dividing the absolute value of the difference between the sample value and the duplicate value by their mean and multiplying by 100.

$$RPD = \frac{|S - D|}{\frac{S + D}{2}} \times 100 \qquad \text{Eq. D-38}$$

where:

RPD = Relative Percent Difference;
S = First Sample Value (original), µg/L; and
D = Second Sample Value (duplicate), µg/L.

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SECTION 6

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TABLE D-1

RECOMMENDED ICP WAVELENGTHS AND ESTIMATED INSTRUMENTAL DETECTION LIMITS

Element	Wavelength, nm[1]	Estimated Detection Limit, µg/L[2]
Aluminum	308.215	45
Antimony	206.833	32
Arsenic	193.696	53
Barium	455.403	2
Beryllium	313.042	0.3
Boron	249.773	5
Cadmium	226.502	4
Calcium	317.933	10
Chromium	267.716	7
Cobalt	228.616	7
Copper	324.754	6
Iron	259.940	7
Lead	220.353	42
Magnesium	279.079	30
Manganese	257.610	2
Molybdenum	202.030	8
Nickel	231.604	15
Potassium	766.491	(See 3)
Selenium	196.026	75
Silver	238.068	7
Sodium	588.955	29
Thallium	190.864	40
Tin	189.99	42
Vanadium	292.402	8
Zinc	213.856	2

(1) The wavelengths listed are recommended because of their sensitivity and overall acceptance. Other wavelengths may be substituted if they can provide the needed sensitivity and are treated with the same corrective techniques for spectral interference. The use of alternate wavelengths shall be reported (in nm) with the sample data.

(2) The estimated instrumental detection limits as shown are taken from "Inductively Coupled Plasma-Atomic Emission Spectroscopy-Prominent Lines," EPA-600/4-79-017. They are given as a guide for an instrumental limit. The actual method detection limits are sample dependent and may vary as the sample matrix varies.

(3) Highly dependent on operating conditions and plasma position.

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TABLE D-2

EXAMPLE OF ANALYTE CONCENTRATION EQUIVALENTS (MG/L) ARISING FROM INTERFERENTS AT THE 100 MG/L LEVEL

Analyte	Wavelength (nm)	Interferent									
		Al	Ca	Cr	Cu	Fe	Mg	Mn	Ni	Ti	V
Aluminum	308.215	--	--	--	--	--	--	0.21	--	--	1.4
Antimony	206.833	0.47	--	2.9	--	0.08	--	--	--	0.25	0.45
Arsenic	193.696	1.3	--	0.44	--	--	--	--	--	--	1.1
Barium	455.403	--	--	--	--	--	--	--	--	--	--
Beryllium	313.042	--	--	--	--	--	--	--	--	0.04	0.05
Boron	249.773	0.04	--	--	--	0.32	--	--	--	--	--
Cadmium	226.502	--	--	--	--	0.03	--	--	0.02	--	--
Calcium	317.933	--	--	0.08	--	0.01	0.01	0.04	--	0.03	0.03
Chromium	267.716	--	--	--	--	0.003	--	0.04	--	--	0.04
Cobalt	228.616	--	--	0.03	--	0.005	--	--	0.03	0.15	--
Copper	324.754	--	--	--	--	0.003	--	--	--	0.05	0.02
Iron	259.940	--	--	--	--	--	--	0.12	--	--	--
Lead	220.353	0.17	--	--	--	--	--	--	--	--	--
Magnesium	279.079	--	0.02	0.11	--	0.13	--	0.25	--	0.07	0.12
Manganese	257.610	0.005	--	0.01	--	0.002	0.002	--	--	--	--
Molybdenum	202.030	0.05	--	--	--	0.03	--	--	--	--	--
Nickel	231.604	--	--	--	--	--	--	--	--	--	--
Selenium	196.026	0.23	--	--	--	0.09	--	--	--	--	--
Silicon	288.158	--	--	0.07	--	--	--	--	--	--	0.01
Sodium	588.995	--	--	--	--	--	--	--	--	0.08	--
Thallium	190.864	0.30	--	--	--	--	--	--	--	--	--
Vanadium	292.402	--	--	0.05	--	0.005	--	--	--	0.02	--
Zinc	213.856	--	--	--	0.14	--	--	--	0.29	--	--

TABLE D-3

SPIKING LEVELS FOR SPIKE SAMPLE ANALYSIS
FOR INORGANIC ANALYSES

Analyte	For ICP and ICP-MS (µg/L)	For GFAA (µg/L)
Aluminum	2,000	
Antimony	500	100
Arsenic	2,000	40
Barium	2,000	
Beryllium	2,000	
Cadmium	50	5
Calcium	*	
Chromium	200	
Cobalt	500	
Copper	250	
Iron	1,000	
Lead	500	20
Magnesium	*	
Manganese	500	
Nickel	500	
Potassium	*	
Selenium	2,000	10
Silver	50	
Sodium	*	
Thallium	2,000	50
Tin	500	
Vanadium	500	
Zinc	500	

* No spike required.

NOTE: Elements without spike levels and not designated with an asterisk, must be spiked at appropriate levels.

TABLE D-4

TUNIG SOLUTION FOR ICP-MS

Analyte	Concentration (µg/L)
^{7}Lithium	100
Cobalt	100
Indium	100
Thallium	100

NOTE: The tuning solution shall consist of the following analytes at the stated concentrations.

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TABLE D-5

TUNING, RESPONSE FACTOR AND MASS CALIBRATION CRITERIA

TUNING CRITERIA	
m/z	**Ion Abundance Criteria**
^{7}Lithium/^{59}Cobalt	0.20 - 1.00
^{59}Cobalt/^{59}Cobalt	1.00
^{115}Indium/^{59}Cobalt	0.75 - 2.00
^{205}Thallium/^{59}Cobalt	0.50 - 1.20
RESPONSE FACTOR CRITERIA	
m/z	**Response Factor Criteria**
^{7}Lithium	> 2,000
^{59}Cobalt	> 20,000
^{115}Indium	> 10,000
^{102}Ruthenium	< 25
^{205}Thallium	> 1,000
MASS CALIBRATION CRITERIA	
m/z	**Exact Mass**
^{7}Lithium	6.9160 - 7.1160
^{59}Cobalt	58.8332 - 59.0332
^{115}Indium	114.8040 - 115.0040
^{205}Thallium	204.8744 - 205.0744

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TABLE D-6

MEMORY TEST SOLUTION FOR ICP-MS

The memory solution shall consist of the following analytes:

Analyte
Aluminum (Al)
Antimony (Sb)
Arsenic (As)
Barium (Ba)
Beryllium (Be)
Calcium (Ca)
Cadmium (Cd)
Carbon (C)
Chloride (Cl)
Chromium (Cr)
Cobalt (Co)
Copper (Cu)
Iron (Fe)
Lead (Pb)
Magnesium (Mg)
Manganese (Mn)
Molybdenum (Mo)
Nickel (Ni)
Phosphorus (P)
Potassium (K)
Selenium (Se)
Silver (Ag)
Sodium (Na)
Sulfur (S)
Titanium (Ti)
Tritium (T)
Vanadium (V)
Zinc (Zn)

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TABLE D-7

INTERNAL STANDARDS WHICH MAY BE USED IN ICP-MS

Internal Standard
Scandium (Sc)
Yttrium (Y)
Rhodium (Rh)
Indium (In)
Terbium (Tb)
Holmium (Ho)
Bismuth (Bi)
Lithium (Li)

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TABLE D-8

RECOMMENDED ELEMENTAL EXPRESSIONS FOR ISOBARIC INTERFERENCES

Analyte	Isobaric Correction	Expression Proportional to Analyte Concentration
Aluminum (Al)	None	$(1.0000)(^{27}M)$
Antimony (Sb)	None	$(1.0000)(^{121}M)$
Arsenic (As)	ArCl, Se	$(1.0000)(^{75}M) - (3.1277)(^{77}M) + (2.5288)(^{82}M)$
Barium (Ba)	None	$(1.0000)(^{135}M)$
Beryllium (Be)	None	$(1.0000)(^{9}M)$
Cadmium (Cd)	MoO, Sn	$(1.0000)(^{114}M) - (0.0268)(^{118}M) - (1.6285)(^{108}M)$
Calcium (Ca)	None	$(1.0000)(^{44}M)$
Chromium (Cr)	None	$(1.0000)(^{52}M)$
Cobalt (Co)	None	$(1.0000)(^{59}M)$
Copper (Cu)	None	$(1.0000)(^{65}M)$
Iron (Fe)	None	$(1.0000)(^{57}M)$
Lead (Pb)	None	$(1.0000)(^{208}M) + (1.0000)(^{207}M) + (1.0000)(^{206}M)$
Magnesium (Mg)	None	$(1.0000)(^{25}M)$
Manganese (Mn)	None	$(1.0000)(^{55}M)$
Nickel (Ni)	None	$(1.0000)(^{60}M)$
Silver (Ag)	None	$(1.0000)(^{107}M)$
Thallium (Tl)	None	$(1.0000)(^{205}M)$
Vanadium (V)	ClO, Cr	$(1.0025)(^{51}M) - (3.1158)(^{53}M) + (0.3533)(^{52}M)$
Zinc (Zn)	None	$(1.0000)(^{66}M)$
^{6}Lithium (Li)	None	$(1.0000)(^{6}M)$
Scandium (Sc)	None	$(1.0000)(^{45}M)$
Yttrium (Y)	None	$(1.0000)(^{89}M)$
Rhodium (Rh)	None	$(1.0000)(^{103}M)$
Indium (In)	Sn	$(1.0000)(^{115}M) - (0.0005)(^{118}M)$
Terbium (Tb)	None	$(1.0000)(^{159}M)$
Holmium (Ho)	None	$(1.0000)(^{165}M)$
Bismuth (Bi)	None	$(1.0000)(^{165}M)$

M = The total ion count rate at the specified mass.

TABLE D-9

CONTRIBUTIONS OF CONCOMITANT ANALYTES TO NEARY ANALYTES FOR ICP-MS WHEN RESOLUTION AND MEASUREMENT SCHEMES VARY

Analyte	Interferent Analyte	Peak Width at 10% of the Peak Height			
		1.0 amu Integration Width		0.8 amu Integration Width	
		0.9 amu	0.3 amu	0.9 amu	0.3 amu
^{121}Sb	^{120}Sn	60	300	3	310
^{121}Sb	^{122}Te	360	730	940	600
^{75}As	^{74}Se, ^{76}Se	50	40	160	35
^{9}Be	^{10}B	100	None	None	None
^{112}Cd	^{113}In	40	560	680	None
^{114}Cd	^{115}In	1.5	380	20	670
^{116}Cd	^{115}In	15	25	0.5	25
^{52}Cr	^{51}V	140	110	110	90
^{53}Cr	^{54}Fe	5	7	15	7
^{59}Co	^{58}Ni, ^{60}Ni	70	610	300	660
^{63}Cu	^{62}Ni, ^{64}Ni	30	30	20	20
^{63}Cu	^{64}Zn	25	25	10	20
^{65}Ni	^{64}Ni	30	30	20	20
^{65}Cu	^{64}Zn, ^{66}Zn	20	25	10	20
^{206}Pb	^{205}Tl	110	50	1	30
^{208}Pb	^{209}Bi	2	130	160	90
^{55}Mn	^{54}Fe, ^{56}Fe	20	250	120	310
^{202}Hg	^{203}Tl	0.01	70	40	None
^{60}Ni	^{59}Co	110	75	160	90
^{62}Ni	^{63}Cu	1	50	20	60
^{107}Ag	^{106}Pd, ^{108}Pd	30	210	5	280
^{107}Ag	^{106}Cd, ^{108}Cd	500	530	80	540
^{109}Ag	^{108}Pd, ^{110}Pd	60	210	5	270
^{109}Ag	^{108}Cd, ^{110}Cd	70	510	90	530
^{205}Tl	^{206}Pb	30	60	140	80
^{51}V	^{52}Cr	15	200	170	220
^{64}Zn	^{65}Cu, ^{63}Cu	20	110	70	140
^{66}Zn	^{65}Cu	60	60	80	60

NOTE: Concentrations listed are the approximate level (mg/L) of interferent which gives an analyte concentration of 10 μg/L.

TABLE D-10

ISOBARIC MOLECULAR-ION INTERFERENCES WHICH COULD AFFECT THE ANALYTES

Analyte	Oxygen Inter.	Hydroxyl Inter.	Nitrogen Inter.	Chlorine Inter.	Sulfur Inter.	Carbon Inter.	Other
^{121}Sb	PdO		AgN			AgC	
^{123}Sb	AgO		AgN	SrCl	ZrS	CdC	
^{75}As	CoO	NiOH	NiN	ArCl	CaS	CuC	
^{138}Ba	SnO	SbOH					
^{137}Ba	SbO	SnOH		MoCl			
^{136}Ba	SnO	SnOH				SnC	
^{135}Ba	SnO	SnOH		MoCl			
^{134}Ba	SnO	SnOH	SnN	MoCl		SnC	
^{132}Ba	SnO, CdO	InOH	SnN	MoCl	MoS	SnC	
^{130}Ba	CdO	CdOH	SnN, CdN	MoCl	MoS	SnC	
^{9}Be							
^{114}Cd	MoO	MoOH	MoN	SeCl	SeS		
^{112}Cd	MoO, ZrO	MoOH	MoN	SeCl, AsCl	SeS	MoC	
^{111}Cd	MoO	MoOH	MoN	GeCl			
^{110}Cd	MoO, ZrO		MoN, ZrN	GeCl, AsCl	SeS	MoC	
^{113}Cd	MoO	MoOH		SeCl, AsCl			
^{116}Cd	MoO						
^{106}Cd	ZrO		MoN, ZrN		GeS	MoC, ZrC	
^{108}Cd	MoO, ZrO	ZrOH	MoN, ZrN	GeCl	SeS, GeS	MoC, ZrC	
^{52}Cr	ArO	ClOH				ArC	Mo^{++}
^{53}Cr	ClO	ArOH	KN	NCl, OCl		KC	
^{50}Cr	SO		ArN		SO	ArC	Sn^{++}
^{54}Cr		ClOH	ArN, CaN			CaC	ArNa
^{59}Co	CaO	CaOH	ScN	MgCl	AlS	TiC	
^{63}Cu	TiO, PO_2	TiOH	TiN	SiCl, MgCl	PS	VC	
^{65}Cu	TiO	TiOH	VN	SiCl	SS, SO_2H	CrC	
^{208}Pb							
^{206}Pb							
^{207}Pb							
^{204}Pb							
^{55}Mn	KO	ArOH	KN		NaS	CaC	Cd^{++}
^{202}Hg	WO						
^{200}Hg	WO	WOH	WN				
^{199}Hg	WO	WOH					
^{201}Hg		WOH					
^{198}Hg	WO	TaOH	WN			WC	
^{204}Hg							

TABLE D-10 (Continued)

Analyte	Oxygen Inter.	Hydroxyl Inter.	Nitrogen Inter.	Chlorine Inter.	Sulfur Inter.	Carbon Inter.	Other
^{196}Hg			WN			WC	
^{58}Ni	CaO	KOH	CaN	NaCl	MgS	TiC	Cd^{++}, Sn^{++}
^{60}Ni	CaO	CaOH	TiN	MgCl, NaCl	SiS	TiC	Sn^{++}
^{62}Ni	TiO	ScOH	TiN	AlCl, MgCl	SiS	TiC, CrC	Sn^{++}
^{61}Ni	ScO	CaOH	TiN	MgCl	SiS	TiC	Sn^{++}
^{64}Ni	TiO	TiOH	TiN, CrN	SiCl, AlCl	SS	CrC	
^{80}Se	ZnO	CuOH	ZnN	ScCl, CaCl	TiS	ZnC	
^{78}Se	NiO	NiOH	ZnN	CaCl, KCl	TiS	ZnC	
^{82}Se	ZnO	CuOH	ZnN	TiCl, ScCl	TiS, CrS		
^{76}Se	NiO	CoOH	NiN	KCl	CaS	ZnC	
^{77}Se	NiO	NiOH	CuN	CaCl, ArCl	ScS	CuC	
^{74}Se	NiO	FeOH	NiN	ClCl, KCl	CaS	NiC	
^{107}Ag	ZrO	ZrOH		GeCl	AsS	MoC	
^{109}Ag		MoOH	MoN	GeCl	SeS	MoC	
^{205}Tl							
^{203}Tl		WOH					
^{51}V	ClO	SOH	ClN	ClO, ClN	FS	KC	
^{50}V	SO		ArN			ArC	Mo^{++}
^{64}Zn	TiO	TiOH	TiN, CrN	SiCl, AlCl	SS	CrC	
^{66}Zn	TiO	TiOH	CrN	PCl, SiCl	SS	FeC	
^{68}Zn	CrO	VOH	FeN	PCl	ArS	FeC	Ba^{++}
^{67}Zn	VO	TiOH, CrOH	CrN	SCl	ClS	MnC	Ba^{++}
^{70}Zn	FeO	CrOH	GeN	ClCl	ArS	NiC	

NOTE: The information provided in this table does not indicate that all of the described interferences need to be tested. However, the table can be consulted for informational purposes if unusual samples are encountered.

TABLE D-11

MASS CHOICES FOR ANALYTES WHICH MUST BE MONITORED
EITHER DURING THE ANALYTICAL RUN OR IN A SEPARATE SCAN FOR ICP-MS

Analytes of Interest	Mass
Aluminum	27
Antimony	121, 123
Arsenic	75
Barium	138, 137, 136, 135, 134, 132, 130
Beryllium	9
Cadmium	114, 112, 111, 110, 113, 116, 106, 108
Calcium	42, 43, 44, 46, 48
Cerium	140
Chlorine	35, 37
Chromium	52, 53, 50, 54
Cobalt	59
Copper	63, 65
Gallium	69
Germanium	72
Iron	56, 54, 57, 58
Krypton	83
Lanthanum	139
Lead	208, 207, 206, 204
Magnesium	24, 25, 26

TABLE D-11 (Continued)

Analytes of Interest	Mass
Manganese	55
Mercury	202, 200, 199, 201
Molybdenum	98, 96, 92, 97, 94
Nickel	58, 60, 62, 61, 64
Palladium	105
Potassium	39
Selenium	80, 78, 82, 76, 77, 74
Silver	107, 109
Sodium	23
Tellurium	125
Thallium	205, 203
Tin	118
Titanium	47, 49
Vanadium	51, 50
Xenon	129
Zinc	64, 66, 68, 67, 70

NOTE: The masses which must be monitored are indicated by underlining, it is strongly recommended that the other elements be monitored to indicate other potential molecular interferences which could affect the data quality.

FIGURE D-1

TEMPLATE FOR CUTTING GLASS-FIBER FILTERS

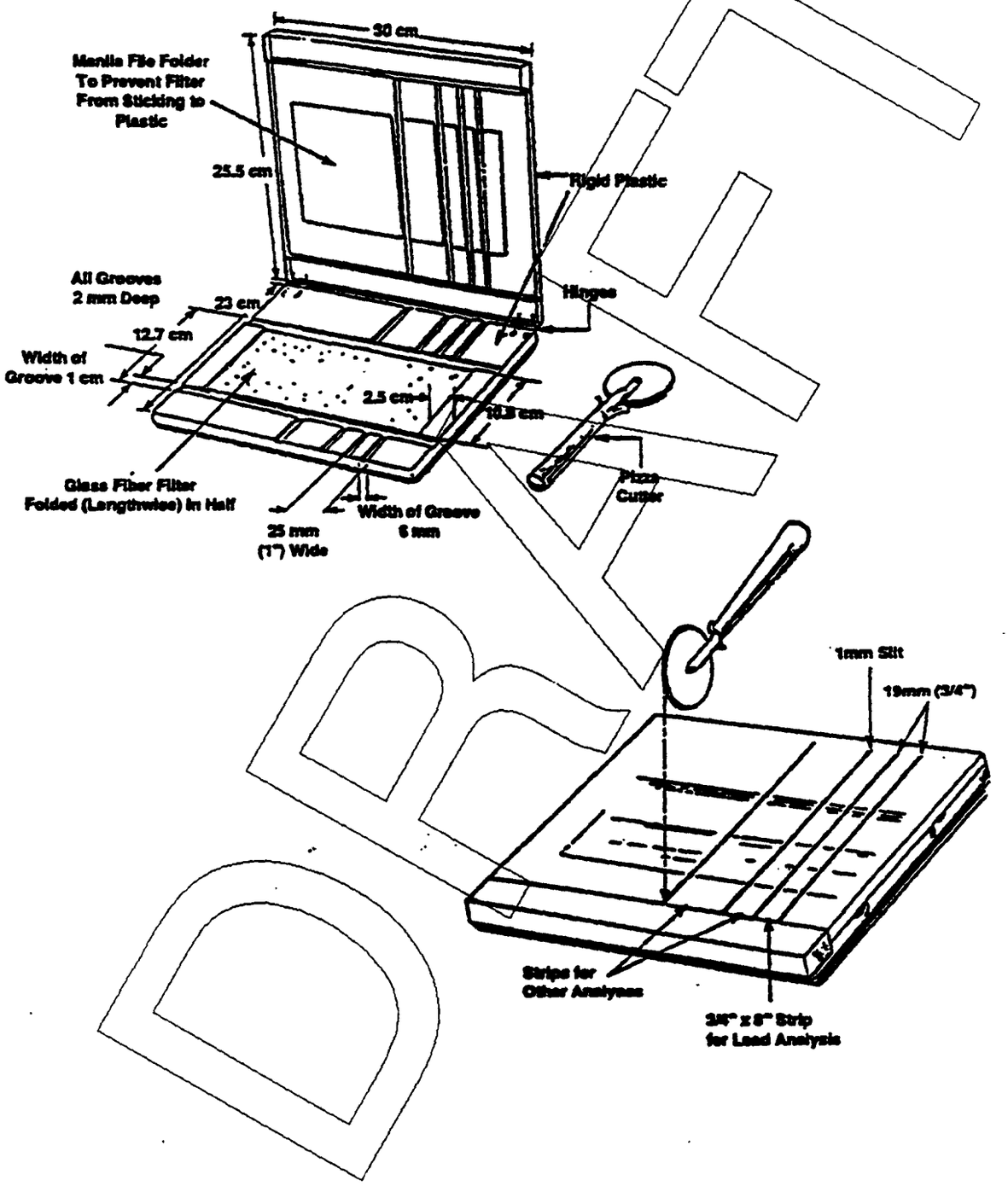

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FIGURE D-2

MICROWAVE DIGESTION SYSTEM

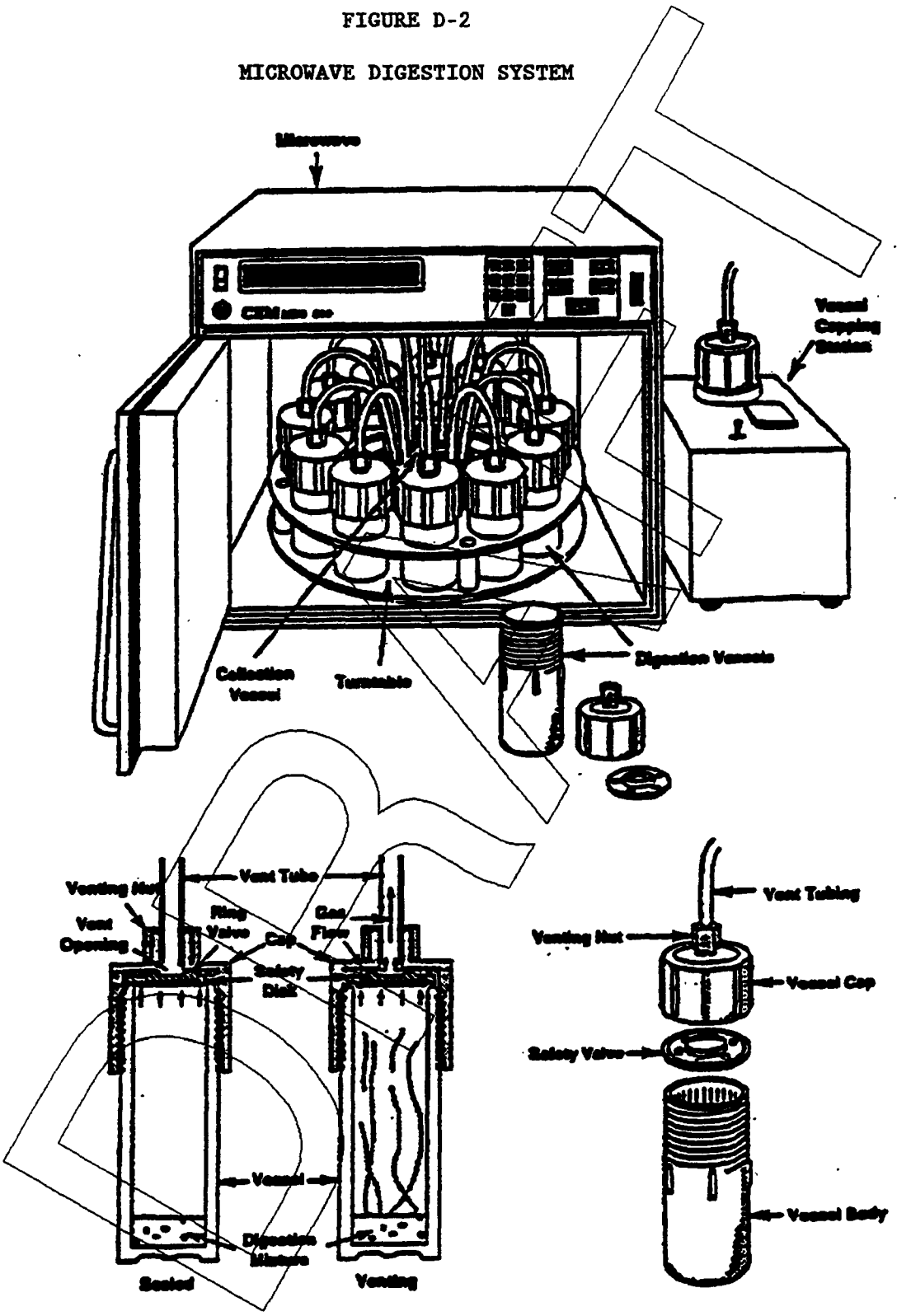

FIGURE D-3
FURNACE ATOMIC ABSORPTION ANALYSES SCHEME

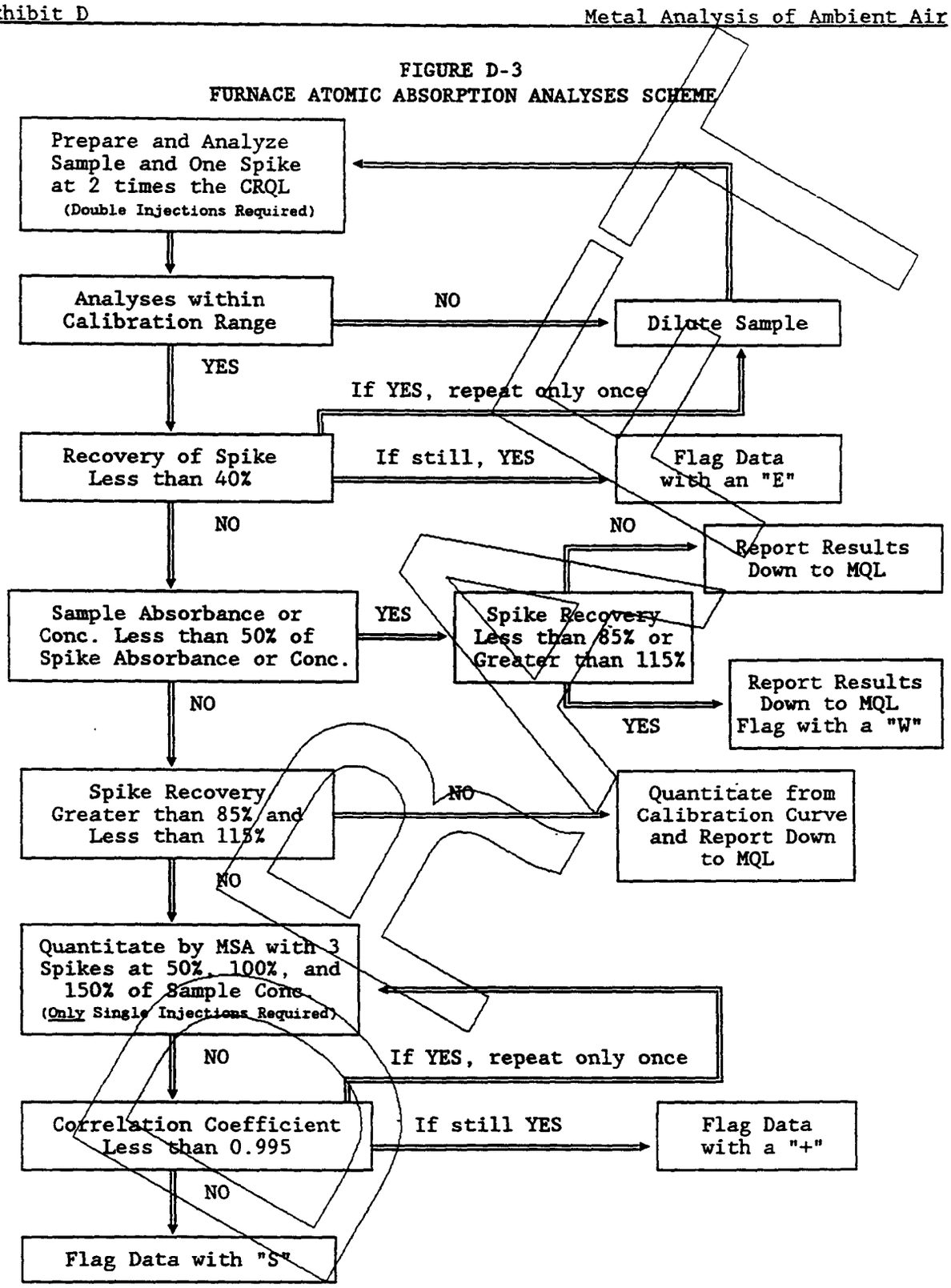

EXHIBIT E

QUALITY ASSURANCE REQUIREMENTS

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December, 1991

EXHIBIT E

QUALITY ASSURANCE REQUIREMENTS

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SECTION 1

INTRODUCTION

Quality assurance (QA) and quality control (QC) are integral parts of EPA's Contract Laboratory Program (CLP). The CLP QA program consists of management review and oversight at the planning, implementation, and completion stages of environmental data generation activities to ensure that data provided are of the quality required. The CLP QC program includes those activities required as part of data generation to ensure that the data are of known and documented quality.

During the planning of an environmental data collection program, QA activities focus on defining data quality objectives and criteria, and designing a QC system to measure and document the quality of data that will be generated. During the implementation of the data collection effort, QA activities ensure that the QC system is functioning effectively, and that deficiencies are identified and corrected. After environmental data are generated, QA activities focus on assessing the quality of data obtained to determine their suitability to support enforcement or remedial decisions.

The purpose of this Exhibit is to describe the processes by which the CLP meets the quality objectives defined. This contract requires a variety of activities which represent the minimum QA/QC operations necessary to satisfy the analytical requirements associated with the determination of the different method analytes. These operations are designed to ensure the generation of comparable data from all Contractors. These requirements do not release the laboratory from maintaining its own QC checks on method and instrument performance.

Appropriate use of data generated under the great range of analytical conditions encountered in ambient air analyses requires reliance on the QC procedures and criteria incorporated into the methods. The methods in this contract have been validated on samples typical of those received by the laboratories participating in the CLP. However, the validation of these methods does not guarantee that they perform equally well for all samples collected under actual field conditions. Inaccuracies can result from causes such as sampling artifacts, equipment malfunctions, and human error. Therefore, the QC component of each method is indispensable.

The data acquired from QC procedures are used to estimate and evaluate analytical results and to determine the necessity for or the effect of corrective actions. The means used for evaluating the analytical results include quantitative and qualitative indicators of quality such as precision, accuracy, and detection limit. In addition, QC data give an overview of the activities required in an integrated program to generate environmental data of known and documented quality required to meet defined objectives.

Necessary components of a complete QA/QC program include internal QC criteria that demonstrate acceptable levels of performance, as determined by QA review. External review of data and procedures is accomplished by the

monitoring activities of the National Program Office, Regional data users, SMO, NEIC, and EMSL/LV. Each external review accomplishes a different purpose. These reviews are described in specific sections of this Exhibit. Performance evaluation samples provide an external QA reference for the program. A laboratory on-site evaluation system is also part of the external QA monitoring. A feedback loop provides the results of the various review functions to the contract laboratories through direct communications with the APOs and TPOs.

This Exhibit is not a guide to constructing quality assurance project plans, quality control systems, or a quality assurance organization. It is, however, an explanation of the QA requirements of the CLP. It outlines some minimum standards for QA/QC programs. It also includes specific items that are required in a QA Plan, and the QA/QC documentation required by this contract. Delivery of this documentation provides the Agency with a complete data package which will stand alone, and limits the need for contact with the Contractor or with an analyst, at a later date, if some aspect of the analysis is questioned.

To ensure that the product delivered by the Contractor meets the requirements of the contract and to improve inter-laboratory data comparison, the Agency requires the following from the Contractor:

- Development and implementation of a QA program and documentation of the key elements of that QA program through a written QA Plan, as described in Section 2 of this Exhibit.
- Preparation of and adherence to written Standard Operating Procedures (SOPs) as described in Section 3 of this Exhibit.
- Adherence to the analytical methods and associated QC and documentation requirements specified in the contract.
- Verification of analytical standards and documentation of the purity of reference standard materials and the purity and accuracy of solutions obtained from private chemical houses.
- Participation in the analysis of laboratory performance evaluation samples, including adherence to corrective action procedures.
- Participation in on-site laboratory evaluations, including adherence to corrective action procedures.
- Submission of all raw data and pertinent documentation for Regional review.
- Submission for Agency review of all original documentation generated during sample analyses.

SECTION 2

QUALITY ASSURANCE PLANS

The Contractor shall establish a quality assurance program with the objective of providing sound analytical chemical measurements. This program shall incorporate the quality control procedures, a corrective action system, and all documentation required during data collection as well as the quality assessment measures performed by management to ensure acceptable data production.

As evidence of such a program, the Contractor shall prepare a written Quality Assurance Plan (QAP) which describes the procedures that are implemented to achieve the following:

- Maintain data integrity, validity, and usability.
- Ensure that analytical measurement systems are maintained in an acceptable state of stability and reproducibility.
- Detect problems through data assessment and establish corrective action procedures to ensure that the analytical process is reliable.
- Document all aspects of the measurement process in order to provide data that are technically sound and legally defensible.

The QAP must present, in specific terms, the policies, organization, objectives, and specific QA and QC activities designed to achieve the data quality requirements in this contract. Where applicable, SOPs pertaining to each element shall be included or referenced as part of the QAP. The QAP must be available during on-site laboratory evaluation and upon written request by the APO. Additional information relevant to the preparation of a QAP can be found in EPA and ASTM publications.

2.1 ELEMENTS OF A QUALITY ASSURANCE PLAN

The following key elements of the Contractors quality program shall be address in the QAP.

2.1.1 Contractor QA Policy and Objectives

2.1.2 Organization and Personnel

- QA Management;
  - Organization;
  - Assignment of QC and QA responsibilities; and

- Reporting relationships.

• Personnel;

- Staff resumes;
- Education and experience requirements pertinent to this Contract; and
- Training progress.

• Facilities and Equipment;

- Instrumentation and backup alternatives; and
- Maintenance activities and schedules.

• Document Control;

- Laboratory notebook policy;
- Sample and data tracking/custody procedures and documentation requirements;
- Logbook maintenance and archiving procedures;
- Case file organization, preparation, and review procedures; and
- Procedures for preparation, approval, review, revision, and distribution of SOPs.

• Analytical Methodology;

- Calibration procedures and frequency;
- Sample/extract handling and storage procedures;
- Sample preparation/extraction procedures;
- Sample analysis procedures; and
- Standards preparation procedures.

• Data Generation;

- Data collection procedures;
- Data reduction procedures;

- Data review procedures;
- Data reporting and authorization procedures; and
- Data management procedures.

• Quality Control Program; and

- Solvent, reagent, and adsorbent check analysis;
- Reference material analysis;
- Internal QC checks; and
- Corrective action and determination of QC limit Procedures.

• Quality Assurance Program Assessment.

- Data audits;
- Systems audits;
- Performance audits;
- Corrective action procedures;
- QA reporting procedures.

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SECTION 3

STANDARD OPERATING PROCEDURES

In order to obtain reliable results, adherence to prescribed analytical methodology is imperative. In any operation that is performed on a repetitive basis, reproducibility is best accomplished through the use of Standard Operating Procedures (SOPs). As defined by the EPA, an SOP is a written document that provides directions for the step-by-step execution of an operation, analysis, or action which is commonly accepted as the method for performing certain routine or repetitive tasks.

SOPs prepared by the Contractor must be functional; i.e., clear, comprehensive, up-to-date, and sufficiently detailed to permit duplication of results by qualified analysts. All SOPs, as presented to the Agency, must reflect activities as they are currently performed in the laboratory. In addition, all SOPs must:

- Be consistent with current EPA regulations, guidelines, and the CLP contract's requirements.
- Be consistent with instrument manufacturer's specific instruction manuals.
- Be available to the EPA during an on-site laboratory evaluation. A complete set of SOPs shall be bound together and available for inspection at such evaluations. During on-site evaluations, laboratory personnel may be asked to demonstrate the application of the SOPs.
- Provide for the development of documentation that is sufficiently complete to record the performance of all tasks required by the protocol.
- Describe the mechanism for demonstrating the validity of data reported by the Contractor and explaining the cause of missing or inconsistent results.
- Describe the corrective measures and feedback mechanism used when analytical results do not meet protocol requirements.
- Be reviewed regularly and updated as necessary when contract, facility, or Contractor procedural modifications are made.
- Be archived for future reference in usability or evidentiary situations.
- Be available at specific work stations as appropriate.

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- Be subject to a document control procedure which precludes the use of outdated or inappropriate SOPs.

3.1 SOP SPECIFICATIONS AND FORMAT

3.1.1 An SOP is defined as a written narrative step-by-step description of laboratory operating procedures including examples of laboratory documentation. The SOPs must accurately describe the actual procedures used in the laboratory, and copies of the written SOPs shall be available to the appropriate laboratory personnel. These procedures are necessary to ensure that analytical data produced under this contract are acceptable for use in EPA enforcement case preparation and litigation. The Contractor's SOPs shall provide mechanisms and documentation to meet each of the following specifications and shall be used by EPA as the basis for laboratory evidence audits.

3.1.2 The format for SOPs may vary depending upon the kind of activity for which they are prepared. However, at a minimum, the following sections must be included:

3.1.2.1 Title page.

3.1.2.2 Scope and application.

3.1.2.3 Definitions.

3.1.2.4 Procedures.

3.1.2.5 QC acceptance criteria.

3.1.2.6 Corrective Action Procedures, including procedures for secondary review of information being generated.

3.1.2.7 Documentation Description and example forms.

3.1.2.8 Miscellaneous notes and precautions.

3.1.2.9 References.

3.2 REQUIRED SOPS

3.2.1 Evidentiary SOPs

The Contractor shall develop and use adequate written SOPs to ensure sample and data accountability. Evidentiary SOPs shall include specific procedures for the following processes as they are performed by the Contractor:

3.2.1.1 Sample receipt and logging

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3.2.1.1.1 The Contractor shall have written SOPs for receiving and logging in the samples. The procedures shall include, documentation of the following information:

- Presence or absence of EPA chain-of-custody forms;
- Presence or absence of airbills or airbill stickers;
- Presence or absence of EPA Traffic Reports or SAS packing lists;
- Presence or absence of custody seals on shipping and/or sample containers and their condition;
- Custody seal numbers, when present;
- Presence or absence of sample tags;
- Sample tag ID numbers;
- Condition of the shipping container;
- Condition of the sample container;
- Verification of agreement or nonagreement of information on receiving documents and sample containers;
- Resolution of problems or discrepancies with SMO; and
- The definition of any terms used to describe sample condition upon receipt.

3.2.1.1.2 The Contractor shall have a designated sample custodian responsible for receipt of samples and have written SOPs describing his/her duties and responsibilities.

3.2.1.2 Sample identification

3.2.1.2.1 The Contractor shall have written SOPs for maintaining identification of EPA samples throughout the laboratory.

3.2.1.2.2 If the Contractor assigns unique laboratory identifiers, written SOPs shall include a description of the method used to assign the unique laboratory identifier and cross-reference to the EPA sample number.

3.2.1.2.3 If the Contractor uses prefixes or suffixes in addition to sample identification numbers, the written SOPs shall include their definitions.

3.2.1.3 Sample security

The Contractor shall have written SOPs for maintenance of the security of samples after log-in and shall demonstrate security of the sample storage and laboratory areas. The SOPs shall specifically include descriptions of all storage areas for EPA samples in the laboratory, and steps taken to prevent sample contamination. The SOPs shall include a list of authorized personnel who have access to secure storage areas.

3.2.1.4 Internal chain-of-custody of samples and data.

The Contractor shall have written SOPs for the chain-of-custody consisting of sample identification, chain-of-custody procedures, sample receiving procedures, and sample tracking procedures. For more information concerning the chain-of-custody procedures see Section 4 of this Exhibit.

3.2.1.5 Internal tracking of samples and data.

3.2.1.5.1 The Contractor shall have written SOPs for tracking the work performed on any particular sample. The tracking SOP shall include the following:

- A description of the documentation used to record sample receipt, sample storage, sample transfers, sample preparations, and sample analyses;
- A description of the documentation used to record instrument calibration and other QA/QC activities; and
- Examples of the document formats and laboratory documentation used in the sample receipt, sample storage, sample transfer, and sample analyses.

3.2.1.6 Laboratory document and information control

3.2.2 **Analytical SOPs**

The Contractor shall develop and use adequeate written SOPs to ensure that all data generated for the CLP are of known, documented, and acceptable quality. Analytical SOPs shall include specific procedures for the following processes as they are performed by the Contractor:

3.2.2.1 The Contractor shall have written SOPs for preventing sample contamination, during sample preparation, cleaning of glassware, storage, and analysis.

3.2.2.2 The Contractor shall have SOPs to ensure traceability of standards used in sample analysis QA/QC.

3.2.3 **Quality Management SOPs**

3.2.3.1 The Contractor shall have written SOPs for technical and managerial review of laboratory operation and data package preparation, laboratory data review/laboratory self inspection system. The procedures shall include but not be limited to documenting the following information:

3.2.3.1.1 Data flow and chain-of-command for data review;

3.2.3.1.2 Procedures for measuring precision and accuracy.

3.2.3.1.3 Evaluation of parameters for identifying systematic errors.

3.2.3.1.4 Procedures to assure that hardcopy deliverables are complete and compliant with the requirements in Exhibit B.

3.2.3.1.5 Demonstration of internal QA inspection procedure (demonstrated by supervisory sign-off on personal notebooks, internal PE samples, etc.).

3.2.3.1.6 Frequency and type of internal audits (e.g., random, quarterly, spot checks, perceived trouble areas).

3.2.3.1.7 Demonstration of problem identification-corrective actions and resumption of analytical processing. Sequence resulting from internal audit (i.e., QA feedback).

3.2.3.1.8 Documentation of audit reports, (internal and external), response, corrective action, etc.

3.2.3.2 The Contractor shall have written SOPs for organization and assembly of all documents relating to each EPA Case, including technical and managerial review. Documents shall be filed on a Case-specific basis. The procedures must ensure that all documents including logbook pages, sample tracking records, chromatographic charts, computer printouts, raw data summaries, correspondence, and any other written documents having reference to the Case are compiled in one location for submission to EPA. The system must include a document numbering and inventory procedure. For more information concerning document control and case file preparation, see Section 5 of this Exhibit.

3.2.3.3 The Contractor shall have written SOPs for sample analysis, management and handling, and reporting of data. The procedures shall include but not be limited to documenting the following information:

3.2.3.3.1 Procedures for controlling and estimating data entry errors.

3.2.3.3.2 Procedures for reviewing changes to data and deliverables and ensuring traceability of updates.

3.2.3.3.3 Life cycle management procedures for testing, modifying and implementing changes to existing computing systems including hardware, software, and documentation or installing new systems.

3.2.3.3.4 Database security, backup and archival procedures including recovery from system failures.

3.2.3.3.5 System maintenance procedures and response time.

3.2.3.3.6 Individual(s) responsible for system operation, maintenance, data integrity and security.

3.2.3.3.7 Specifications for staff training procedures.

3.2.3.4 The Contractor shall have written SOPs for laboratory safety.

3.3 HANDLING OF CONFIDENTIAL INFORMATION

3.3.1 A Contractor conducting work under this contract may receive EPA-designated confidential information from the Agency. Confidential information must be handled separately from other documentation developed under this contract. To accomplish this, the following procedures for the handling of confidential information have been established.

3.3.2 All confidential documents shall be under the supervision of a designated Document Control Officer (DCO).

3.3.3 Any samples or information received with a request of confidentiality shall be handled as "confidential." A separate locked file shall be maintained to store this information and shall be segregated from other nonconfidential information. Data generated from confidential samples shall be treated as confidential. Upon receipt of confidential information, the DCO logs these documents into a Confidential Inventory Log. The information is then made available to authorized personnel but only after it has been signed out to that person by the DCO. The documents shall be returned to the locked file at the conclusion of each working day. Confidential information may not be reproduced except upon approval by the EPA Contracting Officer. The DCO will enter all copies into the document control system. In addition, this information may not be disposed of except upon approval by the EPA Contracting Officer. The DCO shall remove and retain the cover page of any confidential information disposed of for one year and shall keep a record of the disposition in the Confidential Inventory Log.

3.4 SOPS DELIVERY REQUIREMENTS

Within forty-five (45) days of contract receipt, a complete set of SOPs relevant to this contract shall be sent to the TPO, SMO and EMSL/LV. Also, during the term of performance of the contract, copies of SOPs which have been amended or new SOPs which have been written shall be sent to the TPO, EMSL/LV (quality assurance SOPs) and NEIC (evidentiary SOPs).

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SECTION 4

CHAIN-OF-CUSTODY

A sample is physical evidence collected from a facility or from the environment. An essential part of hazardous waste investigation effort is that the evidence gathered be controlled. To accomplish this, the following sample identification, chain-of-custody, sample receiving, and sample tracking procedures have been established.

4.1 SAMPLE IDENTIFICATION

4.1.1 To ensure traceability of samples while in possession of the Contractor, the Contractor shall have a specified method for maintaining identification and tracking of samples throughout the laboratory.

4.1.2 Each air sample and sample preparation container shall be labeled with the EPA sample number or a unique laboratory identifier. If a unique laboratory identifier is used, it shall be cross-referenced to the EPA sample number.

4.2 CHAIN-OF-CUSTODY PROCEDURES

4.2.1 Because of the nature of the data being collected, the custody of EPA samples must be traceable from the time the samples are collected until the associated data are introduced as evidence in legal proceedings. The Contractor shall have procedures ensuring that EPA sample and data custody are maintained and documented. A sample is under custody if the following applies:

4.2.1.1 It is in your possession, or

4.2.1.2 It is in your view after being in your possession, or

4.2.1.3 It was in your possession and you locked it up, or

4.2.1.4 It is in a designated secure area (secure areas shall be accessible to authorized personnel only).

4.3 SAMPLE RECEIVING PROCEDURES

4.3.1 The Contractor shall designate a sample custodian responsible for receiving all samples.

4.3.2 The Contractor shall designate a representative to receive samples in the event that the sample custodian is not available.

4.3.3 The condition of the shipping containers and canisters shall be inspected upon receipt by the sample custodian or his/her representative.

4.3.4 The condition of the custody seals (intact/not intact) shall be inspected upon receipt by the sample custodian or his/her representative.

4.3.5 The sample custodian or his/her representative shall check for the presence or absence of the following documents accompanying the sample shipment:

4.3.5.1 Airbills or airbill stickers.

4.3.5.2 Custody seals.

4.3.5.3 EPA custody records.

4.3.5.4 EPA traffic reports or SAS packing lists.

4.3.5.5 Sample tags.

4.3.6 The sample custodian or his/her representative shall sign and date all forms (e.g., custody records, traffic reports or packing lists, and airbills) accompanying the samples at the time of sample receipt.

4.3.7 The Contractor shall contact SMO to resolve discrepancies and problems such as absent documents, conflicting information, broken custody seals, and unsatisfactory sample condition (e.g., leaking sample bottle).

4.3.8 The Contractor shall record the resolution of discrepancies and problems on Telephone Contact Logs.

4.3.9 The following information shall be recorded on appropriate Form AADC-1 by the sample custodian or his/her representative as samples are received and inspected:

4.3.9.1 Condition of the shipping container.

4.3.9.2 Presence or absence and condition of custody seals on shipping and/or sample containers.

4.3.9.3 Custody seal numbers, when present.

4.3.9.4 Condition of the sample canisters.

4.3.9.5 Presence or absence of airbills or airbill stickers.

4.3.9.6 Airbill or airbill sticker numbers.

4.3.9.7 Presence or absence of EPA custody records.

4.3.9.8 Presence or absence of EPA traffic reports or SAS packing lists.

4.3.9.9 Presence or absence of sample tags.

4.3.9.10 Sample tag identification numbers cross-referenced to the EPA sample numbers.

4.3.9.11 Verification of agreement or non-agreement of information recorded on shipping documents and sample containers.

4.3.9.12 Problems or discrepancies.

4.4 SAMPLE TRACKING PROCEDURES

The Contractor shall maintain records documenting all phases of sample handling from receipt to final analysis. The records shall include documentation of the movement of samples and prepared samples into and out of designated laboratory storage areas.

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SECTION 5

DOCUMENT CONTROL

The goal of the laboratory document control program is to assure that all documents for a specified SDG are accountable upon completion of the project. Accountable documents used by contract laboratories shall include but not be limited to logbooks, chain-of-custody records, sample work sheets, bench sheets, and other documents relating to the sample or sample analyses. The following document control procedures have been established to assure that all laboratory records are assembled and stored for delivery to the EPA or are available upon request from the EPA prior to the delivery schedule.

5.1 PREPRINTED LABORATORY FORMS AND LOGBOOKS

5.1.1 All documents produced by the Contractor which are directly related to the preparation and analysis of EPA samples shall become the property of the EPA and shall be placed in the complete sample delivery group file (CSF). All observations and results recorded by the laboratory but not on preprinted laboratory forms shall be entered into permanent laboratory logbooks. When all data from an SDG are compiled, all original laboratory forms and copies of all SDG-related logbook entries shall be included in the documentation package.

5.1.2 The Contractor shall identify the activity recorded on all laboratory documents which is directly related to the preparation and analysis of EPA samples.

5.1.3 Pre-printed laboratory forms shall contain the name of the laboratory and be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

5.1.4 Logbook entries shall be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

5.1.5 Logbook entries shall be in chronological order. Entries in logbooks, with the exception of instrument run logs and extraction logs, shall include only one SDG per page.

5.1.6 Pages in both bound and unbound logbooks shall be sequentially numbered.

5.1.7 Instrument run logs shall be maintained so as to enable a reconstruction of the run sequence of individual instruments. Because the laboratory must provide copies of the instrument run logs to the EPA, the laboratory may exercise the option of using only laboratory or EPA sample identification numbers in the logs for sample ID rather than

government agency or commercial client names to preserve the confidentiality of commercial clients.

5.1.8 Corrections to supporting documents and raw data shall be made by drawing a single line through the error and entering the correct information. Corrections and additions to supporting documents and raw data shall be dated and initialed. No information shall be obliterated or rendered unreadable. All notations shall be recorded in ink. Unused portions of documents shall be "crossed" out.

5.2 CONSISTENCY OF DOCUMENTATION

5.2.1 The Contractor shall assign a document control officer responsible for the organization and assembly of the CSF.

5.2.2 All copies of laboratory documents shall be complete and legible.

5.2.3 Original documents what include information relating to more than one SDG shall be filled in the CSF of the lowest SDG number. The copy(s) shall be placed in the other CSF(s) and the Contractor shall record the following information on the copy(s) in red ink:

"COPY"

"ORIGINAL IS FILED IN CSF _____"

The Contractor shall sign and date this addition to the copy(s).

5.2.4 Before releasing analytical results, the document control officer shall assemble and cross-check the information on sample tags, custody records, laboratory bench sheets, personal and instrument logs, and other relevant data to ensure that data pertaining to each particular sample or sample delivery group is consistent throughout the CSF.

5.3 DOCUMENT NUMBERING AND INVENTORY PROCEDURE

5.3.1 In order to provide document accountability of the completed analysis records, each item in a CSF shall be inventoried and assigned a serialized number as described in Exhibit B, Section 2.

CSF # - Region - Serialized number (For example: 75-2-0240).

5.3.2 All documents relevant to each SDG, including logbook pages, bench sheets, mass spectra, chromatograms, screening records, re-preparation records, re-analysis records, records of failed or attempted analysis, custody records, library research results, etc., shall be inventoried as a group.

5.3.3 The DCO shall be responsible for ensuring that all documents generated are placed in the CSF for inventory and are delivered to the EPA. The DCO shall place the sample tags in plastic bags in the file. Figure E-1 is an example of a document inventory.

FIGURE E-1

Example

DOCUMENT INVENTORY

Document Control #*	Document Type	No. of Pages
232-2-0001	Case File Document Inventory Sheet	1
232-2-0002	Chain-of-Custody Records	2
232-2-0003	Shipping Manifests	2
232-2-0004	Sample Tags	50
232-2-0005	SMO Inorganics Traffic Reports	10
232-2-0006	Inorganics Analysis Data Summary Sheets	17
232-2-0007	Analysts' Inorganics Notebook Pages	14
232-2-0008	ICP, ICP-MS and AA Instrument Logbook Pages	12
etc.	etc.	etc.

*This number is to be recorded on each set of documents.

5.4 STORAGE OF EPA FILES

The Contractor shall maintain EPA laboratory documents in a secure location.

5.5 SHIPPING DATA PACKAGES AND CSF

5.5.1 The Contractor shall document shipment of deliverables packages to the recipients. These shipments require custody seals on the containers placed such that they cannot be opened without damaging or breaking the seal. The Contractor shall document what was sent, to whom, the date, and the method (carrier) used.

5.5.2 The Contractor shall purge the CSF deliverable to the appropriate EPA Region 180 days after the report submission.

5.5.3 A copy of the transmittal letter for the CSF will be sent to NEIC and SMO.

5.5.4 The Document Control Form is used to document the receipt and inspection of shipping containers and samples. The Contractor shall submit one (1) original FORM AADC-1 for each shipping container.

5.5.5 The Contractor shall sign and date the airbill (if present), examine the shipping containers, and record the presence or absence of custody seals and their conditions.

5.5.6 The Contractor shall note any problems with the samples and follow the instructions explained in Exhibit B, Sample Log-In Sheet.

5.5.7 The Contractor shall submit a completed Document Control Form with each SDG package.

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SECTION 6

ANALYTICAL STANDARDS REQUIREMENTS

The U.S. Environmental Protection Agency will not supply analytical reference standards either for direct analytical measurements or for the purpose of traceability. All Contractors will be required to prepare reference standards from traceable National Institute of Standards and Technology Standard Reference Materials or NIST/EPA approved certified reference material. If the NIST/EPA reference standards are not available, the Contractor can purchase them from private chemical supply houses or venders, those standards necessary to successfully and accurately perform the analyses required in this protocol.

6.1 PREPARATION OF CHEMICAL STANDARDS FROM THE HIGH PURITY BULK MATERIAL

6.1.1 A Contractor may prepare its chemical standards from high purtiy materials. Contractor laboratories should obtain the highest purity possible when purchasing chemical standards; standards purchased at less than 97% purity must be documented as to why a higher purity could not be obtained.

6.1.2 Proper storage of chemical standards is essential in order to safeguard them from decomposition.

6.1.3 The weight of material to be weighed out for a specified volume should be calculated by taking into account the purity of the analyte and the desired concentration. The calculation should be verify by a second person for accuracy. All weighing should be performed on an analytical balance to the nearest 0.1 mg that has been standardized using standard weights and verified by a second person. The solvent used to dissolve the solute should be compatible with the protocol in which the standard is to be used; the solute should be soluble, stable, and nonreactive with the solvent. In the case of a multi-component solution, the components must not react with each other.

6.1.4 Transfer the solute to a volumetric flask and dilute to the specified solution volume with solvent after ensuring dissolution of the solute in the solvent. Sonication or warming may be performed to promote dissolution of the solute. This solution is to be called the primary standard and all subsequent dilutions must be traceable back to the primary standard.

6.1.5 Log notebooks are to be kept for all weighing and dilutions. All subsequent dilutions from the primary standard and the calculations for determining their concentrations are to be recorded and verified by a second person. All solution standards are to be refrigerated when not in use. All solution standards are to be clearly labeled as to the identity

of the compound or compounds, concentration, date prepared, solvent, and initials of the preparer.

6.2 PURCHASE OF CHEMICAL STANDARDS IN SOLUTION

Solutions of analytical reference standards can be purchased by Contractors provided they meet the following criteria.

6.2.1 Contractor laboratories must maintain the following documentation to verify the integrity of the standard solutions they purchase:

6.2.1.1 Purity confirmation of the standard material.

6.2.1.2 Chromatographic and quantitative documentation that the solution standard was QC checked according to the following:

6.2.1.2.1 The Contractor must purchase standards for which the quality is demonstrated statistically and analytically by a method of the supplier's choice. One way this can be demonstrated is to prepare and analyze three solutions; a high standard, a low standard, and a standard at the target concentration (see below). The Contractor must then demonstrate that the analytical results for the high standard and low standard are consistent with the difference in theoretical concentrations. This is done by the Student's t-test in part 6.2.1.2.2 which follows. If this is achieved, the Contractor must then demonstrate that the concentration of the target standard lies midway between the concentrations of the low and high standards. This is done by the Student's t-test. Thus the standard is certified to be within 10 percent of the target concentration.

6.2.1.2.2 If the procedure above is used, the supplier must document that the following have been achieved:

- Two solutions of identical concentration must be prepared independently from neat materials. An aliquot of the first solution must be diluted to the intended concentration (the "target standard"). One aliquot is taken from the second solution and diluted to a concentration 10 percent greater than the target standard. This is called the "high standard." One further aliquot is taken from the second solution and diluted to a concentration 10 percent less that the target standard. This is called the "low standard";

- Six replicate analyses of each standard (a total of 18 analyses) must be performed in the following sequence: low standard, target standard, high standard, low standard, target standard, high standard; and

- The mean and variance of the six results for each solution must be calculated using the following equations:

$$Mean = \frac{Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6}{6} \qquad \text{Eq. E-1}$$

$$Variance = \frac{Y_{12} + Y_{22} + Y_{32} + Y_{42} + Y_{52} + Y_{62} - (6 \times Mean)_2}{5} \qquad \text{Eq. E-2}$$

The values Y_1, Y_2, Y_3, ..., represent the results of the six analyses of each standard. The means of the low, target, and high standards are designated M_1, M_2, and M_3, respectively. The variances of the low, target, and high standards are designated V_1, V_2, and V_3, respectively. Additionally, a pooled variance, Vp, is calculated using the following equation:

$$V_p = \frac{\frac{V_1}{0.81} + V_2 + V_3}{\frac{1.21}{3}} \qquad \text{Eq. E-3}$$

If the square root of Vp is less than one percent of M_2, then M_2^2 /10,000 is to be used as the value of Vp in all subsequent calculations.

- The test statistic must be calculated use the following equation:

$$TEST\ STATISTIC = \frac{\left| \frac{M_3}{1.1} - \frac{M_1}{0.9} \right|}{\left(\frac{V_p}{3}\right)^{0.5}} \qquad \text{Eq. E-4}$$

If the test statistic exceeds 2.13 then the supplier has failed to demonstrate a twenty percent difference between the high and low standards. In such a case, the standards are not acceptable.

- The test statistic must be calculated using the following equation:

$$TEST\ STATISTIC = \frac{\left| M_2 - \left(\frac{M_1}{1.8}\right) - \left(\frac{M_3}{2.2}\right) \right|}{\left(\frac{V_p}{4}\right)^{0.5}} \qquad \text{Eq. E-5}$$

If the test statistic exceeds 2.13, the supplier has failed to demonstrate that the target standard concentration is midway

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between the high and low standards. In such a case, the standards are not acceptable.

- The 95 percent confidence intervals for the mean result of each standard must be calculated using the following equation:

$$\textit{INTERVAL FOR LOW STANDARD} = M_1 \pm (2.13)\left(\frac{V_P}{6}\right)^{0.5} \qquad \text{Eq. E-6}$$

$$\textit{INTERVAL FOR TARGET STANDARD} = M_2 \pm (2.13)\left(\frac{V_P}{6}\right)^{0.5} \qquad \text{Eq. E-7}$$

$$\textit{INTERVAL FOR HIGH STANDARD} = M_3 \pm (2.13)\left(\frac{V_P}{6}\right)^{0.5} \qquad \text{Eq. E-8}$$

These intervals must not overlap. If overlap is observed, then the supplier has failed to demonstrate the ability to discriminate the 10 percent difference in concentrations. In such a case, the standards are not acceptable. In any event, the laboratory is responsible for the quality of the standards employed for analyses under this contract.

6.3 REQUESTING STANDARDS FROM THE EPA STANDARDS REPOSITORY

Solutions of analytical reference materials can be ordered from the U.S. EPA Chemical Standards Repository, depending on availability. The Contractor can place an order for standards only after demonstrating that these standards are not available from commercial vendors in solution.

6.4 DOCUMENTATION OF THE VERIFICATION AND PREPARATION OF CHEMICAL STANDARDS

It is the Contractor's responsibility to maintain the necessary documentation to show that the chemical standards they have used in the performance of CLP analysis conform to the requirements previously listed. Weighing logbooks, calculations, chromatograms, mass spectra, whether produced by the Contractor or purchased from chemical supply houses, must be maintained by the Contractor and may be subject to review during on-site inspection visits. Documentation of standards preparation may be required to be sent to EPA for verification of contract compliance. In those cases where the documentation is supportive of the analytical results of data packages sent to EPA, such documentation is to be kept on file by the Contractors for a period of one year.

SECTION 7

METHOD SPECIFIC QC REQUIREMENTS

The purpose of this section is to outline the minimum QC operations that are an integral part of the analytical requirements associated with the determination of target analytes listed in Exhibit C, using the procedures in Exhibit D, Section 3 for metals collected on filter and analyzed by inductively coupled plasma (ICP) spectrometry, inductively coupled plasma-mass spectrometry (ICP-MS), and graphite furnace atomic absorption (GFAA) spectrometry. This section is <u>not</u> intended as a comprehensive quality control document, rather as a guide to the specific QC operations that must be considered for inorganic analyses. At a minimum, the laboratory is expected to address these operations in preparing the QAP discussed in Section 2 of this Exhibit, and the SOPs discussed in Section 3.

7.1 These operations include the following:

- Instrument Calibration;
- Initial Calibration Verification (ICV) and Continuing Calibration Verification (CCV);
- CRQL Standards;
- Linear Range Standard (LRS) Analyses (Quarterly);
- Initial Calibration Blank (ICB), Continuing Calibration Blank (CCB), and Preparation Blank (PB) Analyses;
- ICP and ICP-MS Interference Check Sample (ICS) Analyses;
- Spike Sample Analyses;
- Duplicate Sample Analyses;
- Laboratory Control Sample (LCS) Analyses;
- Performance Evaluation Sample (PES) Analyses;
- ICP Serial Dilution Analyses;
- Method Quantitation Limit (MQL) Determination; and
- Interelement Corrections for ICP and ICP-MS;
- Internal Standards for ICP-MS; and

- Furnace AA QC Analyses (Method of Standard Additions).

7.1.1 Instrument Calibration

7.1.1.1 Guidelines for instrument calibration are outlined in Exhibit D, Inorganics, Section 3.7.1 for ICP, Section 4.7.1 for ICP-MS, and Section 5.6.1 for GFAA. Each instrument shall be calibrated daily or once every 24 hours and each time the instrument is set up.

7.1.1.2 The calibration standards shall be prepared using the same type of matrix and at the same concentration as the preparation blank, following the procedures outlined in Exhibit D, Section 3.6 for ICP, Section 4.6 for ICP-MS, and Section 5.5 for GFAA.

7.1.2 Initial Calibration Verification (ICV)

7.1.2.1 Immediately after each of the ICP, ICP-MS, and GFAA systems have been calibrated, the accuracy of the initial calibration shall be verified and documented for each analyte by the analysis of EPA ICV solution(s). When resulting measurements exceed the control limits in Exhibit D, Section 3, Table D/IN-3, the analysis shall be terminated, the problem corrected, the instrument recalibrated, and the calibration reverified. For ICP, ICP-MS, and GFAA, the ICV shall be run and reported at each wavelength and mass used for analysis.

7.1.2.2 If the ICVs are not available from EPA, or a certified solution of an analyte is not available from any source, analyses shall be conducted on an independent standard at a concentration other than that used for regular instrument calibration, but within the calibration range. An independent standard is defined as a standard composed of the analytes from a different source than those used in the standards for the instrument calibration.

7.1.3 Continuing Calibration Verification (CCV)

7.1.3.1 To ensure calibration accuracy during each analysis run as required in Exhibit D, Section 3.7.3 for ICP, Section 4.7.3 for ICP-MS, and Section 5.6.3 for GFAA, the laboratory shall analyze a CCV solution, either prepared by EPA or Contractor-prepared, for every wavelength or mass used for analysis at the beginning of the run and after the last analytical sample.

7.1.3.2 Each CCV analyzed shall reflect the conditions of analysis of all associated analytical samples (the preceding 10 analytical samples or the preceding analytical samples up to the previous CCV). The duration of analysis, rinses, and other related operations that may affect the CCV measured result may not apply to the CCV to a greater extent than the extent applied to the associated analytical samples.

7.1.3.3 If the deviation of the CCV is greater than the control limits specified in Exhibit D, Section 3, Table D/IN-3, the analysis shall be terminated, the problem corrected, and the CCV reanalyzed only once. If the reanalysis yields a CCV value within control limits, then the preceding 10 analytical samples or all analytical samples analyzed since the last acceptable calibration verification shall be analyzed for the analytes affected. Otherwise the instrument shall be recalibrated, the calibration verified, and the affected analytical samples rerun.

7.1.4 **CRQL Standards**

7.1.4.1 To verify linearity near the CRQL for ICP, ICP-MS, and AA analysis, the Contractor shall analyze a CRQL standard (CRI and CRA) at two times the CRQL or two times the MQL, whichever is greater. The CRQL standard shall be analyzed at the beginning and end of each sample analysis run or a minimum of twice per eight hour working shift, whichever is more frequent, but not before ICV, as outlined in Exhibit D, Section 3.7.4 for ICP, Section 4.7.4 for ICP-MS, and 5.6.4 for AA. This standard must be run for every wavelength or mass used for analysis, except those for Al, Ba, Ca, Fe, Mg, Na, and K for ICP.

7.1.4.2 Results for the analysis of the CRQL standard must be within ± 15 percent of the true value for each wavelength used for analysis. If not, the analysis shall be terminated, the problem corrected, and the analytical samples since the last acceptable CRI or CRA reanalyzed.

7.1.5 **Linear Range Standard Analysis (Quarterly)**

7.1.5.1 For all ICP and ICP-MS analyses, a linear range verification check standard (LRS) shall be analyzed and reported quarterly (every three calendar months) for each element on FORM III-AAIN as outlined in Exhibit D, Section 3.7.5 for ICP and Section 4.7.5 for ICP-MS. This standard must be run for every wavelength or mass used for analysis.

7.1.5.2 Results for the analysis of the LRS must be within ± 5 percent of the true value for each wavelength or mass used for analysis. If not, the analysis must be terminated and successive dilutions of the standard must be reanalyzed until the control limits are met. The concentration of this standard that meets the control limits is the upper limit of the instrument linear range beyond which results cannot be reported under this contract without dilution of the analytical sample.

7.1.6 **Initial and Continuing Calibration Blanks Analyses**

7.1.6.1 A calibration blank must be analyzed at each wavelength or mass used for analysis immediately after every initial and continuing calibration verification, at a frequency of 10 percent of every two

hours during the run, whichever is more frequent, as outlined in Exhibit D, Sections 3.7.6 and 3.7.7 for ICP, Sections 4.7.6 and 4.7.7 for ICP-MS, and Sections 5.6.5 and 5.6.6 for GFAA. The blank must be analyzed at the beginning of the run and after the last analytical sample.

7.1.6.2 If the absolute value of the blank result exceeds the CRQL (Exhibit C), analysis must be terminated, the problem corrected, and the continuing calibration blank (CCB) reanalyzed. If the reanalysis yields a CCB with an absolute value below the CRQL, all analytical samples analyzed since the last acceptable calibration blank must be reanalyzed. Otherwise, the instrument must be recalibrated, the calibration verified, and the affected analytical sample(s) rerun.

7.1.6.3 Each analytical sample must be bracketed by two consecutive CCBs that have been analyzed within two hours of each other with no more than 10 analytical samples run between the CCBs. The absolute value for each analyte in these two CCBs must fall below the CRQL.

7.1.7 **Preparation Blank (PB) Analysis**

7.1.7.1 At least one PB (or reagent blank) consisting of reagent water processed through each sample preparation and analysis procedure must be prepared and analyzed with every SDG or with each batch of samples digested, (whichever is more frequent), as outlined in Exhibit D, Section 3.7.8 for ICP, Section 4.7.8 for ICP-MS, and Section 5.6.7 for GFAA.

7.1.7.2 The first batch of samples in an SDG shall to be assigned to PB one, the second batch of samples to PB two, etc. Each package must contain the results of all the PB analyses associated with the samples in that SDG.

7.1.7.3 The PB is to be reported for each SDG and used in all analyses to ascertain whether sample concentrations reflect contamination in the following manner:

7.1.7.3.1 If the absolute value of the concentration of the PB is less than or equal to the CRQL (Exhibit C), no correction of sample results is performed.

7.1.7.3.2 If any analyte concentration in the PB is above the CRQL, all associated samples containing less than ten times the blank concentration must be redigested and reanalyzed for that analyte. The sample concentrations are <u>not</u> to be corrected for the blank value.

7.1.7.3.3 If an analyte concentration in the PB is below the negative CRQL, all samples with reported analyte values below ten

times CRQL and associated with the blank must be redigested and reanalyzed.

7.1.7.3.4 The values for the PB must be recorded in µg/L.

7.1.8 **ICP and ICP-MS Interference Check Sample Analysis**

7.1.8.1 To verify interelement and background correction factors, the Contractor must analyze and report the results for an ICP and ICP-MS Interference Check Sample (ICS). The ICS must be analyzed at the beginning and end of each analysis run or a minimum of twice per eight hour working shift, whichever is more frequent, but not before the ICV (see Exhibit D, Section 3.7.9 for ICP and Section 4.7.9 for ICP-MS). The ICP and ICP-MS ICS must be obtained from EPA (EMSL-LV), if available, and analyzed according to the instructions supplied with the ICS.

7.1.8.2 The ICS consists of Solutions A and AB that must contain both analytes and potential interferents. An ICS analysis consists of analyzing the solution for all wavelengths or masses used for each analyte reported by ICP.

7.1.8.3 Results for the ICP analyses of Solutions A and AB during the analytical runs must be within ± 20 percent of the true value for the analytes included in the ICS. If not, terminate the analysis, correct the problem, recalibrate the instrument, and reanalyze the analytical samples analyzed since the last acceptable ICS. If true values for analytes contained in the ICS and analyzed by ICP and ICP-MS are not supplied with the ICS, the mean concentration for each analyte must be determined by initially analyzing the ICS at least five times repetitively for the particular analytes. This mean determination must be made during an analytical run where the results for the previously supplied EPA ICS met all contract specifications. Additionally, the result of this initial mean determination is to be used as the true value for the lifetime of that solution (i.e., until the solution is exhausted).

7.1.9 **Spike Sample Analysis**

7.1.9.1 The spike sample analysis is designed to provide information about the effect of the sample matrix on the digestion and measurement methodology. The spike is added before the sample preparation (i.e., digestion, and/or distillation). At least one spike sample analysis must be performed on each group of samples for each SDG, according to Exhibit D, Section 3.7.10 for ICP, Section 4.7.10 for ICP-MS, and Section 5.6.8 for GFAA and Exhibit D, Table D/IN-3.

7.1.9.2 If the spike analysis is performed on the same sample that is chosen for the duplicate sample analysis, spike calculations must be performed using the results of the sample designated as the "original sample" (see Duplicate Sample Analysis). The average of the duplicate results cannot be used for the purpose of determining percent recovery. Samples identified as field blanks cannot be used for the spike sample analysis.

7.1.9.3 If two analytical methods are used to obtain the reported values for the same analyte within an SDG, spike samples must be run by each method used.

7.1.9.4 If the spike recovery is not within the limits of 75-125 percent, the data for all of the samples received associated with that spike sample and determined by the same analytical method must be flagged with the letter "N", unles the sample concentration is more than four times the spike concentration.

7.1.10 Duplicate Sample Analysis

7.1.10.1 One duplicate sample must be analyzed from each group of samples for each SDG, as outlined in Exhibit D, Section 3.7.11 for ICP, Section 4.7.11 for ICP-MS, and Section 5.6.9 for GFAA. Duplicates cannot be averaged in reporting results.

7.1.10.2 Samples identified as field blanks cannot be used for duplicate sample analysis. EPA may require that a specific sample be used for duplicate sample analysis. If two analytical methods are used to obtain the reported values for the same element for a SDG (e.g., ICP and GFAA), duplicate samples must be run by each method used.

7.1.11 Laboratory Control Sample Analysis

7.1.11.1 The Laboratory Control Sample (LCS) must be analyzed for each analyte using the same sample preparation, analytical methods and QA/QC procedures employed for the EPA samples received, as outlined in Exhibit D, Section 3.7.12 for ICP, Section 4.7.12 for ICP-MS, and Section 5.6.10 for GFAA.

7.1.11.2 The EPA-provided LCS must be prepared and analyzed using each of the procedures applied to the samples received. If the EPA LCS is unavailable, other EPA quality assurance check samples or other certified materials may be used. One LCS must be prepared and analyzed for every group of samples in a SDG or for each batch of samples prepared, whichever is more frequent.

7.1.11.3 If the results of the LCS are not within the control limits established by EPA, the analyses must be terminated, the problem corrected, and the samples associated with the LCS prepared again and

reanalyzed. A control limit of ± 20 percent of the true value must be used if no control limits are provided with the LCS solution.

7.1.12 **Performance Evaluation Sample (PES)**

7.1.12.1 The Performance Evaluation Sample (PES) will assist the Agency in monitoring Contractor performance. The laboratory will not be informed in advance of the analytes in the PES or their concentration.

7.1.12.2 The Contractor must prepare, analyze and report the results of one PES per each SDG, if available, as outlined in Exhibit D, Section 3.

7.1.12.3 Prepare the PES using the procedure described in the sample preparation section of Exhibit D, Section 2, and analyze the PES using the methods described in Exhibit D for the analysis of EPA field samples. All contract required QC must also be met.

7.1.12.4 The Contractor must demonstrate acceptable performance for analyte identification and quantification. If the Contractor achieves a score of less than 75 percent, the Agency may take but is not limited to the following actions: Show Cause and/or Cure Notice, reduction of the number of samples shipped to the laboratory, suspension of sample shipment, a site visit, a full data audit, and/or require the laboratory to analyze a remedial PES.

7.1.13 **ICP Serial Dilution Analyses**

7.1.13.1 The ICP serial dilution analyses is performed to check for the presence of matrix interferences for all ICP instruments at all wavelengths used for each analyte reported by ICP. A serial dilution is not required for ICP-MS determinations. One serial dilution analysis must be performed for each SDG. Identified field blanks may not be used for serial dilution analysis.

7.1.13.2 The serial dilution analysis is performed by diluting a prepared sample aliquot five-fold (1:4). The dilution must be prepared on an analyte-by-analyte bases. The serial dilution is the dilution of the sample, or an aliquot of sample, that contains a concentration level of the analyte within the linear range.

7.1.13.3 If the analyte concentration in the field sample is sufficiently high (minimally factor of 50 above the the MQL), the serial dilution must agree within 10 percent of the initial sample concentration determination after correction for the five fold dilution. If the serial dilution analysis for one or more analyte is not within the 10 percent criteria, a chemical or physical interference effect must be suspected and the data for all analytes exceeding the limit in the samples associated with that serial dilution must be flagged with an "E" on FORMs I-AAIN and XI-AAIN.

7.1.13.4 The values for the initial sample and serial dilution must be recorded on FORM XI-AAIN for all analysis systems, as indicated in Exhibit B, Section 3.

7.1.14 **Method Quantitation Limit Determination**

7.1.14.1 The Method Quantitation Limit (MQL) (in µg/L) must be determined for each instrument used, within 30 days prior to the start of any contract analysis and at least quarterly (every 3 calendar months), as outlined in Exhibit D, Section 3.7.14 for ICP, Section 4.7.15 for ICP-MS, and Section 5.6.13 for GFAA. The MQL must be equal to or less than CRQLs (µg/L) specified in Exhibit C.

7.1.14.2 The MQLs must be determined by multiplying by three the average of the standard deviations obtained on three nonconsecutive days (each analyte in reagent water) at a concentration three times the MQL, with seven consecutive measurements. Each measurement must be performed as though it were a separate analytical sample (i.e., each measurement must be followed by a rinse and/or any other procedure normally performed between the analysis of separate samples). MQLs must be determined and reported for each wavelength or mass used in the analysis of the samples.

7.1.14.3 The quarterly determined MQL for an instrument must always be used as the MQL for that instrument during that quarter. If the instrument is adjusted in any way that may affect the MQL, the MQL for that instrument must be redetermined and the results submitted for use as the established MQL for that instrument for the remainder of the quarter.

7.1.14.4 MQLs must be reported for each instrument and submitted with each data package. If multiple instruments are used for the analysis of an analyte within a SDG, the highest MQL for the analyte must be used for reporting concentration values for that SDG.

7.1.14.5 The MQL for each analyte must be less than or equal to the CRQL. An exception is granted if the analyte concentration in the samples is greater than or equal to five times the reported MQL.

7.1.15 **Interelement Corrections for ICP and ICP-MS**

7.1.15.1 The ICP and ICP-MS interelement correction factors must be determined within three months prior to beginning sample analyses under this contract and at least annually thereafter, as outlined in Exhibit D, Section 3.7.16 for ICP and Section 4.7.16 for ICP-MS. Correction factors for spectral interference must be determined at all wavelengths or masses used for each analyte reported by ICP and ICP-MS.

7.1.15.2 The correction factors must be determined under the same instrument conditions used for sample analysis. If the instrument was adjusted in any way that may affect the ICP and ICP-MS interelement correction factors, the factors must be redetermined and the results submitted for use. The interelement factors determination must be reported for all ICP and ICP-MS analytes, for each instrument used to generate data in the SDG.

7.1.16 **Internal Standard for ICP-MS**

7.1.16.1 The internal standard analyses is performed to check for the presence of physical interferences and correct for them for analyses performed by ICP-MS.

7.1.16.2 A minimum of three internal standards, listed in Table D/IN-7, Exhibit D, bracketing the mass range must be used. The intensity level of an internal standard for each sample, duplicate, spike analysis, and PES must agree within ± 50 percent of the intensity level of the internal standard of the initial calibration blank standard solution (SO). If not, the sample must be reanalyzed after performing a five fold (1:4) dilution. If the intensity level percent difference, %D, remains greater than 50 percent, a physical interference must be suspected, and the data on FORM XV-AAIN must be flagged with an "E." The analytes affected by the interference must be listed in the comment section on the appropriate FORMs I-AAIN, VI-AAIN, VII-AAIN, and VIII-AAIN.

7.1.16.3 The intensity levels of the internal standards for the CCV and CCB solutions must agree within ± 20 percent of the intensity level of the internal standard of the initial calibration blank standard solution (SO). If not, the analysis must be terminated, the problem corrected and the CCV/CCB reanalyzed only once. If the first reanalysis yields a CCV/CCB %D value within control limits, then the preceding 10 analytical samples or all analytical samples analyzed since the last compliant calibration verification must be reanalyzed for the analytes affected. Otherwise, the instrument must be recalibrated, the calibration verified and the affected analytical samples rerun in the context of a new run.

7.1.16.4 The intensity level of the internal standards for the ICV and ICB solutions must agree within ± 20 percent of the intensity level of the internal standard of the initial calibration blank standard solution (SO). If not, the analysis must be terminated, the problem corrected, and a new analytical run must be started.

7.1.16.5 The values for the Internal Standard Percent Difference (%D) must be reported for each ICP-MS analysis on FORM XV-AAIN as indicated in Exhibit B, Section 3.

7.1.17 **Furnace AA QC Analyses (Method of Standard Additions)**

7.1.17.1 Because of the nature of the GFAA techniques, the special procedures summarized in Figure E-2 will be required for quantitation. (These procedures do not replace those in Exhibit D, Section 5.6.12 of this document, but supplement the guidance provided therein.)

7.1.17.1.1 All analyses must fall within the calibration range. In addition, all analyses, except during full Method of Standard Additions (MSA), will require duplicate injection must be reported in raw data as well as the average intensity and concentration values. A maximum of 10 full sample analyses to a maximum of 20 injections may be performed between each consecutive calibration verification and blank. The raw data package must contain intensity and concentration values for both injections, the average value and the relative standard deviation (RSD) or coefficient of variation (CV). For concentrations greater than CRQL, the duplicate injection readings must agree within 15 percent RSD or CV, or the analytical sample must be rerun once (i.e., two additional injections). If the readings are still out, flag the value reported on FORM I-AAIN with an "M." The "M" flag is required for the analytical spike as well as the sample. If the analytical spike for a sample requires an "M" flag, the flag must be reported on FORM I-AAIN for that sample.

If the preparation blank analytical spike recovery is out of control 85-115 percent, the spiking solution must be verified by respiking and rerunning the preparation blank once. If the preparation blank analytical spike recovery is still out of control, correct the problem, respike and reanalyze all analytical samples associated with that blank.

7.1.17.1.2 All GFAA analyses for each analytical sample, including those requiring an "M" flag, will be require at least an analytical spike to determine if the MSA will be required for quantitation. The analytical spike will be required to be at a concentration (in the sample) of two times the CRQL (except for lead which must be at 20 µg/L). This requirement for an analytical spike will include the LCS and the preparation blank. The LCS must be quantitated from the calibration curve and corrective action, if needed, taken accordingly. MSAs are not to be performed on the LCS or preparation blank, regardless of spike recovery results. If the preparation blank analytical spike recovery is out of the control limits 85-115 percent, the spiking solution must be verified by respiking and rerunning the preparation blank once. If the preparation blank analytical spike recovery is still out of control, correct the problem and respike and reanalyze all analytical samples associated with the blank. An analytical spike is not required on the pre-digestion spike sample.

7.1.17.1.3 The analytical spike of a sample must be run immediately after that sample. The percent recovery (%R) of the spike, calculated by the same formula as Spike Sample Analyses (see Spike Sample Analysis, this Exhibit), will then determine how the sample will be quantitated, as follows:

7.1.17.1.3.1 If the spike recovery is < 40 percent, the sample must be diluted by a factor of five to ten and rerun with another spike. This step must only be performed once. If after the dilution the spike recovery is still < 40 percent, report data from the initial undiluted analysis and flag with an "E" to indicate interference problems.

7.1.17.1.3.2 If the spike recovery is ≥ 40 percent and the sample absorbance or concentration is < 50 percent of the spike, report the sample results to the MQL. If the spike is less than 85 percent or greater than 115 percent, flag the result with a "W."

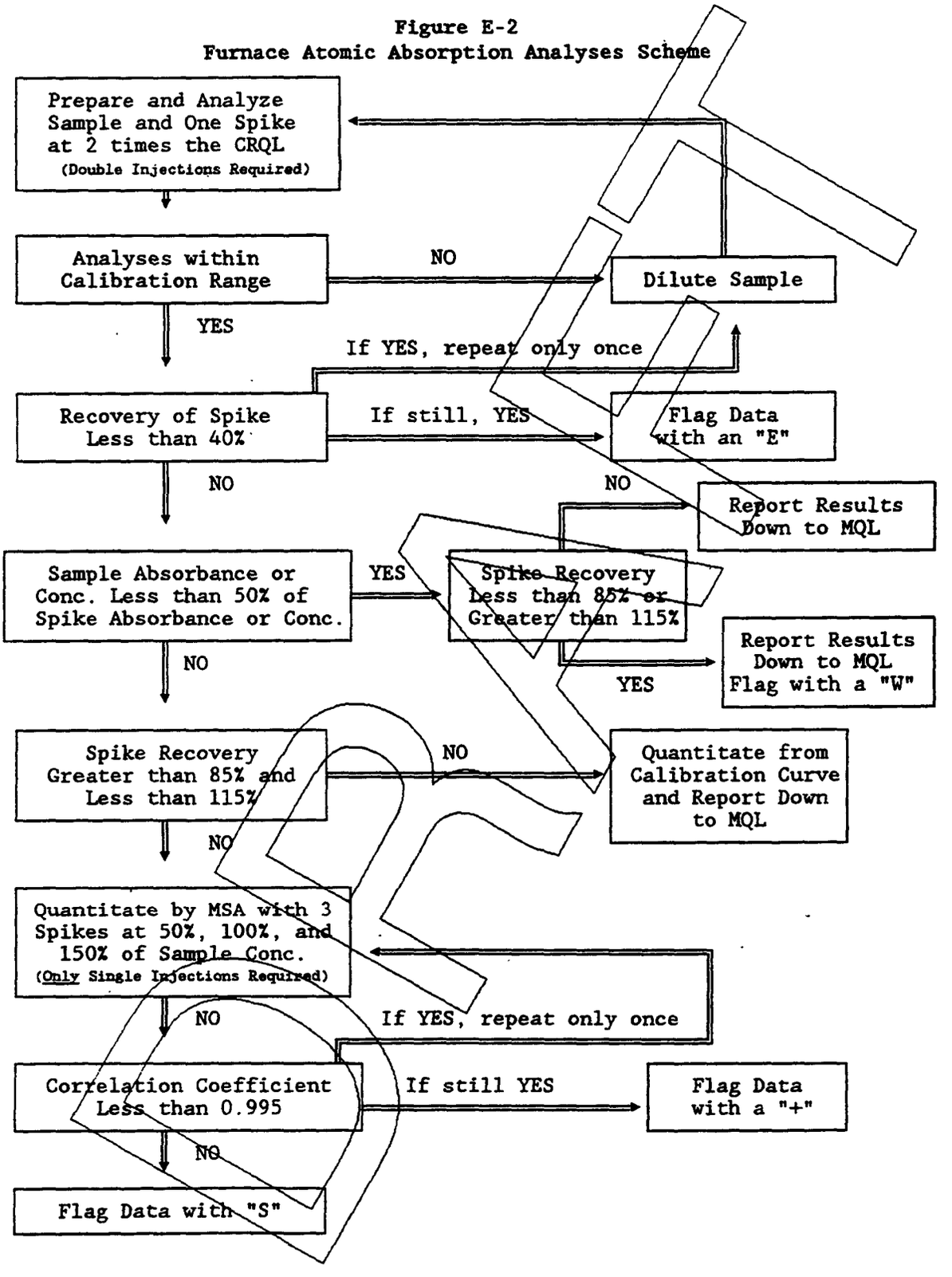
7.1.17.1.3.3 If the sample absorbance or concentration is < 50 percent of the spike and the spike recovery is at or between 85 percent and 115 percent, the sample must be quantitated directly from the calibration curve and reported down to the MQL.

7.1.17.1.3.4 If the sample absorbance or concentration is ≤ 50 percent of the spike and the spike recovery is < 85 percent or greater than 115 percent, the sample must be quantitated by MSA.

7.1.17.1.3.5 The following procedures will be incorporated into MSA analyses.

- Data from MSA calculations must be within the linear range as determined by the calibration curve generated at the beginning of the analytical run.
- The sample and three spikes must be analyzed consecutively for MSA quantitation (the "initial" spike run data is specifically excluded from use in the MSA quantitation). Only single injections are required for MSA quantitation.
- Each full MSA counts as two analytical samples towards determining 10 percent QC frequency (i.e., five full MSAs can be performed between calibration verifications).
- For analytical runs containing only MSAs, single injections can be used for QC samples during that run.
- Spikes must be prepared such that:

Figure E-2
Furnace Atomic Absorption Analyses Scheme



1) Spike 1 is approximately 50 percent of the sample concentration.

2) Spike 2 is approximately 100 percent of the sample concentration.

3) Spike 3 is approximately 150 percent of the sample concentration.

- The data for each MSA analysis must be clearly identified in the raw data documentation (spike concentrations measured intensities or concentration, x-intercept, y-intercept and correlation coefficient). The results shall be reported on FORM X-AAIN. Reported values obtained by MSA must be flagged on FORM I-AAIN with the letter "S" if the correlation coefficient (r) is greater than or equal to 0.995.

- If the correlation coefficient (r) for a particular analysis is less than 0.995, the MSA analysis must be repeated once. If the correlation coefficient is still less than 0.995, report the results on FORM I-IN from the run with the best "r" and flag the result with a "+." On FORM X-AAIN report the results of both MSA analysis and flag with a "+" for any MSA result that yields a correlation coefficient less than 0.995.

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SECTION 8

REGIONAL DATA REVIEW

Contract laboratory data are generated to meet the specific needs of the Regions. In order to verify the usability of data for the intended purpose, each Region reviews data from the perspective of the end-user, based upon functional aspects of data quality. General guidelines for data review have been developed jointly by the Regions and the National Program Office. Each Region uses these guidelines as the basis for data evaluation. Individual Regions may augment the basic guideline review process with additional review based on Region-specific or site-specific concerns. Regional reviews, like the sites under investigation, vary based on the nature of the problems under investigation and the Regional response appropriate to the specific circumstances.

Regional data reviews relating usability of the data to a specific site are part of the collective assessment process. They complement the review done at the SMO, which is designed to identify contractual discrepancies, and the review done at EMSL/LV, which is designed to evaluate Contractor and method performance. These individual evaluations are integrated into a collective review that is necessary for program and laboratory administration and management and may be used to take appropriate action to correct deficiencies in the Contractor's performance.

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SECTION 9

LABORATORY EVALUATION SAMPLES

Although intra-laboratory QC may demonstrate Contractor and method performance that can be tracked over time, an external performance evaluation program is an essential feature of a QA program. As a means of measuring Contractor and method performance, Contractors participate in inter-laboratory comparison studies conducted by the EPA. Results from the analysis of these laboratory evaluation samples will be used by the EPA to verify the Contractor's continuing ability to produce acceptable analytical data. The results are also used to assess the precision and accuracy of the analytical methods for specific analytes.

Sample sets may be provided to participating Contractors as frequently as on an SDG-by-SDG basis as a recognizable QC sample of known composition; as a recognizable QC sample of unknown composition; or not recognizable as a QC material. The laboratory evaluation samples may be sent either by the Regional client or the National Program Office, and may be used for contract action.

Contractors are required to analyze the samples and return the data package and all raw data within the contract required turnaround time.

At a minimum, the results are evaluated for parameter identification, quantification, and sample contamination. Confidence intervals for the quantification of target compounds are based on reported values using population statistics. EPA may adjust the scores on any given laboratory evaluation sample to compensate for unanticipated difficulties with a particular sample. Normally, a fraction of the compounds spiked into the sample are not specifically listed in the contract.

The Contractor shall provide a response regarding its performance on laboratory evaluation samples as specified below:

- No Response is required for a score of 90 or above.
- For a score of 89 to 75, the Contractor shall describe the deficiency(ies) and the corrective action(s) taken in a letter to the APO, TPO, and EMSL/LV, within 14 days of receipt of notification from EPA.
- For a score of less than 75, the Contractor shall be notified by the APO or TPO concerning the remedy for their unacceptable performance. A Contractor may expect, but EPA is not limited to, the following actions: reduction of the number of samples sent under the contract; suspension of sample shipment to the Contractor; a follow-up site visit; a full data audit; analysis of remedial PE samples; and/or contract sanction, such as a Cure Notice.

NOTE: A Contractor's prompt response demonstrating that corrective action has been taken to ensure the Contractor's capability to meet contract requirements will facilitate continuation of full sample delivery.

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SECTION 10

ON-SITE LABORATORY EVALUATIONS

At a frequency dictated by a contract laboratory's performance, the APO, TPO, or their authorized representative will conduct on-site laboratory evaluations. On-site laboratory evaluations are conducted to monitor the Contractor's ability to meet selected terms and conditions specified in the contract. The evaluation process incorporates two separate categories: Quality Assurance Evaluation and an Evidentiary Audit.

10.1 QUALITY ASSURANCE ON-SITE EVALUATION

10.1.1 Quality assurance evaluators inspect the Contractor's facilities to verify the adequacy and maintenance of instrumentation, the continuity of personnel meeting experience or education requirements, and the acceptable performance of analytical and QC procedures. The Contractor should expect items to be monitored will include but not be limited to the following items:

10.1.1.1 Size and appearance of the facility.

10.1.1.2 Quantity, age, availability, scheduled maintenance, and performance of instrumentation.

10.1.1.3 Availability, appropriateness, and utilization of SOPs.

10.1.1.4 Staff qualifications, experience, and personnel training programs.

10.1.1.5 Reagents, standards, and sample storage facilities.

10.1.1.6 Standard preparation logbooks and raw data.

10.1.1.7 Bench sheets and analytical logbook maintenance and review.

10.1.1.8 Review of the Contractor's sample analysis/data package inspection procedures.

10.1.2 Prior to an on-site evaluation, various documentation pertaining to performance of the specific Contractor is integrated in a profile package for discussion during the evaluation. Items that may be included are previous on-site reports, laboratory evaluation sample scores, Regional review of data, Regional QA materials, and data trend reports.

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10.2 EVIDENTIARY AUDIT

Evidence auditors conduct an on-site laboratory evaluation to determine if laboratory policies and procedures are in place to satisfy evidence handling requirements as stated. The evidence audit is comprises the following three activities.

10.2.1 Procedural Audit

The procedural audit consists of review and examination of actual SOPs and accompanying documentation for the following laboratory operations:

- Sample receiving;
- Sample storage;
- Sample identification;
- Sample security;
- Sample tracking (from receipt to completion of analysis); and
- Analytical project file organization and assembly.

10.2.2 Written SOPs Audit

The written SOPs audit consists of review and examination of the written SOPs to determine if they are accurate and complete for the following laboratory operations: sample receiving, sample storage, sample identification, sample security, sample tracking (from receipt to completion of analysis), and analytical project file organization and assembly.

10.2.3 Analytical Project File Evidence Audit

The analytical project file evidence audit consists of review and examination of the analytical project file documentation. The auditors review the files to determine:

- Accuracy of the document inventory;
- Completeness of the file;
- Adequacy and accuracy of the document numbering system;
- Traceability of sample activity;
- Identification of activity recorded on the documents; and

- Error correction methods.

10.3 DISCUSSION OF THE ON-SITE TEAM'S FINDINGS

The quality assurance and evidentiary auditors discuss their findings with the APO/TPO prior to debriefing the Contractor. During the debriefing, the auditors present their findings and recommendations for corrective actions necessary to the Contractor personnel.

10.4 CORRECTIVE ACTION REPORTS IN RESPONSE TO QUALITY ASSURANCE AND EVIDENTIARY AUDIT REPORTS

10.4.1 Following an on-site evaluation, quality assurance and evidentiary audit reports which discuss deficiencies found during the on-site evaluation will be forwarded to the Contractor. The Contractor must discuss the corrective actions taken to resolve the deficiencies discussed during the on-site visit and discussed in the on-site reports in a letter to the APO, TPO, EMSL/LV (response to the quality assurance report) and NEIC (response to the evidentiary report) within 14 days of receipt of the finding or within the time agreed upon between the APO/TPO and the Contractor. If SOPs are required to be written or SOPs are required to be amended, the Contractor must provide the SOPs to the TPO, EMSL/LV (quality assurance/technical SOPs) and NEIC (evidentiary SOPs) within 30 days of receipt of the finding or within the time agreed upon between the APO/TPO and the Contractor.

10.4.2 If the Contractor fails to take appropriate corrective action to resolve the deficiencies discussed in the on-site reports, a Contractor may expect, but the Agency is not limited to, the following actions: reduction of the number of samples sent under the contract; suspension of sample shipment to the Contractor; a follow-up site visit; a full data audit; analysis of remedial PE samples; and/or contract sanction, such as a Cure Notice.

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SECTION 11

DATA MANAGEMENT

Data management procedures are defined as procedures specifying the acquisition or entry, update, correction, deletion, storage, and security of computer readable data and files. These procedures should be in written form and contain a clear definition for all databases and files used to generate or resubmit deliverables. Key areas of concern include: system organization (including personnel and security), documentation operations, traceability, and quality control.

11.1 DATA ENTRY

Data manually entered from hard copy must be checked for accuracy and the error rates estimated. Systems should prevent entry of incorrect or out-of-range data and alert data entry personnel of errors. In addition, data entry error rates must be estimated and recorded on a monthly basis by reentering a statistical sample of the data entered and calculating discrepancy rates by data element.

11.2 CORRECTIONS AND UPDATES

The record of changes in the form of corrections and updates to data originally generated, submitted, and/or resubmitted must be documented to allow traceability of updates. Documentation must include the following for each change:

11.2.1 Justification or rationale for the change.

11.2.2 Initials of the person making the change or changes. Data changes must be implemented and reviewed by a person or group independent of the source generating the deliverable.

11.2.3 Change documentation must be retained according to the schedule of the original deliverable.

11.2.4 Resubmitted diskettes or other deliverables must be reinspected as a part of the laboratory's internal inspection process prior to resubmission. The entire deliverable, not just the changes, must be inspected.

11.2.5 The Laboratory Manager must approve changes to originally submitted deliverables.

11.2.6 Documentation of data changes may be requested by laboratory auditors.

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11.3 LIFE CYCLE MANAGEMENT

Life cycle management procedures must be applied to computer software systems developed by the laboratory to be used to generate and edit contract deliverables. Such systems must be thoroughly tested and documented prior to utilization:

11.3.1 A software test and acceptance plan including test requirements, test results and acceptance criteria must be developed, followed, and available in written form.

11.3.2 System changes must not be made directly to production systems generating deliverables. Changes must be made first to a development system and tested prior to implementation.

11.3.3 Each version of the production system will be given an identification number, date of installation, date of last operation and archived.

11.3.4 System and operations documentation must be developed and maintained for each system. Documentation must include a user's manual and an operations and maintenance manual.

11.4 PERSONNEL IDENTIFICATION REQUIREMENTS

Individual(s) responsible for the following functions must be identified:

11.4.1 System operation and maintenance including documentation and training.

11.4.2 Data base integrity, including data entry, data updating and quality control.

11.4.3 Data and system security, backup and archiving.

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SECTION 12

REFERENCES

Office of Monitoring Systems and Quality Assurance, U.S. Environmental Protection Agency, "Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans", QAMS-005/80, December 1980.

Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Test Methods for Evaluating Solid Waste, Third Edition, SW-846, November 1986.

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EXHIBIT F

EVIDENTIARY REQUIREMENTS

December, 1991

EXHIBIT F

EVIDENTIARY REQUIREMENTS

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SECTION 1

SAMPLE CHAIN-OF-CUSTODY

A sample is physical evidence collected from a facility or from the environment. An essential part of hazardous waste investigation effort is that the evidence gathered be controlled. To accomplish this, the following sample identification, chain-of-custody, sample receiving, and sample tracking procedures have been established.

1.1 SAMPLE IDENTIFICATION

1.1.1 To assure traceability of samples while in possession of the Contractor, the Contractor shall have a specified method for maintaining identification of samples throughout the laboratory.

1.1.2 Each sample and sample preparation container shall be labeled with the EPA sample number or a unique laboratory identifier. If a unique laboratory identifier is used, it shall be cross-referenced to the EPA sample number.

1.2 CHAIN-OF-CUSTODY PROCEDURES

1.2.1 Because of the nature of the data being collected, the custody of EPA samples must be traceable from the time the samples are collected until they are introduced as evidence in legal proceedings. The Contractor shall have procedures ensuring that EPA sample custody is maintained and documented.

1.2.2 A sample is under custody if the following applies:

1.2.2.1 It is in your possession.

1.2.2.2 It is in your view after being in your possession.

1.2.2.3 It was in your possession and you locked it up.

1.2.2.4 It is in a designated secure area (secure areas shall be accessible to authorized personnel only).

1.3 SAMPLE RECEIVING PROCEDURES

1.3.1 The Contractor shall designate a sample custodian responsible for receiving all samples.

1.3.2 The Contractor shall designate a representative to receive samples in the event that the sample custodian is not available. The condition of the shipping containers and sample bottles shall be inspected upon receipt by the sample custodian or his/her representative.

1.3.3 The condition of the custody seals (intact/not intact) shall be inspected upon receipt by the sample custodian or his/her representative.

1.3.4 The sample custodian or his/her representative shall check for the presence or absence of the following documents accompanying the sample shipment:

1.3.4.1 Airbills or airbill stickers.

1.3.4.2 Custody seals.

1.3.4.3 EPA custody records.

1.3.4.4 EPA traffic reports or SAS packing lists.

1.3.4.5 Sample tags.

1.3.5 The sample custodian or his/her representative shall sign and date all forms (e.g., custody records, traffic reports or packing lists, and airbills) accompanying the samples at the time of sample receipt.

1.3.6 The Contractor shall contact SMO to resolve discrepancies and problems such as absent documents, conflicting information, broken custody seals, and unsatisfactory sample condition (e.g., leaking sample bottle).

1.3.7 The Contractor shall record the resolution of discrepancies and problems on Telephone Contact Logs.

1.3.8 The following information shall be recorded on appropriate Form AADC-1 by the sample custodian or his/her representative as samples are received and inspected:

1.3.8.1 Condition of the shipping container.

1.3.8.2 Presence or absence and condition of custody seals on shipping and/or sample containers.

1.3.8.3 Custody seal numbers, when present.

1.3.8.4 Condition of the sample bottles.

1.3.8.5 Presence or absence of airbills or airbill stickers.

1.3.8.6 Airbill or airbill sticker numbers.

1.3.8.7 Presence or absence of EPA custody records.

1.3.8.8 Presence or absence of EPA traffic reports or SAS packing lists.

1.3.8.9 Presence or absence of sample tags.

1.3.8.10 Sample tag identification numbers cross-referenced to the EPA sample numbers.

1.3.8.11 Verification of agreement or non-agreement of information recorded on shipping documents and sample containers.

1.3.8.12 Problems or discrepancies.

1.4 SAMPLE TRACKING PROCEDURES

The Contractor shall maintain records documenting all phases of sample handling from receipt to final analysis. The records shall include documentation of the movement of samples and prepared samples into and out of designated laboratory storage areas.

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SECTION 2

DOCUMENT CONTROL PROCEDURES

The goal of the laboratory document control program is to assure that all documents for a specified SDG will be accounted for when the project is completed. Accountable documents used by contract laboratories shall include but not be limited to logbooks, chain-of-custody records, sample work sheets, bench sheets, and other documents relating to the sample or sample analyses. The following document control procedures have been established to assure that all laboratory records are assembled and stored for delivery to the EPA or are available upon request from the EPA prior to the delivery schedule.

2.1 PREPRINTED LABORATORY FORMS AND LOGBOOKS

2.1.1 All documents produced by the Contractor which are directly related to the preparation and analysis of EPA samples shall become the property of the EPA and shall be placed in the complete sample delivery group file (CSF). All observations and results recorded by the laboratory but not on preprinted laboratory forms shall be entered into permanent laboratory logbooks. When all data from a SDG are compiled, all original laboratory forms and copies of all SDG-related logbook entries shall be included in the documentation package.

2.1.2 The Contractor shall identify the activity recorded on all laboratory documents which is directly related to the preparation and analysis of EPA samples.

2.1.3 Pre-printed laboratory forms shall contain the name of the laboratory and be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

2.1.4 Logbook entries shall be dated (month/day/year) and signed by the person responsible for performing the activity at the time an activity is performed.

2.1.5 Logbook entries shall be in chronological order. Entries in logbooks, with the exception of instrument run logs and extraction logs, shall include only one SDG per page.

2.1.6 Pages in both bound and unbound logbooks shall be sequentially numbered.

2.1.7 Instrument run logs shall be maintained so as to enable a reconstruction of the run sequence of individual instruments. Because the laboratory must provide copies of the instrument run logs to the EPA, the laboratory may exercise the option of using only laboratory or EPA sample identification numbers in the logs for sample ID rather than

government agency or commercial client names to preserve the confidentiality of commercial clients.

2.1.8 Corrections to supporting documents and raw data shall be made by drawing a single line through the error and entering the correct information. Corrections and additions to supporting documents and raw data shall be dated and initialed. No information shall be obliterated or rendered unreadable. All notations shall be recorded in ink. Unused portions of documents shall be "crossed" out.

2.2 CONSISTENCY OF DOCUMENTATION

2.2.1 The Contractor shall assign a document control officer responsible for the organization and assembly of the CSF.

2.2.2 All copies of laboratory documents shall be complete and legible.

2.2.3 Before releasing analytical results, the document control officer shall assemble and cross-check the information on sample tags, custody records, laboratory bench sheets, personal and instrument logs, and other relevant data to ensure that data pertaining to each particular sample or sample delivery group is consistent throughout the CSF.

2.3 DOCUMENT NUMBERING AND INVENTORY PROCEDURES

2.3.1 In order to provide document accountability of the completed analysis records, each item in a CSF shall be inventoried and assigned a serialized number as described in Exhibit B, Section 2.

CSF # - Region - Serialized number (For example: 75-2-0240).

2.3.2 All documents relevant to each SDG, including logbook pages, bench sheets, mass spectra, chromatograms, screening records, re-preparation records, re-analysis records, records of failed or attempted analysis, custody records, library research results, etc., shall be inventoried.

2.3.3 The Document Control Officer (DCO) shall be responsible for ensuring that all documents generated are placed in the CSF for inventory and are delivered to the EPA. The DCO shall place the sample tags in plastic bags in the file. Figure E-1 of Exhibit E is an example of a document inventory.

2.4 STORAGE OF EPA FILES

The Contractor shall maintain EPA laboratory documents in a secure location.

2.5 SHIPPING DATA PACKAGES AND CSF

2.5.1 The Contractor shall document shipment of deliverables packages to the recipients. These shipments require custody seals on the containers placed such that they cannot be opened without damaging or breaking the seal. The Contractor shall document what was sent, to whom, the date, and the method (carrier) used.

2.5.2 The Contractor shall purge the CSF deliverable to the appropriate EPA Region 180 days after the report submission.

2.5.3 A copy of the transmittal letter for the CSF will be sent to NEIC and SMO.

2.5.4 The Document Control form is used to document the receipt and inspection of shipping containers and samples. The Contractor shall submit one original FORM AADC-1 for each shipping container.

2.5.5 The Contractor shall sign and date the airbill (if present), examine the shipping containers, record the presence or absence of custody seals and their conditions.

2.5.6 The Contractor shall note any problems with the samples and follow the instructions explained in Exhibit B, Sample Log-In Sheet.

2.5.7 The Contractor shall submit a completed Document Control Form with each SDG package.

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SECTION 3

STANDARD OPERATING PROCEDURES

The Contractor must have written standard operating procedures (SOPs) for receipt of samples, maintenance of custody, sample identification, sample storage, tracking the analysis of samples, and assembly of completed data.

3.1 SPECIFICATIONS FOR WRITTEN STANDARD OPERATING PROCEDURES

3.1.1 An SOP is defined as a written narrative step-by-step description of laboratory operating procedures including examples of laboratory documentation. The SOPs must accurately describe the actual procedures used in the laboratory, and copies of the written SOPs shall be available to the appropriate laboratory personnel. These procedures are necessary to ensure that analytical data produced under this contract are acceptable for use in EPA enforcement case preparation and litigation.

3.1.2 The Contractor's SOPs shall provide mechanisms and documentation to meet each of the following specifications and shall be used by EPA as the basis for laboratory evidence audits. The Contractor must have written standard operating procedures (SOPs) for:

3.1.2.1 Sample receipt and logging.

3.1.2.2 Sample storage.

3.1.2.3 Preventing sample contamination.

3.1.2.4 Security for laboratory and samples.

3.1.2.5 Traceability of standards.

3.1.2.6 Maintaining instrument records and logbooks.

3.1.2.7 Sample analysis and data control systems.

3.1.2.8 Glassware cleaning.

3.1.2.9 Technical and managerial review of laboratory operation and data package preparation.

3.1.2.10 Internal review of contractually-required quality assurance and quality control data for each individual data package.

3.1.2.11 Sample analysis, data handling, and reporting.

3.1.2.12 Chain-of-Custody.

3.1.2.13 Document control, including Case file preparation.

3.1.3 The Contractor shall have a designated sample custodian responsible for receipt of samples and have written SOPs describing his/her duties and responsibilities.

3.1.4 The Contractor shall have written SOPs for receiving and logging in of the samples. The procedures shall include but not be limited to documenting the following information:

3.1.4.1 Presence or absence of EPA chain-of-custody forms.

3.1.4.2 Presence or absence of airbills or airbill stickers.

3.1.4.3 Presence or absence of EPA Traffic Reports or SAS packing lists.

3.1.4.4 Presence or absence of custody seals on shipping and/or sample containers and their condition.

3.1.4.5 Custody seal numbers, when present.

3.1.4.6 Presence or absence of sample tags.

3.1.4.7 Sample tag ID numbers.

3.1.4.8 Condition of the shipping container.

3.1.4.9 Condition of the sample container.

3.1.4.10 Verification of agreement or nonagreement of information on receiving documents and sample containers.

3.1.4.11 Resolution of problems or discrepancies with the SMO.

3.1.4.12 The definition of any terms used to describe sample condition upon receipt.

3.1.5 The Contractor shall have written SOPs for maintenance of the security of samples after log-in and shall demonstrate security of the sample storage and laboratory areas. The SOPs shall specifically include descriptions of all storage areas for EPA samples in the laboratory, and steps taken to prevent sample contamination. The SOPs shall include a list of authorized personnel who have access or keys to secure storage areas.

3.1.6 The Contractor shall have written SOPs for tracking the work performed on any particular sample. The tracking SOP shall include the following:

3.1.6.1 A description of the documentation used to record sample receipt, sample storage, sample transfers, sample preparations, and sample analyses.

3.1.6.2 A description of the documentation used to record instrument calibration and other QA/QC activities.

3.1.6.3 Examples of the document formats and laboratory documentation used in the sample receipt, sample storage, sample transfer, and sample analyses.

3.1.7 The Contractor shall have written SOPs for maintaining identification of EPA samples throughout the laboratory.

3.1.8 If the Contractor assigns unique laboratory identifiers, written SOPs shall include a description of the method used to assign the unique laboratory identifier and cross-reference to the EPA sample number.

3.1.9 If the Contractor uses prefixes or suffixes in addition to sample identification numbers, the written SOPs shall include their definitions. The Contractor shall have written SOPs describing the method by which the laboratory maintains samples under custody.

3.1.10 The Contractor shall have written SOPs for organization and assembly of all documents relating to each EPA Case, including technical and managerial review. Documents shall be filed on a Case-specific basis. The procedures must ensure that all documents including logbook pages, sample tracking records, chromatographic charts, computer printouts, raw data summaries, correspondence, and any other written documents having reference to the Case are compiled in one location for submission to EPA. The system must include a document numbering and inventory procedure.

3.1.11 The Contractor shall have written SOPs for laboratory safety.

3.1.12 The Contractor shall have written SOPs for cleaning of glassware used in preparing and analyzing samples under this contract.

3.1.13 The Contractor shall have SOPs for traceability of standards used in sample analysis QA/QC.

3.2 HANDLING OF CONFIDENTIAL INFORMATION

3.2.1 A Contractor conducting work under this contract may receive EPA-designated confidential information from the Agency. Confidential information must be handled separately from other documentation developed under this contract. To accomplish this, the following procedures for the handling of confidential information have been established.

3.2.2 All confidential documents shall be under the supervision of a designated Document Control Officer (DCO).

3.2.3 Any samples or information received with a request of confidentiality shall be handled as "confidential." A separate locked file shall be maintained to store this information and shall be segregated from other nonconfidential information. Data generated from confidential samples shall be treated as confidential. Upon receipt of confidential information, the DCO logs these documents into a Confidential Inventory Log. The information is then made available to authorized personnel but only after it has been signed out to that person by the DCO. The documents shall be returned to the locked file at the conclusion of each working day. Confidential information may not be reproduced except upon approval by the EPA Contracting Officer. The DCO will enter all copies into the document control system. In addition, this information may not be disposed of except upon approval by the EPA Contracting Officer. The DCO shall remove and retain the cover page of any confidential information disposed of for one year and shall keep a record of the disposition in the Confidential Inventory Log.

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EXHIBIT G

GLOSSARY OF TERMS

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EXHIBIT G

GLOSSARY OF TERMS

Absorbance - A measure of the decrease in incident light passing through a sample into the detector. It is defined mathematically as:

$$A = \frac{I_{solvent}}{I_{solution}} = \log\frac{I_o}{I} \qquad \text{Eq. G-1}$$

where:

I = Radiation intensity.

Aliquot - A measured portion of a field sample taken for analysis.

Analysis Date/Time - The date and military time (24-hour clock) of the introduction of the sample, standard, or blank into the analysis system.

Analysis Group - An analysis group is a set of no more than twenty analytical samples (as defined below) for the purpose of method Quality Assurance/Quality Control (QA/QC), such that the QA/QC required by Exhibit E is, at a minimum, prepared and analyzed at a frequency of once per twenty analytical samples.

Analysis Replicate - A single analytical sample prossed through the analytical preparation method and analyzed in replicate.

Analysis Run - The actual instrumental analysis of the sample preparations from the time of instrument calibration through the running of the final CCV. All sample preparation analyses during the analysis run are subject to the QC protocols set forth in Exhibit E of this contract unless otherwise specified in the individual methods.

Analysis Spike Sample - An analytical sample taken through the analytical preparation method and then spiked prior to analysis.

Analyte - The element or ion an analysis seeks to determine; the element of interest.

Analytical Preparation - An analytical sample taken through the analytical preparation method. Also referred to as preparation or sample preparation.

Analytical Preparation Method - A method (digestion, dilution, extraction, fusion, etc.) used to dissolve or otherwise release the analyte(s) of interest from its matrix and provide a final solution containing the analyte which is suitable for instrumental or other analysis methods.

Analytical Sample - Any solution or media introduced into an instrument on which an analysis is performed excluding instrument calibration, initial calibration verification, initial calibration blank, continuing calibration verification and continuing calibration blank. Note the following are all defined as analytical samples: undiluted and diluted samples (EPA and non-EPA), predigestion spike samples, duplicate samples, serial dilution samples, analytical spike samples, post-digestion spike samples, interference check samples (ICS), CRQL standard for AA (CRA), CRQL standard for ICP (CRI), laboratory control sample (LCS), preparation blank (PB) and linear range analysis sample (LRS).

Analytical Spike - A post-digestion spike to be prepared prior to analysis by adding a known quantity of the analyte to an aliquot of the prepared sample. The unspiked sample aliquot must compensate for any volume change in the spike samples by addition of ASTM Type II water to the unspiked sample aliquot. The volume of the spiking solution added must not exceed 10% of the analytical sample volume.

ASTM Type II Water - Distilled water with a conductivity of less than 1.0 μmho/cm at 25°C. For additional specifications refer to ASTM D1193-77, "Standard Specification for Reagent Water".

Autozero - Zeroing the instrument at the proper wavelength. It is equivalent to running a standard blank with the absorbance set at zero.

Average Intensity - The average of two different injections (exposures).

Background Correction - A technique to compensate for variable background contribution to the instrument signal in the determination of trace elements.

Batch - A group of samples prepared at the same time.

Calibration - The establishment of an analytical curve based on the absorbance, emission intensity, or other measured characteristic of known standards. Calibration procedures differ for the various methods included in this SOW. Refer to the method of interest for a definition specific to that method.

Calibration Blank - For Inorganics, a volume of deionized distilled water acidified with nitric and/or hydrochloric acid, and containing all of the reagents and in the same concentration as those used in the analytical sample preparation. This blank is not subjected to the preparation method but is produced synthetically.

Calibration Standards - A series of known standard solutions used by the analyst for calibration of the instrument (i.e., preparation of the analytical

curve). The solutions are not subjected to the preparation method but contain the same matrix as the sample preparations to be analyzed.

Calibration Verification (CCV) - A single element or multi-element standard solution prepared by the analyst to be used to verify the stability of the instrument calibration with time and the instrument performance during the analysis of samples. The CCV can either be one or more of the calibration standards and/or an ICV. However, all analyte elements being measured by the particular system must be represented in this standard and the standard must have the same matrix as the samples. The CCV should have a concentration in the middle of the calibrated range. Analytical standard run every 10 analytical samples or every 2 hours, whichever is more frequent, to verify the calibration of the analytical system.

Case - A finite, usually predetermined number of samples collected over a given time period from a particular site. Case numbers are assigned by the Sample Management Office. A Case consists of one or more Sample Delivery Groups.

Coefficient of Variation (CV) - The standard deviation as a percent of the arithmetic mean.

Continuing Calibration - Analytical standard run at least every 12 hours to verify the calibration of the analytical system.

Contract Required Quantitation Limit (CRQL) - Minimum level of quantitation acceptable under the contract Statement of Work. Generally defined as 3.3 (or more) times the standard deviation of seven replicate analyses of the method blank.

Control Limits - A range within which specified measurement results must fall to be compliant. Control limits may be mandatory, requiring corrective action if exceeded, or advisory, requiring that noncompliant data be flagged.

Correlation Coefficient - A number (r) which indicates the degree of dependence between two variables (e.g., concentration - absorbance). The more dependent they are the closer the value to one. Determine on the basis of the least squares line.

Day - Unless otherwise specified, day shall mean calendar day.

DDI - Deionized Distilled water.

Digestion Log - An official record of the sample preparation (digestion).

Dissolved Metals - Analyte elements which have not been digested prior to analysis and which will pass through a 0.45 μm filter.

Dry Weight - The weight of a sample based on percent solids. The weight after drying in an oven.

Duplicate - A second aliquot of a sample that is treated the same as the original sample in order to determine the precision of the method.

EBCDIC - Extended Binary Coded Decimal Interchange Code.

Exposure - A full measurement of an emission line of an analyte from which the concentration of the analyte can be determined in the excitation system in a manner that meets the systems detection limit. It is also referred to as a peak scan.

External Standards - Target analytes analyzed at a known concentration prior to sample analysis, to determine response factors.

Field Blank - Any sample submitted from the field identified as a blank.

Field Sample - A portion of material received to be analyzed that is contained in single or multiple containers and identified by a unique EPA Sample Number.

Flame Atomic Absorption (AA) - Atomic absorption which utilizes flame for excitation.

Graphite Furnace Atomic Absorption (GFAA) - Atomic absorption which utilizes a graphite cell for excitation.

Holding Time - The elapsed time expressed in days from the date of receipt of the sample by the Contractor until the date of its analysis.

Independent Standard - A contractor-prepared standard solution that is composed of analytes from a different source than those used in the standards for the initial calibration.

Inductively Coupled Plasma (ICP) - A technique for the simultaneous or sequential multi-element determination of elements in solution. The basis of the method is the measurement of atomic emission by an optical spectroscopic technique. Characteristic atomic line emission spectra are produced by excitation of the sample in a radio frequency inductively coupled plasma.

In-House - At the Contractor's facility.

Initial Calibration - Analysis of analytical standards for a series of different specified concentrations; used to define the linearity and dynamic range of the response of the analytical instrument to the target analytes.

Initial Calibration Verification (ICV) - Solution(s) obtained from the EPA or prepared from stock standard solutions, metals or salts obtained from a source separate from that (those) utilized to prepare the calibration standards, and that have known concentration values. The ICV is used to verify the concentration of the calibration standards and the adequacy of the instrument calibration of the calibration standards and the adequacy of the instrument calibration. The ICV is not restricted to preparations made by official agencies when EPA sources are not available but should be traceable to an NBS or other certified standard.

Instrument Blank - For inorganics, acidified water analyzed to determine whether carry-over from a previous sample has occurred.

Instrument Detection Limit (IDL) - Determined by multiplying by three the standard deviation obtained for the analysis of a standard solution (each analyte in reagent water) at a concentration of 3x-5x IDL on three nonconsecutive days with seven consecutive measurements per day.

Interference Check Sample - Solution(s) containing both interfering and analyte elements of known concentrations that can be used to verify background and interelement correction factors. This solution must also contain the same matrix as the analytical preparations.

Interferents - Substances which affect the analysis for the element of interest.

Internal Standards - Analytes added to every standard, blank, and sample at a known concentration, prior to analysis. Internal standards are used as the basis for quantitation of the target analysis.

Laboratory - Synonymous with Contractor as used herein.

Laboratory Control Sample - Aliquot spiked with known concentration of specific analytes and subjected to the entire analytical procedure in order to monitor method and contractor performance.

Laboratory Receipt Date - The date on which a sample is received at the Contractor's facility, as recorded on the shipper's delivery receipt and sample Traffic Report. Also referred to as VTSR (validated time of sample receipt).

Linear Range - The concentration range over which the analytical curve remains linear. The range of the instrument for a specific analyte, as determined using calibration standards. The upper limit of this linear range (determined at each analysis) is the highest concentration calibration standard that has a determined value within 10% of the known value.

Mass Spectral Interference - Defined as the inability to detect the internal standard quantification ion due to presence of high levels of mass spectral "noise" at the same mass.

Matrix - The predominant material of which the sample to be analyzed is composed.

Matrix Modifier - Salts used in AA to lessen the effects of chemical interferents, viscosity, and surface tension.

Matrix Spike - Aliquot of a sample fortified (spiked) with known quantities of specific analytes and subjected to the entire analytical procedure in order to indicate the appropriateness of the method for the matrix by measuring recovery.

Method Blank - A solution produced by performing the analytical preparation method without the addition of a sample. The solution thus contains the same concentrations of reagents as all other analytical preparations plus any impurities derived from the preparation process. For preparations containing reagents of variable concentrations, the method blank should match the maximum reagent concentration used in the sample preparation(s).

Method of Standard Additions (MSA) - The addition of 3 increments of a standard solution (spikes) to sample aliquots of the same size. Measurements are made on the original and after each addition. The slope, x-intercept and y-intercept are determined by least-square analysis. The analyte concentration is determined by the absolute value of the x-intercept. Ideally, the spike volume is low relative to the sample volume (approximately 10% of the volume). MSA may counteract matrix effects; it will not counteract spectral effects. Also referred to as Standard Addition.

Method Detection Limit (MDL) - The chemical concentration that produces a signal, due to an analyte, which is equal to the student t_{99} times the standard deviation of a series of measurements on at least seven separate method blanks. In practice, a method detection limit will be substantially higher than an instrumental detection limit. The method detection limit for metals is t_{99} times the standard deviation of seven method blank analyses. Of course, all spectral background techniques must be operative and the same integration times must be utilized as when actual samples are analyzed.

MS-SCAN - The ICP is coupled to a mass selective detector where the instrument is programmed to acquire all mass for target analytes and to disregard all others.

Performance Evaluation (PE) Sample - A sample of known composition provided by EPA for Contractor analysis. Used by EPA to evaluate Contractor performance.

Preparation Blank (also reagent, procedure, and method blank) - For inorganics, an analytical control that contains distilled, deionized water and reagents, which is carried through the entire analytical procedure (digested and analyzed).

Preparation Log - An official record of the sample preparation (digestion).

Protocol - A compilation of the procedures to be followed with respect to sample receipt and handling, analytical methods, data reporting and deliverables, and document control. Used synonymously with Statement of Work (SOW).

Qualitative Accuracy - The ability of an analytical system to correctly identify compounds.

Quality Control (QC) Check Sample - A sample containing known concentrations of analytes that is analyzed by a laboratory to demonstrate that it can obtain acceptable identifications and measurements with procedures to be used to analyze environmental samples containing the same or similar analytes. Analyte concentrations are known by the analyst. Preparation of the QC check sample by a laboratory or standard supplier other than the laboratory performing the analysis is highly desirable.

Quality Control Set - A group of 10 analytical samples plus the CCVs and CCBs that bracket those samples.

Quantitative Accuracy - The ability of an analytical system to correctly measure the concentration of an identified compound.

Recovery - A determination of the accuracy of the analytical procedure made by comparing measured values for a fortified (spiked) sample against the known spike values. Recovery is determined by the following equation:

$$\%\,Surrogate\ Recovery = \frac{Measured\ value}{spiked\ value} \times 100\% \qquad \text{Eq. G-2}$$

Relative Response Factor (RRF) - A measure of the relative mass spectral response of an analyte compared to its internal standard. Relative Response Factors are determined by analysis of standards and are used in the

calculation of concentrations of analytes in samples. RRF is determined by the following equation:

$$RRF = \frac{A_x}{A_{is}} \times \frac{C_{is}}{C_x} \qquad \text{Eq. G-3}$$

where:

A = Area of the characteristic ion measured;
C = Concentration;
is = Internal standard; and
x = Analyte of interest.

Resolution - Also termed separation, the separation between peaks on a chromatogram, calculated by dividing the height of the valley between the peaks by the peak height of the smaller peak being resolved, multiplied by 100.

Retention Time (RT) - The time to elute a specific chemical from a chromatographic column for a specific carrier gas flow rate, measured from the time the chemical is injected into the gas stream until its maximum concentration appears at the detector.

Retention Time Window - Retention time window is determined for each analyte of interest and is the time from injection to elution of a specific chemical from a chromatographic column. The window is determined by three injections of a single component standard over a 24-hour period as plus or minus three times the standard deviation of the absolute retention time for that analyte.

Rounding Rules - If the figure following those to be retained is less than 5, the figure is dropped, and the retained figures are kept unchanged. As an example, 11.443 is rounded off to 11.44.

- If the figure following those to be retained is greater than 5, the figure is dropped, and the last retained figure is raised by 1. As an example, 11.446 is rounded off to 11.45.

- If the figure following those to be retained is 5, and if there are no figures other than zeros beyond the five, the figure 5 is dropped, and the last-place figure retained is increased by one if it is an odd number or it is kept unchanged if an even number. As an example, 11.435 is rounded off to 11.44, while 11.425 is rounded off to 11.42.

- If a series of multiple operations is to be performed (add, subtract, divide, multiply), all figures are carried through the calculations. Then the final answer is rounded to the proper number of significant figures.

NOTE: See forms instructions (Exhibit B) for exceptions.

Run - A continuous analytical sequence consisting of prepared samples and all associated quality assurance measurements as required by the contract Statement of Work.

Sample - A portion of material to be analyzed that is contained in single or multiple containers and identified by a unique sample number.

Sample Delivery Group (SDG) - A unit within a sample Case that is used to identify a group of samples for delivery. An SDG is a group of 20 or fewer samples within a Case, received over a period of up to 14 calendar days. Data from all samples in an SDG are due concurrently. A SDG is defined by one of the following, whichever occurs first:

- Case; or
- Each 20 samples within a Case; or
- Each 14-day calendar period during which samples in a Case are received, beginning with receipt of the first sample in the Case or SDG.

NOTE: Samples may be assigned to SDGs by sample collection method (i.e., all Tenax® tubes in one SDG, all canisters in another).

Sample Number (EPA Sample Number) - A unique identification number designated by EPA for each sample. The EPA Sample Number appears on the sample Traffic Report which documents information on that sample.

Sample Recovery (SR) - The quantity of a component measured in a sample as compared to a known quantity.

Sensitivity - The slope of the analytical curve, i.e., functional relationship between emission intensity and concentration.

Serial Dilution - The dilution of a sample by a known factor. When corrected by the dilution factor, the diluted sample must agree with the original undiluted sample within specified limits. Serial dilution may reflect the influence of interferents.

Standard Analysis - An analytical determination made with known quantities of target compounds; used to determine response factors.

Stock Solution - A standard solution which can be diluted to derive other standards.

Time - When required to record time on any deliverable item, time shall be expressed as Military Time, i.e., a 24-hour clock.

Total Metals - Analyte elements which have been digested prior to analysis.

Traffic Report (TR) - An EPA sample identification form filled out by the sampler, which accompanies the sample during shipment to the laboratory and which is used for documenting sample condition and receipt by the laboratory.

Twelve-Hour Time Period - The twelve (12) hour time period for GC/MS system tuning, standards calibration (initial or continuing calibration) begins at the moment of injection of the BFB analysis that the laboratory submits as documentation of compliant tune. The time period ends after 12 hours has elapsed according to the system clock.

Validated Time of Sample Receipt (VTSR) - The date on which a sample is received at the Contractor's facility, as recorded on the shipper's delivery receipt and Sample Traffic Report.

Viewing Area Adjustment Standard: A solution containing a standard of a strong atom line (i.e., Cu) and a weak ion line (e.g., Ba) used to verify the proper adjustment of the observation height in the plasma for metals analysis by ICP (see Method 200.62-B for details).

10% Frequency - A frequency specification during an analytical sequence allowing for no more than 10 analytical samples between required calibration verification measurements, as specified by the contract Statement of Work.

DRAFT

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
SOLID WASTE AND EMERGENCY
RESPONSE

December 5, 2003

OSWER Directive 9285.7-53

MEMORANDUM

SUBJECT: Human Health Toxicity Values in Superfund Risk Assessments

FROM: Michael B. Cook, Director /s/
Office of Superfund Remediation and Technology Innovation

TO: Superfund National Policy Managers, Regions 1 - 10

Purpose

This memorandum revises the hierarchy of human health toxicity values generally recommended for use in risk assessments, originally presented in Risk Assessment Guidance for Superfund Volume I, Part A, Human Health Evaluation Manual (RAGS) (OSWER 9285.7-02B, EPA/540/1-89/009, December 1989). (http://www.epa.gov/superfund/programs/risk/ragsa/index.htm)

It updates the hierarchy of human health toxicity values and provides guidance for the sources of toxicity information that should generally be used in performing human health risk assessments at Comprehensive Environmental Response Compensation and Liability Act (CERCLA or "Superfund") sites. It does not address the situation where new toxicity information is brought to the attention of the U.S. Environmental Protection Agency (EPA). It also does not provide guidance or address toxicity or reference values for ecological risk.

This memorandum presents current Office of Solid Waste and Emergency Response (OSWER) technical and policy recommendations regarding human health toxicity values in risk assessments. EPA and state personnel may use and accept other technically sound approaches, either on their own initiative, or at the suggestion of potentially responsible parties, or other interested parties. Therefore, interested parties are free to raise questions and objections about the substance of this memorandum and the appropriateness of the application of this document to a particular situation. EPA will, and States should, consider whether the recommendations or interpretations in this memorandum are appropriate in that situation. This memorandum does not impose any requirements or obligations on EPA, States, or other federal agencies, or the regulated community. The sources of authority and requirements in this matter are the relevant

statutes and regulations (e.g., CERCLA, Resource Conservation and Recovery Act). EPA welcomes public comments on this memorandum at any time and may consider such comments in future revisions of this memorandum.

Background

Superfund risk assessments are performed for a number of reasons, including to evaluate whether action is warranted under CERCLA, to establish protective cleanup levels, and to determine the residual risk posed by response actions. Generally, toxicity assessment is an integral part of risk assessment. Volume I, Part A of RAGS provides guidance on how to conduct the human health portion of the risk assessment. Chapter 7.4.1 presents a hierarchy of human health toxicity values for use in risk assessments at Superfund sites. The hierarchy presented in RAGS Part A is being updated to reflect that additional sources of peer reviewed values have become available since 1989. In addition, the EPA Health Effects Assessment Summary Tables (HEAST) document, which was identified as the second tier of data, has not been updated since 1997. As a result, HEAST may not provide the most current source of information on some contaminants.

This revised hierarchy recognizes that EPA should use the best science available on which to base risk assessments. In general, if health assessment information is available in the Integrated Risk Information System ["IRIS," http://www.epa.gov/iris/] for the contaminant under evaluation, risk assessors normally need not search further for additional sources of information. Since EPA's development and use of peer review in toxicity assessments, IRIS assessments have undergone external peer review in accordance with Agency peer review guidance at the time of the assessment. IRIS health assessments contain Agency consensus toxicity values. If such information is not available in IRIS, risk assessors should consider other sources of available data based on the hierarchy presented in this memorandum.

EPA recognizes that there may be other sources of toxicological information. As noted in the December 1993 memorandum entitled "Use of IRIS Values in Superfund Risk Assessment" (OSWER Directive 9285.7-16, December 21, 1993):

> "...IRIS is not the only source of toxicology information, and in some cases more recent, credible and relevant data may come to the Agency's attention. In particular, toxicological information other than that in IRIS may be brought to the Agency by outside parties. Such information should be considered along with the data in IRIS in selecting toxicological values; ultimately, the Agency should evaluate risk based upon its best scientific judgement and consider all credible and relevant information available to it."

This memorandum is intended to help regional risk assessors identify appropriate sources of toxicological information as a means of streamlining decisions. It does not specifically address the situation where additional scientific information is brought to the attention of EPA. In those cases, EPA risk assessors and decision makers should consider the information as appropriate on a case by case basis.

Revised Recommended Human Health Toxicity Value Hierarchy

This memorandum revises the recommended hierarchy of toxicological sources of information which Regional risk assessors and managers should initially consider for site-specific risk assessments. The revised recommended toxicity value hierarchy is as follows:

Tier 1- EPA's IRIS

Tier 2- EPA's Provisional Peer Reviewed Toxicity Values (PPRTVs) – The Office of Research and Development/National Center for Environmental Assessment/Superfund Health Risk Technical Support Center (STSC) develops PPRTVs on a chemical specific basis when requested by EPA's Superfund program.

Tier 3- Other Toxicity Values – Tier 3 includes additional EPA and non-EPA sources of toxicity information. Priority should be given to those sources of information that are the most current, the basis for which is transparent and publicly available, and which have been peer reviewed.

IRIS remains in the first tier of the recommended hierarchy as the generally preferred source of human health toxicity values. IRIS generally contains reference doses (RfDs), reference concentrations (RfCs), cancer slope factors, drinking water unit risk values, and inhalation unit risk values that have gone through a peer review and EPA consensus review process. IRIS normally represents the official Agency scientific position regarding the toxicity of the chemicals based on the data available at the time of the review.

The second tier is EPA's PPRTVs. Generally, PPRTVs are derived for one of two reasons. First, the STSC is conducting a batch wise review of the toxicity values in HEAST (now a Tier 3 source). As such reviews are completed, those toxicity values will be removed from HEAST, and any new toxicity value developed in such a review will be a PPRTV and placed in the PPRTV database. Second, Regional Superfund Offices may request a PPRTV for contaminants lacking a relevant IRIS value. The STSC uses the same methodologies to derive PPRTVs for both.

The third tier includes other sources of information. Priority should be given to sources that provide toxicity information based on similar methods and procedures as those used for Tier I and Tier II, contain values which are peer reviewed, are available to the public, and are transparent about the methods and processes used to develop the values. Consultation with the STSC or headquarters program office is recommended regarding the use of the Tier 3 values for Superfund response decisions when the contaminant appears to be a risk driver for the site. In general, draft toxicity assessments are not appropriate for use until they have been through peer review, the peer review comments have been addressed in a revised draft, and the revised draft is publicly available.

Additional sources may be identified for Tier 3. Toxicity values that fall within the third tier in the hierarchy include, but need not be limited to, the following sources.

- The California Environmental Protection Agency (Cal EPA) toxicity values are peer reviewed and address both cancer and non-cancer effects. Cal EPA toxicity values are available on the Cal EPA internet website at http://www.oehha.ca.gov/risk/chemicalDB//index.asp.

- The Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Levels (MRLs) are estimates of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure. The ATSDR MRLs are peer reviewed and are available at http://www.atsdr.cdc.gov/mrls.html on the ATSDR website.

- HEAST toxicity values are Tier 3 values. As noted above, the STSC is conducting a batch wise review of HEAST toxicity values. The toxicity values remaining in HEAST are considered Tier 3 values. The radionuclides HEAST toxicity values are available at http://www.epa.gov/radiation/heast/. The HEAST values on chemical contaminants are not currently available on an EPA internet site. They may be obtained by contacting a Superfund risk assessor.

Neither IRIS nor the PPRTV database contains radionuclide slope factors. Because EPA's Office of Radiation and Indoor Air (ORIA) obtains peer review on the radionuclide slope factors contained in Table 4 of HEAST (which are available on EPA/ORIA's internet website at http://www.epa.gov/radiation/heast/download.htm), routine consultation with STSC is generally not necessary on these values even when they may be a risk driver on a Superfund site. These radionuclide slope factors have been adopted by EPA in its Preliminary Remediation Goals for Radionuclide Calculator and are available on EPA's internet website at: http://epa-prgs.ornl.gov/radionuclides/ and the Soil Screening Guidance for Radionuclide documents, which are available at: http://www.epa.gov/superfund/resources/radiation/radssg.

Implementation

This memorandum provides a revised recommended hierarchy of human health toxicity values for Superfund sites and represents a revision of Chapter 7 of RAGS, Volume I, Part A. Superfund risk assessors should look to this hierarchy when evaluating risk for CERCLA response actions. Additional sources of toxicity values, which are not specifically referenced in this recommended hierarchy, can be considered.

Additional Information

Questions regarding this guidance or its use and implementation on a particular site should be directed to an EPA Regional Superfund risk assessor or toxicologist. Questions of a more general nature relating to this guidance should be directed to Mr. Dave Crawford of my staff at (703) 603- 8891, Crawford.Dave@epa.gov.

cc: Nancy Riveland, Superfund Lead Region Coordinator, USEPA Region 9
NARPM Co-Chairs
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Stephen Luftig, Senior Advisor to OSWER Assistant Administrator

PROFESSIONAL ENGINEER'S CERTIFICATION

I, Steven Geiger, as a qualified Professional Engineer per 20.4.1.101 NMAC, hereby certify that I have reviewed the Human Health Protectiveness Evaluation for VOCs Released to the Atmosphere—Waste Isolation Pilot Plant (WIPP), as completed for Washington True Solutions/D.O.E., and confirm that it has been prepared in accordance with good engineering, environmental, and risk assessment practices. The approach and intent of calculations contained herein reasonably meet the requirements of the WIPP Hazardous Waste Permit as regulated under 20.4.1 NMAC (incorporating 40 CFR §260.10).

Information provided to support the air dispersion modeling and risk assessment has been gathered from the USEPA, WIPP documentation, and interviews with WIPP employees and contractors. All information in this report has been reviewed for accuracy and completeness by WIPP.

July 14, 2010

Date

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HUMAN HEALTH PROTECTIVENESS EVALUATION VOC RELEASES TO ATMOSPHERE WASTE ISOLATION PILOT PLANT

CARLSBAD, NEW MEXICO

Prepared for
Washington TRU Solutions/ U.S. DOE

July 2010

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Project No. 41009467

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Attachments

Attachment A Air Dispersion Modeling
Attachment B Risk Calculations

The goal of this analysis is to re-evaluate potential human health risks associated with volatile organic compound (VOC) emissions from the WIPP facility to above-ground receptors, based on current information. Carbon tetrachloride is of particular concern, as emission levels of carbon tetrachloride have been increasing in recent years as the waste stream entering the mine has changed over time. In addition to changes in the levels of carbon tetrachloride releases, a number of site conditions and regulatory changes have occurred since the approval of the last version of the RCRA Part B Permit. As such, this re-evaluation is warranted to ensure that air emissions are still health-protective, and to develop updated air emission limits for the exhaust shaft monitoring station to reflect current conditions, updated toxicity data, and regulatory requirements.

A re-evaluation of air emission limits for underground mine workers (i.e., room-based limits) is not included as part of this analysis. In addition, this analysis does not attempt to correlate health-based limits for above-ground receptors with underground room-based limits or with Lower Explosive Limits (LEL) or Immediately Dangerous to Life or Health (IDLH) levels that the room-based limits are based on.

As part of this analysis, the following technical components of the original air emission limit derivation approach were re-evaluated:

- Chemical toxicity. As part of standard USEPA protocol, USEPA regularly reviews the current scientific toxicology literature of chemicals it regulates. As a result of these reviews, USEPA has subsequently revised the toxicity values for several of the VOCs since issuance of the permit.
- Chemical releases from the mine. The original exhaust shaft air emission limits were developed to address cancer risks and non-cancer hazards associated with nine VOCs that were found in waste container head space. The concentrations and relative proportions of VOC releases from the mine have changed significantly since the permit was originally issued.
- Air modeling. Air modeling was performed to predict air concentrations at various on-site and off-site receptor points, based on dispersion of air releases from the exhaust shaft. The USEPA air models have been substantially refined since the original modeling was performed.
- Receptor locations. The Air Dispersion Factors (ADFs) derived during the original air modeling were based on the locations of maximum impact, regardless of whether receptor populations were present at those locations. The revised air modeling evaluated the locations of maximum impact, as well as specific receptor locations, such as off-site residences.
- Exhaust vent configuration. Two exhaust vents were used to vent the exhaust shaft at the time of the original permit application. Air dispersion modeling in support of the permit assumed that both fans were in continuous operation year round. Since the time of the original permit application, a third exhaust vent has been added, allowing the facility to alternate which two vents are in use at any one time. A sensitivity analysis was conducted on vent use and configuration to help identify conditions that would minimize impacts on site air concentrations.
- Receptor populations. The original permit limits were based on potential risks to a full-time, on-site worker who was not OSHA-trained, and thus not protected under OSHA. An

alternative scenario has been evaluated for employees attending classes at the Training Building in the Property Protection Area (PPA).

- Regulatory requirements for derivation of risk-based values. NMED approved the current permit limits using a risk-based approach for establishing the numeric limits. NMED guidance was reviewed to determine if the target allowable risk values used in the permit (1E-5 for workers, 1E-6 for residents) were still the recommended values.

Using an approach similar to that used in the original permit, updated to reflect current toxicity values, state-of-the-practice air modeling, and current emissions from the facility, risks to surface receptors were re-calculated and alternative risk-based exhaust shaft limits were derived.

The nine waste-related VOCs listed in Table 1 below are of particular concern at the WIPP facility. As identified in the original permit, head space gas sampling of waste drums indicated that these 9 chemicals would contribute approximately 99% of the overall inhalation cancer risks and non-cancer hazard indices from waste-derived VOC emissions. Inhalation Unit Risk Factors (URFs) are chemical-specific toxicity values used to quantify cancer risks, and Reference Concentrations (RfCs) are chemical-specific toxicity values used to quantify non-cancer hazard quotients. Table 1 lists the URFs and RfCs for the nine VOCs of concern.

Table 1. Inhalation Unit Risk Factors and Reference Concentrations for the VOCs of Concern

Chemical	As used in Developing the RCRA Permit		Current USEPA Toxicity Values	
	URF $(ug/m^3)^{-1}$	RfC (mg/m^3)	URF $(ug/m^3)^{-1}$	RfC (mg/m^3)
Carbon Tetrachloride	1.5E-5	NE	**6.0E-6**	**1.0E-1**
Chlorobenzene	NA	2.0E-2	NA	**5.0E-2**
Chloroform	2.3E-5	NE	2.3E-5	**9.8E-2**
1,1-Dichloroethene	5.0E-5	NE	**NA**	**2.0E-1**
1,2-Dichloroethane	2.6E-5	NE	2.6E-5	**2.4E+0**
Methylene Chloride	4.7E-7	NE	4.7E-7	**1.0E+0**
1,1,2,2-Tetrachloroethane	5.8E-5	NE	5.8E-5	NA
Toluene	NA	4.0E-1	NA	**5.0E+0**
1,1,1-Trichloroethane	NA	7.0E-1	NA	**5.0E+0**

NA – No applicable toxicity value
NE – Not evaluated for non-cancer effects in the permit.
Bold – Current toxicity values that differ from those presented in the permit.

For some carcinogenic chemicals, both URF and RfC values are available, reflecting both the potential carcinogenicity and the systemic toxicity associated with these chemicals. For those chemicals with both URF and RfC values, NMED based the permit limits on the cancer effects only; non-cancer effects were not evaluated for those chemicals. This was appropriate, as limits based on URF values are lower (more protective) than limits that would have been based on RfC values for these specific chemicals.

As shown in Table 1, toxicity values for 5 VOCs have been revised by USEPA since the original permit was issued. Of particular note, USEPA recently reduced[1] the URF for carbon tetrachloride from 1.5E-5 to 6.0E-6 $(ug/m^3)^{-1}$ (2.5x reduction), indicating that USEPA now believes carbon tetrachloride is not as potent a carcinogen as previously thought. Given that carbon tetrachloride emissions are the primary contributor to risk, this change is significant. The changes for the other 4 VOCs are also significant. The URF for 1,1-dichloroethene has been

[1] USEPA posted the new URF for carbon tetrachloride on the Integrated Risk Information System (IRIS) database on March 31, 2010. A new RfC for carbon tetrachloride was also posted to IRIS on that date.

withdrawn; USEPA now evaluates inhalation effects for this chemical based on the RfC only. In addition, the RfC values for chlorobenzene, toluene, and 1,1,1-trichloroethane have all been increased, indicating that they are not considered as toxic as previously.

As shown in Table 2, recent data collected at the E-300 Drift monitoring station, which is the monitoring station used to monitor permit compliance, indicates that the current concentrations and proportions of VOCs being released differ substantially from those assumed when the permit limits were established. Of the carcinogenic VOCs regulated under the permit, only three (carbon tetrachloride, chloroform and methylene chloride) are currently present in site emissions, with carbon tetrachloride being the primary contributor to risk.

Table 2. Permit Limits vs Current Measured Concentrations

	As Specified in RCRA Part B Permit		Current Conditions Year Ending 12/22/09	
Chemical	Permit Limit (ppbv)	Percent of Total Cancer Risk	Measured Concentrations (ppbv)	Percent of Total Cancer Risk[2]
Carbon Tetrachloride	165	18.7	108.73	77.7
Chlorobenzene	220	0	0	0
Chloroform	180	24.2	10.46	22.2
1,1-Dichloroethene	100	23.8	0	0
1,2-Dichloroethane	45	5.7	0	0
Methylene Chloride	1930	3.8	1.99	0.06
1,1,2,2-Tetrachloroethane	50	23.9	0	0
Toluene	190	0	0.01	0

[2] The relative percent cancer risk contribution of carbon tetrachloride under current conditions includes a recent change in toxicity value from USEPA.

The Long-Term Version of USEPA's Industrial Source Complex (ISCLT3) model was used in the original permit application to develop the ADFs that were used to evaluate risks and back-calculate allowable emission limits. USEPA air models have been substantially refined since the original modeling was performed, and the ISCLT3 model is no longer supported by EPA. Although the short-term version of the ISC modeling system, ISCST3, may be used for certain applications including evaluations of annual impact concentrations, it is now considered to be an alternative model rather than a preferred model. The air dispersion modeling presented in this report was performed using USEPA's preferred dispersion model, which is the American Meteorological Society / USEPA Regulatory Model (AERMOD) version 09292, to predict air concentrations at various on-site and off-site receptor points, resulting from dispersion of air releases from the exhaust shafts. The model was run with five years of meteorological data, much of which was derived from data collected at the WIPP on-site meteorological monitoring station. A detailed description of the implementation of the model is presented in *Attachment A*.

The Air Dispersion Factors (ADFs) were derived for the on-site Property Protection Area (PPA), Livingstone Ridge Allotment, Antelope Ridge Allotment, and off-property. The original modeling conducted for the permit used the locations of maximum impact from each of these areas to derive the ADFs that were used when setting limits. In the case of the PPA, the location of maximum impact was a street near the exhaust vents. For the off-property ADF, the location of maximum impact was identified at the property boundary. Neither of the locations of maximum impact corresponds to the receptor locations of concern. For the PPA, the receptor location of concern is the Training Building. For the off-property location, the receptors of concern are local residents. The revised air modeling evaluated the locations of maximum impact, as well as actual receptor locations at the Training Building, the Mills Ranch and the Smith Ranch. All receptor locations are shown in *Attachment A* figures A-1 and A-2.

The addition of a third exhaust vent provides flexibility, as typically only two vents are in use at any one time. The model was run on an annual basis assuming that only two vents are operating at any given time during the year. The two older vents were labeled V1 and V2 in the model, and the newer vent (labeled V3) is located about 160 feet to the west of the older vents. The following scenarios were evaluated:

- Scenario 1: V1 and V2 operate continuously
- Scenario 2: V1 and V3 operate continuously
- Scenario 3: V2 and V3 operate continuously
- Mixed Scenario: V1 and V2 operate concurrently (Scenario 1) for 20% of the year and highest impacting of Scenarios 2 or 3 operates for the other 80% of the year.

Scenario 1, which assumes that both of the older vents emit continuously throughout the year, is consistently the highest impacting scenario but also the most unlikely based on current operating practices at the WIPP facility. The more realistic Mixed Scenario allows for both of the old vents to emit concurrently for a maximum of 1752 hours per year (20% of the year) while any combination of Scenarios 2 or 3 may operate during the other 7008 hour per year (80% of the year).

Currently, all vents have a release height of 33.2 feet above the ground and are oriented at a 45 degree angle from vertical. A sensitivity analysis was performed to determine the effect of vent height, vent orientation, and use of different combinations of vents on the resultant ADFs. Tables 3a – 3d show the predicted Air Dispersion Factors that would result from the current vent configuration, as well as the ADFs that would result from raising the vent height up to 50 feet above the current height as well as re-orienting the stack so that it emits vertically upward, rather than at an angle. Raising the vent release heights and re-orienting the stacks so that they are directed vertically upward will give the emitted plume greater dispersion characteristics, which will reduce modeled impact concentrations on and near the WIPP site.

Table 3a. ADFs Resulting from the Highest Impacts of Scenarios 1, 2, and 3 Assuming Vent Stacks Oriented at 45° Angle

Area / Receptor	Maximum Modeled ADFs (Unitless)					
	@ Current Vent Height	@ Current Vent Height + 10 ft	@ Current Vent Height + 20 ft	@ Current Vent Height + 30 ft	@ Current Vent Height + 40 ft	@ Current Vent Height + 50 ft
All Modeled Receptors	1.54E-02	5.12E-03	2.97E-03	1.82E-03	1.20E-03	8.37E-04
Property Protection Area	1.54E-02	5.12E-03	2.97E-03	1.82E-03	1.20E-03	8.37E-04
Exclusive Use Area	2.92E-03	1.95E-03	1.74E-03	1.39E-03	1.08E-03	8.11E-04
Off Limits Area	6.79E-04	5.94E-04	5.16E-04	4.58E-04	4.01E-04	3.43E-04
Site Boundary - Off Property	8.81E-05	6.08E-05	5.45E-05	5.13E-05	4.60E-05	4.15E-05
Antelope Ridge	6.79E-04	5.94E-04	5.16E-04	4.58E-04	4.01E-04	3.43E-04
Livingston Ridge	1.77E-04	1.58E-04	1.58E-04	1.32E-04	1.27E-04	1.09E-04
Building 489: Training Bldg.	8.72E-03	4.84E-03	2.75E-03	1.34E-03	5.76E-04	2.16E-04
Resident - Mills Ranch	1.64E-05	1.64E-05	1.30E-05	1.12E-05	7.69E-06	6.99E-06
Resident - Smith Ranch	2.14E-05	1.47E-05	1.34E-05	1.14E-05	9.71E-06	9.45E-06

Table 3b. ADFs Resulting from the Highest Impacts of Scenarios 1, 2, and 3 Assuming Vent Stacks Oriented Vertically Upward

Area / Receptor	Maximum Modeled ADFs (Unitless)					
	@ Current Vent Height	@ Current Vent Height + 10 ft	@ Current Vent Height + 20 ft	@ Current Vent Height + 30 ft	@ Current Vent Height + 40 ft	@ Current Vent Height + 50 ft
All Modeled Receptors	5.22E-03	2.69E-03	1.82E-03	1.21E-03	8.46E-04	6.15E-04
Property Protection Area	5.22E-03	2.69E-03	1.82E-03	1.21E-03	8.46E-04	6.12E-04
Exclusive Use Area	1.97E-03	1.56E-03	1.35E-03	1.06E-03	8.12E-04	6.15E-04
Off Limits Area	6.24E-04	5.21E-04	4.56E-04	4.00E-04	3.47E-04	2.96E-04
Site Boundary - Off Property	8.65E-05	5.79E-05	5.07E-05	4.65E-05	4.16E-05	3.75E-05
Antelope Ridge	6.24E-04	5.21E-04	4.56E-04	4.00E-04	3.47E-04	2.96E-04
Livingston Ridge	1.68E-04	1.45E-04	1.46E-04	1.26E-04	1.17E-04	9.68E-05
Building 489: Training Bldg.	4.99E-03	2.44E-03	1.47E-03	6.95E-04	2.74E-04	9.55E-05
Resident - Mills Ranch	1.56E-05	1.57E-05	1.22E-05	1.08E-05	7.26E-06	6.47E-06
Resident - Smith Ranch	2.11E-05	1.43E-05	1.28E-05	1.09E-05	9.18E-06	8.90E-06

Table 3c. ADFs Resulting from the Highest Impacts of the Mixed Scenario Assuming Vent Stacks Oriented at 45° Angle

Area / Receptor	Maximum Modeled ADFs (Unitless)					
	@ Current Vent Height	@ Current Vent Height + 10 ft	@ Current Vent Height + 20 ft	@ Current Vent Height + 30 ft	@ Current Vent Height + 40 ft	@ Current Vent Height + 50 ft
All Modeled Receptors	1.14E-02	4.71E-03	2.69E-03	1.70E-03	1.14E-03	8.08E-04
Property Protection Area	1.14E-02	4.71E-03	2.69E-03	1.70E-03	1.14E-03	8.08E-04
Exclusive Use Area	2.78E-03	1.91E-03	1.64E-03	1.32E-03	1.03E-03	7.82E-04
Off Limits Area	6.72E-04	5.88E-04	5.10E-04	4.53E-04	3.97E-04	3.40E-04
Site Boundary - Off Property	8.78E-05	6.07E-05	5.44E-05	5.11E-05	4.58E-05	4.14E-05
Antelope Ridge	6.72E-04	5.88E-04	5.10E-04	4.53E-04	3.97E-04	3.40E-04
Livingston Ridge	1.76E-04	1.57E-04	1.53E-04	1.31E-04	1.25E-04	1.09E-04
Building 489: Training Bldg.	6.83E-03	3.86E-03	2.01E-03	1.02E-03	4.61E-04	1.96E-04
Resident - Mills Ranch	1.63E-05	1.64E-05	1.30E-05	1.12E-05	7.68E-06	6.99E-06
Resident - Smith Ranch	2.13E-05	1.47E-05	1.33E-05	1.14E-05	9.70E-06	9.44E-06

Table 3d. ADFs Resulting from the Highest Impacts of the Mixed Scenario Assuming Vent Stacks Oriented Vertically Upward

Area / Receptor	Maximum Modeled ADFs (Unitless)					
	@ Current Vent Height	@ Current Vent Height + 10 ft	@ Current Vent Height + 20 ft	@ Current Vent Height + 30 ft	@ Current Vent Height + 40 ft	@ Current Vent Height + 50 ft
All Modeled Receptors	4.70E-03	2.64E-03	1.68E-03	1.15E-03	8.15E-04	5.97E-04
Property Protection Area	4.70E-03	2.64E-03	1.68E-03	1.15E-03	8.15E-04	5.97E-04
Exclusive Use Area	1.92E-03	1.55E-03	1.28E-03	1.01E-03	7.81E-04	5.97E-04
Off Limits Area	6.17E-04	5.16E-04	4.52E-04	3.97E-04	3.44E-04	2.94E-04
Site Boundary - Off Property	8.62E-05	5.78E-05	5.06E-05	4.62E-05	4.14E-05	3.74E-05
Antelope Ridge	6.17E-04	5.16E-04	4.52E-04	3.97E-04	3.44E-04	2.94E-04
Livingston Ridge	1.68E-04	1.44E-04	1.42E-04	1.26E-04	1.14E-04	9.66E-05
Building 489: Training Bldg.	3.91E-03	1.96E-03	1.07E-03	5.17E-04	2.16E-04	8.69E-05
Resident - Mills Ranch	1.56E-05	1.57E-05	1.22E-05	1.08E-05	7.25E-06	6.47E-06
Resident - Smith Ranch	2.11E-05	1.43E-05	1.28E-05	1.09E-05	9.17E-06	8.89E-06

Consistent with the approach used in the current permit, risks were evaluated at the points of maximum impact for the following receptor populations:

- Full-time, non-waste surface workers in the PPA, assuming this worker population is not protected under OSHA
- Ranch workers in the Livingston Ridge Ranch Allotment
- Ranch workers in the Antelope Ridge Ranch Allotment
- Off-property residents who live at the property boundary

It should be noted that the points of maximum impact for the non-waste surface worker and off-property resident do not correspond to locations where these receptors are likely to be present on a full-time basis. The point of maximum impact at the PPA does not overlap any of the occupied site buildings; the permit assumes that this point reflects concentrations at the Training Building. The point of maximum impact for the off-property resident occurs at the property boundary; the permit assumes that a residence is present at this location.

As part of the current evaluation, risks were also calculated for the following three scenarios, which are thought to represent more realistic exposure conditions at the PPA and off-property locations:

- Site employees who attend training courses in the Training Building. Site information indicates that, on average, employees attend training classes in this building about 1 day every other week. Under this scenario it was assumed that the trainee was the non-OSHA trained receptor with the greatest potential for exposure at the PPA.
- A resident at the Mills Ranch.
- A resident at the Smith Ranch.

For development of air emission limits, the current permit identifies target cumulative risk levels of 1E-5 for on-site workers, and 1E-6 for ranch workers and off-property residents. NMED guidance was reviewed to determine if the target allowable risk values used in the permit (1E-5 for workers, 1E-6 for residents) were still the recommended values. The use of a risk-based approach for developing permit limits appears to be atypical, as the NMED Air Quality Bureau does not usually consider specific risk levels when setting air emission limits. In contrast, the NMED Hazardous Waste Bureau, which does not set permitted air emission limits, regulates chemical exposure using a per chemical target risk of 1E-5, both for industrial and residential scenarios.

The NMED established emission limits as environmental performance standards under the RCRA Miscellaneous Unit Rules (40 CFR 264, Subpart X). NMED considers these worker-based standards protective of human health and the environment for chemicals released into the air exhaust stream as a result of waste disposal in the WIPP repository.

Use of a per chemical 1E-5 target risk for all scenarios would 1) allow higher allowable air emission levels for each chemical, and 2) would make it less likely that the off-property residential scenario could be the limiting factor in deriving limits.

Cancer risks and non-cancer hazard indices were calculated for each receptor population, based on current emission levels from the exhaust shaft. *Attachment B* documents the risk calculation process. The risk results presented in Table 4 reflect two alternative sets of calculations intended to bracket risks under different operating assumptions.

The column labeled "current permit approach" is intended to present risks using an approach similar to that used in the current permit, updated to reflect current conditions. Assumptions included:

- Current emission concentrations were assumed (based on the information in Table 2).
- No modifications of exhaust vents, relative to height or angle of vent orientation, were assumed.
- Two of the three vents were assumed to be in use at any one time. Usage assumed vent 1 and vent 2 operate concurrently (vent scenario 1) for 20% of the year and highest impacting of vent scenarios 2 or 3 operates for the other 80% of the year.
- ADFs were based on current modeling runs; ADFs from the permit were not used.
- ADFs were based on the points of maximum impact in each area, regardless of whether those points corresponded to actual receptor locations.
- For the PPA, a full-time worker was identified as the most exposed individual for calculation of risk, assuming these workers are not protected under OSHA (i.e., the acceptable risk level is 10^{-5}).
- Current URFs and RfCs were used.
- Hazard indices were calculated for all chemicals with published RfCs, including carcinogenic chemicals.

The column labeled "best-case approach" presents risks based on alternative exposure conditions, assuming that the exhaust vents are optimized to minimize ground-level impacts. Assumptions included:

- Current emission concentrations were assumed (based on the information in Table 2).
- Exhaust vents were assumed to be modified to minimize exposure to ground-level receptors, including an increase in stack height of 50 feet, and a change in angle of vent orientation from 45 degrees to vertical.
- Two of the three vents were assumed to be in use at any one time. Usage assumed vent 1 and vent 2 operate concurrently (vent scenario 1) for 20% of the year and highest impacting of vent scenarios 2 or 3 operates for the other 80% of the year.
- ADFs were based on current modeling runs; ADFs from the permit were not used.
- ADFs were based on actual receptor locations. For the PPA, ADFs were based on the location of the Training Building. For the off-property residents, ADFs were based on the location of the Mills and Smith ranches. For the Antelope Ridge Allotment and Livingston Ridge Allotment scenarios, ADFs remained at the points of maximum impact.

- For the PPA, a part-time trainee was identified as the most exposed individual for calculation of risk, assuming fulltime workers who may also be present are fully trained and protected under OSHA.
- Current URFs and RfCs were used.
- Hazard indices were calculated for all chemicals with published RfCs, including carcinogenic chemicals.

Table 4. Sensitivity of Risk Results to Different Calculation Approaches

Receptor	Current Permit Approach			Best Case Approach		
	ADF	Cancer Risk	Hazard Index	ADF	Cancer Risk	Hazard Index
Non-waste Surface Worker	1.14E-2	5.8E-7	4.2E-4	NA	NA	NA
Trainee	NA	NA	NA	8.69E-5	4.4E-10	3.2E-7
Antelope Ridge Rancher	6.72E-4	1.3E-7	2.7E-5	2.94E-4	5.6E-8	1.2E-5
Livingston Ridge Rancher	1.76E-4	3.4E-8	7.0E-6	9.66E-5	1.9E-8	3.8E-6
Resident at Property Boundary	8.78E-5	7.1E-8	1.5E-5	NA	NA	NA
Mills Ranch Resident	NA	NA	NA	6.47E-6	5.2E-9	1.1E-6
Smith Ranch Resident	NA	NA	NA	8.89E-6	7.2E-9	1.5E-6

At current emission rates, all cancer risks and hazard indices are at acceptable levels. Using the current permit approach, the highest cancer risks were 5.8E-7 for non-waste surface workers, considerably lower than the target risk level of 1E-5. Hazard indices were very low for all receptors, with the highest hazard index of 4.2E-4 for non-waste surface workers. Compared to a target hazard of 1.0, these values are essentially negligible. Current emission rates would need to increase more than 1000x before non-cancer effects would pose a hazard to the most-exposed receptor.

Alternative air emission limits were calculated for each of the 4 receptors originally identified in the Permit, using the assumptions described above under "current permit approach". The calculation process is described in *Attachment B*. For the non-waste surface worker scenario, target cumulative risks were set at 1E-5. For the Antelope Ridge Allotment ranch worker, Livingston Ridge Allotment ranch worker, and off-property resident scenarios, target cumulative risks were set at 1E-6. Per chemical target risks were apportioned to reflect the relative contribution of each chemical to overall risk based on current emission rates, as identified in Table 2. Table 5 presents the alternative air emission limits for each of these scenarios. Two of the five carcinogenic compounds are not included in Table 5 because they are not currently detected in the emissions from the WIPP facility at this time. Because of this and because the values are based on conservative exposure assumptions, they are intended for discussion purposes only. Other limits can readily be calculated if more realistic exposure assumptions are used, if an on-site trainee is used instead of a non-waste surface worker, if alternative target risk levels are used, if modifications are made to the current vent system, or if a portion of the risk is assigned to the non-detected compounds.

Table 5. Alternative Air Emission Limits (E-300 Concentrations of Concern)

Receptor	ADF	Alternative Limit (ppbv)		
		Carbon Tetrachloride	Chloroform	Methylene Chloride
Non-waste Surface Worker	1.14E-2	1885	181	35
Antelope Ridge Rancher	6.72E-4	843	81	15
Livingstone Ridge Rancher	1.76E-4	3220	310	59
Off-Property Resident	8.78E-5	1533	147	28

Of the four scenarios evaluated, the Antelope Ridge Allotment Rancher scenario has the lowest alternative air emission limits. However, consistent with the approach used in the current permit, the recommended limits would be based on the non-waste surface worker instead of the Antelope Ridge Allotment Rancher. There are several reasons for this. First, the Antelope Ridge Rancher is a hypothetical individual at a hypothetical location that is not known to actually exist. Furthermore, it is totally within the authority of the DOE to limit entry to this area if necessary to protect the public. Second, the next highest risk is the off-property resident who is also a hypothetical (fence line) case. The lands adjacent to the WIPP site boundary are public lands with little opportunity for a permanent resident.

This evaluation demonstrates that risks associated with current emissions at WIPP do not pose an unacceptable risk to any on-site or off-site receptor populations. Example calculations of alternative air emission limits in *Attachment B* indicate that, even using conservative, technically defensible assumptions, air emission limits could be raised and still be health-protective.

Attachment A – AERMOD Air Dispersion Modeling

Overview of Dispersion Modeling Process

The calculations and model runs were performed in support of the No-Migration Variance Petition (NMVP) and the Resource Conservation and Recovery Act (RCRA) Part B Permit Renewal Application for WIPP. The EPA guidance on the air pathway assessment for NMVPs has specific requirements related to the air dispersion modeling for NMVPs. The model runs should:

- estimate annual average concentrations using ***ISCLT3***;
- use five years of preferable on-site meteorological data, evaluate one year at a time, and use the run that produces the maximum boundary concentration;
- include receptors up to 328 feet (100 meters) beyond the unit boundary to verify that the maximum concentration occurs at the boundary;
- include a fine receptor grid in the maximum concentration area;
- use Cartesian receptor grids;
- correct for the vertical wind profile, if the source is at ground level; and
- specify receptor heights at 5 feet (1.5 meters) (inhalation height).

All of these criteria were included in the dispersion modeling analysis for the WIPP site, with the exception of the first bulleted item above. USEPA air models have been substantially refined since the NMVP guidance was issued, and the ISCLT3 model is no longer supported by EPA. Although the short term version of the ISC modeling system, ISCST3, may be used for certain applications including evaluations of annual impact concentrations, it is now considered to be an alternative model rather than a preferred model. The air dispersion modeling presented in this application was performed using EPA's preferred dispersion model which is the American Meteorological Society / EPA Regulatory Model (AERMOD) version 09292 to predict air pollutant concentrations at various on-site and off-site receptor points, based on the dispersion of air releases from the exhaust shafts. The model was run with five years of meteorological data, much of which was derived from data collected at the WIPP on-site meteorological monitoring station.

The AERMOD modeling system has a number of components. There are several preprocessor programs:

- AERMAP, which generates receptor elevations and other terrain related information;
- AERSURFACE, which generates land use characteristic values of albedo, bowen ratio, and surface roughness length for use with AERMET, and;
- AERMET, which takes meteorological data from the on-site monitors and National Weather Service surface and upper air data, as well as the land use data from AERSURFACE to create meteorological data files that are compatible with AERMOD.

After all the required preprocessors have been run, the AERMOD model may then be setup and run. AERMOD uses Gaussian dispersion algorithms in conjunction with meteorological data, terrain data, and building downwash parameters to estimate impact concentrations downwind of

the sources. In the case of the WIPP project modeling, some additional post processing was necessary, which was accomplished with a series of Excel workbooks.

Development of ADFs

The purpose of the dispersion modeling part of the analysis was to estimate air dispersion factors (ADFs), which are then used in the risk assessment calculations as described in Attachment B. These values represent the maximum impact concentrations of any gaseous airborne hazardous constituent per unit concentration emitted from the mine air exhaust system during WIPP disposal operations. AERMOD was used to predict maximum impact concentrations in $\mu g/m^3$, given an arbitrary input gas concentration of 10,000 $\mu g/m^3$. The ADF was then calculated using the following ratio:

$$\text{Air Dispersion Factor} = \frac{\text{Maximum Impact Concentration } (\mu g/m^3)}{\text{Release Concentration } (\mu g/m^3)} \quad \text{(Eqn. A-1)}$$

In the NMVP petition, the Department of Energy (DOE) must demonstrate that there will be no migration of hazardous constituents above heath-based levels (HBL) beyond the unit boundary.

Given a concentration of volatile organic compounds (VOC) in air released from the mine ventilation exhaust ducts, the air dispersion factor determines the resulting maximum concentration for the NMVP. This concentration is then compared to HBLs to demonstrate no-migration. In the permit application the DOE must demonstrate that there will be no release that may have an adverse effect on human health and the environment due to migration of waste constituents in the air. For the permit renewal application, the maximum concentration is used to calculate the long-term risk to the public, and then compared to acceptable risk levels. Occupational exposure is also required to be assessed in the application.

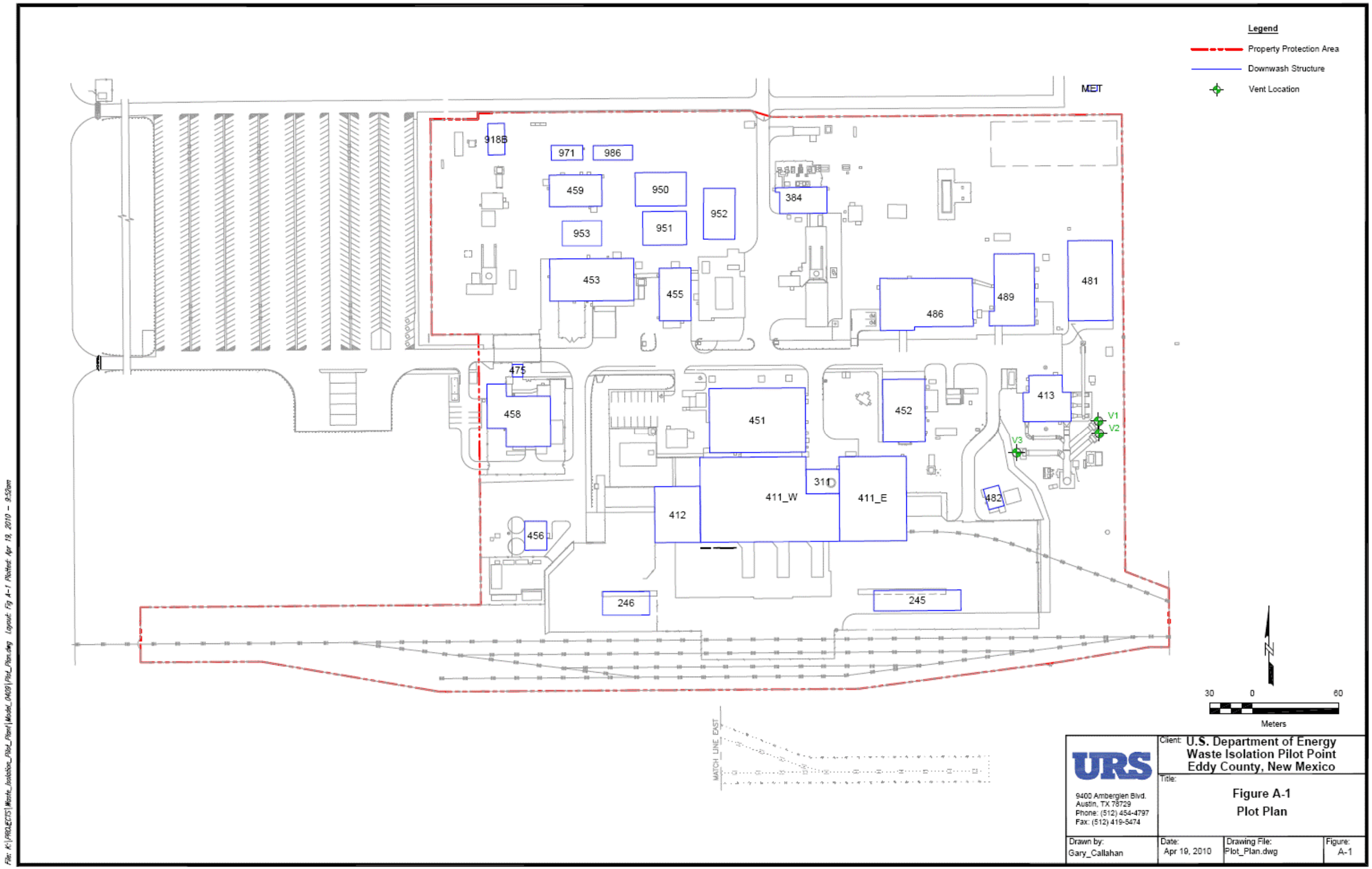
To perform the assessments above, a number of ADFs were determined including

- The maximum ADFs estimated anywhere (which were in the property protection area)
- The maximum ADFs estimated in the training building (which is the nearest structure to the vents where worker exposure would be significant)
- The maximum ADFs estimated in the Exclusive Use Area
- The maximum ADFs estimated in the Off Limits Area
- The maximum ADFs estimated within the Antelope Ridge Allotment
- The maximum ADFs estimated within the Livingston Ridge Allotment
- The maximum ADFs estimated along and 100 meters beyond the property boundary, and
- The ADFs estimated at the nearest residences

Please note that a set of ADFs was generated for each scenario described on page 6.

Site Plan and Area Map

Figure A-1 is a site plan of the WIPP facility that identifies the buildings included in the model as well as the locations of the vents. Figure A-2 is an area map that shows the designations of each component of the WIPP property (including the agricultural allotments) as well as the property boundary and nearest residents.



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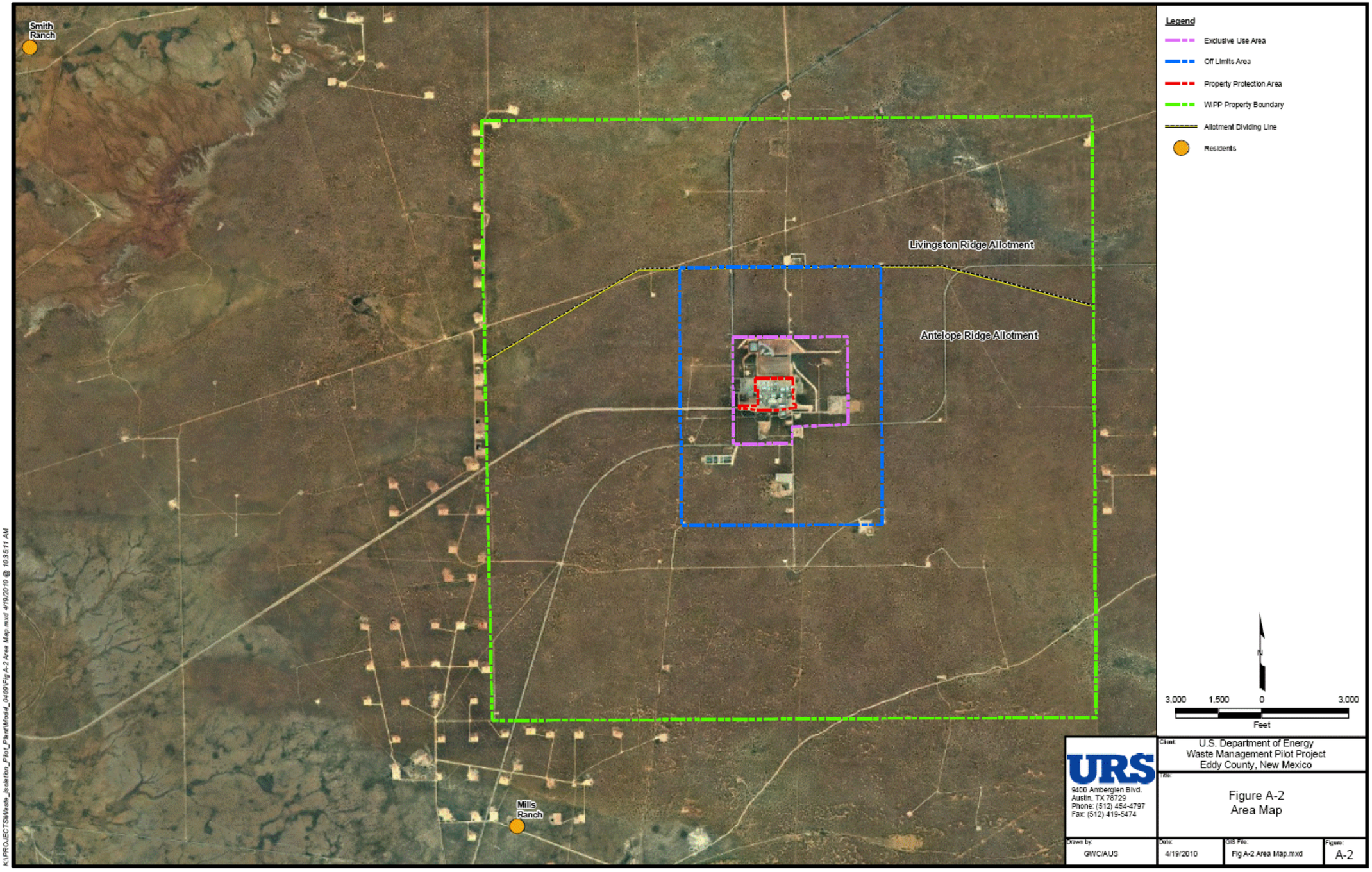
Smith Ranch
Livingston Ridge Allotment
Antelope Ridge Allotment
Mills Ranch
Legend
Exclusive Use Area
Off Limits Area
Property Protection Area
WIPP Property Boundary
Allotment Dividing Line
Residents
N
3,000 1,500 0 3,000
Feet
K:\PROJECTS\Waste_Isolation_Pilot_Plant\Mxd_0409\Fig A-2 Area Map.mxd 4/19/2010 @ 10:35:11 AM
URS
9400 Amberglen Blvd.
Austin, TX 78729
Phone: (512) 454-4797
Fax: (512) 419-5474
Client: U.S. Department of Energy
Waste Management Pilot Project
Eddy County, New Mexico
Title:
Figure A-2
Area Map
Drawn by: GWC/AUS
Date: 4/19/2010
GIS File: Fig A-2 Area Map.mxd
Figure: A-2

Sensitivity Analysis: Vent Configurations and Operating Scenarios

The modeling analysis was designed to generate ADFs for a variety of operating conditions and vent configurations.

Operating Conditions

Although there are three vents available to release exhaust from the mine, typically only two vents are in use at any one time. The two older vents were labeled V1 and V2 in the model, and the newer vent (labeled V3) is located about 160 feet to the west of the older vents. The following scenarios were evaluated:

- Scenario 1: V1 and V2 operate continuously
- Scenario 2: V1 and V3 operate continuously
- Scenario 3: V2 and V3 operate continuously
- Mixed Scenario: V1 and V2 operate concurrently (Scenario 1) for 20% of the year and highest impacting of Scenarios 2 or 3 operates for the other 80% of the year.

Scenario 1, which represents a situation that allows both of the older vents to emit continuously during the year, is consistently the highest impacting scenario but also the most unlikely. The more realistic Mixed Scenario allows for both of the old vents to emit concurrently for a maximum of 20% of each year while any combination of Scenarios 2 or 3 may operate during the other 80% of each year.

Vent Configurations

Currently, all vents have a release height of 33.2 feet above the ground and are oriented at a 45° angle from vertical. However any potential change in vent height or vent orientation could affect predicted impact concentrations and ADFs. Part of the sensitivity analysis was to evaluate the effect of vent height and vent orientation on the resultant ADFs. The vents were modeled in the following configurations:

- Vents oriented at a 45° angle, with a release height of 33.2 feet (current configuration)
- Vents oriented at a 45° angle, with a release height of 43.2 feet
- Vents oriented at a 45° angle, with a release height of 53.2 feet
- Vents oriented at a 45° angle, with a release height of 63.2 feet
- Vents oriented at a 45° angle, with a release height of 73.2 feet
- Vents oriented at a 45° angle, with a release height of 83.2 feet
- Vents oriented vertically upward, with a release height of 33.2 feet
- Vents oriented vertically upward, with a release height of 43.2 feet
- Vents oriented vertically upward, with a release height of 53.2 feet
- Vents oriented vertically upward, with a release height of 63.2 feet
- Vents oriented vertically upward, with a release height of 73.2 feet
- Vents oriented vertically upward, with a release height of 83.2 feet

Raising the vent release heights and re-orienting the vents so that they are directed vertically upward gives the emitted plume greater dispersion characteristics, which reduce modeled impact concentrations and ADFs. Although the change in ADF values with different vent configurations is significant for receptors close to the vents (in the Property Protection Area, in particular), the differences in ADF values for far away receptors is slight.

For each receptor, and ADF value was generated for each of 4 operating scenarios × 12 vent configurations = 48 possible operating conditions.

Emission Rates and Source Parameters

For modeling purposes, the pollutant concentration in each vent was given an arbitrary value of 10,000 μg/m^3 (0.01 g/m^3). The maximum volumetric air flow rate through the mine shafts is 425,000 ft^3/min (200.6 m^3/s). This volumetric flow rate is divided in half as the flow is directed to each of the two open vents. The air flow rate through any single vent is 100.3 m^3/s. Therefore, the generic pollutant emission rate for each individual vent is the concentration multiplied by the volumetric flow rate, which is:

$$0.01 \text{ g/m}^3 \times 100.3 \text{ m}^3/\text{s} = \mathbf{1.003 \text{ g/s}}$$

$$0.02$$

For each vent the model requires the source parameters of release height, exit temperature, stack diameter, and exit velocity. The rationale for these model selections is provided below.

Release Height. The current vent release height is 33.2 feet. Other potential vent configurations include the vent release height at 43.2 ft, 53.2 ft, 63.2 ft, 73.2 ft, and 83.2 ft.

Exit Temperature. The minimum recorded duct temperature between March 2009 and February 2010 of 58 °F was selected as the exit temperature for the analysis. In actuality, the temperature varies throughout the day and from season to season. However, for low exit temperatures, plume dispersion characteristics are poor. In this case the plume remains concentrated, which leads to higher impact concentrations. The selection of an exceedingly low exit temperature is a conservative model selection.

Stack Diameter. The shape of the opening of each vent is square, and all vents are identical. In order to approximate the "diameter" of the vent opening, the area of each opening was calculated, and the radius of a circle with the same area was determined. Each vent opening is a square shape, 130 inches (3.3 meters) per side. Therefore, the area of the opening is:

$$3.3 \text{ m} \times 3.3 \text{ m} = 10.9 \text{ m}^2$$

A circle with the same area would have a diameter of:

$$2 \times \text{sqrt} (10.9 \text{ m} / \pi) = 3.73 \text{ m}$$

Exit Velocity. Like low exit temperatures, low exit velocities also lead to poor dispersion characteristics and higher impact concentrations. In order to estimate the exit velocity from the vents, the minimum allowable volumetric flow rate of 260,000 ft^3/min (122.7 m^3/s) was used. The low flow rate, which corresponds to a low exit velocity, is a conservative modeling selection. This flow rate is divided in half as the flow is directed to each of the two open vents.

The air flow rate through any single vent is 61.4 m^3/s. If the vent emitted vertically upward, the exit velocity may be estimated by dividing the flow rate by the area of the vent opening, which is 10.9 m^2. In this case, the exit velocity is:

$$61.4\ m^3/s \div 10.9\ m^2 = 5.63\ m/s$$

However, the vents are currently oriented at a 45° angle from the vertical. The exit velocity required by the model is, in fact, the *vertical* exit velocity. The vertical component of the exit velocity from the angled vent is:

$$\sin(45°) \times 5.63\ m/s = 3.98\ m/s$$

In summary, the vents were modeled with the source parameters listed in Table A-1. All values in this table are in metric units because these are the units accepted by AERMOD.

Table A-1. Modeled Source Parameters

Source ID	UTM Easting (X) (m)	UTM Northing (Y) (m)	Base Elevation (m)	Release Height (m)	Exit Temperature (K)	Exit Velocity (m/s)	Stack Diameter (m)
V1	613688	3582305	1039.3	10.11 / 13.16 / 16.21 / 19.25 / 22.30 / 25.35 [a]	287.6	3.98 / 5.63 [b]	3.73
V2	613689	3582298	1039.3	10.11 / 13.16 / 16.21 / 19.25 / 22.30 / 25.35 [a]	287.6	3.98 / 5.63 [b]	3.73
V3	613641	3582286	1039.3	10.11 / 13.16 / 16.21 / 19.25 / 22.30 / 25.35 [a]	287.6	3.98 / 5.63 [b]	3.73

[a] Six different possible release heights (33.2 ft, 43.2 ft, 53.2 ft, 63.2 ft, 73.2 ft & 83.2 ft) were included in the analysis.

[b] An exit velocity of 3.98 m/s indicates that the vent is oriented at a 45° angle from the vertical whereas an exit velocity of 5.63 m/s indicates that the vent is oriented vertically upward. Both configurations were included in the analysis.

The locations of all sources (as well as buildings and receptors) were modeled in Zone 13 NAD 83 UTM coordinates.

Model Selection and Control Parameters (AERMOD)

The most recent version of the AMS/EPA Regulatory Air Model (AERMOD Version 09292) developed by the EPA Support Center for Regulatory Air Modeling (SCRAM) was used for this analysis. All regulatory default options were selected. The regulatory default options require:

- Use the elevated terrain algorithms requiring input of terrain height data;
- Use stack-tip downwash (except for building downwash cases);
- Use the calms processing routines; and
- Use the missing data processing routines.

Other important model selections include:

- Each receptor was given a flagpole elevation of 1.5 meters above the ground.
- The model was set to estimate concentrations over an annual averaging period.

- A separate model run was generated for each year of meteorological data.
- Building downwash parameters were included in the model.
- Receptor elevations and hill heights were included in the model.
- A source-group was created for each vent, so that the impact concentrations due to each vent could be evaluated individually.
- The profile base elevation was set to 1038 meters above sea level, which is the elevation of the on-site surface meteorological station.
-

All modeling file are provided electronically on the attached DVD.

Land Use (AERSURFACE)

Several parameters are used to describe the character of the modeled domain, including surface roughness length, albedo and Bowen ratio. These parameters are incorporated into the surface meteorological data set created by AERMET.

AERSURFACE version 08009 was run to estimate which land use parameters best describe the area around the WIPP site. Land Use Land Cover data was obtained from the file U.S. Geological Survey (USGS) website http://edcftp.cr.usgs.gov/pub/data/landcover/states/. The most important input parameter selections for AERSURFACE were:

- The study radius for surface roughness was set a 1 km, which is the default distance recommended by EPA.
- The area around the WIPP site was not divided into sectors, and was evaluated on an annual basis (rather than by season or month). The area within 1 kilometer of the WIPP site is relatively homogeneous with regard to land use, and these parameters are not expected to vary much with seasons.

All AERSURFACE modeling files are included on attached DVD.

Receptor Grid and Terrain Processing (AERMAP)

Discrete cartesian coordinates were placed on top of the WIPP site, in the surrounding areas, along the property boundary, and at the two nearest residences. The model estimates impact concentrations for each individual receptor. All receptors were given a flagpole elevation of 1.5 meters above the ground.

The receptor grids, illustrated in Figures A-3 and A-4, used in the model were designed as follows:

- On the Property Protection Area, receptors were evenly spaced every 10 meters, making a very fine grid of receptors;
- In the area beyond the Property Protection Area but inside the Exclusive Use Area, receptors were evenly spaced every 25 meters;
- In the area beyond the Exclusive Use Area but inside the Off Limits Area (which includes part of the Antelope Ridge Allotment), receptors were evenly spaced every 50 meters;

- In the area beyond the Off Limits Area but inside the WIPP Property Boundary (which includes part of the Antelope Ridge Allotment and all of the Livingston Ridge Allotment), receptors were evenly spaced every 100 meters
- Receptors were also evenly spaced every 100 meters along the WIPP Property Boundary and an additional 100 meters beyond the boundary
- Discrete receptors were also placed at the locations of the two nearest residents, referenced here as Mills Ranch and Smith Ranch.

The model output files provide impact concentrations at each receptor in specific order. In order to evaluate impacts at specific locations, the list of receptors was broken into groups so that specific areas could be evaluated individually. Specifically,

- Receptors 1 – 1385: Property Protection Area;
- Receptors 886-888, 927-929, 968-970, 1009-1011: Training Building;
- Receptors 1386 – 3206: Exclusive Use Area;
- Receptors 3207 – 5022: Off Limits Area (Antelope Ridge);
- Receptors 5023 – 8843: Inside WIPP Property Boundary (Antelope Ridge & Livingston Ridge);
- Receptors 8844 – 9368: Along WIPP Property Boundary and 100 meters beyond;
- Receptor 9369: Mills Ranch
- Receptor 9370: Smith Ranch

Receptor elevations and hill heights were obtained by running AERMAP Version 09040 in conjunction with digital elevation model (DEM) data. 10-meter resolution DEM data was obtained from http://download.geocomm.com for the following New Mexico quad maps:

- BOOTLEG RIDGE
- LOS MEDANOS
- REMUDA BASIN
- THE DIVIDE
- LIVINGSTON RIDGE
- TOWER HILL SOUTH

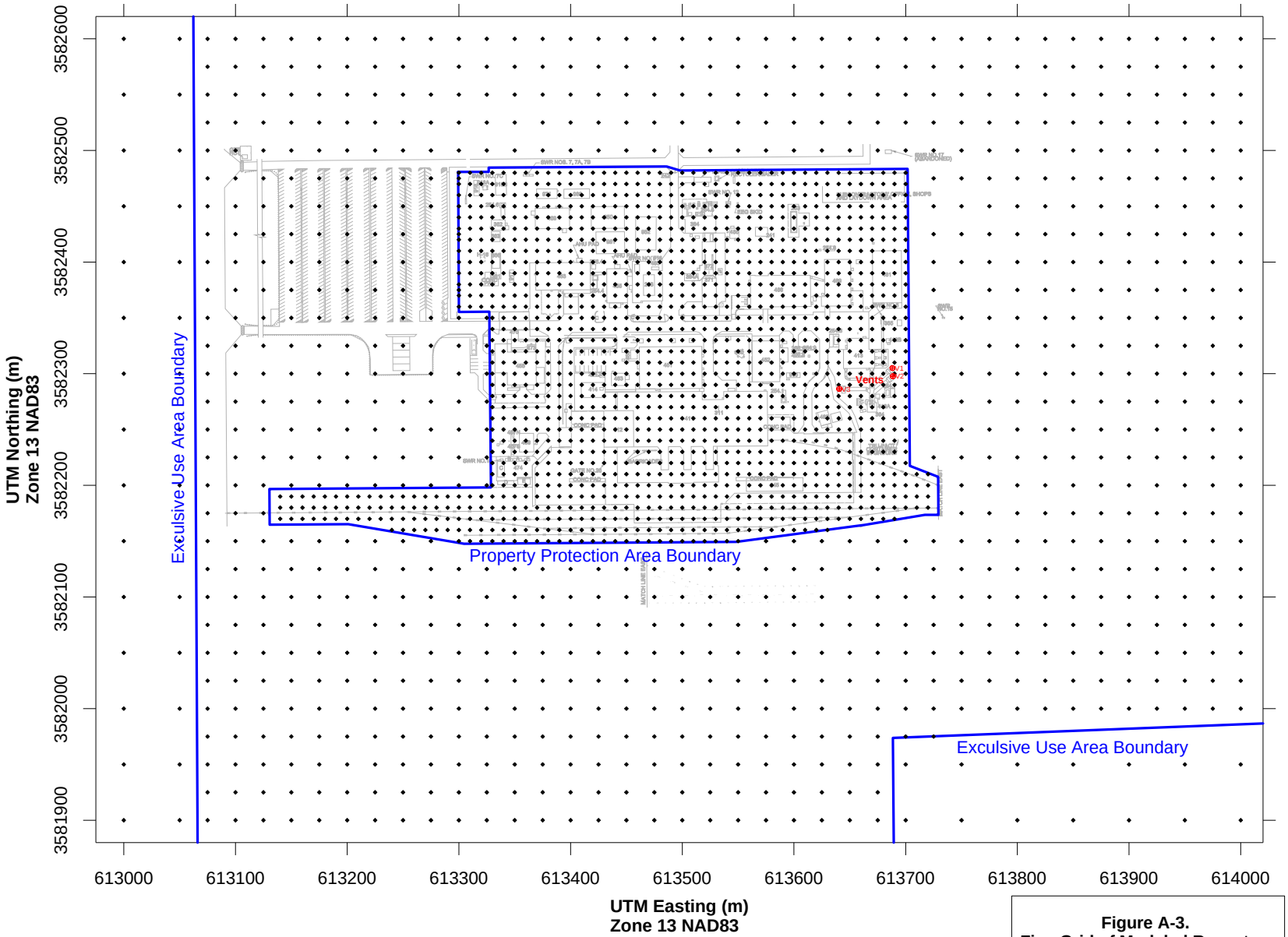

Figure A-3.
Fine Grid of Modeled Receptors

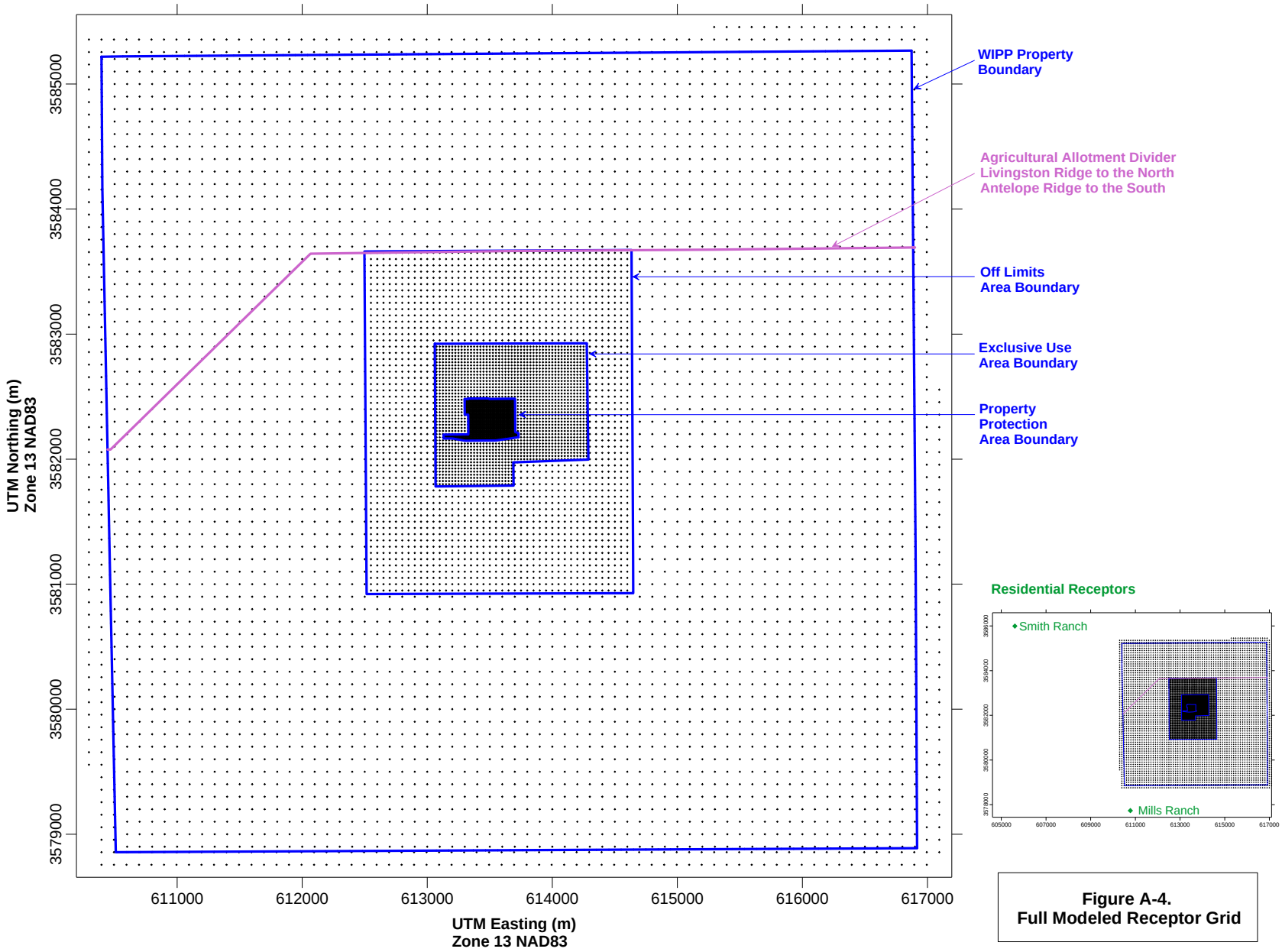

Figure A-4.
Full Modeled Receptor Grid

Building Downwash

In addition to downwash effects due to the vent itself (stack tip downwash); the path of the plume may also be affected by nearby structures, leading to building downwash effects. Direction-specific building downwash parameters were generated for all sources in the model using the EPA Building Parameter Input Program PRIME (BPIPPRM dated 04274). Figure A-3 is a plot plan illustrating both the emission points and buildings included in the dispersion modeling. Building corners were assigned UTM coordinates to identify building shapes and locations. Building heights were also input into the PRIME downwash program. This information, along with emission point coordinates and heights, was used by BPIPPRM to generate downwash inputs to AERMOD.

AERMOD considers direction-specific downwash using the PRIME algorithm as determined by the BPIPPRM program. All BPIPPRM input and output files are provided electronically on the attached DVD. Table A-2 shows the modeled building heights for each structure included in the model.

Table A-2. Heights of Downwash Structures Included in the Dispersion Modeling

Building ID	Height (ft)	Building ID	Height (ft)	Building ID	Height (ft)
918B	14.0	MET	8.5	482	12.5
971	12.0	486	17.5	413	19.5
986	12.0	489	17.5	245	18.5
459	19.0	481	18.0	311	129.1
950	14.5	475	12.0	411_W	46.3
952	14.5	458	15.3	411_E	62.9
951	14.5	456	15.6	953	14.5
455	14.0	412	46.3	246	18.5
453	17.5	451	39.2		
384	18.5	452	30.8		

Met Processing (AERMET)

- The Surface File (with file extension .SFC), which contains boundary layer scaling parameters (such as surface friction velocity, mixing height, and Monin-Obukhov length) and reference-height winds and temperature, and
- The Profile File (with file extension .PFL), which contains one or more levels of winds, temperature and the standard deviation of the fluctuating components of the wind.

Although some parameters are measured directly (i.e. wind speed), others must be estimated (i.e. friction velocity). The AERMET preprocessor program version 06341 was used to generate the SFC and PFL files. Five years of meteorological data (2004 – 2008) were processed for this analysis using:

- Surface data parameters from the WIPP on-site monitor,
- Surface data from the National Climactic Data Center (NCDC) for station 93033 at the Carlsbad Municipal Airport in Integrated Surface Hourly variable length ascii format DS-3505 (formerly TD-3505). This meteorological monitor is located about 30 miles west/southwest of the WIPP site in an area with similar topography and meteorology.

- Upper air data from NCDC for station 02023 in Midland, Texas (the nearest upper air met station to the site) in FSL format.

Meteorological parameters recorded at the WIPP on-site monitor included wind speed, wind direction, temperature, relative humidity, precipitation, and station pressure. These values are recorded every 15 minutes and many of them are recorded at 3 separate tower heights above the ground (which help to generate a robust profile of wind speeds and temperatures). In general, the WIPP on-site surface data was of excellent quality and contained only a small fraction of missing or invalid data. Surface data from the Carlsbad monitor was used as a backup to fill in missing parameters required by AERMOD, as well as filling in missing hours of data. The processed meteorological data file capture 95% of all hours of the 5-year period. EPA recommends using a met set with at least 90% data capture.

Important model selections in the AERMET preprocessor include:

- The time stamp on each hour of met data was converted to local standard time (in this case, Mountain Standard Time). Although the data from the on-site monitor is already in local time, both the NCDC surface and upper air data sets are in Greenwich Mean Time. The time stamp on the surface data from the station in Carlsbad, NM was adjusted by 7 hours, and the time stamp on the upper air data from the station in Midland, TX was adjusted by 6 hours.
- On-site measurements of temperature, wind speed, and wind direction were included at all 3 tower heights (2 m, 10 m, & 50 m above the ground).
- The threshold wind speed, which is a value under which winds are considered to be calm, was set to 0.3 m/s for wind speeds recorded by the on-site monitor.

All AERMET modeling files are included on the attached DVD.

Postprocessing and Modeled Impact Concentrations

For each modeled receptor, AERMOD estimated an annual impact concentration (for each of the 5 years of meteorological data) from each of the 3 vents individually. Each impact concentration is based on a pollutant input concentration of 10,000 $\mu g/m^3$ per vent from the mine. A series of postprocessing steps were required to use the modeled impact concentrations to estimate ADFs for each receptor. The steps listed below illustrate this procedure for receptor 886 (613630, 3582360) in the modeled scenario with the vents in their current configuration (vents release at a 45° angle and at a height of 33.2 feet above the ground). This particular receptor is inside the Training Building.

1. For the vent configuration described above, the AERMOD output files show the predicted annual impact concentrations for each vent for each year:

Table A-3. AERMOD Estimated Annual Impact Concentrations Using the Current Vent Configuration for Receptor 886

	Annual Impact Concentration ($\mu g/m^3$)				
Vent	2004	2005	2006	2007	2008
V1	40.13	39.50	35.83	41.04	37.89
V2	46.53	40.64	39.81	44.52	44.06
V3	17.20	13.59	13.82	12.06	18.51

2. It was assumed that over an entire year, the emissions from one vent are about equal to the emission from another vent. Therefore, the annual impact concentration from one vent may be added to the impact concentration from another vent at the same receptor. For each operating scenario (described in earlier in this attachment), total impact concentrations were estimated.

Table A-4. Estimated Impact Concentrations Using the Current Vent Configuration for Each Operating Scenario at Receptor 886

Operating Scenario	Total Impact Concentration per Operating Scenario (µg/m³)					
	2004	2005	2006	2007	2008	Annual Maximum Over 5-Year Period
Scenario 1 (V1+V2)	86.67	80.14	75.64	85.56	81.95	**86.67**
Scenario 2 (V1+V3)	57.34	53.10	49.65	53.11	56.40	**57.34**
Scenario 3 (V2+V3)	63.74	54.23	53.63	56.59	62.57	**63.74**

3. Of the three operating scenarios, Scenario 1 produced the highest estimated impact concentration of 86.67 µg/m3. The next step is to use Equation A-1 to estimate the ADF.

$$\text{Air Dispersion Factor} = \frac{86.67\ (\mu g/m^3)}{10{,}000\ (\mu g/m^3)} = 8.67E\text{-}3(\mu g/m^3)$$

4. Although Scenario 1 (which assumed that both of the older vents operate at the same time continuously over a 1-year period) produced the highest estimated impact concentration, it is a very unlikely operating scenario for WIPP. Most of the time, one of the older vents will operate in conjunction with the newer vent V3, which is better represented by Scenarios 2 or 3. Therefore a Mixed Scenario that allows for the vents to operate under Scenario 1 for 20% of the year and the maximum of Scenarios 2 and 3 for the other 80% of the year. The Mixed Scenario is a weighted average of the other two scenarios. For example, in 2004, the weighted average impact concentration for the mixed scenario would be:

$$(20\% \times \underset{\textit{from Scenario 1}}{86.67\ \mu g/m^3}) + (80\% \times \underset{\textit{maximum of Scenario 2 \& 3}}{63.74\ \mu g/m^3}) = 68.33\ \mu g/m^3$$

5. The Mixed Scenario impacts for this receptor are presented in Table A-5 below.

Table A-5. Estimated Impact Concentrations Using the Current Vent Configuration for the Mixed Scenario at Receptor 886

Operating Scenario	Total Impact Concentration per Operating Scenario (µg/m³)					
	2004	2005	2006	2007	2008	Annual Maximum Over 5-Year Period
Mixed Scenario (20% Scenario 1 + 80% maximum of Scenarios 2 and 3)	68.33	59.41	58.03	62.38	66.45	**68.33**

This procedure was followed for every receptor and every vent configuration scenario. A series of Excel spreadsheets that calculated all of these postprocessed values are included on the attached DVD.

The maximum predicted ADFs at a variety of receptor locations, operating scenarios, and vent configurations are provided in Tables 3a – 3d in the report.

Electronic Files

The attached DVD contains the modeling input and output data files from

- AERMET
- AERMAP
- AERSURFACE, and
- AERMOD.

Also included are the building downwash data and the series of spreadsheets that include the postprocessing of modeled impacts into maximum ADF values for each sensitivity run.

References

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FR, 2005 Federal Register: Part III Environmental Protection Agency *Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule.* Federal Register 40 CFR Part 51. November 9, 2005

Attachment B - Risk Calculations

Cancer risks and non-cancer hazard quotients, and subsequently alternative risk-based limits, were calculated for the following four above-ground receptor populations identified in the original RCRA Part B permit:

- A resident downwind at the WIPP Land Withdrawal Area (LWA) boundary.
- A rancher within the Antelope Ridge Grazing Lease, within the WIPP LWA boundary.
- A rancher within the Livingston Ridge Grazing Lease, within the WIPP LWA.
- A non-waste surface worker at WIPP.

Three additional scenarios were also evaluated:

- a "trainee" at the Training Building in the PPA, assuming that an individual would attend training courses in the on-site training building on average 1 day every other week, based on documented use of the training facility.,
- A resident at the Mills Ranch.
- A resident at the Smith Ranch.

"Forward" risk calculations were used to calculate potential risks based on 1) current permit levels, and 2) current chemical concentrations at the E-300 Drift monitoring station. The E-300 Drift monitoring station is the station used to demonstrate compliance with the permit limits. Air concentrations, presented in parts per billion volume (ppbv), were converted to units of ug/m^3 using equation 1:

Equation 1:

$$COC = E300 * \left(\frac{MW}{24.45} \right)$$

Where: COC = Concentration of Concern (ug/m^3)
E300 = Concentration at the E-300 Monitoring Station (ppbv)
MW = Molecular Weight (g/mol)

Prior to exiting the mine, airflow from the E-300 Drift monitoring location is combined with two other two airflow pathways (Northern experimental area and Waste Shaft) at a point downwind of the monitoring station, and the combined airflow exiting the mine is directed to the exhaust shaft. The VOC concentration in the exhaust shaft is calculated per equation 2:

Equation 2:

$$ECS_{act} = COC * \left(\frac{V_{panel}}{V_{exhaust-typ}} \right)$$

Where: ECS_{act} = Actual Exhaust Shaft Concentration (ug/m^3)
V_{panel} = Mine Ventilation Rate from Panel Area (130,000 ft^3/min)
$V_{exhaust-typ}$ = Typical Mine Ventilation Exhaust Rate (425,000 ft^3/min)

Dispersion modeling was performed to derive the Air Dispersion Factors (ADFs) used to predict the dilution of VOC concentrations from the exhaust shaft to the receptor locations. The

dispersion modeling approach is described in *Appendix A.* The receptor point concentrations were calculated using equation 3:

Equation 3:

$$R_{con} = ECS_{act} * ADF$$

Where: R_{con} = Receptor concentration (ug/m^3)
ADF = Air dispersion factor, unitless

Standard risk assessment equations were used to calculate cancer risks (equation 4) and non-cancer hazard quotients (equation 5) for each chemical.

Equation 4:

$$Cancer\ Risk = \frac{R_{con} * URF * EF * ED}{AT_c}$$

Equation 5:

$$Hazard\ Quotient = \frac{R_{con} * EF * ED}{AT_{nc} * RfC * 1000}$$

Where: URF = Unit Risk Factor for VOC ($m3/ug^{)-1}$
EF = Exposure Frequency (hours/year)
ED = Exposure Duration (years)
AT_c = Averaging time for carcinogens in hours (70 years total)
AT_{nc} = Averaging time for non-carcinogens in hours (based on Exposure Duration)
RfC = Reference concentration (mg/m^3)

The relative contribution of each chemical to the overall risk from the emissions was then calculated using equation 6.

Equation 6:

$$Percent\ Risk = \frac{Risk_{ind}}{Risk_{cum}} * 100$$

Where: Percent Risk = Relative risk contribution of the individual chemical (percent)
$Risk_{ind}$ = Risk for the individual chemical (unitless)
$Risk_{cum}$ = Cumulative risk for all chemicals combined (unitless)

Alternative risk-based air limits were established by setting allowable cumulative risk levels (all chemicals combined) for the four above ground receptor populations identified In the RCRA Part B permit and for the trainee scenario, as identified above, and then back-calculating allowable air concentrations corresponding to those risk levels. For the on-site worker and trainee scenarios, acceptable cumulative cancer risk (all chemicals combined) was set at 1 x 10^{-5}, for the resident and rancher scenarios, acceptable cancer risk was set at 1 x 10^{-6}. The percent risk values

calculated in equation 6 were used in combination with the allowable cumulative risk levels to allocate target risk levels for each individual chemical, per equation 7.

Equation 7:

$$Risk_{ind} = Risk_{cum} * 0.01 * Percent\ Risk$$

Unlike the carcinogens, alternative limits were not calculated for non-cancer effects. The calculated hazard indices for all non-carcinogens at current air concentrations were well below a hazard index of 1.0, indicating that these chemicals would not pose a potential non-cancer hazard.

Target air concentrations for each carcinogenic chemical were calculated at the receptor point using equation 8, at the exhaust shaft using equation 9, and at the E-300 Drift monitoring station location using equations 10 (concentration in ug/m^3) and 11 (concentration in ppbv).

Equation 8:

$$R_{con} = \frac{Risk * AT_c}{URF * EF * ED}$$

Equation 9:

$$ECS_{act} = \frac{R_{con}}{ADF}$$

Equation 10:

$$COC = ECS_{act} * \left(\frac{V_{exhaust-typ}}{V_{panel}} \right)$$

Equation 11:

$$E300 = COC * \left(\frac{24.45}{MW} \right)$$

Calculation worksheets are presented in Tables B-1 through B-9.

Table B-1
Calculation of Risks and Allowable Air Concentrations
Non-Waste Surface Worker Scenario - PPA
Current Permit Approach
Waste Isolation Pilot Plant (WIPP)

"Forward" Risk Calculations (i.e., Risks) Based on E-300 Monitoring Station

equation 1: $$COC = E300 * \left(\frac{MW}{24.45}\right)$$

equation 2: $$ECS_{act} = COC * \left(\frac{V_{panel}}{V_{exhaust-typ}}\right)$$

equation 3: $$R_{con} = ECS_{act} * ADF$$

equation 4: $$Cancer\ Risk = \frac{R_{con} * URF * EF * ED}{AT_c}$$

equation 5: $$Hazard\ Quotient = \frac{R_{con} * EF * ED}{AT_{nc} * RfC * 1000}$$

equation 6: $$Percent\ Risk = \frac{Chemical\ Risk}{Total\ Risk} * 100$$

E-300 = Concentration at the air monitoring point (ppbv)
MW = Molecular Weight of the VOC (g/mole)
COC = Concentration of concern at E-300 Monitoring Station (ug/m^3)
V_{panel} = Mine ventilation panel rate (130,000 ft^3/min)
$V_{exhaust-typ}$ = typical mine ventilation exhaust rate (425,000 ft^3/min)
ECS_{act} = Actual exhaust shaft concentration for VOC (ug/m^3)
ADF = Air dispersion factor, unitless
Rcon = Receptor concentration (ug/m^3)

AT_c = Averaging time for carcinogens in hours (70 years total)
AT_{nc} = Averaging time for non-carcinogens in hours (based on Exposure Duration)
URF = Unit risk factor for VOC (m^3/ug)$^{-1}$
RfC = Reference concentration (mg/m^3)
EF = Exposure frequency (hours/year)
ED = Exposure duration, years (10 years)
$Risk_{ind}$ = per chemical cancer risk (unitless)
$Risk_{cum}$ = cumulative cancer risks for all chemicals combined (unitless)

Risks and Hazards Based on Current E-300 Limits, Toxicity Values from the Permit, Original ADF

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient* (unitless)	Percent of Total Risk
Carbon Tetrachloride	165	153.84	1038	130,000	425,000	317.56	1.23E-02	3.91	613200		1.5E-05		1920	10	1.83E-06		19
Chlorobenzene	220	112.56	1013	130,000	425,000	309.80	1.23E-02	3.81		87600		2.0E-02	1920	10		4.18E-02	
Chloroform	180	119.39	879	130,000	425,000	268.85	1.23E-02	3.31	613200		2.3E-05		1920	10	2.38E-06		24
1,1-Dichloroethene	100	96.95	397	130,000	425,000	121.29	1.23E-02	1.49	613200		5.0E-05		1920	10	2.34E-06		24
1,2-Dichloroethane	45	98.97	182	130,000	425,000	55.72	1.23E-02	0.69	613200		2.6E-05		1920	10	5.58E-07		6
Methylene Chloride	1930	84.94	6705	130,000	425,000	2050.90	1.23E-02	25.23	613200		4.7E-07		1920	10	3.71E-07		4
1,1,2,2-Tetrachloroethane	50	167.86	343	130,000	425,000	105.00	1.23E-02	1.29	613200		5.8E-05		1920	10	2.35E-06		24
Toluene	190	92.13	716	130,000	425,000	218.99	1.23E-02	2.69		87600		4.0E-01	1920	10		1.48E-03	
1,1,1-Trichloroethane	590	133.42	3220	130,000	425,000	984.80	1.23E-02	12.11		87600		7.0E-01	1920	10		3.79E-03	
														Cumulative	**9.8E-06**	**4.7E-02**	100

* Consistent with the approach used in the permit, non-cancer hazard quotients were only calculated for chemicals with no available URF values.

Risks and Hazards Based on Current Measured Concentrations at E-300 Drift Monitoring Station, Current Toxicity Values, new ADF*

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient (unitless)	Percent of Total Risk
Carbon Tetrachloride	108.73	153.84	684	130,000	425,000	209.26	1.14E-02	2.39	613200	87600	6.0E-06	1.00E-01	1920	10	4.48E-07	0.005229	78
Chlorobenzene	0	112.56	0	130,000	425,000	0	1.14E-02	0	613200	87600		5.0E-02	1920	10		0	
Chloroform	10.46	119.39	51	130,000	425,000	15.62	1.14E-02	0.18	613200	87600	2.3E-05	9.8E-02	1920	10	1.28E-07	3.98E-04	22
1,1-Dichloroethene**	0	96.95	0	130,000	425,000	0	1.14E-02	0	613200	87600		2.0E-01	1920	10		0	
1,2-Dichloroethane	0	98.97	0	130,000	425,000	0	1.14E-02	0	613200	87600	2.6E-05	2.4E+00	1920	10	0	0	0
Methylene Chloride	1.99	84.94	7	130,000	425,000	2.11	1.14E-02	0.024	613200	87600	4.7E-07	1.0E+00	1920	10	3.55E-10	5.28E-06	0.06
1,1,2,2-Tetrachloroethane	0	167.86	0	130,000	425,000	0	1.14E-02	0	613200	87600	5.8E-05		1920	10	0		0
Toluene	0.01	92.13	0.038	130,000	425,000	0.012	1.14E-02	0.00013	613200	87600		5.0E+00	1920	10		5.76E-09	
1,1,1-Trichloroethane	17.56	133.42	96	130,000	425,000	29.31	1.14E-02	0.33	613200	87600		5.0E+00	1920	10		1.46E-05	
														Cumulative	**5.8E-07**	**4.2E-04**	100

* ADF was calculated at the point of maximum impact in the PPA, assuming 45 degree vent angle, no additional stack height, and vent usage of 20% vents 1 & 2, 80% highest impact of vents 1 & 3 or vents 2 & 3
** USEPA has withdrawn the URF for 1,1-DCE; inhalation evaluated based on non-cancer effects.

Table B-1
Calculation of Risks and Allowable Air Concentrations
Non-Waste Surface Worker Scenario - PPA
Current Permit Approach
Waste Isolation Pilot Plant (WIPP)

"Reverse" Risk Calculations (i.e., Allowable Air Concentrations at E-300 Monitoring Station) Based on Target Risk Levels

equation 7: $Risk_{ind} = Risk_{cum} * 0.01 * Percent\ Risk$

equation 8: $R_{con} = \frac{Risk * AT_r}{URF * EF * ED}$

equation 9: $ECS_{act} = \frac{R_{con}}{ADF}$

equation 10: $COC = ECS_{act} * \left(\frac{V_{exhaust-typ}}{V_{panel}}\right)$

equation 11: $E300 = COC * \left(\frac{24.45}{MW}\right)$

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based on Original Permit Assumptions

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-05	1.87E-06	613200		1.5E-05		1920	10	3.98	1.23E-02	323.18	130,000	425,000	1057	153.84	167.9	165
Chlorobenzene				87600		2.0E-02	1920	10		1.23E-02		130,000	425,000		112.56	*	220
Chloroform	1.0E-05	2.42E-06	613200		2.3E-05		1920	10	3.37	1.23E-02	273.61	130,000	425,000	894	119.39	183	180
1,1-Dichloroethene	1.0E-05	2.38E-06	613200		5.0E-05		1920	10	1.52	1.23E-02	123.43	130,000	425,000	404	96.95	102	100
1,2-Dichloroethane	1.0E-05	5.68E-07	613200		2.6E-05		1920	10	0.70	1.23E-02	56.70	130,000	425,000	185	98.97	46	45
Methylene Chloride	1.0E-05	3.78E-07	613200		4.7E-07		1920	10	25.67	1.23E-02	2087.18	130,000	425,000	6823	84.94	1964	1930
1,1,2,2-Tetrachloroethane	1.0E-05	2.39E-06	613200		5.8E-05		1920	10	1.31	1.23E-02	106.86	130,000	425,000	349	167.86	51	50
Toluene				87600		4.0E-01	1920	10		1.23E-02		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane				87600		7.0E-01	1920	10		1.23E-02		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker set at 1E-5, for residents and ranch workers set at 1E-6

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based Re-apportionment of Risk to Reflect Current Conditions, New Toxicity Values, New ADF

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-05	7.77E-06	613200	87600	6.0E-06	1.00E-01	1920	10	41.36	1.14E-02	3628.04	130,000	425,000	11861	153.84	1885	165
Chlorobenzene			613200	87600		5.0E-02	1920	10		1.14E-02		130,000	425,000		112.56	*	220
Chloroform	1.0E-05	2.22E-06	613200	87600	2.3E-05	9.8E-02	1920	10	3.09	1.14E-02	270.86	130,000	425,000	886	119.39	181	180
1,1-Dichloroethene			613200	87600		2.0E-01	1920	10		1.14E-02		130,000	425,000		96.95	*	100
1,2-Dichloroethane	1.0E-05	0	613200	87600	2.6E-05	2.4E+00	1920	10	0	1.14E-02	0	130,000	425,000	0	98.97	0	45
Methylene Chloride***	1.0E-05	6.15E-09	613200	87600	4.7E-07	1.0E+00	1920	10	0.42	1.14E-02	36.66	130,000	425,000	120	84.94	35	1930
1,1,2,2-Tetrachloroethane	1.0E-05	0	613200	87600	5.8E-05		1920	10	0	1.14E-02	0	130,000	425,000	0	167.86	0	50
Toluene			613200	87600		5.0E+00	1920	10		1.14E-02		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane			613200	87600		5.0E+00	1920	10		1.14E-02		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker and trainee set at 1E-5, for residents and ranch workers set at 1E-6

*** Methylene chloride target risk is set at a very low value, based on current emision rates <1% of total risk. As an example, if target risk was arbitrarily set as 1%, E-300 COC would be 561 ppbv.

Table B-2
Calculation of Risks and Allowable Air Concentrations
Off-Site Resident Scenario
Current Permit Approach
Waste Isolation Pilot Plant (WIPP)

"Forward" Risk Calculations (i.e., Risks) Based on E-300 Monitoring Station

equation 1: $$COC = E300 * \left(\frac{MW}{24.45} \right)$$

equation 2: $$ECS_{act} = COC * \left(\frac{V_{panel}}{V_{exhaust-typ}} \right)$$

equation 3: $$R_{con} = ECS_{act} * ADF$$

equation 4: $$Cancer\ Risk = \frac{R_{con} * URF * EF * ED}{AT_c}$$

equation 5: $$Hazard\ Quotient = \frac{R_{con} * EF * ED}{AT_{nc} * RfC * 1000}$$

equation 6: $$Percent\ Risk = \frac{Chemical\ Risk}{Total\ Risk} * 100$$

E-300 = Concentration at the air monitoring point (ppbv)
MW = Molecular Weight of the VOC (g/mole)
COC = Concentration of concern at E-300 Monitoring Station (ug/m^3)
V_{panel} = Mine ventilation panel rate (130,000 ft^3/min)
$V_{exhaust-typ}$ = typical mine ventilation exhaust rate, (425,000 ft^3/min)
ECS_{act} = Actual exhaust shaft concentration for VOC (ug/m^3)
ADF = Air dispersion factor, unitless
Rcon = Receptor concentration (ug/m^3)

AT_c = Averaging time for carcinogens in hours (70 years total)
AT_{nc} = Averaging time for non-carcinogens in hours (based on Exposure Duration)
URF = Unit risk factor for VOC (m^3/ug)$^{-1}$
RfC = Reference concentration (mg/m^3)
EF = Exposure frequency (hours/year)
ED = Exposure duration, years (35 years)
$Risk_{ind}$ = per chemical cancer risk (unitless)
$Risk_{cum}$ = cumulative cancer risks for all chemicals combined (unitless)

Risks and Hazards Based on Current E-300 Limits, Toxicity Values from the Permit, Original ADF

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient* (unitless)	Percent of Total Risk
Carbon Tetrachloride	165	153.84	1038	130,000	425,000	317.56	1.20E-04	0.038	613200		1.5E-05		8760	35	2.86E-07		19
Chlorobenzene	220	112.56	1013	130,000	425,000	309.80	1.20E-04	0.037		306600		2.0E-02	8760	35		1.86E-03	
Chloroform	180	119.39	879	130,000	425,000	268.85	1.20E-04	0.032	613200		2.3E-05		8760	35	3.71E-07		24
1,1-Dichloroethene	100	96.95	397	130,000	425,000	121.29	1.20E-04	0.015	613200		5.0E-05		8760	35	3.64E-07		24
1,2-Dichloroethane	45	98.97	182	130,000	425,000	55.72	1.20E-04	0.0067	613200		2.6E-05		8760	35	8.69E-08		6
Methylene Chloride	1930	84.94	6705	130,000	425,000	2050.90	1.20E-04	0.25	613200		4.7E-07		8760	35	5.78E-08		4
1,1,2,2-Tetrachloroethane	50	167.86	343	130,000	425,000	105.00	1.20E-04	0.013	613200		5.8E-05		8760	35	3.65E-07		24
Toluene	190	92.13	716	130,000	425,000	218.99	1.20E-04	0.026		306600		4.0E-01	8760	35		6.57E-05	
1,1,1-Trichloroethane	590	133.42	3220	130,000	425,000	984.80	1.20E-04	0.12		306600		7.0E-01	8760	35		1.69E-04	
														Cumulative	**1.5E-06**	**2.1E-03**	100

* Consistent with the approach used in the permit, non-cancer hazard quotients were only calculated for chemicals with no available URF values.

Risks and Hazards Based on Current Measured Concentrations at E-300 Drift Monitoring Station, Current Toxicity Values, new ADF*

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient (unitless)	Percent of Total Risk
Carbon Tetrachloride	108.73	153.84	684	130,000	425,000	209.26	8.78E-05	0.018	613200	306600	6.0E-06	1.00E-01	8760	35	5.51E-08	0.000184	78
Chlorobenzene	0	112.56	0	130,000	425,000	0	8.78E-05	0	613200	306600		5.0E-02	8760	35		0	
Chloroform	10.46	119.39	51	130,000	425,000	15.62	8.78E-05	0.0014	613200	306600	2.3E-05	9.8E-02	8760	35	1.58E-08	1.40E-05	22
1,1-Dichloroethene**	0	96.95	0	130,000	425,000	0	8.78E-05	0	613200	306600		2.0E-01	8760	35		0	
1,2-Dichloroethane	0	98.97	0	130,000	425,000	0	8.78E-05	0	613200	306600	2.6E-05	2.4E+00	8760	35	0	0	0
Methylene Chloride	1.99	84.94	7	130,000	425,000	2.11	8.78E-05	0.00019	613200	306600	4.7E-07	1.0E+00	8760	35	4.36E-11	1.86E-07	0.06
1,1,2,2-Tetrachloroethane	0	167.86	0	130,000	425,000	0	8.78E-05	0	613200	306600	5.8E-05		8760	35	0		0
Toluene	0.01	92.13	0.038	130,000	425,000	0.012	8.78E-05	0.0000010	613200	306600		5.0E+00	8760	35		2.02E-10	
1,1,1-Trichloroethane	17.56	133.42	96	130,000	425,000	29.31	8.78E-05	0.0026	613200	306600		5.0E+00	8760	35		5.15E-07	
														Cumulative	**7.1E-08**	**1.5E-05**	100

* ADF was calculated at the point of maximum impact off-property, assuming 45 degree vent angle, no additional stack height, and vent usage of 20% vents 1 & 2, 80% highest impact of vents 1 & 3 or vents 2 & 3
** USEPA has withdrawn the URF for 1,1-DCE; inhalation evaluated based on non-cancer effects.

Table B-2
Calculation of Risks and Allowable Air Concentrations
Off-Site Resident Scenario
Current Permit Approach
Waste Isolation Pilot Plant (WIPP)

"Reverse" Risk Calculations (i.e., Allowable Air Concentrations at E-300 Monitoring Station) Based on Target Risk Levels

equation 7: $$Risk_{ind} = Risk_{cum} * 0.01 * Percent\ Risk$$

equation 8: $$R_{con} = \frac{Risk * AT_c}{URF * EF * ED}$$

equation 9: $$ECS_{act} = \frac{R_{con}}{ADF}$$

equation 10: $$COC = ECS_{act} * \left(\frac{V_{exhaust-typ}}{V_{panel}}\right)$$

equation 11: $$E300 = COC * \left(\frac{24.45}{MW}\right)$$

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based on Original Permit Assumptions

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	1.87E-07	613200		1.5E-05		8760	35	0.025	1.20E-04	207.44	130,000	425,000	678	153.84	108	165
Chlorobenzene				306600		2.0E-02	8760	35		1.20E-04		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.42E-07	613200		2.3E-05		8760	35	0.021	1.20E-04	175.62	130,000	425,000	574	119.39	118	180
1,1-Dichloroethene	1.0E-06	2.38E-07	613200		5.0E-05		8760	35	0.010	1.20E-04	79.23	130,000	425,000	259	96.95	65	100
1,2-Dichloroethane	1.0E-06	5.68E-08	613200		2.6E-05		8760	35	0.0044	1.20E-04	36.40	130,000	425,000	119	98.97	29	45
Methylene Chloride	1.0E-06	3.78E-08	613200		4.7E-07		8760	35	0.16	1.20E-04	1339.71	130,000	425,000	4380	84.94	1261	1930
1,1,2,2-Tetrachloroethane	1.0E-06	2.39E-07	613200		5.8E-05		8760	35	0.0082	1.20E-04	68.59	130,000	425,000	224	167.86	33	50
Toluene				306600		4.0E-01	8760	35		1.20E-04		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane				306600		7.0E-01	8760	35		1.20E-04		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker set at 1E-5, for residents and ranch workers set at 1E-6

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based Re-apportionment of Risk to Reflect Current Conditions, New Toxicity Values, New ADF

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	7.77E-07	613200	306600	6.0E-06	1.00E-01	8760	35	0.26	8.78E-05	2949.93	130,000	425,000	9644	153.84	1533	165
Chlorobenzene			613200	306600		5.0E-02	8760	35		8.78E-05		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.22E-07	613200	306600	2.3E-05	9.8E-02	8760	35	0.019	8.78E-05	220.24	130,000	425,000	720	119.39	147	180
1,1-Dichloroethene			613200	306600		2.0E-01	8760	35		8.78E-05		130,000	425,000		96.95	*	100
1,2-Dichloroethane	1.0E-06	0	613200	306600	2.6E-05	2.4E+00	8760	35	0	8.78E-05	0	130,000	425,000	0	98.97	0	45
Methylene Chloride***	1.0E-06	6.15E-10	613200	87600	4.7E-07	1.0E+00	8760	35	0.0026	8.78E-05	29.81	130,000	425,000	97	84.94	28	1930
1,1,2,2-Tetrachloroethane	1.0E-06	0	613200	306600	5.8E-05		8760	35	0	8.78E-05	0	130,000	425,000	0	167.86	0	50
Toluene			613200	306600		5.0E+00	8760	35		8.78E-05		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane			613200	306600		5.0E+00	8760	35		8.78E-05		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker and trainee set at 1E-5, for residents and ranch workers set at 1E-6

*** Methylene chloride target risk is set at a very low value, based on current emision rates <1% of total risk. As an example, if target risk was arbitrarily set as 1%, E-300 COC would be 456 ppbv.

Table B-3
Calculation of Risks and Allowable Air Concentrations
Antelope Ridge Ranch Worker Scenario
Current Permit Approach
Waste Isolation Pilot Plant (WIPP)

"Forward" Risk Calculations (i.e., Risks) Based on E-300 Monitoring Station

equation 1: $$COC = E300 * \left(\frac{MW}{24.45} \right)$$

equation 2: $$ECS_{act} = COC * \left(\frac{V_{panel}}{V_{exhaust-typ}} \right)$$

equation 3: $$R_{con} = ECS_{act} * ADF$$

equation 4: $$Cancer\ Risk = \frac{R_{con} * URF * EF * ED}{AT_c}$$

equation 5: $$Hazard\ Quotient = \frac{R_{con} * EF * ED}{AT_{nc} * RfC * 1000}$$

equation 6: $$Percent\ Risk = \frac{Chemical\ Risk}{Total\ Risk} * 100$$

E-300 = Concentration at the air monitoring point (ppbv)
MW = Molecular Weight of the VOC (g/mole)
COC = Concentration of concern at E-300 Monitoring Station (ug/m^3)
V_{panel} = Mine ventilation panel rate (130,000 ft^3/min)
$V_{exhaust-typ}$ = typical mine ventilation exhaust rate, (425,000 ft^3/min)
ECS_{act} = Actual exhaust shaft concentration for VOC (ug/m^3)
ADF = Air dispersion factor, unitless
Rcon = Receptor concentration (ug/m^3)

AT_c = Averaging time for carcinogens in hours (70 years total)
AT_{nc} = Averaging time for non-carcinogens in hours (based on Exposure Duration)
URF = Unit risk factor for VOC (m^3/ug)$^{-1}$
RfC = Reference concentration (mg/m^3)
EF = Exposure frequency (hours/year)
ED = Exposure duration, years (35 years)
$Risk_{ind}$ = per chemical cancer risk (unitless)
$Risk_{cum}$ = cumulative cancer risks for all chemicals combined (unitless)

Risks and Hazards Based on Current E-300 Limits, Toxicity Values from the Permit, Original ADF

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient* (unitless)	Percent of Total Risk
Carbon Tetrachloride	165	153.84	1038	130,000	425,000	317.56	6.70E-05	0.021	613200		1.5E-05		2080	35	3.79E-08		19
Chlorobenzene	220	112.56	1013	130,000	425,000	309.80	6.70E-05	0.021		306600		2.0E-02	2080	35		2.46E-04	
Chloroform	180	119.39	879	130,000	425,000	268.85	6.70E-05	0.018	613200		2.3E-05		2080	35	4.92E-08		24
1,1-Dichloroethene	100	96.95	397	130,000	425,000	121.29	6.70E-05	0.0081	613200		5.0E-05		2080	35	4.82E-08		24
1,2-Dichloroethane	45	98.97	182	130,000	425,000	55.72	6.70E-05	0.0037	613200		2.6E-05		2080	35	1.15E-08		6
Methylene Chloride	1930	84.94	6705	130,000	425,000	2050.90	6.70E-05	0.14	613200		4.7E-07		2080	35	7.67E-09		4
1,1,2,2-Tetrachloroethane	50	167.86	343	130,000	425,000	105.00	6.70E-05	0.0070	613200		5.8E-05		2080	35	4.84E-08		24
Toluene	190	92.13	716	130,000	425,000	218.99	6.70E-05	0.015		306600		4.0E-01	2080	35		8.71E-06	
1,1,1-Trichloroethane	590	133.42	3220	130,000	425,000	984.80	6.70E-05	0.066		306600		7.0E-01	2080	35		2.24E-05	
														Cumulative	**2.0E-07**	**2.8E-04**	100

* Consistent with the approach used in the permit, non-cancer hazard quotients were only calculated for chemicals with no available URF values.

Risks and Hazards Based on Current Measured Concentrations at E-300 Drift Monitoring Station, Current Toxicity Values, new ADF*

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient (unitless)	Percent of Total Risk
Carbon Tetrachloride	108.73	153.84	684	130,000	425,000	209.26	6.72E-04	0.14	613200	306600	6.0E-06	1.00E-01	2080	35	1E-07	0.000334	78
Chlorobenzene	0	112.56	0	130,000	425,000	0	6.72E-04	0	613200	306600		5.0E-02	2080	35		0	
Chloroform	10.46	119.39	51	130,000	425,000	15.62	6.72E-04	0.010	613200	306600	2.3E-05	9.8E-02	2080	35	2.87E-08	2.54E-05	22
1,1-Dichloroethene**	0	96.95	0	130,000	425,000	0	6.72E-04	0	613200	306600		2.0E-01	2080	35		0	
1,2-Dichloroethane	0	98.97	0	130,000	425,000	0	6.72E-04	0	613200	306600	2.6E-05	2.4E+00	2080	35	0	0	0
Methylene Chloride	1.99	84.94	7	130,000	425,000	2.11	6.72E-04	0.0014	613200	306600	4.7E-07	1.0E+00	2080	35	7.93E-11	3.37E-07	0.06
1,1,2,2-Tetrachloroethane	0	167.86	0	130,000	425,000	0	6.72E-04	0	613200	306600	5.8E-05		2080	35	0		0
Toluene	0.01	92.13	0.038	130,000	425,000	0.012	6.72E-04	0.0000077	613200	306600		5.0E+00	2080	35		3.68E-10	
1,1,1-Trichloroethane	17.56	133.42	96	130,000	425,000	29.31	6.72E-04	0.0197	613200	306600		5.0E+00	2080	35		9.35E-07	
														Cumulative	**1.3E-07**	**2.7E-05**	100

* ADF was calculated at the point of maximum impact in the Antelope Ridge Alottment, assuming 45 degree vent angle, no additional stack height, and vent usage of 20% vents 1 & 2, 80% highest impact of vents 1 & 3 or vents 2 & 3
** USEPA has withdrawn the URF for 1,1-DCE; inhalation evaluated based on non-cancer effects.

Table B-3
Calculation of Risks and Allowable Air Concentrations
Antelope Ridge Ranch Worker Scenario
Current Permit Approach
Waste Isolation Pilot Plant (WIPP)

"Reverse" Risk Calculations (i.e., Allowable Air Concentrations at E-300 Monitoring Station) Based on Target Risk Levels

equation 7: $Risk_{ind} = Risk_{cum} * 0.01 * Percent\ Risk$

equation 8: $R_{con} = \frac{Risk * AT_c}{URF * EF * ED}$

equation 9: $ECS_{act} = \frac{R_{con}}{ADF}$

equation 10: $COC = ECS_{act} * \left(\frac{V_{exhaust-typ}}{V_{panel}}\right)$

equation 11: $E300 = COC * \left(\frac{24.45}{MW}\right)$

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based on Original Permit Assumptions

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	1.87E-07	613200		1.5E-05		2080	35	0.10	6.70E-05	1564.74	130,000	425,000	5116	153.84	813	165
Chlorobenzene				306600		2.0E-02	2080	35		6.70E-05		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.42E-07	613200		2.3E-05		2080	35	0.089	6.70E-05	1324.74	130,000	425,000	4331	119.39	887	180
1,1-Dichloroethene	1.0E-06	2.38E-07	613200		5.0E-05		2080	35	0.040	6.70E-05	597.64	130,000	425,000	1954	96.95	493	100
1,2-Dichloroethane	1.0E-06	5.68E-08	613200		2.6E-05		2080	35	0.018	6.70E-05	274.54	130,000	425,000	898	98.97	222	45
Methylene Chloride	1.0E-06	3.78E-08	613200		4.7E-07		2080	35	0.68	6.70E-05	10105.54	130,000	425,000	33037	84.94	9510	1930
1,1,2,2-Tetrachloroethane	1.0E-06	2.39E-07	613200		5.8E-05		2080	35	0.035	6.70E-05	517.38	130,000	425,000	1691	167.86	246	50
Toluene				306600		4.0E-01	2080	35		6.70E-05		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane				306600		7.0E-01	2080	35		6.70E-05		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker set at 1E-5, for residents and ranch workers set at 1E-6

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based Re-apportionment of Risk to Reflect Current Conditions, New Toxicity Values, New ADF

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	7.77E-07	613200	306600	6.0E-06	1.00E-01	2080	35	1.09	6.72E-04	1623.22	130,000	425,000	5307	153.84	843	165
Chlorobenzene			613200	306600		5.0E-02	2080	35		6.72E-04		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.22E-07	613200	306600	2.3E-05	9.8E-02	2080	35	0.081	6.72E-04	121.19	130,000	425,000	396	119.39	81	180
1,1-Dichloroethene			613200	306600		2.0E-01	2080	35		6.72E-04		130,000	425,000		96.95	*	100
1,2-Dichloroethane	1.0E-06	0	613200	306600	2.6E-05	2.4E+00	2080	35	0	6.72E-04	0	130,000	425,000	0	98.97	0	45
Methylene Chloride***	1.0E-06	6.15E-10	613200	87600	4.7E-07	1.0E+00	2080	35	0.011	6.72E-04	16.40	130,000	425,000	54	84.94	15	1930
1,1,2,2-Tetrachloroethane	1.0E-06	0	613200	306600	5.8E-05		2080	35	0	6.72E-04	0	130,000	425,000	0	167.86	0	50
Toluene			613200	306600		5.0E+00	2080	35		6.72E-04		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane			613200	306600		5.0E+00	2080	35		6.72E-04		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker and trainee set at 1E-5, for residents and ranch workers set at 1E-6

*** Methylene chloride target risk is set at a very low value, based on current emision rates <1% of total risk. As an example, if target risk was arbitrarily set as 1%, E-300 COC would be 251 ppbv.

Table B-4
Calculation of Risks and Allowable Air Concentrations
Livingston Ridge Ranch Worker Scenario
Current Permit Approach
Waste Isolation Pilot Plant (WIPP)

"Forward" Risk Calculations (i.e., Risks) Based on E-300 Monitoring Station

equation 1: $$COC = E300 * \left(\frac{MW}{24.45}\right)$$

equation 2: $$ECS_{act} = COC * \left(\frac{V_{panel}}{V_{exhaust-typ}}\right)$$

equation 3: $$R_{con} = ECS_{act} * ADF$$

equation 4: $$Cancer\ Risk = \frac{R_{con} * URF * EF * ED}{AT_c}$$

equation 5: $$Hazard\ Quotient = \frac{R_{con} * EF * ED}{AT_{nc} * RfC * 1000}$$

equation 6: $$Percent\ Risk = \frac{Chemical\ Risk}{Total\ Risk} * 100$$

E-300 = Concentration at the air monitoring point (ppbv)
MW = Molecular Weight of the VOC (g/mole)
COC = Concentration of concern at E-300 Monitoring Station (ug/m^3)
V_{panel} = Mine ventilation panel rate (130,000 ft^3/min)
$V_{exhaust-typ}$ = typical mine ventilation exhaust rate, (425,000 ft^3/min)
ECS_{act} = Actual exhaust shaft concentration for VOC (ug/m^3)
ADF = Air dispersion factor, unitless
Rcon = Receptor concentration (ug/m^3)

AT_c = Averaging time for carcinogens in hours (70 years total)
AT_{nc} = Averaging time for non-carcinogens in hours (based on Exposure Duration)
URF = Unit risk factor for VOC (m^3/ug)$^{-1}$
RfC = Reference concentration (mg/m^3)
EF = Exposure frequency (hours/year)
ED = Exposure duration, years (35 years)
$Risk_{ind}$ = per chemical cancer risk (unitless)
$Risk_{cum}$ = cumulative cancer risks for all chemicals combined (unitless)

Risks and Hazards Based on Current E-300 Limits, Toxicity Values from the Permit, Original ADF

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient* (unitless)	Percent of Total Risk
Carbon Tetrachloride	165	153.84	1038	130,000	425,000	317.56	9.80E-05	0.031	613200		1.5E-05		2080	35	5.54E-08		19
Chlorobenzene	220	112.56	1013	130,000	425,000	309.80	9.80E-05	0.030		306600		2.0E-02	2080	35		3.60E-04	
Chloroform	180	119.39	879	130,000	425,000	268.85	9.80E-05	0.026	613200		2.3E-05		2080	35	7.19E-08		24
1,1-Dichloroethene	100	96.95	397	130,000	425,000	121.29	9.80E-05	0.012	613200		5.0E-05		2080	35	7.06E-08		24
1,2-Dichloroethane	45	98.97	182	130,000	425,000	55.72	9.80E-05	0.0055	613200		2.6E-05		2080	35	1.69E-08		6
Methylene Chloride	1930	84.94	6705	130,000	425,000	2050.90	9.80E-05	0.20	613200		4.7E-07		2080	35	1.12E-08		4
1,1,2,2-Tetrachloroethane	50	167.86	343	130,000	425,000	105.00	9.80E-05	0.010	613200		5.8E-05		2080	35	7.09E-08		24
Toluene	190	92.13	716	130,000	425,000	218.99	9.80E-05	0.021		306600		4.0E-01	2080	35		1.27E-05	
1,1,1-Trichloroethane	590	133.42	3220	130,000	425,000	984.80	9.80E-05	0.10		306600		7.0E-01	2080	35		3.27E-05	
														Cumulative	**3.0E-07**	**4.1E-04**	100

* Consistent with the approach used in the permit, non-cancer hazard quotients were only calculated for chemicals with no available URF values.

Risks and Hazards Based on Current Measured Concentrations at E-300 Drift Monitoring Station, Current Toxicity Values, new ADF*

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient (unitless)	Percent of Total Risk
Carbon Tetrachloride	108.73	153.84	684	130,000	425,000	209.26	1.76E-04	0.037	613200	306600	6.0E-06	1.00E-01	2080	35	2.62E-08	8.75E-05	78
Chlorobenzene	0	112.56	0	130,000	425,000	0	1.76E-04	0	613200	306600		5.0E-02	2080	35		0	
Chloroform	10.46	119.39	51	130,000	425,000	15.62	1.76E-04	0.0027	613200	306600	2.3E-05	9.8E-02	2080	35	7.51E-09	6.66E-06	22
1,1-Dichloroethene**	0	96.95	0	130,000	425,000	0	1.76E-04	0	613200	306600		2.0E-01	2080	35		0	
1,2-Dichloroethane	0	98.97	0	130,000	425,000	0	1.76E-04	0	613200	306600	2.6E-05	2.4E+00	2080	35	0	0	0
Methylene Chloride	1.99	84.94	7	130,000	425,000	2.11	1.76E-04	0.00037	613200	306600	4.7E-07	1.0E+00	2080	35	2.08E-11	8.84E-08	0.06
1,1,2,2-Tetrachloroethane	0	167.86	0	130,000	425,000	0	1.76E-04	0	613200	306600	5.8E-05		2080	35	0		0
Toluene	0.01	92.13	0.038	130,000	425,000	0.012	1.76E-04	0.0000020	613200	306600		5.0E+00	2080	35		9.63E-11	
1,1,1-Trichloroethane	17.56	133.42	96	130,000	425,000	29.31	1.76E-04	0.0052	613200	306600		5.0E+00	2080	35		2.45E-07	
														Cumulative	**3.4E-08**	**7.0E-06**	100

* ADF was calculated at the point of maximum impact in the Livingstone Ridge Alottment, assuming 45 degree vent angle, no additional stack height, and vent usage of 20% vents 1 & 2, 80% highest impact of vents 1 & 3 or vents 2 & 3
** USEPA has withdrawn the URF for 1,1-DCE; inhalation evaluated based on non-cancer effects.

Table B-4
Calculation of Risks and Allowable Air Concentrations
Livingston Ridge Ranch Worker Scenario
Current Permit Approach
Waste Isolation Pilot Plant (WIPP)

"Reverse" Risk Calculations (i.e., Allowable Air Concentrations at E-300 Monitoring Station) Based on Target Risk Levels

equation 7:

$$Risk_{ind} = Risk_{cum} * 0.01 * Percent\ Risk$$

equation 8:

$$R_{con} = \frac{Risk * AT_c}{URF * EF * ED}$$

equation 9:

$$ECS_{act} = \frac{R_{con}}{ADF}$$

equation 10:

$$COC = ECS_{act} * \left(\frac{V_{exhaust-typ}}{V_{panel}} \right)$$

equation 11:

$$E300 = COC * \left(\frac{24.45}{MW} \right)$$

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based on Original Permit Assumptions

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	1.87E-07	613200		1.5E-05		2080	35	0.10	9.80E-05	1069.77	130,000	425,000	3497	153.84	556	165
Chlorobenzene				306600		2.0E-02	2080	35		9.80E-05		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.42E-07	613200		2.3E-05		2080	35	0.089	9.80E-05	905.69	130,000	425,000	2961	119.39	606	180
1,1-Dichloroethene	1.0E-06	2.38E-07	613200		5.0E-05		2080	35	0.040	9.80E-05	408.59	130,000	425,000	1336	96.95	337	100
1,2-Dichloroethane	1.0E-06	5.68E-08	613200		2.6E-05		2080	35	0.018	9.80E-05	187.70	130,000	425,000	614	98.97	152	45
Methylene Chloride	1.0E-06	3.78E-08	613200		4.7E-07		2080	35	0.68	9.80E-05	6908.89	130,000	425,000	22587	84.94	6502	1930
1,1,2,2-Tetrachloroethane	1.0E-06	2.39E-07	613200		5.8E-05		2080	35	0.035	9.80E-05	353.72	130,000	425,000	1156	167.86	168	50
Toluene				306600		4.0E-01	2080	35		9.80E-05		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane				306600		7.0E-01	2080	35		9.80E-05		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker set at 1E-5, for residents and ranch workers set at 1E-6

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based Re-apportionment of Risk to Reflect Current Conditions, New Toxicity Values, New ADF

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	7.77E-07	613200	306600	6.0E-06	1.00E-01	2080	35	1.09	1.76E-04	6197.75	130,000	425,000	20262	153.84	3220	165
Chlorobenzene			613200	306600		5.0E-02	2080	35		1.76E-04		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.22E-07	613200	306600	2.3E-05	9.8E-02	2080	35	0.081	1.76E-04	462.72	130,000	425,000	1513	119.39	310	180
1,1-Dichloroethene			613200	306600		2.0E-01	2080	35		1.76E-04		130,000	425,000		96.95	*	100
1,2-Dichloroethane	1.0E-06	0	613200	306600	2.6E-05	2.4E+00	2080	35	0	1.76E-04	0	130,000	425,000	0	98.97	0	45
Methylene Chloride***	1.0E-06	6.15E-10	613200	87600	4.7E-07	1.0E+00	2080	35	0.011	1.76E-04	62.63	130,000	425,000	205	84.94	59	1930
1,1,2,2-Tetrachloroethane	1.0E-06	0	613200	306600	5.8E-05		2080	35	0	1.76E-04	0	130,000	425,000	0	167.86	0	50
Toluene			613200	306600		5.0E+00	2080	35		1.76E-04		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane			613200	306600		5.0E+00	2080	35		1.76E-04		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker and trainee set at 1E-5, for residents and ranch workers set at 1E-6

*** Methylene chloride target risk is set at a very low value, based on current emision rates <1% of total risk. As an example, if target risk was arbitrarily set as 1%, E-300 COC would be 958 ppbv.

Table B-5
Calculation of Risks and Allowable Air Concentrations
Trainee Scenario - PPA
"Best Case" Approach
Waste Isolation Pilot Plant (WIPP)

"Forward" Risk Calculations (i.e., Risks) Based on E-300 Monitoring Station

equation 1: $$COC = E300 * \left(\frac{MW}{24.45}\right)$$

equation 2: $$ECS_{act} = COC * \left(\frac{V_{panel}}{V_{exhaust-typ}}\right)$$

equation 3: $$R_{con} = ECS_{act} * ADF$$

equation 4: $$Cancer\ Risk = \frac{R_{con} * URF * EF * ED}{AT_c}$$

equation 5: $$Hazard\ Quotient = \frac{R_{con} * EF * ED}{AT_{nc} * RfC * 1000}$$

equation 6: $$Percent\ Risk = \frac{Chemical\ Risk}{Total\ Risk} * 100$$

E-300 = Concentration at the air monitoring point (ppbv)
MW = Molecular Weight of the VOC (g/mole)
COC = Concentration of concern at E-300 Monitoring Station (ug/m^3)
V_{panel} = Mine ventilation panel rate (130,000 ft^3/min)
$V_{exhaust-typ}$ = typical mine ventilation exhaust rate (425,000 ft^3/min)
ECS_{act} = Actual exhaust shaft concentration for VOC (ug/m^3)
ADF = Air dispersion factor, unitless
Rcon = Receptor concentration (ug/m^3)
AT_c = Averaging time for carcinogens in hours (70 years total)
AT_{nc} = Averaging time for non-carcinogens in hours (based on Exposure Duration)
URF = Unit risk factor for VOC (m^3/ug)$^{-1}$
RfC = Reference concentration (mg/m^3)
EF = Exposure frequency (hours/year)
ED = Exposure duration, years (10 years)
$Risk_{ind}$ = per chemical cancer risk (unitless)
$Risk_{cum}$ = cumulative cancer risks for all chemicals combined (unitless)

Risks and Hazards Based on Current Measured Concentrations at E-300 Drift Monitoring Station, Current Toxicity Values, new ADF*

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient (unitless)	Percent of Total Risk
Carbon Tetrachloride	108.73	153.84	684	130,000	425,000	209	8.69E-05	0.018	613200	87600	6.0E-06	1.00E-01	192	10	3.42E-10	3.99E-06	78
Chlorobenzene	0	112.56	0	130,000	425,000	0	8.69E-05	0	613200	87600		5.0E-02	192	10		0	
Chloroform	10.46	119.39	51	130,000	425,000	16	8.69E-05	0.0014	613200	87600	2.3E-05	9.8E-02	192	10	9.78E-11	3.04E-07	22
1,1-Dichloroethene**	0	96.95	0	130,000	425,000	0	8.69E-05	0	613200	87600		2.0E-01	192	10		0	
1,2-Dichloroethane	0	98.97	0	130,000	425,000	0	8.69E-05	0	613200	87600	2.6E-05	2.4E+00	192	10	0	0	0
Methylene Chloride	1.99	84.94	7	130,000	425,000	2.1	8.69E-05	0.00018	613200	87600	4.7E-07	1.0E+00	192	10	2.70E-13	4.03E-09	0.06
1,1,2,2-Tetrachloroethane	0	167.86	0	130,000	425,000	0	8.69E-05	0	613200	87600	5.8E-05		192	10	0		0
Toluene	0.01	92.13	0.038	130,000	425,000	0.012	8.69E-05	0.0000010	613200	87600		5.0E+00	192	10		4.39E-12	
1,1,1-Trichloroethane	17.56	133.42	96	130,000	425,000	29	8.69E-05	0.00	613200	87600		5.0E+00	192	10		1.12E-08	
														Cumulative	**4.4E-10**	**3.2E-07**	100

* ADF was calculated at the point of maximum impact in the PPA, assuming vertical vent orientation, 50 ft additional stack height, and vent usage of 20% vents 1 & 2, 80% highest impact of vents 1 & 3 or vents 2 & 3
** USEPA has withdrawn the URF for 1,1-DCE; inhalation evaluated based on non-cancer effects.

"Reverse" Risk Calculations (i.e., Allowable Air Concentrations at E-300 Monitoring Station) Based on Target Risk Levels

equation 7: $$Risk_{ind} = Risk_{cum} * 0.01 * Percent\ Risk$$

equation 8: $$R_{con} = \frac{Risk * AT_c}{URF * EF * ED}$$

equation 9: $$ECS_{act} = \frac{R_{con}}{ADF}$$

equation 10: $$COC = ECS_{act} * \left(\frac{V_{exhaust-typ}}{V_{panel}}\right)$$

equation 11: $$E300 = COC * \left(\frac{24.45}{MW}\right)$$

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based Re-apportionment of Risk to Reflect Current Conditions, New Toxicity Values, New ADF

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-05	7.77E-06	613200	87600	6.0E-06	1.00E-01	192	10	414	8.69E-05	4759451	130,000	425,000	15559744	153.84	2472931	165
Chlorobenzene			613200	87600		5.0E-02	192	10		8.69E-05		130,000	425,000		112.56	*	220
Chloroform	1.0E-05	2.22E-06	613200	87600	2.3E-05	9.8E-02	192	10	31	8.69E-05	355335	130,000	425,000	1161672	119.39	237900	180
1,1-Dichloroethene			613200	87600		2.0E-01	192	10		8.69E-05		130,000	425,000		96.95	*	100
1,2-Dichloroethane	1.0E-05	0	613200	87600	2.6E-05	2.4E+00	192	10	0	8.69E-05	0	130,000	425,000	0	98.97	0	45
Methylene Chloride	1.0E-05	6.15E-09	613200	87600	4.7E-07	1.0E+00	192	10	4.2	8.69E-05	48095	130,000	425,000	157235	84.94	45260	1930
1,1,2,2-Tetrachloroethane	1.0E-05	0	613200	87600	5.8E-05		192	10	0	8.69E-05	0	130,000	425,000	0	167.86	0	50
Toluene			613200	87600		5.0E+00	192	10		8.69E-05		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane			613200	87600		5.0E+00	192	10		8.69E-05		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.
** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker and trainee set at 1E-5, for residents and ranch workers set at 1E-6

Table B-6
Calculation of Risks and Allowable Air Concentrations
Off-Site Resident Scenario - Mills Ranch
"Best Case" Approach
Waste Isolation Pilot Plant (WIPP)

"Forward" Risk Calculations (i.e., Risks) Based on E-300 Monitoring Station

equation 1: $$COC = E300 * \left(\frac{MW}{24.45}\right)$$

equation 2: $$ECS_{act} = COC * \left(\frac{V_{panel}}{V_{exhaust-typ}}\right)$$

equation 3: $$R_{con} = ECS_{act} * ADF$$

equation 4: $$Cancer\ Risk = \frac{R_{con} * URF * EF * ED}{AT_c}$$

equation 5: $$Hazard\ Quotient = \frac{R_{con} * EF * ED}{AT_{nc} * RfC * 1000}$$

equation 6: $$Percent\ Risk = \frac{Chemical\ Risk}{Total\ Risk} * 100$$

E-300 = Concentration at the air monitoring point (ppbv)
MW = Molecular Weight of the VOC (g/mole)
COC = Concentration of concern at E-300 Monitoring Station (ug/m^3)
V_{panel} = Mine ventilation panel rate (130,000 ft^3/min)
$V_{exhaust-typ}$ = typical mine ventilation exhaust rate, (425,000 ft^3/min)
ECS_{act} = Actual exhaust shaft concentration for VOC (ug/m^3)
ADF = Air dispersion factor, unitless
Rcon = Receptor concentration (ug/m^3)

AT_c = Averaging time for carcinogens in hours (70 years total)
AT_{nc} = Averaging time for non-carcinogens in hours (based on Exposure Duration)
URF = Unit risk factor for VOC (m^3/ug)$^{-1}$
RfC = Reference concentration (mg/m^3)
EF = Exposure frequency (hours/year)
ED = Exposure duration, years (35 years)
$Risk_{ind}$ = per chemical cancer risk (unitless)
$Risk_{cum}$ = cumulative cancer risks for all chemicals combined (unitless)

Risks and Hazards Based on Current E-300 Limits, Toxicity Values from the Permit, Original ADF

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient* (unitless)	Percent of Total Risk
Carbon Tetrachloride	165	153.84	1038	130,000	425,000	317.56	1.20E-04	0.038	613200		1.5E-05		8760	35	2.86E-07		19
Chlorobenzene	220	112.56	1013	130,000	425,000	309.80	1.20E-04	0.037		306600		2.0E-02	8760	35		1.86E-03	
Chloroform	180	119.39	879	130,000	425,000	268.85	1.20E-04	0.032	613200		2.3E-05		8760	35	3.71E-07		24
1,1-Dichloroethene	100	96.95	397	130,000	425,000	121.29	1.20E-04	0.015	613200		5.0E-05		8760	35	3.64E-07		24
1,2-Dichloroethane	45	98.97	182	130,000	425,000	55.72	1.20E-04	0.0067	613200		2.6E-05		8760	35	8.69E-08		6
Methylene Chloride	1930	84.94	6705	130,000	425,000	2050.90	1.20E-04	0.25	613200		4.7E-07		8760	35	5.78E-08		4
1,1,2,2-Tetrachloroethane	50	167.86	343	130,000	425,000	105.00	1.20E-04	0.013	613200		5.8E-05		8760	35	3.65E-07		24
Toluene	190	92.13	716	130,000	425,000	218.99	1.20E-04	0.026		306600		4.0E-01	8760	35		6.57E-05	
1,1,1-Trichloroethane	590	133.42	3220	130,000	425,000	984.80	1.20E-04	0.12		306600		7.0E-01	8760	35		1.69E-04	
														Cumulative	**1.5E-06**	**2.1E-03**	100

* Consistent with the approach used in the permit, non-cancer hazard quotients were only calculated for chemicals with no available URF values.

Risks and Hazards Based on Current Measured Concentrations at E-300 Drift Monitoring Station, Current Toxicity Values, new ADF*

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient (unitless)	Percent of Total Risk
Carbon Tetrachloride	108.73	153.84	684	130,000	425,000	209.26	6.47E-06	0.0014	613200	306600	6.0E-06	1.00E-01	8760	35	4.06E-09	1.35E-05	78
Chlorobenzene	0	112.56	0	130,000	425,000	0	6.47E-06	0	613200	306600		5.0E-02	8760	35		0	
Chloroform	10.46	119.39	51	130,000	425,000	15.62	6.47E-06	0.00010	613200	306600	2.3E-05	9.8E-02	8760	35	1.16E-09	1.03E-06	22
1,1-Dichloroethene**	0	96.95	0	130,000	425,000	0	6.47E-06	0	613200	306600		2.0E-01	8760	35		0	
1,2-Dichloroethane	0	98.97	0	130,000	425,000	0	6.47E-06	0	613200	306600	2.6E-05	2.4E+00	8760	35	0	0	0
Methylene Chloride	1.99	84.94	7	130,000	425,000	2.11	6.47E-06	0.000014	613200	306600	4.7E-07	1.0E+00	8760	35	3.22E-12	1.37E-08	0.06
1,1,2,2-Tetrachloroethane	0	167.86	0	130,000	425,000	0	6.47E-06	0	613200	306600	5.8E-05		8760	35	0		0
Toluene	0.01	92.13	0.038	130,000	425,000	0.012	6.47E-06	0.000000075	613200	306600		5.0E+00	8760	35		1.49E-11	
1,1,1-Trichloroethane	17.56	133.42	96	130,000	425,000	29.31	6.47E-06	0.00019	613200	306600		5.0E+00	8760	35		3.79E-08	
														Cumulative	**5.2E-09**	**1.1E-06**	100

* ADF was calculated at the point of maximum impact off-property, assuming vertical vent orientation, 50 ft additional stack height, and vent usage of 20% vents 1 & 2, 80% highest impact of vents 1 & 3 or vents 2 & 3
** USEPA has withdrawn the URF for 1,1-DCE; inhalation evaluated based on non-cancer effects.

Table B-6
Calculation of Risks and Allowable Air Concentrations
Off-Site Resident Scenario - Mills Ranch
"Best Case" Approach
Waste Isolation Pilot Plant (WIPP)

"Reverse" Risk Calculations (i.e., Allowable Air Concentrations at E-300 Monitoring Station) Based on Target Risk Levels

equation 7: $Risk_{ind} = Risk_{cum} * 0.01 * Percent\ Risk$

equation 8: $R_{con} = \frac{Risk * AT_c}{URF * EF * ED}$

equation 9: $ECS_{act} = \frac{R_{con}}{ADF}$

equation 10: $COC = ECS_{act} * \left(\frac{V_{exhaust-typ}}{V_{panel}} \right)$

equation 11: $E300 = COC * \left(\frac{24.45}{MW} \right)$

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based on Original Permit Assumptions

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	1.87E-07	613200		1.5E-05		8760	35	0.025	1.20E-04	207.44	130,000	425,000	678	153.84	108	165
Chlorobenzene				306600		2.0E-02	8760	35		1.20E-04		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.42E-07	613200		2.3E-05		8760	35	0.021	1.20E-04	175.62	130,000	425,000	574	119.39	118	180
1,1-Dichloroethene	1.0E-06	2.38E-07	613200		5.0E-05		8760	35	0.010	1.20E-04	79.23	130,000	425,000	259	96.95	65	100
1,2-Dichloroethane	1.0E-06	5.68E-08	613200		2.6E-05		8760	35	0.0044	1.20E-04	36.40	130,000	425,000	119	98.97	29	45
Methylene Chloride	1.0E-06	3.78E-08	613200		4.7E-07		8760	35	0.16	1.20E-04	1339.71	130,000	425,000	4380	84.94	1261	1930
1,1,2,2-Tetrachloroethane	1.0E-06	2.39E-07	613200		5.8E-05		8760	35	0.0082	1.20E-04	68.59	130,000	425,000	224	167.86	33	50
Toluene				306600		4.0E-01	8760	35		1.20E-04		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane				306600		7.0E-01	8760	35		1.20E-04		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker set at 1E-5, for residents and ranch workers set at 1E-6

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based Re-apportionment of Risk to Reflect Current Conditions, New Toxicity Values, New ADF

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	7.77E-07	613200	306600	6.0E-06	1.00E-01	8760	35	0.26	6.47E-06	40031.46	130,000	425,000	130872	153.84	20800	165
Chlorobenzene			613200	306600		5.0E-02	8760	35		6.47E-06		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.22E-07	613200	306600	2.3E-05	9.8E-02	8760	35	0.019	6.47E-06	2988.70	130,000	425,000	9771	119.39	2001	180
1,1-Dichloroethene			613200	306600		2.0E-01	8760	35		6.47E-06		130,000	425,000		96.95	*	100
1,2-Dichloroethane	1.0E-06	0	613200	306600	2.6E-05	2.4E+00	8760	35	0	6.47E-06	0	130,000	425,000	0	98.97	0	45
Methylene Chloride***	1.0E-06	6.15E-10	613200	87600	4.7E-07	1.0E+00	8760	35	0.0026	6.47E-06	404.53	130,000	425,000	1322	84.94	381	1930
1,1,2,2-Tetrachloroethane	1.0E-06	0	613200	306600	5.8E-05		8760	35	0	6.47E-06	0	130,000	425,000	0	167.86	0	50
Toluene			613200	306600		5.0E+00	8760	35		6.47E-06		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane			613200	306600		5.0E+00	8760	35		6.47E-06		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker and trainee set at 1E-5, for residents and ranch workers set at 1E-6

Table B-7
Calculation of Risks and Allowable Air Concentrations
Off-Site Resident Scenario - Smith Ranch
"Best Case" Approach
Waste Isolation Pilot Plant (WIPP)

"Forward" Risk Calculations (i.e., Risks) Based on E-300 Monitoring Station

equation 1: $$COC = E300 * \left(\frac{MW}{24.45}\right)$$

equation 2: $$ECS_{act} = COC * \left(\frac{V_{panel}}{V_{exhaust-typ}}\right)$$

equation 3: $$R_{con} = ECS_{act} * ADF$$

equation 4: $$Cancer\ Risk = \frac{R_{con} * URF * EF * ED}{AT_c}$$

equation 5: $$Hazard\ Quotient = \frac{R_{con} * EF * ED}{AT_{nc} * RfC * 1000}$$

equation 6: $$Percent\ Risk = \frac{Chemical\ Risk}{Total\ Risk} * 100$$

E-300 = Concentration at the air monitoring point (ppbv)
MW = Molecular Weight of the VOC (g/mole)
COC = Concentration of concern at E-300 Monitoring Station (ug/m^3)
V_{panel} = Mine ventilation panel rate (130,000 ft^3/min)
$V_{exhaust-typ}$ = typical mine ventilation exhaust rate, (425,000 ft^3/min)
ECS_{act} = Actual exhaust shaft concentration for VOC (ug/m^3)
ADF = Air dispersion factor, unitless
Rcon = Receptor concentration (ug/m^3)

AT_c = Averaging time for carcinogens in hours (70 years total)
AT_{nc} = Averaging time for non-carcinogens in hours (based on Exposure Duration)
URF = Unit risk factor for VOC $(m^3/ug)^{-1}$
RfC = Reference concentration (mg/m^3)
EF = Exposure frequency (hours/year)
ED = Exposure duration, years (35 years)
$Risk_{ind}$ = per chemical cancer risk (unitless)
$Risk_{cum}$ = cumulative cancer risks for all chemicals combined (unitless)

Risks and Hazards Based on Current E-300 Limits, Toxicity Values from the Permit, Original ADF

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient* (unitless)	Percent of Total Risk
Carbon Tetrachloride	165	153.84	1038	130,000	425,000	317.56	1.20E-04	0.038	613200		1.5E-05		8760	35	2.86E-07		19
Chlorobenzene	220	112.56	1013	130,000	425,000	309.80	1.20E-04	0.037		306600		2.0E-02	8760	35		1.86E-03	
Chloroform	180	119.39	879	130,000	425,000	268.85	1.20E-04	0.032	613200		2.3E-05		8760	35	3.71E-07		24
1,1-Dichloroethene	100	96.95	397	130,000	425,000	121.29	1.20E-04	0.015	613200		5.0E-05		8760	35	3.64E-07		24
1,2-Dichloroethane	45	98.97	182	130,000	425,000	55.72	1.20E-04	0.0067	613200		2.6E-05		8760	35	8.69E-08		6
Methylene Chloride	1930	84.94	6705	130,000	425,000	2050.90	1.20E-04	0.25	613200		4.7E-07		8760	35	5.78E-08		4
1,1,2,2-Tetrachloroethane	50	167.86	343	130,000	425,000	105.00	1.20E-04	0.013	613200		5.8E-05		8760	35	3.65E-07		24
Toluene	190	92.13	716	130,000	425,000	218.99	1.20E-04	0.026		306600		4.0E-01	8760	35		6.57E-05	
1,1,1-Trichloroethane	590	133.42	3220	130,000	425,000	984.80	1.20E-04	0.12		306600		7.0E-01	8760	35		1.69E-04	
														Cumulative	**1.5E-06**	**2.1E-03**	100

* Consistent with the approach used in the permit, non-cancer hazard quotients were only calculated for chemicals with no available URF values.

Risks and Hazards Based on Current Measured Concentrations at E-300 Drift Monitoring Station, Current Toxicity Values, new ADF*

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient (unitless)	Percent of Total Risk
Carbon Tetrachloride	108.73	153.84	684	130,000	425,000	209.26	8.89E-06	0.0019	613200	306600	6.0E-06	1.00E-01	8760	35	5.58E-09	1.86E-05	78
Chlorobenzene	0	112.56	0	130,000	425,000	0	8.89E-06	0	613200	306600		5.0E-02	8760	35		0	
Chloroform	10.46	119.39	51	130,000	425,000	15.62	8.89E-06	0.00014	613200	306600	2.3E-05	9.8E-02	8760	35	1.60E-09	1.42E-06	22
1,1-Dichloroethene**	0	96.95	0	130,000	425,000	0	8.89E-06	0	613200	306600		2.0E-01	8760	35		0	
1,2-Dichloroethane	0	98.97	0	130,000	425,000	0	8.89E-06	0	613200	306600	2.6E-05	2.4E+00	8760	35	0	0	0
Methylene Chloride	1.99	84.94	7	130,000	425,000	2.11	8.89E-06	0.000019	613200	306600	4.7E-07	1.0E+00	8760	35	4.42E-12	1.88E-08	0.06
1,1,2,2-Tetrachloroethane	0	167.86	0	130,000	425,000	0	8.89E-06	0	613200	306600	5.8E-05		8760	35	0		0
Toluene	0.01	92.13	0.038	130,000	425,000	0.012	8.89E-06	0.00000010	613200	306600		5.0E+00	8760	35		2.05E-11	
1,1,1-Trichloroethane	17.56	133.42	96	130,000	425,000	29.31	8.89E-06	0.00026	613200	306600		5.0E+00	8760	35		5.21E-08	
														Cumulative	**7.2E-09**	**1.5E-06**	100

* ADF was calculated at the point of maximum impact off-property, assuming vertical vent orientation, 50 ft additional stack height, and vent usage of 20% vents 1 & 2, 40% vents 1 & 3, 80% highest impact of vents 1 & 3 or vents 2 & 3
** USEPA has withdrawn the URF for 1,1-DCE; inhalation evaluated based on non-cancer effects.

Table B-7
Calculation of Risks and Allowable Air Concentrations
Off-Site Resident Scenario - Smith Ranch
"Best Case" Approach
Waste Isolation Pilot Plant (WIPP)

"Reverse" Risk Calculations (i.e., Allowable Air Concentrations at E-300 Monitoring Station) Based on Target Risk Levels

equation 7: $Risk_{ind} = Risk_{cum} * 0.01 * Percent\ Risk$

equation 8: $R_{con} = \frac{Risk * AT_c}{URF * EF * ED}$

equation 9: $ECS_{act} = \frac{R_{con}}{ADF}$

equation 10: $COC = ECS_{act} * \left(\frac{V_{exhaust-typ}}{V_{panel}} \right)$

equation 11: $E300 = COC * \left(\frac{24.45}{MW} \right)$

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based on Original Permit Assumptions

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	1.87E-07	613200		1.5E-05		8760	35	0.025	1.20E-04	207.44	130,000	425,000	678	153.84	108	165
Chlorobenzene				306600		2.0E-02	8760	35		1.20E-04		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.42E-07	613200		2.3E-05		8760	35	0.021	1.20E-04	175.62	130,000	425,000	574	119.39	118	180
1,1-Dichloroethene	1.0E-06	2.38E-07	613200		5.0E-05		8760	35	0.010	1.20E-04	79.23	130,000	425,000	259	96.95	65	100
1,2-Dichloroethane	1.0E-06	5.68E-08	613200		2.6E-05		8760	35	0.0044	1.20E-04	36.40	130,000	425,000	119	98.97	29	45
Methylene Chloride	1.0E-06	3.78E-08	613200		4.7E-07		8760	35	0.16	1.20E-04	1339.71	130,000	425,000	4380	84.94	1261	1930
1,1,2,2-Tetrachloroethane	1.0E-06	2.39E-07	613200		5.8E-05		8760	35	0.0082	1.20E-04	68.59	130,000	425,000	224	167.86	33	50
Toluene				306600		4.0E-01	8760	35		1.20E-04		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane				306600		7.0E-01	8760	35		1.20E-04		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker set at 1E-5, for residents and ranch workers set at 1E-6

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based Re-apportionment of Risk to Reflect Current Conditions, New Toxicity Values, New ADF

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	7.77E-07	613200	306600	6.0E-06	1.00E-01	8760	35	0.26	8.89E-06	29134.26	130,000	425,000	95247	153.84	15138	165
Chlorobenzene			613200	306600		5.0E-02	8760	35		8.89E-06		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.22E-07	613200	306600	2.3E-05	9.8E-02	8760	35	0.019	8.89E-06	2175.13	130,000	425,000	7111	119.39	1456	180
1,1-Dichloroethene			613200	306600		2.0E-01	8760	35		8.89E-06		130,000	425,000		96.95	*	100
1,2-Dichloroethane	1.0E-06	0	613200	306600	2.6E-05	2.4E+00	8760	35	0	8.89E-06	0	130,000	425,000	0	98.97	0	45
Methylene Chloride***	1.0E-06	6.15E-10	613200	87600	4.7E-07	1.0E+00	8760	35	0.0026	8.89E-06	294.41	130,000	425,000	962	84.94	277	1930
1,1,2,2-Tetrachloroethane	1.0E-06	0	613200	306600	5.8E-05		8760	35	0	8.89E-06	0	130,000	425,000	0	167.86	0	50
Toluene			613200	306600		5.0E+00	8760	35		8.89E-06		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane			613200	306600		5.0E+00	8760	35		8.89E-06		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker and trainee set at 1E-5, for residents and ranch workers set at 1E-6

Table B-8
Calculation of Risks and Allowable Air Concentrations
Antelope Ridge Ranch Worker Scenario
"Best Case" Approach
Waste Isolation Pilot Plant (WIPP)

"Forward" Risk Calculations (i.e., Risks) Based on E-300 Monitoring Station

equation 1: $$COC = E300 * \left(\frac{MW}{24.45}\right)$$

equation 2: $$ECS_{act} = COC * \left(\frac{V_{panel}}{V_{exhaust-typ}}\right)$$

equation 3: $$R_{con} = ECS_{act} * ADF$$

equation 4: $$Cancer\ Risk = \frac{R_{con} * URF * EF * ED}{AT_c}$$

equation 5: $$Hazard\ Quotient = \frac{R_{can} * EF * ED}{AT_{nc} * RfC * 1000}$$

equation 6: $$Percent\ Risk = \frac{Chemical\ Risk}{Total\ Risk} * 100$$

E-300 = Concentration at the air monitoring point (ppbv)
MW = Molecular Weight of the VOC (g/mole)
COC = Concentration of concern at E-300 Monitoring Station (ug/m^3)
V_{panel} = Mine ventilation panel rate (130,000 ft^3/min)
$V_{exhaust-typ}$ = typical mine ventilation exhaust rate, (425,000 ft^3/min)
ECS_{act} = Actual exhaust shaft concentration for VOC (ug/m^3)
ADF = Air dispersion factor, unitless
Rcon = Receptor concentration (ug/m^3)
AT_c = Averaging time for carcinogens in hours (70 years total)
AT_{nc} = Averaging time for non-carcinogens in hours (based on Exposure Duration)
URF = Unit risk factor for VOC (m^3/ug)$^{-1}$
RfC = Reference concentration (mg/m^3)
EF = Exposure frequency (hours/year)
ED = Exposure duration, years (35 years)
$Risk_{ind}$ = per chemical cancer risk (unitless)
$Risk_{cum}$ = cumulative cancer risks for all chemicals combined (unitless)

Risks and Hazards Based on Current E-300 Limits, Toxicity Values from the Permit, Original ADF

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient* (unitless)	Percent of Total Risk
Carbon Tetrachloride	165	153.84	1038	130,000	425,000	317.56	6.70E-05	0.021	613200		1.5E-05		2080	35	3.79E-08		19
Chlorobenzene	220	112.56	1013	130,000	425,000	309.80	6.70E-05	0.021		306600		2.0E-02	2080	35		2.46E-04	
Chloroform	180	119.39	879	130,000	425,000	268.85	6.70E-05	0.018	613200		2.3E-05		2080	35	4.92E-08		24
1,1-Dichloroethene	100	96.95	397	130,000	425,000	121.29	6.70E-05	0.0081	613200		5.0E-05		2080	35	4.82E-08		24
1,2-Dichloroethane	45	98.97	182	130,000	425,000	55.72	6.70E-05	0.0037	613200		2.6E-05		2080	35	1.15E-08		6
Methylene Chloride	1930	84.94	6705	130,000	425,000	2050.90	6.70E-05	0.14	613200		4.7E-07		2080	35	7.67E-09		4
1,1,2,2-Tetrachloroethane	50	167.86	343	130,000	425,000	105.00	6.70E-05	0.0070	613200		5.8E-05		2080	35	4.84E-08		24
Toluene	190	92.13	716	130,000	425,000	218.99	6.70E-05	0.015		306600		4.0E-01	2080	35		8.71E-06	
1,1,1-Trichloroethane	590	133.42	3220	130,000	425,000	984.80	6.70E-05	0.066		306600		7.0E-01	2080	35		2.24E-05	
														Cumulative	**2.0E-07**	**2.8E-04**	100

* Consistent with the approach used in the permit, non-cancer hazard quotients were only calculated for chemicals with no available URF values.

Risks and Hazards Based on Current Measured Concentrations at E-300 Drift Monitoring Station, Current Toxicity Values, new ADF*

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient (unitless)	Percent of Total Risk
Carbon Tetrachloride	108.73	153.84	684	130,000	425,000	209.26	2.94E-04	0.062	613200	306600	6.0E-06	1.00E-01	2080	35	4.38E-08	0.000146	78
Chlorobenzene	0	112.56	0	130,000	425,000	0	2.94E-04	0	613200	306600		5.0E-02	2080	35		0	
Chloroform	10.46	119.39	51	130,000	425,000	15.62	2.94E-04	0.0046	613200	306600	2.3E-05	9.8E-02	2080	35	1.25E-08	1.11E-05	22
1,1-Dichloroethene**	0	96.95	0	130,000	425,000	0	2.94E-04	0	613200	306600		2.0E-01	2080	35		0	
1,2-Dichloroethane	0	98.97	0	130,000	425,000	0	2.94E-04	0	613200	306600	2.6E-05	2.4E+00	2080	35	0	0	0
Methylene Chloride	1.99	84.94	7	130,000	425,000	2.11	2.94E-04	0.00062	613200	306600	4.7E-07	1.0E+00	2080	35	3.47E-11	1.48E-07	0.06
1,1,2,2-Tetrachloroethane	0	167.86	0	130,000	425,000	0	2.94E-04	0	613200	306600	5.8E-05		2080	35	0		0
Toluene	0.01	92.13	0.038	130,000	425,000	0.012	2.94E-04	0.0000034	613200	306600		5.0E+00	2080	35		1.61E-10	
1,1,1-Trichloroethane	17.56	133.42	96	130,000	425,000	29.31	2.94E-04	0.0086	613200	306600		5.0E+00	2080	35		4.09E-07	
														Cumulative	**5.6E-08**	**1.2E-05**	100

* ADF was calculated at the point of maximum impact in the Antelope Ridge Alottment, assuming vertical vent orientation, 50 ft additional stack height, and vent usage of 20% vents 1 & 2, 80% highest impact of vents 1 & 3 or vents 2 & 3
** USEPA has withdrawn the URF for 1,1-DCE; inhalation evaluated based on non-cancer effects.

Table B-8
Calculation of Risks and Allowable Air Concentrations
Antelope Ridge Ranch Worker Scenario
"Best Case" Approach
Waste Isolation Pilot Plant (WIPP)

"Reverse" Risk Calculations (i.e., Allowable Air Concentrations at E-300 Monitoring Station) Based on Target Risk Levels

equation 7: $Risk_{ind} = Risk_{cum} * 0.01 * Percent\ Risk$

equation 8: $R_{con} = \frac{Risk * AT_c}{URF * EF * ED}$

equation 9: $ECS_{act} = \frac{R_{con}}{ADF}$

equation 10: $COC = ECS_{act} * \left(\frac{V_{exhaust-typ}}{V_{panel}}\right)$

equation 11: $E300 = COC * \left(\frac{24.45}{MW}\right)$

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based on Original Permit Assumptions

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	1.87E-07	613200		1.5E-05		2080	35	0.10	6.70E-05	1564.74	130,000	425,000	5116	153.84	813	165
Chlorobenzene				306600		2.0E-02	2080	35		6.70E-05		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.42E-07	613200		2.3E-05		2080	35	0.089	6.70E-05	1324.74	130,000	425,000	4331	119.39	887	180
1,1-Dichloroethene	1.0E-06	2.38E-07	613200		5.0E-05		2080	35	0.040	6.70E-05	597.64	130,000	425,000	1954	96.95	493	100
1,2-Dichloroethane	1.0E-06	5.68E-08	613200		2.6E-05		2080	35	0.018	6.70E-05	274.54	130,000	425,000	898	98.97	222	45
Methylene Chloride	1.0E-06	3.78E-08	613200		4.7E-07		2080	35	0.68	6.70E-05	10105.54	130,000	425,000	33037	84.94	9510	1930
1,1,2,2-Tetrachloroethane	1.0E-06	2.39E-07	613200		5.8E-05		2080	35	0.035	6.70E-05	517.38	130,000	425,000	1691	167.86	246	50
Toluene				306600		4.0E-01	2080	35		6.70E-05		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane				306600		7.0E-01	2080	35		6.70E-05		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker set at 1E-5, for residents and ranch workers set at 1E-6

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based Re-apportionment of Risk to Reflect Current Conditions, New Toxicity Values, New ADF

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	7.77E-07	613200	306600	6.0E-06	1.00E-01	2080	35	1.09	2.94E-04	3710.22	130,000	425,000	12130	153.84	1928	165
Chlorobenzene			613200	306600		5.0E-02	2080	35		2.94E-04		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.22E-07	613200	306600	2.3E-05	9.8E-02	2080	35	0.081	2.94E-04	277.00	130,000	425,000	906	119.39	185	180
1,1-Dichloroethene			613200	306600		2.0E-01	2080	35		2.94E-04		130,000	425,000		96.95	*	100
1,2-Dichloroethane	1.0E-06	0	613200	306600	2.6E-05	2.4E+00	2080	35	0	2.94E-04	0	130,000	425,000	0	98.97	0	45
Methylene Chloride***	1.0E-06	6.15E-10	613200	87600	4.7E-07	1.0E+00	2080	35	0.011	2.94E-04	37.49	130,000	425,000	123	84.94	35	1930
1,1,2,2-Tetrachloroethane	1.0E-06	0	613200	306600	5.8E-05		2080	35	0	2.94E-04	0	130,000	425,000	0	167.86	0	50
Toluene			613200	306600		5.0E+00	2080	35		2.94E-04		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane			613200	306600		5.0E+00	2080	35		2.94E-04		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker and trainee set at 1E-5, for residents and ranch workers set at 1E-6

Table B-9
Calculation of Risks and Allowable Air Concentrations
Livingston Ridge Ranch Worker Scenario
"Best Case" Approach
Waste Isolation Pilot Plant (WIPP)

"Forward" Risk Calculations (i.e., Risks) Based on E-300 Monitoring Station

equation 1: $$COC = E300 * \left(\frac{MW}{24.45}\right)$$

equation 2: $$ECS_{act} = COC * \left(\frac{V_{panel}}{V_{exhaust-typ}}\right)$$

equation 3: $$R_{con} = ECS_{act} * ADF$$

equation 4: $$Cancer\ Risk = \frac{R_{con} * URF * EF * ED}{AT_c}$$

equation 5: $$Hazard\ Quotient = \frac{R_{con} * EF * ED}{AT_{nc} * RfC * 1000}$$

equation 6: $$Percent\ Risk = \frac{Chemical\ Risk}{Total\ Risk} * 100$$

E-300 = Concentration at the air monitoring point (ppbv)
MW = Molecular Weight of the VOC (g/mole)
COC = Concentration of concern at E-300 Monitoring Station (ug/m^3)
V_{panel} = Mine ventilation panel rate (130,000 ft^3/min)
$V_{exhaust-typ}$ = typical mine ventilation exhaust rate, (425,000 ft^3/min)
ECS_{act} = Actual exhaust shaft concentration for VOC (ug/m^3)
ADF = Air dispersion factor, unitless
Rcon = Receptor concentration (ug/m^3)

AT_c = Averaging time for carcinogens in hours (70 years total)
AT_{nc} = Averaging time for non-carcinogens in hours (based on Exposure Duration)
URF = Unit risk factor for VOC (m^3/ug)$^{-1}$
RfC = Reference concentration (mg/m^3)
EF = Exposure frequency (hours/year)
ED = Exposure duration, years (35 years)
$Risk_{ind}$ = per chemical cancer risk (unitless)
$Risk_{cum}$ = cumulative cancer risks for all chemicals combined (unitless)

Risks and Hazards Based on Current E-300 Limits, Toxicity Values from the Permit, Original ADF

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient* (unitless)	Percent of Total Risk
Carbon Tetrachloride	165	153.84	1038	130,000	425,000	317.56	9.80E-05	0.031	613200		1.5E-05		2080	35	5.54E-08		19
Chlorobenzene	220	112.56	1013	130,000	425,000	309.80	9.80E-05	0.030		306600		2.0E-02	2080	35		3.60E-04	
Chloroform	180	119.39	879	130,000	425,000	268.85	9.80E-05	0.026	613200		2.3E-05		2080	35	7.19E-08		24
1,1-Dichloroethene	100	96.95	397	130,000	425,000	121.29	9.80E-05	0.012	613200		5.0E-05		2080	35	7.06E-08		24
1,2-Dichloroethane	45	98.97	182	130,000	425,000	55.72	9.80E-05	0.0055	613200		2.6E-05		2080	35	1.69E-08		6
Methylene Chloride	1930	84.94	6705	130,000	425,000	2050.90	9.80E-05	0.20	613200		4.7E-07		2080	35	1.12E-08		4
1,1,2,2-Tetrachloroethane	50	167.86	343	130,000	425,000	105.00	9.80E-05	0.010	613200		5.8E-05		2080	35	7.09E-08		24
Toluene	190	92.13	716	130,000	425,000	218.99	9.80E-05	0.021		306600		4.0E-01	2080	35		1.27E-05	
1,1,1-Trichloroethane	590	133.42	3220	130,000	425,000	984.80	9.80E-05	0.10		306600		7.0E-01	2080	35		3.27E-05	
* Consistent with the approach used in the permit, non-cancer hazard quotients were only calculated for chemicals with no available URF values.														**Cumulative**	**3.0E-07**	**4.1E-04**	100

Risks and Hazards Based on Current Measured Concentrations at E-300 Drift Monitoring Station, Current Toxicity Values, new ADF*

Chemical	E-300 (ppbv)	MW (g/mole)	COC (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust-typ}$ (ft^3/min)	ECS_{act} (ug/m^3)	ADF (unitless)	Rcon (ug/m^3)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Cancer Risk (unitless)	Hazard Quotient (unitless)	Percent of Total Risk
Carbon Tetrachloride	108.73	153.84	684	130,000	425,000	209.26	9.66E-05	0.020	613200	306600	6.0E-06	1.00E-01	2080	35	1.44E-08	4.8E-05	78
Chlorobenzene	0	112.56	0	130,000	425,000	0	9.66E-05	0	613200	306600		5.0E-02	2080	35		0	
Chloroform	10.46	119.39	51	130,000	425,000	15.62	9.66E-05	0.0015	613200	306600	2.3E-05	9.8E-02	2080	35	4.12E-09	3.66E-06	22
1,1-Dichloroethene**	0	96.95	0	130,000	425,000	0	9.66E-05	0	613200	306600		2.0E-01	2080	35		0	
1,2-Dichloroethane	0	98.97	0	130,000	425,000	0	9.66E-05	0	613200	306600	2.6E-05	2.4E+00	2080	35	0	0	0
Methylene Chloride	1.99	84.94	7	130,000	425,000	2.11	9.66E-05	0.00020	613200	306600	4.7E-07	1.0E+00	2080	35	1.14E-11	4.85E-08	0.06
1,1,2,2-Tetrachloroethane	0	167.86	0	130,000	425,000	0	9.66E-05	0	613200	306600	5.8E-05		2080	35	0		0
Toluene	0.01	92.13	0.038	130,000	425,000	0.012	9.66E-05	0.0000011	613200	306600		5.0E+00	2080	35		5.29E-11	
1,1,1-Trichloroethane	17.56	133.42	96	130,000	425,000	29.31	9.66E-05	0.0028	613200	306600		5.0E+00	2080	35		1.34E-07	
														Cumulative	**1.9E-08**	**3.8E-06**	100

* ADF was calculated at the point of maximum impact in the Livingstone Ridge Alottment, assuming vertical vent orientation, 50 ft additional stack height, and vent usage of 20% vents 1 & 2, 80% highest impact of vents 1 & 3 or vents 2 & 3
** USEPA has withdrawn the URF for 1,1-DCE; inhalation evaluated based on non-cancer effects.

Table B-9
Calculation of Risks and Allowable Air Concentrations
Livingston Ridge Ranch Worker Scenario
"Best Case" Approach
Waste Isolation Pilot Plant (WIPP)

"Reverse" Risk Calculations (i.e., Allowable Air Concentrations at E-300 Monitoring Station) Based on Target Risk Levels

equation 7:

$$Risk_{ind} = Risk_{cum} * 0.01 * Percent\ Risk$$

equation 8:

$$R_{con} = \frac{Risk * AT_c}{URF * EF * ED}$$

equation 9:

$$ECS_{act} = \frac{R_{con}}{ADF}$$

equation 10:

$$COC = ECS_{act} * \left(\frac{V_{exhaust\text{-}typ}}{V_{panel}} \right)$$

equation 11:

$$E300 = COC * \left(\frac{24.45}{MW} \right)$$

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based on Original Permit Assumptions

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust\text{-}typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	1.87E-07	613200		1.5E-05		2080	35	0.10	9.80E-05	1069.77	130,000	425,000	3497	153.84	556	165
Chlorobenzene				306600		2.0E-02	2080	35		9.80E-05		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.42E-07	613200		2.3E-05		2080	35	0.089	9.80E-05	905.69	130,000	425,000	2961	119.39	606	180
1,1-Dichloroethene	1.0E-06	2.38E-07	613200		5.0E-05		2080	35	0.040	9.80E-05	408.59	130,000	425,000	1336	96.95	337	100
1,2-Dichloroethane	1.0E-06	5.68E-08	613200		2.6E-05		2080	35	0.018	9.80E-05	187.70	130,000	425,000	614	98.97	152	45
Methylene Chloride	1.0E-06	3.78E-08	613200		4.7E-07		2080	35	0.68	9.80E-05	6908.89	130,000	425,000	22587	84.94	6502	1930
1,1,2,2-Tetrachloroethane	1.0E-06	2.39E-07	613200		5.8E-05		2080	35	0.035	9.80E-05	353.72	130,000	425,000	1156	167.86	168	50
Toluene				306600		4.0E-01	2080	35		9.80E-05		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane				306600		7.0E-01	2080	35		9.80E-05		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker set at 1E-5, for residents and ranch workers set at 1E-6

Back-Calculated Concentration of Concern (COC) at E-300 Drift Monitoring Station, Based Re-apportionment of Risk to Reflect Current Conditions, New Toxicity Values, New ADF

Chemical	$Risk_{cum}$ (unitless)**	$Risk_{ind}$ (unitless)	ATc (hours)	ATnc (hours)	URF (m^3/ug)	RfC (mg/m^3)	EF (hrs/year)	ED (years)	Rcon (ug/m^3)	ADF (unitless)	ECS_{act} (ug/m^3)	V_{panel} (ft^3/min)	$V_{exhaust\text{-}typ}$ (ft^3/min)	COC (ug/m^3)	MW (g/mole)	E-300 COC (ppbv)	Current Limits (ppbv)
Carbon Tetrachloride	1.0E-06	7.77E-07	613200	306600	6.0E-06	1.00E-01	2080	35	1.09	9.66E-05	11291.96	130,000	425,000	36916	153.84	5867	165
Chlorobenzene			613200	306600		5.0E-02	2080	35		9.66E-05		130,000	425,000		112.56	*	220
Chloroform	1.0E-06	2.22E-07	613200	306600	2.3E-05	9.8E-02	2080	35	0.081	9.66E-05	843.04	130,000	425,000	2756	119.39	564	180
1,1-Dichloroethene			613200	306600		2.0E-01	2080	35		9.66E-05		130,000	425,000		96.95	*	100
1,2-Dichloroethane	1.0E-06	0	613200	306600	2.6E-05	2.4E+00	2080	35	0	9.66E-05	0	130,000	425,000	0	98.97	0	45
Methylene Chloride***	1.0E-06	6.15E-10	613200	87600	4.7E-07	1.0E+00	2080	35	0.011	9.66E-05	114.11	130,000	425,000	373	84.94	107	1930
1,1,2,2-Tetrachloroethane	1.0E-06	0	613200	306600	5.8E-05		2080	35	0	9.66E-05	0	130,000	425,000	0	167.86	0	50
Toluene			613200	306600		5.0E+00	2080	35		9.66E-05		130,000	425,000		92.13	*	190
1,1,1-Trichloroethane			613200	306600		5.0E+00	2080	35		9.66E-05		130,000	425,000		133.42	*	590

* E-300 COC not calculated for non-carcinogens because these chemicals do not contribute significant hazard. A health-based limit would be orders of magnitude higher than measured concentrations.

** Cumulative Target Risk for all chemicals ($Risk_{cum}$) for surface worker and trainee set at 1E-5, for residents and ranch workers set at 1E-6

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CONF-901105--79

MECHANICAL ANALYSES OF WIPP DISPOSAL ROOMS BACKFILLED WITH EITHER CRUSHED SALT OR CRUSHED SALT-BENTONITE

SAND--90-7086C

DE91 006638

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ABSTRACT

Numerical calculations of disposal room configurations at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, NM are presented. Specifically, the behavior of either crushed salt or a crushed salt-bentonite mixture, when used as a backfill material in disposal rooms, is modeled in conjunction with the creep behavior of the surrounding intact salt. The backfill consolidation model developed at Sandia National Laboratories was implemented into the SPECTROM-32 finite element program. This model includes nonlinear elastic as well as deviatoric and volumetric creep components. Parameters for the models were determined from laboratory tests with deviatoric and hydrostatic loadings. The performance of the intact salt creep model previously implemented into SPECTROM-32 is well documented.

Results from the SPECTROM-32 analyses were compared to a similar study conducted by Sandia National Laboratories using the SANCHO finite element program. The calculated deformations and stresses from the SPECTROM-32 and SANCHO analyses agree reasonably well despite differences in constitutive models and modeling methodology. These results provide estimates of the backfill consolidation through time. The trends in the backfill consolidation can then be used to estimate the permeability of the backfill and subsequent radionuclide transport.

1.0 INTRODUCTION

The U. S. Department of Energy is planning to dispose of transuranic wastes (TRU) at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. The current mission of the WIPP is to provide a research and development facility to demonstrate the safe management, storage, and disposal of TRU wastes generated by U. S. government defense programs. Sandia National Laboratories is conducting procedural and technical activities to assess WIPP compliance with regulatory requirements. Performance of seal, barrier, and backfill materials is being studied as part of these activities. A key candidate component of the room backfill system is crushed salt. Crushed salt is an attractive backfill material because it is readily available from the mining operations, it is compatible with the host rock, and it is expected to reconsolidate into a low permeability mass comparable to the intact salt as a result of the creep closure of the surrounding rock mass. Therefore, an understanding of the mechanical behavior of backfill is important at the WIPP. Optimization of the backfill emplacement is necessary to promote room stability, to enable sufficient backfill consolidation to reduce brine flow and retard the transport of soluble radionuclides, and to maintain sufficient gas permeability to avoid gas pressurization [1].

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The study presented herein was conducted to investigate the consolidation of crushed salt and a crushed salt-bentonite mixture in disposal room configurations at the WIPP. Numerical simulations of the backfill and creeping host rock system to 200 years were performed. The finite element program, SPECTROM-32 [2], was modified [3] to incorporate a crushed salt consolidation model [4]. The model selected for implementation combines nonlinear elastic behavior and volumetric creep consolidation. The creep consolidation model was modified to include a deviatoric component. Results from these analyses are compared to results from similar analyses obtained with the finite element program SANCHO [5]. A notable difference between the two codes is that the SANCHO finite element program is based on finite strain theory and the SPECTROM-32 finite element program is based on infinitesimal or small strain theory.

2.0 PROBLEM DESCRIPTION

2.1 Problem Parameters

The basic problem parameters consist of the room and pillar geometry, depth of the room, mesh refinement of the modeled region, temperature, and boundary conditions (see Figure 2-1). Except for a variation in the mesh refinement, the basic problem parameters in the SPECTROM-32 analyses are identical to the SANCHO analyses. The total strain rates in the crushed salt and the intact salt were assumed to be the sum of elastic and inelastic components as discussed in the next sections. The initial state of stress in the SPECTROM-32 analyses was established by excavating the room instantaneously into an initially lithostatic stress field. Subsequently, the room was assumed to be completely backfilled with either crushed salt or crushed salt-bentonite.

2.2 Backfill Consolidation Model

Development of the creep consolidation constitutive equation used in SPECTROM-32 was guided by general considerations with specific functional forms taken from empirical relations matched to available laboratory data. From the application of thermodynamic concepts, the three-dimensional generalization for creep strain rates is given by [6]. Following this approach, two continuum internal variables were assumed, the average inelastic volumetric strain, $\epsilon^c_{eq_1}$, and the average equivalent inelastic shear strain, $\epsilon^c_{eq_2}$.

$$\dot{\epsilon}^c_{ij} = \dot{\epsilon}^c_{eq_1} \frac{\partial \sigma^I_{eq_1}}{\partial \sigma_{ij}} + \dot{\epsilon}^c_{eq_2} \frac{\partial \sigma^I_{eq_2}}{\partial \sigma_{ij}} \tag{1}$$

For the volumetric portion of Equation 2-1, the invariant strain-rate measure is

$$\dot{\epsilon}^c_{eq_1} = \dot{\epsilon}_v (\sigma_m) \tag{2}$$

The sign convention adopted assumes that tensile stresses and elongation (dilation) are positive. The volumetric strain rate $\dot{\epsilon}^c_v$ is described empirically [4] based on laboratory test data on hydrostatic consolidation of crushed salt as

$$\dot{\epsilon}^c_v = \frac{(1+\epsilon_v)^3}{\rho_0} B_0 \left[1 - e^{-B_1 \sigma_m}\right] e^{\frac{A \epsilon_v}{1+\epsilon_v}} \tag{3}$$

where

ϵ_v = ϵ_{kk}, total volumetric strain

ϵ_v^c = ϵ_{kk}^c, volumetric creep strain

σ_m = $\frac{\sigma_{kk}}{3}$, mean stress

ρ_0 = initial density

B_0, B_1, A = material constants.

The invariant stress measure is given by

$$\sigma_{cq_1}^I = \sigma_m \tag{4}$$

For the deviatoric portion of Equation 2-1, the invariant strain-rate measure is taken to be

$$\dot{\epsilon}_{cq_2}^c = \beta \dot{\epsilon}_{cq_1}^c = \beta \dot{\epsilon}_v (\sigma_m) \tag{5}$$

and the invariant stress is assumed to be a scalar multiple of the octahedral shear stress

$$\sigma_{cq_2}^I = \sigma_e = \sqrt{3J_2} \tag{6}$$

where J_2 is the second invariant of the stress deviator ($J_2 = \frac{1}{2} S_{ij} S_{ij}$). Substituting into Equation 2-1 and performing the required differentiation gives

$$\dot{\epsilon}_{ij}^c = \dot{\epsilon}_v^c \frac{\delta_{ij}}{3} + \beta \dot{\epsilon}_v^c \frac{3 S_{ij}}{2\sigma_e} \tag{7}$$

β is selected such that in a uniaxial test the lateral components of $\dot{\epsilon}_{ij}^c$ equal zero. This requires that $\beta = -\frac{2}{3}$. After substituting for $\dot{\epsilon}_v^c$ in Equation 2-7, the strain rate components are given by

$$\dot{\epsilon}_{ij}^c = \frac{(1+\epsilon_v)^2}{\rho_0} B_0 \left[1 - e^{-B_1 \sigma_m}\right] e^{\frac{A\rho_0}{1+\epsilon_v}} \left\{\frac{\delta_{ij}}{3} - \frac{S_{ij}}{\sigma_e}\right\} \tag{8}$$

Obviously, this creep consolidation equation will allow unlimited consolidation. Therefore, a cap is introduced that eliminates further consolidation when the intact material density ρ_∞ is reached. As an option, the crushed salt material may behave either as a nonlinear elastic material or creeping intact salt following complete consolidation.

2.3 Intact Salt Constitutive Model

A recently proposed WIPP reference constitutive relation for intact salt creep [7] and the previous WIPP reference law [8] were used in the calculations. The WIPP reference elastic-secondary creep model [8], along with a Mises-type flow potential, represented the mechanical behavior of the intact salt in the SANCHO analyses. The SPECTROM-32 analyses used the Munson-Dawson constitutive relation [7] for intact salt creep along with a Tresca flow potential. This combination was recommended [7] because of favorable comparisons with WIPP field tests in a previous study [9].

2.4 Elastic Model

The elastic models used in the SPECTROM-32 and SANCHO analyses were identical. The crushed salt was described using a nonlinear elastic model [3, 4] and the intact salt was assumed to be linear elastic. However, corresponding elastic material constants for crushed salt and intact salt used in the SANCHO analyses were reduced by a factor of 12.5 [5]. This reduction in elastic properties stems from a recommendation [10] that is based on the usage of the early version of the reference constitutive relation for salt creep [7] that produced good agreement between calculated and measured deformations of WIPP field experiments. Since test data do not exist for crushed salt-bentonite mixtures, its elastic properties were assumed to be identical to those of crushed salt. Specific values for the elastic constants may be found in references 3, 4, and 11.

3.0 RESULTS

Results from the SPECTROM-32 analyses of the disposal room backfilled with either crushed salt or crushed salt-bentonite are compared to previously reported results using the SANCHO finite element program [5]. Results from the SANCHO analyses were plotted by digitizing the graphical results.

3.1 Room Closures

Figure 3-1 compares the SPECTROM-32 and SANCHO vertical and horizontal closures along the room periphery corresponding to the roof/floor centerline and the rib midheight, respectively. During the initial 15 years, the closures predicted by SPECTROM-32 are greater and, thereafter, are less than the closures predicted by SANCHO. The closure curves from both analyses for crushed salt backfill are nearly flat after the density of the crushed salt reaches the density of the intact salt. This behavior is not exhibited for the crushed salt-bentonite analyses since full compaction is not reached. Generally, agreement in the calculated deformations from the SPECTROM-32 and SANCHO analyses is within 10 percent (except when the crushed salt becomes fully consolidated) despite distinct differences in the constitutive relations, mesh refinement, material constants, and theoretical basis (finite versus small strain).

3.2 Average Void Fractions

Figure 3-2 provides the time history of the average void fraction remaining in the backfill. The average void fraction [5] is essentially a measure of porosity in the backfill. The trend and magnitude of the average void fractions from both codes in the two analyses agree closely during the initial 5 years. Thereafter, the rate of consolidation is considerably slower in both SANCHO analyses. The crushed salt backfill consolidates completely in 25 years in the SPECTROM-32 analyses; whereas, the corresponding consolidation takes 65 years in the SANCHO analyses. Full consolidation of the crushed salt-bentonite backfill is not reached in either the SPECTROM-32 or SANCHO analyses. The average void fraction remaining in the crushed salt-bentonite backfill after 200 years of simulation is 5.0 and 7.5 percent for SPECTROM-32 and SANCHO analyses, respectively.

3.3 Mean Stresses

Comparison of mean stress (pressure) is of interest since mean stress is the driving force in the backfill consolidation process. Figure 3-3 shows the mean stress history corresponding to the center of the disposal room. During the initial 5 years, pressure rise in the crushed salt is negligible throughout the disposal room. Over the next 50 to 75 years, the magnitude of the mean stress increases more rapidly in the SPECTROM-32 analyses than the SANCHO analyses. This response is indicative of the deformational behavior plotted in Figures 3-1 and 3-2 which show that closure (consolidation) occurs more rapidly in the SPECTROM-32 analyses. The cusps appearing in Figure 3-3 occur after full consolidation of the crushed salt. At this point, the consolidation process ceases. Cusps do not appear in the crushed salt/bentonite curves because full consolidation is not reached within the 200 year simulation period as shown by Figure 3-2. Mean stresses determined in the SPECTROM-32 analyses are 2 to 4 time greater than the mean stresses determined in the SANCHO analyses during the initial 80 years and only 1 to 1.5 greater in the final 100 years. This difference can be attributed to more than an order of magnitude difference in the elastic constants used in the two codes with the SPECTROM-32 constants being the greater of the two. Despite some disparity in magnitude, the trends of the mean stress determined from the two analyses compare favorably. Both analyses of crushed salt backfill show a significant increase in mean stress once full compaction is reached.

4.0 CONCLUSIONS

Based on the comparison of results from the SPECTROM-32 and SANCHO analyses of a disposal room backfilled with crushed salt and crushed salt-bentonite, void fractions in the backfill material are shown to decay significantly such that the backfill becomes an integral part of the sealing system. The creep consolidation model provides a method to estimate the long-term behavior of backfill materials in a disposal room. The calculated deformations and stresses from the two analyses agree reasonably well despite differences in methodology such as the consolidation model, intact salt creep model, strain theory, and material properties. The volumetric behavior of the backfill is based on hydrostatic laboratory tests, but the deviatoric response included is hypothetical. Deviatoric testing of crushed salt specimens is presently underway. Data obtained from these tests will be used to refine the deviatoric response included in the crushed salt constitutive model.

DISCLAIMER

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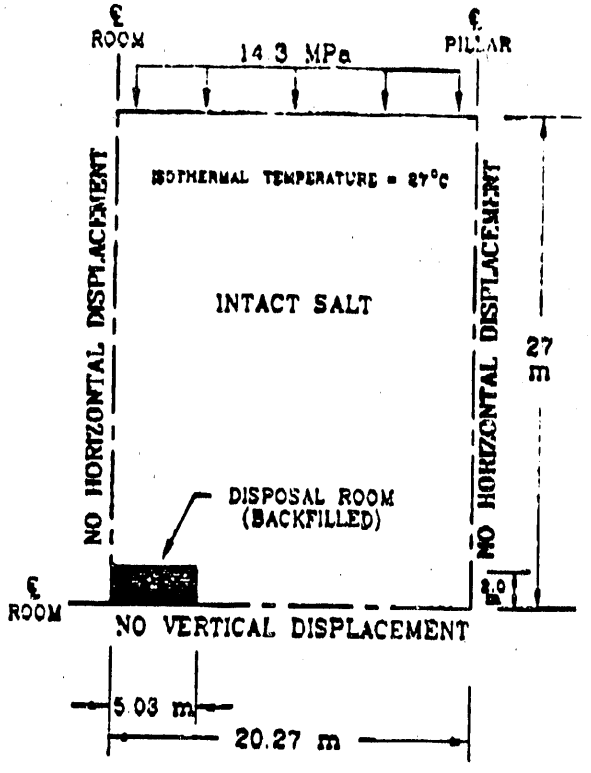

Figure 2-1. Description of Basic Problem Parameters.

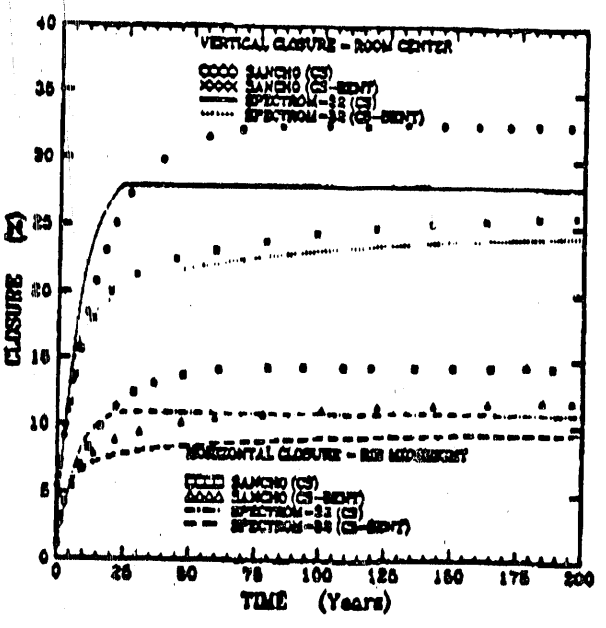

Figure 3-1. Vertical and Horizontal Room Closures for a Backfilled Disposal Room.

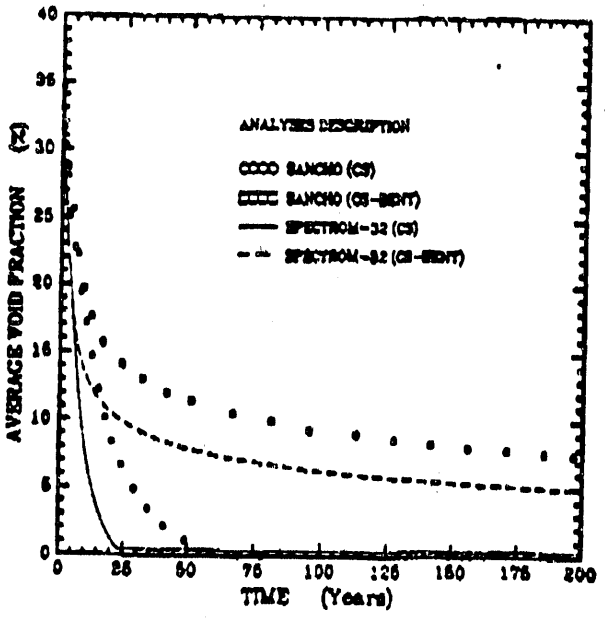

Figure 3-2. Average Void Fraction for a Backfilled Disposal Room.

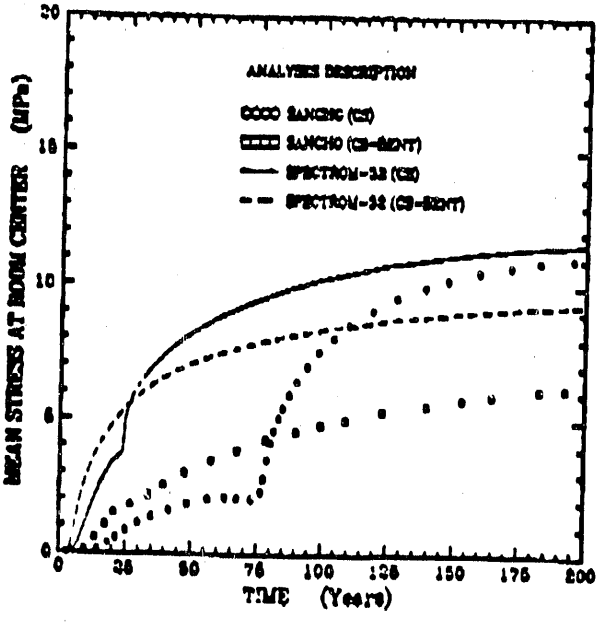

Figure 3-3. Mean Stress (Pressure) at the Center of a Backfilled Disposal Room.

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July 26, 2006

Mr. D. Mercer, Physical Scientist
Carlsbad Field Office
U.S. Department of Energy
P.O. Box 3090
Carlsbad, NM 88221-3090

Subject: ESTIMATION OF HYDROGEN GENERATION RATES FROM RADIOLYSIS IN WIPP PANELS

Dear Mr. Mercer:

Based on my experience in analyzing hydrogen gas generation from radiolysis in transuranic (TRU) waste transportation, Mr. Roger Nelson of DOE-CBFO requested my estimation of radiolytic hydrogen gas generation rates in WIPP repository panels. This letter provides a hydrogen gas generation rate estimate for a representative WIPP panel, discusses the methodology used to obtain that estimate, and discusses potential impacts of flammability from this radiolytic generation of hydrogen.

Summary

Based on an analysis of the Panel 3 inventory, the hydrogen gas generated due to radiolysis from a WIPP panel filled with emplaced contact-handled (CH)-TRU waste can be conservatively estimated to be **4.497E-05** moles per second. An average concentration of 5% (by volume) hydrogen in a filled WIPP panel is reached only after approximately 20 years. While 5% is the lower flammability limit for hydrogen, much higher concentrations, and therefore much longer time periods, are associated with any significant impacts of a potential deflagration event due to the radiolytic generation of hydrogen.

Purpose and Scope

TRU waste disposed of in the WIPP panels has the potential to generate hydrogen from radiolysis. The purpose of this letter is to provide an estimate of the hydrogen gas generation rate in a representative WIPP panel from radiolysis. The Panel 3 inventory (Reference 1) is used as the basis for the gas generation profile from a panel.

Methodology for Estimation of Hydrogen Gas Generation Rate in a WIPP Panel

At the present time, Panels 1 and 2 have been filled with waste and closed, with Panel 3 partially full and continuing to receive waste. For the purpose of this study, it is assumed that Panel 3 is representative of a typical panel at the WIPP site. This is a reasonable assumption given that the current inventory profile with Idaho National Laboratory (INL) being the dominant inventory contributor is likely to be representative of future panels (with INL having the largest remaining fraction of the waste inventory slated for disposal at WIPP). Panels 1 and 2 represent early waste disposal operations and the clean up of the Rocky Flats Environmental Technology Site. Data for the Panel 3 inventory were obtained from the WIPP Waste Information System (WWIS) (Reference 1).

The parameters of interest in estimating the radiolytic hydrogen gas generation rate per WIPP panel are as follows:

- Number of containers by waste material type: The waste material type is a classification used by the WIPP transportation system based on the gas generation potential of the waste (Reference 2). Examples of waste material types are Waste Material Type I.1, Solidified Inorganics (where the potential for hydrogen generation is from the radiolysis of water), and Waste Material Type III.1, Solid Organics (where the potential for hydrogen generation is from radiolysis of the plastic and other organic materials). The radiolytic potential for hydrogen generation is quantified by a "G value" for each waste material type (Reference 3). The hydrogen G value is defined as the number of molecules of hydrogen generated per 100 electron volts (eV) of energy absorbed.

- Decay heat values of the containers: The decay heat values are reported per container and include the error associated with the method used to determine the decay heat value. This parameter, along with the G value, can be used to estimate the hydrogen gas generation rate from the panel.

- Hydrogen gas generation rates of the containers: Hydrogen gas concentrations in the headspace of the containers are available for those containers that were shipped using the headspace hydrogen measurement data. These containers are a subset of the entire Panel 3 inventory (measurement is an option if transportation decay heat limits based on theoretical bounding G values are exceeded). While G values for the different waste materials types exist from the literature based on bounding materials (Reference 3), the headspace measurement data provides a more realistic estimate of the potential hydrogen gas generation from a container. Measured headspace hydrogen data and corresponding hydrogen generation rates and their decay heat values can be used to determine "effective G values" for the different waste material types, which, in turn, can be used to estimate a more realistic hydrogen gas generation rate from the panel.

The governing equation for determining the radiolytic gas generation rate in moles/second (Cg) is as follows (Reference 3):

Equation 1

$$Cg = W \times G \times C$$

where,

W	=	Total decay heat (watts)
G	=	Number of molecules of hydrogen gas produced per 100 eV of energy absorbed
C	=	Conversion constant
	=	(1 joule/W-sec) x (1E7 erg/joule) x (1 eV/1.6E-12 erg) x (1 g-mole/6.02E23 molecules)
	=	1.04E-5 (g-mole)(eV)/(molecule)(W-sec)
	=	1.04E-7 (g-mole)(100 eV)/(molecule)(W-sec).

For waste material types with containers with measurement data, the decay heat values of the containers were summed along with the hydrogen generation rates, and Equation 1 was used to determine the effective G values. For waste materials types without any containers with measurement data, mean G values from the governing WIPP transportation documents were used (Reference 2). The effective G values were then applied by waste material type to the entire Panel 3 inventory to estimate the hydrogen generation rate from the Panel.

These effective G values are more representative of hydrogen generation from CH-TRU waste, as they are based on actual measurements. The theoretical G values of pure materials (like polyethylene) are not representative of the hydrogen gas generated in CH-TRU waste containers, as the waste is a mixture of different materials and a portion of the energy is likely deposited in materials with less gas generation potential (some energy may be deposited in inorganic materials that do not generate any hydrogen). As discussed later, effective G values also are not constant in time and most likely decrease asymptotically as the matrix is depleted.

Panel 3 has 319 containers of Waste Type IV (Solidified Organic material) that do not have a bounding G value and were individually tested to determine the hydrogen generation rate (Reference 2). These hydrogen generation rates are determined at a temperature of 135°F to simulate worst-case transportation conditions (Reference 2). Evidence from previous room temperature testing at the sites shows that hydrogen generation rates are much smaller at lower temperatures (Reference 4). Because the expected temperature in the repository is well below the temperature at which the hydrogen generation rates were determined for these containers, the tested rates were reduced by a factor of two to estimate the hydrogen generation rates from these Waste Type IV containers in the panels.

Finally, the total hydrogen generation rate determined for the containers currently in Panel 3 was scaled up to estimate the rate when the panel is filled with a similar distribution of containers. The scaling factor was based on the percent fill level for the panel in terms of the number of stacks filled (as of June 19, 2006, the time of the data analysis) and the remaining number of stacks available (~63% of the panel was filled at the time of data analysis) (Reference 5).

Results and Discussion

The results of this analysis for the hydrogen gas generation rate for Panel 3 are provided in Table 1. As shown, the scaled hydrogen gas generation rate for the entire panel is **4.497E-05** moles per second. Assuming a full panel inventory of 80,000 55-gallon drum equivalents of waste, this translates to a rate of 0.397 liters of hydrogen per drum per year.

Table 1. Estimate of Hydrogen Gas Generation Rate for a Representative WIPP Panel

Waste Material Type	No. Containers	Inventory (watts)	G Value[a]	Constant	Hydrogen Gas Generation Rate (moles/second)
I.1	3,942	216.522	0.307	1.04E-07	6.913E-06
I.2	4,333	414.408	0.122	1.04E-07	5.258E-06
I.3	0	0.000	0.4	1.04E-07	0.000E+00
II.1	412	59.043	0.055	1.04E-07	3.377E-07
II.2	228	139.822	0	1.04E-07	0.000E+00
II.3	0	0.000	0.08	1.04E-07	0.000E+00
III.1[b]	17,231	1921.012	0.066	1.04E-07	1.319E-05
III.2	107	66.375	0.044	1.04E-07	3.037E-07
III.3	3	4.622	0.044	1.04E-07	2.115E-08
IV.1	319				2.440E-06
				Total	2.846E-05
				Gas generation rate scaled to fill panel	**4.497E-05**

[a] Measurement data used to estimate G values for Waste Material Types I.1, I.2, II.1, III.1, and III.3. Mean values from transportation analysis (Reference 2) used to derive G values for Waste Material Types I.3, II.2, II.3, and III.2.

[b] G value calculated using data for containers that met dose criteria of >0.012 watt*year (Reference 2). A large data set was available and this data is representative of the larger time frames expected in the repository.

To determine the hydrogen concentration in a typical panel as a function of time, an estimate of the overall void volume in a panel is needed. This void volume consists of the following components:

- Void volume in waste containers: Characterization data indicate that CH-TRU waste containers have large void volumes. A typical combustible debris waste 55-gallon drum has been estimated to have a void volume of 155.4 liters or ~75% (Reference 6). For this analysis, conservatively assuming an average of 50% void volume in the containers, the available void volume of 80,000 55-gallon drums = 8.32E+06 liters.

- Available void volume in MgO sacks: In a panel, each stack comprised of three layers of seven-packs is covered with an approximately 24-inch high sack of MgO with a diameter of approximately 72 inches. Assuming 3,630 stacks per panel (Reference 5), the volume occupied by the MgO is roughly 5.81E+06 liters. Conservatively assuming a porosity of 0.3 for the MgO, 0.3 x 5.81E+06 or 1.74E+06 liters of void space is available for hydrogen accumulation.

- Available void volume in the space above the MgO sacks: After the MgO sacks are emplaced on top of the stacks, there is approximately 18 inches of open space above the MgO sacks, which provides an additional void volume in the 33-foot-wide by

300-foot-long rooms. This volume can be calculated as 33' x 300' x 1.5' = 14,850 ft^3 or 4.21E+05 liters per room or 2.94E+06 liters per panel (seven rooms per panel).

Therefore, the total available void volume for gas accumulation is 8.32E+06 + 1.74E+06 + 2.94E+06 = 1.30E+07 liters. Five percent of this volume = 6.5E+05 liters. At a generation rate of 0.397 liters/drum/year, 3.18E+04 liters of hydrogen are generated from the 80,000 drums in a panel in one year. Therefore, 6.5E+05/3.18E+04 or more than 20 years will be needed to reach an average concentration of 5% hydrogen in a panel.

In terms of the potential impacts of flammability from this radiolytic generation of hydrogen, several factors need to be considered:

- The G values used for this analysis, while based on measurement data, are still conservative, as the hydrogen generation rates are assumed to be constant over long time periods in the repository. In reality, as the matrix is depleted, the G values and hydrogen generation rates are expected to decrease asymptotically to very low values. Figure 1 (Reference 7) presents this concept based on theoretical analysis that supports the conclusion that gas generation decreases with increasing dose.

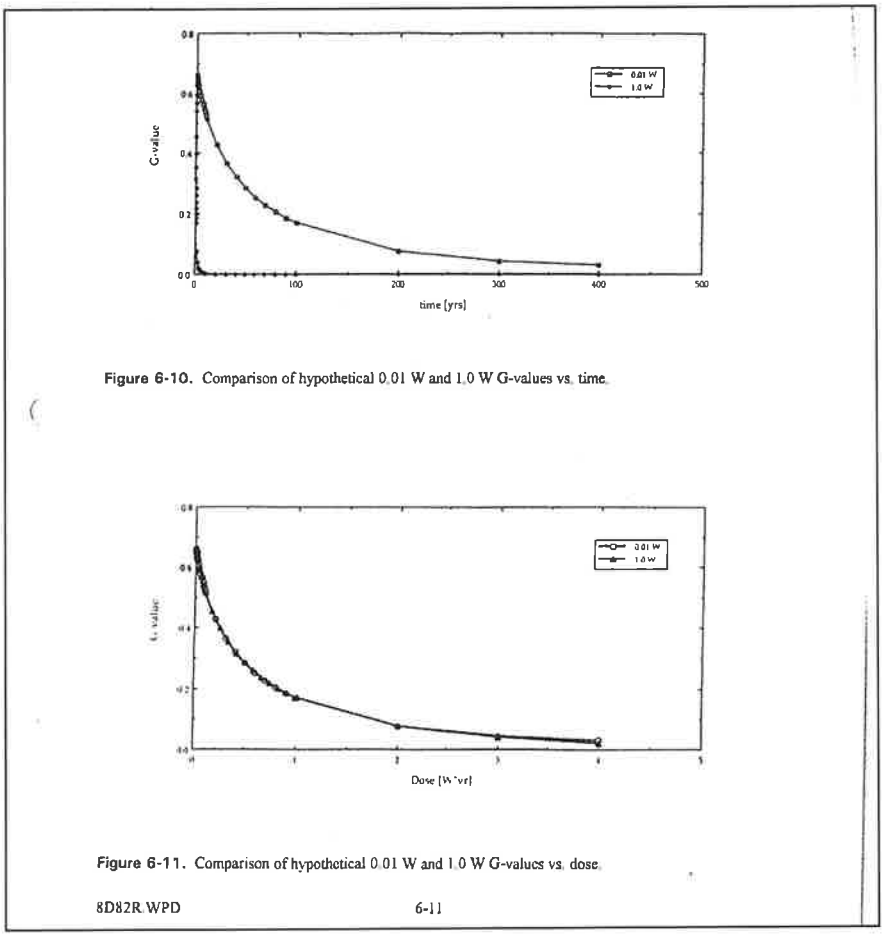


Figure 6-10. Comparison of hypothetical 0.01 W and 1.0 W G-values vs. time.

Figure 6-11. Comparison of hypothetical 0.01 W and 1.0 W G-values vs. dose.

8D82R.WPD 6-11

Figure 1. Theoretical analysis of gas generation as a function of time and dose.

- While 5% is the lower flammability limit for hydrogen, testing at the Savannah River Site (Reference 8) indicates that greater than 15% hydrogen is necessary even for lid ejection from a 55-gallon drum, with no catastrophic failure of the drums observed. These tests were also performed with empty drums. In actual waste drums, the presence of waste tends to reduce the pressure and consequence of a hydrogen deflagration. Given the timeframe to reach 5% hydrogen (20+ years), much longer timeframes will be needed for the radiolytic hydrogen to reach higher concentrations and cause a potentially significant deflagration event in the underground WIPP panels.

- Characterization data (Reference 9) indicate that hydrogen generation in typical combustible debris is often accompanied by the consumption of oxygen. Even if an ignition source is assumed to be present, it is unlikely that the hydrogen and oxygen concentrations in the WIPP panels will lead to ideal conditions with respect to the impacts of a deflagration event.

Conclusions

Hydrogen generation due to radiolysis in the WIPP panels is expected to be a slow process, with an average concentration of 5% hydrogen in the panel reached only after more than 20 years. The hydrogen generation rates used in this analysis are conservative and are expected to decrease over time during the disposal period. Experimental data indicates that hydrogen concentrations well above 5% and, therefore, much longer time periods are needed for a potential deflagration event of any significant impact in a WIPP panel.

References

1. E-mail from K. Richie to M. Devarakonda, subject: Panel 3 w/gas gen, dated June 27, 2006.
2. U.S. Department of Energy, May 2005, "Contact-Handled Transuranic Waste Authorized Methods for Payload Control (CH-TRAMPAC)," Revision 2, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.
3. U.S. Department of Energy, July 2005, Appendix 3.1, "Radiolytic G Values for Waste Materials," CH-TRU Payload Appendices, Revision 1, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.
4. Personal communication between M. Devarakonda (WTS) and M. Rivera (Aspen Resources), subject: Gas generation testing at Rocky Flats Environmental Technology Site, July 13, 2006.
5. E-mail from B. Zimmerly to M. Devarakonda, subject: Panel 3, dated June 23, 2006.
6. U.S. Department of Energy, July 2005, Appendix 3.7, "Aspiration of Unvented Payload Containers of CH-TRU Waste," CH-TRU Payload Appendices, Revision 1, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.
7. Idaho National Engineering and Environmental Laboratory, 1990, "TRUPACT-II Matrix Depletion Program Final Report," *INEL/EXT-98-00987*, Rev. 1, prepared for the U.S. Department of Energy, Idaho Operations Office, Idaho Falls, Idaho.
8. Dykes, K. L., and M. L. Meyer, 1990, "TRU Drum Hydrogen Explosion Tests," WSRC-TR-90-165, Westinghouse Savannah River Company, Aiken, South Carolina.

9. Clements, T. L., Jr., and D. E. Kudera, 1985, "TRU Waste Sampling Program," Vol. 1, EGG-WM-6503, EG&G Idaho, Inc., Idaho Falls, Idaho.

If you have any questions or comments, please feel free to contact me at (505) 878-1344.

Sincerely,

(Original signature on file)

M. Devarakonda, Manager
Technical Support
Retrieval, Characterization and Transportation

DVS:clm

cc: R. Nelson, CBFO ED

Selected Credentials of Author

- Bachelor of Technology, Chemical Engineering, Indian Institute of Technology, Madras, India; 1984
- Ph.D., Environmental Engineering (Department of Civil Engineering), University of Notre Dame, Notre Dame, Indiana; 1988
- 18 years of experience in radioactive waste management, safety analysis, and gas generation analysis in radioactive waste transport
- Committee Member, ANSI 14.32, Gas Generation in Packages Used for Storage or Transportation of Radioactive Materials (currently inactive)
- Subject Matter Expert, Pu-238 Decision Analysis, Sandia National Laboratories (1998)
- Panel Member and Invited Speaker, Packaging and Transportation Symposium 2000, Los Alamos National Laboratory, Santa Fe, New Mexico (November 2000)
- Program Advisory Committee, Waste Management Symposium (2001 – present)
- Expert witness, U.S. Department of Energy, State of New Mexico (2002)
- Technical Program Chair, International Conference on Environmental Remediation and Waste Management (2006 - present)

Attachment E

References

Brush, L.H. 1990. *Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant.* SAND90-0266.

Brush, L.H. 1995. "Systems Prioritization Method – Iteration 2 Baseline Position Paper: Gas Generation in the Waste Isolation Pilot Plant." March 17, 1995. Albuquerque, NM: Sandia National Laboratories. ERMS 228740.

Wang, Y. and L.H. Brush. 1996. "Estimates of Gas-Generation Parameters for the Long-Term WIPP Performance Assessment." Memorandum to M.S. Tierney, January 26, 1996. Sandia National Laboratories. Albuquerque, NM. ERMS 231943.

CHAMPS Work Order

Work Order: 1107579 **Type:** Modification **State:** 10 - Created

Description: 74B610 FAB AND INSTALL BULKHEAD AT P6 RM7 S2750/W1070

Equipment I.D.: 74-B-610 **Room:** S2750/W1070 **Management Level:** ML-1

Equipment Name: BULKHEAD, PANEL 6 RM 7 INTAKE BARRICADE

Function Class: SS **System:** VU03

Location: 534

Dept: UGOPS **USQ Screening or Evaluation No.** S11-0607 (N/A if not Required)

Priority: 4A

Planner: FARNSWORTH, JILL **Assign to:** FARNSWORTH, JILL

Account: W121010101 **Parent:**

INCIDENT ENERGY N/A	ECO NO CE/DATE ECO 12897 Jill Farnsworth 7-28-11	Safety/Date Howard Brown 8/3/11
ALARA/Date Richard Hayes 8/4/11	S/U. Eng/Date N/A	QA/DATE M Davis 8/4/11
RWP NO. N/A CH RAD CON/DATE	NEPA/DATE EXCLUDED; REV.12 ATTACHMENT 1, F	Planner/DATE Jill Farnsworth 7/28/11
FPE/EMM/DATE N/A	CRAFT/DATE Dan Calderon 8/10/11	CRAFT/DATE [illegible] 8-10-11
FWM/DATE [illegible] 8-10-11	WGM/DATE Dave Bromling 8/4/11	WGM/DATE N/A
COM Review/DATE: M Mbuk 8/10/11		

PROPOSED LOCKOUT/TAGOUT [ ]COM LO/TO Tag Number ~~H-WF-[illegible]~~ [ ]PLD LOTO [✓]N/A

PROPOSED PLD LOCKOUT/TAGOUT LOCATION: _____ (N/A for COM Lockout/Tagout)

if PLD, Lockout/Tagout performed at recommended Location _____ / _____ **Person performing PLD** **Date**

COM Release/Date Jim Hall 11/08/11	WGM Release/Date [illegible] 8-17-11
Work Authorized By: Signature Date: Jim Hall 08/17/11	QA Complete Date: M Davis 12/12/11
Work Area Inspection Completed Craft Date: [illegible] 11/9/11	Task Completed: Craft Date: Dan Calderon 11/9/11
FWM Work Comp/Date [illegible] 11-9-11	COM retest Comp/Date N/A
COM Work Complete/Date [illegible] 12/01/11	CE ECO Verified/Date ECO 12897 Jill Farnsworth 12-7-11

Overview of Work Performed: (Problems, solutions, retest requirements, retest results, parts used and cost)

FAB and install Bulkhead at P6 Rm 7 S2750/W1070

RECORDS

Task Preview Performed (sign and Date) See Step 7.1.2

COM, if cancelled, Sign/Date N/A	Planner/Date Jill Farnsworth 12-12-11

ACTION REQUEST

Section 1	ORIGINATOR			1107579
Name: Jill Farnsworth	Phone: 8212	Mail Stop:		Date: 7/20/2011
Equip. No. 74-B-610	Equip. Name:	BULKHEAD, PANEL 6 RM 7 INTAKE BARRICADE	System:	VU03

Description of problem:

Fabricate & Install bulkhead 74-B-610 at the P6RM7 intake point once RM7 is full of CH waste. (S2750/W1070)

Functional Classification: [ ] BOP [ ] SC [X] SS [ ] ITS

Status: [ ] In-Service [X] Out-of-Service [ ] Tagged Out

Compensatory Measure:

N/A

RCRA Inspection Item: [ ] CAS/CAMP [ ]

Section 2 **POD**

Work Order [✓] Nonconformance Condition - NCR Required [ ] Request for Evaluation (RFE) [ ]

Harry Stewart — POD Chairperson

7-21-11 — Date

RFE Assigned To:

Section 3 **Evaluator**

N/A [✓] Normal Wear and Tear (Provide justification) [ ] Nonconforming Condition [ ] Pages(s) Attached [ ]

Evaluator Print/Sign

Date

Section 4 **WORK CONTROL**

PRIORITY 4A

Need Date:

Harry Stewart 7-21-11

WCC Date

Section 5 **MODIFICATION APPROVAL**

TERRY PATTERSON PER TELE TROY PARKER 7-21-11

Maintenance Manager Chairperson Date

Section 6 **WORK GROUP**

Scope Title: [2] 74B610 FAB + Install Bulkhead at P6RM7 S2750/W1070

Work Group:	Craft Code:	Cost Account: N12101

Jill Farnsworth — Assigned Engineer

Field Work Manager: 7-21-11 — Date

Section 7 **WORK GROUP MANAGER**

Work Method: (A,C,E,F,M,MM)	Document Type (1,2,3)	Work Group Mananger: Date
M	3	7-21-11

Comments/Partial Release

COMMENTS

WORK ORDER NUMBER: 1107579 DATE: 08/17/11

COMMENTS PROVIDED BY: Jim Hollen UFO
Name/Organization

NOTE: Provide corrective actions necessary to incorporate comment in "Comments" section.

- ☐ Work instructions not clear. _____
- ☐ Requires additional work instructions. _____
- ☐ Insufficient retest instructions/requirements. _____
- ☐ Requires additional approvals. _____
- ☐ Contact Operations for tag-out at Step _____ or Time _____
- ☐ Not released. State reason: _____
- ☐ Outage required for work. _____
- ☐ Package should be worked with the following: _____
- ☐ Reschedule on: _____
- ☐ Permit required -- Contact: _____
- ☐ Other/Comments:

PARTIAL RELEASE

Instructions for Partial Release: Work through Step 8.1.6

Cognizant Operation Manager _____ Date 08/17/11

Work Group Manager _____ Date 8-17-11

WIPP Plant Work Suspension

1. Work Order Number: 1107579 M Date 8-21-11
2. Reason for Suspension:
   Bulkhead FAB and staged.
3. Steps of work instruction completed: 8.1.6
4. Work Group Manager [signature] Date 8-21-11
5. System and Component status

   OPERATIONS: [signature] Date 11-07-11
6. TO/LO N/A
7. Operations Release [signature] Date 11/07/11
8. Work Group Manager [signature] Date 11-7-11

W.O. NUMBER 1107579M
74B610
FAB & INSTALL BULKHEAD AT P6RM7 INTAKE
S2750/W1070

1.0 INTRODUCTION....2
2.0 REFERENCES....2
3.0 MATERIAL LIST....3
4.0 EQUIPMENT LIST....3
5.0 PRECAUTIONS....4
6.0 LIMITATIONS....4
7.0 PREREQUISITES....5
8.0 PERFORMANCE....6

1.0 INTRODUCTION

Specifically, this work will accomplish the following:

- Fabricate bulkhead sections for a 30' wide x 13.5' tall bulkhead
- Stage bulkhead sections as directed by the UMM
- Install bulkhead sections at the P6RM7 intake point, just to the east of the chain link & brattice barricade once the room is full of CH waste.
- Seal the bulkhead and flashing
- Clean up the work area
- Tag the bulkhead

2.0 REFERENCES

BASELINE (DEVELOPMENTAL)

WP 10-WC3011	Work Control Process
WP 12-HP3600	Radiological Work Permits
WP 12 IS.01	Industrial Safety Program
WP 12 IS.01-1	Industrial Safety Program – Barricades and Barriers
WP 13-1	Quality Assurance Program Description
DOE/WIPP-07-3372	Waste Isolation Pilot Plant Documented Safety Analysis
DOE/WIPP-07-3373	Waste Isolation Pilot Plant Technical Safety Requirements
WP12-FP.01	Fire Protection Program
WIPP-023	Fire Hazards Analysis For the Waste Isolation Pilot Plant Carlsbad, New Mexico
30 CFR Part 57	Federal Mine Safety and Health Regulations for Metal and Non-metal Mines
ECO 12897	Fab & Install 74-B-610 at the P6RM7 intake point once P6RM7 is full of CH waste

REFERENCED (REQUIRED ON-HAND)

MSDS for FlexGrip 550 **(Attachment #4)**
MSDS for DAP Silicone Sealant **(Attachment #5)**
MSDS for GE Silicone GE012A **(Attachment #6)**
12-FP3002 Hot Work Permit (if welding outside of a designated hot work area)

3.0 MATERIAL LIST

ITEM	MATERIAL DESCRIPTION	QTY	UNIT	PR / WHSE STOCK NO.
1	Bulkhead Steel – See Cut Sheet, Attachment #1	N/A	N/A	UG
2	FlexGrip 550	1	Ea.	UG
3	Hilti Spads	As Needed	Ea.	UG
4	Hilti Bolts	As Needed	Ea.	UG
5	Sheet Metal Screws	As Needed	Ea.	UG
6	Brattice Cloth	100	Ft	UG
7	Silicone Sealant	As Needed	Tube	X-51-04105
8	RV Putty Tape	As Needed	Ft.	UG

4.0 EQUIPMENT LIST

PERSONAL PROTECTIVE EQUIPMENT AND SPECIAL TOOLS

DESCRIPTION	USED AT STEP
GLOVES – LEATHER	[ ] 8.1.3
FALL PROTECTION FULL BODY HARNESS	[ ] 8.2.6
FALL PROTECTION TIE-OFF	[ ] 8.2.6
GENERAL - SAFETY GLASSES W/ SIDE SHIELDS	[ ] 8.2.10

Paint Brush
Caulking Gun
Putty Knife
Tape Measure
Hilti Drill
Hilti Gun
Various Hand Tools
Various Shop Tools
Getman Lift Truck (or other suitable man lift device)
Fork Lift

5.0 PRECAUTIONS

The JOB HAZARDS CHECKLIST indicates types of hazards that may be present during the performance of this work. See the indicated section for precautions and mitigating actions.

JOB HAZARDS CHECKLIST

HAZARD	MITIGATED AT SECTION
ROTATING EQUIPMENT PINCH POINT HAZARD	[ ] 8.1.1
HOT WORK ACTIVITY HAZARD	[ ] 8.1.2
SHARP OBJECT HAZARD	[ ] 8.1.3
POTENTIAL RADIOLOGICAL HAZARD	[ ] 8.2.4
HEIGHT HAZARD	[ ] 8.2.6
ADHESIVES & SEALANTS CHEMICAL HAZARD	[ ] 8.2.10

6.0 LIMITATIONS

[ ] 6.1. HOLD AND WITNESS POINTS

NONE

[ ] 6.2. TAGOUT/LOCKOUT

NONE

[ ] 6.3. OTHER LIMITATIONS

- Any employee who has a concern for employee safety, the safety of the environment, or the quality of the activity has the responsibility and authority to suspend the performance of that activity.
- Work shall be stopped when instructions cannot be performed as written.
- Brackets at the beginning of steps are optional place-keeping aids, and may be checked off as work progresses.
- All personnel affixing initials to these work instructions shall provide the information listed in the PERSONNEL DATA TABLE.
- The Technical Safety Requirements (TSRs) Manual contains Limiting Conditions for Operation (LCOs) and Specific Administrative Controls(SACs) which provide specific preventative or mitigative limits and

required actions for identified accident scenarios. Failure to comply with LCOs or SACs and their Required Actions constitutes a violation which must be immediately reported to the FSM. Specific LCOs and SACs applicable during performance of this procedure are referenced within the body of this procedure in bold brackets, e.g. **[LCO 3.X.X.].**

- Failure to complete a surveillance requirement (SR) within its specified frequency SHALL constitute a violation of the associated LCO and must be immediately reported to the Facility Shift Manager (FSM). Specific LCO Surveillances applicable during the performance of this procedure are referenced at the end of the implementing step in bold brackets, e.g. **[SR 4.X.X.X.].**

- If barriers are required for this work package they will be constructed and installed in a manner that will ensure their integrity throughout the expected duration of use and environmental conditions.

7.0 PREREQUISITES

[ ] 7.1. ADMINISTRATIVE

[ ] 7.1.1. Personnel performing this work review these work instructions and appropriate sections of the references listed in the REFERENCED (REQUIRED ON HAND) section.

[ ] 7.1.2. Before starting work, Work Group Manager/Field Work Manager conduct a pre-job safety meeting.

CRAFT	15-17-11 DATE
CRAFT	8/17/11 DATE
WGM/FWM	8-17-11 DATE

[ ] 7.2. TASK PREPARATION

[ ] 7.2.1. Obtain materials and equipment shown in Materials and Equipment section.

8.0 PERFORMANCE

[ ] 8.1. FABRICATE 74-B-610

WARNING

Rotating Equipment/Pinch Point Hazard Exists

This warning applies to section [ ] 8.1.4

Performance of this activity will expose personnel to Rotating Shop Equipment and Pinch Point Hazards associated with lifting heavy pieces of steel

[ ] 8.1.1. Mitigating Steps for Rotating Equipment/Pinch Point Hazards

[ ] 8.1.1.1. Ensure guards and covers provided on rotating equipment are securely in place.

[ ] 8.1.1.2. Ensure loose clothing, long hair or jewelry are contained so as not to become entangled in rotating equipment.

[ ] 8.1.1.3. Never use hands or other body parts to stop rotating, moving equipment or wind-milling equipment.

[ ] 8.1.1.4. Use proper PPE (i.e. gloves, steel-toed boots) when lifting or moving heavy objects such as steel. Always maintain awareness of hand and foot placement in relation to the heavy object so as to avoid pinch points.

[signature] 18-17-11

CRAFT DATE

WARNING

Hot Work Activity Hazard Exists

This warning applies to section [ ] 8.1.4

Performance of this activity may expose personnel to flames, sparks or other ignition sources. Examples of areas of concern are welding, cutting, grinding and open flame soldering in non-designated Hot Work areas.

[ ] 8.1.2. Mitigating Steps for Hot Work Activity Hazards

[ ] 8.1.2.1. A Hot Work Permit is required for work that may generate flames, sparks or other ignition sources that is performed outside of a designated Hot Work Area.

[ ] 8.1.2.2. Shop work must be performed following the posted designated Hot Work Permit requirements.

[ ] 8.1.2.3. Cutting, welding, grinding or open flame soldering of galvanized or stainless steel, cadmium, lead or coated metal surfaces will require Industrial Hygiene evaluation prior to performance of work.

[ ] 8.1.2.4. Perform all Hot Work in accordance with the Hot Work Permit.

WARNING

Sharp Object Hazard Exists

This warning applies to section [ ] 8.1.4

Performance of this activity will expose personnel to sharp steel edges

[ ] 8.1.3. Mitigating Steps for Sharp Object Hazards

[ ] 8.1.3.1. Wear leather or cut resistant gloves as a minimum when handling sheet metal or other types of steel with sharp or rough edges.

[ ] 8.1.4. Fabricate 3 bulkhead sections **OR** modify existing sections using the Cut Sheet **(Attachment #1)** and the drawing on **Attachment #2.** The UMM will determine if there are existing sections that can be modified as opposed to fabricated.

CRAFT 18-17-11 DATE

[ ] 8.1.5. Stage the bulkhead sections per direction from the UMM.

[ ] 8.1.6. UMM have this package suspended until P6RM7 is ready for the bulkhead installation.

WGM/FWM 18-21-11 DATE

[ ] 8.2. INSTALL BULKHEAD 74-B-610 AT P6RM7 INTAKE (S2750/W1070)

[ ] 8.2.1. Underground Mine Manager/Designee ensure that the chain link and brattice barricade has been dropped and secured at the intake point of Panel 6 Room 7 (S2750/W1070).

WGM/FWM/Designee 11-9-11 DATE

[ ] 8.2.2. COM verify that structures, systems and components (SSC's), administrative controls and design features are aligned in proper configuration before releasing this work order for bulkhead installation work. Verify that the waste face is a STATIC WASTE FACE. **[ ] LCO 3.4.2**

COM 11-9-11 DATE

[ ] 8.2.3. Before starting work, Work Group Manager/Field Work Manager conduct a pre-job safety meeting.

CRAFT 11/9/11 DATE

CRAFT 11/9/11 DATE

WGM/FWM 11-9-11 DATE

WARNING

Potential Radiological Hazard Exists

This warning applies to section [ ] 8.2.5

A sign should be posted in the work area indicating whether or not an RWP is required to enter the area.

[ ] 8.2.4. Mitigating Steps for Potential Radiological Hazards

[ ] 8.2.4.1. If RWP is required, request Operations Health Physics (OHP) record number on Sign-Off Sheet. If not required, N/A this step and continue.

N/A _____ / _____
CRAFT DATE

[ ] 8.2.4.2. If RWP is required, all personnel read the RWP, discuss radiological hazards, precautions and mitigating actions to be taken as shown in the RWP. If an RWP is not required, mark sign-off 'N/A' and continue.

N/A _____ / _____
CRAFT DATE

[ ] 8.2.5. WORK AREA INSPECTION

[ ] 8.2.5.1. **UFE/URW** or **IS/IH** personnel monitor the area around the intake point of P6RM7 for carbon tetrachloride (CCl4) using a MiniRAE 3000 while personnel are working in the area. Less than 5 ppm of CCl4 is acceptable to work in. Document the results in Table 1 at the end of these work instructions.

[ ] 8.2.5.2. **Mine Ops Craft:** Inspect work area for safe working conditions (for example ventilation, accessibility, ground control, etc.) and ensure any problems are corrected before starting work.

CRAFT DATE

WARNING

Height Hazard Exists

This warning applies to section [ ] 8.2.7

- Performance of this activity may expose personnel to falling from elevated work platforms while removing chain link, drilling bulkhead installation holes, installing the installation bolts in the back, or sealing the bulkhead.

[ ] 8.2.6. Mitigating Steps for Height Hazards

[ ] 8.2.6.1. Reference Section 4, above, for specific PPE required for the performance of this work.

[ ] 8.2.6.2. Qualified Person determine that the fall protection equipment required, has a current certification and identify the anchorage to be used for attachment of the personal fall protection equipment.

[ ] 8.2.6.3. Lanyards three feet long or less can be attached to the breast (front) "D" ring of the harness. Six-foot lanyards must be attached to the back "D" ring of the harness.

[ ] 8.2.6.4. Establish barriers on the ground around the work area.

NOTE

This note applies to section [ ] 8.2.7

The work of installing the bulkhead in S2750 at the P6RM7 intake point will be occurring around/near a STATIC WASTE FACE. **LCO 3.3.7 AND LCO 3.3.8** do not apply. It will still be prudent to park liquid fueled vehicles greater than 25 feet from the work area once you have finished using them in the work area.

[ ] 8.2.7. Cut chain link along the back and ribs of the bulkhead installation location as needed to obtain a better seal to the salt.

[ ] 8.2.8. Install the bulkhead in P6 at the Room 7 intake point (S2750/W1070) as shown on **Attachment #3,** east of the P6RM7 closure barricade. Use RV putty tape between the bulkhead sections to provide a better seal.

[ ] 8.2.9. Field fit a double thickness of brattice around the bulkhead as the flexible flashing used to seal the bulkhead to the salt. Space the Hilti nails close enough together to provide a tight seal. **Use care when sealing around the VOC tubes on the north rib – don't damage the tubes.**

11/9/11

CRAFT DATE

WARNING

Adhesives & Sealants Chemical Hazard Exists

This warning applies to section [ ] 8.2.11

Performance of this activity may expose personnel to Chemical Hazard – Adhesives and Sealants hazards. Areas of concern are eye, skin, and breathing injuries.

[ ] 8.2.10. Mitigating Steps for Chemical Hazards

[ ] 8.2.10.1. The following MSDS's are provided with this work package:

FlexGrip 550 – Attachment #4
DAP Silicone Sealant – Attachment #5
GE Silicone Sealant – Attachment #6

[ ] 8.2.10.2. When using FlexGrip 550:

- Wear approved eye protection
- Wear protective rubber gloves (Hycron, neoprene, or nitrile)
- Ensure that there is adequate ventilation to prevent vapor fumes from accumulating
- Avoid rubbing your eyes while handling the FlexGrip 550

CRAFT 11-9-11 DATE

[ ] 8.2.10.3. When using DAP Silicone Sealant

- Wear approved eye protection
- Wash skin at meal time and at the end of the shift
- Use suitable gloves (nitrile rubber, butyl rubber)
- Ensure that there is adequate ventilation to prevent vapor fumes from accumulating.

CRAFT 11/9/11 DATE

[ ] 8.2.10.4. When using GE GE012A Silicone Sealant

- Wear approved eye protection
- Ensure that there is adequate ventilation to prevent vapor fumes from accumulating
- Use cloth gloves at a minimum to protect hands.

CRAFT 11/9/11 DATE

[ ] 8.2.11. Seal all the remaining cracks including but not limited to sheet metal seams with FlexGrip 550.

[ ] 8.2.12. Seal the brattice along the floor with loose muck placed on top of the brattice.

[ ] 8.2.13. Seal the brattice-to-salt and brattice-to-metal seams with Silicone Sealant.

[ ] 8.2.14. Remove all tools and debris from the work area when the work is completed.

CRAFT 11/9/11 DATE

[ ] 8.3. TAGGING AND LABELING OF EQUIPMENT

[ ] 8.3.1. Tag the bulkhead with the tag provided with this work package.

CRAFT 11/9/11 DATE

[ ] 8.4. TASK VERIFICATION

[ ] 8.4.1. Equipment Testing

[ ] 8.4.1.1. UMM/Designee ensure that the bulkhead is properly installed and sealed.

WGM/FWM 11-9-11 DATE

[ ] 8.4.2. Operational Testing

NONE

[ ] 8.5. RESTORATION TO OPERATIONAL STATUS

[ ] 8.5.1. Inform UG Services that the work is complete and the bulkhead is ready for use.

Jim Haller / 11/09/11
URW/UFE DATE

WGM/FWM 11-8-11
WGM/FWM DATE

[ ] 8.5.2. Work Group Manager/Field Work Manager conduct post-job review.

WGM/FWM 11-8-11
WGM/FWM DATE

[ ] 8.6. COMMENTS

Document additional action or other data below:

N/A
N

N/A /
CRAFT DATE

N/A /
RESP ENG DATE

[ ] 8.7. PERSONNEL DATA

[ ] 8.7.1. All personnel affixing initials to these work instructions shall provide the information listed in the PERSONNEL DATA table below:

PERSONNEL DATA

PRINTED NAME	SIGNATURE	INITIALS	DATE
Ronnie Crockett	Ronnie Crockett	RC	11/7/11
Mathew Ratzlaff	Mathew Ratzlaff	MR	11/9/11
Jim Hollen	Jim Hollen	JH	12/12/11

TABLE 1 CCL4 READINGS

DATE	TIME	CCL4 READING (PPM)	INSTRUMENT NUMBER	INSTRUMENT OPERATOR
11/7/11	9:35	2.4	652	Ron Crockett
11/8/11	1225	1.9	652	Ron Crockett
11-9-11	0810	.03	619	Jim Hollen

ATTACHMENT #1
CUT SHEET
74-B-610

MODULAR SECTION WITH LEG ATTACHMENT
(2 modular pieces need to be fabricated. Cuts are for one modular piece)

2" x 4" TS

Length	# of Pieces Required
13' 6"	2
9' 8"	2

2" x 2" TS

Length	# of Pieces Required
12' 8"	1
4' 9"	6
10"	2
6"	4

3" x 5" TS

Length	# of Pieces Required
8"	1

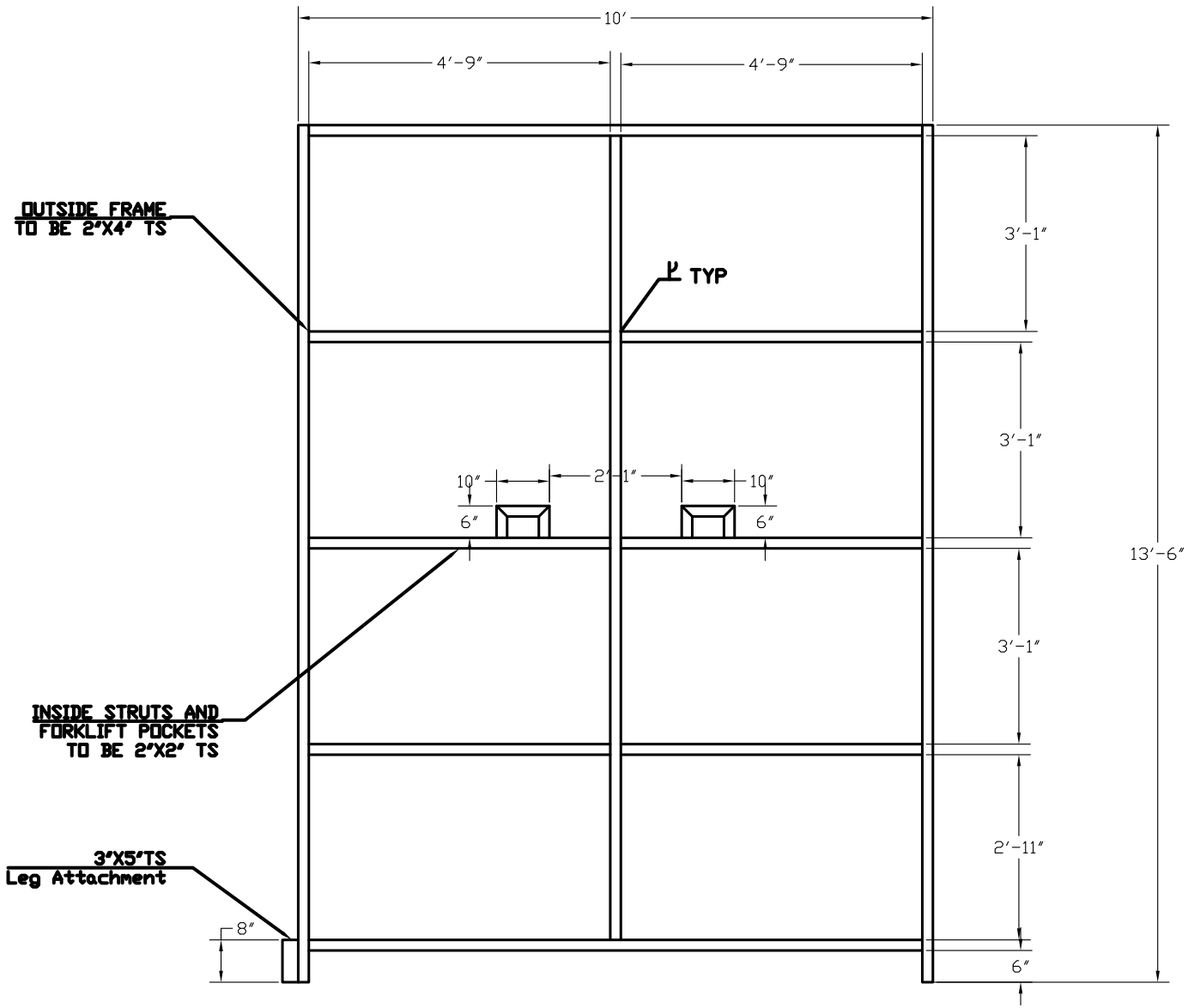
MODULAR SECTION – **NO** LEG ATTACHMENT

2" x 4" TS

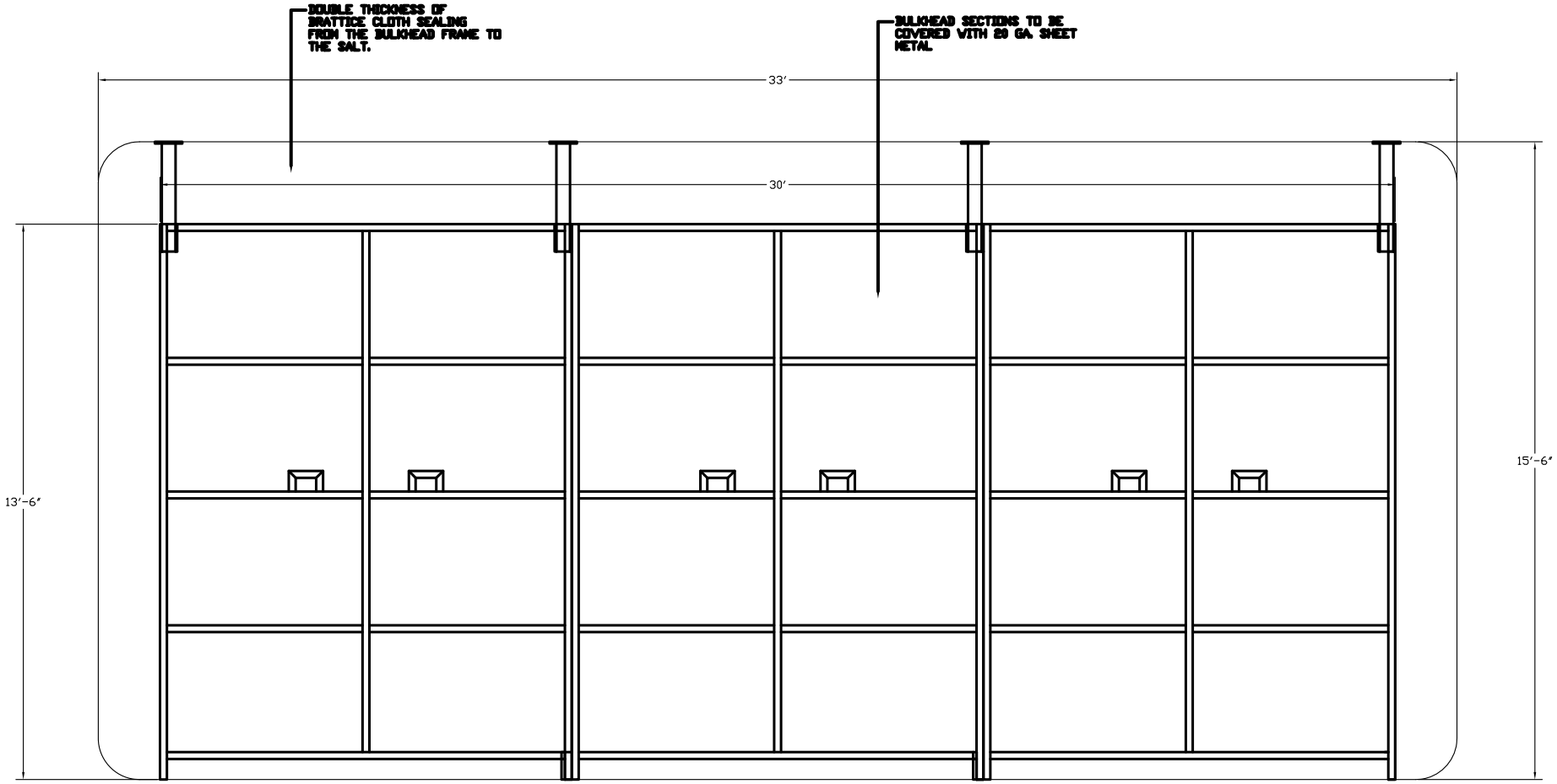
Length	# of Pieces Required
13' 6"	2
9' 8"	2

2" x 2" TS

Length	# of Pieces Required
12' 8"	1
4' 9"	6
10"	2
6"	4



74-B-610 MODULAR SECTION
2 SECTIONS WILL HAVE THE LEG ATTACHMENT
1 SECTION WILL NOT HAVE THE LEG ATTACHMENT



74-B-610
LOOKING WEST
S2750 AT P6 RM7 INTAKE

NOTES:

1. DRIFT DIMENSIONS ARE NOMINAL
2. SHEET METAL SEAMS TO BE SEALED WITH FLEXGRIP 550.
3. PLACE MUCK ALONG THE FLOOR-TO-BRATTICE INTERFACE FOR SEALING.
4. SEAL THE BRATTICE-TO-SALT AND THE METAL-TO-BRATTICE INTERFACES WITH A SEALANT APPROVED BY THE VU03 CE.
5. USE RV PUTTY TAPE TO SEAL BETWEEN THE SECTIONS DURING INSTALLATION

HARDCAST CARLISLE

ATTACHMENT #4
WO # 1107579M

W3234

MATERIAL SAFETY DATA SHEET

1. PRODUCT AND COMPANY IDENTIFICATION

Product Name: FlexGrip 550
Synonyms: Water-Based Mastic

Manufacturer/Supplier
Carlisle Coatings & Waterproofing Incorporated
900 Hensley Lane
Wylie, TX 75098
Internet Address: http://www.ccwcompanies.com/
Fax Number: (972) 442-0076

Phone Numbers
Medical Emergency:
CHEMTREC (USA): (800) 424-9300
CHEMTREC (International):
MSDS Assistance: (972) 442-6545
Fax On Demand: NA
Technical Assistance: (888) 229-2199
Customer Service: (888) 229-0199

2. COMPONENT INFORMATION

Component	CAS No.	Percent Range	Hazardous in Blend
Ethylene Glycol	107-21-1	0.2 - 2	
Methanol	67-56-1	0.5 - 3	

This product is not hazardous according OSHA 29 CFR 1910.1200.
Hazards:
Flammable/Combustible No **Acute Toxin** No **Chronic Toxin** No **Carcinogen** No
Pressure No **Reactive** No **Exposure Limit** ___ **Target Organ** ___ **Other** ___

2A. OTHER INGREDIENTS Greater than 3%

Component	CAS No.
Latex	25067-01-0
Calcium Carbonate	1317-65-3
Clay	1332-58-7
Chlorinated Paraffin	63449-39-8 Blend

3. HAZARDS IDENTIFICATION

Emergency and Hazards Overview:
May cause moderate irritation to eyes. May be harmful if swallowed. Read and understand all health and safety information on the product label and Material Safety Data Sheet before use.

Ratings
Health 1 **Flammability** 0 **Reactivity** 0

Primary Route of Exposure: Skin x Inhalation x Eye x Ingestion x

Health Effect Information

Eye Contact: May cause eye irritation if wiped or rubbed into eyes.

Skin Contact: May cause mild skin irritation on prolonged or repeated contact.

Inhalation: Breathing high concentrations of vapors may cause nausea & irritation of nose, throat, & respiratory tract. Respiratory symptoms associated with pre-existing lung disorders may be aggravated by exposure to this material.

Ingestion: Ingestion of large quantity may cause initial central nervous system stimulation, followed by

depression.

Medical Conditions Aggravated by Exposure: Prolonged exposure to vapors could aggravate pre-existing disorders in lungs, kidney and liver.

4. FIRST AID INFORMATION

Eye Contact: Flush with water for 15 minutes. Get medical attention immediately.

Skin Contact: Wipe off and wash skin with soap and water. Promptly remove contaminated clothing and wash before reuse.

Inhalation: Remove to fresh air. If breathing has stopped, start artificial respiration. Oxygen may be administered. Consult physician immediately

Ingestion: Do not induce vomiting unless directed to do so by a physician. Consult a physician immediately.

Notes to Physician: This product contains ethylene glycol, Hexahydro-1, 3,5-triethyl-s-triazine (not in a reportable amount).

5. FIRES AND EXPLOSION INFORMATION

Flammable Properties

Flash Point: No flash to boiling — **Test Method:** Closed cup

Flame extension: NA — **Test Method:** NA

Flammable Limits in Air

Upper Percent: NA

Lower Percent: NA

Auto ignition Temperature: NA — **Test Method:** NA

NFPA Classification: H 1 F 0 R 0

Extinguishing Media: CO_2, foam, dry chemical or water spray.

Fire Fighting Measures

Special Fire Fighting Procedures and Equipment: Firemen must wear full-face air-supplied masks and full protective clothing.

Unusual Fire and Explosion Conditions: This product is not sensitive to physical shock or static discharge. Exposure of closed container to temperatures above the boiling point could cause pressure buildup and container rupture.

Hazardous Combustion By-Products: CO, CO_2, unburned hydrocarbons, or nitrous oxides.

6. ACCIDENTAL RELEASE MEASURES

Personnel Safeguards: Evacuate non-essential personnel to safe areas. Clean-up responders should wear proper protective clothing and gloves before entering the affected area.

Regulatory Notifications: Certain component of this product is defined as hazardous according to U.S. EPA. Spill reporting requirements and reportable quantities vary by region.

Consult all applicable state and local regulations. For Canada, observe all precautions noted above.

Containment and Clean up: Prevent product from entering drinking water supplies or streams. Observe above precautions, collect liquid with inert, noncombustible material and remove for disposal.

7. HANDLING AND STORAGE INFORMATION

Handling: Normal use condition doesn't produce respirable Silica. However, sanding, grinding, and burning might release respirable Silica. Keep out of reach of children. Launder contaminated clothing. Wash hands with soap and water after use, especially before eating or drinking.

Storage: Store in a dry, well ventilated environment away from heat, above 35 deg F and below 110 deg F. Keep containers closed when not in use. Do not pressurize, cut weld or grind containers.

Empty Container Warnings

Drums: Drums may be reused after wash.

Plastic: Plastic containers may be reused after wash.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION INFORMATION

Exposure Limits and Guidelines

Component	CAS No.	Exposure Limit
Methanol	67-56-1	200 ppm OSHA PEL 200 ppm ACGIH TWA, 250 ppm STEL
Ethylene Glycol	107-21-1	50 ppm OSHA PEL/Ceiling

Personal Protective Equipment

Eye/Face Protection: Wear safety goggles or face shield. Contact lenses should not be worn.

Skin Protection: Use protective rubber gloves (Hycron, neoprene, or nitrile).

Respiratory Protection: Provide adequate ventilation to maintain vapors below PEL/TWA. If vapor levels are exceeded, use NIOSH approved respirator, both during and immediately after application, until vapor levels are below limits.

Personal Hygiene: Avoid rubbing eyes during handling. Use good personal hygiene practices to avoid incidental ingestion.

Engineering Controls / Work Practices

Ventilation: Provide local exhaust or area ventilation to maintain concentration of vapors below PEL/TWA.

Other: Source of clean water should be available in the work area for flushing eyes and skin. Wash thoroughly with soap and water after use and before eating.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance: Gray Mastic	**Vapor Pressure:** 17 mm Hg @ 20°C
Odor: Typical latex with slight ammonia odor	**Vapor Density (air=1):** <air
Physical state: Mastic	**Percent Volatile by Weight:** 34 – 36
pH: 9.0 – 9.5	**Volatile Organic Content:** 75 gpl (water excluded)
DOT Corrosivity: NA	**Molecular Weight:** NA
Boiling Point: 212°F	**Average Carbon Number:** NA
Melting Point: NA	**Viscosity @ 77 F:** >300 K cps
Specific Gravity: 1.28	
Pour Point: NA	
Solubility in Water: Miscible with water	
Octanol / Water Coefficient: Log K_{ow} = NA	

10. STABILITY AND REACTIVITY INFORMATION

Chemical Stability: Stable

Conditions to Avoid: Avoid extreme heat, fire and temperature.

Incompatible Materials to Avoid: Avoid strong acids, strong oxidizers.

11. TOXICOLOGICAL INFORMATION (will only print available data)

Ethylene Glycol
Primary Eye Irritation: Irritating
Primary Skin Irritation: NA
Acute Dermal Toxicity: Product toxicity has not been determined.
Subacute Dermal Toxicity: NA
Dermal Sensitization: NA
Inhalation Toxicity: Product toxicity has not been determined.
Inhalation Sensitization: NA
Oral Toxicity: Product toxicity has not been determined. Following are component data:
LD_{50}, Ethylene Glycol: Rat 4,000 mg/kg
Mutagenicity: NA
Carcinogenicity: NA
Reproductive Toxicity: Product toxicity has not been determined. Following are component data:
Ethylene Glycol: Pregnant Rat 1.25g/kg and above: increased malformed fetus
Pregnant Mice 750 mg/kg and above: increased malformed fetus
Teratogenicity: NA
Immunotoxicity: NA
Neurotoxicity: NA
No other toxicological information available

12. ECOLOGICAL INFORMATION

Ethylene Glycol
Aquatic Toxicity: Not known
Terrestrial Toxicity: Not known
Chemical Fate and Transport: Not known
No other ecological information available

13. DISPOSAL INFORMATION

Regulatory Information: Consult all regulations (federal, state, provincial, local etc.) or a qualified waste disposal firm when characterizing waste for disposal.

Waste Disposal Methods: Recover free liquid. Absorb residue and dispose of according to local, state and Federal EPA regulation. Empty container: may contain explosive vapors. Do Not cut, puncture or weld on or nearby.

14. TRANSPORTATION INFORMATION

U.S. Department of Transportation (DOT)
Highway / Rail: Not regulated by DOT

The DOT description is provided to assist in the proper shipping classification of this product and may not be suitable for all shipping descriptions.

Other: No other information available.

15. REGULATORY INFORMATION

Regulatory Lists

U.S. TSCA Inventory: All components of this material are on the US TSCA Inventory or exempt from listing on the TSCA Inventory.

Sara Section 313: This product contains the following Sara, Title III, Section 313 Chemicals:

Chemical	CAS Number	Percent in Product
Methanol	67-56-1	0.5 - 3
Ethylene Glycol	107-21-1	0.2 - 2

IARC Group: NA

Regulatory Lists Searched

This product contains a mixture of one or more components found on the following State List at or above OSHA de minimis quantities

Health & Safety: NA
Environmental: NA
International: NA
State: FL, MA, MN, PA, NJ, WA
National Inventories: NA

SARA 311 / 312 Categories (For the chemicals above)
Acute: Yes **Chronic:** Yes **Fire:** Yes **Pressure:** No **Reactive:** No
Regulated: No

California Proposition 65 Information: Warning! None in the list

Canadian WHMIS Classification

Methanol

Class: Class B2 and D2B

This product has been classified in accordance with hazard criteria of the Controlled Products Regulations (CPR). This MSDS contains all the information required by the CPR.

Canadian Environmental Protection Act (CEPA)

All reportable chemical substance is listed on the Domestic Substances List (DSL) or otherwise complies with CEPA new substance notification requirements.

National Pollution Release Inventory (NPRI)

This product contains the following chemical subject to the reporting requirements of the CEPA subsection 16(1), NPRI.

Chemical	CAS Number	Percent in Product
Methanol	67-56-1	0.2 – 2
Ethylene Glycol	107-21-1	0.5 – 2

Other Regulations: No other information available.

16. OTHER INFORMATION

Health and Environmental Label Language

All ingredients contained in this product are included on the US EPA Toxic Substances Control Act (TSCA) inventory or exempt from listing on the TSCA inventory. All ingredients contained in this product comply with the requirements of the Canadian Environmental Protection Act (CEPA) and are listed on the Domestic Substance List (DSL) or Non-Domestic Substance List (NDSL)

MSDS Revisions

Previous Version Date: 04/20/05

Section

Old Information: 16- part MSDS version with updated Shipping Information

New Information:

Prepared By: R&D Department **Date:** 08/15/06

Disclaimer of Warranty: The information contained herein is based upon data and information available to us, and reflects our best professional judgment. This product may be formulated in part with components purchased from other companies. In many instances, especially when proprietary or trade secret materials are used, CCWI Company must rely upon the hazard evaluation of such components submitted by that product's manufacturer or importer. No warranty of merchantability, fitness for any use, or any other warranty is expressed or implied regarding the accuracy of such data or information. The results to be obtained from the use thereof, or that any such use does not infringe any patent, since the information contained herein may be applied under conditions of use beyond our control and with which we may be unfamiliar, we do not assume responsibility for the results of such application. This information is furnished upon the condition that the person receiving it shall make his own determination of the suitability of the material for his particular use.

XIAMETER

XIAMETER(R)
Material Safety Data Sheet

ATTACHMENT #5
WO# 1107579M

W3489

Version: 1.5
Revision Date: 2005/06/01

DAP(R) 100% SILICONE RUBBER SEALANT CLEAR, 8641

1. PRODUCT AND COMPANY IDENTIFICATION

Dow Corning Corporation
South Saginaw Road
Midland, Michigan 48686

24 Hour Emergency Telephone: (989) 496-5900
Customer Service: (989) 496-6000
Product Disposal Information: (989) 496-6315
CHEMTREC: (800) 424-9300

MSDS No.: 04061395
Revision Date: 2005/06/01

Generic Description: Silicone elastomer
Physical Form: Paste
Color: Colorless
Odor: Acetic acid odor

NFPA Profile: Health 2 Flammability 1 Instability/Reactivity 0

Note: NFPA = National Fire Protection Association

2. OSHA HAZARDOUS COMPONENTS

CAS Number	Wt %	Component Name
17689-77-9	1.0 - 5.0	Ethyltriacetoxysilane
4253-34-3	1.0 - 5.0	Methyltriacetoxysilane

The above components are hazardous as defined in 29 CFR 1910.1200.

3. HAZARDS IDENTIFICATION

POTENTIAL HEALTH EFFECTS

Acute Effects

Eye: Direct contact may cause moderate irritation.

Skin: May cause moderate irritation.

Inhalation: Material is not likely to present an inhalation hazard at ambient conditions. However, if material is heated or high vapor/aerosol concentrations are attained, central nervous system depression may occur, which is characterized by drowsiness, dizziness, confusion or loss of coordination.

Oral: Low ingestion hazard in normal use.

Prolonged/Repeated Exposure Effects

Skin: No known applicable information.

Inhalation:	No known applicable information.
Oral:	No known applicable information.

Signs and Symptoms of Overexposure

No known applicable information.

Medical Conditions Aggravated by Exposure

No known applicable information.

The above listed potential effects of overexposure are based on actual data, results of studies performed upon similar compositions, component data and/or expert review of the product. Please refer to Section 11 for the detailed toxicology information.

4. FIRST AID MEASURES

Eye:	Immediately flush with water for 15 minutes. Get medical attention.
Skin:	Remove from skin and wash thoroughly with soap and water or waterless cleanser. Get medical attention if irritation or other ill effects develop or persist.
Inhalation:	Material is not likely to present an inhalation hazard at ambient conditions. If material is heated or vapor/mist/dust/fumes are generated, care should be taken to prevent inhalation. In case of exposure to vapor/mist/dust/fumes, move to fresh air.
Oral:	No first aid should be needed.
Comments:	Treat according to person's condition and specifics of exposure.

5. FIRE FIGHTING MEASURES

Flash Point:	> 212 °F / > 100 °C (Closed Cup)
Autoignition Temperature:	Not determined.
Flammability Limits in Air:	Not determined.
Extinguishing Media:	On large fires use dry chemical, foam or water spray. On small fires use carbon dioxide (CO2), dry chemical or water spray. Water can be used to cool fire exposed containers.
Fire Fighting Measures:	Self-contained breathing apparatus and protective clothing should be worn in fighting large fires involving chemicals. Determine the need to evacuate or isolate the area according to your local emergency plan. Use water spray to keep fire exposed containers cool.
Unusual Fire Hazards:	None.

Hazardous Decomposition Products

Thermal breakdown of this product during fire or very high heat conditions may evolve the following hazardous

decomposition products: Carbon oxides and traces of incompletely burned carbon compounds. Silicon dioxide. Formaldehyde.

6. ACCIDENTAL RELEASE MEASURES

Containment/Clean up: Observe all personal protection equipment recommendations described in Sections 5 and 8. Wipe up or scrape up and contain for salvage or disposal. Clean area as appropriate since spilled materials, even in small quantities, may present a slip hazard. Final cleaning may require use of steam, solvents or detergents. Dispose of saturated absorbant or cleaning materials appropriately, since spontaneous heating may occur. Local, state and federal laws and regulations may apply to releases and disposal of this material, as well as those materials and items employed in the cleanup of releases. You will need to determine which federal, state and local laws and regulations are applicable. Sections 13 and 15 of this MSDS provide information regarding certain federal and state requirements.

Note: See section 8 for Personal Protective Equipment for Spills. Call (989) 496-5900, if additional information is required.

7. HANDLING AND STORAGE

Use with adequate ventilation. Product evolves acetic acid (HOAc) when exposed to water or humid air. Provide ventilation during use to control HOAc within exposure guidelines or use respiratory protection. Avoid eye contact. Avoid skin contact. Do not take internally. Avoid breathing vapor. Keep container closed.

Use reasonable care and store away from oxidizing materials. Keep container closed and store away from water or moisture.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Component Exposure Limits

CAS Number	Component Name	Exposure Limits
17689-77-9	Ethyltriacetoxysilane	See acetic acid comments.
4253-34-3	Methyltriacetoxysilane	See acetic acid comments.

Acetic acid is formed upon contact with water or humid air. Provide adequate ventilation to control exposures within guidelines of OSHA PEL: TWA 10 ppm and ACGIH TLV: TWA 10 ppm, STEL 15 ppm.

Engineering Controls

Local Ventilation: Recommended.
General Ventilation: Recommended.

Personal Protective Equipment for Routine Handling

DAP(R) 100% SILICONE RUBBER SEALANT CLEAR, 8641

Eyes:	Use proper protection - safety glasses as a minimum.
Skin:	Wash at mealtime and end of shift. Contaminated clothing and shoes should be removed as soon as practical and thoroughly cleaned before reuse. Chemical protective gloves are recommended.
Suitable Gloves:	Nitrile Rubber. Butyl Rubber.
Inhalation:	Use respiratory protection unless adequate local exhaust ventilation is provided or exposure assessment demonstrates that exposures are within recommended exposure guidelines. IH personnel can assist in judging the adequacy of existing engineering controls.
Suitable Respirator:	Respiratory protection is not needed under ambient conditions. If vapor/mist/dust/fumes are generated when material is heated or handled, the following is advised. General and local exhaust ventilation is recommended to maintain vapor exposures below recommended limits. Where concentrations are above recommended limits or are unknown, appropriate respiratory protection should be worn. Follow OSHA respirator regulations (29 CFR 1910.134) and use NIOSH/MSHA approved respirators.

Personal Protective Equipment for Spills

Eyes:	Use full face respirator.
Skin:	Wash at mealtime and end of shift. Contaminated clothing and shoes should be removed as soon as practical and thoroughly cleaned before reuse. Chemical protective gloves are recommended.
Inhalation/Suitable Respirator:	Respiratory protection recommended. Follow OSHA Respirator Regulations (29 CFR 1910.134) and use NIOSH/MHSA approved respirators. Protection provided by air purifying respirators against exposure to any hazardous chemical is limited. Use a positive pressure air supplied respirator if there is any potential for uncontrolled release, exposure levels are unknown, or any other circumstance where air purifying respirators may not provide adequate protection.
Precautionary Measures:	Avoid eye contact. Avoid skin contact. Do not take internally. Avoid breathing vapor. Keep container closed. Use reasonable care.
Comments:	Product evolves acetic acid (HOAc) when exposed to water or humid air. Provide ventilation during use to control HOAc within exposure guidelines or use respiratory protection. When heated to temperatures above 150 C (300 F) in the presence of air, product may form formaldehyde vapors. Physical and health hazard information is readily available from Dow Corning Corporation and the Material Safety Data Sheet.

Note: These precautions are for room temperature handling. Use at elevated temperature or aerosol/spray applications may require added precautions.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical Form: Paste

DAP(R) 100% SILICONE RUBBER SEALANT CLEAR, 8641

Color:	Colorless
Odor:	Acetic acid odor
Specific Gravity @ 25°C:	1.007
Viscosity:	Not determined.
Freezing/Melting Point:	Not determined.
Boiling Point:	Not determined.
Vapor Pressure @ 25°C:	Not determined.
Vapor Density:	Not determined.
Solubility in Water:	Not determined.
pH:	Not determined.
Volatile Content:	Not determined.

Note: The above information is not intended for use in preparing product specifications.

10. STABILITY AND REACTIVITY

Chemical Stability:	Stable.
Hazardous Polymerization:	Hazardous polymerization will not occur.
Conditions to Avoid:	None.
Materials to Avoid:	Oxidizing material can cause a reaction. Water, moisture, or humid air can cause hazardous vapors to form as described in Section 8.

11. TOXICOLOGICAL INFORMATION

Special Hazard Information on Components

No known applicable information.

12. ECOLOGICAL INFORMATION

Environmental Fate and Distribution

Complete information is not yet available.

Environmental Effects

Complete information is not yet available.

Fate and Effects in Waste Water Treatment Plants

Complete information is not yet available.

Ecotoxicity Classification Criteria

Hazard Parameters (LC50 or EC50)	High	Medium	Low
Acute Aquatic Toxicity (mg/L)	<=1	>1 and <=100	>100
Acute Terrestrial Toxicity	<=100	>100 and <= 2000	>2000

DAP(R) 100% SILICONE RUBBER SEALANT CLEAR, 8641

This table is adapted from "Environmental Toxicology and Risk Assessment", ASTM STP 1179, p.34, 1993.

This table can be used to classify the ecotoxicity of this product when ecotoxicity data is listed above. Please read the other information presented in the section concerning the overall ecological safety of this material.

13. DISPOSAL CONSIDERATIONS

RCRA Hazard Class (40 CFR 261)

When a decision is made to discard this material, as received, is it classified as a hazardous waste? No

State or local laws may impose additional regulatory requirements regarding disposal.

Call (989) 496-6315, if additional information is required.

14. TRANSPORT INFORMATION

DOT Road Shipment Information (49 CFR 172.101)

Not subject to DOT.

Ocean Shipment (IMDG)

Not subject to IMDG code.

Air Shipment (IATA)

Not subject to IATA regulations.

15. REGULATORY INFORMATION

Contents of this MSDS comply with the OSHA Hazard Communication Standard 29 CFR 1910.1200.

TSCA Status: All chemical substances in this material are included on or exempted from listing on the TSCA Inventory of Chemical Substances.

EPA SARA Title III Chemical Listings

Section 302 Extremely Hazardous Substances (40 CFR 355):
None.

Section 304 CERCLA Hazardous Substances (40 CFR 302):
None.

Section 311/312 Hazard Class (40 CFR 370):
Acute: Yes
Chronic: No
Fire: No

Pressure: No
Reactive: No

Section 313 Toxic Chemicals (40 CFR 372):
None present or none present in regulated quantities.

Supplemental State Compliance Information

California

Warning: This product contains the following chemical(s) listed by the State of California under the Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65) as being known to cause cancer, birth defects or other reproductive harm.

None known.

Massachusetts

CAS Number	Wt %	Component Name
7631-86-9	7.0 - 13.0	Silica, amorphous

New Jersey

CAS Number	Wt %	Component Name
70131-67-8	> 60.0	Dimethyl siloxane, hydroxy-terminated
7631-86-9	7.0 - 13.0	Silica, amorphous
64742-46-7	<=7.0	Hydrotreated middle petroleum distillates
17689-77-9	1.0 - 5.0	Ethyltriacetoxysilane
4253-34-3	1.0 - 5.0	Methyltriacetoxysilane

Pennsylvania

CAS Number	Wt %	Component Name
70131-67-8	> 60.0	Dimethyl siloxane, hydroxy-terminated
7631-86-9	7.0 - 13.0	Silica, amorphous
64742-46-7	<=7.0	Hydrotreated middle petroleum distillates

DAP(R) 100% SILICONE RUBBER SEALANT CLEAR, 8641

16. OTHER INFORMATION

Prepared by: Dow Corning Corporation

These data are offered in good faith as typical values and not as product specifications. No warranty, either expressed or implied, is hereby made. The recommended industrial hygiene and safe handling procedures are believed to be generally applicable. However, each user should review these recommendations in the specific context of the intended use and determine whether they are appropriate.

XIAMETER(R) is a trademark of Dow Corning Corporation

http://www.xiameter.com

GE Silicones

ATTACHMENT #6
WO# 1107579M

W0385.1

COPYRIGHT GENERAL ELECTRIC CO.

FORMAT: USA
PRODUCT: GE012A

MATERIAL SAFETY DATA SHEET
SILICONE RUBBER COMPOUND

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

MANUFACTURED BY:
GE SILICONES
260 HUDSON RIVER ROAD
WATERFORD, NY 12188

EMERGENCY PHONE (24 HRS)
(518) 237-3330

SUPPLIED BY:
GE SILICONES
260 HUDSON RIVER ROAD
WATERFORD, NY 12188

EMERGENCY PHONE (24 HRS)
(518) 237-3330

REVISED: 09/21/00
PREPARER: CE HANNIGAN
CHEMICAL FAMILY/USE: SILICONE RUBBER SEALANT
FORMULA: MIXTURE

2. COMPOSITION/INFORMATION ON INGREDIENTS

PRODUCT COMPOSITION/ CAS REG NO.	APPROX. WGT. %	ACGIH TLV TWA	ACGIH TLV STEL	OSHA PEL TWA	OSHA PEL STEL	UNITS
1. HAZARDOUS METHYLTRIACETOXYSILANE 4253-34-3	1-5	10(R)	NE	10(R)	NE	PPM
2. NON-HAZARDOUS POLYDIMETHYLSILOXANE SILANOL/STPD 70131-67-8	60-80	-	NE	-	NE	-
DIMETHYLPOLYSILOXANE 63148-62-9	5-10	NE	NA	NE	NA	NA
TREATED FUMED SILICA 68611-44-9	5-10	10	NE	15	NE	MG/M3

See Section 15 for description of any WHMIS Trade Secret(s).

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW:
This section not in use
POTENTIAL HEALTH EFFECTS:
INGESTION:
May be harmful if swallowed.
1^ SKIN CONTACT:
Uncured product contact will irritate lips, gums and tongue.
Uncured product contact may irritate the skin.
INHALATION:
Causes irritation of the mouth, nose, and throat.
Applies only in uncured state.
EYE CONTACT:
Uncured product contact irritates eyes.
MEDICAL CONDITIONS AGGRAVATED:
None known.
SUBCHRONIC (TARGET ORGAN) EFFECTS:
None known
CHRONIC EFFECTS/CARCINOGENICITY:
This product or one of its ingredients present 0.1% or more
is NOT listed as a carcinogen or suspected carcinogen by
NTP, IARC, or OSHA.
PRODUCTS/INGREDIENTS
This space reserved for special use.
PRINCIPLE ROUTES OF EXPOSURE:
Dermal - skin.
Inhalation.
OTHER:
Acetic acid released during curing.

---

4. FIRST AID MEASURES

INGESTION:
Rinse mouth with water several times.
SKIN:
To clean from skin, remove completely with a dry cloth or paper
towel, before washing with detergent and water.
Get medical attention if irritation persists.
INHALATION:
Move person to fresh air.
EYES:
In case of contact, immediately flush eyes with plenty of water
for at least 15 minutes and get medical attention if irritation
persists.
NOTE TO PHYSICIAN:
None known.

---

5. FIRE FIGHTING MEASURES

FLASH POINT: NA (C) NA (F)
METHOD : NA
IGNITION TEMP : UNK (C) UNK (F)
1^ FLAMMABLE LIMITS IN AIR - LOWER (%): UNK

FLAMMABLE LIMITS IN AIR - UPPER (%): UNK
SENSITIVITY TO MECHANICAL IMPACT (Y/N): NO
SENSITIVITY TO STATIC DISCHARGE:
Sensitivity to static discharge is not expected.
EXTINGUISHING MEDIA:
All standard firefighting media
SPECIAL FIREFIGHTING PROCEDURES:
None known.

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6. ACCIDENTAL RELEASE MEASURES

ACTION TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED:
Wipe, scrape or soak up in an inert material and put in a container for disposal.
Wash walking surfaces with detergent and water to reduce slipping hazard.
Wear proper protective equipment as specified in the protective equipment section.
Increase area ventilation.

---

7. HANDLING AND STORAGE

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE:
Keep container closed when not in use.
Avoid contact with skin and eyes.
Use only in a well ventilated area.
Remove contact lenses before using sealant. Do not handle lenses until all sealant has been cleaned from the fingertips, nails and cuticles. Residual sealant may remain on fingers for several days and transfer to lenses and cause severe eye irritation.
Product releases acetic acid during application and curing.
Use mechanical ventilation to stay below TLV of 10 ppm acetic acid.
Uncured product contact irritates eyes.
Uncured product contact may irritate skin.
Use in a well ventilated area to prevent irritation by vapors.

---

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

ENGINEERING CONTROLS:
Eyewash stations.
Use in a well ventilated area.
1^ RESPIRATORY PROTECTION:
Use in a well ventilated area.
Use approved NIOSH respiratory protection if TLV exceeded or

overexposure is likely.
PROTECTIVE GLOVES:
Cloth gloves.
EYE AND FACE PROTECTION:
Safety glasses.
OTHER PROTECTIVE EQUIPMENT:
None known.
VENTILATION:
Use only in well ventilated area.

---

9. PHYSICAL AND CHEMICAL PROPERTIES

PRODUCT INFORMATION:

BOILING POINT	:	NA	(C)	NA	(F)
VAPOR PRESSURE(20 C)(MM HG)	:	NA			
VAPOR DENSITY (AIR=1)	:	NA			
FREEZING POINT	:	NA	(C)	NA	(F)
MELTING POINT	:	NA	(C)	NA	(F)
PHYSICAL STATE	:	SOLID			
ODOR	:	ACETIC ACID			
COLOR	:	TRANSLUCENT			
ODOR THRESHOLD (PPM)	:	UNK			
% VOLATILE BY VOLUME	:	<3.9			
EVAP. RATE(BUTYL ACETATE=1)	:	<1			
SPECIFIC GRAVITY (WATER=1)	:	1.04			
DENSITY (KG/M3)	:	1040			
ACID/ALKALINITY (MEQ/G)	:	NA			
PH	:	NA			
VOC EXCL.H2O & EXEMPTS(G/L)	:	<41			
SOLUBILITY IN WATER (20 C)	:	INSOLUBLE			

SOLUBILITY IN ORGANIC SOLVENT (STATE SOLVENT): TOLUENE

---

10. STABILITY AND REACTIVITY

STABILITY: STABLE
HAZARDOUS POLYMERIZATION: WILL NOT OCCUR
HAZARDOUS THERMAL DECOMPOSITION/COMBUSTION PRODUCTS:
Carbon monoxide.
Carbon dioxide.
Silicon dioxide.
Acetic acid.
1^ INCOMPATIBILITY (MATERIALS TO AVOID):
None known.
CONDITIONS TO AVOID:
None known.

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11. TOXICOLOGICAL INFORMATION

PRODUCT INFORMATION:
ACUTE ORAL LD50 (MG/KG): NA
ACUTE DERMAL LD50 (MG/KG): NA
ACUTE INHALATION LC50 (MG/L): NA
OTHER:
None.

AMES TEST: UNKNOWN

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12. ECOLOGICAL INFORMATION

ECOTOXICOLOGICAL INFORMATION: No data at this time
CHEMICAL FATE INFORMATION: No data at this time

---

13. DISPOSAL CONSIDERATIONS

DISPOSAL METHOD:
Disposal should be made in accordance with federal, state and local regulations.

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14. TRANSPORT INFORMATION

DOT SHIPPING NAME: NONE
DOT HAZARD CLASS: NOT DOT REGULATED
DOT LABEL(S): NONE
UN/NA NUMBER: NONE
PLACARDS: NONE
IATA:
NOT REGULATED BY IATA
IMO IMDG-code: NOT REGULATED FOR OCEAN TRANSPORTATION
EMS No: NA
EUROPEAN CLASS:
RID (OCTI): NONE
1^ ADR (ECE) : NONE
RAR (IATA): NONE

---

15. REGULATORY INFORMATION

SARA SECTION 302:
None Found
SARA (311,312) HAZARD CLASS:
ACUTE HEALTH HAZARD
SARA (313) CHEMICALS:
NONE
CPSC CLASSIFICATION: NA
WHMIS HAZARD CLASS:
D2A VERY TOXIC MATERIALS
D2B TOXIC MATERIALS
WHMIS TRADE SECRET:
None
EXPORT:
SCHDLE B/HTSUS: 3214.10 Mastic Based on Rubber
ECCN: EAR99
HAZARD RATING SYSTEMS
HMIS FLAMMABILITY 0 , REACTIVITY 0 , HEALTH 2
NFPA FLAMMABILITY 0 , REACTIVITY 0 , HEALTH 2
CALIFORNIA PROPOSITION 65:
NONE

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16. OTHER INFORMATION

This product or its components are on the European inventory of existing commercial chemicals (EINECS).....
.....
These data are offered in good faith as typical values and not as product specifications. No warranty, either expressed or implied, is made. The recommended industrial hygiene and safe handling procedures are believed to be generally applicable. However, each user should review these recommendations in the specific context of the intended use and determine whether they are appropriate.
.....

C =	ceiling limit	NEGL =	negligible
EST=	estimated	NF =	none found
NA =	not applicable	UNKN =	unknown
NE =	none established	REC =	recommended
ND =	none determined	V =	recomm. By vendor
By-product = reaction by-product, TSCA inventory status not required under 40 CFR part 720.30(h-2)		SKN =	skin
		TS =	trade secret
		R =	recommended
		MST =	mist
STEL = short term exposure limit		NT =	not tested

.....

DATE PRINTED: 09/25/00

Working Copy

Modification Impact Sheet

WORK ORDER NO. 1107579 M

SIGNATURE SIGN-OFF

1. Spare parts needed?	YES	(NO)	
2. Before equipment operation?	YES	(NO)	
3. Store stock request No. N/A	YES	(NO)	4. CE: JD Farnsworth 7-28-11
5. Fire protection system training needed?	YES	NO	
6. Before equipment operation?	YES	NO	8. FPE: N/A
7. CTS Number: N/A	YES	NO	9. EMM: N/A
10. New PMP or revision to existing needed?	YES	(NO)	
11. Before equipment operation?	YES	(NO)	
12. CTS Number: N/A	YES	(NO)	13. WGM: Maintenance Signature Required
14. Maintenance training needed?	YES	(NO)	
15. Before equipment operation?	YES	(NO)	
16. CTS Number: N/A	YES	(NO)	17. WGM: Maintenance Signature Required
18. New operating procedure or revision to existing procedure needed?	YES	(NO)	
19. Before equipment operation?	YES	(NO)	
20. CTS Number: N/A	YES	(NO)	21. COM:
22. Operations training needed?	YES	(NO)	
23. New panel schedule needed?	YES	(NO)	
24. Before equipment operation?	YES	(NO)	
25. CTS Number: N/A	YES	(NO)	26. COM:

Hazard Identification Checklist

AJHA ID:	Waste Isolation Pilot Plant:
Work Title: WO #1107579M	Date Of Walkdown 8-1-11
Work Scope: FAB + INSTALL 74-B-610 @ P6RM7 INTAKE	

Yes	Hazard
	1. **Portable heating equipment used?**
	2. **Fire system maintenance?** Will the maintenance involve a special fire suppression system such as Halon, Dry Chemical or C02?
	3. **Confined space entry?**
	- **Permit-required confined space?**
	. . . Atmospheric hazards exist in the space?
	. . . Atmospheric hazards introduced ?
	. . . Engulfment/entrapment hazards?
	. . . Potential for introducing adjacent hazards ?
	. . . Mechanical, electrical, or physical safety hazards?
	. . . Reclassify from permit required confined space (PRCS) to non-permit required confined space (NPCS)?
	- **Non-Permit Confined Space?**
	. . . Atmospheric hazards introduced ?
	. . . Potential for introducing adjacent hazards ?
	. . . Mechanical, electrical, or physical safety hazards ?
	- **Space not classified?**
	. . . Will the space be entered for hazard identification?
	4. **Operation of internal combustion engine within a building or enclosed space?** (Not Underground)
	5. **Prepping surfaces, painting, or finishing?**
	- **Preparing surfaces?**
	. . . Abrasive blasting?
	. . . Bead blasting?

	- **Spray painting?**
	- **Flammable or combustible materials?**
	- **Solvent-based paints?**
	- **New paints/products being used?**
	6. Lead or lead-containing materials? This includes work with lead paint, lead shielding, melting and pouring of lead, lead soldering, and any other activity involving lead or lead containing materials
	7. Significant noise sources?
	8. Airborne dusts/particulates ?
	9. Thermal stress (heat or cold stress/hypothermia)?
	- **Heat stress?**
	. . . Radiant heat?
	- **Special-high heat stress situations?**
	- **Cold stress/hypothermia?**
	10. Gas cylinders (bottles) used or affected by the work?
	11. Hot work (Welding, torch cutting, grinding, burning, braising) ? Activity involves elec arc, oxy-fuel gas welding/cutting operations, heavy grinding, brazing, light grinding, tig-welding, or similar activities?
	- **Grinding Activities ?**
	. . . On Uncoated Steel ?
	. . . On Coated Steel or Concrete ?
	. . . On Other (Specify in Comments)
	- **Arc Welding on Carbon Steel?**
	12. Heavy, frequent or awkward lifting?
	13. Ergonomic hazards?
	- **Awkward posture?**
	- **Highly repetitive motion?**
	- **Moderate to high hand-arm vibration?**
	14. Poor Illumination?
	15. Construction, structure modification, or additions?
	- **Installation of new floor coverings?**
	- **Glues and/or adhesives?**
	- **Modifications affecting fire protection features?**

	- Concrete and masonry construction?
	. . . Forms and shoring?
	. . . Concrete pumps?
	. . . Use of a loading skip with a concrete mixer one cubic yard or greater?
	. . . Conveyor/pug mills/concrete batch plants?
	. . . Use of a pneumatic hose? NOTE: IF YES, THEN SEE THE SECTION ON PNEUMATIC TOOLS
	. . . Installing pre-cast concrete?
	. . . Masonry wall construction?
	- Steel erection?
	16. Demolition work?
	- Structure damaged by fire, flood, explosion, or other cause?
	- Hazardous chemicals, gases, explosives, or flammable materials?
	- Multistory structure?
	- Stairs or passageways?
	- Chutes?
	. . . Chute steeper than 45 degrees?
	- Removal of materials through floor openings?
	- Removal of walls, masonry sections, or chimneys?
	- Manual removal of floors?
	- Mechanical demolition?
	- Removal of walls, floors, and material with equipment?
	17. Chemicals/chemical products?
	- Chemicals/chemical products used?
	. . . Explosive-or shock-sensitive chemicals used
	. . . Flammable chemicals used?
	. . . Combustible chemicals used?
	- New chemicals/chemical products?
	- Potential release of gas/vapor?
	18. Aerial lifts/ elevating work platforms?
	- Work on or near electrical conductors?
	- Lift used within 20 feet of high voltage conductor?

	- Will lift/platform be use while in motion?
	- Vehicle mounted platform?
	- Uneven Ground?
	19. Portable ladder?
	- Exposure to elevation of 6 feet or greater?
	- Step ladder used?
	- Straight ladder used?
	- Extension ladder used?
	- Rolling ladder used (stairs)?
	20. Falls from elevation?
	- Personal fall arrest (or restraint) system used?
	- Standard fall protection is NOT feasible?
	21. Slip or trip hazards?
	22. Hazards from falling objects?
	23. Roof work/access?
	- Working within 6 feet of the edge of a flat roof?
	- Roof/structure properly maintained?
	- Roof/structure not maintained?
	24. Hoisting, rigging, or cranes?
	- Mobile crane?
	. . . Boom assembly or dismantling?
	. . . Work near electrical power or communication lines?
	- Overhead or gantry crane?
	. . . Remote operation?
	- Material hoists or monorail cranes?
	- Critical lift?
	- Rigging with lifting eyes or swivel hoist rings?
	25. Use of forklift?
	- Critical lift?
	- Moving explosive or flammable materials?
	- Work near electrical power lines or other overhead obstructions?
	26. Use of motor vehicles?

	- 50-150 Volts?
	. . . Circuit breaker or fused switch operation, door/covers closed?
	. . . Circuit breaker or fused switch operation, door/covers open?
	. . . Verifying absence of power, energized work, < 1.2 cal/sq. cm ?
	. . . Verifying absence of power, > 1.2 cal/sq. cm ?
	. . . Remove bolted covers, < 1.2 cal/sq.cm ?
	. . . Trouble shooting miner?
	- 151-600 Volts?
	. . . Work on energized parts, < 1.2 cal/sq. cm ?
	. . . Work on energized parts, > 1.2 cal/sq. cm ?
	. . . Work on energized parts, > 5 cal/sq. cm, ≤ 8 cal/sq. cm?
	. . . Circuit breaker or fused switch operation, door / covers closed?
	. . . Circuit breaker or fused switch operation, door / covers open?
	. . . Insert or remove power circuit breakers?
	. . . Insert or remove low voltage starter buckets?
	. . . Phasing?
	. . . Moving Insulated Energized Mining Cable *(151 - 600 Volts)*?
	. . . Racking breaker to connect/disconnect position?
	. . . Remove bolted covers, < 1.2 cal/sq. cm *(151-600 Volts)?*
	. . . Remove bolted covers, ≥ 1.2 cal/sq. cm ?
	. . . Verifying absence of power, < 1.2 cal/sq. cm?
	. . . Verifying absence of power, ≥ 1.2 cal/sq. cm, ≤ 5 cal/sq. cm?
	. . . Verifying absence of power, > 5 cal/sq. cm, ≤ 8 cal/sq. cm?
	- 601-15,000 Volts?
	. . . CB, fused switch, LIS operation, doors/covers closed?
	. . . CB, fused switch, LIS operation, doors/covers open?
	. . . Verifying absence of power ?
	. . . Insert/Remove Power Circuit Breakers?
	. . . Insert / Remove Low Voltage Starter Buckets?
	. . . Phasing *(601 - 15,000 Volts)* ?
	. . . Moving Insulated Energized Mining Cable?
	. . . Racking breaker to connect/disconnect position *(601 - 15,000 Volts) ?*

	- Use of vehicle off road?
	- Use of vehicles underground?
	- Light utility vehicles used (e.g., golf carts, and gators, etc.)?
	- Pinch point or 'running-under' obstacle?
	27. Heavy equipment operation?
	- Hauling material over public roads?
	- Overhead and other obstructions?
	- Work near possible flying debris?
	28. Transport equipment, hauling, or loading/off loading?
	- Transportation and receipt of hazardous materials?
	- Service of multi-piece and single piece rim wheels?
	- Powered mobile equipment operated off-highway?
	- Towing or pulling loads?
	29. Stored Energy?
	30. Electrical shock hazards ?
	31. Electrical Maintenance Work?
	- Battery – Gel Sealed?
	. . . Verifying absence of voltage?
	. . . Replacing the battery?
	. . . Cleaning / brushing terminals?
	. . . Removing the battery leads?
	. . . Applying torque to the bolts?
	. . . Taking voltage readings ?
	- Battery – Lead Acid?
	. . . Verifying absence of power?
	. . . Adding water?
	. . . Replacing battery?
	. . . Cleaning/brushing terminals?
	. . . Taking voltage readings?
	. . . Testing specific gravity?
	. . . Removing battery leads?
	. . . Applying torque to bolts?

	. . . Remove bolted covers?
	. . . Work on energized parts, >1.2 cal/sq. cm, ≤ 8 cal/sq. cm?
	. . . Installing grounding clusters?
	. . . Trouble shoot miner, <1.2 cal/sq. cm?
	32. Fiber Optic Installation or Maintenance?
	33. Use of Laser?
	34. Portable hand-held tools used?
	- Powered tools?
	. . . Compressed air? (Including pneumatic tool)?
	- Hand tools?
	. . . Power drill?
	35. Rotating/Articulating machinery?
	36. Machine guarding issues?
	37. Pinch Point
	38. Blind penetration of walls, floors, ceilings, roofs, other surfaces?
	- Penetrates a fire/smoke barrier?
	- Rebar cut during penetration?
	- Potential contact with energized electrical circuit, including heat trace?
	39. Waste generation?
	- Combustible/flammable waste?
	- Dangerous waste/hazardous waste?
	- Other waste?
	- Waste minimization technique?
	40. Hazardous waste activity?
	- Combustible waste forms?
	- Hazardous waste activity at TSD?
	- Hazardous waste characterization, cleanup, or disturbance?
	41. Radiation Hazard?
	42. Excavation?
	43. Working outside?
	- Working over or near water?
	- Desert Animals?

	- **Potential severe weather?**
	- **High wind exposure?**
	- **Lightning?**
	44. Working alone ?
	45. Multiple discipline? (Work requiring more than one crew)?
	46. Adjacent hazardous activities?
	47. Changing conditions?
	48. Ground control hazards?
	49. Mine ventilation?
	50. Sharp objects? Workers will be handling sharp objects such as knives, awls, screwdrivers, razors, shards or objects with sharp edges such as metal flashing, opened cans, or damaged metal surfaces.
	51. Rented or Sub-contractor Equipment?
	52. Biohazards?
	53. User Added Hazards (1)
	54. User Added Hazards (2)
	55. User Added Hazards (3)
	56. User Added Hazards (4)
	57. User Added Hazards (5)
	58. User Added Hazards (6)

	59. User Added Hazards (7)
	60. User Added Hazards (8)
	61. User Added Hazards (9)
	62. User Added Hazards (10)

Comments:

Comments:

Comments:

Walk Down Participants			
Print Name	**Signature**	**Craft/Organization**	**Date**
JILL FARNSWORTH	Jill Farnsworth	ME	8-1-11
DAN CALDERON	Dan Calderon	MPS/Welder	8/1/11
RONNIE CROCKETT	Ronnie Crockett	U/G Safety / Wrks	8/1/11

Task Lead		
Print Name	**Signature**	**Date**
KATHY LITTLETON per tele for FARNSWORTH	Kathy Littleton	12-1-11

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RECORDS

LA-7674-MS
Informal Report

Gas Generation from Radiolytic Attack of TRU-Contaminated Hydrogenous Waste

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545

LA-7674-MS
Informal Report
UC-70
Issued: June 1979

Gas Generation from Radiolytic Attack of TRU-Contaminated Hydrogenous Waste

Al Zerwekh

GAS GENERATION FROM RADIOLYTIC ATTACK OF TRU-CONTAMINATED HYDROGENOUS WASTE

by

Al Zerwekh

ABSTRACT

In 1970, the Waste Management and Transportation Division of the Atomic Energy Commission ordered a segregation of transuranic (TRU)-contaminated solid wastes. Those below a contamination level of 10 nCi/g could still be buried; those above had to be stored retrievably for 20 yr. The possibility that alpha-radiolysis of hydrogenous materials might produce toxic, corrosive, and flammable gases in retrievably stored waste prompted an investigation of gas identities and generation rates in the laboratory and field. Typical waste mixtures were synthesized and contaminated for laboratory experiments, and drums of actual TRU-contaminated waste were instrumented for field testing. Several levels of contamination were studied, as well as pressure, temperature, and moisture effects. G(gas) values were determined for various waste matrices, and degradation products were examined.

I. INTRODUCTION

In 1970, the Waste Management and Transportation Division of the Atomic Energy Commission (AEC) issued an Immediate Action Directive[1] specifying that solid waste contaminated with ^{233}U and its daughter products, plutonium, and transplutonium nuclides (except ^{238}Pu and ^{241}Pu) could continue to be buried at AEC-approved sites if their radioactivity levels did not exceed 10 nCi/g of waste matrix. Plutonium-238 and plutonium-241 were to be handled as transuranic radionuclides (TRU) when so indicated by ^{239}Pu impurities or when required by local burial criteria. Solid wastes contaminated at $\geq$10 nCi/g could no longer be buried, but would be stored at AEC sites, segregated from other radioactively contaminated solid waste, with combustible and noncombustible TRU-contaminated waste packaged separately. The packaging and storing conditions must allow the packages to be retrieved readily for 20 yr in an intact, contamination-free condition.[2]

It was suspected that alpha radiolysis of cellulosic and plastic materials could produce toxic, corrosive, and flammable gases.[3] The presence, or subsequent chemical reactions, of these gases could violate the "intact, contamination-free condition" criterion. However, disagreement on the theoretical magnitude of the gas generation problem did exist.[4] Consequently, an investigation was undertaken to determine actual gas generation rates by laboratory and field experiments.

II. HISTORY

Characteristically, the TRU elements are long-lived (half-lives measured in thousands of years) and decay by emitting discrete energy alpha particles, gamma quanta, and x rays. Because the alpha particles carry practically all the decay energy, the radiolysis effects of gamma and x rays will be significant. Figure 1 provides simplified decay schemes for all TRU elements expected in contaminated solid wastes.

Only rarely will a single plutonium isotope be encountered in solid waste. Table I shows that a mixture of plutonium isotopes will be present. If the percentage of ^{241}Pu is appreciable, as for reactor-produced plutonium, and the plutonium is more than 1 yr old, significant concentrations of ^{241}Am will have grown in. The specific activity of a given radioisotope depends upon its half-life. The specific activities of various TRU nuclides, daughters, and plutonium mixtures are given in Table II.

Most of the early radiation chemistry research involved the radiolysis of water, dilute salt solutions, or gaseous mixtures, using the alpha particles released by the decay of radium and radon.[6] In recent years, a more direct interest in alpha radiolysis has arisen because of the increasing volumes of stored solid hydrogenous wastes contaminated with TRU elements. The waste matrices result from the large quantities of cellulosic wiping materials, discarded laboratory clothing, and rubber gloves used in TRU facilities.

Typically, an average of 34 kg of wastes are packaged and stored in 210-ℓ mild steel drums fitted with a 2.3-mm 100% cross-linked high-density polyethylene liner. Criticality calculations limit the ^{239}Pu content to ≤200 g per drum. Pashman[3] concluded that a maximum pressure of 240 kPa could be contained by a typical drum and liner, but that this pressure might be exceeded in 20 yr by a drum containing even less than the 200-g limit if the ^{239}Pu were distributed evenly in the waste matrix. Michels[4] theorized that H_2 gas pressure build-up would not be significant. He estimated <2 kPa in 20 yr for 200 g ^{239}Pu in a 210-ℓ drum of contaminated waste sealed for storage. However, no supporting data were available. McLain[5] reported H_2 concentrations greater than the minimum explosive mixture following exhumation of culverts containing plutonium-contaminated wastes after 5 yr. The same report refers to radiolysis studies by Bibler,[7] which show that a gas mixture of 48-50% H_2, 38% CO_2, and 13% CO is formed from contaminated cellulosic waste. Various amounts of ^{244}Cm absorbed by paper tissue produced a mixture of 49% H_2, 36% CO_2, and 15% CO at a rate that would become significant in less than 20 yr.[7] Kazanjian[8] ground 1 g ^{239}Pu oxide with combustible material and observed a build-up of gas pressure in 3 months. Extrapolated to 20 yr, the amount of H_2 produced would exceed explosive limits in air in a closed storage facility.

Because of the semiqualitative and limited data in these early reports, we decided to establish an array of simulated waste matrices and to introduce known amounts of radioactive contamination. Detailed analyses of the emitted gases would enable more accurate extrapolations to buried and stored wastes.

III. EXPERIMENTS

A. Laboratory Array

The basis chosen for the experimental array would simulate a "maximum allowable" ^{239}Pu loading; that is, 200 g ^{239}Pu in 34 kg waste. This level of contamination is equivalent to 4 x 10^5 nCi/g waste. For the laboratory-scale experiments, 300-cm^3 stainless steel pressure cylinders were chosen, and each was loaded with 52.5 g of waste matrix. We assumed that there would be a straight-line relationship between energy input and gas generation. Therefore, we attempted to obtain 20 yr of data in 6 months by increasing the rate of alpha attack by a factor of 40. To minimize the quantity of radioactive material present, heat source grade (80%) ^{238}Pu was substituted for weapons grade (94.5%) ^{239}Pu. For each type of waste matrix, there were three different levels of contamination: high, medium, and low. The high level was 62 mg of heat source grade ^{238}Pu in 52.5 g waste to simulate in 6 months the energy dissipation of 200 g ^{239}Pu over 20 yr. The medium level of contamination was 31 mg of ^{238}Pu in 52.5 g of matrix; the low was 6.2 mg. Each cylinder was equipped with a 103.4-kPa (15-psi) pressure gauge and a valve to allow air-free sampling of the contents. On the basis of waste sorting and categorizing at the Los Alamos Scientific

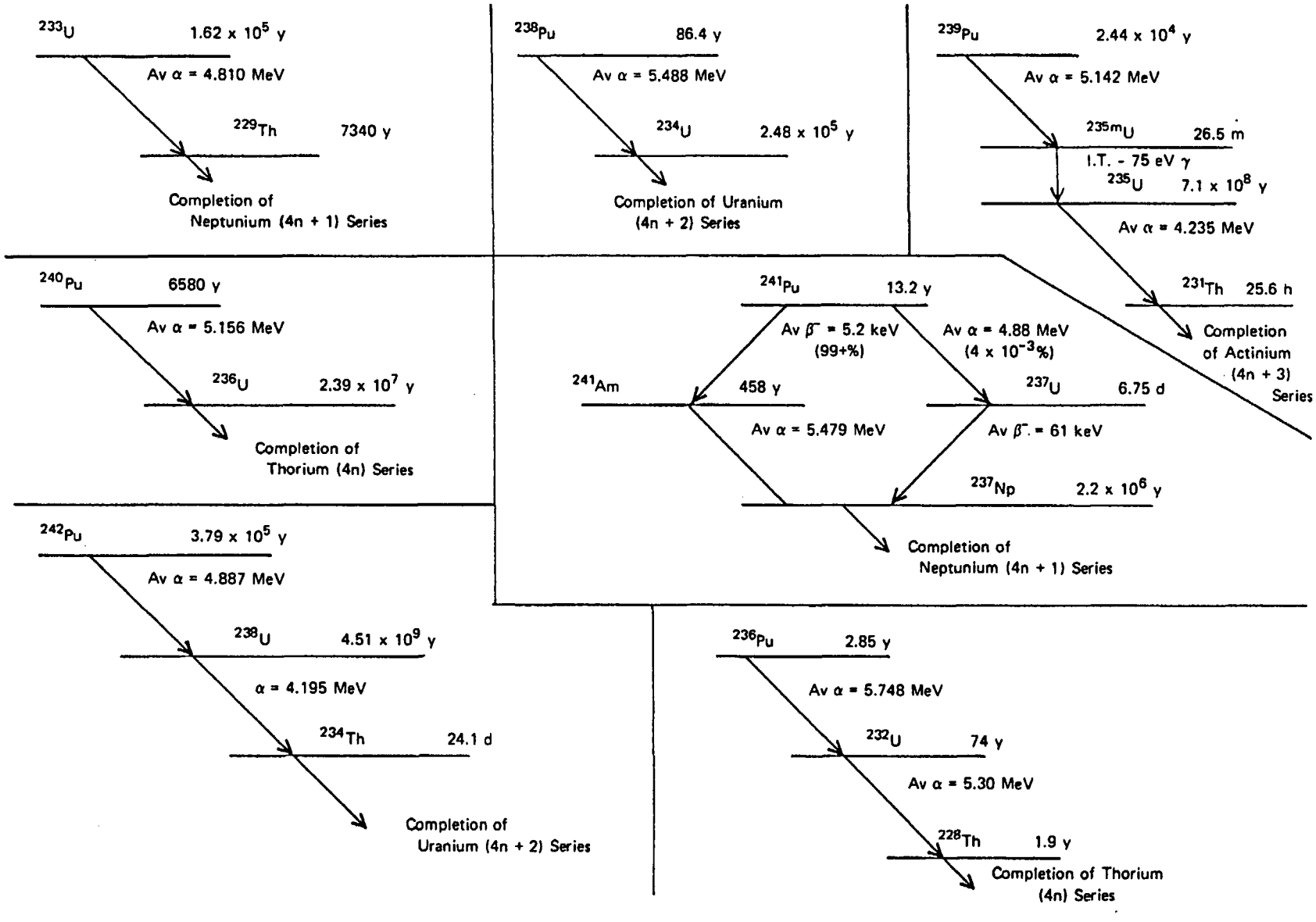


Fig. 1.
Simplified decay schemes for TRU elements.

TABLE I

TYPICAL ISOTOPIC COMPOSITION FOR VARIOUS PLUTONIUM TYPES (wt%)

Type	Burnup 10^3 MWD/T	^{236}Pu	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu
Weapons grade	--	--	--	94.5	5.0	0.5	--
Pressurized	14.5 ± 1	5.1×10^{-6}	0.42	67.0	21.7	9.2	2.1
water	24.0 ± 2	1.2×10^{-5}	1.0	58.5	23.9	11.9	4.4
reactor	29.5 ± 1.5	1.7×10^{-5}	1.4	56.5	23.5	13.0	5.2
	32.5 ± 0.5	2.1×10^{-5}	1.7	55.5	24.3	13.4	5.7
Boiling	19.0 ± 1.5	8.0×10^{-6}	0.9	61.7	22.4	11.3	3.4
water	23.0 ± 0.5	1.1×10^{-5}	1.3	56.9	23.8	12.7	5.3
reactor	27.0 ± 1.0	1.4×10^{-5}	1.7	52.4	25.0	13.7	6.6
	28.0 ± 1.0	1.5×10^{-5}	1.8	54.2	23.8	13.5	6.4
^{238}Pu fuel	--	1.0×10^{-5}	80.0	16.3	3.0	0.6	0.1
Weapons grade	--	--	--	94.5	5.0	0.5	--
Pressurized	14.5 ± 1	5.1×10^{-6}	0.42	67.0	21.7	9.2	2.1
water	24.0 ± 2	1.2×10^{-5}	1.0	58.5	23.9	11.9	4.4
reactor	29.5 ± 1.5	1.7×10^{-5}	1.4	56.5	23.5	13.0	5.2
	32.5 ± 0.5	2.1×10^{-5}	1.7	55.5	24.3	13.4	5.7
Boiling	19.0 ± 1.5	8.0×10^{-6}	0.9	61.7	22.4	11.3	3.4
water	23.0 ± 0.5	1.1×10^{-5}	1.3	56.9	23.8	12.7	5.3
reactor	27.0 ± 1.0	1.4×10^{-5}	1.7	52.4	25.0	13.7	6.6
	28.0 ± 1.0	1.5×10^{-5}	1.8	54.2	23.8	13.5	6.4
^{238}Pu fuel	--	1.0×10^{-5}	80.0	16.3	3.0	0.6	0.1

Laboratory (LASL),[9] the following hydrogenous wastes were chosen for laboratory radiolysis studies.

1. A cellulosics mixture consisting of paper wipes, paper tissues, embossed paper table towel with polyethylene backing (diaper paper), cheesecloth, and cotton laboratory smock material.
2. Hypalon (chlorosulfonated polyethylene) drybox gloves.
3. Isoprene surgical gloves.
4. Polyethylene (low-density) bags, 0.05 mm thick.
5. Tygon (vinyl chloride-acetate copolymer) tubing.
6. Neoprene drybox gloves.
7. Lucite (methylmethacralate) sheet plastic.
8. Polyvinyl chloride, 0.3-mm-thick bagout material.
9. Vinyl Bakelite, 0.3-mm bagout material.
10. Polyethylene (high-density) drum liner material, 2.3 mm thick.

Each of these materials was cut into pieces approximately 5 by 5 cm, except for the Lucite and Tygon, which were cut 1 by 5 cm, and laid out in a flat array to be contaminated with ^{238}Pu contained in 2 *M* HNO_3. The plutonium solution was placed on the pieces with a medicine dropper in as uniform a pattern as possible. The material was allowed to dry, and then was loaded into the 300-cm^3 stainless steel cylinders (Fig. 2). A control cylinder was prepared

TABLE II

SPECIFIC ACTIVITIES OF TRU AND DAUGHTER NUCLIDES

Nuclide	Specific Activity (Ci/g)
^{233}U	0.009 51
^{235}U	0.000 002 15
^{238}U	0.000 000 335
^{238}Pu	17.5
^{239}Pu	0.061 6
^{240}Pu	0.227
^{241}Pu	112.
^{242}Pu	0.003 91
^{241}Am	3.25
Heat source Pu	14.
Weapons grade Pu	0.07[a]

[a]Based on composition given in Table I with ^{241}Pu excluded because of negligible α-activity contribution.

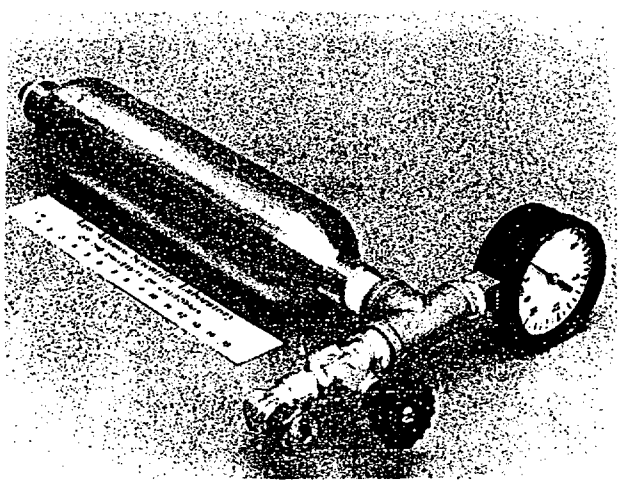


Fig. 2.
Laboratory experimental cylinder.

in exactly the same manner, except that no radioactive contaminant was added. Gas samples were removed periodically and subjected to mass spectrographic analysis. Unless otherwise noted, cylinders were stored at 20°C. After various periods of time up to 315 days, 22 of the cylinders were opened and their irradiated contents removed for examination and identification of degradation products.

Because temperatures in some storage facilities could reach 55°C, thermal effects on radiolysis were also studied. Three cylinders containing 62 mg ^{238}Pu/52.5 g cellulosic waste were stored at −13°C, 20°C, and 55°C. The pressure in each was recorded daily, and the rates of pressure increase were compared.

To determine if increasing pressure would affect gas production rates (approach to equilibrium), one cylinder containing 62 mg ^{238}Pu/52.5-g cellulosic waste was fitted with a 0- to 689.5-kPa (100-psi) gauge, and sampled only after the pressure had reached full scale. The gaseous contents of this cylinder were also examined for evidence of recombination of gases; water was found.

Strongly contaminated (4×10^5 nCi/g waste) samples of vinyl Bakelite and polyvinyl chloride were placed in all-glass systems because of the possibility of HCl generation. It was undesirable to pressurize this apparatus; therefore, significant pressure buildup was avoided by using Orsat-type gas burets to collect the formed gases.

Because free liquids are not permitted in contaminated waste, radioactively contaminated oils are sorbed on vermiculite before disposal. Vacuum pump oil is a significant fraction of this type of liquid waste. Therefore, two 300-cm^3 stainless steel cylinders containing contaminated, sorbed, DuoSeal® vacuum pump oil were prepared. The first contained 35 g of oil on 17.5 g of vermiculite. Before sorption, 62 mg ^{238}Pu as oxide was dispersed thoroughly in the oil. The second cylinder contained the same quantities of DuoSeal and vermiculite, and was contaminated with 31 mg of ^{238}Pu as oxide. The cylinder containing the higher TRU loading began pressurizing 48 h after closure. The cylinder with half as much contamination began pressurization in 108 h.

The presence of sorbed water in TRU solid waste was believed to affect the rate of gas production from alpha attack. If this were true, then cellulosics could be prime suspects because they absorb water so readily. Therefore, we prepared an experimental cylinder containing 52.5 g of cheesecloth and 52.5 g of water by soaking the cloth and then handwringing it to remove as much water as possible. The wet cellulosic was then contaminated with 62 mg of ^{238}Pu as chloride solution. Gas generation in

this cylinder was significantly higher than a comparable cylinder of dry cellulosics.

Matrices of simulated waste typical of that generated at Mound Laboratory were prepared and contaminated with ^{238}Pu at three different levels (Table III). They were equilibrated in 300-cm^3 stainless steel cylinders at ambient laboratory temperature (20°C) for more than 400 days with no readable pressure on 0- to 105-kPa gauges.

Two candidate prefilter materials, GORETEX with WEBRIL BACK® and GORETEX HEAVY POLYESTER®, were cut into 5-cm^2 pieces and contaminated as follows: 1.30 g of the former with 647 mg $^{239}PuO_2$, and 7.93 g of the latter with 592 mg $^{239}PuO_2$. The contamination layers on the filter material appeared to be uniform, with 4 to 8 mg of PuO_2 per cm^2 of material. This layer of contamination was just less than the thickness required to cause a significant pressure drop across filters fabricated from these materials.

While some of these experiments were in progress, various considerations suggested the likelihood of retrievable storage times of greater than 20 yr. Therefore, the experimental period was extended beyond the original 6 months, with selected cylinders still under test.

B. Field Array

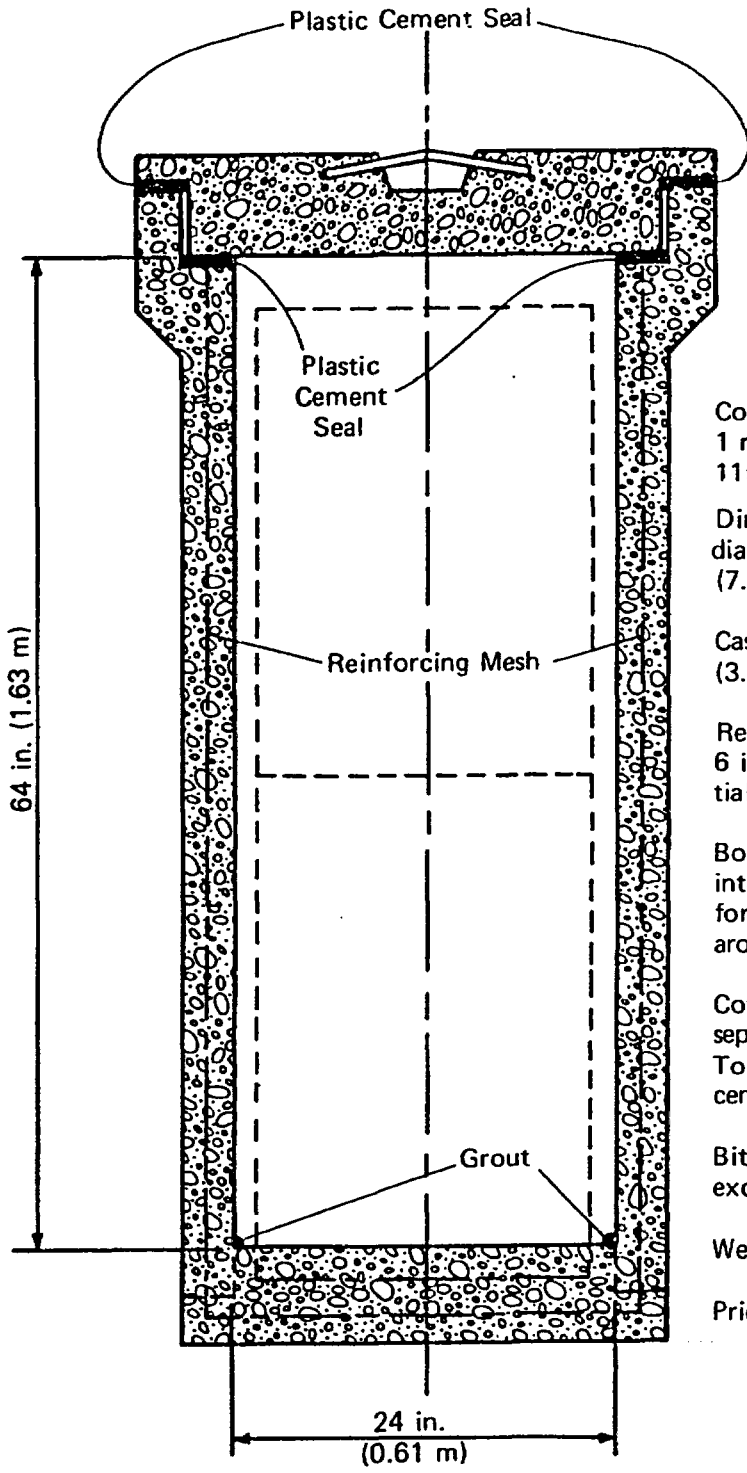
1. Drums Containing ^{238}Pu. In the LASL plutonium production facility, several containers of ^{238}Pu-contaminated solid wastes were available for field evaluation. Their waste contents included drybox sweepings, cheesecloth, emery paper, PuO_2-ThO_2-Mo cermets in chunks and powder, male and female die parts containing pressed cermet disks, foil, steel wool, brass and stainless steel capsules of impure ^{238}Pu oxide, paper, rags, and neoprene artifacts. To supplement the laboratory results with actual field data, an instrumented array of 115-ℓ drums containing the ^{238}Pu-contaminated wastes was set up. The individual wastes were "bagged out" in 0.3-mm polyvinyl chloride (PVC) and placed inside standard 115-ℓ mild steel drums. Two of these drums were then stacked in a concrete storage cask (Fig. 3) and placed in a trench in the LASL waste disposal area. Twenty casks constituted a cell, isolated from the balance of the trench by earthen barriers. The first trench had six cells, the second and third had five each, conforming to the real estate available. For convenience, drums to be studied were placed in the top positions in the casks and instrumented to provide data for (1) temperature inside and outside the drum and underneath the cask

TABLE III

CONTAMINATION LEVELS OF SIMULATED MOUND LABORATORY WASTE

Matrices	Wt% of Drum Contents	Contamination Levels (nCi/g)[a]		
		Strong	Medium	Weak
Plastics 45% polyethylene 45% polypropylene 10% polyvinyl chloride	19	15×10^6	7.5×10^6	2×10^6
Gloves, drybox Neoprene/Hypalon/Pb	56	4×10^6	2×10^6	4×10^6
Cellulosics Rags Paper	25	2×10^6	1.5×10^6	1×10^6

[a]Total ^{238}Pu on waste: 22.8 mg, strong; 12.1 mg, medium; 3.6 mg, weak.



Scale: 1 in. = 1 ft.
(2.54 cm = 30.48 cm)

Concrete Cask
1 required per each pair of 115-ℓ drums.

Dimensions, nominal: 24 in. (0.61m) diam., 64 in. (1.63 m) long, 3-in. (7.6-cm) wall.

Cast reinforced concrete, 5000 psi (3.4×10^3 kPa) compression.

Reinforcing mesh: Longitudinal, No.6, 6 in. (15.24 cm) o.c., Circumferential, No.6, 2 in. (5.08 cm) o.c.

Bottom 6 in, (15.24 cm) thick, cast integrally with longitudinal reinforcing folded into bottom. Grouted around joint of side wall and bottom.

Cover 6 in. (15.24 cm) thick, cast separately, with flush lifting hook. To be sealed in place with plastic cement, roofing type, after filling.

Bitumin coating on cask exterior, except lid.

Weight, 2500 lb (1134 kg).

Price, Approx. $190 (1978).

Fig. 3.
Section through center of concrete cask.

and (2) pressure inside and outside the drum. In addition, gas samples can be withdrawn from the drums, the casks, or the head space outside the casks in each cell. Soil moisture beneath the cask can also be measured. Figure 4 shows the heads of some of the casks with the sampling connections in place. The covers were sealed to the casks with an asphaltic-type plastic cement. The casks were then covered with galvanized, corrugated iron decking (Fig. 5) to allow air space. The iron decking was covered with 1 m of earth backfill. After 94 days' storage, gas samples were withdrawn from the instrumented drums and casks and appropriate temperatures were recorded. Periodic monitoring of temperatures and gas compositions has continued.

2. Drums Containing ^{239}Pu. Approximately 300 mild steel 210-ℓ drums filled with ^{239}Pu-contaminated solid wastes had also accumulated in the LASL waste disposal area. The oldest of these drums had been exposed to the elements for more than 2 yr. A representative group was selected, the gas contents sampled, and the drums were opened to ascertain the state of preservation of the containers and contents. An air-free sampling device was designed and fabricated.[10] Each selected drum was sampled; gas was withdrawn for mass spectrographic analysis. The hole in the drum was resealed, the drum opened at the head, and the contents examined for evidence of radiolytic attack.

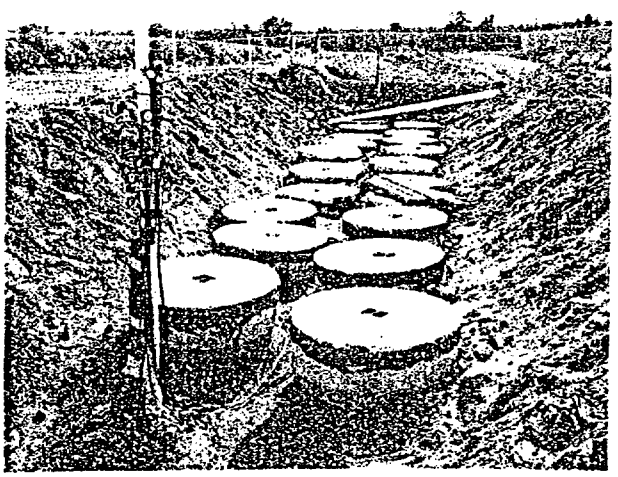


Fig. 4.
Casks with sampling connections in place.

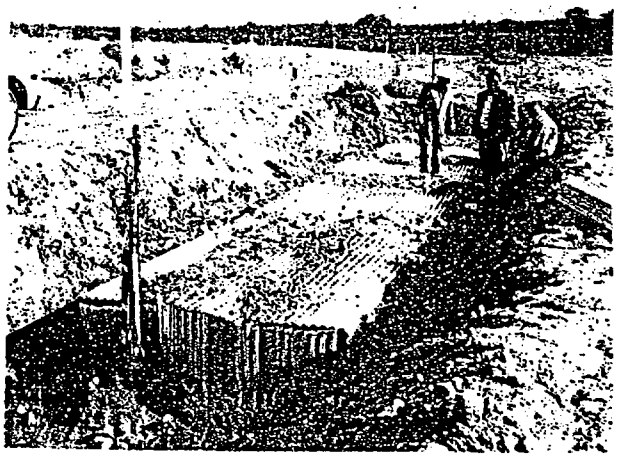


Fig. 5.
Corrugated iron decking in place over casks.

C. Explosimeter Studies

Thirteen 115-ℓ drums of ^{239}Pu-contaminated waste, contained in concrete casks in trench storage at the LASL waste storage area, were instrumented to monitor gas composition and pressure inside and outside the drums, and temperature in and around them, as well as under the casks. The distribution of TRU in the waste matrices is completely random and uncontrolled. The drums chosen to monitor were those with comparatively high (~20 g) ^{239}Pu content, generally present as the oxide. The waste matrices included "combustibles," plastics, paper, "trash," filters, rags, and plastic vials and bags, "sweepings," crucibles, scrap metal, and graphite powder. Periodic sampling and analyses of the gas mixtures generated in these drums showed some of them to be potentially explosive. None of the drums pressurized above 1 atm, due to diffusion of gases through the gasketed drum closures, the concrete casks, and the soil overburden. The escaping gases are not radioactive, so their diffusion to and dilution by the atmosphere is harmless. Actually, it is fortuitous because pressurization of the drums would be unacceptable. Radiolytic attack on the hydrogenous contents of experimental cylinders and waste containers alike have generated gas mixtures containing H_2, CO, CO_2, and CH_4, and occasionally, especially in the presence of temperatures above ambient (20°C), hydrocarbons with molecular

weights up to 60. To determine the explosible limits of these radioactively generated gas mixtures, a laboratory explosimeter was developed (Fig. 6). It consists of a rubber-stoppered Florence flask fitted with a stopcock and two electrodes that allow a radio-frequency arc to pass through the contained gas mixture. A range of gas mixtures for testing was obtained by diluting the gaseous contents from the experimental cylinders with air and argon. Gas samples withdrawn from the waste drums in the field array were tested for explosibility without dilution.

IV. RESULTS

A. Laboratory Array

As stated previously, the experimental array was set up using ^{238}Pu in an attempt to compress 20-yr "retrievable storage time" into 6 months' experimental time. Therefore, the actual quantities of ^{238}Pu used were a factor of 40 higher than an equivalent energy dissipation from 200 g ^{239}Pu. The watt was selected as the fundamental energy term for the experiments and the associated calculations because it has the most universal application to the many scientific disciplines involved with radioactive waste management. Also it was assumed that the mean density of the hydrogenous waste used was 1.0. Therefore, the net volume of the experimental cylinders was taken to be 250 cm^3. Observed pressures and the net volume were used to calculate the moles of evolved gas and the G values. Each time the pressure in a cylinder reached 103.4 to 117.2 kPa (15 to 17 psi) it was sampled, reducing the pressure to 6.9 kPa (1 psi). Mass spectrographic analysis determined the composition of the withdrawn gas.

As the experiments proceeded, it became obvious that only the two higher contamination levels of ^{238}Pu on the polyethylene and cellulosics were evolving gas at any significant rate (Figs. 7 and 8). The other waste matrices in the array, even at the

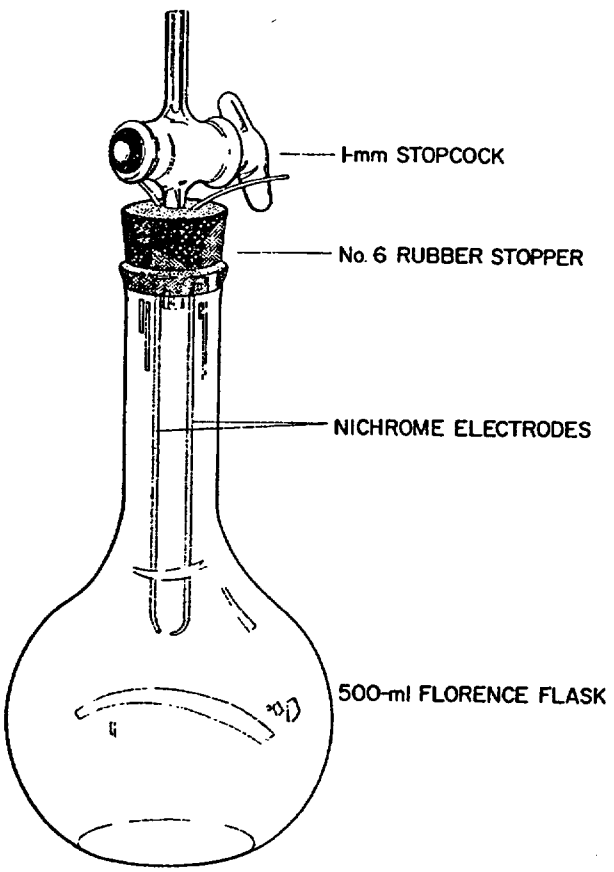


Fig. 6.
Explosimeter.

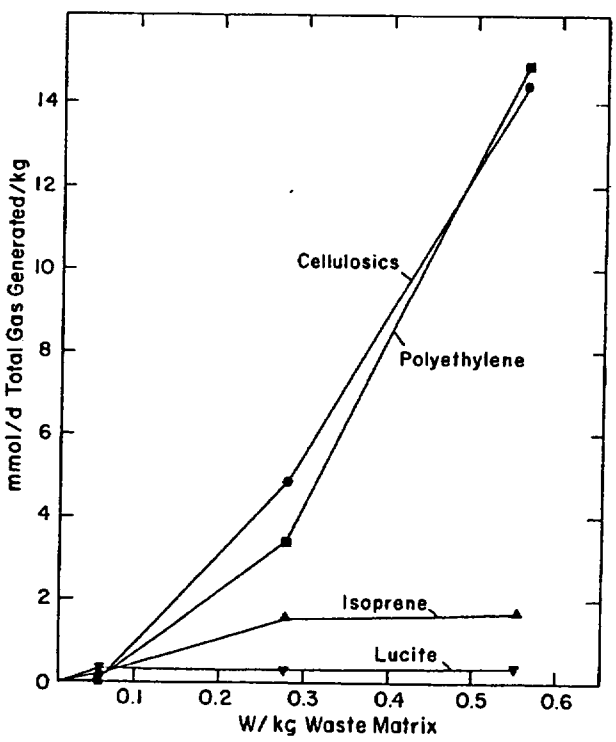


Fig. 7.
Gas generation in experimental waste matrices.

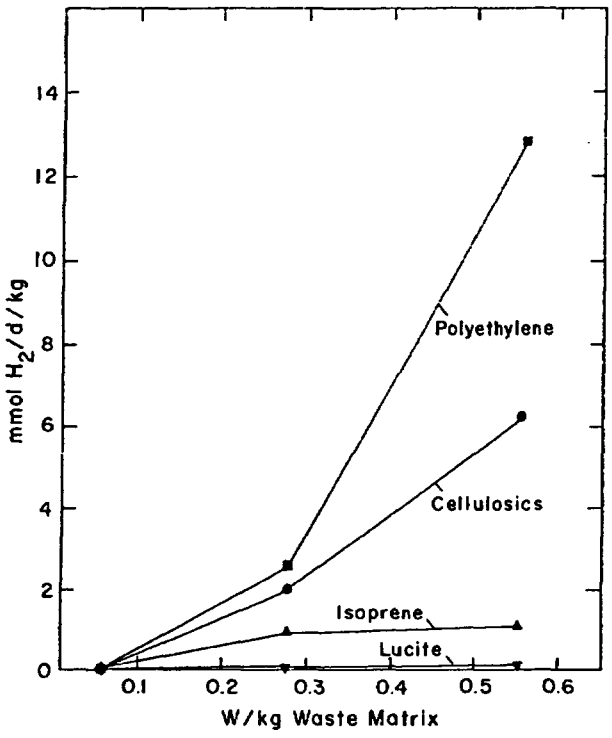


Fig. 8.
Hydrogen generation in experimental waste matrices.

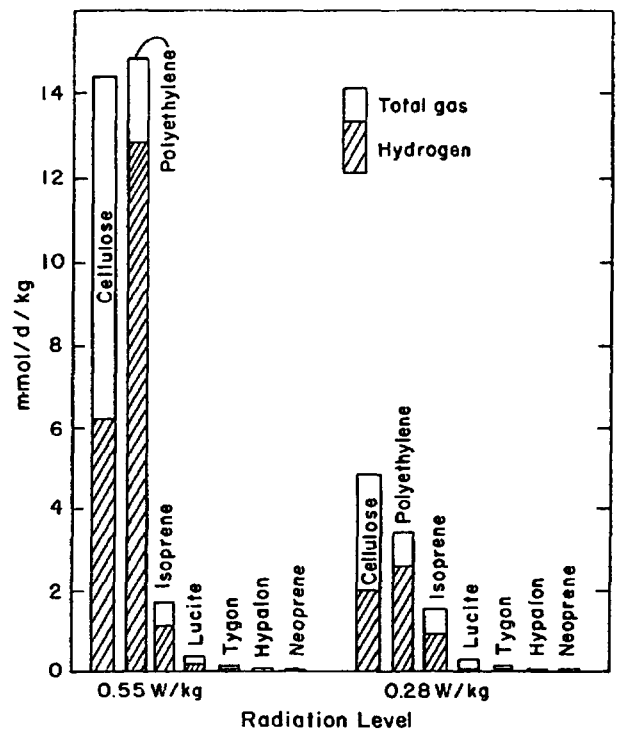


Fig. 9.
Comparison of gas generation from various waste matrices.

highest contamination levels (with the possible exception of isoprene), showed no significant pressure increases for the initial 6 months' experiments (Fig. 9). Analyses of gas mixtures from experimental cylinders are shown in Figs. 10 through 15. Cylinder 1 (Fig. 10) contained dry cellulosics. Note that the major components of the gas mixture generated by this waste matrix are H_2 and CO_2. The quantities of the other combustible gases in the mixture, CO and CH_4, are not significant. Cylinder 29 (Fig. 11) contained thin, low-density polyethylene bag material. The significant component of the gas mixture is H_2. Cylinder 24 (Fig. 12) contained a mixture of cellulosics, plastics, and rubbers, representative of the average TRU-contaminated waste generated at LASL. Here again, the major components of the radiolytically generated gas mixture are H_2 and CO_2. The contents of Cylinder 35 (Fig. 13) were wet cellulosics, and again we see mainly H_2 and CO_2 generated by alpha attack of the matrix. Cylinders 33 and 34 (Figs. 14 and 15) contained DuoSeal® vacuum pump oil sorbed on vermiculite. H_2 was the only gas present in significant quantity in the mixture, with CH_4 a distant second. CO_2 never exceeded 0.6%, CO 0.7%. O_2 was not plotted on the graph because it was <0.1% at the first sampling, and never exceeded that value. Atmospheric N_2 was depleted by repeated dilution and virtually disappeared after the third sampling. In no case was N_2 or NO_x generated, nor did it enter into any reactions in any of the cylinders.

After termination of the experiments, the cylinders were opened as noted above. A tan powder was found throughout all the cellulosics waste matrices. For those cylinders containing only cellulosics, approximately 10% of the original weight of the waste was powdered. For cylinders containing a mixture of waste, the weight of powder was proportionately less, indicating that it was mostly a degradation product of cellulosics. The powder contained approximately 50% of the TRU contaminant that was added originally. It was highly combustible, with an ash content of <1%. No other waste matrices showed similar degradation products except

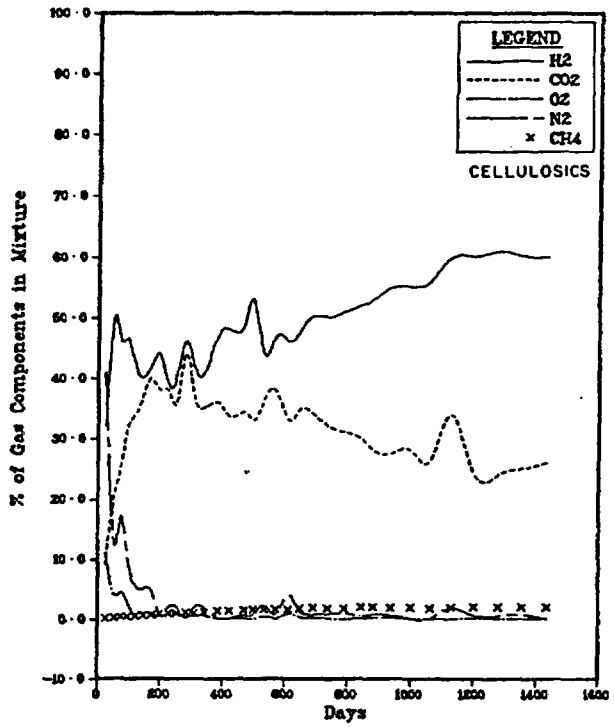


Fig. 10.
Gas mixture in Cylinder 1.

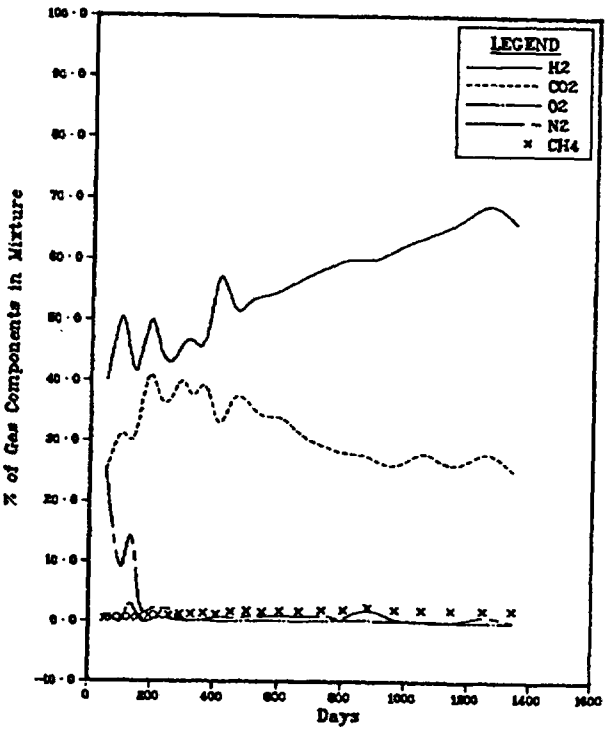


Fig. 12.
Cylinder 24. Cellulosics, plastics, and rubbers.

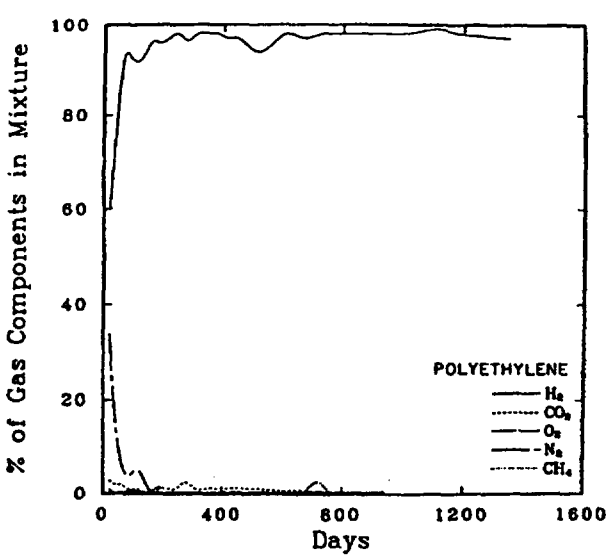


Fig. 11.
Gas mixture in Cylinder 29.

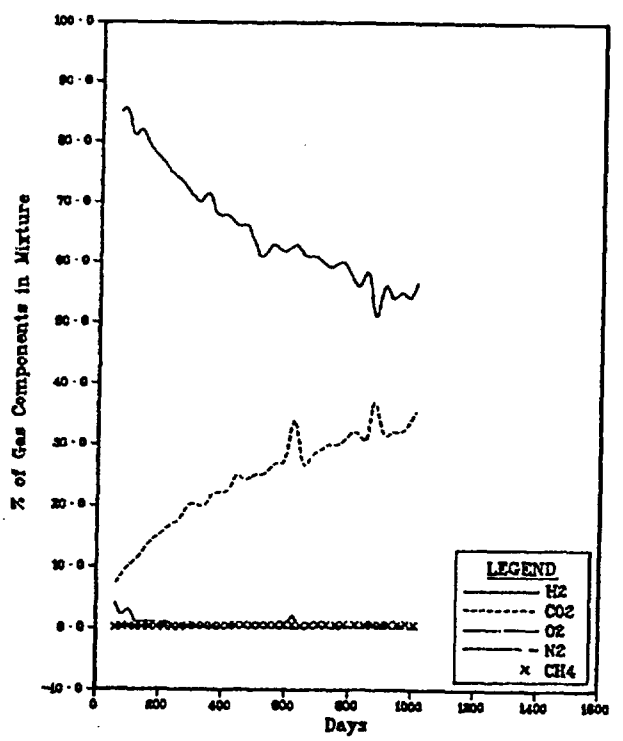


Fig. 13.
Wet cellulosics.

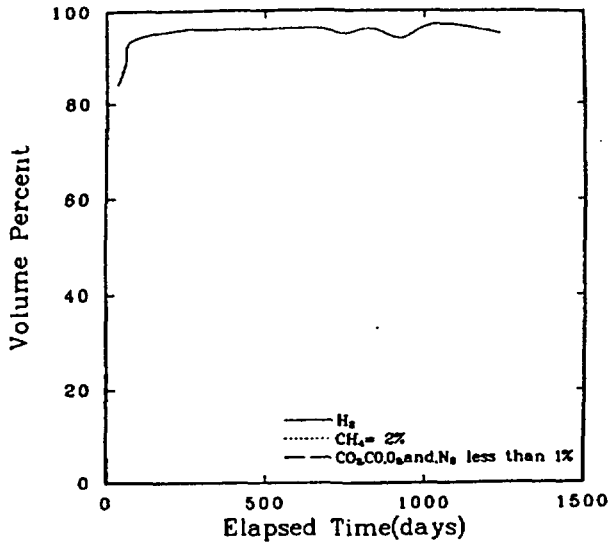


Fig. 14.
DuoSeal® on vermiculite.

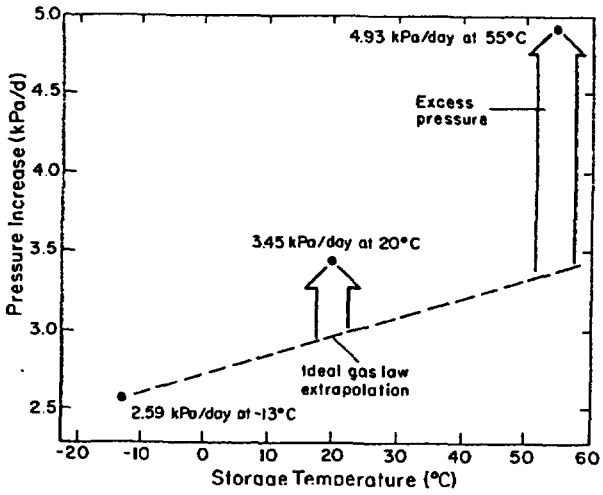


Fig. 16.
Enhancement of gas generation with increasing temperature.

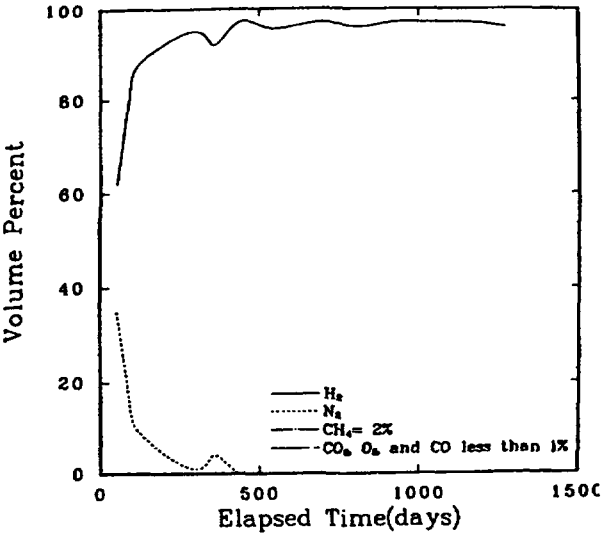


Fig. 15.
DuoSeal® on vermiculite.

strongly contaminated neoprene drybox glove material. A rust-colored granular material was separated from the original neoprene loading and found to leave a residue of 50 wt% ash after ignition at 1000°C for 30 min.

Three of the experimental cylinders, each loaded with 52.5 g of cellulosics and contaminated with 62 mg of ^{238}Pu, were stored at −13°C, 20°C (room temperature), and 55°C. Each continued to generate a gas mixture of H_2, CO, CO_2, and CH_4. The composition of the mixture generally was independent of the storage temperature. However, the 55°C cylinder also generated a gas of about 60 molecular weight. The rates of pressure increase were significantly different, increasing with temperature at a rate greater than predicted by the ideal gas law. An analysis of variance performed on the data indicated that the pressure differences were highly significant and could not be attributed to experimental error, suggesting a synergistic enhancement of gas generation with increasing temperature. Figure 16 illustrates this enhancement. Figure 17 compares gas production rates for two cylinders containing cellulosics and identical quantities of ^{238}Pu contaminant. Both cylinders were held at ambient temperature (20°C) for a year. Cylinder 1 was then cooled to −13°C from day 370 to day 430. During this same time, Cylinder 22 was heated at 55°C. The effects of these temperature changes are apparent in the graph. The cylinders were returned to room temperature (20°C), and then at day 540, Cylinder 22 was put back into the oven, and has been held at 38°C since, whereas Cylinder 1 was continued at 20°C. Note that the immediate effect on Cylinder 22 was increased rate of gas production, but with time the effect became less pronounced. In addition, the traces on the graph representing both cylinders

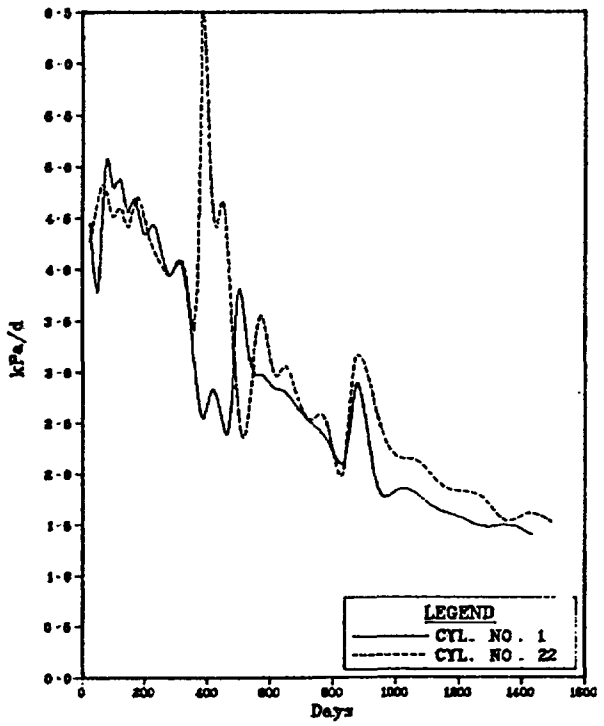


Fig. 17.
Temperature effects.

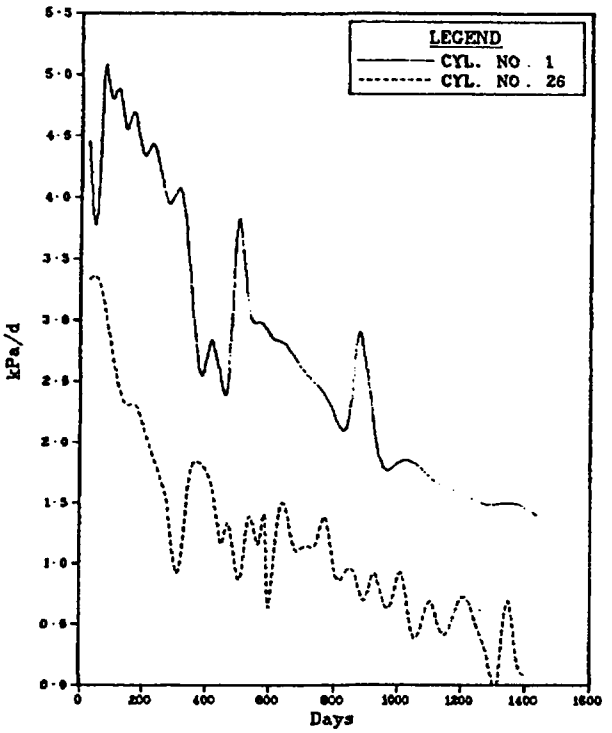


Fig. 18.
Comparison of rates of gas pressure build-up in two experimental cylinders.

show a continuing decrease in rate of gas production, probably due to less effective deposition of energy in the waste substrates from the alpha particles. This phenomenon is typical of all laboratory cylinders that were and are being studied. Thorough mechanical shaking of Cylinders 1 and 22 on two different occasions did not change the rate; the cylinders may have been packed too tightly to permit the agitation to rearrange their contents.

Experimental Cylinder 26, loaded with 52.5 g cellulosics and contaminated with 62 mg of ^{238}Pu, was fitted with a 689.5-kPa (100-psi) gauge. It was stored at ambient temperature (20°C) and was not sampled until it pressurized to full scale. This required 285 days, during which time the rate of pressure increase showed a steady decrease. Figure 18 compares the rate of pressure increase for this cylinder with that of Cylinder 1, filled with similarly contaminated cellulosics, but fitted with a 103.4-kPa (15-psi) gauge, and sampled each time it pressurized to full scale. The graph shows that the rate of gas formation was less in the more highly pressurized cylinder. It also shows that in both cylinders there was a diminution in rate with time, a phenomenon previously discussed. The gases formed in Cylinder 26 were the same as those formed in other cylinders filled with contaminated cellulosics (Table IV). In addition, water was found in this gas mixture, but not in the gas mixture from Cylinder 1, where the gas was withdrawn frequently. After the gas composition sample was withdrawn from Cylinder 26 at ~3.9 yr, an additional series of samples was withdrawn over a 60-day period, gradually lowering the pressure in the cylinder from 669 to 48 kPa. Water was determined repeatedly in these samples, and was being generated at the rate of 10.5 μg H_2O/g cellulosic waste/yr.

The strongly contaminated vinyl Bakelite and polyvinyl chloride (PVC) samples were placed in all-glass apparatus because we suspected that HCl might be a degradation product. Vinyl Bakelite produced 100 cm^3 of gas in 69 days. This gas was

TABLE IV

COMPOSITION OF GAS MIXTURE IN CYLINDER 26 (mol%)

Component	285 Days	371 Days	508 Days	1426 Days
H_2	50	51	50	54
CO_2	32	32	35	36
CO	10	10	7	4
CH_4	0.8	0.9	1.0	1.0
O_2	<0.1	<0.1	<0.1	<0.1
N_2	8	6	6	3

analyzed mass spectrographically and found to contain 4% H_2, 2% CO, 0.9% CO_2, and 0.2% CH_4. The spectrograph did not detect Cl or HCl, but wet chemical analysis found 0.06% Cl. At the time the gas sample was taken, the contaminated matrix was still intact, pliable, and only slightly darkened in color. Kazanjian and Horrell[11] estimated that PVC would withstand indefinite alpha attack from low-level waste at ambient temperature. However, they found a strong synergism between thermal and radiative effects when the temperature was 60°C and the radiation several orders of magnitude greater than that found in ordinary TRU waste. Attack by heat produces up to 50 wt% chlorine from chlorinated vinyls; therefore, we assumed that radiolytic decomposition would be comparable. Obviously this was not the case. In an additional 280 days, these materials continued to darken and were somewhat embrittled, but still intact, and the vinyl Bakelite had produced only an additional 10 cm^3 of gas. The PVC bagout material showed resistance to radiolytic attack similar to that shown by the vinyl Bakelite. In 335 days it produced only 10 cm^3 of gas mixture, containing 0.6% H_2, 0.1% CO, 1.0% CO_2, and 0.1% CH_4. The balance of the sample was oxygen-depleted air.

Cylinder 36 contains 52.5 g of 100% cross-linked high-density polethylene cut into pieces ~1 by 5 cm and contaminated with 62 mg ^{238}Pu. The contaminant was placed on the plastic as was the chloride solution, and dried in place before loading. The cylinder was fitted with the usual 103.4-kPa (15-psi) pressure gauge and has been closed for >1300 days without pressurizing. At day 674, and again at day 1318, gas samples were withdrawn. Table V shows the results.

TABLE V

GAS MIXTURE FROM RADIOLYTIC ATTACK OF HIGH-DENSITY POLYETHYLENE

Days Elapsed	Gas Composition (mol%) H_2	CH_4	O_2	CO	CO_2	N_2
674	5.0	0.1	<0.1	<0.1	17	77
1318	4.0	<0.1	<0.1	0.4	20	75

Matrices typical of Mound Laboratory wastes contaminated with ^{238}Pu at three different levels (Table III) were equilibrated in 300-cm^3, stainless steel cylinders (Fig. 2) at ambient laboratory temperature (20°C) for more than 400 days without pressure increase. Mass spectrographic analysis of a gas sample from the cylinder containing the most highly contaminated matrix showed the following composition: H_2, 0.6%; CH_4, <0.1%; O_2, 14.8%; CO_2, 3.9%; CO, 0.8%; and N_2, 79.1%. Examination of the cylinder's contents showed that the rags and paper had deteriorated the most, and neoprene the least. Figure 19 shows the waste matrices after removal from the test cylinder. If such wastes were to be reprocessed, they would require very careful handling because the disintegrated cellulosics contained the typical brown powder previously described: very low density, easily airborne, and highly contaminated.

B. Field Array

1. Drums Containing ^{239}Pu. Table VI gives details of 20 drums selected for analysis and examination. Little evidence for gas generation from radiolytic attack was seen, and no pressurization was detected. It is virtually impossible to maintain a gas-tight seal on a typical waste storage drum. Therefore, any gases formed during the ~2-yr storage could easily have diffused to the atmosphere, and air probably diffused into the drums. Drum 128 appeared to have been better sealed than the others in the test group, and to have generated

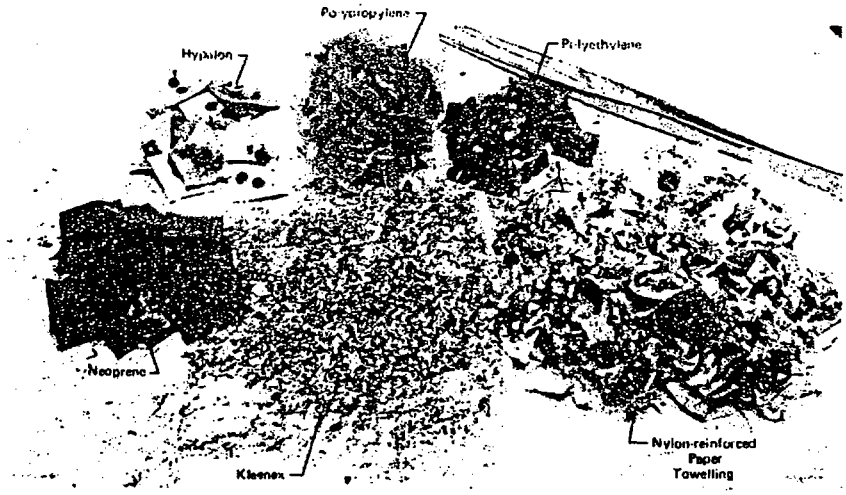


Fig. 19.
Degraded wastes removed from test cylinder.

enough gases to contain a potentially explosible mixture, but it was not pressurized above 1 atm. The drum contained empty 2-ℓ glass bottles that had held plutonium recovery solutions. Apparently they were not well rinsed before being discarded.

To see what the cumulative effect of a quantity of ^{239}Pu-contaminated waste-filled containers might be, a closed, underground storage cell containing

2 - 57-ℓ drums,
304 - 115-ℓ drums,
197 - 210-ℓ drums, and
52 - fiber glass reinforced plastic covered plywood boxes, of assorted sizes,

had gas samples withdrawn after remaining undisturbed for more than a year. This underground cell is approximately 15 m long, 8 m wide, and 8 m deep. The total volume of the waste is 407.5 m^3. The atmosphere in the cell was sampled at one end near the top, and at the opposite end near the bottom. The results of the mass spectrographic analysis of the cell atmosphere are shown in Table VII.

2. Drums Containing ^{238}Pu. Thirteen 115-ℓ drums stored in covered trenches at the LASL waste burial site were chosen for instrumentation and monitoring. These drums, filled with ^{238}Pu-contaminated waste, continue to generate gases, and presumably are representative of all drums in that storage. There is no way to measure the quantity of gas produced because it continually diffuses to the atmosphere through drum gaskets, cask walls, and earthen overburden. It is not contaminated. However, as shown in Table VIII, changes in the composition of the gas mixtures have taken place between samplings. This may be due partly to seasonal thermal cycling. It undoubtedly is enhanced by the periodic removal of gas samples. Each sampling removes 1 to 2% of the gaseous contents of the drum, and we must assume there is inward diffusion of air to bring the pressure in the drum back to 1 atm. This would account for the persistence of oxygen in some of the mixtures in spite of the continuing production of CO and CO_2. Drum 232, at day 245, appeared to contain an explosive mixture. It was sampled and tested in the explosimeter with negative results. Note that the H_2 percentage decreased with age, whereas the O_2 and N_2 increased, indicating an influx of air. Drum 301 was sampled at day 36, and the gaseous mixture was explosive. As it has grown older, the H_2 and CO_2 percentages in the mixtures have increased steadily; the O_2 had dropped to <0.1%. Clearly, the contaminant is dispersed much more effectively in some drums than in others. The gaseous contents of Drum 330 reached an explosible state in 200 days. Note the decrease in H_2 and the increase in O_2 and N_2 that followed. Again, apparently caused by an inward diffusion of air.

TABLE VI

115- and 210-ℓ DRUMS OF ^{239}Pu-CONTAMINATED WASTE SELECTED FROM STORAGE FOR ANALYSIS AND EXAMINATION

Drum No.	Months in Storage	Description of Contents	Net Wt of Contents (kg)	^{239}Pu Content		Gases Present (mol%)						
				g	nCi/g matrix	H_2	CH_4	O_2	Ar	CO_2	CO	N_2
1A	28	Leached plant process solids	30.1	113	2.6×10^6	0	0	23	1	0.2	0.5	72
2B	28	Leached plant process solids	30.0	113	2.6×10^6	0	0.9	20	1	0.3	0.2	78
12	15	NUMEC and Hanford plant process solids	28.6	28.6	2.3×10^4	0.1	0	19	1	0.6	0.4	67
42	11	Plastic trash	28.1	7.0	1.8×10^4	0	0	22	1	0.1	0.4	79
43	12	Plastic and rubber packaging material	18.6	5.0	1.9×10^4	0.1	0	21	1	0.2	0.5	70
49	9	Offsite processing solids and junk	33.6	16.2	3.4×10^4	0	0	22	1	0.1	0.5	79
66	9	Hanford and plant processing solids	32.7	13.5	2.9×10^4	0	0	23	1	0.4	0.5	74
94	6	Glass residue from process area	39.1	1.6	2.9×10^3	0	0	22	1	0.1	0.3	78
95	7	Cellulose residue	9.5	3.2	2.4×10^4	0	0	23	1	0.2	0.7	73
126	7	Sorted wastes (glass)	28.6	7.5	1.8×10^4	0	0	19	1	0.1	0.4	78
128	6	Sorted wastes (glass)	25.7	1.3	3.5×10^3	18	0.2	13	0.7	16	5	48
141	5	Sorted wastes (rubber)	38.3	2.6	4.7×10^3	0	0	19	1	0.1	0.4	78
149	6	Sorted wastes (cellulosics)	11.2	0.5	3.1×10^3	0	0	20	1	0.4	0.5	68
151	5	Hanford processing solids	29.2	35.5	8.6×10^4	0	0	20	1	0.4	0.4	77
161	6	Sorted process-generated solids	11.3	0.7	4.3×10^3	0	0	18	1	0.6	0.6	78
163	6	Sorted process-generated solids	43.1	2.5	4.1×10^3	0	0	20	1	0.1	0.4	79
194	7	Hanford processing solids	12.4	42.5	2.4×10^5	0	0	20	1	0.3	0.4	70
201	6	Hanford processing solids	68.8	149.6	1.5×10^5	0	0	20	1	0.7	0.4	79
248	2	Hanford processing solids	46.8	101.4	1.5×10^5	0.1	0	18	1	3	0.3	68
270	2	Hanford processing solids	28.7	72.8	1.8×10^5	0	0	19	1	0.8	0.3	70

TABLE VII

ATMOSPHERE FOUND IN CLOSED INTERIM STORAGE CELL GAS COMPONENT (mol%)

	H_2	CH_2	O_2	CO	CO_2	N_2
Top	<0.1	<0.1	21	0.2	0.4	77
Bottom	<0.1	<0.1	20	0.1	0.5	78

3. **Explosimeter Studies.** The explosimeter data obtained for the above drums showed the need to establish some parameters for predicting explosiveness. The variety of gas mixtures needed for this study was not available in the field array; therefore, the mixtures were synthesized from the gaseous contents of the laboratory experimental cylinders, air, and argon. Hydrogen commonly is accepted to be explosible in air when present in the 4- to 76-vol% range. We suspected that the typical gas mixture found in contaminated waste containers (H_2, CO, CO_2, CH_4, residual air, and possible traces of hydrocarbons) might have different explosible limits. In an attempt to establish these limits, more than 80 explosimeter tests were performed. The results are shown in Table IX.

V. DISCUSSION

In addition to the work reported here, Kazanjian[6] and Bibler[7] have studied gas production by radiolytic attack of hydrogenous waste and have found similar mixtures of gases, hydrogen being the predominant gas produced. Because the conditions of the experiments varied, it is difficult to compare results. Kazanjian states that "appreciable amounts of hydrogen are usually produced, but will not be accompanied by oxygen in a drum for most of the storage period." This is in agreement with our findings, but does not take into account the probability of air diffusion into the drums.

The volume of gases generated by the alpha radiolytic attack of hydrogenous materials is dependent on the quantity of radionuclide present, the size and distribution of the particles of TRU material, and the identity of the hydrogenous substrate. To avoid the possibility of achieving criticality in waste storage, ^{239}Pu is limited to 200 g of weapons-grade material per 210-ℓ drum. This is a contamination equivalent to 4×10^5 nCi/g waste. In actual practice, this level of contamination seldom is achieved. Studies of several years' records for contaminated waste stored at LASL and also at INEL indicate that very few drums contain anywhere near the limit. The average is <10 g of ^{239}Pu per 210-ℓ drum, and many drums contain 1 g or less. Such drums do not generate measurable quantities of gas.

Elevated temperature was found to increase the rate of gas formation (Fig. 17) and additional work in progress corroborates this finding. However, careful study of Fig. 17 reveals that this effect appears to diminish with time. For a long-term isolation, I believe it will cease to be significant. Extrapolation of the curve shown in Fig. 20 reinforces this belief. Please recall the temperature history of Cylinder 22: 1 yr at 20°C, 0.25 yr at 55, 0.23 yr at 20, and 3.5 yr at 38 (to present).

The rate of gas formation decreases as pressure increases (as observed in Fig. 18); the possible benefit in case of deep underground disposal is obvious. If, as the data seem to indicate, this phenomenon is the result of recombining H_2 and O_2, then the rate of water formation probably would be greater initially than the 10.5 mg of H_2O/kg of cellulosic waste/yr observed. However, it would diminish as H_2 production diminished (Fig. 21) and a source of O_2 was no longer available. Extrapolation of this curve shows that the diminution of water production probably would take place during the working life of a repository; for the long term, the gas and water production would be insignificant. Molecke has affirmed[12] that shallow land burial or underground storage does not create a problem—but at the rate of gas generation shown, radiolytically generated gas formation in a sealed deep geologic disposal appears not to be a problem, either. The author believes that the ongoing LASL research and development radiolysis studies for the Waste Isolation Pilot Plant (WIPP) will corroborate this statement.

TABLE VIII

DATA FROM ^{238}Pu-CONTAMINATED WASTE IN COVERED-TRENCH STORAGE

Drum No.	^{238}Pu Content (g)	Waste Content (kg)	Days in Storage	Temperature (°C)				Gas Composition (mol%)					
				Inside Drum	Outside Drum	Ambient	Soil Under Cask	H_2	CH_4	O_2	Co_2	CO	N_2
223	14.9	17.9	(Dec) 41	12.5	11.5	2.0	7.0	0.8	0.1	16.0	6.3	2.0	74.0
			(Jul) 626	23.5	24.0	23.0	19.0	0.9	0.1	11.2	7.5	0.8	78.6
			(Oct)1078	23.5	23.5	23.0	15.0	0.8	<0.1	11.0	8.0	2.0	78.0
224	22.1	14.5	(Dec) 41	18.0	12.5	2.0	7.0	0.2	<0.1	19.0	1.4	0.7	77.0
			(Jan) 434	21.0	18.0	4.0	12.0	0.2	<0.1	18.5	1.0	0.2	78.5
			(Oct)1078	31.5	23.5	23.0	15.0	0.2	<0.1	17.0	1.0	0.5	80
232	29.4	10.2	(Jul) 245	29.0	24.0	27.0	16.0	8.0	0.5	6.0	17.0	6.0	61.0
			(Jan) 434	23.5	17.5	4.0	12.0	6.0	0.3	6.6	12.0	3.0	71.0
			(Jul) 626	32.5	27.0	23.0	19.0	2.9	0.2	10.0	8.8	0.9	76.4
			(Oct)1081	32.0	25.5	23.0	15.0	2.0	<0.1	9.0	8.0	1.0	79
281	19.7	26.0	(Jul) 229	--	24.5	23.0	19.0	1.3	0.2	15.9	4.1	0.8	76.8
			(Jan) 400	--	17.5	4.0	15.5	3.4	0.1	13.3	7.1	<0.1	75.1
			(Oct) 677	--	23.0	23.0	15.0	2.0	0.1	13.0	6.0	1.0	77.0
301	18.7	23.6	(Jan) 36[a]	--	15.0	4.0	11.0	11.0	0.5	10.0	11.0	4.0	62.0
			(Jul) 222	--	25.0	23.0	19.0	41.9	1.4	<0.1	23.2	10.1	22.9
			(Oct) 683	--	23.0	23.0	15.0	55.0	2.0	<0.1	25.0	13.0	5.0
330	17.4	10.9	(Jun) 23	20.5	21.0	19.0	19.0	1.7	<0.1	18.1	3.0	1.2	75.0
			(Jan) 200[a]	15.5	15.5	4.0	15.5	9.1	0.4	11.0	12.4	<0.1	66.3
			(Oct) 457	23.5	23.5	23.0	15.0	4.0	0.3	12.0	10.0	4.0	69
380	27.5	27.7	(Apr) 15	16.0	12.0	13.5	15.0	1.8	0.2	18.5	3.9	2.6	72.1
			(May) 35	22.0	20.0	21.0	10.5	1.7	0.2	17.9	3.9	2.0	73.5
			(Oct) 195	25.0	23.0	23.0	15.0	1.0	0.2	18.0	3.0	2.0	75.0

[a]These samples were tested and found explosive.

TABLE IX

SELECTED EXPLOSIMETER TESTS ON VARIOUS GAS MIXTURES

Expl Test No.	Gas Composition						Explosible	Matrix
	H_2	CH_4	O_2	CO_2	CO	N_2		
53	4.1	0.2	19.2	2.5	1.5	71.6	No	Cellulosics
52	4.3	0.1	9.8	0.1	0.2	36.6	No	DuoSeal® on vermiculite
59	4.5	0.2	19.1	2.8	1.4	71.1	No	Cellulosics
49	5.0	<0.1	11.7	2.0	0.9	43.3	No	Water-soaked cellulosics
62	5.0	0.1	19.7	0.1	0.2	73.5	No	DuoSeal® on vermiculite
50	5.2	0.2	14.8	2.5	0.8	55.4	No	Cellulosics, plastics, rubbers
70	5.3	0.1	15.3	0.1	0.2	58.4	No	DuoSeal® on vermiculite
67	5.4	<0.1	5.4	2.5	1.0	20.1	No	Water-soaked cellulosics
66	5.5	0.2	5.7	2.8	1.9	21.1	No	Cellulosics
68	5.5	0.2	7.1	3.2	1.5	27.0	No	Cellulosics
51	5.5	0.2	19.6	0.1	0.3	73.5	No	DuoSeal® on vermiculite
48	5.6	<0.1	6.8	1.9	0.9	24.4	No	Water-soaked cellulosics
58	5.9	0.2	4.8	3.0	2.0	18.0	No	Cellulosics
69	5.9	<0.1	9.9	<0.1	0.3	37.0	No	Polyethylene
57	6.0	<0.1	5.0	2.0	1.0	18.0	No	Water-soaked cellulosics
60	6.0	<0.1	9.8	2.5	1.1	36.9	No	Water-soaked cellulosics
42	6.1	0.2	6.5	3.6	1.9	23.6	Yes	Cellulosics
72	6.1	0.2	7.4	3.6	2.0	27.0	Yes	Cellulosics
44	6.2	<0.1	6.0	2.1	0.9	21.0	No	Water-soaked cellulosics
46	6.3	<0.1	6.7	<0.1	0.3	24.3	No	Polyethylene
74	6.3	0.2	7.3	<0.1	0.1	27.8	No	DuoSeal® on vermiculite
71	6.4	<0.1	18.7	2.9	1.0	70.0	No	Water-soaked cellulosics
75	6.5	0.2	7.4	3.0	0.7	27.0	Yes	Cellulosics, plastics, rubbers
45	6.6	0.2	6.5	<0.1	0.2	24.1	No	DuoSeal® on vermiculite
61	6.7	<0.1	14.3	<0.1	0.2	54.8	No	Polyethylene
55	6.8	<0.1	6.2	0.1	0.3	24.0	Yes	Polyethylene
76	6.8	0.3	7.0	4.6	0.1	26.3	Yes	Cellulosics
43	6.8	0.2	7.9	0.1	0.2	29.2	Yes	DuoSeal® on vermiculite
73	6.9	<0.1	7.4	3.2	1.2	26.5	Yes	Water-soaked cellulosics
40	6.9	0.3	9.0	6.0	2.0	34.0	Yes	Cellulosics
56	7.0	<0.1	6.4	3.0	1.0	24.0	Yes	Water-soaked cellulosics
64	7.0	0.2	6.6	3.0	1.0	25.0	Yes	Cellulosics, plastics, rubbers
47	7.1	0.3	6.9	5.4	2.0	25.2	Yes	Cellulosics
41	7.3	0.2	7.0	4.0	1.0	26.0	Yes	Cellulosics, plastics, rubbers,
78	7.6	<0.1	6.1	<0.1	0.1	22.2	No	Polyethylene

TABLE IX (cont)

79	7.9	<0.1	6.5	3.0	<0.1	23.5	Yes	Water-soaked cellulosics
77	8.0	0.3	7.2	4.5	0.3	26.9	Yes	Cellulosics
65	8.1	<0.1	7.9	3.0	1.0	29.0	Yes	Water-soaked cellulosics
54	8.2	3.0	5.5	5.0	<0.1	18.0	No	Cellulosics
63	8.2	0.2	5.9	0.1	0.2	22.0	Yes	DuoSeal® on vermiculite
27	8.7	0.2	10.7	0.1	0.2	40.0	Yes	DuoSeal® on vermiculite
39	8.8	<0.1	9.0	3.0	1.0	32.0	Yes	Water-soaked cellulosics
38	8.9	<0.1	9.1	0.2	0.2	33.0	Yes	Polyethylene
1	9.0	0.5	6.0	17.0	6.0	61.0	No	Hydrogenous solid trash, Drum 232
81	9.1	0.4	11.0	12.4	<0.1	66.3	Yes	Hydrogenous solid trash, Drum 330
35	9.2	0.4	9.2	5.4	2.9	34.0	Yes	Cellulosics
32	9.8	0.2	9.4	0.1	0.2	36.0	Yes	DuoSeal® on vermiculite
29	9.9	0.4	10.2	6.6	2.2	38.1	Yes	Cellulosics, plastics, rubbers
37	10.1	<0.1	8.8	2.9	1.4	32.5	Yes	Water-soaked cellulosics
30	10.2	<0.1	9.8	0.2	0.2	37.5	Yes	Polyethylene
28	11.0	0.5	10.2	10.9	4.2	62.4	Yes	Hydrogenous solid trash, Drum 301
36	11.1	0.4	9.1	7.0	3.3	33.6	Yes	Cellulosics
31	13.5	<0.1	9.3	4.0	2.0	35.0	Yes	Water-soaked cellulosics
34	15.1	0.7	7.0	14.4	6.5	55.6	No	Hydrogenous solid trash
23	24.9	1.0	9.9	16.8	7.4	37.3	No	Cellulosics
8	25.8	0.8	11.1	15.8	4.1	41.5	Yes	Cellulosics, plastics, rubber
9	26.0	1.0	10.0	19.0	8.0	36.0	No	Cellulosics
18	27.1	0.8	8.8	21.3	7.9	33.5	No	Cellulosics
22	29.0	1.0	9.0	18.0	8.0	34.0	No	Cellulosics
16	36.4	0.1	7.9	7.6	3.3	29.2	No	Water-soaked cellulosics
4	40.5	0.1	10.6	6.0	3.0	39.0	Yes	Water-soaked cellulosics
12	42.8	1.0	11.6	0.3	0.2	43.6	No[a]	DuoSeal® on vermiculite
13	47.2	0.3	10.0	0.6	0.3	40.2	Yes	Polyethylene
19	48.7	0.2	10.4	0.5	0.4	39.1	Yes	Polyethylene

[a]Apparently anomalous behavior.

The remarkable resistance of chlorinated polyvinyls and high-density cross-linked polyethylene to radiolytic attack undoubtedly accounts for their continued use in packaging TRU-contaminated waste. It is known[11] that PVC will eventually deteriorate, but if the waste previously is emplaced safely in a geologic formation, then the plastic will no longer be required as the primary containment. Clearly, the insignificant quantities of gas generated by radiolytic attack of these materials will not present problems. There was concern that if PVC were incinerated before disposal, the quantity of HCl produced would create serious corrosion problems. Waste containing PVC has been burned in the LASL Controlled Air Incinerator; the offgas train has contained the HCl without problems, and no corrosion damage was noted in either stage of the incinerator. Obviously high-density polyethylene can be combusted easily if that is desired. It has also shown excellent resistance to attack (Table V) when contaminated with more than 400 times the amount of alpha that it could be exposed to at maximum

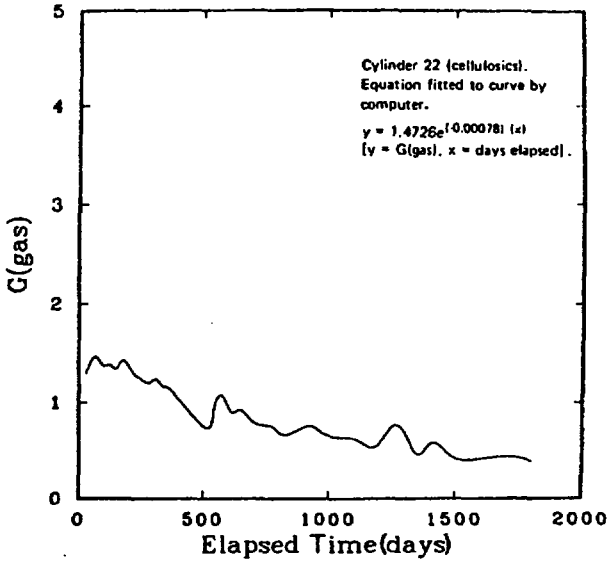


Fig. 20.
G = gas molecules evolved per 100 eV.

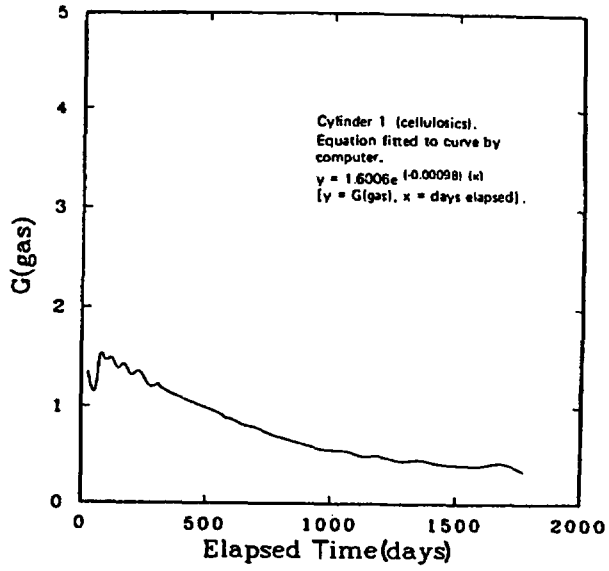


Fig. 22.
G = gas molecules evolved per 100 eV.

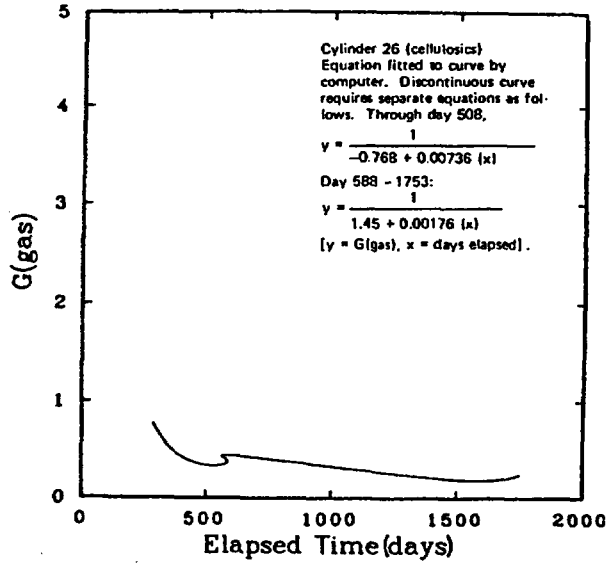


Fig. 21.
G = gas molecules evolved per 100 eV.

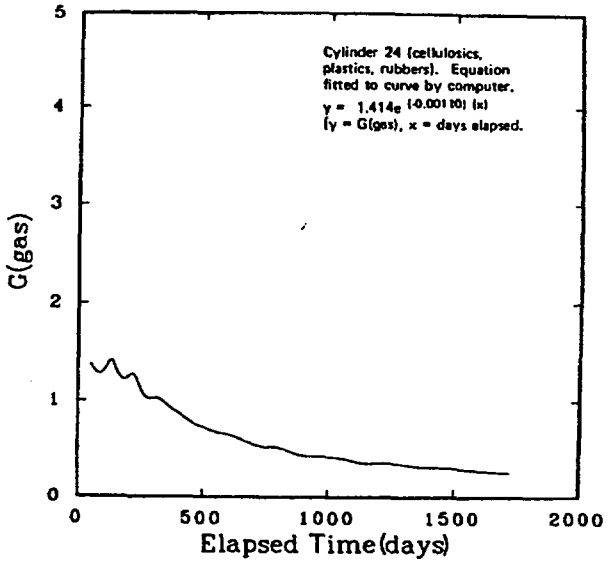


Fig. 23.
G = gas molecules evolved per 100 eV.

TRU loading. Certainly it is reasonable to assume that its useful service life is more than enough to allow time for final disposal.

G(gas) values for additional laboratory experimental cylinders are shown in Figs. 22 through 28. G(gas) is defined as molecules of gas produced by each 100 eV of energy deposited in the waste substrate. As previously specified, it will vary with the physical state of the contaminant and the identity of the waste. Each time one of the experimental

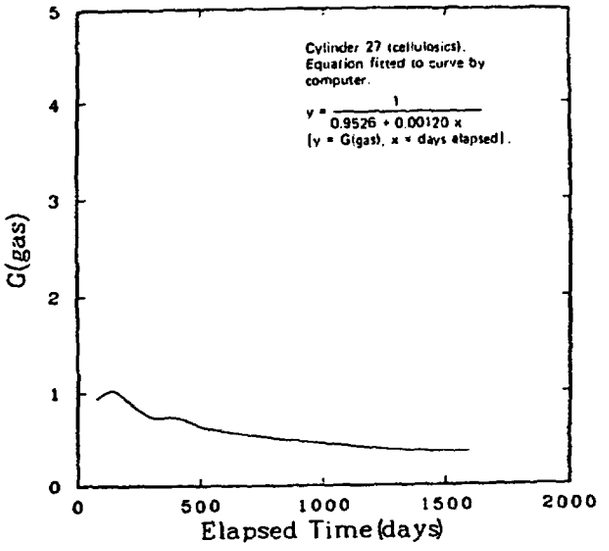


Fig. 24.
G = gas molecules evolved per 100 eV.

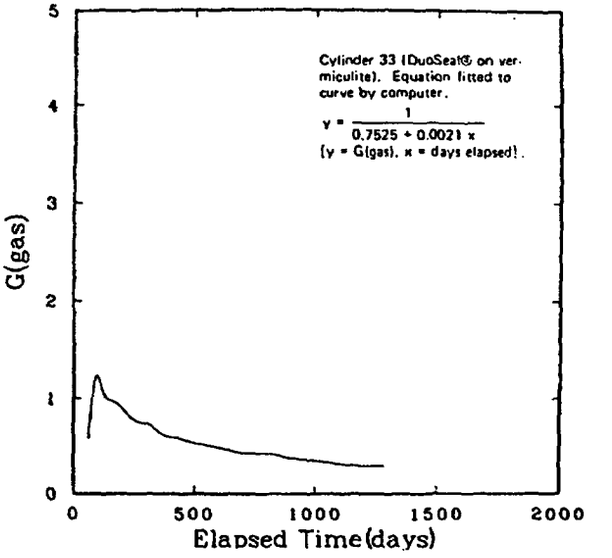


Fig. 26.
G = gas molecules evolved per 100 eV.

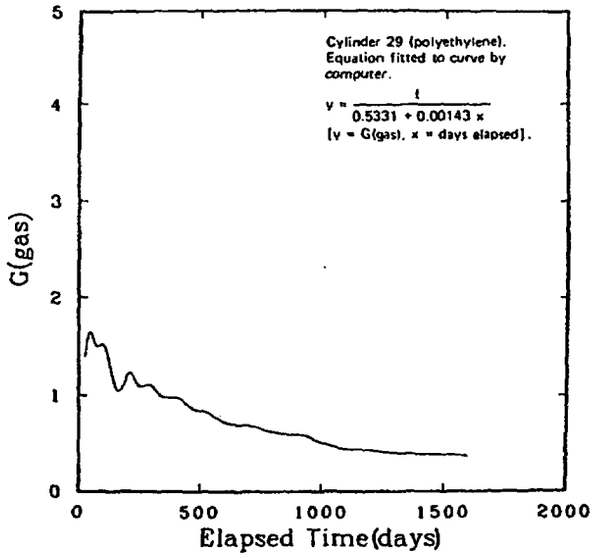


Fig. 25.
G = gas molecules evolved per 100 eV.

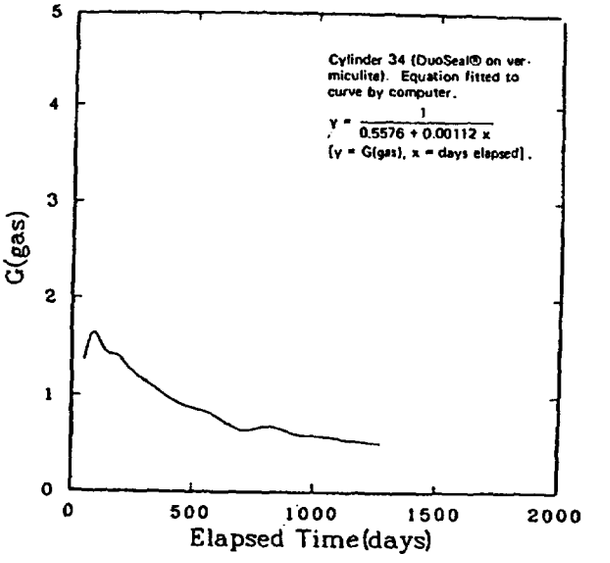


Fig. 27.
G = gas molecules evolved per 100 eV.

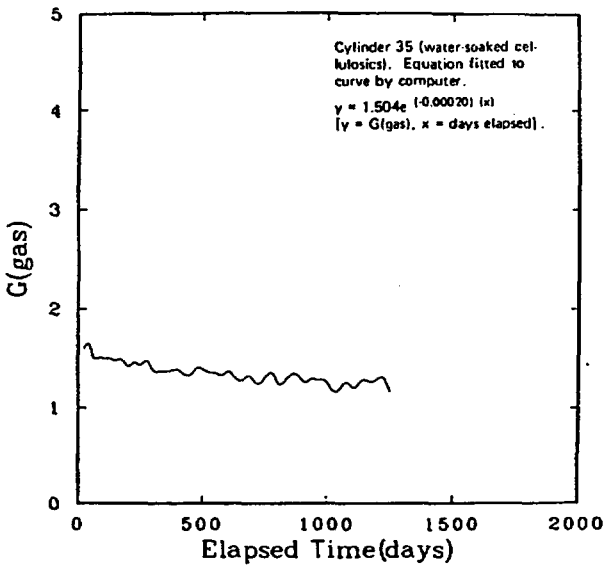


Fig. 28.
G = gas molecules evolved per 100 eV.

cylinders was sampled, the ΔP was converted to gas volume using a formula derived from the ideal gas law

$$\frac{(V)\ (\Delta P)}{1206\ (T\cdot_K)\ (\text{psi-cm}^3)/(\text{mole K})}$$

where V = effective volume of cylinder.
G(gas) was computed by

100 (mM gas) (6.02 × 10^{23})/(eV per day) (days).

As previously described, the rate of gas formation decreased with time. Clearly, decrease in G(gas) was directly proportional. Figure 22 shows the G(gas) curve for Cylinder 1, which contained dry cellulosics contaminated with 62 mg ^{238}Pu. This curve represents 38 data points. In other words, it pressurized to ~110 kPa 38 times in 4.9 yr. It reached full scale the first time in 24 days; most recently it required 91 days. The G(gas) computed for the first sample was 1.35, the highest value was 1.52, and the most recent was 0.34. Note that the shape of the curve is typical of the results observed for most of the experimental cylinders—the value decreases initially, then increases, then begins a slow, steady decline. By using the equation derived from the data points for a specific curve, it is possible to extrapolate the gas production for that specific contaminated waste under those specific conditions to any desired time.

Cylinder 27 (Fig. 24) is of interest because it was contaminated with 31 mg of ^{238}Pu as the chloride. This medium-level contamination generated less gas initially; it took 72 days to pressurize to full scale, and the G(gas) was 0.93. At 4.5 yr, after pressurizing 12 times, it required 188 days to pressurize for the 13th time, and the G(gas) was 0.36, compared to 0.34 for Cylinder 1 at 4.9 yr. The contaminant for this latter cylinder was 62 mg ^{238}Pu as the nitrate. The nitrate form gives a higher gas yield initially. This was not believed to be significant because, in contaminated waste exposed to air, the plutonium is converted to oxide in approximately 1 month.[13]

The amount of gas generation from polyethylene (Fig. 25) is very similar to that from cellulosics (Fig. 22). The gas composition is significantly different (compare Figs. 10 and 11); the polyethylene produces almost all H_2. Cylinders 33 and 34 (Figs. 26 and 27) contain oil sorbed on vermiculite. Each was contaminated with ^{238}Pu as the oxide, the former with 62 mg and the latter with half that amount. The finely divided oxidé was dispersed thoroughly in the oil before it was added to the vermiculite. After the sorption, no free liquid remained, so the PuO_2 could not settle out. The strongly contaminated sample required 28 days to reach full pressure (~110 kPa) the first time; the G(gas) was 1.22. In 3.6 yr, this cylinder pressurized 20 times, producing 212.5 mM of gas. The final pressurization took 104 days; the G(gas) was 0.30. The medium-level contamination sample took 49 days to reach full pressure the first time; the G(gas) was 1.37. It pressurized 16 times in 3.7 yr, producing 171.6 mM of gas. The final pressurization required 121 days; the G(gas) was 0.52. The remarkable efficiency of half as much contamination in the same quantity of substrate is not understood. Cylinder 35 (Fig. 28) contained the most efficient gas producer of all—62

mg ^{238}Pu on 52.5 g cellulosics soaked with 52.5 g H_2O. First pressurization, 21 days, G(gas) 1.59; second time, 21 days, G(gas) 1.65, which is the highest G value. The sample has pressurized 48 times in 3.5 yr, producing 533.2 mM gas. The latest pressurization required 27 days; the G(gas) was 1.16. There seems little doubt that the H_2O, in addition to the cellulose, is producing gas from alpha attack. These findings do not agree with Kazanjian's.[8]

The data from the ^{239}Pu and ^{238}Pu-contaminated waste retrievably stored at the LASL disposal area show there is no radiolytically generated gas problem in the ^{239}Pu interim storage. The drums that were opened (Table VI) showed some evidence of corrosion on the inside (Fig. 29), but the 0.13-mm polyethylene bags of waste were intact until they were ripped open intentionally (Fig. 30). The individual 0.3-mm PVC bagouts inside were in good shape as far as the PVC was concerned, but the masking tape closures had failed. Figure 31 shows the contrast in the resistance of the two materials to what was probably a combination of chemical and radiolytic attack. The spin-off from this evidence was a decision to replace the masking tape with vinyl plastic tape for future bagout closures. The deterioration of the contents of these bagouts resembled that shown in Fig. 19. If this waste were to be processed, the oldest waste probably is potentially the most hazardous because it is the most degraded and the least well categorized.

Containers of ^{238}Pu-contaminated waste definitely are generating gases from radiolytic attack. Their contents degrade rapidly from the alpha attack, and also from the heat (~0.5 W/g) given off by the contaminant. If an effort is made to reprocess this material, extreme caution must be exercised to prevent spark generation before the gaseous contents of these drums are analyzed and/or replaced with inert gas. Scrupulous handling will be required to avoid dispersing the finely divided, low-density degradation products present. Each cask (containing two 115-ℓ drums) weighs in excess of 1140 kg. Moving them will be a difficult and expensive job. They are isolated on a high and dry mesa in volcanic ash (tuff), which never has a moisture content >3%. It is my opinion that this storage in an already contaminated, dedicated waste disposal area would be satisfactory for many years.

The following conclusions can be drawn from the explosimeter data. If the H_2 content of the gaseous

Fig. 29.
Opened waste drum showing polyethylene bag intact.

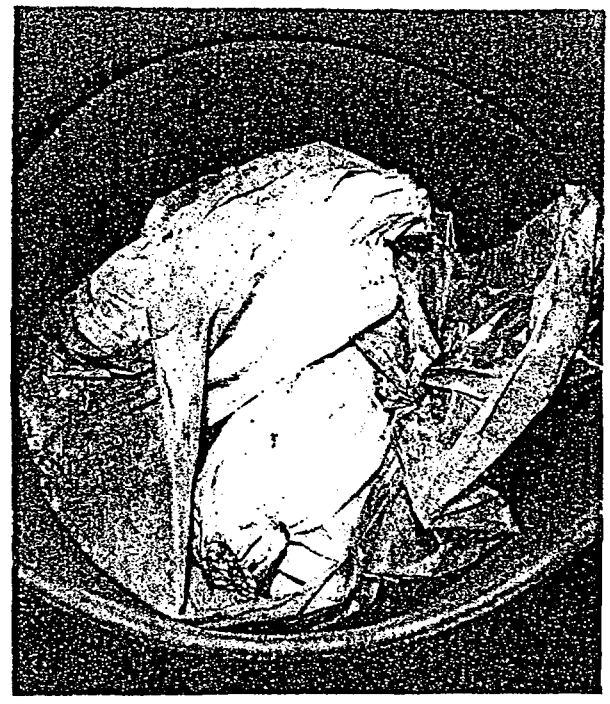


Fig. 30.
Individual bags of waste.

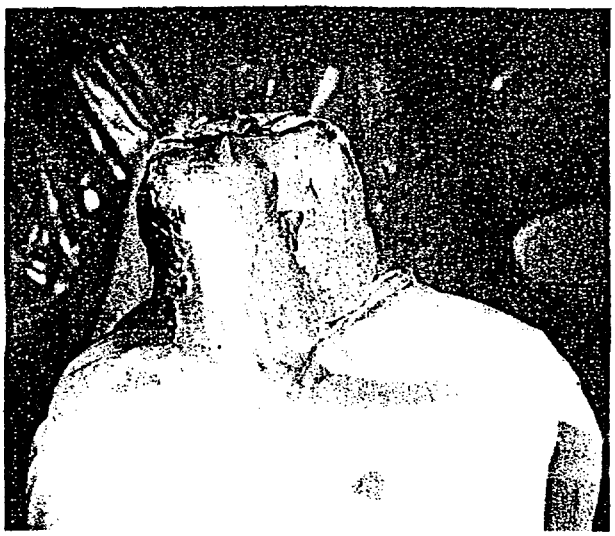


Fig. 31.
Contrast in resistance of materials.

mixture is 6 mol% or below, it probably is not explosible. A gaseous mixture with relatively high H_2 content and low O_2 may not be explosible, as shown by tests 9, 16, 18, and 23 (Table IX). A potential hazard exists because of the generation of a combustible gas mixture in some of these drums, but it appears to be a problem that diminishes with time, and in no case has it been demonstrated to be insurmountable for near-surface storage. Because of the likelihood of air diffusion into any storage drum, all drums of ^{238}Pu-contaminated hydrogenous waste in interim storage must be considered potentially explosive until their gaseous contents have been analyzed and/or replaced with inert gas. We reiterate the importance of this consideration when recovering or reprocessing ^{238}Pu-contaminated interim storage waste. A drum-sampling device[10] has been developed and successfully used, repeatedly, to sample the gaseous contents of waste drums without exposure to air.

The program for studying gas generation by radiolytic attack of hydrogenous materials is continuing, with special emphasis on conditions which are anticipated in the Waste Isolation Pilot Plant deep geologic disposal.

ACKNOWLEDGMENT

I appreciate the help of coworker Stanley Kosiewicz in collecting and interpreting some of the data used in this report, and the cooperation of numerous coworkers in LASL groups CMB-1 and H-7.

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CONSTRUCTION METHODS ASSESSMENT
FOR
COMPACTED SALT PANEL CLOSURES

December 2012

NUCLEAR WASTE PARTNERSHIP LLC

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1. INTRODUCTION

In 2011, a new panel closure system (PCS) design was proposed to close the hazardous waste disposal units at the Waste Isolation Pilot Plant (WIPP). The proposed PCS, referred to as the WIPP Panel Closure (WPC), consisted of two barriers (i.e., either two standard bulkheads or one standard bulkhead and one block wall, if a block wall was previously installed) and emplacement of a minimum of 100 feet of compacted run-of-mine (ROM) salt between the two barriers. The proposed ROM salt PCS design called for emplacing three distinct zones ranging in compaction from 85% to 70% of the in-situ density of salt. ROM salt densities are reported as a percentage of the in-situ density of salt which is assumed to be 135 pounds per cubic foot (SDD AU00).

Compaction of ROM salt in zones, per the proposed draft specifications, had not been performed at the WIPP. Concerns over the constructability of the WPC arose due to the limited size of the drifts in which the WPC would be installed and the expected performance of the available equipment. A test plan was developed to demonstrate if the WPC could be constructed in accordance with the proposed compaction specifications using equipment currently at the WIPP or equipment that is readily available by renting or leasing. The proposed design was modified from three distinct horizontal layers to two zones. A lower zone was placed horizontally up to a height that could safely accommodate the equipment and an upper zone placed diagonally up to the back. If the compaction specifications could not be met, then the test plan would identify what level of compaction could be achieved. And finally, the best practices for the construction of the WPC would be established.

Three scenarios were developed for the test plan (Figure 1). Scenario 1 consisted of 1% (by weight) water added to the ROM salt and compaction of the material. Scenario 2 consisted of compaction of the ROM salt with no additional water added. Scenario 3 consisted of the ROM salt simply being placed and pushed up tight to the back without adding water or compaction.

The test plan also included laboratory testing to determine the moisture/density properties of the ROM salt used for this demonstration.

This report presents the data from the laboratory testing, a description of the emplacement and compaction methodology; and the moisture/density testing results for all three scenarios.

2. SUMMARY

2.1. Laboratory Testing

Sieve analysis, moisture determination and proctor evaluations were performed in the lab to determine the characteristics of the ROM salt used in the field testing. Gradational analysis indicates that about 9% of the ROM salt sample was greater than 3 inches, 7% passed the #80 screen, and about 3% passed the #200 screen. The natural moisture content of the ROM salt averaged 0.4%. The results of a modified proctor evaluation, using a 6 inch diameter mold,

produced a maximum density of about 108 to 109 pounds per cubic foot (80% to 81% of the density of in-situ salt) with optimum moisture of between 2.5% and 4.5%. The maximum density using a 4 inch diameter mold was a bit lower at about 107 pounds per cubic foot (79% of the density of in-situ salt) and the optimum moisture was higher at about 6%. The field testing showed that Scenario 1 and Scenario 2 were able to achieve about 93% (101 pounds per cubic foot) of the maximum proctor density on the lower zone and about 78% (85 pounds per cubic foot) on the upper zone. Scenario 3 field testing showed that the density achieved was about 83% (90 pounds per cubic foot) of the maximum proctor density.

The ASTM nuclear density method used for moisture/density determination was evaluated for use in salt prior to field testing. The nuclear density method produced acceptable density values but did not produce reasonable percent moisture values when compared to moisture sampling by ASTM D2216. The nuclear density method used for field testing was backed up by occasional sand-cone tests. The moisture content was determined from grab samples taken near the nuclear density locations.

2.2. Construction Scenarios

Scenario 1 consisted of ROM salt with 1% water added and compacted into two zones; a lower zone consisting of 6 inch thick horizontal lifts and an upper zone consisting of 12 inch thick diagonal lifts. The lower zone was 4 feet thick and the upper zone was 8.5 feet thick. The thicknesses of the lower and upper zone were based on the operational clearance required for the equipment used to emplace and compact the ROM salt. The density achieved for either zone did not reach the proposed compaction specification. Density measurements, at select locations, were taken after multiple compaction passes to determine a correlation between density and compaction effort.

A load-haul-dump (LHD) was used to place each lift of the lower zone and roughly smooth it out. A skid-steer loader was needed to get a uniform lift thickness of 6 to 8 inch. Placing the lifts with a consistent and uniform thickness proved challenging. The walk-behind roller compactor was awkward to maneuver but was simple to operate.

As anticipated, on the upper zone, the LHD could place ROM salt to within about 18 to 24 inches of the back. A modified Fletcher scaler with the push-plate attachment, worked well to push the ROM salt tight to the back. The slope of each lift, on the upper zone, was about 30 degrees once emplacement and compaction was completed. The first seven lifts of the upper zone were compacted using the boom to push the material tight and then the push-plate was vibrated. This method was discontinued because the vibration caused material to loosen and slide down the slope of the lift. The remaining lifts were compacted by just using the boom to push the push-plate into the lift.

Water was added to the ROM salt using an adjustable nozzle set to deliver 20 gallons per minute and timing the length of application based on the cubic yards of ROM salt in each lift. Results from moisture sampling showed that this method was fairly consistent. For the lower zone after six

compaction passes the moisture averaged about 1.4% and for the upper zone the moisture averaged about 1.3%. The natural moisture for ROM salt was determined to be 0.25% to 0.5%.

The average dry density achieved for the lower zone after six compaction passes was about 75% of the in-situ density of salt. The draft specification called for 85%. The average dry density for the upper zone after one compaction pass was about 63% of the in-situ density of salt. At 3 feet, 5 feet and 7 feet from the back, the average dry density of the upper zone was about 63%, 64% and 62% respectively. The draft specification called for 80% for the lower portion of the upper zone and 70% for the upper portion of the upper zone.

A crew of two qualified miners was used to construct the lower and upper zones. This crew worked a 10 hour shift, 4 days per week. The lower zone was constructed at a rate of about 181 cubic feet per hour and the upper zone at a rate of 162 cubic feet per hour. These rates do not include equipment down time, time to perform support actives or testing. Accounting for equipment down time and support activities, the projected time to construct both an intake and exhaust WPC with a drift height of 12.5 feet would be about 61 shifts. Moisture/density testing would add an additional 2 to 4 hours per set of tests.

Scenario 2 consisted of ROM salt compacted into two zones, the same as with Scenario 1, but no additional water was added to the ROM salt. The lower zone was constructed with 6 inch thick horizontal lifts and the upper zone was constructed with 12 inch thick diagonal lifts. The lower zone was 4 feet thick and the upper zone was 8.5 feet thick. As with Scenario 1, the thickness of the lower and upper zones were based on the operational clearances required for the equipment used for emplacement and compaction of the ROM salt.

The lower zone of Scenario 2 was constructed using an LHD to place ROM salt for each lift. A skid-steer loader was needed to get a uniform lift thickness of 6 to 8 inches. Equipment operator proficiency improved from Scenario 1 to Scenario 2, but placing the lifts with a consistent and uniform thickness was still challenging. Three different compaction methods were used on the lower lifts; walk-behind roller compactor, LHD with empty bucket and LHD with full bucket. Each method achieved about the same level of compaction.

On the upper zone, the LHD could place ROM salt to within about 18 to 24 inches of the back. The Fletcher with the push-plate attachment was used to push the ROM salt tight to the back. The slope of each lift on the upper zone was about 30 degrees once emplacement and compaction was completed.

The average dry density achieved for the lower zone of Scenario 2 after four or six compaction passes was about 75% of the in-situ density of salt. The draft specification called for 85%. The average dry density for the upper zone of Scenario 2 after one compaction pass was about 63% of the in-situ density of salt. At 3 feet, 5 feet and 7 feet from the back, the average dry density of the upper zone was about 63%, 63% and 62% respectively. The draft specification called for 80% for the lower portion of the upper zone and 70% for the upper portion of the upper zone.

The crew used to construct the lower zone and the upper zone of Scenario 2 consisted of two qualified miners. Construction work was performed on a 10 hour shift, 4 days per week. The lower zone was constructed at a rate of about 283 cubic feet per hour and the upper zone was constructed at a rate of 239 cubic feet per hour. These rates do not include equipment down time and support activities or testing. The construction rates for Scenario 2 are significantly better than those achieved during Scenario 1 and are attributable to an improved equipment operator proficiency placing and compacting the lifts. Accounting for equipment down time and support activities, the projected time to construct both an intake and exhaust WPC with a drift height of 12.5 feet would be about 42 shifts. Moisture/density testing would add an additional 2 to 4 hours per set of tests.

Scenario 3 consisted of ROM salt, with no water added and no compaction, placed and pushed tight to the back. The ROM salt was emplaced with the LHD to a height within 18 to 24 inches of the back. Two to four buckets (7.20 to 14.40 cubic yards) of ROM salt were placed with the LHD, and then the Fletcher with the push-plate attachment was used to push the ROM salt tight to the back. An additional two to three feet of ROM salt was placed on the floor to enable the Fletcher to reach the top of the loosely placed ROM salt and push it tight to the back. One or two passes pushing up the ROM salt was necessary to get it tight to the back. The slope of the lifts after the ROM salt was pushed tight to the back was about 30 degrees.

The average dry density achieved for the loosely placed ROM salt of Scenario 3 was about 67% of the in-situ density of salt. At 3 feet, 5 feet and 8 feet from the back, the average dry density was about 66%, 68% and 66% respectively.

A crew of two qualified miners was used to emplace the ROM salt of Scenario 3. This crew worked a 10 hour shift for 5 days. This zone was constructed at a rate of about 690 cubic feet per hour. This rate does not include equipment down time and support actives or testing. Accounting for equipment down time and support activities, the projected time to construct both an intake and exhaust WPC with a drift height of 12.5 feet would be about 15 shifts. Moisture/density testing would add an additional 2 to 4 hours per set of tests.

Scenario 1 and Scenario 2 produced very similar results. The dry density achieved in both scenarios for the lower zone was about 75% of the in-situ density of salt. Based on the results from Scenario 2, both the walk-behind roller compactor and the LHD achieved the same compaction level. Scenario 1 and Scenario 2 also had similar results for the upper zone with a dry density of about 63% of the in-situ density of salt achieved. Both scenarios did show a slight variation in dry density at 3 feet, 5 feet and 7 feet from the back at 63%, 63% to 64% and 62% respectively.

Scenario 3 was similar to the upper zone on Scenario 1 and Scenario 2 in both construction technique and achievable compaction. The average dry density achieved for Scenario 3 was about 67% of the in-situ density of salt. This is slightly higher than the 63% achieved by Scenario 1 and Scenario 2.

All three scenarios were not able to achieve the proposed compaction specifications. But these scenarios did show what level of compaction can be achieved with the equipment currently available at the WIPP and demonstrated techniques that could be used for the construction of the WPC.

The three scenarios provided an estimate on WPC construction time. The shortest construction time was for Scenario 3, which is the simplest to construct, at about 15 shifts to construct the intake and exhaust drift WPCs. For Scenario 2, the construction time for the WPCs would be about 42 shifts and for Scenario 1 the construction time would be about 61 shifts. The construction of Scenario 1 and 2 are identical except that Scenario 1 adds 1% water by weight to the ROM salt. The Scenario 2 construction time is shorter than that of Scenario 1 primarily due to the improved equipment operator proficiency in placing and compacting both the lower zone and upper zone lifts.

3. LABORATORY TESTING

Laboratory testing was performed by Pettigrew & Associates (Pettigrew), located in Hobbs, New Mexico. Pettigrew is a qualified supplier for Quality Control for the WIPP, accredited by the American Association of State Highway and Transportation Officials (AASHTO), Materials Reference Laboratory (AMRL) and the AASHTO Cement and Concrete Research Laboratory (CCRL).

Sieve analysis, per ASTM C 136, was performed on the ROM salt used for proctor testing and the ROM salt that was used for the construction methods evaluation. The results of these sieve analysis are presented in Appendix A. SA-1 through SA-3 is the sieve analysis data on the material used for the proctor testing. SA-4 is the sieve analysis of the ROM salt used for the field demonstration. Both the proctor test ROM salt and construction ROM salt samples were taken from the same stock pile. When the proctor material was taken, large chunks were avoided. Whereas, the construction sample consisted of whatever size material was in the sample location. Of the construction ROM salt, 9% of the material was greater than 3 inches in size, of which occasionally pieces were up to 7 to 9 inches in size. Of the finer material, only 7% passed the #80 screen and only 3.1% passed the #200 screen.

Moisture of the ROM salt was determined by ASTM D 2216 and averaged 0.36% with a high of 0.9% and a low approaching 0%.

Standard Proctor evaluations were performed in accordance with ASTM D-1557. The Proctor evaluation was used to determine the optimal moisture to achieve the maximum density. The moisture added during the performance of the evaluation was in the form of fresh water as opposed to brine because fresh water would also be used in the field assessment. Larger material that was inappropriate for the proctor mold size used was screened off prior to placement of material into the molds.

Two proctor evaluations were run using 6 inch molds and one evaluation using the 4 inch mold. Excess water bled from both the 4 inch and 6 inch molds once the moisture content was over 3%. A best-fit curve was generated from the data to determine the optimum moisture and maximum density. The maximum density for the 6 inch mold evaluations was between 108 to 109 pounds per cubic foot (80% to 81% of the density of in-situ salt). The optimum moisture varied significantly from about 2.5% and to about 4.5%. The evaluation, using the 4 inch mold, produced a maximum density of about 107 pounds per cubic foot (79% of the density of in-situ salt) with optimum moisture of about 6%. Appendix A contains a graph summarizing the proctor evaluations.

The optimum moistures produced by the proctor evaluations were not used in the field testing. Scenario 1 of the field testing called for the addition of 1% water to the ROM salt. This would give total moisture of between 1.25% and 1.5%. This is more in line with the plans for the WIPP shaft seals (SAND96-1326/1).

Moisture/density testing by the nuclear method is not common in salt. A small ROM salt pad was constructed near the test area to determine if the nuclear method would provide adequate results. The nuclear method results were compared to sand-cone and balloon density methods and standard moisture sampling. Technical problems were experienced with the sand-cone and balloon density methods. Only one sand-cone could be taken and no valid balloon tests were achieved. Several nuclear moisture/density tests were made after a trench calibration of the instrument was made. As anticipated, the nuclear method did not accurately determine moisture content. The nuclear density results were in good agreement with the sand-cone density determination. For the field moisture/density testing, the nuclear method was used for density and occasional sand-cone density tests were performed as a check. Table 1 in Appendix D-1 compares the density results by the nuclear and sand cone methods for scenario 1. Samples were collected at or near where the density tests were made to determine moisture content in the lab. Data from this testing can be found in Appendix A, Test No. SG 1 through SG 12 and SC 1.

Four nuclear density tests were made at the stock pile of ROM salt used to construct the lower and upper lifts. These tests were made to determine the density of the stock pile at different time periods and are reported as a percentage of the in-situ density of salt. Test SG 58 was at a portion of the stock pile that had been undisturbed for about two months; SG 59 was at a portion that was added to the stock pile four days earlier; and SG166 and SG167 were in ROM salt placed on the stock pile within an hour of the testing. Test SG 58 in the older portion of the stockpile showed a density of 71.9%. Test SG 59 in the newer portion of the stockpile showed a density of 68.1%. Test SG 166 and SG 167 in the youngest portion of the stockpile showed densities of 64% and 63% respectively. These tests seem to indicate that settling or self compaction of the stockpile occurs rapidly. The loose density of ROM salt is about 65%. The test data for SG 58, SG 59, SG 166 and SG 167 can be found in Appendix A. Note that the densities for SG 58 and 59 are not corrected for moisture, whereas the densities for SG 166 and 167 are corrected for moisture.

4. FIELD TESTING

4.1. LOCATION

The field testing was conducted in the southern portion of the WIPP underground adjacent to Panel 5 in the W-30 drift, between S-3310 and S-3650 and south of Bulkhead 506. Bulkhead 506 was used to simulate the bulkhead portion of the proposed WPC. The drift width was about 16 feet wide and the height was about 12.5 feet. The length of drift available for testing was about 230 feet.

4.2. EQUIPMENT

The following list of equipment was used in the field testing.

- Load-haul-dump (LHD) with 3.6 cubic yard bucket capacity
- Skid-steer loader
- Fletcher Scaler (modified with a push plate attachment)
- Walk-behind steel wheel vibratory roller compactor
- 500-gallon water tank
- Electric water pump
- 1 inch dia. Water hose
- Adjustable water nozzle
- Auxiliary Fan
- 30 inch dia. ventilation tubing

The LHD was the primary piece of equipment used to place ROM salt for the lifts for the lower zone and upper zone. The skid-steer loader was used to work the lower zone lifts to the desired thickness. Water was added to the ROM salt using the 500-gallon tank, water pump, hose and adjustable nozzle. The nozzle was adjusted to maintain a consistent flow rate of 20 gallons per minute. This rate also provided a good spray pattern. Compaction of the lifts of the lower zone was accomplished using a walk-behind steel wheel roller compactor or LHD. Information on the roller compactor, the LHD, and the Fletcher scaler can be found in Appendix G. On the upper zone, a push-plate attachment on the Fletcher scaler, was used to push the ROM salt tight to the back and to compact the material. The push-plate was fabricated in-house using 1 inch plate steel, 4 inch steel channel and 4 inch steel tubing and had a height and width of 2 feet. The auxiliary fan and ventilation tubing was set up in an exhausting configuration to provide fresh air and remove diesel smoke and dust from the work area.

4.3. SCENARIO 1

The test parameters for Scenario 1 were as follow. One percent water (by weight) was added to the ROM salt. Compaction of the lower zone was by the walk-behind roller compactor and compaction of the upper zone was by the Fletcher with the push-plate.

Figure 1 shows the configuration of the test area. The lower zone was approximately 63 feet in length, 16 feet wide and 4 feet thick. A 2:1 slope was constructed for the lower zone on the end near the bulkhead. The upper zone was comprised of two areas. Towards the bulkhead, un-compacted ROM salt with no water added was placed to provide a "back-stop" for the ROM salt that would be placed and compacted for the remainder of the upper zone. The compacted portion of the upper zone was approximately 32 feet in length, 16 feet wide and 8.5 feet high. The slope angle on the upper zone was about 30 degrees after compaction of each lift.

4.3.1. LOWER ZONE

The lower zone was constructed using the LHD to place ROM salt in horizontal lifts of about 6 inches thick. The LHD that was used had a capacity of 3.6 cubic yards of ROM salt per bucket and six buckets were required to get the lift thickness of 6 inches. The LHD could not provide an adequately uniform lift thickness, so the skid-steer loader was used to even out the lifts. After placement, compaction and testing of the second lift, a change was made to improve the water distribution through the thickness of the lift. Instead of the full six inches of ROM salt being placed, placement of the lift was split in two. About 3 inches of ROM salt would be placed, water added, another 3 inches placed and the final water added to the lift. It was a little easier for both the LHD and skid-steer loader to spread and evenly distribute the ROM salt in the thinner layers. Figure 2 shows the LHD placing ROM salt on a lower zone lift. Placement of each lift was challenging for the equipment operator and time consuming. The placement of each lift took an average of 2 hours and 12 minutes.

One percent water was added to the lifts either after the lift was placed or halfway through the placement. Based on the loose density of the ROM salt at 88 pounds per cubic foot, 2.85 gallons of water must be added per cubic yard to get 1% water added. For the six LHD buckets placed each lift, about 62 gallons of water would be required to get 1% added moisture. An adjustable nozzle was set to deliver 20 gallons per minute. The volume delivered by the nozzle was initially set and periodically checked by recording the time to fill a container of known volume. Water was added to each lift uniformly with the nozzle and timed to get the necessary volume. The time necessary to add water was about 3 minutes per lift. Moisture sample results are presented for the lower zone in Appendix B-1, Appendix D-1, and Appendix F-1. The average moisture for the compacted samples taken on the lower zone was 1.4%. The moisture content for ROM salt ranges from 0.25% to about 0.5%.

Most of the moisture results were similar, but the results of the last lift of the lower zone were significantly lower. This is likely because the last lift was completed on a Friday afternoon and moisture/density testing was not performed until the next Monday. The moisture content for these tests was much lower than the previous tests perhaps due to the ventilation passing through the test area causing the water to evaporate. The moisture for lift 7 averaged 0.3% which is within the natural range.

A walk-behind steel wheel vibratory roller compactor was used to compact the lifts of the lower zone. Specifications and data on the compactor are contained in Appendix G. Six compaction passes were made on each lift with moisture/density testing after two, four and six passes. The compaction passes were started at one rib and the compactor was run the length of the lift and back in the same path then shifted a half drum width and run the length and back again. This sequence was repeated until the opposite rib was reached. Figure 3 shows the roller compactor in use on a lift. Each set of two compaction passes averaged about 17 minutes and a set of six averaged about 51 minutes.

The time to place, add water and compact a single lift averaged about 3 hours and 5 minutes.

Field testing of the lower zone was performed in accordance with ASTM standards for nuclear methods (ASTM D-6938) and for the sand-cone method (ASTM D-1556). Four density tests were made using the nuclear method. Generally, two tests were made along the centerline of the drift and two tests were made between the centerline of the drift and the rib. All four tests were performed in the middle third of the lift's length. One to four moisture samples were taken at locations near the nuclear tests. The nuclear method results were not used for moisture content determination. Sand-cone tests were performed periodically as checks to the nuclear tests. The densities by the nuclear method and by sand-cone were in general agreement.

Information on placement, compaction and moisture/density testing on the lower zone, is contained in Appendix B-1, Appendix D-1, and Appendix F-1. Table 1 summarizes the results from the lower zone.

Table 1 - Scenario 1 Lower Zone Moisture/Density

Average Compactor Speed (ft/min)	Cumulative Number of Compaction Passes	Moisture %	Dry Density%*
132	2	1.6	74.1
141	4	1.7	74.5
148	6	1.4	74.8

* Density reported as a percentage of the in-situ density of salt

The results show that the average achievable dry density on the lower zone was 74.8% after six compaction passes. The density does increase slightly as the number of compaction passes increases. The results also indicated that dividing the lift height in two and adding water to each half did not improve the compaction of the lifts. The actual densities achieved for the lower zone were significantly less than the proposed value of 85% of the in-situ density of salt.

A moisture/density test (SG 78) was made on the last lift of the lower zone 25 days after the initial tests were performed. The test results were a density of 80.5% of the in-situ density of salt with moisture of 0.2%. The original density averaged 73.8% with moisture of 0.3%. The increase in density could be due to the combination of the operation of heavy equipment on the lift during the construction of the upper zone and settling of the material.

The height of the lower zone was determined by the operational clearance needed for the LHD. The height of the LHD to the top of the cab is about 7.5 feet, so an operational clearance of 8.5 feet was maintained. The available operational clearance set the upper zone to 8.5 feet high and the lower zone to the difference from the total drift height. The height of the drift in the test area was 12.5 feet. In order to maintain the operational clearance, the thickness of the lower zone was about 4 feet.

4.3.2. UPPER ZONE

The upper zone was constructed using the LHD to place ROM salt, the Fletcher, with the push-plate, was used to push the ROM salt tight to the back and compact the material. Initially several feet of un-compacted ROM salt was placed tight to the back to provide a back-stop for the compacted lifts. The lifts of the upper zone were placed on a slope of about 30 degrees. This slope was the result of pushing the ROM salt tight to the back to create the back-stop. The LHD placed two buckets per lift. This resulted in a lift thickness of about 12 inches. The LHD could place the material to within about 18 to 24 inches of the back. An average of about 13 minutes was needed to place the ROM salt on each lift.

Once the ROM salt was placed but not pushed up and compacted, water was added using the nozzle set to a volume of 20 gallons per minute. Two LHD buckets (7.2 cubic yards) required one minute of water to be added. The average moisture for the upper zone was about 1.3%. Pushing the ROM salt tight to the back and compacting the material tended to mix the water into the lift, but dry or very wet areas were common.

The Fletcher with the push-plate, was used to push the ROM salt tight to the back usually starting along the left rib and working to the right. Compaction of the upper zone lifts usually started in the upper left hand corner and worked across to the opposite rib by moving the plate about a foot, half of the plate width, each time. When the opposite rib was reached the plate would be moved back to the left rib and down about a foot and worked to the opposite rib. This cycle was followed until the bottom of the lift was compacted. Figure 4 shows the push-plate attachment for the Fletcher and Figure 5 shows the compaction on a lift of the upper zone.

Two methods of compaction were tried on the upper zone. The modified Fletcher had the push-plate attached to the jack-hammer head of the machine. By activating the jack-hammer, the push-plate could be vibrated like a plate compactor. For the first method, the boom was used to push the material tight and maintain pressure as the jack-hammer was activated for 5 seconds to vibrate the push-plate. This method was used for lifts 1 through 7 of the upper lift. The method was discontinued because the vibration from the jack-hammer caused the adjacent ROM salt to loosen and slide down the slope. The remaining lifts were completed using only the Fletcher's boom extension to push the push-plate into the slope.

Pushing up and compacting the lifts of the upper zone with the jack-hammer action averaged about 76 minutes per lift. Pushing up and compacting the lifts of the upper zone by just pushing into the slope averaged about 53 minutes per lift. Originally two and three compaction passes per lift were planned. However, spending 2 to 3 hours compacting each lift was not operationally practical; thus, the additional compaction passes were not preformed.

Field testing of the upper zone was performed in accordance with ASTM standards for nuclear methods (ASTM D-6938) and for the sand-cone method (ASTM D-1556). Six density tests were made using the nuclear method. Generally two tests were made about 3 feet down from the back of the drift, two tests were made about 5 feet down from the back and two tests were made about 7 feet down from the back. The nuclear density tests varied from a few feet from the ribs to near the centerline of the drift. Moisture samples were taken at each nuclear density test. The nuclear method results were not used for moisture content determination. Sand-cone tests were taken periodically as checks to the nuclear tests. The densities achieved by the nuclear method and by sand-cone were in general agreement.

Appendix C-1, Appendix E-1 and Appendix F-1 contain information on placement, compaction and testing of the upper zone. The average dry density achieved using the push plate with vibration was 63.3% of the in-situ density of salt. The average dry density achieved by just pushing the material was 64.6% for lifts 13 through 19 but the average dropped to 63.3% by lift 32.

Table 2 and Table 3 summarize the results of the upper zone.

Table 2 - Scenario 1 Upper Zone Moisture/Density

Compaction Type	Number of Compaction passes	Moisture %	Dry Density %*
Push-plate with 5 seconds Vibration	1	1.1	63.3
Push Plate	1	1.4	63.3

* Density reported as a percentage of the in-situ density of salt

Table 3 - Scenario 1 Moisture/Density by Position in the Upper Zone

Distance from Back of Drift	Moisture %	Dry Density %*
3 feet	1.2	63.4
5 feet	1.3	64.6
7 feet	1.4	61.5

* Density reported as a percentage of the in-situ density of salt

The results show that the average achievable dry density on the upper zone is 63.3% after one compaction pass whether or not the vibration was activated. The dry density does vary by the position in the upper zone. The middle has the highest density at 64.6% and surprisingly the lowest is close to the bottom of the zone at 61.5%. Close to the back the average was 63.4%. The proposed design called for 80% density in the lower half of the upper zone and 70% in the upper half of the upper zone. The actual average density achieved did not meet the proposed density.

4.3.3. CONSTRUCTION TIME

The crew used to construct the lower zone and the upper zone consisted of two qualified miners. Construction work was performed on a 10 hour shift, 4 days per week. As part of the construction methods assessment, each process to construct the lower and upper zones was documented and the data collected can be found in Appendix F. Excluding down time, the time necessary to place, wet, and compact each lift of the lower zone averaged about 3 hours and 5 minutes. This equates to about 181 cubic feet of lift constructed per hour. Excluding down time, the time necessary to place, wet, and compact each lift of the upper zone averaged about 1 hour and 12 minutes. This equates to about 162 cubic feet of lift constructed per hour. In a 10 hour shift, about 6.5 hours of work can be performed. About 80% or 5.2 hours per shift could be expected to be worked accounting for equipment down time and support work. Assuming the 5.2 hours per shift and the rates determined above, the time necessary to construct a WPC in an intake drift, that is 12.5 feet high and 20 feet wide, would be about 36 shifts and in an exhaust drift, that is 12.5 feet high and 14 feet wide, would be about 25 shifts. The preceding construction time estimate does not include time necessary for moisture/density testing. For each set of tests, an additional 2 to 4 hours should be added to the total construction time.

4.4. SCENARIO 2

The test parameters for Scenario 2 were as follows. No water was added to the ROM salt. Six lifts of the lower zone were compacted by the walk-behind roller compactor and four lifts of the lower zone were compacted by the LHD. The lifts of the upper zone were compacted using the Fletcher with the push-plate attachment.

Figure 1 shows the configuration of Scenario 2 in relation to the other two scenario test areas. The lower zone was approximately 33 feet in length, 16 feet wide and 4 feet thick. The upper zone was approximately 39 feet in length, 16 feet wide and 8.5 feet high. The slope angle on the upper zone was about 30 degrees after compaction of each lift.

4.4.1. LOWER ZONE

The ramp that was constructed to aid in the placement and compaction of the Scenario 1 ROM salt was removed prior to placement of the Scenario 2 lower lifts. The lower lifts were constructed using the LHD to place the ROM salt in horizontal lifts of about 6 inches thick. The LHD used had a capacity of 3.6 cubic yards of ROM salt per bucket and three buckets were required to get the lift thickness of 6 inches. As with Scenario 1, the LHD could not provide an adequately uniform lift thickness, so the skid-steer loader was used to even out the lifts. The placement of each lift took an average of 38 minutes. The placement of the lower lifts for

Scenario 2 took less time than in Scenario 1 because the length of the lower lift for Scenario 2 is about half that of Scenario 1, no water was added and operator proficiency was improved.

A walk-behind steel wheel vibratory roller compactor was used to compact the first six lifts of the lower zone. The compactor used was the same one used for Scenario 1 and the data on the compactor are contained in Appendix G. The last four lifts of the lower zone were compacted using the LHD. The LHD bucket was empty during compaction of two lifts and full during compaction of two lifts. The full LHD bucket adds about 4.3 tons to the weight of the LHD. Using either the compactor or LHD, six compaction passes were made on each lift. The compaction passes were started at one rib and the compactor/LHD was run the length of the lift and back in the same path then shifted about one foot and run the length and back again. This sequence was repeated until the opposite rib was reached. Each set of two compaction passes averaged about 8 minutes and a set of six averaged about 25 minutes. Using either the walk-behind roller compactor or the LHD, the compaction times were comparable. The compaction times are less for Scenario 2, because the length of the lift is about half that of Scenario 1.

Moisture/density testing was performed on selected lifts after two, four and six compaction passes. Density testing of the lower zone was performed in accordance with ASTM standard for nuclear methods (ASTM D-6938). The sand-cone method for determining density could not be used because the walls of the hole dug for the sand-cone test would collapse under the base plate. Four density tests were made after each set of two compaction passes. Generally, two tests were made along the centerline of the drift and two were made between the centerline of the drift and the rib. All four tests were performed on the middle third of the lifts length. Moisture samples were taken per ASTM D-2216 near the location of each of the density tests. The nuclear method results were not used for moisture content determination.

Information on placement, compaction and moisture/density testing on the lower zone, is contained in Appendix B-2, Appendix D-2 and Appendix F-2. Table 4 summarizes the results from the lower zone.

Table 4 - Scenario 2 Lower Zone Moisture/Density

Roller Compactor			
Average Compactor Speed (ft/min)	Cumulative Number of Compaction Passes	Moisture %	Dry Density%*
98.0	2	0.4	74.6
73.5	4	0.4	75.5
100.2	6	0.4	74.7
LHD - Empty Bucket			
Average Compactor Speed (ft/min)	Cumulative Number of Compaction Passes	Moisture %	Dry Density%*
93.5	2	0.1	73.8
93.5	4	0.0	73.0
83.1	6	0.3	74.9
LHD – full bucket			
Average Compactor Speed (ft/min)	Cumulative Number of Compaction Passes	Moisture %	Dry Density%*
95.0	2	0.4	72.5
83.1	4	0.4	75.0
95.0	6	0.4	75.3

* Density reported as a percentage of the in-situ density of salt

The results show that using either the roller compactor or LHD with loaded bucket, the achievable dry density was about 75% after four compaction passes. After six compaction passes, the LHD with an empty bucket was able to achieve an average dry density of just under 75%. The actual densities achieved for the lower zone were significantly less than the proposed value of 85%.

The average compactor speed is lower in Scenario 2 than in Scenario 1. This is likely attributable to the shorter length of the Scenario 2 lifts. The proportion of time repositioning the compactor is greater relative to the time to travel the length of the lift.

The height of the lower zone was determined by the operational clearance needed for the LHD. The height of the LHD to the top of the cab is about 7.5 feet, so an operational clearance of 8.5 feet was maintained. The available operational clearance set the upper zone to 8.5 feet high and the lower zone to the difference from the total drift height. The height of the drift in the test area was 12.5 feet. In order to maintain the operational clearance, the thickness of the lower zone was about 4 feet.

4.4.2. UPPER ZONE

The upper zone was constructed using the LHD to place ROM salt, the Fletcher, with the push-plate attachment, was used to push the ROM salt tight to the back and compact the material. The upper zone of Scenario I was used as the back-stop for the upper zone of Scenario 2. The lifts of the upper zone were placed on a slope of about 30 degrees. This slope matches that of the upper zone of Scenario 1. The LHD placed two buckets per lift. This resulted in a lift thickness of about 12 inches. The LHD could place the material to within about 18 to 24 inches of the back. An average of about 13 minutes was needed to place the ROM salt on each lift. This time is similar to that of Scenarios 1 and the upper zone dimensions for both scenarios are similar.

The Fletcher with the push-plate was used to push the ROM salt tight to the back usually starting along the left rib and working to the right. Compaction of the upper zone lifts usually started in the upper left hand corner and worked across to the opposite rib by moving the plate about a foot, half of the plate width, each time. When the opposite rib was reached the plate would be moved back to the left rib and down about a foot and worked to the opposite rib. This cycle was followed until the bottom of the lift was compacted. Figure 4 shows the push-plate attachment for the Fletcher and Figure 5 shows the compaction of a lift of the upper zone.

The upper zone lifts were compacted using the Fletcher's boom extension to push the push-plate into the slope. The push plate was not vibrated during compaction because of the adverse effects it had on the compaction of the Scenario 1 upper zone lifts.

Pushing up and compacting the lifts of the upper zone averaged about 43 minutes. Improved operator proficiency reduced the average compaction time in Scenario 2 from that of Scenario 1. Only one compaction pass was performed per lift. Additional compaction passes would not be operationally practical due to the time necessary to perform each pass.

Moisture/density testing was performed in accordance with ASTM standards for nuclear methods (ASTM D-6938). As with the lower zone, the sand-cone method for determining density could not be used because the walls of the test hole would collapse under the base plate. Six density tests were made on selected lifts. Generally two tests were made about 3 feet down from the back of the drift, two tests were made about 5 feet down from the back and

two tests were made about 7 feet down from the back. The nuclear density tests varied from a few feet from the ribs to near the drift centerline. Moisture samples were taken in accordance with ASTM D-2216 at each nuclear density test. The nuclear method results were not used for moisture content determination.

Appendix C-2, Appendix E-2 and Appendix F-2 contain information on placement, compaction and testing of the upper zone. The average dry density achieved was 62.5% of the in-situ density of salt.

Table 5 summarizes the results of the Scenario 2 upper zone.

Table 5 - Scenario 2 Upper Zone Moisture/Density

	Moisture %	Dry Density %*
Upper Zone Lifts Average	0.4	62.5
Distance from Back of Drift	Moisture %	Dry Density %*
3 feet	0.4	62.9
5 feet	0.5	63.1
7 feet	0.3	61.5

* Density reported as a percentage of the in-situ density of salt

The results show that the average achievable dry density on the upper zone is about 62.5% after one compaction pass. The dry density does vary by the position in the upper zone. The middle has the highest density at 63.1%. The lowest density is near the bottom of the zone at 61.5%. Close to the back the average was 62.9%. The proposed design called for 80% density in the lower half of the upper zone and 70% in the upper half of the upper zone. The actual average density achieved did not meet the proposed density.

4.4.3. CONSTRUCTION TIME

The crew used to construct the lower zone and the upper zone of Scenario 2 consisted of two qualified miners. Construction work was performed on a 10 hour shift, 4 days per week. As part of the construction methods assessment, each process to construct the lower and upper zones was documented and the data collected can be found in Appendix F-2. Excluding down time, the time necessary to place and compact each lift of the lower zone averaged about 1

hour and 2 minutes. This equates to about 283 cubic feet of lift constructed per hour. Excluding down time, the time necessary to place and compact each lift of the upper zone averaged about 49 minutes. This equates to about 239 cubic feet of lift constructed per hour. In a 10 hour shift, about 6.5 hours of work can be performed. About 80% or 5.2 hours per shift could be expected to be worked accounting for equipment down time and support work. Assuming the 5.2 hours per shift and the rates determined above, the time necessary to construct a WPC in an intake drift, that is 12.5 feet high and 20 feet wide, would be about 24 shifts and in an exhaust drift, that is 12.5 feet high and 14 feet wide, would be about 18 shifts. The preceding construction time estimate does not include time necessary for moisture/density testing. For each set of tests, an additional 2 to 4 hours should be added to the total construction time.

4.5. SCENARIO 3

The test parameters for Scenario 3 were as follow. An LHD was used to emplace ROM salt and the Fletcher with the push-plate attachment was used to push the ROM salt tight to the back.

Figure 1 shows the configuration of the test area and the relation to the other two scenarios. The zone was approximately 44 feet in length, 16 feet wide and 12.5 feet high. The upper (back) portion of the zone was approximately 37 feet in length, 16 feet wide and 12.5 feet high. The slope angle on the zone was about 35 degrees after each lift was pushed tight to the back.

4.5.1. ROM SALT PLACEMENT

An LHD was used to emplace buckets of ROM salt as high as possible. A typically lift was constructed with the LHD placing four buckets of ROM salt and then pushing the ROM salt to within 18 to 24 inches of the back. The LHD that was used had a bucket capacity of 3.6 cubic yards. After the LHD had placed the ROM salt for each lift, the Fletcher with the push-plate attachment was use to push the ROM salt tight to the back. But it was apparent after the first buckets were emplaced that the Fletcher could not effectively reach the back from the original floor. To reduce the distance the Fletcher had to reach the back, two to three feet of ROM salt was placed to build up the floor. Initially seven buckets were placed on the floor and later two to four buckets were emplaced as needed to allow the Fletcher to maintain the height needed to reach the back.

The Fletcher was used to push the ROM salt tight to the back usually starting along the left rib and working to the right. Most of the time this was done with one pass across the face. If the slope became steeper, then two passes were made to keep the salt from sliding down the slope. The placement of each lift took an average of 30 minutes.

Field testing of the zone was performed in accordance with ASTM standards for nuclear methods (ASTM D-6938). Six density tests were made using the nuclear method. Generally two tests were made about 3 feet down from the back of the drift, two tests were made about 5 feet down from the back and two tests were made about 8 feet down from the back. The nuclear density tests varied from a few feet from the ribs to near the drift centerline. Moisture samples were taken at each nuclear density test. The nuclear method results were not used for moisture content determination. The sand-cone method for determining density could not be used because the walls of the hole dug for the sand-cone test would collapse under the base plate.

Information on placement and moisture/density testing on the zone is contained in Appendix C-3, Appendix E-3 and Appendix F-3. Table 6 summarizes the results from the Scenario 3 lifts.

Table 6 - Scenario 3 Moisture/Density by Position in the Lift

Distance from Back of Drift	Moisture %	Dry Density %*
3 feet	0.5	66.5
5 feet	0.4	68.0
8 feet	0.4	66.0

* Density reported as a percentage of the in-situ density of salt

The results show that the average achievable dry density was 66.8%. The dry density does vary by the position on the lift. The middle has the highest density at 68.0% and surprisingly the lowest is close to the bottom of the zone at 66.0%. Close to the back the average was 66.5%.

4.5.2. CONSTRUCTION TIME

The crew, used to construct the lower zone and the upper zone, consisted of two qualified miners. Construction work was performed on a 10 hour shift for five days. As part of the construction methods assessment, each construction process was documented and the data collected can be found in Appendix F-3. The time necessary to emplace and push up each lift of the zone averaged 30 minutes. This equates to about 690 cubic feet of lift constructed per hour. In a 10 hour shift, about 6.5 hours are available for work to be performed. About 80% of the available time, or 5.2 hours per shift, could be expected to be used for actual work. This would account for equipment down time and support work. Assuming the 5.2 hours per shift and the rate determined above, the time necessary to construct a WPC in an intake drift, that is 12.5 feet high and 20 feet wide, would be about 9 shifts. The time necessary to construct a WPC in the exhaust drift, that is 12.5 feet high and 14 feet wide, would be about 6 shifts. This time

estimate does not include time necessary to perform moisture/density testing. For each set of tests, an additional 2 to 4 hours should be added to the total construction time.

5. REFERENCES

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2. Waste Isolation Pilot Plant Shaft Sealing System Compliance Submittal Design Report, SAND96-1326/1.
3. U.S. Department of Energy, Waste Isolation Pilot Plant, Work Order Number 1202108C, Compacted Salt Evaluation.
4. U.S. Department of Energy, Waste Isolation Pilot Plant, Construction Methods Assessment for Compacted Salt Panel Closures Interim Report for Scenario 1 Testing.

Figure 1 – Compacted Salt Test Area Plan and Cross Section

Figure 2 - LHD Placing ROM Salt on Lower Zone Lift

Figure 3 - Walk-behind Roller Compactor Compacting Lower Zone Lift

Figure 4 - Fletcher with Push-Plate Attachment

Figure 5 - Fletcher Compacting Upper Zone

APPENDIX A

Appendix A Contains The Following;

1. Laboratory Test Reports for the Nuclear Density Testing and Sand-Cone Testing Performed Prior To The Actual Field Testing
2. Laboratory Test Reports For the Sieve Analysis Performed On The ROM Salt Used For The Proctor Evaluation And On The ROM Salt Used For The Field Testing
3. Proctor Evaluation Data

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.
1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18
DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 5, 2012

Depth: See Below

Depth of Probe: See Below

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 1	On W. 30 Drift 80' S. of Bulkhead and 5' W. of E.Wall	74.7 *	1.2	1st Lift Probe Depth 6"
SG 2	On W. 30 Drift 70' S. of Bulkhead and 5' W. of E.Wall	74.8 *	1.5	1st Lift Probe Depth 6"
SG 3	On W. 30 Drift 70' S. of Bulkhead and 10' W. of E. Wall	74.7 *	2.3	1st Lift Probe Depth 4"
SG 4	On W. 30 Drift 80' S. of Bulkhead and 10' W. of E.Wall	75.0 *	1.6	1st Lift Probe Depth 4"
SG 5	On W. 30 Drift 80' S. of Bulkhead and 6' W. of E.Wall	74.4 *	2.4	1st Lift Probe Depth 6"
SG 6	On W. 30 Drift 70' S. of Bulkhead and 6' W. of E. Wall	76.6 *	1.4	1st Lift Probe Depth 6"

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Correction 21.6

Required Compaction: 85%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: Erica M Hart

BY: for Debra Hicks **P.E.**

Lab No.: 12 10870-10875

Copies To: Washington TRU Solutions, LLC

LABORATORY TEST REPORT
PETTIGREW & ASSOCIATES, P.A.
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HOBBS, NM 88240
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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 5, 2012

Depth: See Below

Depth of Probe: See Below

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 7	On W. 30 Drift 70' S. of Bulkhead and 10' W. of E.Wall	75.8 *	2.0	1st Lift Probe Depth 4"
SG 8	On W. 30 Drift 80' S. of Bulkhead and 10' W. of E.Wall	75.6 *	2.3	1st Lift Probe Depth 5"
SG 9	On W. 30 Drift 80' S. of Bulkhead and 5' W. of E.Wall	75.9 *	1.7	1st Lift Probe Depth 5"
SG 10	On W. 30' Drift 70' S. of Bulkhead and 5' W. of E.Wall	76.3 *	1.5	1st Lift Probe Depth 6"
SG 11	On W. 30' Drift 70' S. of Bulkhead and 10' W. of E.Wall	76.7 *	2.2	1st Lift Probe Depth 4"
SG 12	On W. 30 Drift 80' S. of Bulkhead and 10' W. of E.Wall	75.6 *	2.1	1st Lift Probe Depth 4"

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 21.6

Required Compaction: 85%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

Lab No.: 12 10876-10882

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BY: Erica M Hart

BY: for Debra Hicks **P.E.**

LABORATORY TEST REPORT

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AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 26, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 58	Old Salt Pile Not part of Closure	71.9 *	0.0	N/A
SG 59	New Salt Pile Not part of Closure	68.1 *	-0.1	N/A

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections -9.7

Required Compaction: 80%

Densometer ID: 5071

*** Does Not Meet Specifications; NO MOISTURE CORRECTION APPLIED.**

PETTIGREW & ASSOCIATES

Lab No.: 12 11877-11880

Copies To: Washington TRU Solutions, LLC

BY: Erica M Hart

BY: for Debra Hicks **P.E.**

LABORATORY TEST REPORT

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(575) 393-9827

AASHTO R18
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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: September 5, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 166	On Drift W-30 Stockpile on E. 140 N.Side	64.0 *	0.6	3rd Region
SG 167	On Drift W-30 Stockpile on E. 140 on S.Side	62.5 *	0.5	3rd Region

Control Density: 135.0
ASTM D: 1557

Optimum Moisture: 0.0%

Required Compaction: 70-80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: _____

BY: _____ **P.E.**

Lab No.: 12 15893-15895

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HOBBS, NM 88240
(575) 393-9827

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DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 1556 Sand Cone

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 5, 2012

Depth: See Below

Depth of Probe: N/A

Test No.	Location	Dry Density % Max	% Moisture	Depth
SC 1	On W. 30 Drift 80' S. of Bulkhead and 10' W. of E.Wall (Corresponds to SG 4)	77.0 *	1.6	1st Lift Depth 4"

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 85%

Densometer ID: N/A

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: Erica M Hart

BY: for Debra Hicks **P.E.**

Lab No.: 12 10883

Copies To: Washington TRU Solutions, LLC

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.
1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18
DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 88221

Type of Test: Sieve Analysis of Fine and Coarse Aggregate
ASTM: C 136

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Type of Material: ROM Salt

Date of Test: 5/22/2012

Location: WIPP Site

Test No: SA-1

Screen Size		% Passing	Required Limits
50.0 mm	2"	100	--
25.0 mm	1"	80	--
19.0 mm	3/4"	77	--
12.5 mm	1/2"	71	--
9.5 mm	3/8"	68	--
4.75 mm	#4	53	--
2.36 mm	#8	35	--
2.0 mm	#10	31	--
1.18 mm	#16	21	--
600 µm	#30	12	--
425 µm	#40	10	--
300 µm	#50	7	--
180 µm	#80	4	--
150 µm	#100	3	--
75 µm	#200	1.2	--
Moisture (%)		0.1	

Delivered 5/18/2012

Lab No.: 12 10356

Copies To: Washington TRU Solutions, LLC

PETTIGREW & ASSOCIATES

By: Teresa M. Hart

By: for Debra Hicks P.E.

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 88221

Type of Test: Sieve Analysis of Fine and Coarse Aggregate
ASTM: C 136

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Type of Material: Course ROM Salt

Date of Test: 5/22/2012

Location: WIPP Site

Test No: SA-2

Screen Size		% Passing	Required Limits
50.0 mm	2"	100	--
25.0 mm	1"	82	--
19.0 mm	3/4"	78	--
12.5 mm	1/2"	68	--
9.5 mm	3/8"	57	--
4.75 mm	#4	29	--
2.36 mm	#8	13	--
2.0 mm	#10	11	--
1.18 mm	#16	6	--
600 µm	#30	4	--
425 µm	#40	3	--
300 µm	#50	3	--
180 µm	#80	2	--
150 µm	#100	2	--
75 µm	#200	0.7	--
Moisture (%)		0.1	

Delivered 5/18/2012

Lab No.: 12 10357

Copies To: Washington TRU Solutions, LLC

PETTIGREW & ASSOCIATES

By: Erica M. Hart

By: for Debra Hicks P.E.

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 88221

Type of Test: Sieve Analysis of Fine and Coarse Aggregate
ASTM: C 136

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Type of Material: Course ROM Salt

Date of Test: 5/22/2012

Location: WIPP Site

Test No: SA-3

Screen Size		% Passing	Required Limits
50.0 mm	2"	100	--
25.0 mm	1"	98	--
19.0 mm	3/4"	95	--
12.5 mm	1/2"	90	--
9.5 mm	3/8"	85	--
4.75 mm	#4	67	--
2.36 mm	#8	45	--
2.0 mm	#10	41	--
1.18 mm	#16	29	--
600 µm	#30	18	--
425 µm	#40	14	--
300 µm	#50	11	--
180 µm	#80	7	--
150 µm	#100	5	--
75 µm	#200	2.0	--
Moisture (%)		0.0	

Delivered 5/18/2012

Lab No.: 12 10358-10359

Copies To: Washington TRU Solutions, LLC

PETTIGREW & ASSOCIATES

By: Erica M. Hatt

By: for Debra Hicks **P.E.**

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

1110 N. GRIMES
HOBBS, NM 88240
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AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 88221

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Type of Test: Materials Finer than #200 Sieve in Mineral Aggregates by Washing
ASTM: C 117

Sieve Analysis of Fine and Coarse Aggregate
ASTM: C 136

Type of Material: ROM Salt

Date of Test: 6/19/2012

Location: Wipp Site Underground from Stockpile

Test No: SA-4

Screen Size		% Passing	Required Limits
75.0 mm	3"	91	
63.0 mm	2½"	85	
50.0 mm	2"	82	
37.5 mm	1½"	80	
31.5 mm	1¼"	78	
25.0 mm	1"	76	
19.0 mm	3/4"	74	
12.5 mm	1/2"	71	
9.5 mm	3/8"	67	
4.75 mm	#4	52	
2.0 mm	#10	32	
425 µm	#40	13	
180 µm	#80	7	
75 µm	#200	3.1	
Moisture (%)		0.0	

Sampled and Delivered 6/18/2012

Lab No.: 12 11226-11227

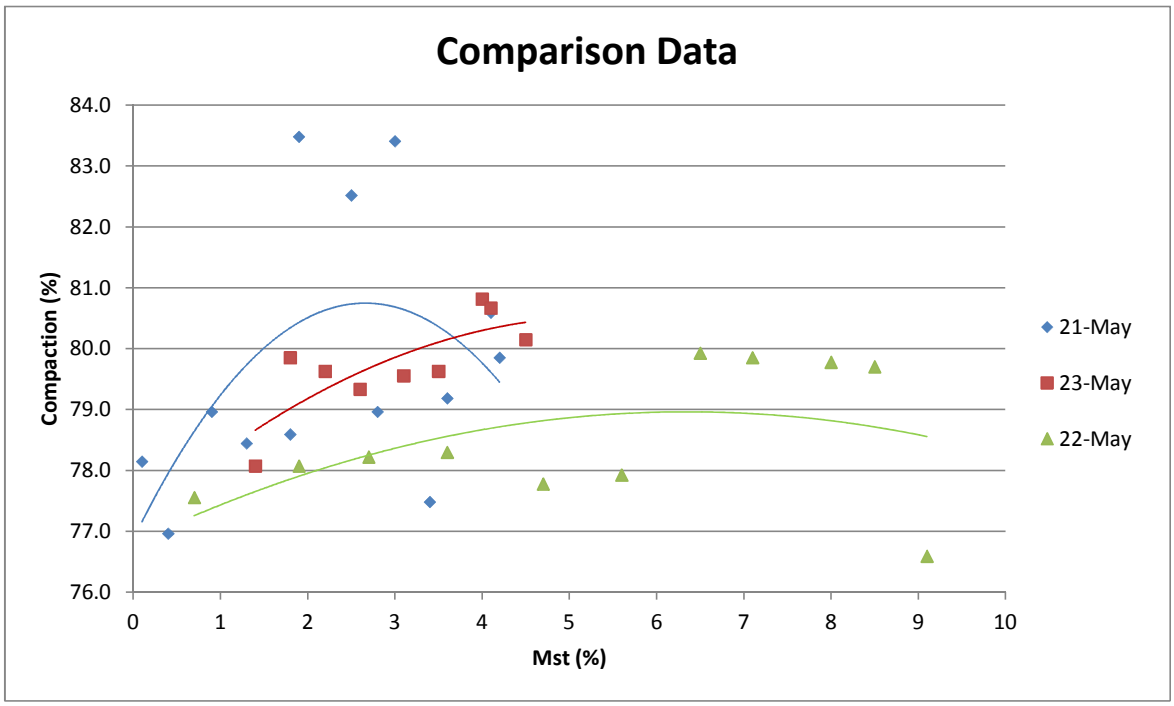
Copies To: Washington TRU Solutions, LLC

PETTIGREW & ASSOCIATES

By: Erica M. Slaff

By: for Debra Hicks **P.E.**

PROCTOR EVALUATION DATA



6 inch mold		6 inch mold		4 inch mold	
21-May		23-May		22-May	
%Mst.	Dry Density	%Mst.	Dry Density	%Mst.	Dry Density
0.1	78.1	1.4	78.1	0.7	77.6
0.4	77	1.8	79.9	1.9	78.1
0.9	79	2.2	79.6	2.7	78.2
1.3	78.4	2.6	79.3	3.6	78.3
1.8	78.6	3.1	79.6	4.7	77.8
1.9	83.8	3.5	79.6	5.6	77.9
2.5	82.5	4	80.8	6.5	79.9
2.8	79	4.1	80.7	7.1	79.9
3	83.4	4.5	80.1	8	79.8
3.4	77.5			8.5	79.7
3.6	79.2			9.1	76.6
4.2	79.9				
4.1	80.6				

APPENDIX B -1

Appendix B – 1 Contains The Following From Scenario 1;

1. The Work Package Data Log Sheets Attachment A – Lower Zone Lift Placement Information
2. The Work Package Data Log Sheets Attachment B – Lower Zone Lift Testing Results

Lower Zone

Scenario: 1

Test Region 1

ATTACHMENT A
Page 1 of 1

Date	Lift #	LHD #	Buckets Placed	Total cuyd placed	Time Water Applied (min.)	Water Applied approx (gal.)	Moisture sample# or %
6/4/2012	1	002C	7.5	27	4	80	
6/6/2012	2	002C	6	21.6	3:00	60	1.6%
6/7/2012	3	002C	3	10.8	1:30	30	1.5%
6/11/2012	3	002C	3	10.8	1:30	30	
6/12/2012	4	002C	3.5	12.6	1:45	35	1.9%
6/12/2012	4	002C	2.5	9	1:20	26.7	
6/13/2012	5	002C	3	10.8	1:30	30	
6/13/2012	5	002C	3	10.8	1:30	30	
6/14/2012	6	002C	3	10.8	1:30	30	
6/14/2012	6	002C	3	10.8	1:30	30	
6/14/2012	7	002C	3	10.8	1:30	30	0.3%
6/14/2012	7	002C	3	10.8	1:30	30	

Attachment to WO#1202108C

Lower Zone

Scenario:1

Test Region:1

ATTACHMENT B

Date	Lift #	Compactor Type	Compactor Speed (ft/min)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance off North Area Boundary (ft)	Sample Number	Wet Density	Moisture %	Dry Density
6/5/2012	1	ROLLER	116.93	6						
6/7/2012	2	ROLLER	132.28	2	4.5	36	SG14	73.3	2.2	71.8
6/7/2012	2	ROLLER	132.28	2	4.5	45	SG13	73.6	1.2	74.2
6/7/2012	2	ROLLER	132.25	2	13	37	SG15	75.9	1.2	74.4
6/7/2012	2	ROLLER	132.28	2	12.5	44	SG16	77.3	2.1	75.6
6/7/2012	2	ROLLER	141.31	4	8.25	43	SG17	77.6	2	76.1
6/7/2012	2	ROLLER	141.31	4	8	34.5	SG18	76.8	1.2	75.9
6/7/2012	2	ROLLER	141.31	4	12.5	36	SG19	73.9	1.2	72.9
6/7/2012	2	ROLLER	141.31	4	12.5	46	SG20	77	1.7	75.8
6/7/2012	2	ROLLER	148.12	6	8	41	SG21	77.3	2.3	75.6
6/7/2012	2	ROLLER	148.12	6	7.9	33.9	SG22	75.9	1.1	75
6/7/2012	2	ROLLER	148.12	6	11.7	46.4	SG23	78.1	1.5	76.7

Attachment to WO#1202108C

Lower Zone

Scenario:1

Test Region:1

ATTACHMENT B

Date	Lift #	Compactor Type	Compactor Speed (ft/min)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance off North Area Boundary (ft)	Sample Number	Wet Density	Moisture %	Dry Density
6/7/2012	2	ROLLER	148.12	6	13.5	37	SG24	76.3	1.5	75
6/11/2012	3	ROLLER	153.75	2	5.5	35.8	SG25	74.4	1.2	74.4
6/11/2012	3	ROLLER	153.75	2	5.5	32.8	SG26	76.1	2.8	74.1
6/11/2012	3	ROLLER	153.75	2	11.75	34	SG27	74.2	1.3	73.1
6/11/2012	3	ROLLER	153.75	2	11.75	42.5	SG28	74	0.7	73.3
6/11/2012	3	ROLLER	145.59	4	6.5	41	SG29	74.6	1.9	73.2
6/11/2012	3	ROLLER	145.59	4	5.5	31.5	SG30	76.1	1.7	74.7
6/11/2012	3	ROLLER	145.59	4	11.5	33	SG31	73.3	1.2	72.4
6/11/2012	3	ROLLER	145.59	4	13.5	43	SG32	75.9	0.7	75.3
6/11/2012	3	ROLLER	131.59	6	6.5	31	SG34	77.4	2.2	75.9
6/11/2012	3	ROLLER	131.59	6	6.5	40	SG33	77.4	1.6	76.3
6/11/2012	3	ROLLER	131.59	6	13.5	31	SG35	74.1	1.2	73

Attachment to WO#1202108C

Lower Zone

Scenario:1

Test Region:1

Date	Lift #	Compactor Type	Compactor Speed (ft/min)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance off North Area Boundary (ft)	Sample Number	Wet Density	Moisture %	Dry Density
6/11/2012	3	ROLLER	131.59	6	13.75	41	SG36	74.3	1.1	73.5
6/13/2012	4	ROLLER	155.94	2	6.25	40.75	SG37	76.2	1.7	74.9
6/13/2012	4	ROLLER	155.94	2	6.33	32	SG38	77.4	1.7	76.1
6/13/2012	4	ROLLER	155.94	2	13.5	32	SG39	75	1.7	73.8
6/13/2012	4	ROLLER	155.94	2	13.3	40.67	SG40	74	1.7	73.6
6/13/2012	4	ROLLER	155.65	4	6	41.25	SG41	76.1	2.1	74.3
6/13/2012	4	ROLLER	155.65	4	6.3	32	SG42	75.3	2.1	73.7
6/13/2012	4	ROLLER	155.65	4	11	32	SG43	76.9	2.1	75.3
6/13/2012	4	ROLLER	155.65	4	10.5	41.75	SG44	76.6	2.7	74.7
6/13/2012	4	ROLLER	189.61	6	7.5	40	SG45	77.1	2.7	75.1
6/13/2012	4	ROLLER	189.61	6	7.5	33	SG46	78.3	2.6	76.3
6/13/2012	4	ROLLER	189.61	6	13	33	SG47	76.3	2.7	74.3

Lower Zone

Scenario:1

Test Region:1

Date	Lift #	Compactor Type	Compactor Speed (ft/min)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance off North Area Boundary (ft)	Sample Number	Wet Density	Moisture %	Dry Density
6/13/2012	4	ROLLER	189.91	6	13	41	SG48	76.2	2.7	74.1
6/18/2012	7	ROLLER	132.28	6	2.5	35	SG49	73	0.4	73.3
6/18/2012	7	ROLLER	132.28	6	8	35	SG50	74	0.3	73.6
6/18/2012	7	ROLLER	132.28	6	13	35	SG51	74.8	0.3	74.5

APPENDIX B – 2

Appendix B – 2 Contains The Following From Scenario 2;

1. The Work Package Data Log Sheets Attachment A – Lower Zone Lift Placement Information
2. The Work Package Data Log Sheets Attachment B – Lower Zone Lift Testing Results

Lower Zone

Scenario: 2

Test Region: 2

ATTACHMENT A
Page 1 of 1

Date	Lift #	LHD #	Buckets Placed	Total cuyd placed	Time Water Applied (min.)	Water Applied approx (gal.)	Moisture sample# or %
7/24/2012	1	002C	3	10.8	0	0	N/A
7/24/2012	2	002C	3	10.8	0	0	N/A
7/24/2012	3	002C	3	10.8	0	0	N/A
7/24/2012	4	002C	3	10.8	0	0	N/A
7/25/2012	5	002C	3	10.8	0	0	N/A
7/26/2012	6	002C	3	10.8	0	0	N/A
7/26/2012	7	002C	3	10.8	0	0	N/A
7/26/2012	8	002C	3	10.8	0	0	N/A
7/30/2012	9	002C	3	10.8	0	0	N/A
7/30/2012	10	002C	3	10.8	0	0	N/A

Attachment to WO#1202108C

Lower Zone

Scenario: 2

Test Region: 2

ATTACHMENT B

Date	Lift #	Compactor Type	Compactor Speed (ft/min)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance off North Area Boundary (ft)	Sample Number	Moisture %	Density
7/25/2012	4	ROLLER	102.5	2	8	13	SG85	0.3	75.0
7/25/2012	4	ROLLER	102.5	2	8	7	SG86	0.3	73.3
7/25/2012	4	ROLLER	102.5	2	13.5	8.5	SG87	0.3	74.6
7/25/2012	4	ROLLER	102.5	2	13.5	15	SG88	0.3	76.1
7/25/2012	4	ROLLER	79	4	8.5	10.5	SG89	0.4	77.8
7/25/2012	4	ROLLER	79	4	8.5	6	SG90	0	75.9
7/25/2012	4	ROLLER	79	4	13.5	9	SG91	0.2	72.6
7/25/2012	4	ROLLER	79	4	13.5	16	SG92	0.3	76.4
7/25/2012	4	ROLLER	117.5	6	8	12	SG93	0.4	74.9
7/25/2012	4	ROLLER	117.5	6	6.5	6	SG94	0.3	73.9
7/25/2012	4	ROLLER	117.5	6	12.5	8	SG95	0.3	75.1
7/25/2012	4	ROLLER	117.5	6	14	13.5	SG96	0.2	76.7

Attachment to WO#1202108C

Lower Zone

Scenario: 2

Test Region: 2

Date	Lift #	Compactor Type	Compactor Speed (ft/min)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance off North Area Boundary (ft)	Sample Number	Moisture %	Density
7/26/2012	6	ROLLER	93.5	2	6.5	14	SG97	0.6	75.3
7/26/2012	6	ROLLER	93.5	2	6.5	9	SG98	0.3	73.0
7/26/2012	6	ROLLER	93.5	2	8	12	SG99	0.5	74.1
7/26/2012	6	ROLLER	93.5	2	15	12.5	SG100	0.4	75.0
7/26/2012	6	ROLLER	68.0	4	8.5	15	SG101	0.5	78.3
7/26/2012	6	ROLLER	68.0	4	8.5	7	SG102	0.5	75.0
7/26/2012	6	ROLLER	68.0	4	12.5	9.5	SG103	0.5	75.1
7/26/2012	6	ROLLER	68.0	4	13	16	SG104	0.5	73.0
7/26/2012	6	ROLLER	83.0	6	8	12.5	SG105	0.5	74.7
7/26/2012	6	ROLLER	83.0	6	9	4.5	SG106	0.5	71.5
7/26/2012	6	ROLLER	83.0	6	14	7	SG107	0.5	74.0
7/26/2012	6	ROLLER	83.0	6	14	14	SG108	0.4	76.6

Attachment to WO#1202108C

Lower Zone

Scenario: 2

Test Region: 2

Date	Lift #	Compactor Type	Compactor Speed (ft/min)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance off North Area Boundary (ft)	Sample Number	Moisture %	Density
7/30/2012	8	LHD	93.5	2	7.5	15	SG109	0	74.7
7/30/2012	8	LHD	93.5	2	7	6.5	SG110	0.1	73.1
7/30/2012	8	LHD	93.5	2	12.5	7	SG111	0.1	72.6
7/30/2012	8	LHD	93.5	2	12	14.5	SG112	0	74.6
7/30/2012	8	LHD	93.5	4	8.5	14	SG113	0	76.6
7/30/2012	8	LHD	93.5	4	8.5	5.5	SG114	0.1	68.4
7/30/2012	8	LHD	93.5	4	13.5	6	SG115	0	72.4
7/30/2012	8	LHD	93.5	4	13.5	14	SG116	0	74.5
7/30/2012	8	LHD	83.1	6	8	13	SG117	0	77.2
7/30/2012	8	LHD	83.1	6	7	5	SG118	0	75.5
7/30/2012	8	LHD	83.1	6	13.5	5.5	SG119	0.4	72.0
7/30/2012	8	LHD	83.1	6	11.5	13.5	SG120	0.7	75.0

Attachment to WO#1202108C

Lower Zone

Scenario: 2

Test Region: 2

Date	Lift #	Compactor Type	Compactor Speed (ft/min)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance off North Area Boundary (ft)	Sample Number	Moisture %	Density
7/31/2012	10	LHD	95.0	2	6.5	14	SG121	0.3	74.1
7/31/2012	10	LHD	95.0	2	7.5	4.5	SG122	0.3	72.5
7/31/2012	10	LHD	95.0	2	12	6.5	SG123	0.4	70.1
7/31/2012	10	LHD	95.0	2	12	14	SG124	0.4	73.3
7/31/2012	10	LHD	83.1	4	7	12.5	SG125	0.4	76.4
7/31/2012	10	LHD	83.1	4	7	3.5	SG126	0.3	74.1
7/31/2012	10	LHD	83.1	4	12	4.5	SG127	0.5	73.8
7/31/2012	10	LHD	83.1	4	12	12	SG128	0.5	75.7
7/31/2012	10	LHD	95.0	6	8.5	13	SG129	0.4	78.1
7/31/2012	10	LHD	95.0	6	6	5.5	SG130	0.3	72.1
7/31/2012	10	LHD	95.0	6	11	6	SG131	0.4	73.9
7/31/2012	10	LHD	95.0	6	11	13.5	SG132	0.4	76.9

Attachment to WO#1202108C

APPENDIX C -1

Appendix C - 1 Contains The Following From Scenario 1;

1. The Work Package Data Log Sheets Attachment C – Upper Zone Lift Placement Information
2. The Work Package Data Log Sheets Attachment D – Upper Zone Lift Placement Information

Upper Zone

Scenario:1

Test Region:1

ATTACHMENT C

Date	Staged Batch #	LHD #	Buckets Staged	Total cuyd staged	Water Applied approx (gal.)	Time Water Applied (min.)	Moisture sample# or %
6/21/2012	1	002C	2	7.2	20	1:00	
6/25/2012	2	002C	2	7.2	20	1:00	
6/25/2012	3	002C	2	7.2	20	1:00	1.3%
6/26/2012	4	002C	2	7.2	20	1:00	
6/27/2012	5	002C	2	7.2	20	1:00	
6/27/2012	6	002C	2	7.2	20	1:00	
6/28/2012	7	002C	2	7.2	20	1:00	0.8%
7/2/2012	8	002C	2	7.2	20	1:00	
7/2/2012	9	002C	2	7.2	20	1:00	
7/2/2012	10	002C	2	7.2	20	1:00	
7/9/2012	11	002C	2	7.2	20	1:00	
7/9/2012	12	002C	2	7.2	20	1:00	

Attachment to WO#1202108C

Upper Zone

Scenario: 1

Test Region: 1

ATTACHMENT C
Page 2 of 3

Date	Staged Batch #	LHD #	Buckets Staged	Total cuyd staged	Water Applied approx (gal.)	Time Water Applied (min.)	Moisture sample# or %
7/9/2012	13	002C	2	7.2	20	1:00	1.10%
7/9/2012	14	002C	2	7.2	20	1:00	
7/11/2012	15	002C	2	7.2	20	1:00	
7/11/2012	16	002C	2	7.2	20	1:00	
7/12/2012	17	002C	2	7.2	20	1:00	
7/12/2012	18	002C	2	7.2	20	1:00	
7/12/2012	19	002C	2	7.2	20	1:00	1.60%
7/16/2012	20	002C	2	7.2	20	1:00	
7/17/2012	21	002C	2	7.2	20	1:00	
7/17/2012	22	002C	2	7.2	20	1:00	
7/17/2012	23	002C	2	7.2	20	1:00	
7/17/2012	24	002C	2	7.2	20	1:00	

Attachment to WO#1202108C

Upper Zone

Scenario: 1

Test Region: 1

ATTACHMENT C
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Date	Staged Batch #	LHD #	Buckets Staged	Total cuyd staged	Water Applied approx (gal.)	Time Water Applied (min.)	Moisture sample# or %
6/17/2012	25	002C	2	7.2	20	1:00	
6/18/2012	26	002C	2	7.2	20	1:00	
6/18/2012	27	002C	2	7.2	20	1:00	
6/18/2012	28	002C	2	7.2	20	1:00	
6/19/2012	29	002C	2	7.2	20	1:00	
6/19/2012	30	002C	2	7.2	20	1:00	
6/19/2012	31	002C	2	7.2	20	1:00	
6/19/2012	32	002C	2	7.2	20	1:00	

Attachment to WO#1202108C

Upper Zone

Scenario:1

Test Region: 1

ATTACHMENT D

Date	Lift #	Staged Batch #	LHD#	Buckets Placed	Plate Impact Time (sec)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance from Back (ft)	Sample Number	Wet Density	Moisture %	Dry Density
6/26/2012	3	3	002C	2	5	1	3	3	SG52	59.7	0.9	58.4
6/26/2012	3	3	002C	2	5	1	7	2.75	SG53	63.2	1.6	62.1
6/26/2012	3	3	002C	2	5	1	11	3	SG54	68.8	0.7	68.3
6/26/2012	3	3	002C	2	5	1	3.5	4.75	SG55	61.5	2	60.1
6/26/2012	3	3	002C	2	5	1	7	4.75	SG56	64.6	1.2	63.9
6/26/2012	3	3	002C	2	5	1	10	4.5	SG57	62.1	1.4	61.2
6/29/2012	7	7	002C	2	5	1	5	8	SG60	64.4	0.6	64.1
6/29/2012	7	7	002C	2	5	1	12	8	SG61	61	1	60.4
6/29/2012	7	7	002C	2	5	1	6	6	SG62	67.4	0.8	66.8
6/29/2012	7	7	002C	2	5	1	15	6	SG63	65.6	0.7	65.1
6/29/2012	7	7	002C	2	5	1	8	4	SG64	63.4	0.9	62.8
6/29/2012	7	7	002C	2	5	1	6	4	SG65	67.6	1	66.8

Attachment to WO#1202108C

Upper Zone

Scenario:1

Test Region:1

Date	Lift #	Staged Batch #	LHD#	Buckets Placed	Plate Impact Time (sec)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance from Back (ft)	Sample Number	Wet Density	Moisture %	Dry Density
7/10/2012	13	13	002C	2	0	1	3	6.5	SG66	70.4	1.7	68.7
7/10/2012	13	13	002C	2	0	1	8.5	5	SG67	73.9	1.7	72.9
7/10/2012	13	13	002C	2	0	1	2.5	5	SG68	71.9	0.9	71.3
7/10/2012	13	13	002C	2	0	1	12.5	4	SG69	70.9	0.4	70.5
7/10/2012	13	13	002C	2	0	1	3.5	2.75	SG70	67.7	0.6	67.3
7/10/2012	13	13	002C	2	0	1	10	2.5	SG71	67.1	1.5	66
7/11/2012	19	19	002C	2	0	1	4.5	7	SG72	55.5	1.7	55
7/11/2012	19	19	002C	2	0	1	11.5	7	SG73	62.5	2.2	61.1
7/11/2012	19	19	002C	2	0	1	5.5	5	SG74	62.3	1.7	61
7/11/2012	19	19	002C	2	0	1	14.5	5	SG75	60.4	0.7	59.9
7/11/2012	19	19	002C	2	0	1	4	3.5	SG76	61.4	1.8	60.1
7/11/2012	19	19	002C	2	0	1	11.5	3	SG77	66.4	1.6	66.4

Attachment to WO#1202108C

Upper Zone

Scenario:1

Test Region:1

ATTACHMENT D

Date	Lift #	Staged Batch #	LHD#	Buckets Placed	Plate Impact Time (sec)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance from Back (ft)	Sample Number	Wet Density	Moisture %	Dry Density
7/23/2012	32	32	002C	2	0	1	4	7.5	SG79	59.6	2.1	57.9
7/23/2012	32	32	002C	2	0	1	12	6.5	SG80	56.3	2.2	54.7
7/23/2012	32	32	002C	2	0	1	405	4	SG81	65.3	0.6	64.6
7/23/2012	32	32	002C	2	0	1	13	4	SG82	61	1.1	60.3
7/23/2012	32	32	002C	2	0	1	4	2	SG83	61.7	1.1	61
7/23/2012	32	32	002C	2	0	1	11	2	SG84	61.2	0.7	60.7

Attachment to WO#1202108C

APPENDIX C – 2

Appendix C - 2 Contains The Following From Scenario 2;

1. The Work Package Data Log Sheets Attachment C – Upper Zone Lift Placement Information
2. The Work Package Data Log Sheets Attachment D – Upper Zone Lift Placement Information

Upper Zone

Scenario: 2

Test Region: 2

ATTACHMENT C

Date	Staged Batch #	LHD #	Buckets Staged	Total cuyd staged	Water Applied approx (gal.)	Time Water Applied (min.)	Moisture sample# or %
8/8/2012	1	002C	2	7.2	0	N/A	N/A
8/8/2012	2	002C	2	7.2	0	N/A	N/A
8/8/2012	3	002C	2	7.2	0	N/A	N/A
8/9/2012	4	002C	2	7.2	0	N/A	N/A
8/9/2012	5	002C	2	7.2	0	N/A	N/A
8/9/2012	6	002C	2	7.2	0	N/A	N/A
8/9/2012	7	002C	2	7.2	0	N/A	N/A
8/13/2012	8	002C	2	7.2	0	N/A	N/A
8/13/2012	9	002C	2	7.2	0	N/A	N/A
8/13/2012	10	002C	2	7.2	0	N/A	N/A
8/14/2012	11	002C	2	7.2	0	N/A	N/A
8/14/2012	12	002C	2	7.2	0	N/A	N/A

Attachment to WO#1202108C

Upper Zone

Scenario: 2

Test Region: 2

ATTACHMENT C

Date	Staged Batch #	LHD #	Buckets Staged	Total cuyd staged	Water Applied approx (gal.)	Time Water Applied (min.)	Moisture sample# or %
8/15/2012	13	002C	2	7.2	0	N/A	N/A
8/15/2012	14	002C	2	7.2	0	N/A	N/A
8/15/2012	15	002C	2	7.2	0	N/A	N/A
8/15/2012	16	002C	2	7.2	0	N/A	N/A
8/15/2012	17	002C	2	7.2	0	N/A	N/A
8/16/2012	18	002C	2	7.2	0	N/A	N/A
8/16/2012	19	002C	2	7.2	0	N/A	N/A
8/20/2012	20	002C	2	7.2	0	N/A	N/A
8/20/2012	21	002C	2	7.2	0	N/A	N/A
8/20/2012	22	002C	2	7.2	0	N/A	N/A
8/20/2012	23	002C	2	7.2	0	N/A	N/A

Attachment to WO#1202108C

Upper Zone

Scenario: 2

Test Region: 2

Date	Staged Batch #	LHD #	Buckets Staged	Total cuyd staged	Water Applied approx (gal.)	Time Water Applied (min.)	Moisture sample# or %
8/21/2012	24	002C	2	7.2	0	N/A	N/A
8/21/2012	25	002C	2	7.2	0	N/A	N/A
8/21/2012	26	002C	2	7.2	0	N/A	N/A
8/21/2012	27	002C	2	7.2	0	N/A	N/A
8/22/2012	28	002C	2	7.2	0	N/A	N/A
8/22/2012	29	002C	2	7.2	0	N/A	N/A
8/22/2012	30	002C	2	7.2	0	N/A	N/A
8/23/2012	31	002C	2	7.2	0	N/A	N/A
8/23/2012	32	002C	2	7.2	0	N/A	N/A
8/23/2012	33	002C	2	7.2	0	N/A	N/A
8/23/2012	34	002C	2	7.2	0	N/A	N/A
8/23/2012	35	002C	2	7.2	0	N/A	N/A
8/23/2012	36	002C	2	7.2	0	N/A	N/A

Attachment to WO#1202108C

Upper Zone

Scenario: 2

Test Region: 2

ATTACHMENT C

Date	Staged Batch #	LHD #	Buckets Staged	Total cuyd staged	Water Applied approx (gal.)	Time Water Applied (min.)	Moisture sample# or %
8/24/2012	37	002C	2	7.2	0	N/A	N/A
8/24/2012	38	002C	2	7.2	0	N/A	N/A
8/24/2012	39	002C	2	7.2	0	N/A	N/A
8/24/2012	40	002C	2	7.2	0	N/A	N/A

Attachment to WO#1202108C

Upper Zone

Scenario: 2

Test Region: 2

ATTACHMENT D

Date	Lift #	Staged Batch #	LHD#	Buckets Placed	Plate Impact Time (sec)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance from Back (ft)	Sample Number	Moisture %	Density %
8/14/2012	10	10	002C	2	0	1	3.5	6	SG136	0.3	65.1
8/14/2012	10	10	002C	2	0	1	11	7	SG137	0.4	66.5
8/14/2012	10	10	002C	2	0	1	6	4.5	SG138	0.4	64.7
8/14/2012	10	10	002C	2	0	1	13	4	SG139	0.4	65.3
8/14/2012	10	10	002C	2	0	1	3	3	SG140	0.4	63.6
8/14/2012	10	10	002C	2	0	1	10	3	SG141	0.4	62.1
8/16/2012	17	17	002C	2	0	1	3	7.5	SG142	0.3	55.1
8/16/2012	17	17	002C	2	0	1	14	8	SG143	0.4	59.0
8/16/2012	17	17	002C	2	0	1	5	5.5	SG144	0.4	61.3
8/16/2012	17	17	002C	2	0	1	12	5	SG145	0.4	63.7
8/16/2012	17	17	002C	2	0	1	3	3	SG146	0.4	63.6
8/16/2012	17	17	002C	2	0	1	14	3	SG147	0.4	58.8

Attachment to WO#1202108C

Upper Zone

Scenario: 2

Test Region: 2

Date	Lift #	Staged Batch #	LHD#	Buckets Placed	Plate Impact Time (sec)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance from Back (ft)	Sample Number	Moisture %	Density %
8/22/2012	27	30	002C	2	0	1	2	8	SG148	0.4	60.8
8/22/2012	27	30	002C	2	0	1	12	7.5	SG149	0.3	61.7
8/22/2012	27	30	002C	2	0	1	5	5	SG150	0.6	61.1
8/22/2012	27	30	002C	2	0	1	12	4	SG151	0.5	63.1
8/22/2012	27	30	002C	2	0	1	5	3	SG152	0.5	64.1
8/22/2012	27	30	002C	2	0	1	12	2.5	SG153	0.4	63.6
8/24/2012	37	37	002C	2	0	1	2	7.5	SG154	0.3	61.7
8/24/2012	37	37	002C	2	0	1	13	8	SG155	0.2	62.1
8/24/2012	37	37	002C	2	0	1	4	5.5	SG156	0.4	61.3
8/24/2012	37	37	002C	2	0	1	13	5.5	SG157	0.5	64.2
8/24/2012	37	37	002C	2	0	1	4	2.5	SG158	0.4	65.3
8/24/2012	37	37	002C	2	0	1	13	2.5	SG159	0.3	62.1

Attachment to WO#1202108C

APPENDIX C-3

Appendix C - 3 Contains The Following From Scenario 3;

1. The Work Package Data Log Sheets Attachment C – ROM Salt Placement Information
2. The Work Package Data Log Sheets Attachment D – ROM Salt Placement Information

Scenario: 3

Test Region: 3

ATTACHMENT C

Date	Staged Batch #	LHD #	Buckets Staged	Total cuyd staged	Water Applied approx (gal.)	Time Water Applied (min.)	Moisture sample# or %
9/4/2012	1	002C	2	7.2	N/A	N/A	N/A
9/4/2012	2	002C	9	32.4	N/A	N/A	N/A
9/5/2012	3	002C	4	14.4	N/A	N/A	N/A
9/5/2012	4	002C	4	14.4	N/A	N/A	N/A
9/5/2012	5	002C	2	7.2	N/A	N/A	N/A
9/5/2012	6	002C	2	7.2	N/A	N/A	N/A
9/5/2012	7	002C	6	21.6	N/A	N/A	N/A
9/6/2012	8	002C	2	7.2	N/A	N/A	N/A
9/6/2012	9	002C	2	7.2	N/A	N/A	N/A
9/6/2012	10	002C	2	7.2	N/A	N/A	N/A
9/6/2012	11	002C	2	7.2	N/A	N/A	N/A
9/6/2012	12	002C	2	7.2	N/A	N/A	N/A

Attachment to WO#1202108C

Scenario: 3

Test Region: 3

Date	Staged Batch #	LHD #	Buckets Staged	Total cuyd staged	Water Applied approx (gal.)	Time Water Applied (min.)	Moisture sample# or %
9/6/2012	13	002C	2	7.2	N/A	N/A	N/A
9/6/2012	14	002C	2	7.2	N/A	N/A	N/A
9/6/2012	15	002C	4	14.4	N/A	N/A	N/A
9/6/2012	16	002C	2	7.2	N/A	N/A	N/A
9/6/2012	17	002C	4	14.4	N/A	N/A	N/A
9/7/2012	18	138	2	7.2	N/A	N/A	N/A
9/7/2012	19	138	2	7.2	N/A	N/A	N/A
9/7/2012	20	138	4	14.4	N/A	N/A	N/A
9/7/2012	21	138	4	14.4	N/A	N/A	N/A
9/6/2012	22	138	4	14.4	N/A	N/A	N/A
9/6/2012	23	138	4	14.4	N/A	N/A	N/A
9/6/2012	24	138	4	14.4	N/A	N/A	N/A

Attachment to WO#1202108C

Scenario: 3

Test Region: 3

ATTACHMENT C
Page 3 of 3

Date	Staged Batch #	LHD #	Buckets Staged	Total cuyd staged	Water Applied approx (gal.)	Time Water Applied (min.)	Moisture sample# or %
9/7/2012	25	138	4	14.4	N/A	N/A	N/A
9/7/2012	26	138	4	14.4	N/A	N/A	N/A
9/8/2012	27	138	2	7.2	N/A	N/A	N/A
9/8/2012	28	138	4	14.4	N/A	N/A	N/A
9/8/2012	29	138	4	14.4	N/A	N/A	N/A

Attachment to WO#1202108C

Scenario:____3

Test Region:__3

ATTACHMENT D

Page 1 of 2

Date	Lift #	Staged Batch #	LHD#	Buckets Placed	Plate Impact Time (sec)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance from Back (ft)	Sample Number	Wet Density	Moisture %	Dry Density
9/5/2012	5	5	002C	2	N/A	N/A	3'	8'	SG160	64.8	0.4	64.5
9/5/2012	5	5	002C	2	N/A	N/A	12'	8'6"	SG161	63.3	0.3	63.1
9/5/2012	5	5	002C	2	N/A	N/A	3'	4'6"	SG162	68.4	0.5	68.1
9/5/2012	5	5	002C	2	N/A	N/A	14'	4'6"	SG163	67.9	0.5	67.6
9/5/2012	5	5	002C	2	N/A	N/A	6'	3'	SG164	65.2	0.5	64.8
9/5/2012	5	5	002C	2	N/A	N/A	13'	3'	SG165	65.1	0.5	64.7
9/5/2012	Stock Pile	N/A	N/A	N/A	N/A	N/A	E140	North End	SG166	64.5	0.6	64.0
9/5/2012	Stock Pile	N/A	N/A	N/A	N/A	N/A	E140	South End	SG167	63.1	0.5	62.5

Attachment to WO#1202108C

Scenario: 3

Test Region: 3

Date	Lift #	Staged Batch #	LHD#	Buckets Placed	Plate Impact Time (sec)	Cumulative Number of Compaction (No. of Passes)	Sample Location Distance off West Rib (ft)	Sample Locaton Distance from Back (ft)	Sample Number	Wet Density	Moisture %	Dry Density
9/7/2012	17	17	002C	2	N/A	N/A	2'8"	9'7"	SG168	58.9	0.3	61.6
9/7/2012	17	17	002C	2	N/A	N/A	13'	8'10"	SG169	65.8	0.4	65.6
9/7/2012	17	17	002C	2	N/A	N/A	3'	5'1"	SG170	65.3	0.4	65.1
9/7/2012	17	17	002C	2	N/A	N/A	14'6"	6'	SG171	63.5	0.4	63.3
9/7/2012	17	17	002C	2	N/A	N/A	2'10"	3'2"	SG172	67.1	0.4	66.9
9/7/2012	17	17	002C	2	N/A	N/A	13'4"	3'7"	SG173	63.2	0.4	63.0
9/10/2012	29	29	138	4	N/A	N/A	6'6"	8'	SG174	69.7	0.3	71.7
9/10/2012	29	29	138	4	N/A	N/A	13'6"	8'6"	SG175	68.9	0.4	69.6
9/10/2012	29	29	138	4	N/A	N/A	4'	5'6"	SG176	71.1	0.4	71.0
9/10/2012	29	29	138	4	N/A	N/A	10'	6'	SG177	72.9	0.3	73.0
9/10/2012	29	29	138	4	N/A	N/A	6'	3'	SG178	70.4	0.4	70.1
9/10/2012	29	29	138	4	N/A	N/A	12'	3'	SG179	69.4	0.5	69.2

Attachment to WO#1202108C

APPENDIX D – 1

Appendix D - 1 Contains The Following From Scenario 1;

1. Table 1, Comparison Of Nuclear Density Sampling And Sand Cone Sampling At Corresponding Locations
2. The Laboratory Test Reports For The Nuclear Density Testing Performed On The Lifts Of The Lower Zone
3. The Laboratory Test Reports For The Sand-Cone Testing Performed On The Lifts Of The Lower Zone

Comparison of Nuclear Density Sampling and Sand Cone Sampling At Corresponding Locations

Lower Zone

SG Number	Density	Moisture*		SC Number	Density	Moisture*
SG16	75.6	2.1		SC2	77.9	1.2
SG19	72.9	1.2		SC3	72.0	1.2
SG22	75.0	1.1		SC4	74.1	1.1
SG28	73.3	0.7		SC5	75.7	1.6
Average	74.2	1.3			74.9	1.3

Upper Zone

SG Number	Density	Moisture*		SC Number	Density	Moisture*
SG53	62.1	1.6		SC6	67.5	1.5
SG60	64.1	0.6		SC7	65.0	0.6
SG67	72.9	1.7		SC10	76.4	1.7
SG69	70.5	0.4		SC11	70.2	0.4
SG71	66.0	1.5		SC12	67.6	1.5
SG79	56.4	2.1		SC13	67.9	2.1
SG81	64.6	0.6		SC14	62.1	0.6
Average	65.2	1.2			68.1	1.2

*Moisture determination by ASTM D2216

Table 1

LABORATORY TEST REPORT
PETTIGREW & ASSOCIATES, P.A.
1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18
DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 7, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 13	On W. 30 Drift 80' S. of Bulkhead and 10' W. of E. Wall	74.2 *	1.2	2nd Lift
SG 14	On W. 30 Drift 70' S. of Bulkhead and 10' W. of E. Wall	71.8 *	2.2	2nd Lift
SG 15	On W. 30 Drift 70' S. of Bulkhead and 5' W. of E. Wall	74.4 *	1.2	2nd Lift
SG 16	On W. 30 Drift 80' S. of Bulkhead and 5' W. of E.Wall	75.6 *	2.1	2nd Lift
SG 17	On W. 30 Drift 80' S. of Bulkhead and 12' W. of E.Wall	76.1 *	2.0	2nd Lift
SG 18	On W. 30 Drift 70' S. of Bulkhead and 12' W. of E.Wall	75.9 *	1.2	2nd Lift

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trech Corrections 19.7

Required Compaction: 85%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: Erica M Hart

Lab No.: 12 10884-10889

Copies To: Washington TRU Solutions, LLC

BY: for Debra Hicks **P.E.**

LABORATORY TEST REPORT

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P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 7, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 19	On W. 30 Drift 70' S. of Bulkhead and 6' W. of E.Wall	72.9 *	1.2	2nd Lift
SG 20	On W. 30 Drift 80' S. of Bulkhead and 6' W. of E.Wall	75.8 *	1.7	2nd Lift
SG 21	On W. 30 Drift 80' S. and 10' W. of E. Wall	75.6 *	2.3	2nd Lift
SG 22	On W. 30 Drift 70' S. and 10' W. of E. Wall	75.0 *	1.1	2nd Lift
SG 23	On W. 30 Drift 70' S. and 5' W. of E.Wall	76.7 *	1.5	2nd Lift
SG 24	On W. 30 Drift 80' S. of Bulkhead and 5' W. of E.Wall	75.0 *	1.5	2nd Lift

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 19.7

Required Compaction: 85%

Densometer ID: 5071

*** Does Not Meet Specifications**

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4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 11, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 25	On Drift W.30 80' S. of Bulkhead and 10' W. of E. Wall	74.4 *	1.2	3rd Lift
SG 26	On Drift W.30 70' S. of Bulkhead and 8' W. of E. Wall	74.1 *	2.8	3rd Lift
SG 27	On Drift W.30 70' S. of Bulkhead and 4' W. of E. Wall	73.1 *	1.3	3rd Lift
SG 28	On Drift W. 30 80' S. of Bulkhead and 5' W. of E. Wall	73.3 *	0.7	3rd Lift
SG 29	On Drift W. 30 70' S. of Bulkhead and 10' W. of E. Wall	73.2 *	1.9	3rd Lift
SG 30	On Drift W. 30 70' S. of Bulkhead and 10' W. of E. Wall	74.7 *	1.7	3rd Lift

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 11.9

Required Compaction: 80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

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To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 11, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 31	On Drift W.30 70' S. of Bulkhead and 5' W. of E. Wall	72.4 *	1.2	3rd Lift
SG 32	On Drift W.30 80' S. of Bulkhead and 5' W. of E.Wall	75.3 *	0.7	3rd Lift
SG 33	On Drift W.30 80' S. of Bulkhead and 9' W. of E. Wall	76.3 *	1.6	3rd Lift
SG 34	On Drift W. 30 70' S. of Bulkhead and 9' W. of E. Wall	75.9 *	2.2	3rd Lift
SG 35	On Drift W. 30 70' S. of Bulkhead and 4' W. of E. Wall	73.0 *	1.2	3rd Lift
SG 36	On Drift W. 30 80' S. of Bulkhead and 5' W. of E. Wall	73.5 *	1.1	3rd Lift

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 11.9

Required Compaction: 80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: Erica M. Hart

BY: for Debra Hicks **P.E.**

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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 13, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 37	On Drift W.30 80' S. of Bulkhead and 12' W. of E. Wall	74.9 *	1.7	4th Lift
SG 38	On Drift W.30 70' S. of Bulkhead and 12' W. of E. Wall	76.1 *	1.7	4th Lift
SG 39	On Drift W.30 70' S. of Bulkhead and 4' W. of E. Wall	73.8 *	1.7	4th Lift
SG 40	On Drift W. 30 80' S. of Bulkhead and 4' W. of E. Wall	73.6 *	1.7	4th Lift
SG 41	On Drift W. 30 80' S. of Bulkhead and 10' W. of E.Wall	74.3 *	2.1	4th Lift
SG 42	On Drift W. 30 70' S. of Bulkhead and 10' W. of E. Wall	73.7 *	2.1	4th Lift

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

*** Does Not Meet Specifications; 3 Moisture Samples taken Per TY; Moistures and Percent Maximum Dry Density were Corrected using Moistures from SG 37, 43 & 48.**

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To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 13, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 43	On Drift W.30 70' S. of Bulkhead and 4' W. of E.Wall	75.3 *	2.1	4th Lift
SG 44	On Drift W.30 80' S. of Bulkhead and 4' W. of E.Wall	74.7 *	2.7	4th Lift
SG 45	On Drift W.30 80' S. of Bulkhead and 10' W. of E.Wall	75.1 *	2.7	4th Lift
SG 46	On Drift W. 30 70' S. of Bulkhead and 10' W. of E. Wall	76.3 *	2.6	4th Lift
SG 47	On Drift W. 30 70' S. of Bulkhead and 5' W. of E. Wall	74.3 *	2.7	4th Lift
SG 48	On Drift W. 30 80' S. of Bulkhead and 5' W. of E.Wall	74.1 *	2.7	4th Lift

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

*** Does Not Meet Specifications; 3 Moisture Samples taken Per TY; Moistures and Percent Maximum Dry Density were Corrected using Moistures from SG 37, 43 & 48.**

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To: Washington TRU Solutions, LLC
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P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 18, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 49	On Drift W. 30 80' S. of Bulkhead and 4' E. of W. Wall	73.3 *	0.4	7th Lift
SG 50	On Drift W. 30 80' S. of Bulkhead and 10' W. of E. Wall	73.6 *	0.3	7th Lift
SG 51	On Drift W.30 80' S. of Bulkhead and 4' W. of E. Wall	74.5 *	0.3	7th Lift

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 7.8

Required Compaction: 80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: Erica M. Hart

Lab No.: 12 11261-11264

BY: for Debra Hicks **P.E.**

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LABORATORY TEST REPORT

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WILLIAM M. HICKS. III, P.E./P.S.

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4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 13, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 78	Bottom Zone	80.5	0.2	Top Zone Lift 19

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections -4.4

Required Compaction: 70-80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

BY: Erica M Hart

Lab No.: 12 12058

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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 1556 Sand Cone

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 7, 2012

Depth: See Below

Depth of Probe: N/A

Test No.	Location	Dry Density % Max	% Moisture	Depth
SC 2	On W. 30 Drift 80' S. of Bulkhead and 5' W. of E.Wall (Corresponds to SG 16)	77.9 *	1.2	2nd Lift Depth 6"
SC 3	On W. 30 Drift 70' S. of Bulkhead and 6' W. of E.Wall (Corresponds to SG 19)	72.0 *	1.2	2nd Lift Depth 6"
SC 4	On W. 30 Drift 70' S. and 10' W. of E.Wall (Corresponds to SG 22)	74.1 *	1.1	2nd Lift Depth 6"

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 85%

Densometer ID: N/A

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: Erica M Hart

Lab No.: 12 10897

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BY: for Debra Hicks **P.E.**

LABORATORY TEST REPORT

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(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 1556 Sand Cone

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 11, 2012

Depth: See Below

Depth of Probe: N/A

Test No.	Location	Dry Density % Max	% Moisture	Depth
SC 5	On Drift W. 30 80' S. of Bulkhead and 5' W. of E. Wall (Corresponds to SG 28)	75.7	1.6	3rd Lift Depth 6"

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 85%

Densometer ID: N/A

PETTIGREW & ASSOCIATES

BY: Erica M Hart

Lab No.: 12 11083

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BY: for Debra Hicks **P.E.**

APPENDIX D – 2

Appendix D – 2 Contains The Following From Scenario 2;

1. The Laboratory Test Reports For The Nuclear Density Testing Performed On The Lifts Of The Lower Zone

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

1110 N. GRIMES
HOBBS, NM 88240
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DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 25, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 85	On Drift W. 30 15' E. of W. Wall and 15' S. of Salt Wall	75.0 *	0.3	4th Lift Bottom Layer
SG 86	On Drift W. 30 15' E. of W.Wall and 8' S. of Salt Wall	73.3 *	0.3	4th Lift Bottom Layer
SG 87	On Drift W. 30 4' W. of E. Wall and 8' S. of Salt Wall	74.6 *	0.3	4th Lift Bottom Layer
SG 88	On Drift W. 30 4' W. of E. Wall and 15' S. of Salt Wall	76.1 *	0.3	4th Lift Bottom Layer
SG 89	On Drift W. 30 15' E. of W.Wall and 15' S. of Salt Wall	77.8 *	0.4	4th Lift Bottom Layer
SG 90	On Drift W. 30 15' E. of W.Wall and 6' S. of Salt Wall	75.9 *	0.0	4th Lift Bottom Layer

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 12.1

Required Compaction: 70-80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

BY: Erica M Hart

Lab No.: 12 12612-12617

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LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.
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AASHTO R18
DEBRA P. HICKS, P.E./L.S.I.
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4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 25, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 91	On Drift W. 30 5' W. of E. Wall and 6' S. of N. Wall	72.6 *	0.2	4th Lift Bottom Layer
SG 92	On Drift W. 30 5' W. of E. Wall and 15' S. of Salt Wall	76.4 *	0.3	4th Lift Bottom Layer
SG 93	On Drift W. 30 15' E. of W. Wall and 12' S. of Salt Wall	74.9 *	0.4	4th Lift Bottom Layer
SG 94	On Drift W. 30 15' E. of W.Wall and 8' S. of Salt Wall	73.9 *	0.3	4th Lift Bottom Layer
SG 95	On Drift W. 30 4' W. of E. Wall and 8' S. of Salt Wall	75.1 *	0.3	4th Lift Bottom Layer
SG 96	On Drift W. 30 4' from E. Wall and 15' S. of N.Wall	76.7 *	0.2	4th Lift Bottom Layer

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 12.1

Required Compaction: 70-80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

BY: Erica M Hart

Lab No.: 12 12618-12624

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BY: for Debra Hicks **P.E.**

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HOBBS, NM 88240
(575) 393-9827

AASHTO R18
DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 26, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 97	On Drift W. 30 15' E. of W. Wall and 15' S. of Salt Wall	75.3 *	0.6	On Bottom
SG 98	On Drift W. 30 15' E. of W. Wall and 8' S. of Salt Wall	73.0 *	0.3	On Bottom
SG 99	On Drift W.30 5' W. of E. Wall and 8' S. of Salt Wall	74.1 *	0.5	On Bottom
SG 100	On Drift W. 30 15' S. of Salt Wall and 5' W. of E. Wall	75.0 *	0.4	On Bottom
SG 101	On Drift W. 30 15' E. of W. Wall and 15' S. of Salt Wall	78.3 *	0.5	On Bottom
SG 102	On Drift W. 30 15' E. of W. Wall and 6' S. of Salt Wall	75.0 *	0.5	On Bottom

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 12.1

Required Compaction: 70-80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

BY: Erica M. Hart

Lab No.: 12 12625-12630

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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 26, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 103	On Drift W. 30 6' W. of E. Wall and 8' S. of Salt Wall	75.1 *	0.5	On Bottom
SG 104	On Drift W. 30 6' W. of E. Wall and 15' S. of Salt Wall	73.0 *	0.5	On Bottom
SG 105	On Drift W.30 15' E. of W.Wall and 17' S. of Salt	74.7 *	0.5	On Bottom
SG 106	On Drift W. 30 15' E. of W. Wall and 8' S. of Salt Wall	71.5 *	0.5	On Bottom
SG 107	On Drift W. 30 6' W. of E. Wall and 8' S. of Salt Wall	74.0 *	0.5	On Bottom
SG 108	On Drift W. 30 6' W. of E. Wall and 15' S. of Salt Wall	76.6 *	0.4	On Bottom

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 12.1

Required Compaction: 70-80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

BY: Erica M. Hart

Lab No.: 12 12631-12637

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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 30, 2012

Depth: See Below

Depth of Probe: See Below

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 109	On Drift W. 30 15' E. of W.Wall and 15' S. of Salt Wall	74.7 *	0.0	Probe of Depth 5" On Bottom
SG 110	On Drift W. 30 15' E. of W. Wall and 8' S. of Salt Wall	73.1 *	0.1	Probe of Depth 6" On Bottom
SG 111	On Drift W. 30 5' W. of E. Wall and 8' S. of Salt Wall	72.6 *	0.1	Probe of Depth 6" On Bottom
SG 112	On Drift W. 30 5' W. of E. Wall and 15' S. of Salt Wall	74.6 *	0.0	Probe of Depth 6" On Bottom
SG 113	On Drift W. 30 15' E. of W.Wall and 13' S. of Salt Wall	76.6 *	0.0	Probe of Depth 5" On Bottom
SG 114	On Drift W. 30 15' E. of W. Wall and 8' S. of Salt Wall	68.4 *	0.1	Probe of Depth 5" On Bottom

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 6.3

Required Compaction: 70-80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

BY: Erica M. Hunt

Lab No.: 12 12848-12853

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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 30, 2012

Depth: See Below

Depth of Probe: See Below

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 115	On Drift W. 30, 6' W. of E. Wall and 8' S. of Salt Wall	72.4 *	0.0	Probe of Depth 5" On Bottom
SG 116	On Drift W. 30 6' W. of E. Wal and 15' S. of Salt Wall	74.5 *	0.0	Probe of Depth 6" On Bottom
SG 117	On Drift W. 30 6' E. of W.Wall and 15' S. of Salt Wall	77.2 *	0.0	Probe of Depth 6" On Bottom
SG 118	On Drift W. 30 15' E. of W.Wall and 8' S. of Salt Wall	75.5 *	0.0	Probe of Depth 6" On Bottom
SG 119	On Drift W.30 5' W. of E. Wall and 8' S. of Salt Wall	72.0 *	0.4	Probe of Depth 6" On Bottom
SG 120	On Drift W. 30 6' W. of E. Wall and 16' S. of Salt Wall	75.0 *	0.7	Probe of Depth 5" On Bottom

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 6.3

Required Compaction: 70-80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

Lab No.: 12 12854-12860

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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 31, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 121	On Drift W. 30 15' E. of W. Wall and 15' S. of Salt Wall	74.1 *	0.3	On Bottom 10th Lift
SG 122	On Drift W. 30 15' E. of W. Wall and 8' S. of Salt Wall	72.5 *	0.3	On Bottom 10th Lift
SG 123	On Drift W. 30 8' W. of E. Wall and 8' S. of Salt Wall	70.1 *	0.4	On Bottom 10th Lift
SG 124	On Drift W. 30 8' W. of E. Wall and 15' S.of Salt Wall	73.3 *	0.4	On Bottom 10th Lift
SG 125	On Drift W. 30 15' E. of W. Wall and 16' S. of Salt Wall	76.4 *	0.4	On Bottom 10th Lift
SG 126	On Drift W. 30 15' E. of W. Wall and 6' S. of Salt Wall	74.1 *	0.3	On Bottom 10th Lift

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 5.1

Required Compaction: 70-80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

Lab No.: 12 12832-12837

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BY: for Debra Hicks **P.E.**

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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 31, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 127	On Drift W. 30 8' S. of Salt Wall and 6' W. of E. Wall	73.8 *	0.5	On Bottom 10th Lift
SG 128	On Drift W. 30 15' S.of Salt Wall and 6' W. of E.Wall	75.7 *	0.5	On Bottom 10th Lift
SG 129	On Drift W. 30 15' E. of W. Wall and 15' S. of Salt Wall	78.1 *	0.4	On Bottom 10th Lift
SG 130	On Drift W. 30 15' E. of W. Wall and 10' S. of Salt Wall	72.1 *	0.3	On Bottom 10th Lift
SG 131	On Drift W. 30 8' W. of E. Wall and 10' S. of Salt Wall	73.9 *	0.4	On Bottom 10th Lift
SG 132	On Drift W. 30 15' S. of Salt Wall and 8' W. of E. Wall	76.9 *	0.4	On Bottom 10th Lift

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 5.1

Required Compaction: 70-80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

Lab No.: 12 12838-12843

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BY: Debra Hicks **P.E.**

APPENDIX E -1

Appendix E – 1 Contains The Following From Scenario 1;

1. The Laboratory Test Reports For The Nuclear Density Testing Performed On The Lifts Of The Upper Zone
2. The Laboratory Test Reports For The Sand-Cone Testing Performed On The Lifts Of The Upper Zone

LABORATORY TEST REPORT
PETTIGREW & ASSOCIATES, P.A.
1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 26, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 52	On Drift W. 30 5' E. of W. Wall; 4' Below Back	58.4 *	0.9	3rd Lift Upper Zone
SG 53	On Drift W. 30 10' E. of W. Wall; 4' Below Back	62.1 *	1.6	3rd Lift Upper Zone
SG 54	On Drift W. 30 5' W. of E. Wall; 4' Below Back	68.3 *	0.7	3rd Lift Upper Zone

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections -9.7

Required Compaction: 80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

Lab No.: 12 11871-11873

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BY: Staff for Debra Hicks P.E.

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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 26, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 55	On Drift W. 30 5' E. of W. Wall; 5'6" Below Back	60.1 *	2.0	3rd Lift Upper Zone
SG 56	On Drift W. 30 10' E. of W. Wall; 5'6" Below Back	63.9 *	1.2	3rd Lift Upper Zone
SG 57	On Drift W. 30 5' W. of E. Wall; 5'6" Below Back	61.2 *	1.4	3rd Lift Upper Zone

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections -9.7

Required Compaction: 80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

Lab No.: 12 11874-11876

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BY: for Debra Hicks P.E.

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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 29, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 60	On Drift W. 30 5' E. of W. Wall; On Bottom Step; 8' Below Back	64.1 *	0.6	7th Lift; Top Zone
SG 61	On Drift W. 30 12' E. of W. Wall; On Bottom Step; 8' Below Back	60.4 *	1.0	7th Lift; Top Zone
SG 62	On Drift W. 30 6' E. of W. Wall; On Middle Step; 6' Below Back	66.8 *	0.8	7th Lift; Top Zone

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections -2.5

Required Compaction: 80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

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BY: for Debra Hicks **P.E.**

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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 29, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 63	On Drift W. 30 15' E. of W. Wall; On Middle Step; 6' Below Back	65.1 *	0.7	7th Lift; Top Zone
SG 64	On Drift W. 30 6' E. of W. Wall; On Top Step; 4' Below Back	62.8 *	0.9	7th Lift; Top Zone
SG 65	On Drift W. 30 6' W. of E. Wall; On Top Step; 4' Below Back	66.8 *	1.0	7th Lift; Top Zone

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections -2.5

Required Compaction: 80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: Erica M Hart

BY: for Debra Hicks **P.E.**

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WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 10, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 66	On Drift W. 30 5' E. of W. Wall and 5' Below Back	68.7 *	1.7	Upper Zone Lift 13
SG 67	On Drift W. 30 12' E. of W. Wall and 5' Below Back	72.9 *	1.7	Upper Zone Lift 13
SG 68	On Drift W. 30 4' E. of W. Wall and 4' Below Back	71.3 *	0.9	Upper Zone Lift 13
SG 69	On Drift W. 30 10' E. of W. Wall and 4' Below Back	70.5 *	0.4	Upper Zone Lift 13
SG 70	On Drift W. 30 5' W. of E. Wall and 3' Below Back	67.3 *	0.6	Upper Zone Lift 13
SG 71	On Drift W. 30 10' E. of W. Wall and 3' Below Back	66.0 *	1.5	Upper Zone Lift 13

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections -5.3

Required Compaction: 80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

*** Does Not Meet Specifications; SG 66 Moisture Invaild used Moisture from SG 67 for Correction**

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To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 13, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 72	On Drift W. 30 5' E. of W. Wall and 8' Below Back	55.0 *	1.7	Top Zone Lift 19
SG 73	On Drift W. 30 12' E. of W. Wall and 8' Below Back	61.1 *	2.2	Top Zone Lift 19
SG 74	On Drift W. 30 7' E. of W. Wall and 5' Below Back	61.0 *	1.7	Top Zone Lift 19
SG 75	On Drift W. 30 4' W. of E. Wall and 5' Below Back	59.9 *	0.7	Top Zone Lift 19
SG 76	On Drift W. 30 4' E. of W. Wall and 3½' Below Back	60.1 *	1.8	Top Zone Lift 19
SG 77	On Drift W. 30 5' W. of E. Wall and 3½' Below Back	66.4 *	1.6	Top Zone Lift 19

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections -4.4

Required Compaction: 70-80%

Densometer ID: 5071

*** Does Not Meet Specifications**

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BY: Erica M Hart

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4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 23, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 79	On Drift W. 30 4' E. of W. Wall and 10' Below Back	56.4 *	2.1	Upper Zone 32nd Lift
SG 80	On Drift W.30 4' W. of E. Wall and 10' Below Back	54.7 *	2.2	Upper Zone 32nd Lift
SG 81	On Drift W. 30 8' E. of W. Wall and 4½' Below Back	64.6 *	0.6	Upper Zone 32nd Lift
SG 82	On Drift W. 30 4½' W. of E. Wall and 4½' Below Back	60.3 *	1.1	Upper Zone 32nd Lift
SG 83	On Drift W. 30 5' E. of W. Wall and 3' Below Back	61.0 *	1.1	Upper Zone 32nd Lift
SG 84	On Drift W. 30 6' W. of E. Wall and 3' Below Back	60.7 *	0.7	Upper Zone 32nd Lift

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 6.1

Required Compaction: 70-80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

BY: Erica M Hart

Lab No.: 12 12825-12831

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Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 31, 2012

Depth: See Below

Depth of Probe: 5"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 133	On Drift W. 30 6' E. of W. Wall and 6' Below Back	60.8 *	0.9	On Bottom 10th Lift
SG 134	On Drift W. 30 6' W. of E. Wall and 5' Below Back	59.9 *	0.9	On Bottom 10th Lift
SG 135	On Drift W. 30 4' E. of W.Wall and 4' Below Back	56.4 *	0.1	On Bottom 10th Lift

SG 133, 134, and 135 Taken eight days after
SG 79, 80, and 83 respectively

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 5.1

Required Compaction: 70-80%

Densometer ID: 5071

PETTIGREW & ASSOCIATES

BY: Erica M. Hart

Lab No.: 12 12844-12847

BY: for Debra Hicks **P.E.**

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LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 1556 Sand Cone

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 26, 2012

Depth: See Below

Depth of Probe: N/A

Test No.	Location	Dry Density % Max	% Moisture	Depth
SC 6	On Drift W. 30 10' E. of W. Wall; 4' Below Back (Corresponds to SG 53)	67.5	1.5	3rd Lift Upper Zone

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 80%

Densometer ID: N/A

PETTIGREW & ASSOCIATES

Lab No.: 12 11881

Copies To: Washington TRU Solutions, LLC

BY: Erica M Hart

BY: for Debra Hicks P.E.

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

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HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 1556 Sand Cone

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 29, 2012

Depth: See Below

Depth of Probe: N/A

Test No.	Location	Dry Density % Max	% Moisture	Depth
SC 7	On Drift W. 30 5' E. of W. Wall; On Bottom Step; 8' Below Back (Corresponds to SG 60)	65.0	0.6	7th Lift; Top Zone

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 80%

Densometer ID: N/A

PETTIGREW & ASSOCIATES

Lab No.: 12 11890

Copies To: Washington TRU Solutions, LLC

BY: Erica M Hurt

BY: for Debra Hicks P.E.

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 1556 Sand Cone

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 29, 2012

Depth: See Below

Depth of Probe: N/A

Test No.	Location	Dry Density % Max		% Moisture	Depth
SC 8	On Drift W. 30 15' E. of W. Wall; On Middle Step; 6' Below Back (Corresponds to SG 63)	--	*	0.7	7th Lift; Top Zone

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 80%

Densometer ID: N/A

***Invalid Test. Technician indicated the surface was still sloped, thus the data was erroneous.**

PETTIGREW & ASSOCIATES

Lab No.: 12 11891

Copies To: Washington TRU Solutions, LLC

BY: Erica M Hunt

BY: for Debra Hicks **P.E.**

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

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HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 1556 Sand Cone

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: June 29, 2012

Depth: See Below

Depth of Probe: N/A

Test No.	Location	Dry Density % Max		% Moisture	Depth
SC 9	On Drift W. 30 6' W. of E. Wall; On Top Step; 4' Below Back (Corresponds to SG 65)	--	*	1.0	7th Lift; Top Zone

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 80%

Densometer ID: N/A

***Invalid Test. Technician indicated the surface was still sloped, thus the data was erroneous.**

PETTIGREW & ASSOCIATES

Lab No.: 12 11892

Copies To: Washington TRU Solutions, LLC

BY: Erica M Hart

BY: Debra Hicks **P.E.**

LABORATORY TEST REPORT
PETTIGREW & ASSOCIATES, P.A.
1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 1556 Sand Cone

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 10, 2012

Depth: See Below

Depth of Probe: N/A

Test No.	Location	Dry Density % Max	% Moisture	Depth
SC 10	On Drift W. 30 12' E. of W. Wall and 5' Below Back (Corresponds to SG 67)	76.4 *	1.7	Upper Zone Lift 13

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 80%

Densometer ID: N/A

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: Erica M Hart

BY: for Debra Hicks **P.E.**

Lab No.: 12 12046

Copies To: Washington TRU Solutions, LLC

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

1110 N. GRIMES
HOBBS, NM 88240
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DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 1556 Sand Cone

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 10, 2012

Depth: See Below

Depth of Probe: N/A

Test No.	Location	Dry Density % Max	% Moisture	Depth
SC 11	On Drift W. 30 10' E. of W. Wall and 4' Below Back (Corresponds to SG 69)	70.2 *	0.4	Upper Zone Lift 13

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 80%

Densometer ID: N/A

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

Lab No.: 12 12048

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BY: Erica M Hart

BY: for Debra Hicks **P.E.**

LABORATORY TEST REPORT

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HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 1556 Sand Cone

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 10, 2012

Depth: See Below

Depth of Probe: N/A

Test No.	Location	Dry Density % Max	% Moisture	Depth
SC 12	On Drift W. 30 10' E. of W. Wall and 3' Below Back (Corresponds to SG 71)	67.6 *	1.5	Upper Zone Lift 13

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 80%

Densometer ID: N/A

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

Lab No.: 12 12050

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BY: Erica M Hart

BY: for Debra Hicks **P.E.**

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 1556 Sand Cone

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 23, 2012

Depth: See Below

Depth of Probe: N/A

Test No.	Location	Dry Density % Max	% Moisture	Depth
SC 13	On Drift W. 30 4' E. of W. Wall and 10' Below Back (Corresponds to SG 79)	67.9 *	2.1	Upper Zone 32nd Lift

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 70-80%

Densometer ID: N/A

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

Lab No.: 12 12825

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BY: _____

BY: _____ **P.E.**

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 1556 Sand Cone

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: July 23, 2012

Depth: See Below

Depth of Probe: N/A

Test No.	Location	Dry Density % Max	% Moisture	Depth
SC 14	On Drift W. 30 8' E. of W.Wall and 4½' Below Back (Corresponds to SG 81)	62.1 *	0.6	Upper Zone 32nd Lift

Control Density: 135.0
ASTM D 1557

Optimum Moisture: 0.0%

Required Compaction: 70-80%

Densometer ID: N/A

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

Lab No.: 12 12825

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BY: _____

BY: _____ **P.E.**

APPENDIX E – 2

Appendix E – 2 Contains The Following From Scenario 2;

1. The Laboratory Test Reports For The Nuclear Density Testing Performed On The Lifts Of The Upper Zone

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: August 14, 2012

Depth: See Below

Depth of Probe: 5"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 136	On Drift W - 30 3'6" E. of W. Rib and 6'3" from Back	65.1 *	0.3	10th Lift
SG 137	On Drift W - 30 11'2" E. of W. Rib and 6'7" from Back	66.5 *	0.4	10th Lift
SG 138	On Drift W - 30 6'3" E. of W. Rib and 4'6" from Back	64.7 *	0.4	10th Lift
SG 139	On Drift W - 30 13' E. of W. Rib and 4' 3" from Back	65.3 *	0.4	10th Lift
SG 140	On Drift W - 30 3' E. of W. Rib and 2'10" from Back	63.6 *	0.4	10th Lift
SG 141	On Drift W - 30 10' E. of W. Rib and 2'9" from Back	62.1 *	0.4	10th Lift

Control Density: 135.0

Optimum Moisture: 0.0%
STD/STAT Trench Corrections -4.8

Required Compaction: 70-80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: Erica M. Hart

BY: for Debra Hicks **P.E.**

Lab No.: 12 12954-12960

Copies To: Washington TRU Solutions, LLC

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: August 16, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 142	On Salt wall W-30; 5' E. of the W. wall and 10' below back	55.1 *	0.3	7th Lift
SG 143	On Salt wall W-30; 5' W. of the E. wall and 10' below back	59.0 *	0.4	7th Lift
SG 144	On Salt wall W-30; 6' E. of the W. wall and 8' below back	61.3 *	0.4	7th Lift
SG 145	On Salt wall W-30; 6' W. of the E. wall and 8' below back	63.7 *	0.4	7th Lift
SG 146	On Salt wall W-30; 5' E. of the W. wall and 4' below back	63.6 *	0.4	7th Lift
SG 147	On Salt wall W-30; 6' W. of the E. wall and 4' below back	58.8 *	0.4	7th Lift

Control Density: 135.0
ASTM D: 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections -8.7

Required Compaction: 70-80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: _____

BY: for Debra Hicks **P.E.**

Lab No.: 12 14022-14028

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LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.
1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18
DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for Compacted Salt Testing
Project No. 2012.1112

Date of Test: August 22, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 148	On Drift W-30 5' E. of W. Wall and 10' below back	60.8 *	0.4	27th Lift on Top Zone
SG 149	On Drift W-30 6' W. of E. Wall and 10' below back	61.7 *	0.3	27th Lift on Top Zone
SG 150	On Drift W-30 6' E. of W.Wall and 7' below back	61.1 *	0.6	27th Lift on Top Zone
SG 151	On Drift W-30 5' W. of E. Wall and 7' below back	63.1 *	0.5	27th Lift on Top Zone
SG 152	On Drift W-30 5' E. of W.Wall and 4' below back	64.1 *	0.5	27th Lift on Top Zone
SG 153	On Drift W-30 5' W. of E. Wall and 4' below back	63.6 *	0.4	27th Lift on Top Zone

Control Density: 135.0
ASTM D: 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections -6.0

Required Compaction: 70-80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: Erica M. Hart

BY: for Debra Hicks **P.E.**

Lab No.: 12 15116-15122

Copies To: Washington TRU Solutions, LLC

LABORATORY TEST REPORT

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AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: August 24, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 154	On Drift W-30 6' E. of W. Wall and 10' below back	61.7 *	0.3	34th Lift on Top Zone
SG 155	On Drift W-30 3' W. of E. Wall and 10' below back	62.1 *	0.2	34th Lift on Top Zone
SG 156	On Drift W-30 6' E. of W. Wall and 7' below back	61.3 *	0.4	34th Lift on Top Zone
SG 157	On Drift W-30 7' W. of E. Wall and 7' below back	64.2 *	0.5	34th Lift on Top Zone
SG 158	On Drift W-30 7' E. of W.Wall and 4' below back	65.3 *	0.4	34th Lift on Top Zone
SG 159	On Drift W-30 5' W. of E. Wall and 4' below back	62.1 *	0.3	34th Lift on Top Zone

Control Density: 135.0
ASTM D: 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 2.2

Required Compaction: 70-80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: Erica M. Hart

BY: for Debra H. Hicks **P.E.**

Lab No.: 12 15123-15129

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APPENDIX E – 3

Appendix E – 3 Contains The Following From Scenario 3;

1. The Laboratory Test Reports For The Nuclear Density Testing Performed On The ROM Salt Placement

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

100 E. Navajo Drive, Suite 100
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS, III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: September 5, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 160	On Drift W-30 6' E. of W. Wall and 10' below back	64.5 *	0.4	3rd Test Region Lift
SG 161	On Drift W-30 5' W. of E. Wall and 10' below back	63.1 *	0.3	3rd Test Region Lift
SG 162	On Drift W-30 6' E. of W. Wall and 7' below back	68.1 *	0.5	3rd Test Region Lift
SG 163	On Drift W-30 5' W. of E. Wall and 7' below back	67.6 *	0.5	3rd Test Region Lift
SG 164	On Drift W-30 6' E. of W. Wall and 4' below back	64.8 *	0.5	3rd Test Region Lift
SG 165	On Drift W-30 7' W. of E.Wall and 4' below back	64.7 *	0.5	3rd Test Region Lift

Control Density: 135.0
ASTM D: 1557

Optimum Moisture: 0.0%
STD/STAT Trench Corrections 2.2

Required Compaction: 70-80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: _____

BY: _____ **P.E.**

Lab No.: 12 15887-15892

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LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

100 E. Navajo Drive, Suite 100
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: September 7, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 168	On Drift W-30 5' E. of W. Wall and 10' Below Back	61.6 *	0.3	3rd Test Region Lift
SG 169	On Drift W-30 4' W. of E. Wall and 10' Below Back	65.6 *	0.4	3rd Test Region Lift
SG 170	On Drift W-30 4' E. of W. Wall and 7½' Below Back	65.1 *	0.4	3rd Test Region Lift
SG 171	On Drift W-30 4' W. of E. Wall and 7½ Below Back	63.3 *	0.4	3rd Test Region Lift
SG 172	On Drift W-30 5' E. of W. Wall and 4' Below Back	66.9 *	0.4	3rd Test Region Lift
SG 173	On Drift W-30 3' W. of E. Wall and 4' Below Back	63.0 *	0.4	3rd Test Region Lift

Control Density: 135.0
ASTM D: 1557

Optimum Moisture: 0.0%

Required Compaction: 70-80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: _____

Lab No.: 12 15896-15902

Copies To: Washington TRU Solutions, LLC

BY: _____ **P.E.**

LABORATORY TEST REPORT

PETTIGREW & ASSOCIATES, P.A.

1110 N. GRIMES
HOBBS, NM 88240
(575) 393-9827

AASHTO R18

DEBRA P. HICKS, P.E./L.S.I.
WILLIAM M. HICKS. III, P.E./P.S.

To: Washington TRU Solutions, LLC
4021 NATIONAL PARKS HIGHWAY
P. O. BOX 2078
Carlsbad, NM 8822

Material: ROM Salt

Test Method: ASTM: D 6938

Project: Lab and Field Testing Services for
Compacted Salt Testing
Project No. 2012.1112

Date of Test: September 10, 2012

Depth: See Below

Depth of Probe: 6"

Test No.	Location	Dry Density % Max	% Moisture	Depth
SG 174	On Drift W-30 WR 6'6" and Back 8'0"	71.7 *	0.3	3rd Region
SG 175	On Drift W-30 WR 13' 6" and Back 8'6"	69.6 *	0.4	3rd Region
SG 176	On Drift W-30 WR 4'0" and Back 5'6"	71.0 *	0.4	3rd Region
SG 177	On Drift W-30 WR 10' 0" and Back 6'0"	73.0 *	0.3	3rd Region
SG 178	On Drift W-30 WR 6'0" and Back 3'0"	70.1 *	0.4	3rd Region
SG 179	On Drift W-30 WR 12'0" and Back 3'0"	69.2 *	0.5	3rd Region

Control Density: 135.0
ASTM D: 1557

Optimum Moisture: 0.0%
STD/STAT 3170/511

Required Compaction: 70-80%

Densometer ID: 5071

*** Does Not Meet Specifications**

PETTIGREW & ASSOCIATES

BY: _____

BY: _____ **P.E.**

Lab No.: 12 15821-15827

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APPENDIX F – 1

Appendix F - 1 Contains The Following From Scenario 1;

1. The Summary Sheets For The Lower Lift Placement, Compaction And Down Time
2. The Summary Sheets For The Upper Lift Placement, Compaction And Down Time
3. The Summary Sheet For The Lower And Upper Lift Moisture/Density Data

Scenario: 1

Test Region: 1

Time

Lift #	Emplacement Time	Water Time	Compaction Time 2 Passes	Compaction Time 4 Passes	Compaction Time 6 Passes	Upper Zone Compaction Time	Down Time	Total Time
1	150	4	31	18	18		25	246
2	180	3	17	18	19		45	282
3	150	3	16	18	19		15	221
4	91	3	14	17	15			140
5	83	3	16	18	14			134
6	92	3	14	11	14			134
7	178	3	16	16	13		50	276
				Lower Zone Total Time (Hr) = 23.9				
				Lower Zone Total Time Without Down Time (Hr) = 21.65				
				Average Cubic Foot Per Hour = 181				
							*Time In Minutes	

Scenario: 1

Test Region: 1

Time

Lift #	Emplacement Time	Water Time	Compaction Time 2 Passes	Compaction Time 4 Passes	Compaction Time 6 Passes	Upper Zone Compaction Time	Down Time	Total Time
1	15	1				85	30	131
2	8	1				100	141	250
3	12	1				79		92
4	15	1				60	90	166
5	9	1				62		72
6	15	1				80		96
7	15	1				68		84
8	13	1				63	30	107
9	11	1				60		72
10	16	1				45		62
11	19	1				47	60	127
12	13	1				33		47
							*Time In Minutes	

Scenario: 1

Test Region: 1

Time

Lift #	Emplacement Time	Water Time	Compaction Time 2 Passes	Compaction Time 4 Passes	Compaction Time 6 Passes	Upper Zone Compaction Time	Down Time	Total Time
13	14	1				45		60
14	13	1				66	45	125
15	15	1				60		76
16	10	1				75		86
17	13	1				46		60
18	14	1				60		75
19	10	1				55		66
20	15	1				60	120	196
21	11	1				64		76
22	9	1				46		56
23	13	1				40		54
24	15	1				45		61
							*Time In Minutes	

Scenario: 1

Test Region: 1

Time

Lift #	Emplacement Time	Water Time	Compaction Time 2 Passes	Compaction Time 4 Passes	Compaction Time 6 Passes	Upper Zone Compaction Time	Down Time	Total Time
25	14	1				50		65
26	15	1				53	30	99
27	14	1				48		63
28	13	1				52		66
29	13	1				54		68
30	11	1				45		57
31	11	1				48		60
32	15	1				60		76
				Upper Zone Total Time (Hr) = 47.5				
				Upper Zone Total Time Without Down Time (Hr) = 38.4				
				Averae Cubic Foot Per Hour = 162				
							*Time In Minutes	

AVERAGE

Scenario: 1

Test Region: 1

Date	Lift #	Compactor Type	Avg. Compactor Speed (ft/min)	Cumulative Number of Compaction (No. of Passes)	Maximum Density %	Minimum Density %	Avg. Wet Density %	Avg. Moisture %	Avg. Dry Density %
6/5/12-6/15/12	1 - 7	ROLLER	132.28	2	77.4	71.8	75.1	1.6	74.1
6/5/12-6/15/12	1 - 7	ROLLER	141.31	4	76.6	72.4	75.8	1.7	74.5
6/5/12-6/15/12	1 - 7	ROLLER	148.12	6	78.2	73.3	76.0	1.4	74.8
UPPER ZONE									
6/26/12-6/29/12	3-7	PUSHPLATE W/VIBRATION		1	68.3	58.4	64.1	1.1	63.3
7/10/12-7/11/12	13-32	PUSHPLATE W/O VIBRATION		1	72.6	54.6	64.2	1.4	63.3
	3' From Back				68.3	58.4	64.1	1.2	63.4
	5' From Back				72.9	59.9	65.4	1.3	64.6
	7' From Back				68.7	54.7	62.5	1.4	61.5

APPENDIX F – 2

Appendix F - 2 Contains The Following From Scenario 2;

1. The Summary Sheets For The Lower Lift Placement, Compaction And Down Time
2. The Summary Sheets For The Upper Lift Placement, Compaction And Down Time
3. The Summary Sheet For The Lower And Upper Lift Moisture/Density Data

Lower Zone

Scenario: 2

Test Region: 2

Time

Time in minutes unless otherwise noted:

Lift #	Emplacement Time	Water Time	Compaction Time 2 Passes	Compaction Time 4 Passes	Compaction Time 6 Passes	Upper Zone Compaction Time	Down Time	Total Time
1	45	0	10	6	6	N/A	0	67
2	37					N/A	0	61
3						N/A		
4		0	7	9	7	N/A	0	61
5	40	0				N/A	0	64
6			8	11	9	N/A		66
7	31					N/A		55
8		0	8	8	9	N/A	0	63
9						N/A		
10		0	7	9	7	N/A	0	61
Avg.	38	0	8	9	8	N/A	0	62
*segment averages used to fill missing data								
				Lower Zone Total Time (Hr)* = 10.3				
				Lower Zone Total Time Without Down Time (Hr)* = 10.3				
				Average Cubic Foot Per Hour = 283				

Lower Zone

Scenario: 2

Test Region: 2

Time

Time in minutes unless otherwise noted:

Lift #	Emplacement Time	Water Time	Compaction Time 2 Passes	Compaction Time 4 Passes	Compaction Time 6 Passes	Upper Zone Compaction Time	Down Time	Total Time
1	29	0	N/A	N/A	N/A	63	0	92
2	13	0	N/A	N/A	N/A	36	0	49
4	10	0	N/A	N/A	N/A	70	0	80
5	5	0	N/A	N/A	N/A	55	0	60
6	10	0	N/A	N/A	N/A	65	0	75
7	10	0	N/A	N/A	N/A	35	0	45
13		0	N/A	N/A	N/A	23	0	36
14	9	0	N/A	N/A	N/A	27	0	36
15	27	0	N/A	N/A	N/A	32	10	69
16	15	0	N/A	N/A	N/A		0	15
18			N/A	N/A	N/A		0	45
19			N/A	N/A	N/A		0	55
20	25	0	N/A	N/A	N/A	41	0	66
21		0	N/A	N/A	N/A		0	50
22		0	N/A	N/A	N/A		0	35
23		0	N/A	N/A	N/A		0	38
24	12	0	N/A	N/A	N/A	32	0	44
25	8	0	N/A	N/A	N/A	40	0	48

Lower Zone

Scenario: 2

Test Region: 2

Time

Time in minutes unless otherwise noted:

Lift #	Emplacement Time	Water Time	Compaction Time 2 Passes	Compaction Time 4 Passes	Compaction Time 6 Passes	Upper Zone Compaction Time	Down Time	Total Time
26	6	0	N/A	N/A	N/A		0	49
28		0	N/A	N/A	N/A		0	48
29		0	N/A	N/A	N/A		0	48
30		0	N/A	N/A	N/A		0	49
31		0	N/A	N/A	N/A	43	0	43
32	11	0	N/A	N/A	N/A	43	0	54
33	8	0	N/A	N/A	N/A	42	0	50
34		0	N/A	N/A	N/A		0	40
35		0	N/A	N/A	N/A		0	42
36		0	N/A	N/A	N/A		0	28
38		0	N/A	N/A	N/A		0	35
39	7	0	N/A	N/A	N/A	37	0	44
40	8	0	N/A	N/A	N/A		0	51
Avg.	13					43	0	49
*segment averages used to fill missing data								
				Upper Zone Total Time (Hr)* = 32.7				
				Upper Zone Total Time Without Down Time (Hr) = 32.5				
				Average Cubic Foot Per Hour = 239				

AVERAGE
Scenario: 2

Test Region: 2

Date	Lift #	Compactor Type	Avg. Compactor Speed (ft/min)	Cumulative Number of Compaction (No. of Passes)	Maximum Density %	Minimum Density %	Avg. Wet Density %	Avg. Moisture %	Avg. Dry Density %
Roller Compactor									
7/25/12-7/26/12	1 - 6	ROLLER	98	2	76.1	73.0	75.0	0.4	74.6
7/25/12-7/26/12	1 - 6	ROLLER	73.5	4	78.3	72.6	76.4	0.4	75.5
7/25/12-7/26/12	1 - 6	ROLLER	100.2	6	77.3	71.5	75.8	0.4	74.7
LHD - Empty Bucket									
7/26/12- 7/30/12	7 - 8	LHD	93.5	2	74.7	72.6	73.8	0.1	73.8
7/26/12- 7/30/13	7 - 8	LHD	93.5	4	76.6	68.4	73.0	0.0	73.0
7/26/12- 7/30/14	7 - 7	LHD	83.1	6	77.2	72.0	74.9	0.3	74.9
LHD - Full Bucket									
7/30/12-7/31/12	9 - 10	LHD	95.0	2	74.1	70.1	72.5	0.4	72.5
7/30/12-7/31/13	9 - 10	LHD	83.1	4	76.4	73.8	75.4	0.4	75.0
7/30/12-7/31/14	9 - 10	LHD	95.0	6	78.1	76.9	75.6	0.4	75.3
UPPER ZONE									
8/8/12-8/24/12	1 - 40	PUSHPLATE W/O VIBRATION		1	66.5	55.1	62.7	0.4	62.5
Distance From Back									
	3' From Back				65.3	58.8	63.1	0.4	62.9
	5' From Back				65.3	61.1	63.4	0.5	63.1
	7' From Back				66.5	55.1	61.7	0.3	61.5

APPENDIX F - 3

Appendix F – 3 Contains The Following From Scenario 3;

1. The Summary Sheets For ROM Salt Placement And Down Time
2. The Summary Sheet For The Moisture/Density Data

Scenario 3

Test Region 3

Time

Lift #	Emplacement Time	Water Time	Compaction Time 2 Passes	Compaction Time 4 Passes	Compaction Time 6 Passes	Upper Zone Compaction Time	Down Time	Total Time
1	6	N/A	N/A	N/A	N/A	N/A	0	6
2	82	N/A	N/A	N/A	N/A	N/A	0	82
3	37	N/A	N/A	N/A	N/A	N/A	0	37
4	33	N/A	N/A	N/A	N/A	N/A	0	33
5	33	N/A	N/A	N/A	N/A	N/A	0	33
6	29	N/A	N/A	N/A	N/A	N/A	0	30
7	29	N/A	N/A	N/A	N/A	N/A	0	30
8	31	N/A	N/A	N/A	N/A	N/A	5	36
9	20	N/A	N/A	N/A	N/A	N/A	0	20
				Zone total time (hr) =14.5				
				Zone total time without down time (hr) = 14.1				
				Average cubic foot per hour = 690				

Lift #	Emplacement Time	Water Time	Compaction Time 2 Passes	Compaction Time 4 Passes	Compaction Time 6 Passes	Upper Zone Compaction Time	Down Time	Total Time
10	21	N/A	N/A	N/A	N/A	N/A	0	21
11	22	N/A	N/A	N/A	N/A	N/A	0	22
12	22	N/A	N/A	N/A	N/A	N/A	0	22
13	25	N/A	N/A	N/A	N/A	N/A	0	25
14	21	N/A	N/A	N/A	N/A	N/A	12	33
15	41	N/A	N/A	N/A	N/A	N/A	0	41
16	39	N/A	N/A	N/A	N/A	N/A	0	39
17	39	N/A	N/A	N/A	N/A	N/A	0	39
18	34	N/A	N/A	N/A	N/A	N/A	0	34
19	19	N/A	N/A	N/A	N/A	N/A	7	26

Scenario 3

Test Region 3

Time

Lift #	Emplacement Time	Water Time	Compaction Time 2 Passes	Compaction Time 4 Passes	Compaction Time 6 Passes	Upper Zone Compaction Time	Down Time	Total Time
20	25	N/A	N/A	N/A	N/A	N/A	0	25
21	27	N/A	N/A	N/A	N/A	N/A	0	27
22	24	N/A	N/A	N/A	N/A	N/A	0	24
23	28	N/A	N/A	N/A	N/A	N/A	0	28
24	44	N/A	N/A	N/A	N/A	N/A	0	44
25	27	N/A	N/A	N/A	N/A	N/A	0	27
26	21	N/A	N/A	N/A	N/A	N/A	0	21
27	20	N/A	N/A	N/A	N/A	N/A	0	20
28	24	N/A	N/A	N/A	N/A	N/A	0	24
29	23	N/A	N/A	N/A	N/A	N/A	0	23

AVERAGE

Scenario: 3

Test Region: 3

Date	Lift #	Compactor Type	Avg. Compactor Speed (ft/min)	Cumulative Number of Compaction (No. of Passes)	Maximum Density %	Minimum Density %	Avg. Wet Density %	Avg. Moisture %	Avg. Dry Density %
9/4/12 - 9/5/12	1 - 5	N/A	N/A	N/A	68.1	63.1	65.8	0.5	65.5
9/5/12 - 9/7/12	6 -17	N/A	N/A	N/A	66.9	61.6	64.0	0.4	64.3
9/7/12 - 9/8/12	18 - 29	N/A	N/A	N/A	73.0	69.2	70.4	0.4	70.8
	3' From Back				70.1	63.0	66.7	0.5	66.5
	5' From Back				73.0	63.3	68.2	0.4	68.0
	8' From Back				71.7	63.1	65.2	0.4	66.0

APPENDIX G

Appendix G Contains The Following;

1. The Data Sheet For The Walk-Behind Vibratory Roller Compactor Used To Compact The Lower Lifts
2. The Data Sheet For The LHD Used To Place The Lower And Upper Lifts
3. The Data Sheet For The Fletcher Scaler Used To Pushup And Compact Upper Zone Lifts

RD 7H-ES Double Drum Vibratory Roller

Item Number: 0009408

Request a product demonstration or training
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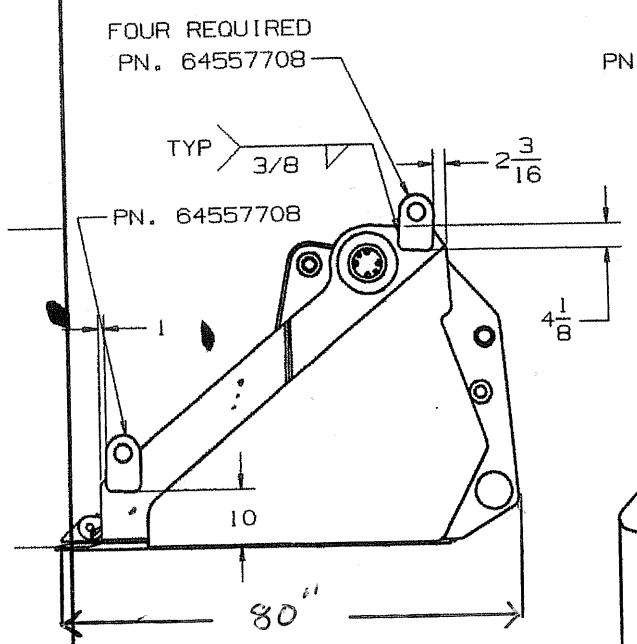
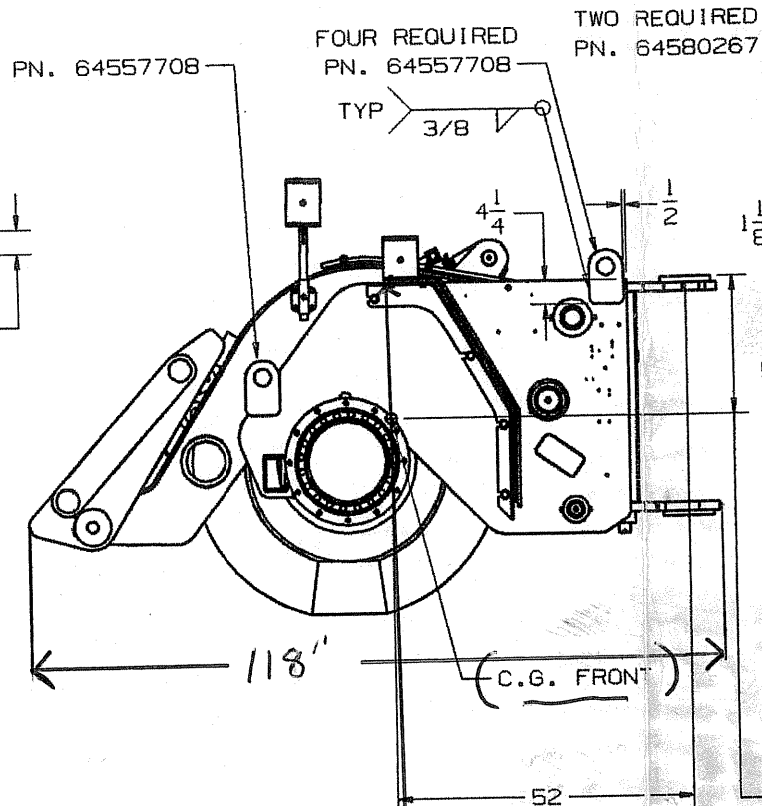
Description **Technical Data** Accessories Manuals Brochures Like Models

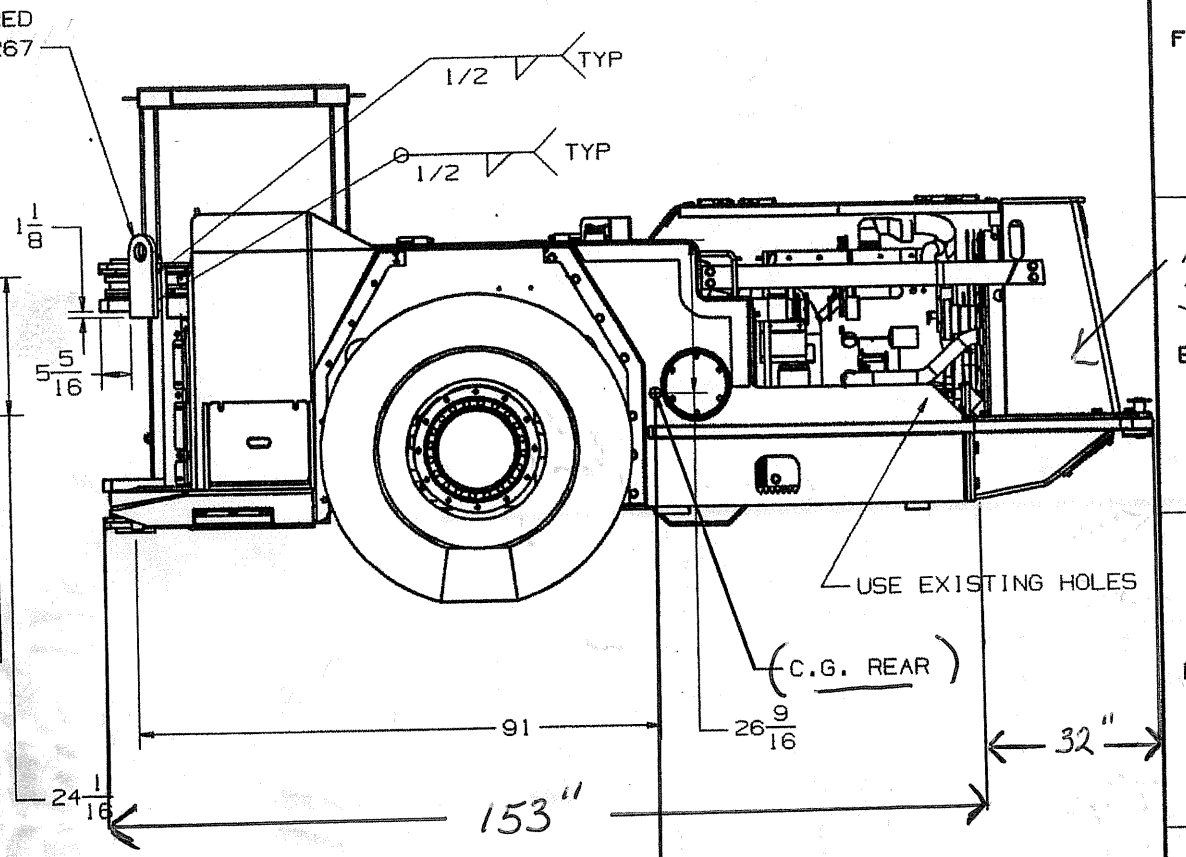
Description	Metric		Imperial	
Length x width x height (handle in working position)	2631 x 697.9 x 1166	mm	103.6 x 27.48 x 45.9	in
Length x width x height (guide handle in transport position)	1226.8 x 697.9 x 2215	mm	48.3 x 27.48 x 87.2	in
Shipping size	1473 x 914 x 2311	mm	58 x 36 x 91	in
Dry Weight	772.5	kg	1703	lb
Operating weight	829.6	kg	1829	lb
Shipping weight (including packaging)	795.1	kg	1753	lb
Drum width	650	mm	25.5	in
Drum diameter	420	mm	16.52	in
Curb clearance (R/L)	233.7 / 233.7	mm	9.2 / 9.2	in
Side clearance (R/L)	29.5 / 29.5	mm	1.16 / 1.16	in
Water tank capacity	53	l	14	US gal
Sprinkling system	gravity fed		gravity fed	
Engine Type	Hatz, diesel			
Fuel type	Diesel		Diesel	
Starting system	Electric Start or Hand crank		Electric Start or Hand crank	
Displacement	445	cm^3	27.2	in^3
Max. Rated Power at Rated Speed*	6.1 kW at 2600 rpm		8.2 hp at 2600 rpm	
Power Rating Specification	ISO 3046/1 IFN		ISO 3046/1 IFN	
Operating speed	2600	1/min	2600	rpm
Fuel consumption	1.63	l/h	.43	US gal/h
Fuel tank capacity	5	l	1.3	US gal
Hydraulic tank capacity	30	l	8	US gal
Dynamic (centrifugal) force	13	kN	2921.5	lbf
Frequency	55	Hz	3300	vpm
Static linear force per drum (f/r)	5.01 / 7.51	N/mm	28.69 / 43.04	lb/in
Dynamic linear force per drum (f/r)	10.03 / 10.03	N/mm	57.28 / 57.28	lb/in
Total linear force per drum (f/r)	15.04 / 17.54	N/mm	85.97 / 100.32	lb/in
Static weight per drum (f/r)	331.8 / 497.8	kg	731.6 / 1097.4	lb
Variable speeds - Forward	0-4.0	km/h	0-2.5	mph
Variable speeds - Forward	0-67	m/min	0-220	ft/min
Variable speeds - Reverse	0-2.0	km/h	0-1.2	mph
Variable speeds - Reverse	0-32	m/min	0-105	ft/min
Gradeability without vibration	40	%	40	%



6000 lbs
3 TONS



Center Point of gravity
11,000
5.5 TONS



Center Point of Gravity 16,500 lbs
≈ 8.5 TONS

HARD NOSE 3000 lbs
1.5 TONS

0	-	29/03/06	-	(null)	
REV.	BY	DATE	ECN No.	DESCRIPTION OF CHANGES IN REVISION	No OF CHGS

PRODUCT LINE: EJC-LOADERS	TOLERANCES UNLESS OTHERWISE SPECIFIED	DIMENSIONS IN INCHES
MATERIAL:	FRACTIONAL ±1/16	DECIMAL .X ±.06 .XX ±.03 .XXX ±.01
(null)	ANGLES ±1.0	
-	145	
-	-	
HEAT TREATMENT:	-	
-	-	
WELD STANDARDS: ALL WELDS	-	
TO COMPLY TO CSA W47.1/W59	-	
SURFACE TREATMENT:	HIGHER LEVEL: -	WEIGHT -
-	SIMILAR TO: -	

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SHT 1 OF 1	DWG. NO. 64580263

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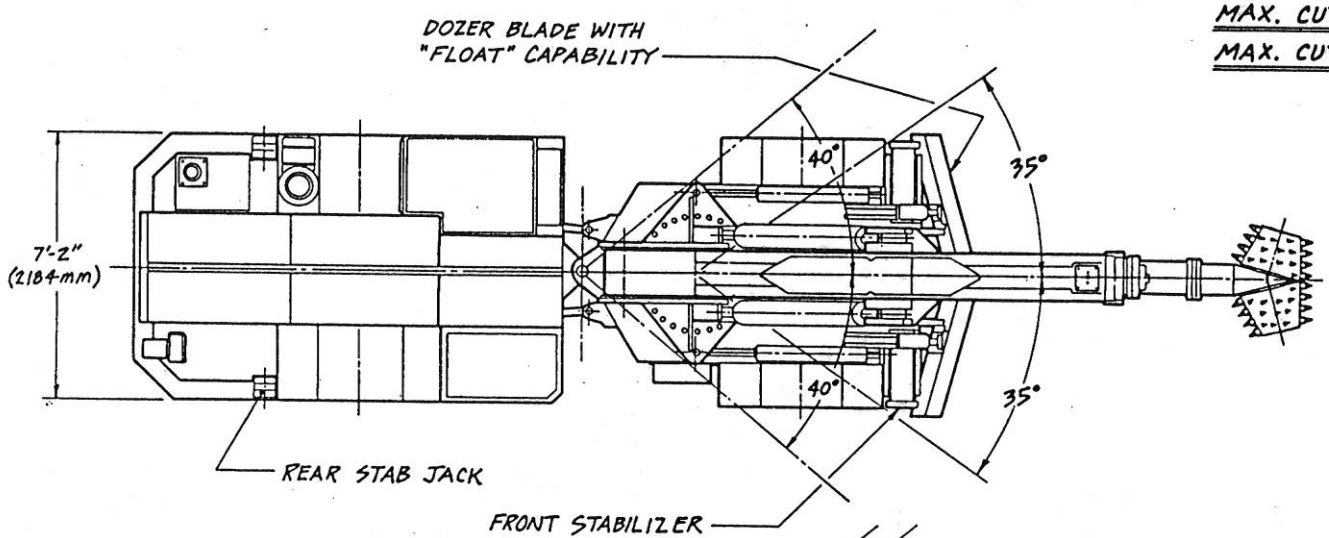
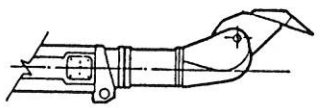
EJCDH-III

UNIGRAPHICS

MAX. CUTTING HEIGHT: 22'-10" (6960 mm)
MAX. CUTTING WIDTH: 29'-2" (8890 mm)





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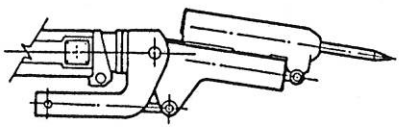

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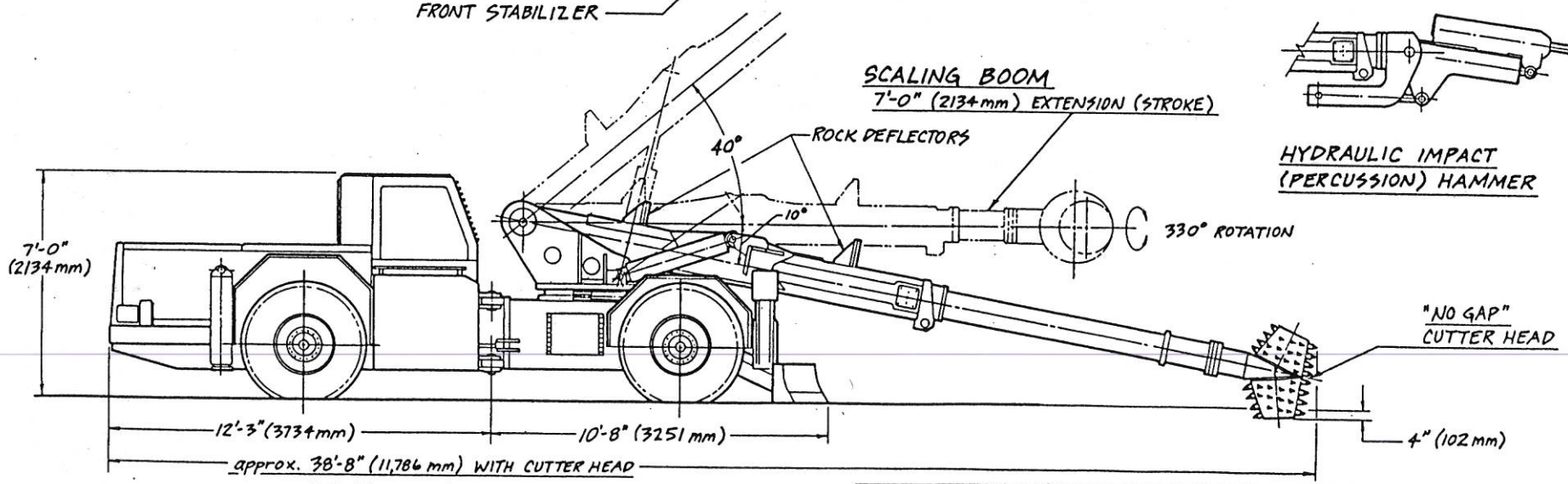

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